Staff Reports To
The President's Commission On

THE ACCIDENT AT THREE MILE ISLAND

Reports Of The Public Health And Safety Task Force

THE PRESIDENT'S COMMISSION ON THE ACCIDENT AT THREE MILE ISLAND

JOHN G. KEMENY, CHAIRMAN
President, Dartmouth College

BRUCE BABBITT
Governor of Arizona

PATRICK E. HAGGERTY
Honorary Chairman and
General Director
Texas Instruments Incorporated

CAROLYN LEWIS
Associate Professor
Graduate School of Journalism
Columbia University

PAUL A. MARKS
Vice President for Health Sciences
and Frode Jensen Professor
Columbia University

CORA B. MARRETT
Professor of Sociology and
Afro-American Studies
University of Wisconsin-Madison

LLOYD McBRIDE
President
United Steelworkers of America

HARRY C. McPHERSON
Partner
Verner, Liipfert,
Bernhard, and McPherson

RUSSELL W. PETERSON
President
National Audubon Society

THOMAS H. PIGFORD
Professor and Chairman
Department of Nuclear
Engineering
University of California
at Berkeley

THEODORE B. TAYLOR
Visiting Lecturer
Department of Mechanical
and Aerospace Engineering
Princeton University

ANNE D. TRUNK
Resident
Middletown, Pennsylvania

Stanley M. Gorinson
Chief Counsel

Vincent L. Johnson
Director of Technical Staff

Barbara Jorgenson
Public Information Director

REPORTS OF THE
PUBLIC HEALTH AND SAFETY TASK FORCE

ON

PUBLIC HEALTH AND SAFETY SUMMARY

HEALTH PHYSICS AND DOSIMETRY

RADIATION HEALTH EFFECTS

BEHAVIORAL EFFECTS

PUBLIC HEALTH AND EPIDEMIOLOGY

October 1979
Washington, D. C.

This document is solely the work of the Commission staff and does not necessarily represent the views of the President's Commission or any member of the Commission.

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

Stock Number 052-003-00732-1

TABLE OF CONTENTS

TABLE OF CONTENTS

INTRODUCTION

In the Charter of the President's Commission on the Accident at Three Mile Island (TMI), the Commission was given the responsibility to evaluate "the actual and potential impact of the events [of the accident] on the public health and safety and on the health and safety of the workers." Accordingly, the Public Health and Safety Task Force of the Commission set out the following objectives:

- To identify and evaluate the real and potential effects on the health and safety of the public, both the general population and the workers, resulting from the events of the nuclear reactor accident at TMI.

- To assess the health hazards associated with the radiation exposure -- carcinogenic, teratogenic, and genetic -- based on an analysis of the radiation dosimetry and the task force's best scientific knowledge of the biological effects of radiation on exposed populations.

- To assess the mental health and behavioral responses of the general population under stress during and following the accident, and of the nuclear plant workers during and following the accident.

- To assess the impact of the accident on the effectiveness of the health-care delivery system and its capacity to respond under nuclear accident emergency conditions.

- To examine the availability of information needed to make decisions on protection of the public health and safety.

- To determine what measures can be taken to prevent physical illness resulting from low-level radiation and emotional illness in the event of a nuclear reactor accident.

- To identify areas requiring research and improvement to protect the health and safety of the public exposed as a result of the nuclear reactor accident.

Four task groups were formed to carry out the investigations -- namely, Health Physics and Dosimetry, Radiation Health Effects, Behavioral Effects, and Public Health and Epidemiology. Each group consisted of a team of staff scientists expert in their respective fields, including physics, biophysics, medicine, epidemiology, preventive medicine and public health, health administration, radiology, psychiatry, pediatrics, social medicine, psychology, genetics, biochemistry, radiobiology, sociology, biostatistics, health sciences, and computer sciences. In all, over 75 scientists, consultants, and advisors (with assistance of colleagues from the legal staff) contributed to the final Public Health and Safety Task Force Report to the Commission.

The following summary of the task force reports defines the key issues and identifies the major findings from the accident concerned with four major health areas of the investigation: (1) the amount of radioactivity released and the radiation exposures to the general population and the workers; (2) the real and potential radiation risks to health of the general public and the workers, such as radiation-induced cancer, developmental abnormalities, and genetically related ill-health; (3) the behavioral responses of the public and the workers to the stress of the nuclear emergency; and (4) the broad and substantive health issues that bear directly on public health and safety of the workers during the normal operation of a nuclear power plant and during a nuclear accident, specifically at TMI. The body of the task force report consists of four interrelated reports; namely, those of the Health Physics and Dosimetry Task Group, the Radiation Health Effects Task Group, the Behavioral Effects Task Group, and the Public Health and Epidemiology Task Group.

SUMMARY OF THE HEALTH PHYSICS AND DOSIMETRY TASK GROUP REPORT

INTRODUCTION

The general objectives of the Health Physics and Dosimetry Task Group included: (1) to determine the radiation dose to the people living within the area of 50 miles around the Three Mile Island Nuclear Station during the period of March 28 to April 15, 1979; (2) to determine the radiation dose to the workers at the nuclear power plant during the period of March 28 to June 30, 1979 -- the cutoff date necessitated by the deadline of the Commission's report; and (3) to evaluate federal, state, and utility company programs concerned with the protection of human populations and their environment from the possible hazards of ionizing radiation, and the efficacy of these radiation protection programs during the nuclear accident at TMI.

The task force identified the important events requiring analysis for the measurement of the radioactivity released into the environment, for the assessment of the radiation doses to the public and to the workers, and the response of federal, state, and the utility company programs for radiation protection. Among these are: the identification of initial damage to the nuclear fuel; the release of radioactivity into the atmosphere; the declaration of the site emergency and notification of the Pennsylvania State Bureau of Radiological Health; the notification of the national radiological assistance program to draw on extensive resources to provide assistance during the emergency; the radiological indications of the uncontrolled escape of large amounts of radioactivity into the containment building; the declaration of the general emergency because of high radiation levels; the earliest releases of radioactivity into the environment resulting in raised levels of radiation in the areas where the general public lived; and the identification of the radioactive noble gases and iodine in the radiation releases.

RADIATION DOSE TO THE GENERAL POPULATION

Normal Radiation Exposure

Radioactivity occurs naturally in the environment and is constantly being created in nature. Humans receive radiation exposure from this natural radioactivity, from cosmic rays from outer space, from the earth's crust, and also from those various human activities involving radiation and unrelated to nuclear power. Natural radioactivity occurs everywhere -- in air, in water, in soil, in foods, and in our own bodies -- and is called "background" radiation. The radioactive elements (or radioisotopes) found in our external and internal environment are extremely varied in the energies of their different radiations, and in the time of their decay -- that **is**, to undergo spontaneous disintegration with the emission of radioactive particles or rays. The radiation dose absorbed in the cells and tissues of the body, whether from natural or manmade radiation, is frequently measured in rems; the rem is one form of physical radiation unit which takes into account the amount of radiant energy deposited in the body tissues and the type of radiation -

alpha, beta, or gamma radiation, or neutrons. When the dose is measured over a time period, say rems per hour, this is called doserate. When the radiation dose level is low, as in the case of natural background, the radiation dose unit frequently used is the millirem (mrem), or one-thousandth of a rem.

Some familiarity with these quantities and radiation units is necessary for understanding the significance of normal or accidental radioactive releases to the environment from nuclear power plants. Man is constantly exposed to naturally occurring radiation; each year, the average American is exposed to about 100-200 millirems of natural background radiation depending on where that person lives. The variation depends primarily on altitude and on the long-lived radionuclides in the earth's crust. In Harrisburg, Pa., the average annual whole-body dose to the individual due to natural background radiation is estimated to be 116 millirems. In general in Harrisburg, about 45 millirems per year of this whole-body dose come from cosmic radiation and 45 millirems per year from terrestial radiation. By comparison, each of these annual dose-rate values is about doubled in Denver, Colo., to about 75 millirems per year from cosmic radiation and 90 millirems per year terrestial radiation, respectively. The internal radiation annual dose-rate is relatively constant in all individuals (about 28 millirems per year) from naturally occurring radioisotopes in the body, primarily potassium-40.

About half of the radiation to which the general population is exposed annually comes from natural sources and the remainder from man-made sources. The average annual background radiation exposure to an individual is very low; comparisons between levels in Harrisburg, Pa. (average), Denver, Colo. (high), Las Vegas, Nev. (low), and the overall range in the United States, in millirems per year (mrem/yr), are given in the following table:

Radiation Source	Harrisburg, Pa.	Denver, Colo.	Las Vegas, Nev.	Range, U.S.
Cosmic Radiation	42.0	74.9	49.6	40-160
Terrestial Radiation	45.6	89.7	19.9	0-120
Internal Radiation	28.0	28.0	28.0	28
Total (mrem/yr)	116	193	98	70-310

The remainder of man's radiation exposure, due to manmade radiation, is primarily (an additional 40 percent) due to medical and dental x-rays. Nuclear weapons testing and fallout, technologically enhanced natural radiation (e.g., uranium tailings), consumer products (e.g., television sets), and nuclear energy plants provide only a very small fraction (about 0.15 percent) of the total amount. The 1978 estimates of the annual collective dose (that is, the average yearly dose summed up for the entire population) of radiation exposures to the U.S. population -- somewhat more than 200 million Americans -- based on data summarized by the Interagency Task Force on Ionizing Radiation (1979) -- are listed below:

Radiation Source	Annual Collective Dose (Person-rems per Year)
Natural background (e.g., cosmic and terrestial radiation)	20 million
Medical and dental x-rays (e.g., x-ray diagnosis)	17 million
Nuclear weapons (e.g., manufacture and testing)	about 1.3 million
Technology-enhanced (e.g., uranium tailings)	1 million
Nuclear energy (e.g., nuclear power plants)	0.06 million
Consumer products (e.g., television sets)	0.006 million
Total	about 39 million

Under normal conditions, the 2,163,000 persons living in the 50-mile area surrounding TMI would receive an annual collective dose of about 440,000 person-rems; about 240,000 person-rems would come from natural background radiation. (In contrast, the collective dose to that population resulting from the radioactive releases during the Till accident was approximately 0.5 percent of the normal annual exposure rate, or about 1 percent of natural background radiation.)

Radiation Exposure During the TMI Accident

Nuclear radiation doses are measured with instruments or detectors called thermoluminescent dosimeters (TLDs); TLD measurements formed the basis for estimating the total external gamma radiation doses (due almost exclusively to the radioactive noble gas xenon-133 and a few other short-lived radioactive gases in the radioactive cloud) to the population during the TMI accident. The main TLD dosimetry instruments were located within a 15-mile distance of the plant. Individual doses within a few miles of the nuclear plant were relatively low; some 260 people living mostly on the east bank of the Susquehanna River possibly each received between 20 to 70 millirems. One person on a nearby island for 9-1/2 hours during the initial days of the accident received about 50 millirems. All other persons living outside a one-mile radius and within 10 miles from the plant could have received an average dose of less than 20 millirems. Almost all recorded excess exposure above background levels occurred within a 10-mile radius. There were no recordable radiation levels above natural background at a distance greater than 10 miles from the nuclear plant at any time during the accident.

The total release of radioactivity into the atmosphere from the damaged nuclear power plant during the period of March 28 to April 15, 1979, was calculated to be about 2.4 million curies,1/ primarily consisting of radioactive noble gases. 2/ Approximately 10-15 curies of radioactive iodine were released into the environment. This total release of radioactivity, known as the source term, was one way to determine the radiation doses to the entire population (collective dose) and to the individual in the population (average dose), taking into account meteorological weather conditions and population distribution demographic data at the time of the accident. Another way to determine the collective dose was by use of the TLD radiation dose measurements.

The collective dose to the population is a measure of the potential health impact resulting from the total radiation dose received by the entire population; for the TMI site, a 50-mile radius and approximately 2,163,000 persons were included in the calculation. Since this value is obtained by summing the estimated radiation doses (measured in rems) received by each person in the affected area, the collective dose unit is the person-rem. The collective dose above normal background levels to all persons within a 50-mile radius of TMI, based on the TLD radiation dosimetry, was estimated to be about 2,800 person-rems outdoors and unshielded. Since most people spent most of their time indoors and partially shielded by buildings, and assuming that the radiation dose indoors was about three-quarters of that outdoors, a more accurate collective dose to this exposed population is estimated to be about 2,000 person-rems above normal background levels.3/ The average dose to any individual in the population living within 50 miles of the nuclear reactor, therefore, is estimated to be about one millirem. The average dose to an individual living within 10 miles of the plant is estimated to be about 6.5 millirems.

There are a number of ways to evaluate the magnitude of the radiation releases and the exposures to the general population. If the maximum dose to any member of the public exposed within just a few miles of the reactor site was no more than 70 millirems, this may be considered to be equivalent to about one-half of the normal exposure the average American receives from natural background radiation each year; probably no more than 250 persons out of the entire population could have received this dose, and most of them received less. Another way of considering it is that this dose is equivalent to the difference between annual background radiation exposure in Harrisburg and Denver, Colo. An average dose of 6.5 millirems is about 5 percent of the exposure from natural background radiation annually in Harrisburg, and equivalent to the difference of living 2 weeks in Denver.

The radioactivity released during the accident entered the air, water, soil, and food, and could ultimately have become incorporated into the human body by breathing, swallowing, and absorbing it through the skin. This could result in an internal radiation dose to the tissues of the body. During the TMI accident, the identity and concentrations of radionuclides present in the environment were determined by the utility company and by the various federal agencies. Sampling analyses included milk, air, water, fruit and vegetable produce, soil, vegetation, fish, river sediment, and silt. Any increase in internal radiation dose due to radioactivity released during the accident came primarily from radioactive xenon-133, iodine-131, and cesium-137. Extremely small increases in the radionuclide concentrations of iodine-131 were reported in cows' and goats' milk, and in water and air; of cesium-137 in fish, and of xenon-133 and krypton-85 in aii. The highest doses due to ingestion and inhalation of iodine-131 would occur in the thyroid gland, since iodine concentrates in that gland. However, wholebody scanning of a large number of the general public living near TMI during the accident detected no radioactive iodine in this population; no radioisotopes related to the TMI accident were found.

The internal radiation dose due to ingestion of cesium-137 was negligible. The internal dose from inhalation of xenon-133 and krypton-85, primarily due to radiation exposure of the lung tissue, was only a small fraction of that of the external dose. Overall, the internal doses due to the radioisotopes released at TNT were negligible, and would have been only'a minute fraction of the average annual dose received due to naturally occurring, internally deposited radioisotopes in the body.

RADIATION DOSES TO THE WORKERS AT THREE MILE ISLAND

The radiation exposure to the nuclear plant workers during the accident at TMI came primarily from external radiation and some from internal radioactivity. Thermoluminescent dosimeters in badges were used to measure the external gamma and beta radiation doses. Before the accident, the collective dose to about 1,000 workers at TMI under normal operating conditions varied from about 20-150 person-rems each month. About 5,000 workers were on-site at some time during the March 28-June 30, 1979, interval; the majority received no recordable radiation exposure. Most of these additional workers were brought to the Three Mile Island plant during the accident and did not receive measurable exposures. About 1,000 workers received measurable doses of radiation -- that is, greater than 50 millirems during the accident. The collective dose for these 1,000 workers from the time of the accident on March 28, 1979, through June 30, 1979, was about 1,000 person-rems.

The average whole-body dose to these 1,000 workers was about one rem during this 3-month period. Two hundred and seventy-nine workers received more than 0.5 rem, but less than 3 rems of whole-body gamma radiation exposure; three workers received about 4 rems (on March 28 or 29); and none received more than 5 rems, the annual limit permitted. In addition to the three workers who received whole-body overexposures during the accident -- greater than a 3-rem whole-body dose per quarter -- two workers received overexposures to their hands of about 50 and 150 rems, respectively. The worker who received 150 rems to his fingers also received a whole-body dose of about 4 rems. No overexposures were recorded due to beta radiation. Whole-body counting of plant personnel was inaccurate, and the procedures and the collective records provided little reliable information on internal body doses of the workers. A few showed measurable levels of radioactive iodine-131 and cesium-137; it is probable that the radiation recorded by whole-body counting other than natural background was due to external contamination.

In spite of the high gamma radiation exposure rates of up to 1,000 R/hr 4/ measured in the auxiliary building on March 28, the radiation doses to the workers were quite low. However, the collective dose to the workers of about 1,000 person-rems will increase as the decontamination and recovery at the TMI plant proceeds. It is difficult to predict the eventual total collective dose, since that will depend on methods of decontamination and recovery of the containment building and the reactor vessel.

SUMMARY OF THE RADIATION HEALTH EFFECTS TASK GROUP REPORT

INTRODUCTION

The highly publicized events during the early days of the accident included: (1) the various releases of radioactive materials into the atmosphere and into the Susquehanna River; (2) the accumulation of hydrogen generated in the reactor-pressure vessel; and (3) the risk of major releases of large amounts of radioactive debris from the damaged nuclear core. These threatened the health and safety of the public and the workers, and led to concern about possible acute and delayed health effects of exposure to ionizing radiation.

Some release of low levels of radioactivity normally occurs into the environment during the routine operation of a nuclear reactor power plant. The accident at TMI set off a series of events that raised the threat of risks of much higher levels of radiation exposure of the public due to uncontrolled releases of radioactivity. Low-level ionizing radiations (e.g., radiation doses of a few rems or less) are thought to be able to contribute to three kinds of health effects. First, some of the cells injured by radiation may occasionally transform into potential cancer cells, and after a period of time there may be an increased risk of cancer developing in the exposed individual. This health effect is called "carcinogenesis." Second, if the embryo or fetus is exposed during pregnancy, sufficient radiation damage of developing cells and tissues may lead to developmental abnormalities in the newborn. This health effect is called "teratogenesis." Third, if radiation injures reproductive cells of the testis or ovary, the hereditary structure of the cells can be altered, and some of the injury can be expressed in the descendants of the exposed individual. This health effect is called "mutagenesis" or "genetic effect." There are other health effects of ionizing radiations, but these three important health effects -- carcinogenic, teratogenic, and genetic -- stand out because it is possible that low levels of radiation may increase the risk of these effects.

Much scientific information on these effects has been gained from animal experiments, and for carcinogenesis, from epidemiological studies of exposed human populations. Scientists generally believe or assume that any exposure to radiation carries some risk of carcinogenesis, or -- if reproductive cells are irradiated -- some risk of genetic effect, and that as the dose of radiation increases above low levels, the risk of these health effects increases in exposed human populations. These latter observations have led to public confusion and fear about the possible health effects of low-level ionizing radiation from the radioactive releases during the nuclear accident at Three Mile Island.

Radiation scientists are generally in close agreement on the following broad and substantive issues of such health effects:

- Cancer arising in the various organs and tissues of the body is the principal late effect in individuals exposed to low or intermediate levels of radiation. The different organs and tissues vary in relative susceptibility to radiation-induced cancer; the female breast, the thyroid gland (especially in young children and females), and the blood-forming organs (in regard to leukemia) seem to be more susceptible than some other organs.

- The deleterious effects on growth and development of the embryo and fetus are related to the stage at which the radiation exposure occurs. A threshold level of radiation dose may exist below which gross clinically evident developmental abnormalities will not be observed. However, these levels would vary greatly depending on the particular developmental abnormality.

- The paucity of data from exposed human populations has made it necessary to estimate the risks of genetically related ill-health based mainly on laboratory mouse experiments. Knowledge of fundamental mechanisms of radiation injury at the genetic level permits greater assurance for relating scientific information from laboratory experiments to man.

However, there is still very much scientists do not know about the potential health hazards of low-level radiation:

- We do not know what the radiation health effects, if any, are at dose rates as low as a few hundred millirems per year -- higher than natural background radiation. It is probable that if health effects do occur, they will be impossible to distinguish from similar effects owing to nonradiation related environmental or other factors.

- The epidemiological data on exposed human populations are uncertain regarding the dose-response relationships for various radiation-induced cancers. Since this is especially the case for low radiation levels, where no unequivocal data exist, it has been necessary to estimate human cancer risk at low radiation levels primarily from observations at relatively high radiation levels on the basis of various assumptions. However, it is not known whether the carcinogenic effectiveness observed at high radiation dose levels applies also at low levels.

- There are no reliable methods of estimating the repair of injured cells and tissues of the body exposed to low radiation doses, nor is it possible to identify persons who may be particularly susceptible to radiation injury (as, for example, a genetically determined increase or decrease susceptibility to radiation injury).

- All epidemiological surveys of irradiated human populations exposed in the past are incomplete with respect to ascertainment of cancer incidence in terms of providing a basis for analysis and conclusions, since there is only limited information on the radiation doses in some of these studies, and limited and incomplete data on cancer incidence and/or variable followup data.

- We do not know the role of competing environmental and other host factors -- biological, chemical, or physical factors -- existing at the time of exposure, or following exposure, which may affect and influence the carcinogenic, teratogenic, or genetic health effects of low-level radiation.

RADIATION-INDUCED CANCER

There are valid practical reasons for assuming proportionality in dose-effect relationships for the estimation of radiation-induced cancer risk in the general population exposed in the vicinity of TMI. It should be recognized, however, that the assumption that the risk for low-level gamma radiation (the predominant radiation exposure at TMI), is proportional to observed risk at high levels may overestimate the cancer risk; the actual risk would be much less. 5/ It is estimated that the number of excess fatal cancers, if any, that might occur over the remaining lifetime of the 2 million persons living within 50 miles of the nuclear power plant and exposed to an average whole-body dose of about one millirem is much less than one; a similar number is estimated for excess nonfatal cancers. These numbers are estimated to be only a very small fraction of the potential lifetime risk of radiation-induced cancer which may arise in this population from natural background radiation exposure.

The estimated number of cancer cases from all causes normally occurring in this population of about 2 million people over its remaining lifetime is 541,000 (325,000 fatal cancers and 216,000 nonfatal cancers). The estimated excess number of fatal and nonfatal cancers associated with the increase in radiation exposure due to the accident is extremely low, and could be zero; it would not be possible to detect or to distinguish this excess either in the population or in the individual. The number of excess cancers, if any, would be so small that it would not be possible to detect such an increase statistically in the more than half a million cancers that would occur in the population even if the TMI accident had not happened. Furthermore, cancers caused by radiation are no different from any other cancers resulting from other causes; therefore, a particular cancer cannot be distinguished as having been caused by radiation. The lifetime cancer risk in individuals exposed to maximum doses of approximately 50 mrems is about one or less chance in 100,000 for fatal and a like risk for nonfatal cancer, i.e., a total cancer risk of about two in 100,000, with zero not excluded. The additional radiation-induced risk of skin, lung, or thyroid gland cancer due to beta radiation and internally deposited radioisotopes is estimated to be extremely small, and may be regarded as encompassed within the cancer risk values expressed above for whole-body radiation exposure.

We conclude, therefore, since the total amount of radioactivity released during the accident at TMI was so small, and the total population exposed so limited, that there may be no additional detectable cancers resulting from the radiation. In other words, if there are any additional cancer cases, the number will be so small that it will not be possible to demonstrate this excess or to distinguish these cases among the 541,000 persons (of the 2 million population) living within a 50-mile radius of TMI, who would for other reasons develop cancer during the course of their lifetimes.

CONCEPT OF ESTIMATION OF RISK OF RADIATION-INDUCED CANCER

In all these calculations of the risk of radiation-induced cancer, several different methods have been applied for estimating the number of cancer cases that may be caused by the radioactivity released. While different methods may lead to different estimates, all of them arrive at a very small number -- less than one and possibly zero -- in 2 million people. For example, consider an estimate of "0.7 additional cancer deaths due to the released radioactivity." What does this mean?

The number 0.7 is an estimate of an average, which is a mathematical concept such as the one that appears in the statement: "The average American family has 2.3 children." In the case of TMI, what it really meant is that each of some 2 million individuals have a very small additional chance of dying of cancer, and when all of these very small probabilities are added up, they add up to the number 0.7. In such a situation a mathematical law known as a Poisson distribution (named after a French mathematician) applies. If the estimated average is 0.7, then the actual probabilities work out as follows: There is a roughly 50 percent chance that there will be no additional cancer deaths, a 35 percent chance that one individual will die of cancer, a 12 percent chance that two people will die of cancer, and it is practically certain that there will not be as many as five cancer deaths.

Similar probabilities can be calculated for the other estimates. All of them have in common the following fact: It is entirely possible that not a single extra cancer death will result from the radioactivity released during the accident at Three Mile Island. And for all the estimates, it is practically certain that the additional number of cancer deaths will be less than 10.

We know from statistics on cancer deaths that in a population of this size, eventually some 325,000 people will die of cancer, for reasons having nothing to do with the nuclear power plant accident. Again, this number is only an estimate, and the actual figure could be as much as 1,000 higher or 1,000 lower. Therefore, there is no conceivable statistical method known by which fewer than 10 additional deaths could ever be detected. A cancer caused by nuclear radiation is no different than a cancer from other causes. We conclude, therefore, that there may be no additional deaths due to this radiation, or if there are, they will be so few that it will never be possible to determine that even a single death occurred as a consequence of the accident at TMI.

GENETICALLY RELATED ILL-HEALTH

There is persuasive scientific evidence which suggests that if an average human population were exposed to one rem (1,000 millirems) of irradiation during their reproductive life span when they can produce children, we might expect to see about 5 to 75 cases of additional genetically related diseases (such as mental retardation or diabetes) in one million children born to the irradiated parents. Genetically related ill-health is extremely common in humans under normal conditions; about 10 percent of all live births are affected. Therefore, the increase due to 1,000 millirems of radiation would represent a very small number of cases of genetically related ill-health in addition to the 107,000 cases (an increase of only about 1 one-thousandth of one percent) of genetic disorders expected to develop in that newborn population.

Since there are no direct data from human epidemiological studies, the basis for this estimate comes mainly from laboratory experiments in which the reproductive cells of the testes and ovaries of mice are irradiated. That such experiments in mice have applicability to man is suggested by the following:

1. The hereditary material of life, or genetic material, of all organisms is chemically similar.

2. The reproductive cells of the testes and ovaries of mice are similar to those in humans and are expected to be pertinent for assessment of genetic ill-health due to irradiation.

3. Radiation, as well as a great many other toxic agents, can produce similar kinds of changes in the hereditary material in both the mouse and humans, both within the genes and chromosomes. These changes, or mutations, in the genes of the parents can, under certain circumstances, be transmitted to the offspring and thus result in inherited or genetically related diseases -- abnormal anatomical, physiological, or behavioral health conditions.

4. Many of the inherited diseases appear to have analogues in inherited diseases in mice.

Genetic mutations resulting in genetically related ill-health probably do not only come from exposures to radiation or chemicals. Most of the newly arising genetic mutations in humans result from unknown or as yet unidentified events, called "spontaneous mutations," within the reproductive cells that can lead to "mistakes" in genes when they are being formed and reproduced for newly formed reproductive cells. Natural background radiation in our environment appears to account for only a very small fraction of mutations resulting in genetic disease. We know very little about the precise contribution of chemicals in our environment to genetic ill-health. Radiation and other toxic agents will increase the probability of a genetic mutation occurring, but they will not produce any different kinds of genetic diseases than occur from other causes of mutations.

During the accident at Three Mile Island, the collective dose to the reproductive cells of the testes and the ovaries of the 2 million persons living within 50 miles of the plant was about 2,000 person-rems, with an average individual dose of one millirem. In this population, assuming a 30-year generation time, we would expect about 3,000 cases of genetically related ill-health among the approximately 28,000 live children born each year; these are unrelated to the radiation from the nuclear power plant accident. From an additional dose of one millirem above natural background radiation, we would expect about 0.0001 to about 0.002 additional radiation-induced cases of genetically related ill-health. This 0.002 case is an "average" number and is miniscule, representing less than 1 in 10 million live births. Furthermore, this may result ultimately in a total of no more than about one additional case of genetically related ill-health in a million liveborn children during all generations in the future. This number of "additional cases" is so small that it can never be detected or distinguished, if it does occur, among the cases of genetically related ill-health in each generation during all future human existence. We conclude, therefore, it is probable that there will be no detectable cases of genetically related ill-health resulting from the radiation exposure to the general population following the accident at Three Mile Island.

DEVELOPMENTAL ABNORMALITIES

Approximately 2,160,000 people live within a 50-mile radius of Three Mile Island; it is estimated that in this population, based on vital statistics data, about 28,000 children will be born in 1979. In this newborn population, about 300 children would normally be expected to be born with developmental abnormalities in the absence of any added radiation exposure as a result of the accident at TMI. The estimated average individual radiation dose to the fetus of pregnant women exposed during the accident (perhaps only onehalf of the one millirem) was below any threshold dose level known to cause detectable cases of developmental abnormality in the human embryo or fetus, or in laboratory animal experiments. In addition, the estimated dose may be too high, since many pregnant women left the area in the vicinity of the nuclear plant. And finally, if the maximum dose received by the workers were received by a pregnant woman working at the plant during the accident, the dose level to the fetus still would not exceed a threshold to cause any detectable developmental abnormality. We can conclude, therefore, that no case of developmental abnormality may be expected to occur in a new-born child as a result of radiation exposure of a pregnant woman from the accident at Three Mile Island.

SUMMARY OF THE BEHAVIORAL EFFECTS
TASK GROUP REPORT

INTRODUCTION

The highly publicized events during the first week of the accident -- the release of radioactivity into the atmosphere, the generation of a large hydrogen bubble in the reactor-pressure vessel, and the possibility of these events presenting a great threat to life -- led to the governor's advisories that all people living or working within a 10-mile radius remain indoors, and all pregnant women and preschool-age children living within 5 miles of the plant leave the area immediately. Nearby schools were closed. Plans were considered for evacuation of almost a third of a million residents. Although these plans were never carried out in the form of an official order, a large number of families decided to leave the area voluntarily.

OBJECTIVES

The overall objective of the Behavioral Effects Task Group was to examine the effects on the mental health, attitudes, and behavioral responses of the general population and the nuclear plant workers directly affected by the accident at Three Mile Island. Of particular interest were: (1) the behavioral response of the general population under stress during the accident; and (2) the behavioral response of the workers under stress during the accident. For the purposes of this study, the accident at TMI was considered to take place between March 28 and April 10, the date of reopening of the schools in the TMI area. During or shortly after the accident, several researchers from colleges and universities near the TMI site began sample surveys of the approximately 750,000 people living within 20 miles of TMI. Most of these studies employed reliable measures of psychological effects, with small but carefully drawn samples of the general population and/or high-risk groups, such as mothers of preschool children, within the general population. These studies formed the basis for identifying the immediate and short-term behavioral effects of the accident on the general population and several important groups within it.

To be of value to the Commission, the studies conducted by local researchers were focused and expanded. The Behavioral Effects Task Group located studies of high-risk groups in the general population and sought control groups from whom comparable data could be collected. Each comparison was selected in such a way as to provide an understanding of the mental health and behavioral effects from the time of the accident (in late March and early April) to September, when the findings of the Commission were to be analyzed and reported. The task force added a study of the nuclear workers, expanded data collection in previously begun studies of the general population and of mothers of preschool children, and added a study of the behavioral effects on 7th, 9th, and 11th grade students.

"Mental health" is a broad subject, and the data and limited time available for analyses made it possible only to cover narrow aspects of it. Though narrow, these aspects, centering on measures of psychological distress, upset, and demoralization,6/ are important and appropriate to what is known about the most characteristic responses to stress situations. Moreover, it has been possible to construct reasonably reliable measures of several other important behavioral effects.

The studies carried out by the Behavioral Effects Task Group are based on detailed surveys of about 2,500 persons from four different population groups: (1) the general population of male and female heads of households located within 20 miles of TMI; (2) mothers of preschool children from the same area and a similar "control" population from Wilkes-Barre, which is about 90 miles away; (3) teenagers in the 7th, 9th, and 11th grades from a school district within the 20-mile radius of TMI; and (4) nuclear workers employed at TMI at the time of the accident and a "control" group of workers from the Peach Bottom nuclear plant about 40 miles away. In addition, an interview study was conducted of clients at community mental health centers. These persons, most of whom were suffering from chronic mental disorders, provided valuable information that was used to identify unusually high scores on a measure of demoralization.

The study of household heads in the general population consisted of three different surveys. The first was studied in April 1979, directly following the accident; the second in May; and the third, and largest, in July. The mothers of preschool children from the TMI area were first studied in a sampling in May, and then in an additional sampling in July, at the time that a control sample of Wilkes-Barre mothers with preschool children was added. The study of the teenagers was carried out in the end of May. The study of the workers was begun in August and completed in the middle of September.

THE MAIN MEASURES OF MENTAL HEALTH, ATTITUDES, AND BEHAVIOR

A core of similar measures of mental health, attitudes, and behavior was used in each study, except for the study of teenagers, which was limited to specific measures of distress developed for that study. The areas covered by measures in the other three studies are: (1) recall of immediate upset at the time of the accident; (2) staying in or leaving the TMI area at the time of the accident; (3) demoralization since the accident; (4) perceived threat to physical health; (5) attitude toward continuing to live in the TMI area; (6) attitude toward nuclear power, including TMI; (7) trust in authorities; and (8) for the workers, their concern about the future of their occupation and their perceptions of hostility from the wider community.

In all the behavioral studies, the major measures of objective threat stemming from the accident were: (1) living within or living outside the 5-mile radius of TMI; and (2) having or not having preschool age children in one's family. For the workers, an added measure of objective threat was whether they worked at TMI, rather than Peach Bottom, at the time of the accident. For teenagers, an added measure was whether or not their families left the area following the accident, because this was a factor outside the control of the teenagers themselves.

- Demoralization was sharply elevated immediately after the accident, but dissipated rapidly among most groups. A substantial minority, about 10 percent of the household heads, showed severe demoralization right after the accident that was directly attributable to the accident itself. These 10 percent are an increase of about two-thirds over the 15 percent or so who would ordinarily show such a high level of demoralization for a variety of reasons other than the accident. The most demoralized persons were household heads and teenagers living within 5 miles of TMI, and mothers and teenage siblings of preschool children. Teenagers who left the area temporarily were more distressed than those who did not. Levels of demoralization among workers at TMI were high in comparison to Peach Bottom workers, and to males in the general population, several months after the accident.

- Although the perceived threat to physical health from the TMI accident was higher in the general population immediately after the accident than later on, most people were considerably reassured by July. Workers at both TMI and Peach Bottom also expressed a fairly low level of concern about the threat of their work situation to their physical health. However, workers at TMI were more uncertain about health effects than workers at Peach Bottom. Household heads living within 5 miles of TMI were more uncertain than those living outside. And mothers of preschool children in the TMI area felt more uncertain than mothers of preschool children in Wilkes-Barre.

- Feelings of the population within 20 miles of TMI about continuing to live in the area were mixed and uncertain. Relatively unfavorable attitudes, though still generally uncertain rather than negative, were expressed by people living within 5 miles of TMI, and by mothers of preschool children. The only group with somewhat negative attitudes were those at risk on two counts, mothers of preschool children who live within five miles of TMI.

- Attitudes toward nuclear power and reactivation of the TMI-1 and -2 nuclear power plants in the general population living within 20 miles of the plant showed uncertainty, with a leaning toward negative feelings. Mothers of preschool children expressed the most negative attitudes.

- Among people living in the 20-mile area around TMI, distrust of federal and state authorities and the utilities was high immediately after the accident. Although it was somewhat lower by May, as early as can be estimated, it continued to be higher than the average in the nation throughout the period of the study. Workers at both TMI and Peach Bottom, like the general population, expressed considerable distrust of federal and state authorities. They diverged from the general population, however, in expressing generally trusting attitudes toward the utilities.

- Workers at both TMI and Peach Bottom expressed fairly low levels of concern about the future of their occupation. They also were similar in perceiving people in their communities as holding less-than-positive attitudes toward them. Since there was no evidence of a difference between TMI and Peach Bottom on these matters, neither of these findings contributes to understanding the basis for the elevated level of demoralization among TMI workers that continued to be evident in August and through September, when the study ended.

In brief, the accident at TMI had a pronounced demoralizing effect on the general population in the TMI area, including its teenagers and mothers of preschool children. However, this effect proved transient in all groups studied except the workers, who continue to show relatively high levels of demoralization. Moreover, the groups in the general population and the workers, in their different ways, have continuing problems of trust that stem directly from the TMI accident. For both the workers and general population, the mental health and behavioral effects are understandable in terms of the objective realities of the threats they faced during the accident at TMI.

SUMMARY OF THE PUBLIC HEALTH AND EPIDEMIOLOGY TASK GROUP REPORT

INTRODUCTION

The Public Health and Epidemiology Task Group, in carrying out its investigation, addressed broad and substantive health issues, including the policies; practices; and procedures related to public and worker health and safety during the normal development and routine operation of a nuclear power plant, as well as during response to a nuclear accident. The task group report examines and discusses:

- The measures taken to prevent or minimize public and worker exposure to radiation from the nuclear power plant, and to prepare for protective actions in response to the potential health hazards during a radiological emergency.

- The designated authorities and responsibilities for these radiation-related health and safety matters at the federal, state and local agency levels, and in the utility.

- The means by which health-related responsibilities are implemented.

- The response of federal, state, and local health agencies during the accident at TMI.

GENERAL ISSUES

Activities specifically oriented toward the protection of the health of the public and nuclear workers from exposure to radioactivity from commercial nuclear power plants include: (a) promulgation, implementation -- monitoring and surveillance -- and enforcement of radiation protection standards, (b) siting of plants in areas of low population density; (c) surveillance for radiation-related health effects; and (d) preparation for response to radiological accidents through emergency planning, education, and available support resources.

The Nuclear Regulatory Commission (NRC) has primary responsibility for (and almost exclusive authority over) the health and safety issues in the operation of commercial nuclear power plants. The Public Health Service of the U.S. Department of Health, Education, and Welfare (HEW), whose primary responsibility is to protect and promote the health of the public, has some limited responsibilities for responding to a radiological emergency such as a nuclear reactor accident. HEW and/or other federal health-related agencies do not, however, have specific authority in radiological health matters relating to the location, construction, and routine operation of nuclear power plants; this authority rests almost exclusively with NRC.

Radiation Protection Standards

The Federal Radiation Council (FRC), established under the Atomic Energy Act, provided guidance to federal agencies in the formulation of radiation protection standards. In 1970, the FRC was dissolved and its activities transferred to the Environmental Protection Agency (EPA). The EPA sets allowable off-site radiation exposure levels; NRC standards for maximum exposures to individuals in the general population must be consistent with EPA standards. EPA provides guidance for radiation exposure to on-site populations; NRC, however, has sole authority to set occupational radiation standards in the commercial nuclear power industry. NRC chooses, by policy, to follow EPA guides on such exposures, but is not compelled to do so.

Radiation protection standards promulgated by the NRC take the form of (a) maximum permissible dose levels to individuals for on-site (worker) and off-site (public) populations, and (b) the design objectives for exposure levels that are "as low as reasonably achievable" (ALARA). Numerical standards are set for maximum permissible dose levels to individuals; no numerical levels are set for collective dose to the entire population, or for ALARA design objectives.

Off-site radiation exposure is monitored by means of mathematical models applied to radioactive emissions, and verified by direct environmental radiological measurements -- radiation sampling of air, soil, water, etc. The NRC regulations for environmental monitoring leave details and methods of implementation to the licensee -- the utility company -- subject to NRC regulation and inspection. The utility is required to report to the NRC radiation exposure levels that exceed natural background, and by an amount above prescribed maximum permissible limits. On-site radiation exposures are monitored by environmental dosimetry, air sampling, placed throughout the restricted area, and in designated locations in the nuclear power plant such as stack monitors.

Measurement of occupational exposure to radiation and reporting of radiation exposures are required by the NRC for nuclear plant workers, who, in the utility's judgment, are likely to receive at least 25 percent of the permissible dose in a quarter, a designated 3-month period in a year. The utility is required to report to the NRC (1) annual summary statistics on these occupational exposures; (2) cases of occupational overexposure; and (3) accumulated individual occupational exposure upon termination of employment. The NRC does not require data on workers' non-occupational exposure histories -- medical and dental x-rays.

Cost-benefit analysis is used by the NRC in making ALARA decisions about systems for off-site radiation dose reduction. During construction of a nuclear power plant, installation of safety features designed to reduce off-site exposures below the maximum permissible levels are to be considered by the untility in terms of the cost of installing the safety feature versus the benefit of dose reduction valued arbitrarily at $1,000 per person-rem. Cost-benefit analysis is not applied by the NRC for investment in safety features designed to reduce occupational exposure.

Worker Protection from Radiation Exposure

The primary goal of radiation protection in occupational health in the nuclear industry is to minimize the total radiation dose delivered to workers and thus to prevent any radiation health effects. Maximum permissible dose limits for individual workers are intended to ensure that the probability of harm is negligible for any one individual. This permissible dose for an takes into account the radiation dose from both a single exposure as well as that over a long period of time, the occupational lifetime of a radiation worker.

The basic principles of radiation protection of nuclear workers are directed toward achieving exposure reduction while carrying out the work that must be done. That is accomplished in three ways: time, distance, and biological shielding.

- Time. The mechanical and engineering design and the operation of a nuclear power plant are directed toward decreasing the time that plant personnel must spend in a radiation area in order to carry out the essential responsibilities and duties of their jobs. Because radiation exposure is the product of dose-rate and time, the reduction in time spent in the job results in a decrease in total radiation exposure.

- Distance. Radiation exposure is reduced with increasing distance from the source of the radiation. Thus, wherever possible, workers are kept at a distance from the source of radiation. Where tasks require that they be close to the radiation source, special equipment is frequently used to provide additional distance when carrying out their duties.

- Biological shielding. Physical shielding, such as walls, lead, concrete, etc., provides barriers to external radiation exposure so that work can be carried out in a safe area. For protection against ingestion of uncontained radioactive materials, a number of protective measures are used, including adequate ventilation to remove the radioactive materials from the worker environment, respirators that prevent the inhalation or ingestion of radioactive materials in the air, protective clothing to prevent absorption through the skin, etc.

The occupational exposure limit, the maximum permissible dose limit for nuclear workers covered under NRC regulations, limits radiation exposure to 3 rems (whole-body) per quarter, but permits 12 rems (whole-body) per year under certain circumstances. In 1977, among workers receiving a measurable dose in the United States, only a small proportion (270 out of 44,233 nuclear power plant workers) received doses greater than 5 rems. The average whole-body dose of reactor workers with measurable doses has been relatively constant, 640-870 rems annually since 1973

As summarized in the report of the Health Physics and Dosimetry Task Group, the occupational exposure experienced at TMI-1 and -2 prior to the accident indicated an average level of radiological protection. For the 14-month period from January 1978 through February 1979, the average radiation dose to the individual nuclear worker ranged from 38-126 rems per month; the numbers of nuclear workers who were exposed ranged from 569 to 1,179 per month. There is no record of any exposure of nuclear workers at TMI over the maximum permissible limits during any quarter prior to the accident.

Siting of Nuclear Power Plants

The NRC plant site-selection criteria established by regulation (10 CFR Part 100) require the following considerations for a proposed nuclear power plant site: (1) physical suitability of the site -- geology/seismology, hydrology, etc.; and (2) current and projected population density living in the surrounding area. Site suitability is also a function of estimated radiological consequences of a nuclear reactor accident. The applicant for an NRC license is required to assess the potential releases of radioactivity produced by a postulated design-basis accident. The magnitude of these potential releases is estimated on the basis of the engineered safeguards designed into the plant. The boundaries of the exclusion area -- the licensee's property -- and the low population zone (LPZ) -- the area surrounding the exclusion area, in which the population size and distribution is such that "appropriate measures could be taken in their behalf in the event of a serious accident" -- are identified by distances at which individuals would receive NRC-specified levels of radiation exposure in the event of the design-basis accident.

The radial distance of the LPZ is thus dependent on the engineered safeguards designed into the proposed nuclear power plant, and the capacity to take protective action on behalf of the people living in the area, in the event of a design-basis accident. The LPZ siting concept is incorporated into the NRC's emergency planning guidelines which direct the licensee to arrange for protective action for the people living in the LPZ in the event of a radiological accident.

Although NRC site-selection criteria must be satisfied, primary responsibility for nuclear power plant siting remains with the state and local authorities that maintain control over land-use decisions. An increasing number of states have established boards or commissions to review and approve siting of proposed power plants; in the absence of such an authority, plant siting decisions remain with local zoning boards and public utility commissions. There was no nuclear power plant siting authority in the state of Pennsylvania at the time the TMI nuclear power plant was being considered. An interagency state commission was created by lesiglation in 1978; the state Department of Health is not included in the membership of that interagency commission.

Radiological Health

Scientific information on the health effects of ionizing radiation is available from biomedical radiation health research, both from epidemiological studies of exposed human populations and from laboratory animal experiments. These data are continually examined by scientists in an effort to understand the relationship between radiation dose -- particularly exposure to low levels of radiation -- and adverse health effects. Although there is general consensus on the health effects of high radiation doses, little is known about the effects of exposure to low doses. A number of federal agencies fund such biomedical research -- in fiscal year 1978, $76.5 million was spent by the federal government. Of this amount, the Department of Energy (DOE) provided 63 percent, and the Department of Health, Education, and Welfare (HEW), provided 20 percent. The balance of funds were provided by the departments of Agriculture and Defense, the NRC, the EPA, the Veterans' Administration, and the National Aeronautics and Space Administration (NASA). DOE funded 78 percent of all federally supported human health effects research ($13.6 million); more than half of this was allocated for followup studies of the Japanese A-bomb survivors in Hiroshima and Nagasaki.

The NRC has sole regulatory authority over radiological health matters directly related to the workers in commercial nuclear power plants. No other federal health agency, including the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA), has authority in these matters. The NRC requires medical examinations of all applicants for initial or renewal nuclear reactor operator licenses to assure "the physical condition and general health of the applicant are not such as might cause operational errors endangering the public health and safety." This NRC regulation and its accompanying guide do not address the use of required medical examinations for detection of possible radiation-related health effects, nor do they require medical examination of workers other than licensed reactor operators.

<u>Response to Radiological Emergencies</u>

During a nuclear power plant accident, emergency preparedness to Protect the public health and safety involves a number of health authorities and a variety of federal, state, and local agencies and activities. Major efforts in this area include the following:

1. The NRC requires the utility to maintain site emergency plans that include: (a) procedures for on-site management of emergencies; (b) protective actions, including evacuation of personnel; (c) arrangements for on-site and off-site emergency medical care for injured contaminated workers; (d) arrangements for notifying off-site emergency preparedness agencies of a radiation incident at the reactor site; and (e) assurance of the capability of off-site agencies to take protective action on behalf of the LPZ population. The utility is required to have annual drills of its site emergency plan, and to improve the plan based on critiques of the drill. The NRC provides guidance, review, and concurrence on emergency plans developed by states to respond to radiological emergencies. There are no requirements placed on states to prepare and maintain such plans; however, and the NRC has not made concurrence of state plans a condition of nuclear power plant licensing.

2. Protective action guides (PAGs) are provided by federal agencies to assist states in developing emergency plans and responding to radiological emergencies. The EPA indicates levels of airborne radioactivity at which protective action, such as evacuation, should be considered. The HEW PAGs indicate: (1) levels of radioactive contamination of food and animal feed at which protective action should be considered; and (2) plans for prevention of adverse health effects of exposure, including use of radioprotective agents such as potassium iodide.

3. Federal assistance in the event of a peacetime nuclear emergency is available through the Interagency Radiological Assistance Plan (TRAP), which was developed in 1961. DOE is designated lead agency in the agreement, and is responsible for administering and implementing the plan. DOE has available, on request, the resources of TRAP signatory agencies, namely the Defense Civil Preparedness Agency, the departments of Agriculture, Commerce, Defense, HEW, Labor, and Transportation, the EPA, Interstate Commerce Commission, National Aeronautics and Space Administration, NRC, and the Postal Service. DOE also has its own Radiological Assistance Program (RAP) which, in collaboration with the DOE network of national laboratories, such as Brookhaven National Laboratory and Oak Ridge National Laboratory, provides technical assistance to the states on request.

The Use of Thyroid-Blocking Agents for Protection of the Public

An important constituent of a release of a large quantity of radioactive materials to the environment would be a number of isotopes of radioiodine, which could affect large numbers of people after the incident. Engineered safequards, in the form of elaborate technical and chemical systems in the plant, are used to protect the public from radioiodine and other radionuclides by preventing the dissemination of these radioactive materials to the environment. There are a number of chemical agents known to mitigate the consequences of radioactive materials once taken into the body. However, only the use of stable iodide, as a thyroid-blocking agent to prevent thyroid uptake of radioiodines, is considered sufficiently safe and reliable for human use.

Other thyroid-blocking agents are available as countermeasures against radiation, including other ionic agents such as thioyanate and iodate, and organic anti-thyroid agents that are used clinically -- propylthiouracil -- but iodide (as potassium iodide, KI) appears to be the most useful and effective, with the least side effects. Iodide is the most suitable form for thyroid-blocking purposes in humans.

Over the past 20 years, there has been increasing interest in the potential of protective actions for alleviating some of the health effects of the release of radioactive materials in the event of a nuclear reactor accident. Protective actions relating to the release of radioiodine have received considerable attention -- particularly the administration of natural iodine in a form that would block the admission of radioactive iodine by the thyroid gland. The pharmacology of the blocking action of iodide has been known for about 25 years, and the efficacy of its use in humans for some 15 years. In 1977, the National Council on Radiation Protection and Measurements (NCRP) published a study on "Protection of the Thyroid Gland in the Event of Releases of Radioiodine." In this report, the NCRP: (1) considers the feasibility of utilizing thyroid-blocking agents for protection of the public in case of off-site releases; (2) defines the efficacy of such agents and the contraindications for their use; and (3) assesses the potential for use of thyroid-blocking agents. However, the NCRP does not take any position concerning the question of utilizing blocking agents in any given situation.

In the summary and recommendations of the NCRP report,.three important principles are presented: (1) "A major protective action to be considered after a serious accident at a nuclear power facility involving the release of radioiodine is the use of stable iodide as a thyroid-blocking agent;" (2) "If the initial estimate at the facility indicates that the thyroid total absorbed doses of 10-30 rad or more are projected, the blocking agent should be administered immediately to employees at the facility and to other support personnel coming to or working near the facility;" and (3) "For people beyond the immediate vicinity of the reactor, the decision to administer stable iodide (to the general public), to instruct them to remain indoors, or to evacuate them would depend on the type of accident, on preplanned estimates of release, on wind direction, and, later, on monitoring data as they become available."

Potassium iodide (U.S. Pharmacopeia) is approved for human use. Because the recommended daily dose of iodide to large numbers of persons would require a considerable amount of the chemical agent, it would have been necessary to develop an appropriate form of the agent -- KI stockpiled for emergency use only in the event of release of radioiodines from a nuclear power reactor. The U.S. Food and Drug Administration (FDA) has reviewed the problem and in December 1978 published, in the Federal Register, a notice to establish requirements for manufacture of potassium iodide to be stockpiled for emergency use. At the time of the TMI accident, no pharmaceutical firm had responded to this notice for meeting analytical controls and stability requirements for manufacture of the drug. Thus, no commercially available thyroid-blocking agent for human use was available in large enough quantities to protect the general public at the time of the TMI accident.

SPECIFIC ISSUES -- THREE MILE ISLAND NUCLEAR STATION

Metropolitan Edison

Administrative, health physics, and personnel policy procedures at Metropolitan Edison (Met Ed) define the health and safety practices in effect during routine and emergency operations of the TMI nuclear power plant.

1. Routine environmental monitoring of radioactivity at TMI follows NRC regulations. At the time of the accident at TMI, thermoluminescent dosimeters were in place at 20 locations around the site. Environmental sampling of air, soil, river, and rain water is conducted routinely. Met Ed reports a summary of all environmental monitoring through General Public Utilities Corporation (GPU) to the NRC annually.

2. The personnel radiation dosimetry program at Met Ed follows NRC regulations. Procedures for medical evaluation at Met Ed, however, contain features which exceed those required by NRC. For example, Met Ed health physics procedures require pre-employment and biannual medical examinations of <u>all</u> radiation workers -- those in jobs that could result in exposures up to 300 millirems or more in a quarter -- for the detection of radiation-related health effects, and for baseline data to be used in evaluating any potential health effects resulting from accidental overexposures. Met Ed does not retrieve past medical records of new

employees, and does not request information on past or present non-occupational radiation exposure such as medical and dental x-rays.

3. Met Ed conducts two types of emergency drills during routine operations to prepare for possible plant accidents. One type, which is designed to test the site emergency plan, is conducted once a year. Representatives from off-site agencies may observe and critique the on-site drill, but their actual participation is limited to testing the notification system. A second type is designed to test the on-site emergency medical care procedures. This annual drill involves simulation of worker injuries involving contamination that require on-site emergency treatment, decontamination, and transport to the Hershey Medical Center in Hershey, Pa. Two community physicians are retained by Met Ed to provide on-site emergency care. Both these physicians have participated in drills only as observers; neither has administered emergency medical care under simulated or actual contaminated conditions.

NRC regulations for health physics training of nuclear reactor workers leave the curriculum requirements to the discretion of the utility. No specific criteria or guidance are offered by the NRC on training course content, frequency, attendance testing procedures, etc. Met Ed conducts a series of such health physics training courses; participation at these courses is required for personnel at several different levels.

RESPONSE TO THE ACCIDENT AT THREE MILE ISLAND

Utility Response to the Accident

A number of health-related problems emerged during the accident at TMI. These included:

1. The number of functioning protective respirators available was inadequate -- some workers who were respirator-qualified were required to use respirators for which they had not been fitted or tested, and respirators also were used by some workers who were not respirator-qualified.

2. Certain essential dosimetry instruments located in the health physics laboratory were inaccessible due to high radiation levels in the area.

3. There was no potassium iodide available at the nuclear plant in the event of radioiodine exposure of workers; the agent was obtained on the first day of the accident and stored for possible future use.

4. Met Ed did not notify its radiation emergency medical services (community physicians and the Hershey Medical Center) of the accident to ensure their readiness to respond and to apprise them of the current status and the potential seriousness of the accident.

State Response to the Accident

States have primary responsibility for protection of the public health and safety. The accident at TMI revealed that the state health and health-related agencies, as well as the TMI-area medical care facilities, had insufficient resources to respond effectively to the actual and potential threat to the health and safety of the public and the workers. A number of problems were evident.

1. Responsibility for radiological protection in Pennsylvania rests with the Department of Environmental Resources. At the time of the TMI accident, the Pennsylvania Department of Health had no specific authority or capability for radiological protection of the public, and no formal liaison existed between the two agencies. The state secretary of health had to appoint a private medical consultant to advise him on radiological health matters that arose during the accident.

2. The state environmental radiological monitoring capacity at the time of the accident consisted of only a few thermoluminescent dosimeters placed alongside utility dosimeters to verify routine measurements of radiation levels; no emergency response capability for environmental monitoring existed at the state level. Once off-site exposures were detected during the accident, the state called the DOE/RAP for help in environmental monitoring.

3. Pennsylvania required emergency planning for areas within 5 miles of a nuclear power plant. The 5-mile area around TMI did not include any hospitals. The hospitals within a 10-mile radius did not have emergency plans for radiation accidents at the time of the TMI incident. Few hospitals were prepared to receive and treat patients with serious radiation injuries or contamination. Contingency plans for limited patient treatment and for patient evacuation were developed during the initial days of the emergency. In addition, there were no directives given by the governor or the secretary of health on protective actions to be taken by health-care facilities during the accident. For example, decisions on whether and how to evacuate hospitals and nursing homes in the area were left to the administrators of those facilities. Similarly, when the emergency subsided, no directives were given on when and how to terminate the protective actions that had been taken voluntarily by health-care institutions and individuals.

4. Pennsylvania had no plans for procurement, distribution, or use of potassium iodide as a thyroid-blocking agent for the general public in the event of a radiological emergency. After the state received potassium iodide supplies from HEW during the accident, the State Department of Health chose to store the drug rather than provide it to distribution points within the community of TMI.

Federal Response to the Accident

Several federal agencies responded to the accident at TMI, each with some responsibility to protect the public health and safety. The NRC assumed responsibility at the TMI site at mid-day Friday, March 30, 1979, to provide advice to the governor on protection actions, such as evacuation, to assist in the reactor accident management, to provide technical assistance and advice, and to attempt to prevent any further radioactive releases into the environment. DOE and the EPA provided technical assistance and advice on radiological monitoring and surveillance. HEW provided technical assistance and advice on a variety of health matters, including environmental radiological monitoring and protective action -- the provision of 250,000 vials of potassium iodide as a thyroid-blocking agent in the event of large releases of radioactive iodine into the environment.

A second level of response by HEW took the form of deliberations and recommendations on health-related matters by Washington-based health officials. During the accident, HEW officials in Washington repeatedly expressed a desire to consult with NRC officials on the public health implications of any NRC decisions relating to large-scale evacuation from the area and to actions taken to bring the damaged reactor to a safe condition. Although meetings were held with both HEW and NRC representatives, these were informational briefing sessions rather than consultative on health issues. Although HEW was a party to the TRAP, the plan was not followed and apparently not known to all the Washington-based health officials; because the accident involved an NRC-licensed facility, DOE did not notify the other federal agencies, but left this responsibility to the NRC. In general, the initial and continuing notification and involvement of HEW during the accident was arranged mainly on an ad hoc basis.

The HEW health officials in Washington made two recommendations concerning protection of the public health and safety. The first was the recommendation to the White House that consideration be given to evacuation of all persons living within 20 miles of the plant, and that residents of the area be notified of a possible evacuation. This decision was based primarily on the uncertainty of the status of the damaged reactor, and the time that would be available to evacuate the area in the event of further releases of radioactivity. The second decision concerned recommendations for the immediate administration of potassium iodide to the TMI workers, and the distribution of vials of potassium iodide to the general population. Each of these HEW decisions had been made without consultation with Pennsylvania state officials or the governor. Furthermore, they were made with only limited information on the status of the reactor accident, on the emergency response at the state and local levels, and on the concomitant activities of other federal and state health-related agencies. It remains unclear whether the HEW recommendation on evacuation was transmitted beyond the White House. The recommendations concerning distribution and use of potassium iodide, however, were sent to the governor, although they were contrary to the decisions of the Pennsylvania Secretary of Health and his advisor on the disposition of the potassium iodide. The HEW recommendations were viewed as directives by the Pennsylvania Secretary of Health; this led to direct conflict with HEW officials.

Direct assistance was also provided by the HEW personnel in the vicinity of TMI. This involved a variety of activities including: (a) placement of dosimeters in the TMI area to supplement environmental monitoring of radioactive releases by other agencies; (b) continuous sampling of food, milk, and water for radioactive contamination; (c) procurement and delivery of supplies of potassium iodide sufficient for the population living within 20 miles of the damaged plant; (d) training of federal radiation health physicians if needed; and (e) assessment of the personnel dosimetry records for the workers at the TMI plant in the event that followup epidemiological studies of these workers would be considered.

NOTES

1/ A curie is the unit of intensity of radioactivity; it is named after Marie and Pierre Curie, who discovered radium in 1889.

2/ Noble gases, such as helium, neon, krypton, xenon, and radon, are gaseous elements which do not undergo chemical reactions when taken into the body. At TMI, the amount of radioactivity released into the environment has been estimated to be from 2.4 to 13 million curies, consisting almost entirely of xenon-133.

3/ Some scientists have reported much higher estimates of the population dose, but their estimates were not supported by the investigation of the technical staff of the Commission.

4/ R, or roentgen, is the unit of radiation dose in air, and for the types of radiations emitted during the TMI accident, an R is equivalent to a rem; it is named after Wilhelm Conrad Roentgen who discovered x-rays in 1896.

5/ The Committee on the Biological Effects on Ionizing Radiation (BEIR) of the National Academy of Sciences -- National Research Council is presently examining the complex problem of low-level radiation health effects in human populations; the BEIR committee report is not yet complete and thus not available for use by the President's Commission.

6/ "Demoralization" is the term used by Dr. Jerome Frank to describe the psychological symptoms and reactions a person is likely to develop "...when he finds that he cannot meet the demands placed on him by his environment, and cannot extricate himself from his predicament" (1973). Demoralization can coincide with diagnosable psychiatric disorders, but may also occur in the absence of such disorders. The various sources of the intractable predicaments include, for example, situations of extreme environmental stress such as combat or natural disasters; physical illnesses, especially those that are chronic; and crippling psychiatric symptoms of, for example, the kinds associated with severe psychotic episodes. Hence, an elevated score on a scale measuring demoralization is something like elevated physical temperature: It tells us that there is something wrong; it does not in itself tell us what is wrong.

REPORT OF THE
PUBLIC HEALTH AND SAFETY TASK FORCE

ON

HEALTH PHYSICS AND DOSIMETRY

BY

HEALTH PHYSICS AND DOSIMETRY TASK GROUP

John A. Auxier,
(Task Group Leader)
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Carol D. Berger
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Charles M. Eisenhauer
National Bureau of Standards
Gaithersburg, Maryland

Thomas F. Gesell
School of Public Health
University of Texas
Houston, Texas

Alun R. Jones
Atomic Energy of Canada, Ltd.
Chalk River, Ontario

Mary Ellen Masterson
Memorial Sloan-Kettering
Cancer Center
New York, New York

October 1979
Washington, D.C.

PREFACE

The main body of this report is written to be understood by the layperson; thus, it may appear to suffer from a lack of scientific rigor. For example, the rad and rem, in general, differ numerically, and always differ from the roentgen; for the particular radiations of interest for the accident at Three Mile Island, they differ by only about 10 percent, which is small in comparison to some other uncertainties. The appendices are somewhat more technical in presentation, although lay language has been used whenever possible. The lay reader is referred to the glossary for the technical definitions in this report.

TABLE OF CONTENTS

I. SUMMARY

The primary task of this group was to determine the radiation doses that the worker population and the general public within a 50-mile radius of Three Mile Island (TMI) received as a result of the incident that began on March 28, 1979. Estimations were made for dose to the whole body, lung, thyroid, skin, and extremities; details and calculational techniques for the estimations are included in the body and appendices of this report.

The whole-body dose to the population was estimated through thermoluminescent dosimeter (TLD) measurements and through the use of computer modeling of radioactive releases from the plant as they dispersed in the environment. Two different figures for the most likely collective population dose within a 50-mile radius of the plant between the dates of March 28, 1979, and April 15, 1979, were obtained. These numbers are 2,800 person-rems (by TLD measurement) and 500 person-rems (by computer modeling). Insufficient time has elapsed to analyze the possible areas of difference between these two techniques, but the task group has not eliminated either number as incorrect. For this report and for the use of other task groups, the stated current best value of collective dose is the more conservative one -- 2,800 person-rems. The fact that the most probable collective dose lies below 2,800 person-rems cannot be ruled out.

This collective dose of 2,800 person-rems is applicable to those who remained outdoors during the first few days of the accident. There is some protection afforded by staying inside, as most people did, and therefore the actual dose, incorporating a shelter factor, is estimated to be 2,000 person-rems.

The collective dose to TMI plant personnel from the day of the accident to the end of June 1979 is approximately 1,000 person-rems based on analysis of personnel dosimeter data. The maximum whole-body dose received by an individual was 4.2 rems.

Based on the above and additional dose calculations from internal deposition of radionucludes (determined by environmental and effluent sampling), average exposure levels to various organs and the whole body are summarized in Table 1 and in the body of this report. Discussions of calculational, analytical, and other details are included in the various appendices.

The health physics and monitoring program was reviewed extensively. As might be expected, it has both important strengths and weaknesses. The task group found that considerable work in this area had been done by contractors, that the overall monitoring program was aimed at documenting routine releases as opposed to those due to accidents, and that normal maintenance of instruments and housekeeping were below the standards for a good health physics program.

TABLE 1: Comparison of Natural Backgrounds, NRC Guidelines, and Actual Exposures from the TMI Accident.

Critical Organ	Average Normal Background Levels(1)	Average Levels Attributed to TMI Accident	Maximum Permissible Limit*	Collective Dose
Whole-Body (general population)	100-150 mrem/year	<20 mrem (2)	500 mrem/year	2,000 person-reins
Whole-Body (occupational)	100-150 mrem/year	ti1000 mrem (3, 4)	3 rem/quarter	1,000 person-reins
Extremity Dose (occupational)	100-150 mrem/year	50 rem (5) 150 rem (5)	18.75 rem/quarter 75 rem/year	
Extremity Dose (general population)	100-150 mrem/year	0	3 rem/year	
Skin Dose (general population)	100-150 mrem/year	<20 mrem (6)	7.5 rem/year	
Thyroid -- Adult (general population)	100-150 mrem/year	0.6 mrem (7)	3,000 mrem/year	
Thyroid -- Infant	100-150 mrem/year	6.9 mrem (7)	1,500 mrem/year up to 16 years of age	
Thyroid -- Adult (occupational)	100-150 mrem/year	52.8 mrem	30 rem/year	

* Based on 10CFR-20 and ICRP-9.

(1) Note that annual person-reins due to the natural radiation environment within 50 miles of TMI is 0.12 x 2 million=240,000 person-reins.

(2) 260 people on the east bank of the river may have received between 20 and 70 mrem; almost all due to noble gases. Dose to lung tissue slightly greater for persons inhaling the noble gases (see Appendix F, Table F-6).

(3) This value is average for personnel with slightly measurable exposure. Many personnel had no exposure above background.

(4) Maximum dose noted was 4.2 reins (4,200 mrem).

(5) Only two over-exposures identified. The worker who received 150 reins to the fingers also received 4.2 reins whole-body dose.

(6) No data available for assessment but the added dose due to beta-rays is assumed to be insignificant (see section VIII).

(7) From ingestion of cow's milk. This is not an average over the entire population as very few people drank contaminated milk.

(8) From inhalation. Not a population average. Dose to the population beyond 10 miles from the plant site is probably somewhat lower than these values (see text).

II. INTRODUCTION

The objectives of the Health Physics and Dosimetry Task Group were:

- To determine the dose distribution and total doses to the population within a 50-mile radius of TMI for the period of March 28 to April 15, 1979 -- the great bulk of the off-site exposure occurred by April 15.

- To determine the dose distribution and total doses to persons working in the plant between March 28 and June 1, 1979 -- occupational exposures are reported monthly, and the June 30 figures were the latest available at the time this analysis was done.

- To evaluate the health physics and monitoring program, and related functions of the facility and its contractors.

- To state findings of deficiencies.

The chapters of this report are intended:

- To describe the sequence of events bearing on health physics, dosimetry, and environmental monitoring.

- To evaluate all TLD data and plot these to show lines of approximately equal dose -- technically, dose lineg.

- To determine the rate of release of radioactivity from the station vent (stack) and the total amount of radioactivity released through April 15, 1979.

- To assess the various potential physical and physiological pathways for radioactivity to get into the bodies of people within a 50-mile radius of TMI and to estimate the doses to the population for these pathways.

- To estimate the dose distribution and total dose to the population due to the accident.

- To evaluate the health physics and monitoring procedures in use by the plant at the time of the accident.

The following chapters address these objectives in a general way. The appendices provide detailed technical discussions where needed.

III. SEQUENCE OF EVENTS

DATE	TIME	EVENT	REFERENCE
3/28/79	4:00- 6:18 a.m.	Reactor coolant pressure drops after reactor trip, resulting in emergency core cooling system (ECCS) initiation.	Nuclear Regulatory Commission (NRC)- Sequence of Events (SOE)
3/28/79	4:38 a.m.	Operator turned off reactor coolant sump pump. (8,120 gallons pumped into auxiliary buildings.)	NRC-SOE
3/28/79	5:42 a.m.	Condenser pump exhaust sampled. Activities indicate a primary-to-secondary leak.	NRC-SOE
3/28/79	6:00 a.m.	Richard Dubiel suspects core damage occurred.	Dubiel (interview)
3/28/79	6:02 a.m.	Radiation chemistry technician (Rad/Chem) sampled reactor coolant; Gross S-y analysis a factor of 10 from normal activities (indication of fuel failure?).	NRC-SOE
3/28/79	7:01 a.m.	Fuel-handling building exhaust iodine monitor downstream of filters (HPR-221B) reached alarm setpoint.	Strip Charts NRC-SOE
3/28/79	7:02 a.m.	Shift supervisor phoned Pennsylvania Emergency Management Agency duty office -- informed him of site emergency and requested that Pennsylvania State Bureau of Radiological Health (PSBRH) be notified.	NRC-SOE
3/28/79	7:13 a.m.	First call to Radiation Management Corporation (RMC), one of the licensee's health physics (HP) consultant firms (no information of topics of discussion).	General Public Utilities Corp- ation (GPU) F. Rocco, RMC (interview), NRC- SOE
3/28/79	7:15 a.m.	Brookhaven National Laboratory (BNL) notified of incident by personnel at power station. Suggested interagency radiological team go on alert status.	BNL Chronology

DATE	TIME	EVENT	REFERENCE
3/28/79	7:15 a.m.	Rad/Chem tech toured auxiliary building and told emergency workers (repair party and monitoring team) to evacuate.	NRC Interview
3/28/79	7:15 a.m.	N. Greenhouse received Inter-agency Radiological Assistance Program (TRAP) call from BNL police. His return call to R. Bensel at TMI revealed the situation. Greenhouse advised to have IRAP team stand by, but not respond at this time.	**N. A.** Greenhouse (interview)
3/28/79	7:24 a.m.	General emergency declared by station manager when dome monitor exceeded 800 R/hr.	NRC Emergency Status Board
3/28/79	7:25 a.m.	Met Ed on-site radiation monitoring team dispatched.	GPU Chronology
3/28/79	7:32 a.m.	Spent fuel demineralizer area monitor (SFR-3402) on 305 feet of elevation of auxiliary building reads 250-900 mR/hr.	NRC Interviews
3/28/79	7:35 a.m.	Stack monitor (HPR-219) retched alarm setpoint (2.8 x 10 pci/cc or 0.3 uci/sec. release).	Strip Chart
3/28/79	7:48 a.m.	Initial survey made by Met Ed in downwind direction to the west side of the island.	NRC-SOE
3/28/79	7:55 a.m.	Met Ed on-site team reports less than 1 mR/hr. at Till north gate.	GPU Chronology
3/28/79	7:56 a.m.	On-site radiation monitoring team reports less than 1 mR/hr. at western boundary site.	GPU Chronology
3/28/79	8:00 a.m.	Met Ed requests that the radiological environmental monitoring program be increased to the maximum regime.	GPU Chronology
3/28/79	8:00 a.m.	There was a 2 mph wind at 90 degrees which shifted at 11:47 a.m. to 150 degrees and 6 mph.	Mr. McCool, SOE (interview)

DATE	TIME	EVENT	REFERENCE
3/28/79	8:12 a.m.	Results of first air sample collected on the island, but outside the plant, a single-channel portable NaI detector reveals less than minimum detectable activity (MDA).	NRC Interviews
3/28/79	8:18 a.m.	Isolation achieved by reactor containment due to 4 psig pressures.	Line Printer/ NRC-SOE
3/28/79	8:30 a.m.	Radiation protection foreman contaminated after trip to TMI-2 auxiliary building via 305 feet elevation.	NRC Interviews
3/28/79	8:30 a.m.	Stack monitor (HPR-219) charcoal cartridge changed.	NRC Interviews
3/28/79	8:30 a.m.	Some on-site readings of 7-14 mR/hr. reported by Met Ed team. Off-site, less than 1 mR/hr. with a few locations of 1-3 mR/hr.	GPU Chronology
3/28/79	8:42 a.m.	Met Ed Emergency Plan fully implemented. All communications made, accountability completed. Teams monitoring off-site and on-site on east and west shore. Full flow of information to PSBRH.	GPU Chronology
3/28/79	9:22 a.m.	Air sample take} in Goldsboro showed 1 x 10 pci/cn10 of 1-131. (MPC = 1 x 10 pci/cc.)	NRC-SOE
3/28/79	10:45 a.m.	PSBRH notified of first off-site exposure rates (3 mR/hr.). Location unknown.	T. Gerusky (interview)
3/28/79	11:00 a.m.	M. Reilly (PSBRH) requested BNL-IRAP assistance in response to second call by C. Meinhold of BNL.	N.A. Greenhouse/ T. Gerusky/BNL Chronology

*inaccurate reading due to high Xe-133 levels.

DATE	TIME	EVENT	REFERENCE
3/28/79	11:00 a.m.	NRC calls DOE Emergency Operations Center requesting TRAP assistance.	DOE/IRAP Chronology
3/28/79	11:10 a.m.	The Island was evacuated of all non-essential personnel.	NRC/Licensee Log
3/28/79	11:25 a.m.	On-site readings 5-10 mR/hr. (with high of 365 mR/hr. on western boundary site). Off-site readings began to show some increases with average readings on Route 441 and on west shore of 1-5 mr/hr. and high of 13 mR/hr. at Kunkel School (west-northwest of site on east shore approximately 6 miles away).	GPU-SOE
3/28/79	1:30 p.m.	DOE air and ground radiological assistance team.	DOE-Deutch Report TRAP Chronology
3/28/79	1:50 p.m.	Reactor containment pressure spike noted on strip chart.	Line Printer/ NRC-SOE
3/28/79	1:50 p.m.	First hydrogen explosion in containment.	GPU/DOE
3/28/79	2:00 p.m.	BNL helicopter with IRAP team reaches vicinity 4 to 4-1/2 miles due north of TMI at 1,500 feet. A helicopter mounted rotor blades positioning alarm sounded. This monitor can be activated by external S-y fields. Observation of stack plumes in the area indicated that the aircraft was approximately downwind of TMI.	N.A. Greenhouse (interview)
3/28/79	2:00 p.m.	BNL team lands at Capital City airport and makes a set of initial measurements.	BNL Chronology/ DOE-Deutch Report
3/28/79	2:15 p.m.	DOE-AMS helicopter arrived and began tracking the plume.	NRC-SOE
3/28/79	2:27 p.m.	Off-site readings in Middletown indicated 1-2 mR/hr. Air samplers detected levels of 1-141 airborne activity in 10 uci/cc_gange with a high of 1.2 x 10 uci/cc in Middletown square.	GPU Chronology

DATE	TIME	EVENT	REFERENCE
3/28/79	2:30 p.m.	BNL-IRAP team began air sampling with radioiodine monitor and standard hi-volume air sampler on the flight-line on the south side of Capital City airport buildings. Location was approximately 30 degrees west of the prevailing wind vector from TMI at the time.	**N. A.** Greenhouse (interview)
3/28/79	3:28 p.m.	Reading of 50 mR/hr. recorded off-site on Route 441 east of plant by Met Ed.	GPU Chronology
3/28/79	4:00-6:00 p.m.	On-site readings 50 mR/hr. range with a high of 210 mR/hr. at northwest boundary at 5:20 p.m. On-site air samples indicated up to 2 x 10 pci/cc 1-131. Off-site readings less than 1 mR/hr. wit# air samples of up to 9.6 x 10 Wi/cc 1-131.	GPU Chronology
3/28/79	4:45 p.m.	Phone report from TMI to M. Reilly (PSBRH) reported radiation levels at the north gate of the plant increasing from 30 mR/hr. to 50 mR/hr.	**N. A.** Greenhouse
3/28/79	4:45 p.m.	AMS called M. Reilly (PSBRH) and reported 230 KeV lines from Xe-133m dominant in the plume, which occupied an approximately 30 degree sector centered directly north of TMI.	**N. A.** Greenhouse
3/28/79	6:00 p.m.	BNL team reports air radioiodine activity to less than MDA (1 x 10^{-5} Wi/cc). Sample taken in plume read 2 mR/hr. at a point 5 miles north of plagl. Later analyzed to be 6 x 10 pci/cc 1-131.	BNL Chronology
3/28/79	6:00 p.m.	BNL team surveyed plume downwind from the plant. Peak radiation levels were 1-2 mR/hr. at distances 5-10 miles from the plant. Radiation levels variable depending on plume height and direction.	BNL Chronology

DATE	TIME	EVENT	REFERENCE
3/28/79	7:43 p.m.	On-site readings begin to decrease to 10-20 mR/hr. range w/high reading of 42 mR/hr. behind TMI-1 warehouse. Off-site readings less than 1 mR/hr.	GPU Chronology
3/28/79	10:30 p.m.	H. Hahn (NEST) notified DOE that the plume was traveling out 7 miles from the plant.	DOE-Deutch Report
3/28/79	Midnight	On-site readings increased to 10-30 mR/hr. range with 150 mR/hr recorded in front of service building. On-site samples indicated positive 1-131 airborne activity.	GPU Chronology
3/28/79	Midnight	BNL sampling and direct measurements stopped. Basis was less than 1,000 mR whole body dose and less than 500 mR thyroid dose from 1-131 (as recommended by EPA). This information was important in the state's determination that no protective actions were required.	BNL Chronology
3/28/79	Midnight	On-site readings less than 20-30 mR/hr. with high of 150 mR/hr. at 5:32 a.m. at western boundary fence. Off-site reading less than 1 mR/hr. with no detectable 1-131 airborne activity.	GPU Chronology
3/29/79	Noon	On-site readings generally 5-10 mR/hr. Off-site readings close to west shore with no detectable 1-131 airborne activity.	GPU Chronology
3/29/79	During Day	Collected TLDs which had been exposed for 3 to 6 months by Teledyne, Inc., and RMC; distributed more TLDs.	Met Ed

DATE	TIME	EVENT	REFERENCE
3/29/79	9:37 a.m.	NEST flight: Plume area 30 degrees wide in northern direction (west edge) Rutherford Heights/Lingustown (east edge). Seeing mostly Xe-133, 0.1 mR/hr.	DOE-Deutch Report
3/29/79	All Day	Food and Drug Administration (FDA) initiated collection of food and water samples. Sent to FDA's Winchester Engineering and Analytical Center (WEAC) for analysis.	FDA/BRH Chronology
3/29/79	1:18 p.m.	On-site readings 1-5 mR/hr. with high reading of 40 mR/hr. at north parking lot.	GPU Chronology
3/29/79	3:00 p.m.	Met Ed pulled TLDs from 17 fixed positions located within a 15-mile radius of the site. TLDs had been in place for 3 months.	NRC PN-67E
3/29/79	4:00 p.m.	Bettis Atomic Power Lab TRAP team starts support activities.	IRAP Chronology
3/29/79	4:00 p.m.	BNL returns to Brookhaven on basis of low plume levels (origin of directive for departure of BNL unknown).	BNL Chronology
3/30/79	Midnight - 11:55 a.m.	On- and off-site readings generally less than 0.5 mR/hr. Some on-site readings 1-30 mR/hr. in downwind direction with some intermittent readings as high as 80-100 mR/hr. with 6 mR/hr. recorded at Goldsboro at 4:25 p.m. and 5:16 p.m.	GPU Chronology
3/30/79	5:35 a.m.	Fire in TMI-1 auxiliary building (picked up from intercom). Fire in ventilation system.	NRC-Region I Log
3/30/79	6:00 a.m.	AMS helicopter detects 1.2 R/hr. in plume over reactor building (time approximate).	DOE-Deutch

DATE	TIME	EVENT	REFERENCE
3/30/79	7:10 a.m.	TMI-2 began venting its make-up tank to vent header. Release to environment was expected. Met Ed's radiation monitoring team positioned in downwind direction and Met Ed helicopter positioned directly over TMI-2.	GPU Chronology
3/30/79	7:22 a.m.	Releases due to venting of TMI-2 make-up tank reached 100 mR/hr. at west fence. A few helicopter readings 600 feet above the plant reached 150-180 mR/hr. Off-site readings close to plant dropped off and were generally less than 2 mR/hr.	GPU Chronology
3/30/79	7:56 a.m.	Helicopter readings of 1 R/hr. over TMI-2 at 600 feet.	GPU Chronology
3/30/79	7:59 a.m.	Helicopter readings of 400 mR/hr. at 600 feet over TMI-2.	GPU Chronology
3/30/79	8:00 a.m.	Helicopter reading - 150 mR/hr. at 700 feet over TMI-2.	GPU Chronology
3/30/79	8:01 a.m.	Radiation levels recorded by helicopter, directly over TMI-2 at 600 feet, were 1,200 mR/hr. On-site rate increased to 10-30 mR/hr. on west boundary. Off-site locations close to plant increased to 5-18 mR/hr.	GPU Chronology
3/30/79	8:05 a.m.	Helicopter reading of 11 mR/hr. at 600 feet over west shore.	GPU Chronology
3/30/79	9:06 a.m.	After make-up tank venting, off-site reading of 13 mR/hr. on west shore directly south of the Island. Met Ed feels that, in conjunction with meteorology data, this was the maximum off-site dose rate due to tank venting.	GPU Chronology
3/30/79	6:00 p.m.	BNL receives call to place TRAP team on alert by Bettis personnel. Team departed for Harrisburg.	BNL Chronology

DATE	TIME	EVENT	REFERENCE
3/30/79	7:45 p.m.	Air sample a~ Observation Center read 1 x 10 Vci/cc 1-131 airborne activity.	GPU Chronology
3/30/79	8:00 p.m.	Argonne personnel arrive.	DOE-Deutch Report
3/30/79	8:00 p.m.	Helicopter reading of 1,200 mR/hr. at 600 feet over TMI-2.	GPU Chronology
3/31/79	1:30 a.m.	60-100 mR/hr. in auxiliary boiler area.	GPU Chronology
3/31/79	2:25 a.m.	150 mR/hr. at east site boundary.	GPU Chronology
3/31/79	During Day	Collected Teledyne and RMC TLDs after 2-day exposure; distributed more TLDs. Distributed first batch of NRC TLDs.	Met Ed/NRC
3/31/79	During Day	EPA and FDA/BRH distribute TLDs.	FDA/BRH; EPA
3/31/79	9:00-Noon	Off-site readings increased to 5-10 mR/hr. range with high readings of 35 and 38 mR/hr. recorded at 9:27 a.m. and 9:32 a.m. on Route 411, northeast of TMI-1-B cooling tower.	GPU Chronology
3/31/79	11:15 a.m.	100 mR/hr. at east site boundary.	GPU Chronology
3/31/79	1:00 p.m.	BNL team obtained samples of soil, water, and vegetation. Direct radiation level measured at each sampling site which was 0.1 mR/hr. or less. No radio-iodine found.	BNL Chronology
3/31/79	2:10 p.m.	Plume top at 2,800 feet - bottom at ground level. 1.5 mR/hr. at 300 feet from site; 0.2 mR/hr. at 10 miles, at 1,800 feet - AMS flight.	DOE-Deutch Report
3/31/79	2:37 p.m.	56 mR/hr. at east site boundary.	GPU Chronology
3/31/79	5:00 p.m.	Initial field placement of FDA TLD packets.	FDA/BRH Chronology

DATE	TIME	EVENT	REFERENCE
4/1/79	During Day	Collected NRC TLDs after 1-day exposure; NRC distributed more NRC TLDs.	NRC
4/1/79	During Day	NRC established 37 TO stations at distances from 1 to 12 miles from plant.	NRC PN-67H
4/1/79	12:50 p.m.	Bettis sample analysis of reactor coolant bleed (sample of 3/31/79). Isotope — uCi/cc Xe-133 — 1.18 -2 Xe-133m — 3 x 10 2 2 Xe-135 — 1.35 x 10 Cs-137 — 1.5 x 10 2 -2 Ba-140 — 7.9 x 10	NRC-Region I Incident Response Form Tapes 3-1
4/2/79	During Day	Collected and distributed 1-day NRC TLDs. Lead shielding was used for first time to prevent exposure during distribution and collection.	NRC
4/3/79	During Day	Collected and distributed 3-day Teledyne and RMC TLDs. Collected and distributed 1-day NRC TLDs.	Met Ed/NRC
4/4/79	During Day	Collected and distributed 1-day NRC TLDs.	NRC
4/4-4/8/79		Daily urine samples collected from 33 residents living close to the plant. Sent to National Institutes of Health (NIH) for analysis. Results negative.	FDA/BRH Chronology
4/5/79	During Day	Collected and distributed 1-day NRC TLDs.	NRC
4/6/79	During Day	Collected and distributed 3-day Teledyne and RMC TLDs. Collected and distributed 1-day NRC TLDs.	Met Ed/NRC
4/7/79	During Day	Collected 1-day NRC TLDs.	NRC
4/9/79	During Day	Collected and distributed 3-day Teledyne and RMC TLDs.	Met Ed
4/12/79	During Day	Collected and distributed 3-day Teledyne and RMC TLDs.	Met Ed

DATE	TIME	EVENT	REFERENCE
4/15/79	During Day	Collected and distributed 3-day Teledyne and RMC TLDs.	Met Ed
4/18/79	During Day	Collected TLDs that had been deployed for 3-1/2 months; later read out by RMC for state of Pennsylvania and by Idaho National Engineering Laboratory for DOE.	D. Beaver, PSBRH (letter)

IV. POPULATION DOSES BASED ON TLD MEASUREMENTS

Estimates of total dose to the population are based on measurements from thermoluminescent dosimeters (TLDs) that were in place at the time of the accident and processed by several different organizations. Dosimeters were provided by Teledyne, Inc., and were placed at 20 locations at distances ranging from 0.2 mile to 15 miles from TMI. Additional TLDs were supplied for 10 of these locations by Radiation Management Corporation (RMC) and at four of these locations by the U.S. Department of Energy (DOE) and RMC. The state of Pennsylvania deployed and recovered the latter four sets. In addition to the dosimetry systems that were in place at the time of the accident as a part of routine monitoring programs, federal agencies deployed additional dosimeters beginning on the third day of the accident. The Nuclear Regulatory Commission (NRC) deployed dosimeters at 47 sites, the U.S. Department of Health, Education, and Welfare's (HEW) Bureau of Radiological Health (BRH) deployed 237 dosimeters at 173 sites, and the U.S. Environmental Protection Agency (EPA) deployed dosimeters at 59 sites and on 54 persons.

The procedures for calibration, processing, and reading these dosimeters were reviewed. Adjustments were made for estimated background values and energy dependence. Data from TLDs placed by NRC on the third day of the accident were rejected because the handling procedures were inappropriate for this evacuation. Because of their late deployment and distance from the source, the dosimeters placed by the other two federal agencies did not provide useful data.

The population distribution used to calculate the collective dose is based on projection of 1970 census data to the year 1980, as given in the Final Safety Analysis Report (FSAR) for TMI-2. Adjustments were made to account for the fact that only one person is known to have been at the many summer cottage sites on the islands near the plant at the time of the accident.

The doses measured by the TLDs would be applicable to people who were outdoors all during the first few days of the accident. Because most people spent most of that time indoors, some protection can be assumed due to absorption of gamma radiation in the structural materials of houses and offices. It is estimated that the average dose received indoors is about three-quarters that of outdoors (See Appendix C).

Persons within a 2-mile radius of the plant probably received the highest doses. The dose to the one person known to have been on one of the nearby islands for about 9-1/2 hours during the first few days of the accident is estimated to be about 50 millirems (mrem). In addition, about 260 people living mostly on the east bank of the river, may each have received between 20 and 70 mrem. All other people probably received less than 20 mrem.

In estimating health effects of low doses to a population, it is important to know collective dose -- the sum of the doses received by every person in the affected area. This is usually given in units of person-rems. The collective dose was calculated by multiplying the average dose at each of 160 areas surrounding the TMI plant by the population in that area and summing the products. The average dose in each area was estimated by interpolating between the locations at which TLD measurements were available. The collective outdoor dose to people within a 50-mile radius of TMI was calculated to be about 2,800 person-rems. Assuming that doses indoors were three-quarters of those received outdoors, the actual collective dose to the population is estimated to be 2,000 person-rems (see Appendices B and C).

V. RADIOACTIVITY RELEASED

As part of the general objectives of the task group, the dose to the general population was assessed by determining the total release of radioisotopes from the auxiliary building stack and using computer models of the release rate with time, taking into account meteorological and population distribution data. The source term, or release rate with time, was inferred from the response of a stationary gamma radiation monitor located at the base of and external to the stack. This monitor was chosen because its location was closest to ideal for calculation of a proportional release rate and because it did not go off-scale at any time during the incident. This detector also was less influenced by stationary sources of radiation, such as filter banks, which would have increased the error in calculation. Total release during the period from March 28, 1979, to April 15, 1979, was calculated to be 2.4 million curies, with the relative concentration of the various isotopes calculated from an assumption about reactor core inventory at the time of the reactor shutdown (see Appendix D).

VI. CALCULATED POPULATION DOSES BASED ON RADIOACTIVITY RELEASED

A series of computer programs, which form a model of the dispersion of the source term, were generated at Oak Ridge National Laboratory, Lawrence Livermore Laboratory, and the Tennessee Valley Authority Environmental Laboratory. It must be stressed that computer modeling is only an approximation of real events, and that a degree of uncertainty is associated with its use. In their original form, two of the models used to calculate collective population dose were not ideally suited to the unique meteorological and release-rate situation during the TMI incident, but with appropriate program modifications these models, nonetheless, gave values of about a 390- and 980-person-rem collective dose to the unshielded population within a 50-mile radius of the TMI plant. The third computer model was better suited to manipulation of real-time release and meteorological data. It served as a basis for calculating a collective unshielded population dose of 276 person-rems within a 50-mile radius of the TMI plant. This calculation was extended over a period of 9 days (March 28 to April 5) from the start of the accident -- over 95 percent of the dose was experienced during this interval.

There are many variables that influence the final calculation of collective dose by this means. These variables lead this task group to the conclusion that results could be in error by as much as an order of magnitude. Bearing these variables in mind, the task group's best estimates of the most likely collective population dose within a 50-mile radius of TMI, from March 28 to April 15, 1979 (by this technique), is 500 person-rems. The most likely upper value is 5,000 person-rems. The most likely lower value is less than 50 person-rems (see Appendix D).

The average dose to the skin from beta radiation could be as much as a factor of four higher than the whole-body gamma dose if any given person were submersed in the plume; the maximum permissible dose to the skin is a factor of six higher than that to the whole body. Based on this factor, the fact that a person situated within the plume would have some shielding by clothing, the fact that no accurate method existed to determine points of plume touchdown, and the fact that there were no reported measurements of integrated beta dose from TLDs, this task group did not attempt to assess the contribution of beta irradiation to skin dose. The ratio of beta dose to permissible limit, however, is assumed to be small in comparison to the ratio of gamma dose to permissible limit.

VII. ANALYSIS OF DOSES DUE TO INHALED AND INGESTED RADIOISOTOPES

In addition to the dose delivered by external radiation, an internal dose can be produced by radionuclides that have been incorporated into the human body. The pathways by which radionuclides enter the body include inhalation, ingestion, and absorption through the skin. Upon entry, the degree to which nuclides systemically are incorporated depends on many factors, including concentration and chemical form of the nuclide, and the dietary habits, general health, and body weight of the individual. Once inside the body, the amount of dose a person receives depends on the nuclide, its distribution in the body, body size, and the rate at which the nuclide is eliminated from the body. Because these factors can vary widely from person to person, it is very difficult to assess with great certainty the dose to any single individual. However, based on knowledge of the factors associated with the average healthy person, a useful estimate of internal dose can be made.

To determine the identity and concentrations of radionuclides present in the environment at TMI, environmental sampling programs were undertaken by a variety of organizations. The organizations that supplied data to the Commission staff included Teledyne, RMC, NRC, EPA, HEW, and DOE. Representatives from these groups sampled such things as milk, air, water, produce, soil, vegetation, fish, river sediment, and silt in the TMI vicinity.

The environmental sampling data collected during the accident at TMI have been reviewed and statistically analyzed. These data were compared to data obtained prior to the accident -- from Jan. 1, 1978, to Dec. 12, 1978, during the course of routine radiological monitoring in the TMI vicinity. On the basis of this comparison, it is concluded that, as a result of the accident, increases in radionuclide concentrations occurred in the following areas (values are average measured concentrations):

- Iodine-131 in cows' milk (9.4 picocuries/liter);
- Iodine-131 in goats' milk (30 picocuries/liter);
- Iodine-131 in nondrinking water on-site (10.2 picocuries/liter);
- Iodine-131 in air off- and on-site (45 picocuries/cubic meter, 5.8 picocuries/cubic meter);
- Cesium-137 in fish (0.35 picocuries/gram);
- Xenon-133 in air off- and on-site (25 picocuries/cubic meter, 4,900 picocuries/cubic meter); and
- Krypton-85 in air off- and on-site (20 picocuries/cubic meter, 70 picocuries/cubic meter).

The methods used for calculating internal dose as well as the measured environmental concentrations are explained in Appendix F. In dealing with environmental sampling d:'a, each measurement has an associated minumum detectable limit (MDL) -- the smallest level of radiation that can be detected above background. In the data reported from the various organizations at TMI, the majority of the values were negative -- below MDL. The actual concentrations of radionuclides in these samples are not known. If one arbitrarily assigns a value of zero, or the MDL, to the large number of negative samples, the weighted average can be seriously biased to be too high or too low. Too low an average would be obtained if a value of zero were assumed. Too high an average could be obtained if MDLs were assumed in cases where one organization reported many negative values with an MDL much higher than the positive values reported by other organizations. In the light of these considerations, doses were calculated based on the mean positive values (average of values above MDLs). Although considered to be the most prudent assumption, the internal doses calculated based on mean positive concentrations are likely to be overestimates.

In the case of noble gases, the environmental sampling data were insufficient for dose calculation. Upper limits of internal dose due to noble gases have been based on the assumption of continuous plume touchdown.

INTERNAL DOSE DUE TO IODINE-131

Calculations were performed to determine the dose due to ingestion and inhalation of iodine-131 based on the concentrations measured in milk samples and in the air on and after March 28. Because iodine concentrates in the thyroid gland, the highest doses occur in the thyroid. A summary of internal doses due to iodine-131 is given below.

Intake Mode	Organ	Dose (mrem)
cows' milk ingestion	newborn thyroid	6.9
	1-year-old thyroid	4.7
	adult thyroid	0.6
	ovaries	0.00002
	testes	0.00002
	red bone marrow	0.00009
	total body	0.0003
inhalation (off-site)	newborn thyroid	2.0
	1-year-old thyroid	6.5
	adult thyroid	5.4
	ovaries	0.0002
	testes	0.0001
	red bone marrow	0.0007
inhalation (on-site)	adult thyroid	52.8
	ovaries	0.002
	testes	0.001
	red bone marrow	0.007
	total body	0.03

The doses given for cows' milk ingestion are estimates of the dose that would result if an individual consumed one liter of cows' milk per day for 46 days.

In the case of inhalation of iodine-131 off-site, it should be noted that most of the air sampling took place within 3 miles of TMI. Therefore, the dose estimates are valid only for the population level in this region. The dose received by people living more than 10 miles from the plant was probably somewhat lower.

INTERNAL DOSE DUE TO CESIUM-137

Because cesium is an analogue of potassium, it does not concentrate in a single organ the way iodine concentrates in the thyroid. Instead, it distributes nearly uniformly throughout the body. A person eating one kilogram (2.2 pounds) of river fish containing cesium-137 at the average concentration measured would receive a dose of 0.02 mrem over the total body.

INTERNAL DOSE DUE TO RADIOACTIVE NOBLE GASES

Although noble gases are inert chemically, they are soluble in body tissues. It is mistakenly believed that they can enter the body and produce an internal dose only when the radioactive gases are at ground level and are inhaled. On the contrary, a cloud of radioactive gases can deliver an external gamma dose whether it is elevated or at ground level. Therefore, in order to estimate with confidence the internal dose due to noble gases, knowledge of ground level concentrations is necessary. Unfortunately, only 35 environmental measurements of noble gas concentrations in air were reported from April 5 to April 25. Based on TLD measurements and knowledge of the sequence of events at TMI, one can infer that a significant fraction of the releases took place prior to April 4. Therefore, sampling data are insufficient for the estimation of internal dose due to noble gases.

An alternate approach, described in detail in Appendix F, has been taken. EPA data identified the presence of xenon-133 and krypton-85 in the TMI vicinity. On the average, EPA measured xenon in concentrations 70 times higher than krypton. Because xenon has a physical half-life much shorter than that of krypton (5 days versus 11 years) and because EPA's earliest measurements were taken on April 4, one can infer that much more xenon than krypton was released. This is consistent with knowledge of the reactor core inventory. If a person were immersed in a cloud of xenon-133, then, of course, an external gamma dose would be delivered to the individual. The internalization of some xenon would cause the total-body dose to be increased over the external total-body dose by 0.6 percent. The dose to the lungs would be increased by 6 percent. If, therefore, the TO indicates that the maximum external gamma dose received by an individual is 50 mrem, and if that dose was due to continous total immersion of that individual in a cloud of xenon, then total-body internal dose would be 50 times 0.006, which equals 0.3 mrem. Similarly, internal lung dose would be 50 times 0.06, or 3 mrem. Therefore, internal dose due to inhalation of xenon is small compared to the external dose.

DOSES DUE TO NATURALLY OCCURRING, INTERNALLY DEPOSITED RADIONUCLIDES

In order to gain some perspective on the doses due to internalization of radionuclides released during the accident at TMI, one may compare these doses to doses due to naturally occurring, internally deposited radionuclides. The average annual dose to a man in the United States due to internal radiation is approximately 27 mrem to soft tissue -- including thyroid and gonads -- 60 mrem to bone surfaces, 24 mrem to red bone marrow, and 124 mrem to the lungs. (The value of 124 mrem to the lungs includes dose due to inhalation of naturally occurring radioactive gases such as radon.)

WHOLE-BODY COUNTING OF THE GENERAL POPULATION

As part of the methodology used to assess internal dose to the general population within a 50-mile radius or TMI, NRC contracted Helgeson Nuclear Services, Inc., to perform a series of whole-body counts. The whole-body counts were conducted on 760 residents who lived within 3 miles of TMI; no radioisotopes related to TMI were found. The only isotopes identified and quantified by the whole-body counting facility were naturally occurring ones, including radium and its daughter products, which were found in 60 percent of those counted. Levels were on the order of 6.48 ± 4.7 nCi. The highest level noted was 32 ± 9 nCi. Even though these nuclides are unrelated to TMI, and the levels -- if they are real and accurate -- are low, investigation into the situation led to some interesting observations.

The radium body burdens were only noted at certain times of the day and when weather and wind conditions were stable. In addition, no correlation between the levels of radium and age or body size was found. One would expect to see higher body burdens in large adults. The conclusion is that the majority of the observed radium body burdens can be attributed to background fluctuations seen by the whole-body counter detector, not to internally deposited radium. In essence, the data indicates that no TMI-related nuclides were found in the residents, and that the radium body burdens were merely artifacts of counting (see Appendix E).

VIII. ANALYSIS OF DOSES RECEIVED BY PERSONNEL WITHIN THE PLANT AREA

Doses absorbed by workers at a nuclear power station come from external radiation, beta and gamma rays, and from absorbed radioactivity. External radiation is monitored with personnel dosimeters carried by the workers. Absorbed radioactivity is measured with a whole-body counter or urine analysis.

TLDs were used to measure the gamma- and beta-ray doses at TMI. They were read during the first few days of the accident by Met Ed staff using an automatic TLD reader. On March 30, a second TLD reader was received from the manufacturer -- the Harshaw Chemical Company. Two manufacturer's representatives accompanied the delivery. Before their arrival, one technician, who had little relevant experience, operated the reader continously for 48 hours.

Although the measurement of external doses and the records must be viewed with caution because of the problems that have been noted, the doses were measured and a summary of the records follows.

The two most important aspects of dose to a working population are:

- o the collective dose (person-rem); and
- o the number and size of doses to workers that exceed NRC quarterly and annual dose limits (3 and S rems, respectively) for whole-body exposure.

Table 2 shows how these aspects of external whole-body doses were affected by the accident.

The sum of the collective doses through the end of June is about 1,000 person-rems. The total will continue to grow beyond June 30, 1979, as the decontamination at TMI proceeds. It is difficult to predict the eventual total, because this will depend on decisions to be made about decontamination of the containment building and the reactor vessel.

In addition to the whole-body overexposures described in Table 2, two workers received overexposures to their hands. These doses have been estimated by the NRC at about 50 and 150 rems. The worker who received 150 rems to his fingers also received a whole body dose of about 4 rems. In the light of the gamma-exposure rates measured in the auxiliary building, up to 1,000 roentgens/hour on March 28, the reported doses to workers at TMI were not high.

Whole-body counting of plant personnel at TMI was performed by two subcontracted facilities, in order to aid in assessing internal dose. The isotopes identified were normal background isotopes within the body, such as potassium-40 and cesium-137, and varied fission products were quantified at such large amounts -- 23,000 nanocuries of iodine-131 were recorded in one subject -- that a detailed analysis of over 7,000 counts was warranted. Examination of the data ultimately resulted in an inability to reach conclusions with regard to the techniques of the whole-body counting facilities. Visual inspection of each facility confirmed this fact.

There appeared, to this task group, to be such a problem with external body contamination of many subjects, cross-contamination (from subjects to the vault), inadequate subtraction of background radiations, and poor housekeeping that it was impossible to assess accurately internal dose by this means. Because the task group did not have access to individual names or useful identifying numbers, it was not possible to trace a specific subject's body count when high levels of any given isotope were revealed. It was, therefore, impossible to verify the data.

Aside from this problem, each facility's choice of electronics settings raises doubts as to whether they can measure adequately the typical fission products found around a nuclear power plant in normal operation. There also were many instances of each facility failing to identify a significant amount of a given isotope.

With a few minor but important changes in their techniques, it is well within the capability of each of the two whole-body count facilities to do an adequate job of monitoring the internal doses of the plant personnel. These changes should be made as soon as possible, because the proposed clean-up process at TMI will require accurate internal as well as external personnel dosimetry (see Appendix E).

TABLE 2: Collective Doses Experienced by Those Occupationally Exposed at TMI

Month	Collective Dose (person-rem)	Number of Workers Within 0.5-3 rems	Number of Workers Within 3-5 rems	Number of Workers 5 rems
Background*	20-150	0.70**		
March 1979	334	221	3^^^	0
April 1979	140	49	0	0
May 1979	351	7	0	0
June 1979	157	2	0	0

*Typical range of occupational exposures prior to the accident.

**Implies that typically less than one worker per month is exposed in the range of 0.5-3 rems.

***Considered overexposures.

IX. REVIEW OF HEALTH PHYSICS AND MONITORING PROCEDURES IN USE AT TMI AT THE TIME OF THE ACCIDENT

In most aspects, the health physics (HP) and monitoring procedures for TMI are typical of a number of large nuclear facilities in the United States. For the facilities that fall under the regulatory control of the NRC, the minimum requirements are specified in 10 CFR Parts 20, 50, and 75. During the licensing process and during startup and operation, the procedures and their implementation are subject to continued review by NRC inspectors from the Office of Inspection and Enforcement (NRC/I&E). This insures that the procedures meet minumum requirements and are followed to a sufficient degree to satisfy the NRC/I&E inspectors.

The task group was disturbed repeatedly by general problem areas at TMI that are not subject to quantitative evaluation by NRC/I&E and that, in general, should not need to be regulated in a formal manner; they are normally handled as an aspect of HP professionalism. These problem areas include the following:

- An exceptional percentage (well over half) of health physics and monitoring instruments were not functional at the time of the accident (reference 1).
- The quality of the general housekeeping throughout the plant area is poor. One general characteristic of a good health physics program for nuclear power plants is absolute cleanliness and freedom from unnecessary equipment and trash in areas subject to contamination.
- An unusually high percentage of health physics work, especially the environmental monitoring, is done by other firms under contract with Metropolitan Edison Company (Met Ed). A check with chief health physicists at four other nuclear power stations verified that TMI depends much more strongly than most other nuclear power plants on contracted work. Much of the work so contracted actually is performed by still other firms. For example, in the course of this investigation, the diffusion of responsibility made it necessary to hold discussions and return for discussions with staff from Met Ed, Porter-Gertz, RMC, and Helgeson Nuclear Services, Inc., in order to investigate the whole-body counting work.

The staff of this task group is of the opinion that the high percentage of inoperable instruments could have contributed to difficulties in getting data during the first several hours of the accident before the Radiological Assistance Program (RAP) teams began to arrive, and to difficulties in achieving good health physics techniques with regard to plant personnel safety. It is not possible to specify particular difficulties resulting from these.

Decontamination of the facility could be more difficult, and the amount of contaminated materials to be disposed of could be increased if the containment building was as unkempt as the rest of the plant. As it cannot be inspected, this is, of course, speculation.

Also, the task group staff is of the opinion that better control of the overall health physics and monitoring programs could have been maintained and all data could have been more readily and quickly available, if more of the work had been accomplished by the Met Ed staff and if fewer contractors had been involved.

X. TASK GROUP FINDINGS

GENERAL

- The nuclear power station emergency plans did not specify important locations in terms of a nationally consistent set of geographical coordinates. If such coordinates were given, it would be possible during the period following an accident to locate all places and facilities that could be expected to be affected by the accident.

- The stationary radiation monitors at TMI did not have sufficient radiation rate ranges to monitor both routine operations and accident levels. The final stack monitors were especially important for analysis and were not supplemented with monitors in each major duct leading to the stack. Flow rates for gases in these ducts and in the stack should be recorded continously.

- The professional and technical health physics staff was not adequate to provide full support for emergency operations during the early stages of the accident. A multiplicity of contractors and subcontractors was used to provide both routine and emergency support.

HEALTH PHYSICS

- The emergency control center for HP operations and the analytical laboratory for use in emergencies were located in an area that became uninhabitable in the early hours of the accident. It is important that a shielded area where an uncontaminated air supply can be maintained is available for this purpose.

- The supply of instruments, respirators, and other support equipment that should have been available for emergency conditions was inadequate, partially due to lack of maintenance. Approximately 50 percent of the portable instruments were out of service at the time of the accident (reference 2).

- In addition to having an inadequate supply of general health physics instruments, the power station was lacking a rapidly available high-resolution spectrometry system to provide immediate identification of radionuclides in air samples, water samples, surface swipes, etc.

- The whole-body counting facilities used at TMI were not operated by personnel with sufficient training to adjust the system to nuclear power station needs under accident conditions. Lack of proper housekeeping, electronic manipulations, and inaccurate interpretation of results were noted. Consideration was not given to fluctuating background interference in the final calculations of body burden.

ENVIRONMENTAL MONITORING

- The environmental TLD monitoring program did not provide a particularly good basis for post-accident evaluation of doses. The program was designed for monitoring routine low-level releases; there were too few areas in which measurements of the early releases from the accident could be made.

- The number of stations with TLDs in place before and during the accident was inadequate for assessing the dose to the population with an uncertainty of less than a factor of two. In 3 of the 16 compass sectors, there were no stations (see Appendix B, Figure B-1). No stations were located beyond a radius of 15 miles. This resulted in inadequate coverage near large population centers (see Appendix A, Figure A-3; Note: City names are for identification and do not indicate the presence of TLD stations). The estimated dose in the city of Harrisburg, which contributed about 25 percent of the collective dose, is based on TLD reading at one station.

GLOSSARY

<u>Alpha radiation</u> - Extremely short-range but damaging type of radiation. Physically, an alpha particle is a helium nucleus and, generally speaking, cannot penetrate the dead skin layer. Alpha-emitting materials must be incorporated into the body before they can damage.

<u>Background radiation</u> - The radiation present in nature -- uranium and thorium deposits, radioactive natural potassuim, and cosmic rays. The cumulative dose from these sources is usually about 100-200 mrem per year, but can reach levels of 1,000-1,500 mrem per year in some regions.

<u>Beta radiation</u> - An intermediate penetrating form of radiation. Physically, a beta particle is an electron that can travel several feet in the air. Beta-emitting materials can cause exposure internally or externally; they are generally not important except when incorporated into the body.

<u>Biological half-life</u> - The time required for the body to eliminate one-half of a radioactive or stable substance. For example, tritium has a radiological half-life of about 12 years, but a biological half-life of only about 10 days.

<u>Body burden</u> - The amount of radioactive material that would give a member of the public a dose of 500 mrem/year -- if lodged internally. Body burdens can be greatly different for different radioactive substances.

<u>Collective dose</u> - The sum of the individual doses received by each member of the population. It generally is given in units of person-rems. The collective dose for a geographical area is often calculated as the product of the population of that area and the average dose per individual.

<u>Contamination</u> - Radioactive material in an uncontained, undesired form. For example, dirt on foodstuffs is a form of nonradioactive contamination.

<u>Core inventory</u> - The amount of all radioactive isotopes found in a reactor core at a given time of interest.

<u>Cosmic rays</u> - High-energy particles and photons originating from nuclear reactions taking place in the sun and other parts of our galaxy and beyond. The intensity of cosmic rays increases with altitude above sea level.

<u>Dose</u> - A quantity used to describe the amount of radiation in a "field," or to a material such as tissue. Frequent units are rad, roentgen, and rem. For the purposes of this report, these units may be considered interchangeable. The unit rem, or millirem (mrem), is used in the body of the report.

<u>Dose-rate</u> - A dose-rate is dose per unit time, usually dose per hour. Individual doses are expressed in rems or millirems (mrem). The dose rate at the front of a radium-dial clock is about 3 mrem per hour.

Dosimetry - The science of determining radiation fields and dose to individuals or materials by using any and all known types of detectors and calculational techniques.

Fission products - The nuclides resulting from fission of nuclear fuel. They generally decay by beta-gamma emission with a half-life from a few hours to many years. Spent fuel contains only a small proportion (one percent) of fission products; the remainder is mainly uranium.

Gamma radiation - An extremely long-range penetrating radiation. Physically, a gamma ray is an electromagnetic wave just as light **is**, but of much shorter wavelength. As a very general statement, gamma emitters are more hazardous externally than internally, when compared with beta- and alpha-emitting materials.

Geiger counter - An instrument that detects radiation -- this term sometimes applies to the radiation detector within'the instrument. It generally responds to beta and gamma rays. This instrument does not give a reliable estimate of dose, except under special conditions not generally applicable to the TMI accident.

Genetic effects - Damage to the gene-bearing chromosomes that may be transmitted through the germ cells to the progeny and to succeeding generations.

Half-life - The time required for half of a given radioactive substance to decay. For example, iodine-131 has a half-life of 8 days; uranimum-238, 4.5 billion years. Half-life is not a measure of toxicity.

Health physics - The practice of protecting humans and their environment from the possible hazards of radiation.

Iodine-131 - A radioactive isotope of iodine. Iodine-131 is one of the most troublesome of all fission products because it concentrates selectively in the thyroid. It can be absorbed on activated charcoal, and has an 8-day half-life. It is not normally present in the environment.

MDL - Minimum Detectable Level. The lowest level of any specific radiation that can be detected with statistical significance above instrumental background levels.

MPC - Maximum Permissible Concentration. The level of any radioactive element in air, water, etc., that would cause a member of the public to receive 500 milligrams per year to any part of the body, if continually exposed. The MPC for radiation workers is 10 times the public limit (generally).

MPE (MPL) - Maximum Permissible Exposure (Maximum Permissible Limit). The maximum allowable exposure to nonoccupational workers is specified by the NRC to 500 mrems whole-body exposure. Also, radiation levels must be controlled so that no individual can receive a dose to the whole body of 2 mrem in any one hour or 100 mrem in any 7 days.

Mid-lethal dose - The mid-lethal dose for humans (given in a short time) is 400,000 mrem. This means if a large number of subjects are exposed over the whole body to 400 rems, one-half will die from low lymphocyte levels within 40 days, if no medical attention is given.

Noble gases - Helium, neon, krypton, xenon, argon, and radon. These gases do not undergo chemical reactions and, therefore, are not taken into the body by usual routes, although they may diffuse into the blood from the lungs. Radon is naturally radioactive; radioactive isotopes of the others can exist, some being created as fission products.

Plutonium-239 - Created by neutron capture in uranium-238, 239Pu is the primary fuel for fast reactors and a secondary fuel (being burned in place) for thermal reactors (light water). Plutonium is created in thermal reactors and burned in fast reactors.

Potassium-40 - A natural radioactive isotope that occurs in glass, tiles etc. It is also found in tissue and accounts for 20 mrem per year of the natural dose to humans.

Radioactive decay - The process by which unstable elements decay into stable elements. All radioactive substances will eventually decay.

Somatic effects - Those bodily effects that cannot be passed on to future generations -- for example, skin reddening, nausea, increased probability of cancer, etc.

Source term - The release rate of radioisotopes as it varies with time (release rate) or the total release over time until release becomes negligible (total source term). This can be an actual "measured" value based on various assumptions. The units of this value are generally curies per unit time or total curies of specified isotopes.

TLD - Thermoluminescent Dosimeter. A material, generally a salt such as lithium fluoride, which can store energy absorbed from nuclear radiation. This stored energy is later released from the chip by heating and evaluated electronically to give information about the total radiation dose.

Thorium - A principal natural radioactive element, which is present in granite, sands, etc., and whose decay products account for a portion of our natural radiation exposure. There is four times as much thorium as uranium in the earth's crust.

Uranium - A principal natural radioactive element, which is more abundant than silver. The decay products account for a large portion of our natural radiation exposure.

Whole-body counting - A technique used to measure the internally deposited radioisotopes within the body by employing an external radiation detector. Results generally are expressed in the form of a percent of the maximum permissible body burden of the isotope in question. This technique can identify and measure accurately normal body radiations as well as those that are taken into the body due to such things as injection, ingestion, and inhalation from atmospheric releases, medical diagnostic and therapeutic techniques, etc.

METHODOLOGY

The task group would like to express our thanks to the colleagues, consultants, and advisors whose contributions were vital to the effective accomplishment of our task. These include: Carmen Benkovitz, Brookhaven National Laboratory; Pamela Bryant, National Radiological Protection Board, United Kingdom; Sherri Cotter, Oak Ridge National Laboratory; Marvin Dickerson, Lawrence Livermore Laboratory; George Greenly, Lawrence Livermore Laboratory; Paul Gudiksen, Lawrence Livermore Laboratory; John Laughlin, Memorial Sloan-Kettering Cancer Center; Craig Little, Oak Ridge National Laboratory; Charles W. Miller, Oak Ridge National Laboratory; Robert Moore, Oak Ridge National Laboratory; Thomas Sullivan, Lawrence Livermore Laboratory; and William Wilkie, Tennessee Valley Authority.

We would also like to acknowledge our indebtedness to the following for the admirable care and skill they brought to our effort: Thomas Black, Oak Ridge National Laboratory; Richard Greene, Oak Ridge National Laboratory; Mary Johnson, Oak Ridge National Laboratory; Andrew Loebl, Oak Ridge National Laboratory; Mi-Huong Nguyen, National Bureau of Standards; Bryce Powers, Oak Ridge National Laboratory; Richard Riley, Memorial Sloan-Kettering Cancer Center; and Pat Zanzonico, Memorial Sloan-Kettering Cancer Center.

REFERENCES

1. "Investigation into the March 28, 1979, Three Mile Island Accident by Office of Inspection and Enforcement," Office of U.S. Nuclear Regulatory Commission, NUREG-0600 (1979), pp. II 3-59.

2. Ibid., II 1-34.

APPENDIX A

MEASUREMENT OF DOSES AT AND AROUND THREE MILE ISLAND WITH THERMOLUMINESCENT DOSIMETERS

Thermoluminescent dosimeters (TLDs) were placed at 20 sites around Three Mile Island before the accident, and more were added at additional sites during the release of radioactivity from TMI. TLDs also were used to measure the occupational exposures during the accident.

The dosimeters at the 20 surrounding sites have been used to estimate the doses to people living around TMI at distances of up to 50 miles. The dosimeters themselves are calibrated in terms of exposure. The exposures are needed to calculate the collective dose equivalent to the surrounding population. This collective dose equivalent (DE) is:

$$\sum_{i=1}^{i=160} Ej \times f \times g \times Ni \quad \text{(person-rem)}$$

where Ei is the exposure in each segment of each sector surrounding TMI;

f is the ratio of dose equivalent (rems) to exposure (roentgens);

g is a shielding factor; and

Ni is the number of people in segment i.

The exposure in each of the 160 segments formed from 16 directions and 10 distance intervals is derived by interpolating and extrapolating measurements at the 20 measurement sites.

For the purpose of the investigation, it is necessary to subtract from the measured exposures a natural background exposure based on measurements made at the sites in 1978. Thus, the collective DE measured is consequent on the accident.

The exposures were reported by Met Ed, the Bureau of Radiological Health (BRH) of the state of Pennsylvania, the U.S. Environmental Protection Agency (EPA), the Nuclear Regulatory Commission (NRC), and the Bureau of Radiological Health of the U.S. Department of Health, Education, and Welfare (HEW). The agencies used TLDs of different kinds. This report analyzes the data in the light of the characteristics of the dosimeters and the nature of the released radioactivity. It also presents other data gathered from TLDs set out both during the release and after most of the dose was absorbed, and sets forth the reasons why the remaining data were not used in the calculation of the collective DE (see Appendix B).

The TLD data for the occupationally exposed were acquired from a dosimetry system in use before the accident, although the system was augmented during the accident. The data are summarized in terms of collective DE and its distribution until the end of June. The quality of these data is also reviewed.

THERMOLUMINESCENSE DOSIMETRY

When crystalline materials absorb energy from ionizing radiation, electrons are freed from valence bonds. In some crystalline materials, a proportion of the freed electrons are trapped at centers that are generally associated with impurity atoms within the material. In certain cases the electrons are permanently trapped at room temperature, but when the material is heated to a suitable temperature, the electrons can escape from the traps. Suitable in this context means a temperature well above room temperature, but well below the melting point of the material. After escaping from the trap, the electron loses energy, which appears as an emitted quantrum of light.

The number of electrons trapped is related -- generally proportionally -- to the energy absorbed, as is the number of light quanta emitted. Thus, a measure of energy absorbed (dose is the amount of energy absorbed per unit mass) can be obtained when the light emitted on heating the material is reproducibly measured.

Thermoluminescent materials may be natural or man-made. A good example of the first is fluorite -- a mineral form of calcium fluoride (reference 1). A popular man-made material is lithium fluoride, containing small amounts of magnesium and titanium, among other impurities (reference 2).

There are a number of properties of thermoluminescent materials that affect their usefulness; they are described below.

Sensitivity of Thermoluminescent Materials

The sensitivity of a thermoluminescent (TL) material is measured by the amount of light emitted per unit dose per unit mass. It is evident that a high sensitivity is desired because it makes the measurement of dose easier. It is convenient to express the sensitivity of all TL materials relative to one material. The material chosen, because it is so widely used, is an industrial formulation of lithium fluoride known as TLD-100. Table A-1 shows the relative sensitivity of a number of TL materials. The figures are only approximate because the sensitivity depends on the exact formulation, physical form, heat treatment, reader design, and reading technique.

TABLE A-1: Relative Sensitivities of Thermoluminescent Materials

Thermoluminescent Material	Relative Sensitivity*
Lithium Fluoride (Magnesium, Titanium)	1
Natural Calcium Fluoride	23
Calcium Fluoride (Manganese)	3-10
Calcium Fluoride (Dysprosium)	30
Calcium Sulphate (Dysprosium)	20
Calcium Sulphate (Manganese)	70
Lithium Borate (Manganese)	0.3

*Larger numbers imply greater sensitivity.

The table makes clear that the activating impurity (in parentheses) plays a crucial role in determining the sensitivity.

Range of Measurement

The sensitivity determines, along with other factors, the lowest exposure that can be measured. At low exposures, other sources of light compete with the thermoluminesence and render uncertain the measurements. There are basically two sources of such light. The first is light emitted from the TLD that is not related to the ionizing radiation being measured. This may stem from extraneous exposure to radiation, rubbing of the TLD, or its exposure to visible or ultraviolet light. Second, the TLD and its immediate surroundings become incandescent on heating; this, too, manifests itself as light.

Generally, the light from a TLD is proportional to the dose absorbed. However, above a certain dose, a TLD generally shows an increase in sensitivity. This change in sensitivity with dose does not prevent the use of TLD so long as the change is reproducible. However, at a higher dose still, the response saturates; there is a maximum amount of light that can be generated. That dose level represents an upper limit of measurement.

Table A-2 shows the approximate range of exposures that are measurable practically with different TL materials.

TABLE A-2: Approximate Useful Exposure Range of Various TL Phosphors

TL Material	Useful Range of Measurement Lower (mrem)	Upper (R)
Lithium Fluoride (Magnesium, Titanium)	1.0	100,000
Natural Calcium Fluoride	1.0	10,000
Calcium Fluoride (Manganese)	1.0	300,000
Calcium Fluoride (Dysprosium)	0.1	1,000,000
Calcium Sulphate (Manganese)	0.1	10,000
Calcium Sulphate (Dysprosium)	0.1	100,000
Lithium Borate (Manganese)	10.0	1,000,000

In practice, the lower limit of usefulness is set by techniques used with the dosimeters and by background radiation.

Fading

Even at low temperatures, some of the electrons escape from the traps. If sufficent time passes between the radiation and the subsequent heating, a loss of acquired signal occurs. Eventually this sets a limit on the time and temperature at which the TLDs can be stored between radiation and heating. This property is called fading. This can be expressed as the time it takes for the TL material to lose 10 percent of its original sensitivity, as in Table A-3.

Fading rates observed critically depend on heat treatment of the material both before and after irradiation.

Repeated Use

TL materials generally can be used many times. However, if the property of the TMI material is to reamin the same, it is often necessary to subject it to a regime of heating at controlled times and temperatures after heating to release the light. This process is called annealing. Its close control is needed for some TL materials to obtain reproducible results. Some materials, such as lithium fluoride, require quite elaborate annealing cycles for reproducible results after large exposures (ti100R) have been obtained. Others, such as calcium sulphate (dysprosium), do not require annealing to restore their former sensitivity.

TABLE A-3: Fading Characteristics of TL Phosphors

TL Material	Time After Irradiation for 10 Percent Loss of Acquired Signal at Room Temperature
Lithium Fluoride (Magnesium, Titanium)	> 6 months
Natural Calcium Fluoride	> 1 year
Calcium Fluoride (Manganese)	ti 1 month
Calcium Fluoride (Dysprosium)	< 1 month
Calcium Sulphate (Manganese)	> 1 day
Calcium Sulphate (Dysprosium)	6 months
Lithium Borate (Manganese)	1-7 weeks

SENSITIVITY DEPENDENCE ON GAMMA-RAY ENERGY

TLDs generally are calibrated using high energy gamma rays -- those emitted by the isotopes cesium-137, cobalt-60, or radium-226, and its decay products. Ideally, a TLD should give the same response to a unit exposure regardless of the energy of gamma rays. This would allow the TLD to be calibrated with gamma rays of other energies without introducing error.

If a TLD could be made from elements having the same atomic number as the elements in air, such an ideal dosimeter could be realized. Because actual TL materials are not equivalent in atomic number to air in this respect, their response to exposure changes with energy. This change is particularly marked at low energies. Table A-4 illustrates this point.

Over-response can be modified by the materials that surround the TLD. Sometimes the surrounding material is designed -- by a judicious choice of elements, thicknesses, and shapes -- to make the response as independent of energy as possible.

THERMOLUMINESCENCE APPLIED TO ENVIRONMENTAL GAMMA MONITORING

Gamma-ray exposures around nuclear facilities are measured before and during their operation. The measurements are used to assess the additional gamma-ray exposure to the surrounding people both during

TABLE A-4: TL Material Response to Exposure Changes	
Thermoluminescent Material	Response to 1 roentgen of 3 Kev gamma rays / Response to 1 roentgen of cobalt-60 Y-rays (1.17, 1.33 MeV)
Lithium Fluoride	1.25
Calcium Fluoride	13
Calcium Sulphate	10
Lithium Borate	0.9

normal operation and in the event of an abnormal release of radioactivity. This exposure should be held below certain limits and should be kept as low as reasonably achievable. The measurements are used to assess the extent to which these two objectives are met.

Because background gamma-ray exposure rates are quite low -- about 40 mrem/year -- it is necessary to measure rather small exposures acquired over long periods of time ("months). Generally, environmental measurements are made quarterly (sometimes annually) because the background fluctuates seasonally due to, in part, soil moisture changes. In particular, there can be a marked reduction in the first quarter if the snow cover is thick.

The gamma rays in the environment are quite high in energy, but generally lose energy by scattering in the air before reaching the dosimeter. The energy of the gamma rays emitted by accidental radioactive releases will depend on which radioisotopes are released. Before an accident, it is hard to predict which isotopes will be released, and hence it is difficult to predict their gamma-ray energy.

It can be seen that for quarterly measurements, the TLDs must be capable of measuring 10 mrem acquired over a period of 3 months without severe errors due to fading. Referring to the previous section, which dealt with the questions of range of measurement and fading, it can be seen that the following TL materials are suitable: lithium fluoride (magnesium, titanium); natural calcium fluoride; and calcium sulphate (dysprosium- or thaleium-activated).

Natural calcium fluoride is itself slightly radioactive, which results in self-exposure. This makes the measurement of small exposures acquired over a long time more difficult, because the self-exposure must be accurately subtracted.

Calcium sulphate (dysprosium- or thaleium-activated) is very sensitive, but it is energy dependent in its response. This must be compensated for by surrounding it with a compensating shield. This is not simple to design properly, because the resulting response should be independent of gamma-ray direction as well as energy.

Probably lithium fluoride is the most suitable TLD for measurements of exposures of 10 mrem and upwards, although considerable care must be taken to obtain good accuracy at 10 mrem because of the low sensitivity of available lithium fluoride TLDs.

For smaller exposures (ti l mrem), the greater sensitivity of calcium sulphate (dysprosium- or thaleium-activated) makes it the TLD of choice.

To obtain reliable and accurate environmental measurements, careful and time-consuming techniques are needed. TLDs show considerable variability in sensitivity. Accuracy can be improved by calibrating each individual dosimeter. This can be done once, and the TLD identity and individual sensitivity can be stored. Alternatively, it can be done after each reading. In either case, the reading is then corrected for individual sensitivity.

Accuracy also is improved by grouping several TLDs in each package and measuring the average and spread in readings. An excessive spread in reading calls into question the significance of the average reading. Packaging and mounting of the TLDs must be done with care to minimize the unwanted effects of high temperature, moisture, light, and contamination -- thermoluminescent and radioactive.

A special problem is caused by transit exposure. This is the exposure that a dosimeter receives: (a) after it has been "zeroed" by a reading or annealing process, but before it is deployed for measurement; and (b) from the time of deployment for measurement to the time of reading. This transit exposure must be subtracted from the reading because it is not part of the exposure to be measured. In some cases, it can form a substantial part of the total exposure. It may be subtracted by using a control dosimeter that has been exposed to the transit exposure, and perhaps other known exposures, only.

When monitoring the increase in exposure due to the operation of a nuclear facility, it also is necessary to subtract that part of the exposure due to terrestrial gamma rays, cosmic rays, and gamma rays from nuclear weapon fallout. The sum of these components is estimated by using a second type of control dosimeter, which is deployed at a different time (usually before) or a different place (too distant to be affected by the operation of the nuclear facility).

The required performance of TLDs used for environmental monitoring has been specified by an American National Standard (reference 6). Although the standard adequately specifies the performance of TLDs for measuring exposures from environmental gamma rays, it does not do so for the measurement of X-rays and gamma rays from Xe-133.

TLD DATA OBTAINED AT TMI

Spatial Coverage

At the time of the accident, five separate sets of environmental TLDs were in place at 20 sites as a part of routine monitoring programs. Dosimeters were provided and read for Met Ed by Teledyne and by RMC (reference 20). These dosimeters were received, deployed, recovered, and returned by Met Ed's consultant, Porter-Gertz (reference 20). All 20 sites were provided with Teledyne dosimeters and 10 of the 20 sites were provided with RMC dosimeters. In addition, Met Ed deployed Harshaw personnel dosimeters at 11 sites around the fence line of the plant. The state of Pennsylvania deployed dosimeters from two sources at four of the sites. Dosimeters were provided to the state by RMC and RAP, which is operated for the NRC by DOE's Radiological and Environmental Sciences Laboratory, located at the Idaho National Engineering Laboratory. The descriptions of these 20 sites and the designations of the dosimeters deployed there are given in Table-5. The locations are identified on the maps in Figures A-1 to A-3 (reference 21). The sites on the fence line where Met Ed deployed HS personnel dosimeters are listed in Table A-6.

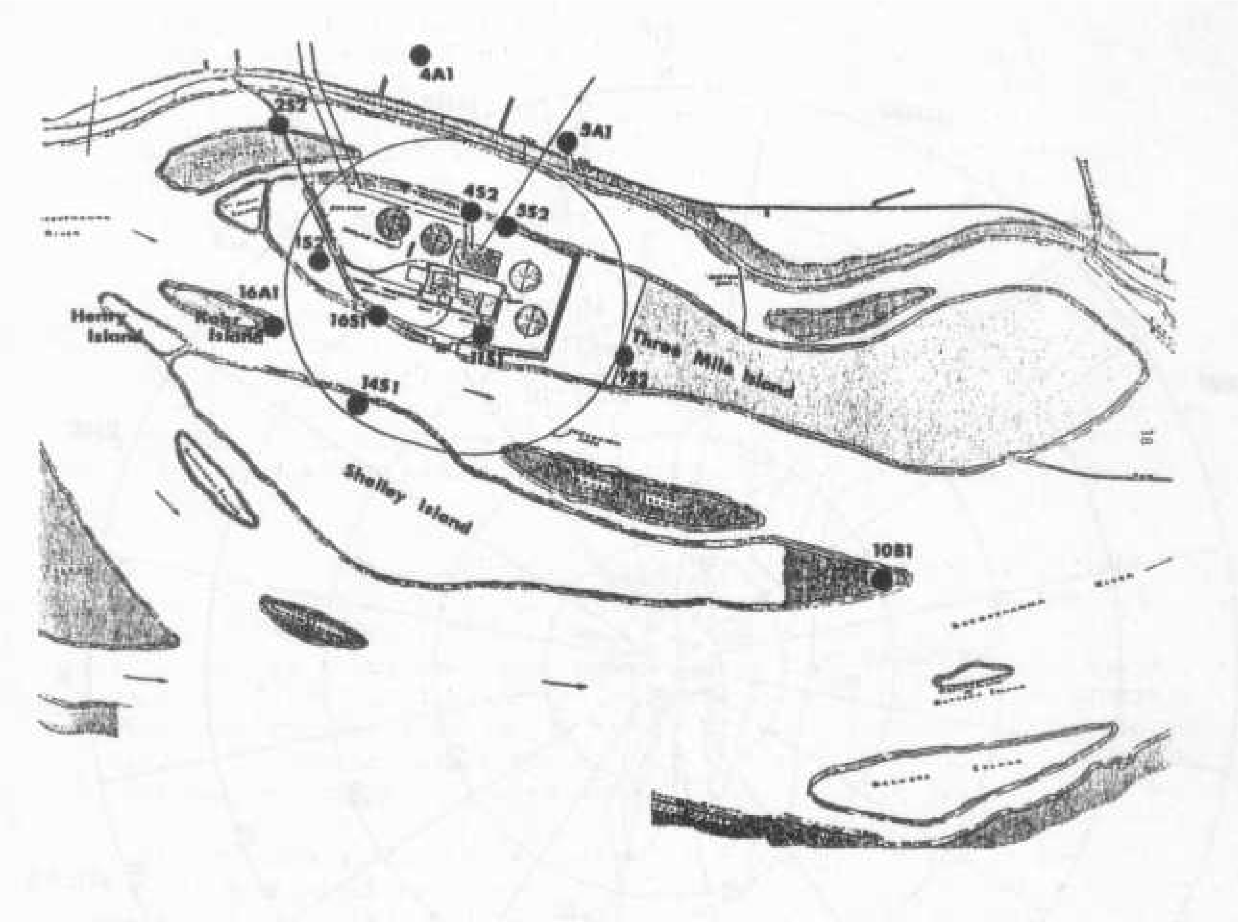
Additional dosimeters were deployed after the accident began. The NRC deployed dosimeters at 37 sites beginning on March 31, 1979, and at an additional 10 sites beginning on April 5, 1979 (reference 21). These dosimeters were provided and read by RMC; they employed a system totally different from the system used for the Met Ed and Pennslyvania dosimeters. Some of the NRC dosimeters were deployed at Met Ed sites; this correspondence is indicated in Table A-7, which describes the NRC locations. These locations are also indicated on the maps in Figures A-4 and A-5.

The BRH at HEW deployed 237 dosimeters at 173 sites within a 20-mile radius of the plant (reference 19). They began deployment on the evening of March 31, 1979, and finished by April 2, 1979. Within a 10-mile radius of the plant, the number of dosimeters per sector was based on sector population. Where possible, a dosimeter was deployed both indoors and outdoors at a location.

The EPA deployed dosimeters at TMI according to five schemes (reference 17):

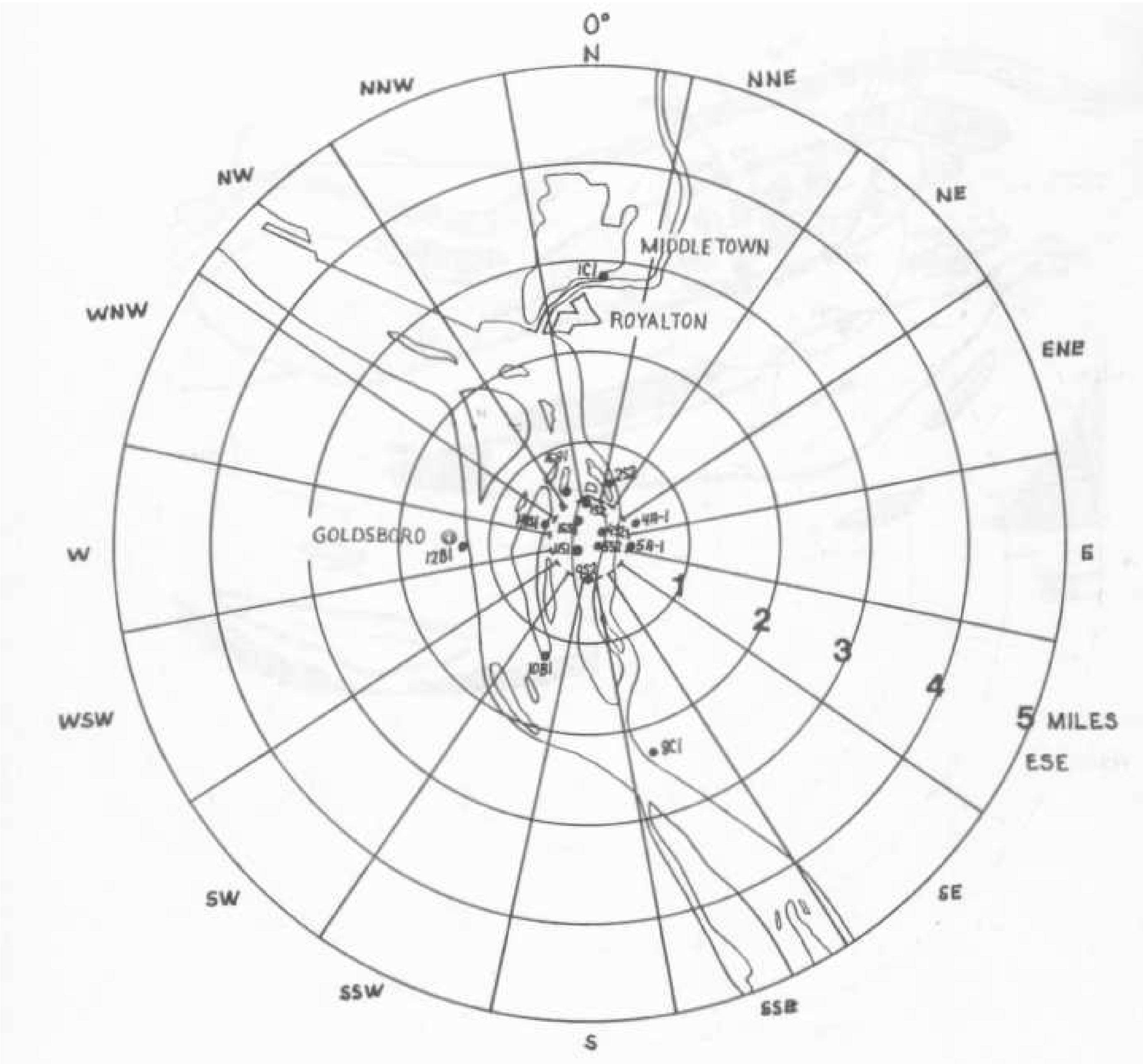
- at selected station locations at resi' nnces within 10 miles of TMI:
- at nearby large cities -- Carlisle, Lebanon, Lancaster, and York;
- at three locations 30 miles from TMI, to be used in estimating regional background; and
- on 54 residents near TLD stations.

FIGURE A-1: Location of Met Ed Dosimetry Sites Within a One-Mile Radius of TMI, March 28 - April 6, 1979



Source: Ad Hoc Population Dose Assessment Group, "Population Dose and Health Impact of the Accident at the Three Mile Island Nuclear Station," Figure 3-1, May 1979

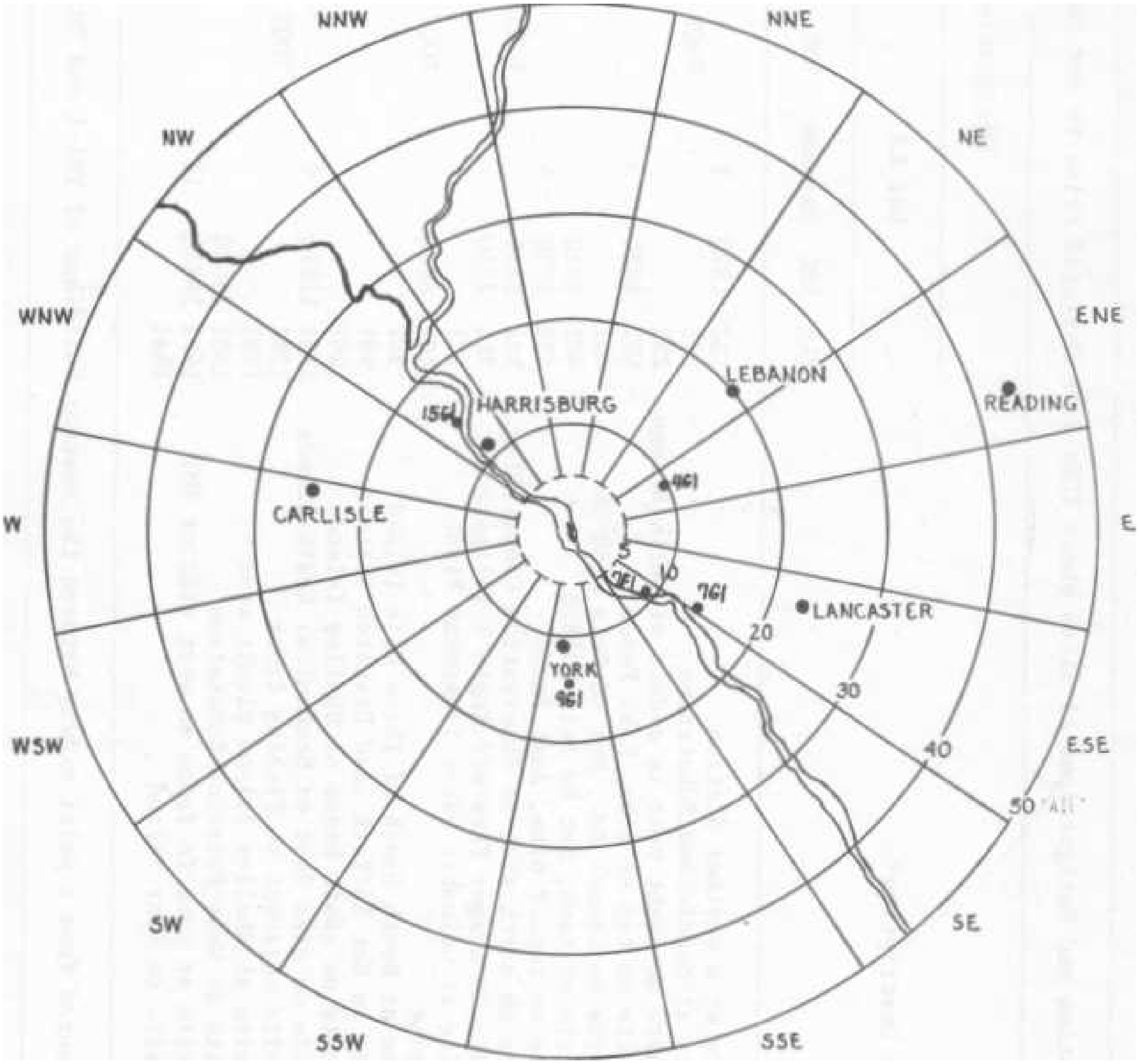
FIGURE A-2: Location of Met Ed Dosimetry Sites Within a 5-Mile Radius of TMI, March 28 - April 6, 1979



Source: Ad Hoc Population Dose Assessment Group, "Population Dose and Health Impact of the Accident at the Three Mile Island Nuclear Station," Figure 3-2, May 1979.

FIGURE A-3: Location of Met Ed Dosimetry Sites Outside a 5-Mile Radius of TMI, March 28 - April 6, 1979

0'
NORTH



5

Source: Ad Hoc Population Dose Assessment Group, "Population Dose and Health Impact of the Accident at the Three Mile Island Nuclear Station," Figure 3-3, May 1979.

TABLE A-5: Description and Designations of Sites Where TLDs Were Deployed Prior to and During the Accident

Site Description*	Designations				
	Met Ed			Pennsylvania	
	TI	RMC	Harshaw	RMC	DOE Idaho
0.4 miles N of site at N Weather Station	1S2	1S2Q	1		
2.6 miles N of site at Middletown Substation	lCl			TOQT 2	1
0.7 miles NNE of site on light pole in middle of North Bridge	2S2				
0.3 miles ENE of site on top of dike, East Fence	4S2	4S2Q	3		
0.5 miles ENE of site on Laurel Rd., Met Ed Pole #668-OL	4A1				
10 miles ENE of site at Lawn, Met Ed Pole #J1813	4G1	4G1Q			
0.2 miles E of site on top of dike, East Fence	5S2	5S2Q	4		
0.4 miles E of site on north side of Observation Center Bldg.	5A1	5A1Q		TOQT 3	2
9 miles SE of site at Drager Farm off Engle's Tollgate Rd.	7F1	7F1Q			
15 miles SE of site at Columbia Water Treatment Plant	7G1				
2.3 miles SSE of site	8C1	8C1Q		TOQT 4	3
0.4 miles S of site at South Beach of Three Mile Island	9S2				
13 miles S of site in Met Ed York Load Dispatch Station	9G1				
1.1 miles SSW of site on south beach of Shelley Island	10BI				
0.1 miles SW of site on dike west of Mechanical Draft Towers	llSl	11S1Q	9		
1.6 miles WSW of site adjacent to Fishing Creek	12B1			TOQT 1	4
0.4 miles WNW of site at Shelley Island picnic area	14S1				
15 miles NW of site at West Fairview Substation	15G1	15G1Q			
0.2 miles **NNW** of site at gate in fence on west side of TMI	1651	16SIQ	11		
0.4 miles NNW of site on Kohr Island	16A1				

*All distances measured from a point midway between the reactor buildings of TMI-1 and TMI-2.

TABLE A-6: Description and Designations of Sites Where Met Ed - Harshaw Personnel Dosimeters Were Deployed Around the Fence Line

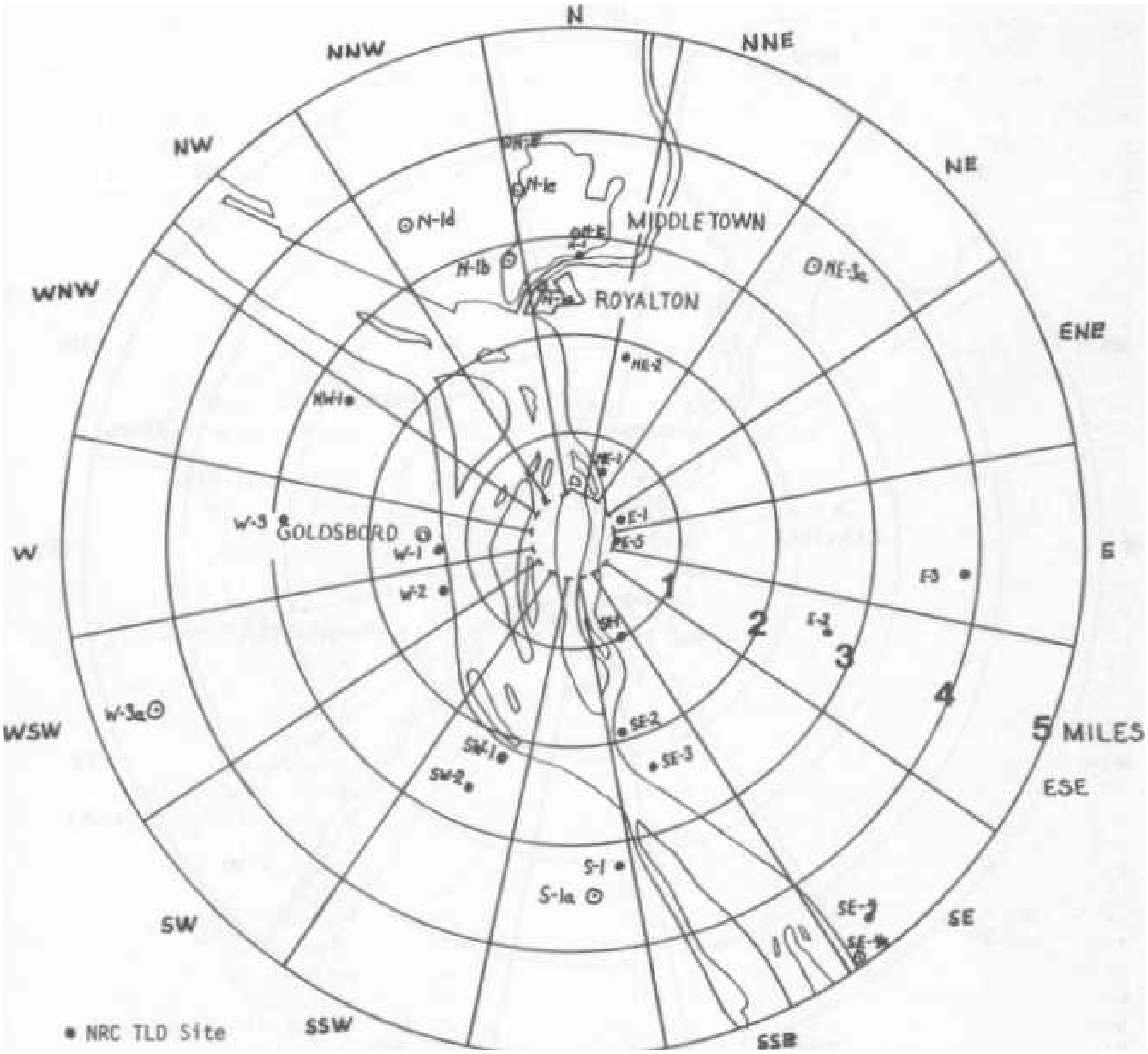
Site Number	Corresponding Environmental Dosimetry Site Designation	Site Description
1	1S2	North Weather Station
2		Near End of North Bridge
3	4S2	Dike East Fence Unit 1
4	5S2	Dike East Fence Unit 2
5		East Dike by Emergency Disc
6		Midpoint South Security Fence
7		Construction Guard House
8		West Roof of Radiation Monitoring Pit
9	11S1	West Dike Fence MDCT 1
10		Fence Between 1-2 Intake
11	16S1	Gate 19 Boat Dock

TABLE A-7: NRC TLD Locations and Corresponding Met Ed Locations

Station NRC	Met Ed	Distance (Miles)	Direction (Degrees)	Sector	Description
N-la		2.4	356	N	School (added 4/5/79)
N-1	lC1	2.6	358	N	Middletown
N-lc		3.0	0	N	School (added 4/5/79)
N-le		3.5	349	N	School (added 4/5/79)
N-If		4.0	351	N	School (added 4/5/79)
N-2		5.1	0	N	Clifton
N-3		7.4	6	N	Hummelstown
N-4		9.3	0	N	Union Deposit
N-5		12.6	3	N	--
NE-1	2S2	0.8	25	NNE	North Gate
NE-2		1.8	19	NNE	Geyers Ch
NE-3		3.1	17	NNE	Township School
NE-3a		3.6	44	NE	School (added 4/5/79)
NE-4		6.7	47	NE	
E-1	4A1	0.5	61	ENE	1200' N of E-la
E-5(E-la)	5A1	0.4	90	E	Residence
E-3		3.9	94	E	Newville
E-4		7.0	94	E	Elizabethtown
E-2		2.7	110	ESE	Unpopulated area
SE-4		4.6	137	SE	Highway 441
SE-4a		5.0	146	SE	School (added 4/5/79)
SE-5	7F1	7.0	135	SE	Bainbridge
SE-1		1.0	151	SSE	Unnamed comm. on Hwy.441
SE-2		1.9	162	SSE	Falmouth
SE-3	8C1	2.3	160	SSE	Falmouth
S-1		3.2	169	S	York Haven
S-la		3.35	173	S	School (added 4/5/79)
S-2		5.3	178	S	Conewago Hts
S-3		9.0	181	S	Emigsville
S-4	9G1	12.0	184	S	Woodland View
SW-1		2.2	200	SSW	Bashore Island
SW-2		2.6	203	SSW	Pleasant Grove
SW-3		8.3	225	SW	Zions View
SW-4		10.4	225	SW	Eastmont
W-2	12B2	1.3	252	WSW	Goldsboro
W-3a		4.4	247	WSW	School (added 4/5/79)
W-1		1.3	263	W	Goldsboro
W-3		2.9	270	W	Unnamed community
W-4		5.9	272	W	Lewisberry
W-5		7.4	262	W	Lewisberry
NW-1		2.6	303	WNW	Harrisburg Airport
NW-3		7.4	297	WNW	New Cumberland
NW-2		5.9	310	NW	Highspire
NW-4		9.6	306	NW	Harrisburg
NW-5	15G1	13.8	312	NW	Harrisburg
Nib		2.75	346	**NNW**	School (added 4/5/79)
Nld		3.5	333	**NNW**	School (added 4/5/79)

FIGURE A-4: Location or NRC Dosimetry Sites Within a 5-Mile Radius of TMI, March 31 - April 7, 1979

00

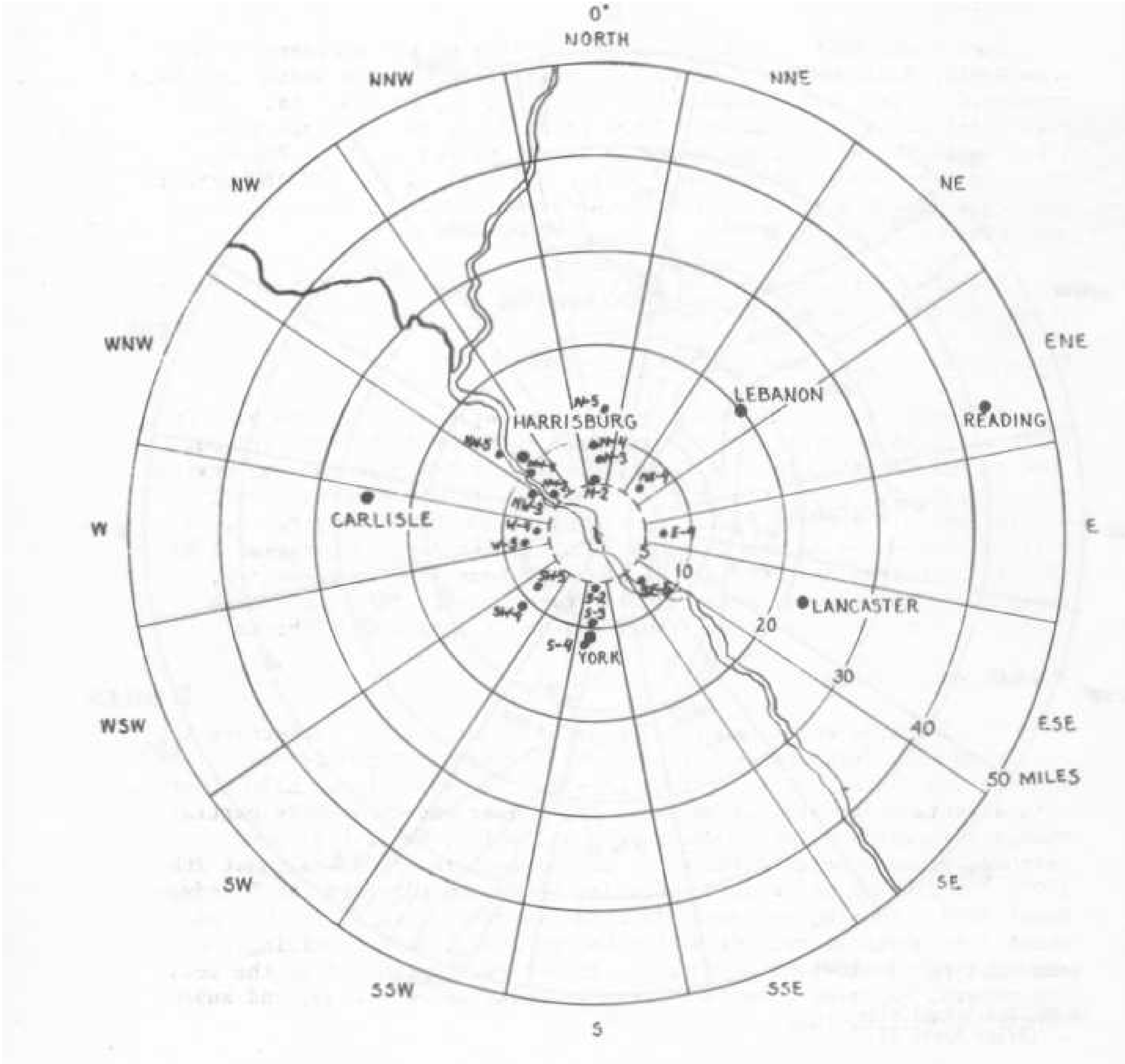


'I NRC TO School site
(After April 5)

S

Source: Ad Hoc Population Dose Assessment Group, "Population Dose and Health Impact of the Accident at the Three Mile Island Nuclear Station," Figure 3-4, May 1979.

FIGURE A-5: Location of NRC Dosimetry Sites Outside a 5-Mile Radius of TMI, March 31 - April 7, 1979



Source: Ad Hoc Population Dose Assessment Group, "Population Dose and Health Impact of the Accident at the Three Mile Island Nuclear Station," Figure 3-5, May 1979.

EPA dosimeters were prepared and read in Las Vegas, Nev. The dosimeters were deployed beginning March 31, 1979. Deployment was completed by April 3, 1979.

Temporal Coverage

Some dosimeters were in place at the time of the accident; others were deployed afterwards. After the accident began, the dosimeters were exchanged at intervals ranging from about one day to about one month. Figure A-6 provides a summary of the start dates and exchange frequencies of the various dosimeter systems employed at TMI. For the dosimeters in place before the accident, as well as the NRC dosimeters, the beginning date represents the time at which all of the dosimeters were placed.

For the remaining dosimeters, the start date is the time when the first dosimeters were deployed.

Discussion of Individual Dosimetry Systems

A variety of dosimetry systems was employed at TMI. The principal features of these systems are summarized in Table A-10. The systems used by Met Ed, the state of Pennsylvania, and EPA were ongoing environmental dosimetry services. HEW used dosimeters whose normal function was to evaluate medical radiation devices. The NRC-RMC system was a relatively new system developed by Panasonic in Japan and marketed by RMC in the United States. All of these systems are, in principle, capable of making environmental measurements, if sufficiently high exposures occur in the energy range for which they are calibrated.

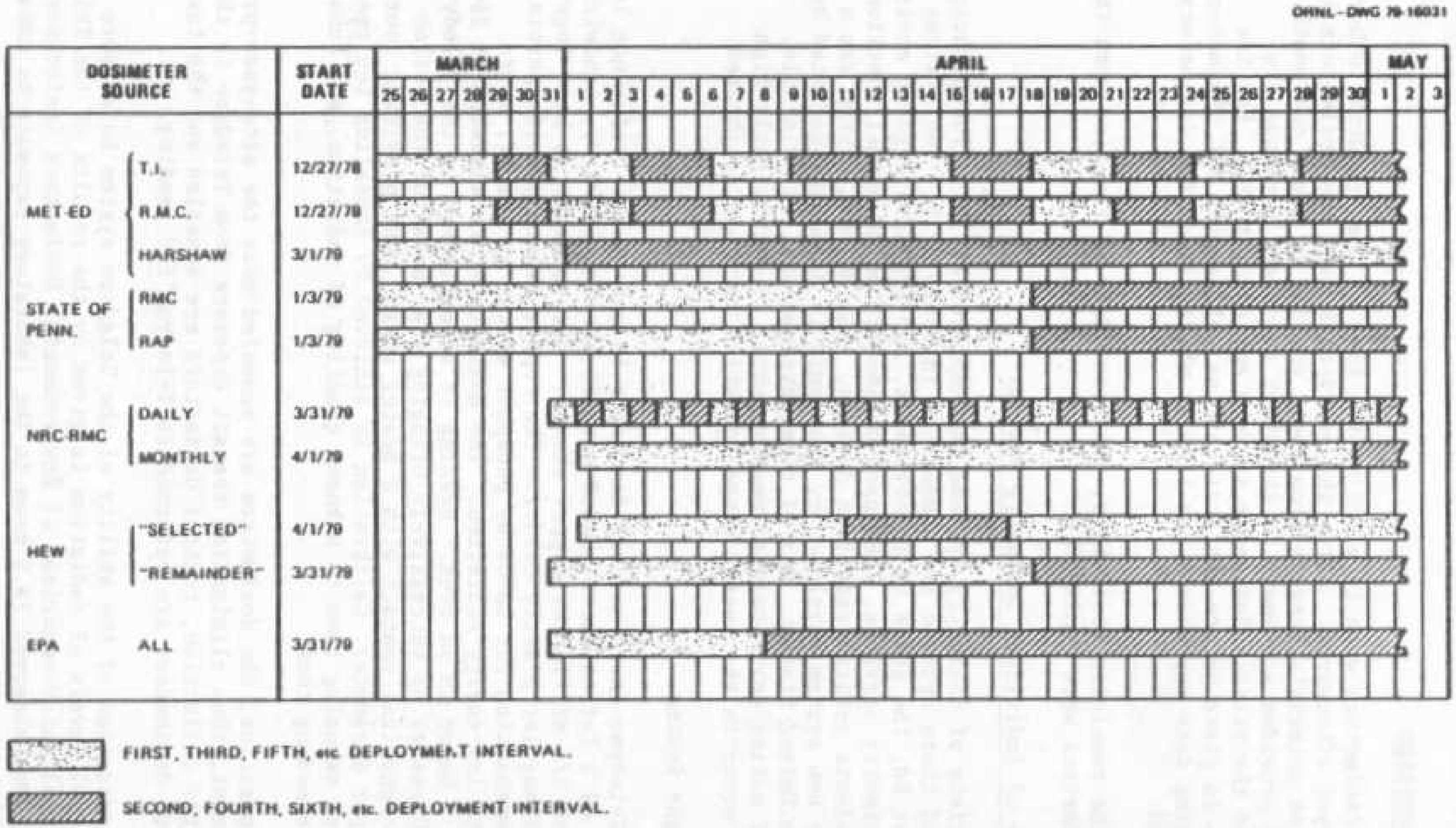
The Teledyne System

The Teledyne environmental dosimeter in use at TMI (reference 16) consisted of a Teflon sheet loaded with 25 percent $CaSO_4:Dy$, sandwiched between two 1/2 millimeter copper sheets. The assembly is held together with a rectangular plastic holder. The copper sheets provide partial energy compensation for $CaSO_4:Dy$ phosphor which, by itself, over-responds to low-energy radiation. The dosimeters are annealed at 260-280°C for 2 hours in an oven. Reading is accomplished in the Teledyne Model 8300 reader by successively bringing four areas of the Teflon sheet into physical contact with a heater strip, thus providing four readouts per dosimeter. Calibration is achieved by annealing the read dosimeters, exposing them to a known quantity of radiation, and subsequently rereading them.

In operation, the dosimeters are annealed near the site just prior to deployment, thus eliminating transit exposure from Teledyne to the site. After collection, control dosimeters are annealed and the test and control dosimeters are returned to Teledyne for reading.

An indication of the ability of the Teledyne system to measure environmental levels of radiation is given by the results of the Third International Intercomparison of Environmental Dosimeters (reference 15). Teledyne observed 78.9 mrem in the laboratory exposure to cobalt-

FIGURE A-6: Deployment Intervals of the Various Dosimetry Systems Employed at TMI



0

Source: Oak Ridge National Laboratory, DWG 79-16031, 1979.

TABLE A-8: EPA Sampling and Monitoring Locations

Station	AZ (0)	Distance (Miles)	Associated Town and Location Description
001	290	6.2	Frogtown, Pa. - Robert Bean Gulf Station
002	320	5.2	*Highspire, Pa. - Highspire Fire Station No. 1
003	325	3.5	Meade Heights, Pa. - Harrisburg Int. Airport
004	360	3.0	*Middletown, Pa. - Elwood's Sunoco Station
005	040	2.6	Royalton, Pa. - Londonderry Township Bldg.
006	055	3.0	Royalton, Pa. - Blandine Hershberger Res.
007	080	6.6	Elizabethtown, Pa. - Koser's Fruit Market
008	070	8.2	*Bellaire, Pa. - Robert Risser Residence
009	100	3.0	Newville, Pa. - Earl Nissley Residence
010	095	6.3	^Elizabethtown, Pa. - Arco Service Station
011	130	2.9	Falmouth, Pa. - Charlus Brooks Residence
012	120	6.9	Maytown, Pa. - Bassler's Church
013	150	3.0	Falmouth, Pa. - Dick Libbart Residence
014	145	5.3	*Bainbridge, Pa. - Bainbridge Fire Company
015	155	6.6	*Saginaw, Pa. - United Methodist Church
016	180	6.7	*Manchester, Pa. - Manchester Fire Department
017	180	3.2	*York Haven, Pa. - York Haven Fire Station
018	205	2.7	Pleasant Grove, Pa. - George Ziegler Residence
019	205	5.0	Strinestown, Pa. - Brenner Mobil Service Station
020	240	2.5	Woodside, Pa. - Zane Reeser Residence
021	250	4.2	*Newberrytown, Pa. - EXXON Kwick Station
022	275	5.0	Yocumtown, Pa. - IML Freight Yard
023	265	2.7	Goldsboro, Pa. - Mueller Residence
024	275	26.0	*Carlisle, Pa. - Union Fire Company No. 1
025	360	7.0	*Hummelstown, Pa. - Keffer's EXXON Service Station
026	025	10.0	*Hershey, Pa. - Arco Service Station
027	040	10.0	Cambelltown, Pa. - Gulf Service Station
028	055	20.0	*Lebanon, Pa. - Goodwill Fire Company
029	110	25.0	Lancaster, Pa. - Southern Manhiem Fire Company
030	180	13.0	*York, Pa. - Springetts Fire Company No. 1
031	270	1.4	*Goldsboro, Pa. - Woody Miller Residence
032	255	1.9	Goldsboro, Pa. - Harold Bare Residence
033	205	2.9	Pleasant Grove, Pa. - George Shaffer Residence
034	305	2.7	Plainfield, Pa. - Polites Residence
035	63	3.0	Royalton, Pa. - George Hershberger Residence
036	90	0.5	Middletown, Pa. - TMI Observation Point
BKGJASI	110	30.6	Lancaster, Pa. - 5.6 Miles E on Hwy. 30
BKGJASII	275	32.0	Plainfield, Pa. - Myers Garage (EXXON)
BKGVANIII	55	25.0	Lebanon, Pa. - 5 Miles E on Hwy. 422

Sampling stations located in indicated town. Other sampling stations are located near indicated town.

TABLE A-9: EPA Special TLD Arcs

Station	AZ (0)	Distance (Miles)	Associated Town and Location Description
1	331	6.7	Ebenezer, Pa. - 1 mile east of Host Inn Motel on Hwy. 441
1A	339	5.3	Ebenezer, Pa. - 2 miles east of Sta. 1, Inter. 441 & 283
2	350	2.6	*Middletown, Pa. - South edge of Middletown on Hwy. 441
3	360	1.6	Olmstead AFB, Pa. - 1.1 miles south of Station 2 on Hwy. 441
4	34	0.7	Olmstead AFB, Pa., - 1.1 miles south of Station 3 on Hwy. 441
5	157	1.5	Falmouth, Pa. - 1.9 miles south of Station 4 on Hwy. 441
6	147	3.6	Falmouth, Pa. - 2.4 miles south of Station 5 on Hwy. 441
7	144	1.9	Bainbridge, Pa. - 1.2 miles south of Station 6 on Hwy. 441
8	145	2.7	Bainbridge, Pa. - 0.8 miles south of Station 7 on Hwy. 441
9	142	7.4	Billmeyer, Pa. - 1.5 miles south of Station 8 on Hwy. 441
10	278	5.1	Yocumtown, Pa. - 1.2 miles southeast from Jct. of 262 East and Susquehanna Trail on Susquehanna Trail
11	285	5.1	Yocumtown, Pa. - Jct. of Benhower Rd. and 262 East
12	292	4.2	Yocumtown, Pa. - 1 mile east of Station 11 on 262 East
13	299	3.0	Plainfield, Pa. - 1.3 miles east of Station 12 on 262 East
14	291	2.2	Goldsboro, Pa. - 1.3 miles east of Station 13 on 262 East
15	266	1.3	*Goldsboro, Pa. - Miller Res. (Sta. 31)
16	224	1.9	Goldsboro, Pa. - 1.3 miles south of Goldsboro, PA on 262 East, Bare Res. (Sta. 32)
17	199	2.2	*Cly, Pa. - Jct. 262 and 295 West
18	182	3.0	York Haven, Pa. - 0.6 miles south of Jct. 382 and 262 on Hwy. 382, Shaffer Res. (Sta. 33)
19	173	3.1	*York Haven, Pa. - Across from Drover Bank

TABLE A-10: Summary of Principal Features of Dosimetry Systems Employed at Three Mile Island

Dosimeter Source		Phosphor(s)	Number of Elements	Dosimeter Designation	Packaging	Reader
Met Ed	T.I.	$CaSO_4$:Dy in Teflon	4	25% $CaSO_4$:Dy	Plastic plus Cu filter	Teledyne 7300
	RMC	$CaSO_4$:Tm Powder	2	RMC UD 200S	Glass encapsulation plus energy comp. filter	RMC UD 505A
	Harshaw	LiF	2	TLD Card	Plastic and aluminum	Harshaw 2271
State of Pennsylvania	RMC	$CaSO_4$:Tm Powder	2	UD 200S	Glass encapsulation plus energy comp. filter	RMC UD 505A
	RAP	Lif Chips	5	Noncommercial	Laminated cardboard plastic and aluminized mylar	Harshaw 2000
NRC-RMC		$Li_2B_4O_7$:Cu, Ag/$CaSO_4$:Tm $CaSO_4$:Tm	2/2 3	RMC UD 801 RMC Ud 804	Plastic/lead Plastic/lead	RMC UD 710
HEW		Lif Chips	8	Noncommercial	Plastic, paper, and aluminum	Harshaw Atlas
EPA		CaF:Dy Chips	2	Harshaw 2271-G2	Teflon enclosed chips with 1.2 mm Cd for energy compensation	Harshaw 2271

60, whereas the average result of all participants was 86.0 mrem. The independently estimated exposure was 91.7 mrem. In the field test, Teledyne observed 34.7 mrem; the average of participants was 31.5. The independently estimated field exposure was 34.9 mrem.

Statistical error expressed as one standard deviation is stated in the product literature to be ± 0.2 mrem or ± 3 percent (whichever is greater). The data reported for TMI both before and during the accident (reference 20) exhibit larger statistical variations, however. For 1978, the average statistical error for all sites and for four quarters was 4.3 percent. Data obtained during the accident exhibited even greater statistical error. The average percent standard deviation (coefficient of variation) was computed for all Teledyne values that exceeded 15 mrem during the period of the accident up to April 6. It was found to be 13.2 percent, well above the stated 3 percent. An examination of the individual readings revealed a pattern of three similar readings and one elevated reading. The elevated readings usually occurred in "area four" of the dosimeter, although they occasionally occurred in area one. The problem is illustrated in Table A-11, which is the Teledyne dosimetry report for the period March 29, 1979, to March 31, 1979. The apparently unusually high values are enclosed in boxes. This problem also occurred in data gathered by Teledyne to test the compliance of their dosimetry system with NRC Regulatory Guide 4.13 (reference 14). Both unusually low and unusally high readings occurred occasionally.

The energy dependence of the Teledyne dosimeter was measured both before and during the accident using X-rays as well as Xe-133 sources. The results, which are somewhat equivocal, are discussed in detail later in this appendix.

Teledyne is in the process of testing its system for conformance to the NRC Regulatory Guide 4.13 (reference 14). They have provided internal reports that show compliance with the linearity, uniformity, reproducibility, dependence-on-length-of-field cycle, moisture dependence, light dependence, self-irradiation, sensitivity, and directional dependence.

The RMC System Used by Met Ed and the State of Pennsylvania

The RMC UD 200S dosimeter consists of two elements composed of glass-encapsulated $CaSO_4$:Tm powder. The elements are in a cylindrical configuration and are surrounded by complex, multi-element energy compensation shields. Reading is accomplished in the RMC UD 505A reader. The UD 505A is a manually operated hot nitrogen gas reader of Panasonic manufacture marketed by RMC (reference 12).

In operation, the dosimeters are annealed-at 400°C for 4 minutes. In addition to the test dosimeters, additional dosimeters are prepared for the purpose of measuring the intransit dose, which is subtracted from the gross test dosimeter readings to obtain the net exposure. This net exposure includes all radiation at the field site. Calibration is achieved from a previously determined instrumental response curve. This response curve is verified with each batch by use of dosimeters exposed to 18 mrem from a Cs-137 source. RMC participated in the Third International Intercomparison of Environmental Dosimeters. They obtained a laboratory result of 73.6 mrem. The average of all participants was 86.2 mrem, and the independently estimated exposure was 91.7 mrem. The RMC field result was 26.0 mrem. The average result of all participants was 31.5 mrem, and an independent measurement with a pressurized ion-chamber gave 34.9 mrem.

RMC states that a typical error, as estimated from the variance of four individual readings (2 dosimeters per station, 2 elements per dosimeter), is ± 0.6 mrem for a response of 8 mrem, where ± 0.6 represents the 95-percent confidence limit. This corresponds to ± 7.5 percent. An examination of the random error associated with the measurements made in the environs of TMI revealed 8.3 percent (95-percent confidence) for 1978 and 12.1 percent for the measurements made during the period of the accident.

The energy response of the dosimeter in the range of 25 KeV to 10 MeV is reported by RMC (reference 13) to depart from unity by only a few percent. At 80 KeV it over-responds by about 5 percent. The exposures made by the National Bureau of Standards (NBS) shortly after the accident indicated a somewhat greater over-response. RMC converts the exposures measured in roentgens to rads, and thus rems, by multiplying the exposure results by 0.955.

For purposes of exposure estimation, the reported rems are simply used as roentgens because the expected over-response and the roentgen-rem conversion factor almost exactly cancel out.

RMC has tested the UD 200S dosimeter and UD 505A reader system for conformance to most of the provisions of the NRC Regulatory Guide (RG) 4.13. They did not test for light dependence or moisture dependence, as they claim that the design of the dosimeter precludes interference from these factors. The dosimetry system was shown to conform to RG 4.13 for the tests performed.

The Harshaw System

This system is described in the section on personnel dosimetry.

The Radiological Assistance Program (RAP)

These dosimeters employ ^{7}LiF chips (Harshaw TLD-700) in a laminated nylon and cardboard field package (reference 11). The energy dependence of LiF is minimal, and the packaging would not be expected to affect significantly the intrinsic energy dependence of the phosphor. These dosimeters also were tested in the Third International Intercomparison of Environmental Dosimeters. They obtained a value of 31.8 mrems for the field exposure. The average of all participants was 31.5 mrem and the independently evaluated exposure was 34.9 mrem. They obtained a laboratory result of 90.0 mrem. The average of all participants was 86.2 mrem and the independently evaluated exposure was 91.7 mrem.

TABLE A-11: Teledyne Exposure Report Illustrating Apparently Unusually High Readings in the First and Fourth Areas

Net Exposures in Millirems

Ident.	Area 1	Area 2	Area 3	Area 4	Average	Std. Dev.
TM-lC1A	2.8	2.8	2.8	4.2	3.3	0.7
TM-7F1A	1.1	1.0	1.1	1.3	1.1	0.1
TM-15G1A	1.8	1.8	1.9	2.4	1.9	0.3
TM-12B1A	9.1	8.3	8.5	11.7	9.4	1.6
TM-9G1A	1.4	1.3	1.4	1.5 ,	1.4	0.1
TM-5A1A	6.6	6.7	7.5	12.4	8.3	2.8
TM-4A1A	32.0	29.1	29.1	47.0	34.3	8.6
TM-2S2A	30.6	28.1	30.6	40.8	32.5	5.6
TM-1S2A	18.1	17.3	19.8	24.9	20.0	3.4
TM-16S1A	77.1	70.0	78.4	109.4	83.7	17.5
TM-11S1A	[126.01	102.8	101.6	98.0	107.1	12.7
TM-9S2A	28.8	23.1	23.5	25.8	25.3	2.6
TM-4S2A	101.0	105.7	118.3	1 .	124.3	32.7
TM-5S2A	47.7	43.1	46.5	65.8	49.3	11.2
TM-4G1A	1.1	1.1	1.2	1.	1.2	0.2
TM-8C1A	10.7	9.4	9.9	12.9	10.7	1.6
TM-7G1A	1.0	1.0	1.0	1.1	1.0	0.1
TM-16A1	43.8	43.3	45.4	48.0	45.1	2.1
TM-14S1	60.3	45.3	39.9	49.8	48.8	8.6
TM-lOBl	15.9	14.1	14.1	15.4	14.9	0.9
TM-5A1	9.9	7.0	6.7	7.5	7.8	1.5
TM-5A1	9.2	7.0	6.5	7.1	7.4	1.2

These Net Exposure Values Resulted After Subtracting an Average Control Reading of 0.4 mrem, Derived from the Following Control Dosimeters

Control 01	0.6	0.4	0.3	0.3	0.4	0.1
Control 02	0.2	0.3	0.3	0.3	0.3	0.0
Control 03	0.4	0.3	0.3	0.4	0.4	0.1
Control 04	0.6	0.7	0.7	0.6	0.7	0.1

In operation, test and control dosimeters are annealed at the Idaho National Engineering Laboratory (INEL). The dosimeters are sent to the state of Pennsylvania, where the control dosimeters are stored in a lead shield and test dosimeters are placed at four sites. Approximately every quarter, the dosimeters are exchanged, and the exposed dosimeters returned to INEL for evaluation. Because only four sites were covered by this system, the task group did not perform a detailed evaluation of the limitations and errors associated with the system.

The NRC-RMC System

Shortly after the accident began, NRC contracted with RMC to provide dosimeters from its new automatic system (reference 21). This dosimeter utilizes one or two phosphors ($CaSO_4$:Tm and $Li_2B_4O_7$) behind a variety of windows. Readout is unusual in that the heating is supplied by infrared radiation and is very rapid. The system appears to be sound, but because of its newness, it has not been evaluated with respect to the NRC RG 4.13. The average standard error of the mean for the monthly NRC-RMC results was found to be approximately 2m, or 8 percent. Because of the way in which the dosimeters were handled, especially in the first few days (see Appendix B), the results were not used to make the best estimate of the off-site doses; however, they are incorporated into estimates of the upper and lower bounds.

The HEW System

HEW, through the BRH, operates a dosimetry program for the purpose of evaluating X-ray exposures (reference 19). The system utilizes LiF chips in a noncommercial holder. These dosimeters were pressed into service after the accident at TMI. The system was never intended for use in environmental dosimetry, and no historical background data were available, so the results are not useful for evaluating population dose in this situation. The deployment certainly was warranted, however, and had the accident resulted in much more serious releases, these dosimeters would have been extremely useful. The results of the HEW program give additional confidence that no large releases occurred after their deployment. HEW also collected samples of unexposed photographic film (Kodak Kodacolor-400) from retail outlets in the vicinity of TMI. They calibrated the film for radiation response and read it with a densitometer. They estimated that less than 10 mrem was delivered to the film from Middletown and that this was consistent with the dosimetry results.

The EPA System

The EPA carries out an environmental dosimetry program in support of the Nevada Test Site. Dosimeters from this program were pressed into service after the accident at TMI (reference 17). The dosimeters are Harshaw cards each containing two chips of CaF:Dy. The dosimeter package includes 1.2-millimeter thick cadmium energy compensation filters. They were prepared and read in Las Vegas. Nev. The reader employed was the Harshaw Model 2271.

Due to the late deployment, the distance from the reactor, and lack of historical background measurements, the data were not considered useful in making population dose estimates. Like the HEW dosimeters, these provide additional confidence that no large release occurred after they were deployed. They also would have been very useful had the accident resulted in much larger releases.

SELECTION OF DATA FOR INCORPORATION INTO POPULATION DOSE ESTIMATES

Although a number of TLD systems were used in the environs of TMI, only four were selected for use in computing the best estimate of the population dose. An additional system was used in the formal estimate of the bounds of the population dose. The four systems selected for incorporation were the Met Ed-Teledyne, Met Ed-RMC, Pennsylvania-RMC, and Pennsylvania-RAP. The additional system used for estimating the bounds of the population dose was the NRC-RMC system. These four systems were selected because they:

- were ongoing routine systems in place at the time of the accident;
- had historical background data available for substraction; and
- had been tested successfully in the Third International Intercomparison of Environmental Dosimeters.

The HEW and EPA data were characterized by late deployment and by sufficiently large errors and low sensitivity that they were deemed not to be useful in estimating the population dose. These systems were quite useful, however, in that they provided much greater spatial coverage than those dosimeters in place at the time of the accident and gave additional assurance that no large exposures occurred during the period when they were in place. They would have been invaluable in case of serious releases post-accident. The NRC-RMC data were characterized by sufficient sensitivity, but suffered from a lack of historical background and less-than-ideal procedures for deployment -- especially during the first few days. Dosimeters were exchanged daily and spent a large fraction of the deployment interval in transit. Thus, the daily NRC-RMC results tended to overestimate the actual exposures.

TREATMENT OF SELECTED DATA

Met Ed-Teledyne Results

Energy Dependence Adjustment

The Environmental TLDs that were deployed around the Three Mile Island site were exposed during the accident to gamma rays emitted from a mixture of radio-xenons and -kryptons. The calibration TLDs that provided readings used in the computation of exposures were exposed to gamma rays from Cs-137. Insofar as the TLDs respond differently to the calibration gamma rays and to those incident on the TLDs during the accident, the exposures calculated are in error. If this error is significant, it should be corrected and an estimate of uncertainties made.

Table A-12 shows the distribution of photon energies incident on the TLDs during the period of the accident.This table, calculated from release data supplied by Met Ed, "Third Interim Report on Three Mile Island Nuclear Station Unit 2 Accident," July 16, 1979, and from calculations by R.H. Clarke (reference 5), provides data on exposure due to a semi-infinite cloud of gamma-emitters. The figures in parentheses are percentages due to scattered gamma rays. These generally are degraded in energy and can have energies between KeV and the emission energy of the gamma ray.

The proportions are only approximate, but the table illustrates that:

- on the first day of the accident about one-third of the exposure was due to low energy (30-100 KeV) gamma rays; and

- with time, this proportion rose and was predominate after the first day.

The environmental dosimeters deployed by Met Ed during the accident period were of two kinds. At 10 of the dosimetry sites there were $CaSO_4$:Tm dosimeters enclosed in glass bulbs and fitted with energy correction filters. These were provided and read by RMC. At all 20 dosimetry sites, $CaSO_4$:Dy in Teflon dosimeters, sandwiched between 0.5-mm copper sheets, was used. These instruments were manufactured and read by Teledyne.

The RMC dosimeters, within their energy-correction shields, appear to have small energy and directional dependence, even at low energies, according to measurements reported by T. Yamashita, et al. (reference 3).

The Teledyne dosimeters appear to over-respond to low-energy gamma rays; this is shown in Figure A-7. The curve was calculated from the published data on the energy dependence of the dosimeter by itself and the calculated attenuation of 0.5 mm of copper. The points represent results obtained by Teledyne from exposures of the entire dosimeter. These exposures were made and measured by P. Plato of the University of Michigan. The curve indicates an over-response of about 2.1:1 for gamma-ray energies between 60 and 90 KeV.

In addition to testing the Teledyne TLDs with X-rays, they were also tested with zenon-133 gamma rays. The dosimeters were subjected to known exposures from a xenon-133 source from various directions. The exposures were performed at the Sloan-Kettering Institute, where they were also measured through the use of an ion-chamber -- which is nearly energy independent and has calibration traceable to the NBS. The dosimeters were then read by Teledyne. The results are summarized below.

FIGURE A-7: Energy Response of $CaSo_4$:Dy Teflon Dosimeter Between 0.5 mm Copper Sheets

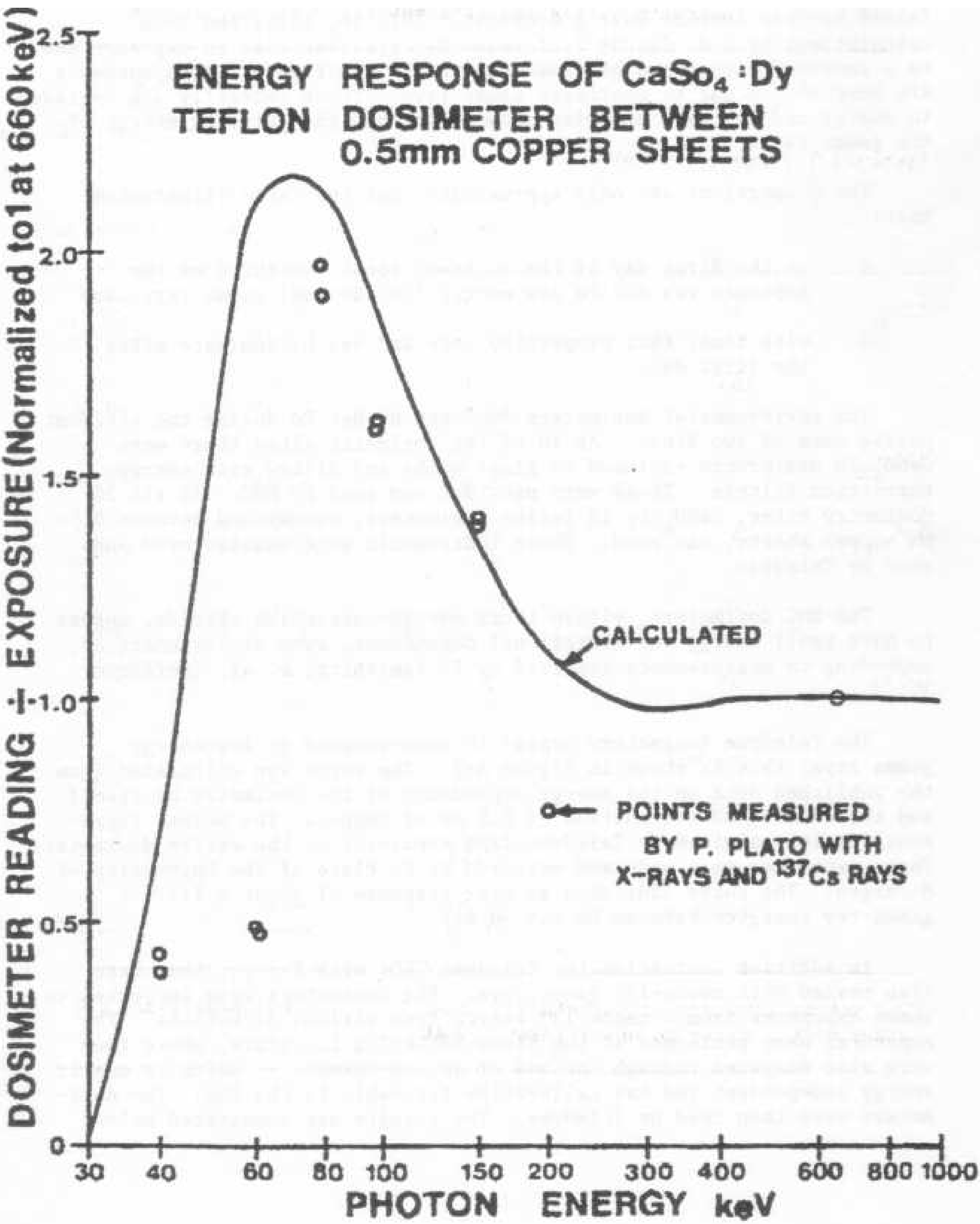


TABLE A-12: Percentages of Exposures Resulting from Noble Gases Released During the Accident at Three Mile Island*

Isotopes	y Energy in KeV	Period of Time: 3/28-7:00 a.m. to 3/29-4:00 p.m.	3/29-5:00 p.m. to 3/31-4:00 p.m.	3/31-5:00 p.m. to 4/3-3:00 p.m.
^{133}Xe	81	2.9 (17.9)	10.8 (65.3)	12.7 (76.4)
	160	0 (0.6)	0 (1.2)	0 (1.3)
^{133m}Xe	230	0 (0.6)	0 (1.1)	0 (1.0)
^{135}Xe	250	9.8 (35.2)	3.9 (15.3)	1.6 (6.3)
	610	1.2 (2.4)	0.5 (1.1)	0.2 (0.5)
135 Xe	527	2.3 (5.7)	0.2 (0.5)	----
^{88}Kr	160-360	0.1 (0.9)		----
	500-1,000	1.1 (1.5)		
	> 1,000	9.3 (8.8)	----	----

*The values enclosed in parentheses refer to scattered radiation, all other values refer to unscattered radiation.

TABLE A-13: Angular Dependence of Teledyne Dosimeters

Angle of Incidence (in degrees)	TLD Reading (Mean for 3 Dosimeters) / Ion-Chamber Reading
0	0.91
30	0.83
45	0.88
60	1.50
90	3.62

At first glance these results do not appear to agree with the X-ray measurements and the calculated values shown in Figure A-7. However, the xenon-133 source emits both X-rays in the energy range 30-35 KeV and gamma rays at 81 KeV. At short distances, where no absorption occurs, the X-rays produce 73 percent of the exposure. Under the conditions of the experiment, 0.5 mm between the source and the TLDs and 1.3 mm of glass surrounding the source, the proportion of the exposure due to the X-rays still would have been considerable. The chamber used is nearly independent of energy over the range 30-80 KeV. The TLD, sandwiched between 0.5-mm copper sheets, is very insensitive to X-rays in the energy range 30-35 KeV and over-responds to the 81 KeV gamma rays. Therefore, the ratio of TLD reading to ion-chamber is close to unity, because the TLD over-responds to gamma rays and under-responds to X-rays.

It should also be noted that the response changes with direction as well. At an angle of incidence of 90 degrees, the TLD is not shielded by copper sheets, and the calcium sulphate TLDs' high sensitivity to low-energy photons is most evident.

Although the xenon-133 X-rays played an important role in these measurements, they were less important in the exposure of the population around TMI. Table A-14 shows the contributions from the X- and gamma rays when the xenon-133 is distributed through a semi-infinite cloud. This corresponds to the situation when the plume touches down.

TABLE A-14: Exposure and Dose

Exposure and Exposure Rate (mrem/hr)		Dose Rate From 1 Ci/g of xenon-133			
		Whole-Body	Bone Marrow	Testes	Ovaries
20 KeV X-rays	24.5	8.8	7.4	7.6	0.2
80 KeV gamma rays	26.8	20.4	29.5	14.7	8.0

If shelter factors are taken into account, the difference between the X- and gamma rays is increased. If plume touchdown does not occur, the difference is increased further because the range in air of the 80 KeV gamma rays is higher than that of the 30 KeV X-rays.

Because the Teledyne dosimeters are more sensitive to the xenon-133 gamma rays than RMC dosimeters are, the ratio of the readings from the two types should reflect the energy distribution of the gamma rays and the time dependence of this energy distribution. Table A-15 reflects both these points.

In principle, the difference in readings between the two sets of dosimeters might be due to simple errors in calibration by one or both of the two dosimeter readers (RMC or Teledyne). However, there are two reasons for believing that this is not so:

- First, the ratio is significantly lower in the first measurement period; this is consistent with the higher proportion of higher energy gamma rays in the first period.

- Second, the ratio of the Teledyne to RMC readings in 1978 at sites away from the immediate vicinity of Three Mile Island was 1.10 + 0.11:1.

For these reasons, for the first measurement period, the ratio of Teledyne to RMC readings is taken as the measure of over-response of the Teledyne dosimeters due to their energy dependence. This ratio is 1.19:1.

For the later measurement periods, it can be seen from the figure showing the energy dependence of the Teledyne dosimeter that the over-response of the dosimeter must be between one and 2.2. The actual value is hard to determine because it depends on factors that cannot be determined precisely. These factors include:

- the energy distribution of the incident gamma rays, most of which have been scattered; and

- the direction distribution of the incident gamma rays, which is determined by the plume direction, height, and dispersion.

The maximum error due to energy dependence is minimized by taking an average of the maximum and minimum (2.2 and 2.0) over-response, which is 1.6. This value can be compared with the average of the ratios shown in Table A-15 for all periods except the first. This ratio is 1.42 ± .09:1. For all measurements after March 29, an average of these two estimates of overestimates is proposed -- the over-response of the Teledyne dosimeters due to energy response is assumed to be 1.5.

At four sites around TMI, it is possible to make comparisons between the Teledyne dosimeters and other types. Table A-16 shows the exposures measured with the different TLDs at various sites.

TABLE A-15: Ratio of Teledyne/RMC Readings
(With Background Subtracted)

Location	Period 12/27/78 - 3/29/79	3/29/79 - 3/31/79	3/31/79 - 4/3/79	4/3/79 - 4/6/79
E, 0.4 miles	X	1.57	1.53	X
N, 0.4 miles	1.07	1.32	X	X
NNW, 0.2 miles	1.12	1.36	1.23	X
SW, 0.1 miles	1.32	1.42	1.28	1.56
ENE, 0.3 miles	1.27	1.74	1.32	1.76
E, 0.2 miles	1.19	1.35	1.26	1.36
SSE, 2.3 miles	X	1.30	X	X
Mean	1.19	1.44	1.32	1.56

X-Reading ?Background + 5 mR or?t 2 X Background.

TABLE A-16: Comparison of Different Dosimeters at the Same Site

Dosimeter Type	Manufacturer	Agency	Exposures in mR Site Number 1	2	8	4
$CaSO$:Dy	Teledyne	Met Ed	12.0	22.5	15.2	15.4
$CaSO4$:Tm	RMC	Met Ed	----	13.7	11.5	----
$CaSO_{4'}$Tm	RMC	state of Pennsylvania	5.7	15.6	11.0	10.1
LiF:Mg, Ti	Harshaw	state of Pennsylvania	2.3	11.0	8.8	8.3

Taking the sum of the exposures at all four sites, the Teledyne dosimeter over-responds by 1.54:1 and 2.14:1 with respect to the RMC and Harshaw dosimeters, respectively. The exposures in the table relate to exposures taken over the whole accident period.

The correction factors applied to the Teledyne dosimeter (1.19 and 1.5), because of considerations of energy and angular dependence, would appear, therefore, to be conservative.

<u>Background Subtraction.</u> Historical background data were available for the Teledyne system. Because natural background rates can fluctuate seasonally, primarily due to variations in soil moisture and snow cover, it was deemed appropriate to use the data from the first-quarter of 1978 as the natural background rate. A large fraction of the accident doses were recorded by the first quarter 1979 dosimeters. For each dosimetry period after the accident, the historical background rate was multiplied by the appropriate time period and subtracted from the results to obtain a net exposure due to the accident. Because the accident took place at the end of the quarter, second-quarter 1978 data also could have been factored into the background estimates. Because second-quarter 1978 background data were considerably higher than data from the first quarter, the net effect would have been to reduce the dose apparently due to the accident.

<u>Error Estimate.</u> Based on the task force evaluation of the Teledyne system, a systematic error of 15 percent was chosen. As discussed previously in this appendix, the statistical error -- two standard deviations from the mean of the four elements -- was taken to be 13 percent plus 0.2 mrem, added in quadrature. The statistical error for the background measurements was taken to be 4.3 percent. The statistical error of the net exposure attributable to the accident was calculated by combining the error associated with the gross exposures and the background exposures by standard propagation-of-error techniques.

<u>Data.</u> The Met Ed-Teledyne raw data, adjusted for transit and instrumental background, but not historical background, are presented in Table A-18 with the historical background rate (mrem standard month

TABLE A-17: Met Ed Teledyne First Quarter 1979 Background Rate and Total Exposures Including Background for the Period 12/27/78 to 4/15/79

Site Identification	1st Quarter 1978 Background Rate (mR/mo.)	Total Exposures Including Natural Background (mrem) 12/27/78 to 3/29/79	3/29/79 to 3/31/79	3/31/79 to 4/03/79	4/03/79 to 4/06/79	4/06/79 to 4/09/79	4/09/79 to 4/12/79	4/12/79 to 4/15/79
1Cl	4.10	20.1	3.2	1.4	0.5	0.5	0.6	0.3
7Fl	6.57	24.1	1.1	0.5	0.9	1.0	0.7	0.5
15G1	5.13	18.4	1.9	-0.7	0.5	0.8	0.4	0.5
12Bl	3.57	16.3	9.4	0.2	1.2	1.3	0.3	0.1
9G1	5.60	21.3	1.4	0.1	0.6	0.9	0.6	0.5
5A1	4.60	18.6	8.3	7.7	3.0	1.2	2.2	0.2
4A1	4.60	20.2	34.3	41.4	2.2	0.7	0.6	0.4
2S2	4.07	43.7	32.5	3.4	0.9	0.6	0.3	0.2
1S2	4.67	97.2	20.0	-0.1	0.6	1.4	0.4	0.2
16S1	6.40	1044.2	83.7	7.0	1.5	1.0	0.6	0.6
11S1	5.07	216.0	107.1	45.0	21.8	8.5	1.1	0.6
9S2	4.67	25.0	25.1	4.6	1.8	1.3	0.4	0.3
4S2	4.80	35.5	124.3	28.0	7.9	1.6	0.6	0.2
5S2	4.30	30.5	49.3	26.7	15.5	6.0	2.7	0.2
4G1	5.30	17.2	1.2	0.6	0.6	0.7	0.4	0.3
8C1	3.50	13.0	10.7	1.7	1.3	1.0	0.4	0.1
7G1	7.20	25.8	1.0	-0.5	0.8	1.1	0.7	0.4
16A1	2.03	907.7 453.4*	45.1	1.7	0.9	0.7	0.4	0.2
14S1	2.17	131.2 148.3*	48.8	9.5	1.5	0.9	0.3	0.1
1OB1	1.97	40.6 36.6*	14.9	0.4	1.1	0.8	0.6	0.4

At these three sites, two dosimeters were left in place for **six** months; thus, two readings are available. This practice is followed because the sites are inaccessible during the normal quarterly exchange time (Jan 1).

Table A-18: Net Exposures Attributable to the Accident Obtained from Met Ed-Teledyne Data

Site Designation	Net Exposures Attributable to the Accident (mrem)													
	12/27/78 - 3/29/79		3/29/79 - 3/31/79		3/31/79 - 4/03/79		4/03/79 - 4/06/79		4/06/79 - 4/09/79		4/09/79 - 4/12/79		4/12/79 - 4/15/79	
	X	2a	X	2a	X	2a	X	2a	X	2a	X	2a	X	2a
1C1	6.5	2.2	2.0	0.3	0.7	0.2	0.1	0.1	0.1	0.1	0.1	0.1	-0.1	0.1
7F1	3.6	2.7	0.4	0.2	-0.1	0.1	0.2	0.2	0.2	0.2	0.0	0.1	-0.1	0.1
15G1	2.4	2.1	1.0	0.2	-0.8	0.1	0.0	0.1	0.1	0.2	-0.1	0.1	0.0	0.1
12B1	4.6	1.8	6.1	0.8	-0.1	0.1	0.6	0.2	0.6	0.2	0.0	0.1	-0.2	0.1
9G1	3.7	2.4	0.7	0.2	-0.3	0.1	0.0	0.1	0.2	0.2	0.0	0.1	0.0	0.1
5A1	4.0	2.1	5.3	0.7	4.8	0.7	1.7	0.3	0.5	0.2	1.2	0.2	-0.2	0.1
4A1	5.3	2.2	22.7	3.0	27.3	3.6	1.2	0.2	0.2	0.1	0.1	0.1	0.0	0.1
2S2	26.4	4.8	21.5	2.8	2.0	0.3	0.3	0.2	0.1	0.1	-0.1	0.1	-0.1	0.1
1S2	69.8	10.6	13.1	1.7	-0.4	0.1	0.1	0.1	0.6	0.2	0.0	0.1	-0.2	0.1
16S1	861.1	114.0	55.5	7.3	4.2	0.6	0.6	0.2	0.2	0.2	0.0	0.1	0.0	0.1
1151	168.6	23.6	71.2	9.3	29.7	3.9	14.2	1.9	5.3	0.7	0.4	0.2	0.1	0.1
9S2	9.2	2.8	16.5	2.2	2.8	0.4	0.9	0.2	0.6	0.2	0.0	0.1	-0.1	0.1
4S2	17.6	4.0	82.7	10.8	18.4	2.4	5.0	0.7	0.8	0.2	0.1	0.1	-0.2	0.1
5S2	14.7	3.4	32.7	4.3	17.5	2.3	10.0	1.3	3.7	0.5	1.5	0.3	-0.1	0.1
4G1	1.0	1.9	0.6	0.2	0.1	0.1	0.1	0.1	0.1	0.1	-0.1	0.1	-0.1	0.1
8C1	2.0	1.4	7.0	1.0	0.9	0.2	0.6	0.2	0.4	0.2	0.0	0.1	-0.2	0.1
7G1	3.4	2.9	0.4	0.2	-0.8	0.1	0.1	0.2	0.3	0.2	0.0	0.1	-0.2	0.1
16A1	758.0	99.0	30.0	3.9	1.0	0.2	0.5	0.2	0.3	0.1	0.1	0.1	0.0	0.1
14S1	119.9	15.3	32.4	4.2	6.2	0.8	0.9	0.2	0.5	0.2	0.1	0.1	-0.1	0.1
1OB1	27.4	4.3	9.8	1.3	0.1	0.1	0.6	0.2	0.4	0.2	0.3	0.1	0.1	0.1

TABLE A-19: Met Ed-RMC First-Quarter 1978 Background Rate and Total Exposures Including Background for the Period 12/27/78 to 4/15/79

Site Identification	1st Quarter 1978 Background Rate (mrem/mo.)	Total Exposures Including Natural Background (mrem)						
		12/27/78 to 3/29/79	3/29/79 to 3/31/79	3/31/79 to 4/03/79	4/03/79 to 4/06/79	4/06/79 to 4/09/79	4/09/79 to 4/12/79	4/12/79 to 4/15/79
7F1Q	6.15	23.3	0.8	1.5	0.9	1.0	1.0	0.9
15G1Q	4.70	17.6	1.1	0.8	0.7	0.6	0.6	0.7
5A1Q	4.57	16.1	5.4	5.2	2.0	1.3	1.8	0.6
1S2Q	5.71	95.7	15.3	1.3	0.8	0.9	0.8	0.7
16S1Q	3.93	929.4	61.6	5.6	1.3	0.9	0.8	0.9
11S1Q	5.35	168.5	75.7	35.2	14.2	5.5	1.0	0.9
4S2Q	4.91	31.4	71.4	21.3	4.7	1.0	1.0	0.7
5S2Q	4.32	27.7	36.6	21.2	11.5	4.7	2.2	0.9
4G1Q	4.94	17.7	0.6	1.4	0.7	0.8	0.8	0.7
8C1Q	4.07*	12.6	8.4	2.6	1.1	0.7	0.7	0.6

*Second Quarter 1978: First quarter missing.

TABLE A-20: Net Exposures Attributable to the Accident Obtained from Met Ed-RMC Data

Site Designation	Net Exposures Attributable to the Accident (mrem)													
	12/27/78 - 3/29/79		3/29/79 - 3/31/79		3/31/79 - 4/3/79		4/3/79 - 4/6/79		4/6/79 - 4/9/79		4/9/79 - 4/12/79		4/12/79 - 4/15/79	
	X	2a	X	2a	X	2a	X	2a	X	2a	X	2a	X	2 a
7F1Q	4.7	3.2	0.4	0.1	0.9	0.2	0.3	0.2	0.4	0.2	0.4	0.2	0.3	0.1
15G1Q	3.4	2.4	0.8	0.2	0.3	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1
5A1Q	2.3	2.3	5.1	0.7	4.7	0.6	1.5	0.3	0.8	0.2	1.3	0.2	0.1	0.1
1S2Q	78.4	11.7	14.9	1.9	0.7	0.2	0.2	0.1	0.3	0.1	0.2	0.1	0.2	0.1
16S1Q	917.5	112.5	61.3	7.5	5.2	0.7	0.9	0.2	0.5	0.1	0.4	0.1	0.5	0.1
11S1Q	152.3	20.4	75.3	9.2	34.7	4.3	13.7	1.7	4.9	0.7	0.5	0.2	0.4	0.2
4S2Q	16.5	4.0	71.1	8.6	20.8	2.6	4.2	0.6	0.6	0.2	0.5	0.2	0.2	0.1
5S2Q	14.6	3.5	36.3	4.4	20.8	2.6	11.1	1.4	4.3	0.6	1.8	0.3	0.4	0.1
4G1Q	2.8	2.5	0.3	0.1	0.9	0.2	0.2	0.1	0.3	0.1	0.3	0.1	0.2	0.1
8CIQ	0.3	1.8	8.1	1.0	2.2	0.3	0.7	0.2	0.2	0.1	0.2	0.1	0.2	0.1

TABLE A-21: NRC-RMC Backgrounds, Gross Exposures Measured During the Accident, and Net Exposures Attributable to the Accident

"Background" (mrem)		Exposures Including Background (mrem)		Net Exposures Attributable to the Accident			
				3/31/79 - 4/01/79		4/01/79 - 5/01/79	
5/01/79 to 5/31/79	5/31/79 to 6/28/79	3/31/79 to 4/01/79	4/01/79 to 5/01/79	x	2 a	X	2 a
5.600	5.500	25.000	8.200	24.8	2.0	2.5	0.8
4.900	4.800	7.000	4.900	6.8	0.6	-0.1	0.6
4.900	4.800		4.900		-	-0.1	0.6
4.600	4.400	1.000		0.8	0.1		-
5.200	5.600	1.600	5.700	1.4	0.1	0.1	0.6
5.300	4.600	2.100	5.500	1.9	0.2	0.4	0.6
4.900	4.900		5.200			0.1	0.6
5.300	5.000	1.200	5.500	1.0	0.1	0.2	0.6
5.400	5.200	1.000	5.600	0.8	0.1	0.1	0.6
5.800	5.500		5.600	-	-	-0.2	0.6
5.500	5.000	4.600	5.300	4.4	0.4	-0.1	0.6
4.100	3.900	5.500	4.100	5.4	0.4	0.0	0.5
5.600	4.800	1.400	6.200	1.2	0.1	0.8	0.7
4.900	4.900	1.300	5.300	1.1	0.1	0.2	0.6
5.400	5.400	0.900	7.200	0.7	0.7	1.6	0.7
4.300	4.300	3.000	7.300	2.9	0.2	2.9	0.7
4.100	3.900	0.900	5.700	0.8	0.1	1.6	0.6
4.300	4.200	0.900	6.100	0.8	0.1	1.7	0.6
5.700	5.800	1.100	6.500	0.9	0.1	0.6	0.7
4.600	4.500	1.200	5.800	1.0	0.1	1.1	0.6
6.400	5.900	1.000	7.900	0.8	0.1	1.5	0.8
4.700	4.200	0.900	7.000	0.7	0.1	2.4	0.7
5.100	4.400	1.600	7.300	0.4	0.1	2.4	0.7
4.500	5.200	1.000	5.900	0.8	0.1	0.9	0.6
6.900	6.900	1.200	7.600	1.0	0.1	0.5	0.8
5.200	4.000	1.100	5.900	0.9	0.1	1.1	0.6
6.100	4.900	0.900	6.500	0.7	0.1	0.8	0.7
6.600	5.300	1.200	6.300	1.0	0.1	0.1	0.7
5.500	4.800	2.500	5.700	2.3	0.2	0.4	0.6
5.400	4.500	3.000	7.700	2.8	0.2	2.6	0.7
		2.300	7.600		-		-
5.100	4.500	3.500	8.900	3.3	0.3	3.9	0.8
5.200	5.200	10.100	15.700	9.9	0.8	10.3	1.3
4.900	4.100	4.300	5.300	4.1	0.3	0.6	0.6
5.800	5.100	2.100	6.700	1.9	0.2	1.1	0.7
6.000	4.600	2.500	5.900	2.3	0.2	0.4	0.6

where a standard month equals 30.4 days) for the first quarter of 1978. Sites 16A1, 14S1, and 10Bl normally are inaccessible in the winter months, so two dosimeters are deployed at each of these three sites for 6 months. One of these pairs, site 16A1, is discordant by a factor of two. After carefully examining the situation, the task group determined that the larger of the two values was more likely to be correct, so the smaller value was discarded. The shielding of one dosimeter by the other and inadequate heating of the dosimeter were given as reasons for an incorrect, reduced value; no plausible reasons were given for an incorrect high reading. For the remaining two stations, the pairs of values were averaged for use in estimating population dose.

Net Adjusted Data. For the period Dec. 27, 1978, to March 29, 1979, the net adjusted data were obtained by subtracting the historical background data from the readings during the accident and by making an energy adjustment by dividing the results by 1.19. The random errors were calculated as discussed above; the results are presented in Table A-18.

Met Ed-RMC Data

Background Subtraction. Just as with the Teledyne data, historical natural background data are available for the RMC dosimeters. The firstquarter of 1978 natural background data was used to estimate the background rates during the accident. For each dosimetry period after the accident, the historical background rate was multiplied by the appropriate time period and subtracted from the results to obtain a net exposure.

Error Estimate. Based on the task group evaluation of the RMC system, a systematic error of 15 percent was chosen. As discussed above, the statistical error (two standard deviations from the mean of the four elements) was taken to be 8.3 percent for the background measurements and 12.1 percent for the measurements made during the accident. An additional 0.1 mrem was added in quadrature, with the 12.1 percent for measurements taken during the accident to account for errors associated with measuring small quantities.

Data. The Met Ed-RMC data, which are adjusted for transit and instrumental background but not historical background, are presented in Table A-20 with the historical background rate (mrem standard month -- where a standard month equals 30.4 days) for the first quarter of 1978. No energy adjustment was deemed necessary. The net exposures attributable to the accident, together with the statistical error, are shown in Table A-20.

NRC Data

Background Subtraction. Historical background data were not available for most of the NRC dosimeter locations. In the few locations that overlapped with the Met Ed locations, the Met Ed-Teledyne or Met Ed-RMC data could be used. The task group chose to use background data collected during May and June for subtraction purposes. Because essentially all of the dose delivered to the environmental dosimeters as a consequence of the accident were due to noble gases, and because these noble gases do not persist or concentrate in the local environment, the assumption was considered valid.

Error Estimate. The systematic error of this system was considered to be 15 percent. The statistical error (two standard deviations from the mean) was found to be 8 percent. Some of the NRC-RMC dosimeters were changed daily; others were left in place for a month. Because the dosimeters changed on a daily basis spent a substantial fraction of their deployment time in transit, and especially because no shield was available for transit during the first few days, the daily readings are not considered to be of adequate quality for use in estimating population dose.

Data. The NRC-RMC background data, gross results during the accident, and results with background subtracted are provided in Table A-21.

State of Pennsylvania: Comparison of Several Systems

The state of Pennsylvania data concern only four stations and represent a check of the utility data on the part of the state. Historical backgrounds were subtracted in a manner similar to the Met Ed data discussed above. No other adjustments were made and no errors were estimated. Table A-15 gives the state of Pennsylvania data, together with the approximately corresponding data from other sources. This table appears in an earlier part of this appendix, where it was employed as evidence for the over-response of the Teledyne dosimeters.

Met Ed-Harshaw Dosimeters

These data did not reach the Commission staff in time for incorporation in this report.

OCCUPATIONAL EXPOSURES

The occupational exposures at Three Mile Island are measured with lithium fluoride TLDs (of a formulation known as TLD-100) manufactured by the Harshaw Chemical Company. The same company manufactures the automatic reader that is used to identify the dosimeters and to evaluate the penetration and skin doses of the wearers of the dosimeters.

Each wearer is provided with a card carrying two dosimeters. Each dosimeter is 0.125 inches square and 0.035 inches thick, and is held and sealed between sheets of Teflon 0.0025 inches thick. The card is identified by a hole code for automatic reading. The dosimeter card is contained in a polycarbonate holder. The holder has a hole to admit beta particles, so that one of the two dosimeters is covered only by a paper label -- if the holder is worn with the holder facing away from the wearer's body. This dosimeter is used to estimate skin doses. The second dosimeter is covered by 0.025 inches of aluminum and 0.040 inches of polycarbonate; it is used for direct estimation of the penetrating dose from gamma rays.

Beta doses' are calculated as follows:

$$D_S = \frac{(R_1 - 1.15 R_2)}{b}$$

where D_S = beta dose

R_1= reading of the dosimeter behind the open window

R_2= reading of the dosimeter behind the aluminum shield

b = the ratio of sensitivities to beta and gamma doses.

The value of b used for computing beta doses at Three Mile Island is 0.26. This value is correct for beta particles with end-point energies of 0.8 MeV. Its use can lead to an overestimate of doses of about three from SR-90/Y-90 sources. For beta particles from Xe-133 this value leads to an underestimate of about three.

The dosimeters are calibrated by being exposed in their holders to 100 mrem from a Cs-137 source, whose output is measured by an ion-chamber with calibration traceable to NBS. As a cross-check, this normally is done at Three Mile Island. TLDs exposed in this way periodically are returned to the manufacturer for evaluation. Similarly, the manufacturer sends exposed dosimeters to Three Mile Island for evaluation there.

The dosimeters were read, up to the time of the accident, using one automatic TLD reader -- Harshaw Model 2271. The reader identifies each card and evaluates both dosimeters. These data are printed and punched on paper tape. Finally, the data are supplied to a computer for processing to provide dose records for each worker. The computer produces monthly summaries of dose distribution, collective dose equivalent, and number of badged workers.

During the accident, the automatic TLD reader was moved to the observation center at 9:05 a.m. on March 29 because of high exposure rates (ti40mrem/hr) at its normal position. The Observation Center is 0.4 miles east of the site, where the exposure rate was relatively low (about 5 mrem) between March 29 and March 31. At 1:30 p.m. on March 30, a second automatic TLD reader arrived from the Harshaw Chemical Company. The reader was accompanied by two staff members from Harshaw, who remained to operate it. On April 8, the Harshaw staff left, but the second reader was left for continued operations. The second reader was equipped with a beta source to produce standards for calibration. The Cs-137 source at the site was not available for providing standards for the first reader; however, after the stock of exposed calibration dosimeters was depleted, further exposed dosimeters were obtained from the Peach Bottom Nuclear Station.

OCCUPATIONAL EXPOSURE RECORDED DURING THE ACCIDENT

Determining the amount of occupational exposure that resulted from the accident is not easy. The occupational exposure that occurred before the accident could be considered as a background. However, the background fluctuates widely, depending on the phase of reactor operation.

It also can be remarked that electricity generation at TMI-2 ceased on March 28. It, therefore, is arguable that all collective dose equivalent (DE) acquired there after that date can be regarded as a consequence of the accident until a benefit is obtained when power production is resumed. It is, therefore, not necessary to subtract a background occupational exposure.

There are three important aspects of occupational exposures:

- the collective DE, because it is often assumed that the harm done to the society, which includes the occupationally exposed, is proportional to this quantity;

- the distribution of DE, and, in particular, the number of people whose DE approaches or exceeds quarterly and annual limits; and

- the DE received by those whose DE exceeded limits.

To show how the collective DE was affected by the accident, Table A-22 presents the DE on a monthly basis.

Before the accident, the collective DE varied from about 20 to 150 person-rems each month. During the accident and up to the end of June, a collective DE of about 980 person-rems had been accumulated. It should be noted that the collective DE will continue to accumulate, but predictions of its final total cannot be made. This total will depend on decisions yet to be made about the operation of Three Mile Island.

Except during the month of March, average DE has not been elevated in comparison with pre-accident figures; this is because the work force has been so enlarged.

Most of the additional workers who were brought to TMI did not receive measurable exposures. Table A-22 lists, in parentheses, the number of workers who were measurably exposed and their average monthly dose. The numbers actually exposed did not rise during the accident as much as the number of workers at the site; however, of course, their average DE rose significantly.

Table A-23 shows how the collective DEs are distributed before and during the accident. The numbers in the first column are a measure of workers who, while furnished with dosimeters, were not exposed at levels measurably above background. As noted above, from April onward they represent more than one-half of those on site. The significance of the numbers receiving more than 0.5 rem per month is that this rate, if continued for a year, leads to a DE exceeding 5 rems. Any workers receiving more than 3 rems have exceeded the quarterly limit in one month.

TABLE A-22: Collective Dose Equivalents Before and During the Accident (Person-rem)

Month	Number of Occupationally Exposed	Average DE (mrem)	Collective DE (person-rem)
Jan. 1978	573 (569)*	39 (39)	22.1
Feb. 1978	641 (625)	37 (38)	23.9
Mar. 1978	1146 (1016)	98 (110)	112
Unit 2 Criticality Date: March 28, 1979			
Apr. 1978	1221 (1179)	122 (126)	149
May 1978	850 (824)	54 (56)	45.8
Jan. 1979	793 (755)	42 (44)	33.1
Feb. 1979	995 (963)	118 (121)	117
Accident Date: March 28, 1979			
Mar. 1979	1131 (1017)	295 (328)	334
Apr. 1979	4505 (1337)	31 (105)	140
May 1979	5282 (1778)	66 (197)	351
June 1979	2869 (1057)	55 (149)	157

*The figures in parentheses are those "measurably exposed."

TABLE A-23: Dose Equivalent Distributions Before and During the Accident Number of Occupationally Exposed in Each DE Interval

Month	<0.5	0.5-1	1-2	2-3	3-4	4-5 rem
Jan. 1978	569	0	0	0	0	0
Feb. 1978	625	0	0	0	0	0
Mar. 1978	978	37	1	0	0	0
Unit 2 Criticality Date: March 28, 1978						
Apr. 1978	1118	63	8	0	0	0
May 1978	822	1	1	0	0	0
Jan. 1979	47	2	0	0	0	0
Feb. 1979	925	37	1	0	0	0
Accident Date: March 28, 1979						
Mar. 1979	793	165	52	4	1	2
Apr. 1979	1288	43	6	0	0	0
May 1979	1771	5	2	0	0	0
June 1979	1056	1	0	0	0	0

It can be seen that there was a significant increase in March 1979 in those receiving more than 0.5 rem; this reflects a large increase in the exposure during the 4 days immediately following the accident. This was also the only period in which overexposures were detected.

Finally, overexposures resulting from the accident must be considered. In the first category are whole-body overexposures, as recorded by personnel dosimeters (TLD). Table A-24 summarizes the reported data.

The overexposures exceeded the quarterly limit of 3 rems, but not the annual limit of 5 rems -- two of the DEs exceeded 4 rems. Good fortune played a role in preventing any DE over 5 rems; and accumulation of one rem in the annual total is not rare. Although beta doses are estimated and reported from the personnel dosimeter readings, no overexposures were reported. Two overexposures to the extremities were also determined by NRC; the results are presented below in Table A-25.

TABLE A-24: Whole-Body Overexposures Consequent on the Accident

Identity	1st Quarter Whole-Body DE (rem)	Date of Exposure and DE Reported
Auxiliary Operator	3.87	March 28 (3.17 rem)
Chemistry Foreman	4.12	March 29 (4.1 rem)
Engineer	4.18	March 29 (3.14 rem)

TABLE A-25: Extremity Overexposures

Identity	1st Quarter Extremity DE Term (rems)	Date	Part Affected
Health Physics Foreman	44-45	March 29	Hands & Forearm
Chemistry Foreman	147	March 29	Fingers

The extremity dose to the health physics foreman was calculated (reference 9) on the basis of:

- dose rate measurements made at the time of the exposure;
- time and distance estimates made after the exposure; and

- contamination measurements made with a side window Geiger tube on the same day as the accident.

The whole-body TLD reading was used as a check on the time and distance estimate.

The chemistry foreman is the person referred to in Table A-24 whose whole-body DE was 4.12 rems in the first quarter. The DE to his fingers was based on:

- dose-rate measurement made at the time of the exposure by the chemistry foreman; and

- time and distance estimates made after the exposure.

In addition to the extremity exposure, the chemistry foreman was contaminated on his head. It was estimated that the resulting skin DE was 6 to 13 rems in the first quarter and 4 to 19 rems in the second. These calculated doses were based on estimations of 1-131 contamination alone. However, longer-lived contaminants (1-133, Cs-134, Cs-137, Co-60) were also identified; when these have been evaluated, they could significantly increase the estimate of skin DE.

THE QUALITY OF THE DATA AVAILABLE ON OCCUPATIONAL EXPOSURES

At the best of times, personnel dosimetry is an inexact form of measurement. Whole-body and skin DE generally are based on personnel dosimeter readings. The relationship between the exposure and the DE are critically affected by the following factors:

- the energy of gamma rays or beta rays;

- the direction of the radiation;

- the distance between source and dosimeter wearer; and

- the protective clothing worn by the dosimeter wearer.

An error in the estimation of whole-body DE by a factor of two can easily occur; a factor-of-six error can occur, for example, when an 80 KeV gamma ray source is behind the dosimeter wearer (reference 8).

In the case of beta rays, larger errors can occur because the dosimeter used for detecting beta rays can be completely shielded even though some parts of the body are exposed.

During the early stages of the accident, personnel dosimetry problems were worsened by the change of routine brought about by the accident. Some idea of these difficulties can be gained from a direct quotation from the report of the NRC investigation (reference 7) of the accident:

During the period [3:00 a.m.] March 28 through the afternoon of March 29, TLD badges were read on an as-requested basis on-site at the normal location. The TLDs were read by any radiation/chemistry technician or radiation protection foreman that was available at any time. Procedure 1642 states that a TLD reader calibration test should be done on or near each badge exchange or reading period. This test was not performed prior to reading TLD badges during the incident. The last recorded test was performed on Feb. 28, 1979. That test indicates acceptable results. Sometime on the afternoon of March 29, the TLD reader and support equipment was moved from its normal location in a trailer on-site to the Observation Center. The equipment was placed into operation and some TLD badges were read. No records indicate that a reader calibration test was performed. The TLD system was operated until about [7:00 a.m.] March 31 by Radiation/Chemistry Technician C, who had received two hours of on-the-job training on June 6, 1977, and had not operated the equipment in about a year and a half. He did not have a copy of the procedure for either operation or documentation of TLD results available. He performed this job for about 48 continuous hours without sleep. His work included zeroing all the April TLD badges that had been stored on-site in the TLD trailer and reading TLD badges as they were turned in. He indicated that he had little or no help through this period.

The reliable operation of a TLD system, including an automatic reader, requires an operator who is alert, well-trained, and experienced. Because it appears that these qualities must have been lacking, the probability of dosimetry errors of both omission and commission was high.

One source of error is the fading characteristic of the TLDs in use. Because of their construction, the TLD cards cannot be annealed before irradiation. Consequently, they are subject to a relatively high rate of fading. Under normal conditions, when the TLDs are read monthly, fading errors are minimized by waiting for 2 days before reading and applying a fading correction. Under the conditions prevailing during the accident, when the turnaround of dosimeters was often much faster, the fading would be reduced. This error tends to overestimate the dose.

Because the dosimeters used are lithium fluoride, their energy dependence is not large. Measurements made with this dosimeter, when bare (reference 10), suggest that the change in response with energy would be less than 20 percent for photon energies above 30 KeV.

Lack of calibration dosimeters exposed at known levels during part of the time meant that the readings depended on the inherent stability of the reader.

Beta dosimetry using TLDs 0.035 inches thick is only reliable when the beta spectra are known. During the accident period, these spectra changed as the fission products aged. Complicating this picture were the variation in protective clothing worn and the fact that dosimeters were sometimes worn inside the clothing and sometimes outside. For these reasons, beta doses recorded should be treated with great caution. In view of the distance and shielding involved, it is improbable that overexposures to the skin occurred when the whole body was not overexposed (this does not apply to cases of skin contamination).

In view of the circumstances in which the TLD readings were made, it is likely that some exposures were never recorded or were wrongly attributed. For instance, five persons who were exposed by reason of their work had no recorded DE. This information was revealed by an NRC study of a sample of 200 records; it probably means that there were other missing records.

Because of the nature of the work done during the accident period, appreciable extremity doses were probable. No extremity dosimeters were used; neither were the whole-body dosimeters strapped to the wrist, which would have been better than nothing.

The two extremity doses reported by the NRC were not obtained from direct dosimeter readings and depended on a chain of factors, some of which were subject to much uncertainty.

Because extremity dosimeters were not used, the strong possibility exists that there were other extremity overexposures that were not recorded.

CONCLUSIONS

- For reasons already given, the available data on occupational exposure at Three Mile Island must be treated with caution. They may be incomplete.

- The occupational collective DE is smaller than that received by the surrounding population. However, the occupational collective DE is appreciable (1,000 person-rems reported by the end of June) and is still rising.

- Reported overexposures have been few and were not excessive. None were reported after March 29, 1979.

- The collective DE and the extent of overexposure is not large in relation to the radiation fields and contamination levels measured during the later stages of the accident.

APPENDIX A REFERENCES

1. Schayes, R., Lorthair, M., and L'Heureux, M., "Thermoluminescent Properties of Natural Calcium Fluoride," Luminescence Dosimetry, CONF-650637 (1967), p. 138.

2. Cameron, J.R., Zimmerman, D., Kenny, G., Burch, R., Bland, R., and Grant, R., "Thermoluminescent Radiation Dosimetry Utilizing LiF," Health Physics, 10 (1964), p. 25.

3. Yamashita, T., Norda, N., Omishi, H., Kitamura, S., "Calcium Sulphate Activated by Thulium or Dysprosium for Thermoluminescence Dosimetry," Health Physics, 21 (1971), p. 295.

4. Dauch, J.E., "An Automatic Personnel Dosimeter System Using a Multi-Area Dy-Activated CaSO4 Dosimeter." Proceedings of Fourth International Conference on Luminescence Dosimetry. Krakow, 1974, p. 651.

5. Clarke, R.H., "The Relationship Between Doses to Human Body Organs and Exposure in a Cloud of Gamma Emitting Nuclides," 3862 (1976). Central Electricity Generating Board, RD/13/N.

6. American National Standard Performance, "Testing and Procedural Specifications for Thermoluminescence Dosimetry (Environmental Applications)," American National Standards Institute, ANSI N545 (1975).

7. "Investigation into the March 28, 1979, Three Mile Island Accident by Office of Inspection and Enforcement," Office of U.S. Nuclear Regulatory Commission, NUREG-0600 (1979), pp. 11-3-59.

8. Jones, A.R., "Proposed Calibration Factors for Various Dosimeters at Different Energies," Health Physics (1966), p. 663.

9. Slobodien, M.J., "Appendix II-B," NUREG 0600 (1979).

10. Pendurkar, H.K., Boulenger, R., Ghoos, L., Nicasi, W., Mertens, E., "Energy Response of Certain Thermoluminescent Dosimeters and Their Application to the Dose Measurements," RIS¢ Report 249 (1971), p. 1089.

11. Jones, D., Letter and Enclosures addressed to Frank Grossman from the Radiological and Environmental Sciences Laboratory of the Idaho National Engineering Laboratory by Donald E. Jones, Chief, Dosimetry Branch, 1979.

12. Hiraki, H., "Thermoluminescent Dosimeter (TLD) III. Development of a TLD Reader with a Digital Display," National Technical Report 18, No. 2 (April 1972), pp. 1-9.

13. Radiation Management Corporation, "Radiation Management Corporation Environmental Thermoluminescent Dosimetry System: Evaluation of Compliance with U.S. NRC Regulatory Guide 4.13," Internal RMC Report, RMC-TR-78-10 (1978).

14. Klotz, A., series of internal Teledyne Isotopes, Inc., reports dealing with various aspects of the Teledyne dosimeter's conformance to NRC Regulatory Guide 4.13 and ANSI Standard N-545-1975 (1978).

15. Slane, D., Internal Teledyne memorandum addressed to M. Pasquini and dated Jan. 10, 1978. This memorandum was supplied to the Commission staff by David Martin of Teledyne, 1978.

16. Teledyne Isotopes, Inc., "Teledyne Product Bulletin #BBI," transmitted to John Buchanan by Hewitt W. Jeter of Teledyne under a cover letter dated April 19, 1979.

17. Bretthauer, E., Letter and enclosures sent to Ms. Carol Berger of the Commission staff from the U.S. Environmental Protection Agency by Erich W. Bretthauer, Director of the Nuclear Radiation Assessment Division. The letter is undated; the enclosure is dated July 1979.

18. Beaver, D., Letter to Ms. Carol Berger dated July 20, 1979, from the Commonwealth of Pennsylvania Bureau of Radiation Protection by Donald Beaver, Radiation Health Physicist, 1979.

19. Villforth, John, Letter and enclosures sent to Erich Bretthauer of the EPA dated May 7, 1979, from the U.S. Department of Health, Education, and Welfare, Bureau of Radiological Health by John C. Villforth, HEW Three Mile Island Incident Coordinator.

20. Metropolitan Edison Company, Material supplied to the Commission at its request, 1979.

21. Battist, L., Buchanan, J., Congel, F., Nelson, C., Nelson, M., Peterson, H., and Rosenstein, M., "Population Dose and Health Impact of the Accident at the Three Mile Island Nuclear Station," Sup. Doc., Washington, D.C., Stock #017-001-00408-1 (1979).

APPENDIX B

CALCULATION OF COLLECTIVE DOSES AT THREE MILE ISLAND

Collective doses were estimated from the population distribution within a 50-mile radius of Three Mile Island and from the doses measured by TLDs provided by Teledyne, RMC, DOE, and NRC. In addition, the state of Pennsylvania placed TLDs at four locations. The TLD data evaluated in Appendix A was used as input to a computer code that calculates collective dose.

POPULATION DISTRIBUTION

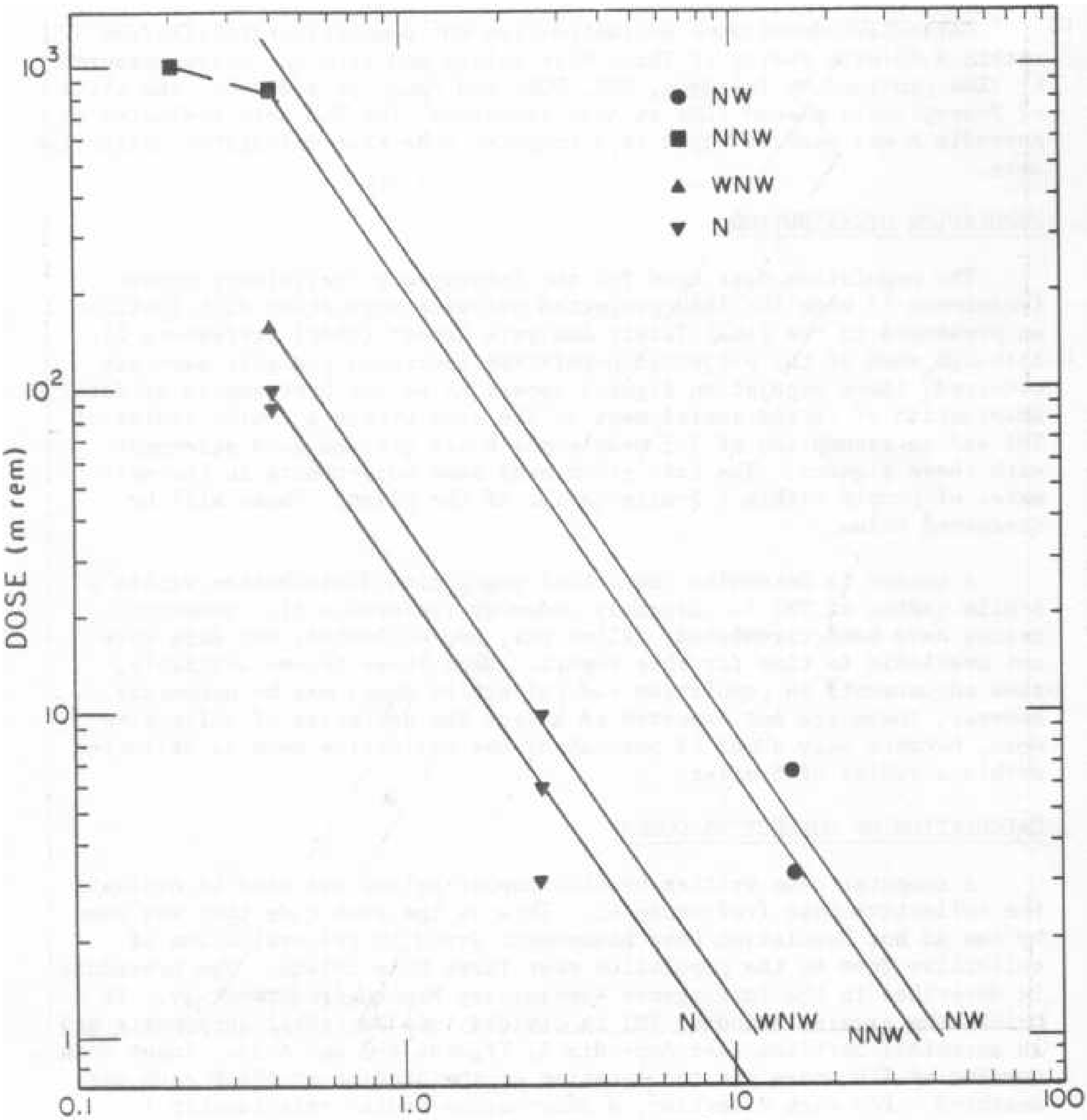
The population data used for the Interagency Preliminary Report (reference 1) were the 1980 projected off-site population distributions as presented in the Final Safety Analysis Report (FSAR) (reference 2). Although some of the projected population increases probably have not occurred, these population figures appear to be the best source of data. Examination of recent aerial maps of the area within a 2-mile radius of TMI and an assumption of 2.5 people per house yielded good agreement with these figures. The task group made some adjustments in the estimates of people within a 2-mile radius of the plant. These will be discussed below.

A census to determine the actual population distribution within a 5-mile radius of TMI is currently underway (reference 3). Questionnaires have been circulated, filled out, and collected, but data were not available in time for this report. When these become available, some adjustments in population and collective doses may be necessary. However, these are not expected to affect the estimates of collective dose, because only about 13 percent of the collective dose is delivered within a radius of 5 miles.

CALCULATION OF COLLECTIVE DOSES

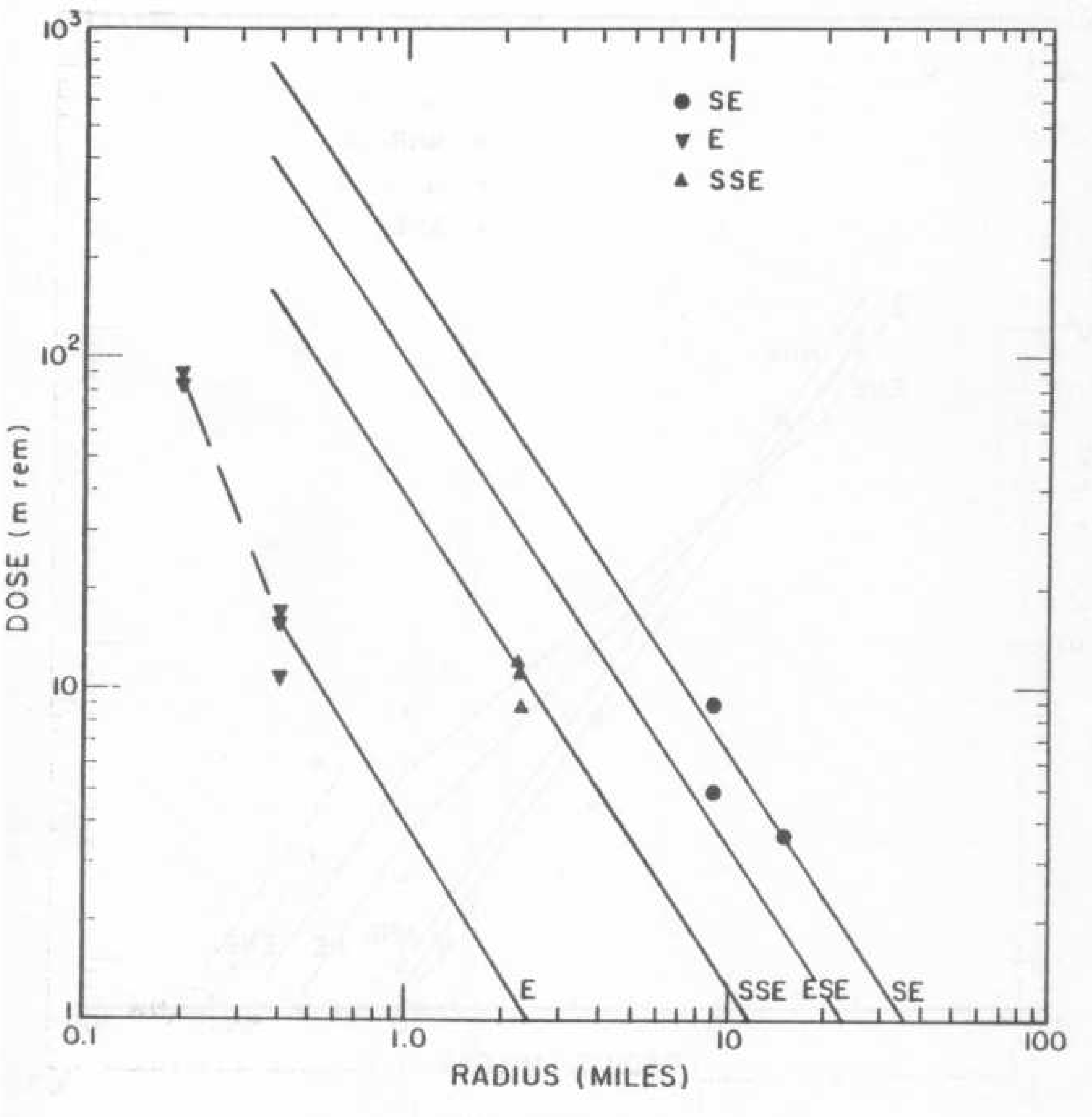
A computer code written by Christopher Nelson was used to evaluate the collective dose (reference 4). This is the same code that was used by the Ad Hoc Population Dose Assessment Group in its evaluation of collective dose to the population near Three Mile Island. The procedure is described in the Interagency Preliminary Report (reference 1). In brief, the area surrounding TMI is divided into 10 radial increments and 16 azimuthal sections (see Appendix A, Figures A-2 and A-3). Input data consist of TLD doses and the location of the station at which each was measured. For each direction, a dose-versus-radius relationship is constructed by log-log interpolation between measured values. If necessary, the dose$_1$ig extrapolated into 0.4 miles or out to 50 miles, assuming an r decrease with distance. For the northeast, east-southeast, and west directions, where there were no Met Ed TLDs in place, and for the north-northwest direction, where there were no NRC TLDs in place, doses were estimated by linear interpolation from neighboring sectors. Figures B-1, B-2, B-3, and B-4 show plots of dose-versus-radius for different directions. The symbols represent measured data, and the straight lines represent values interpolated or extrapolated

FIGURE B-1: Calculated and Measured Doses as a Function of Radial Distance From TMI



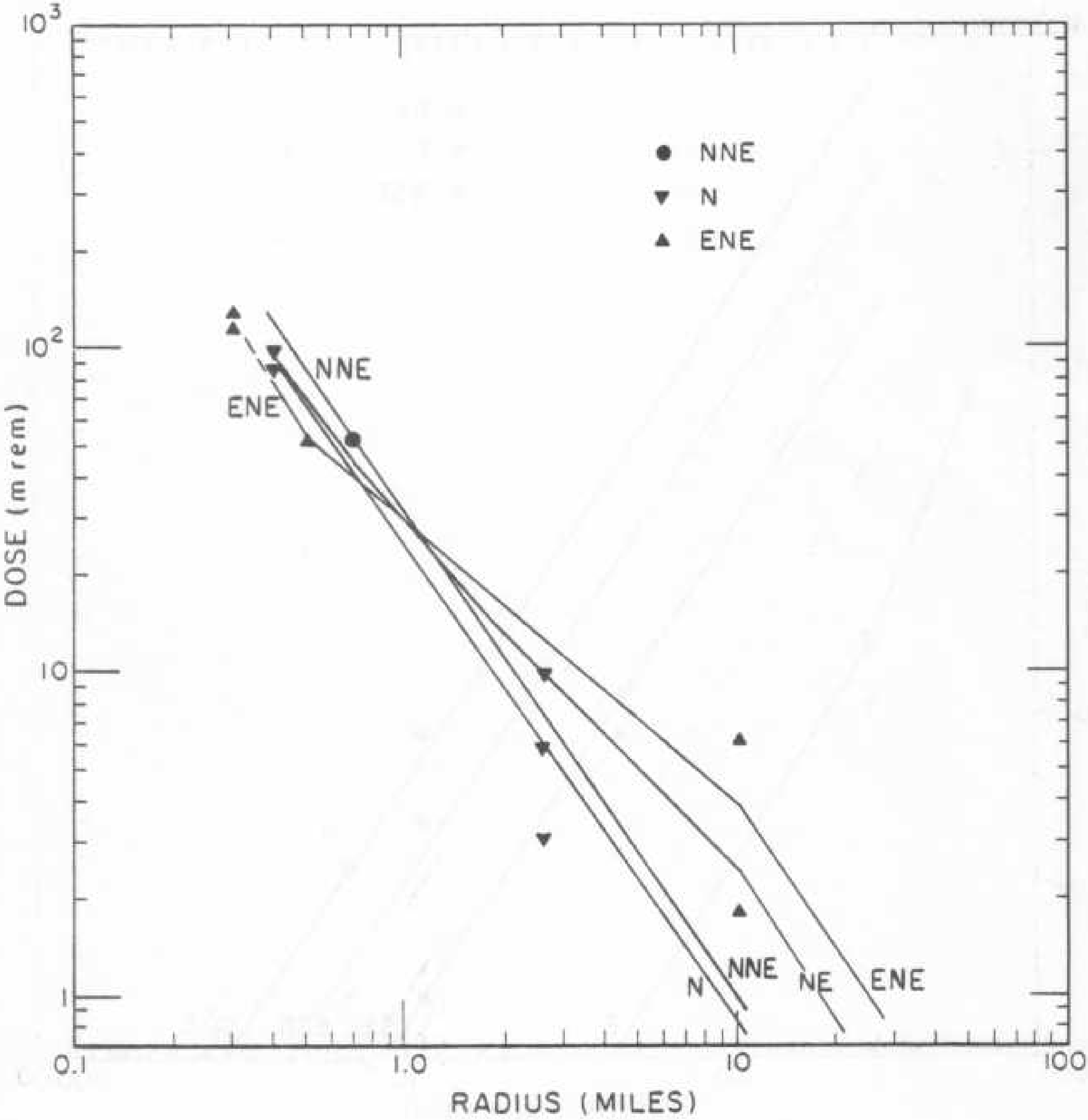
Symbols indicate measured values; straight lines indicate values calculated by interpolation or extrapolation from measured values.

FIGURE B-2: Calculated and Measured Doses as a Function of Radial Distance From TNT



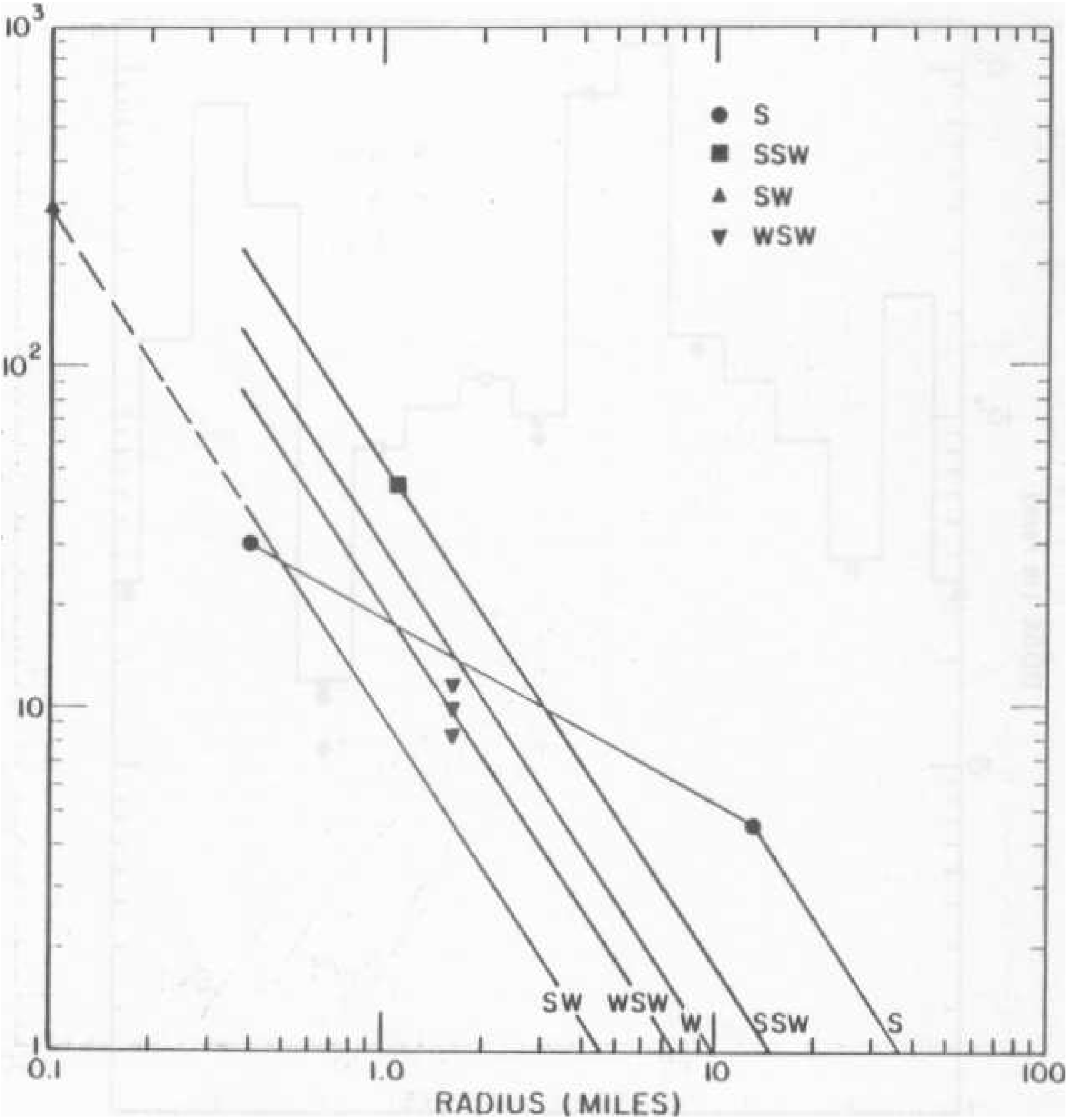
Symbols indicate measured values; straight lines indicate values calculated by interpolation or extrapolation from measured values.

FIGURE B-3: Calculated and Measured Doses as a Function of Radial Distance From TMI



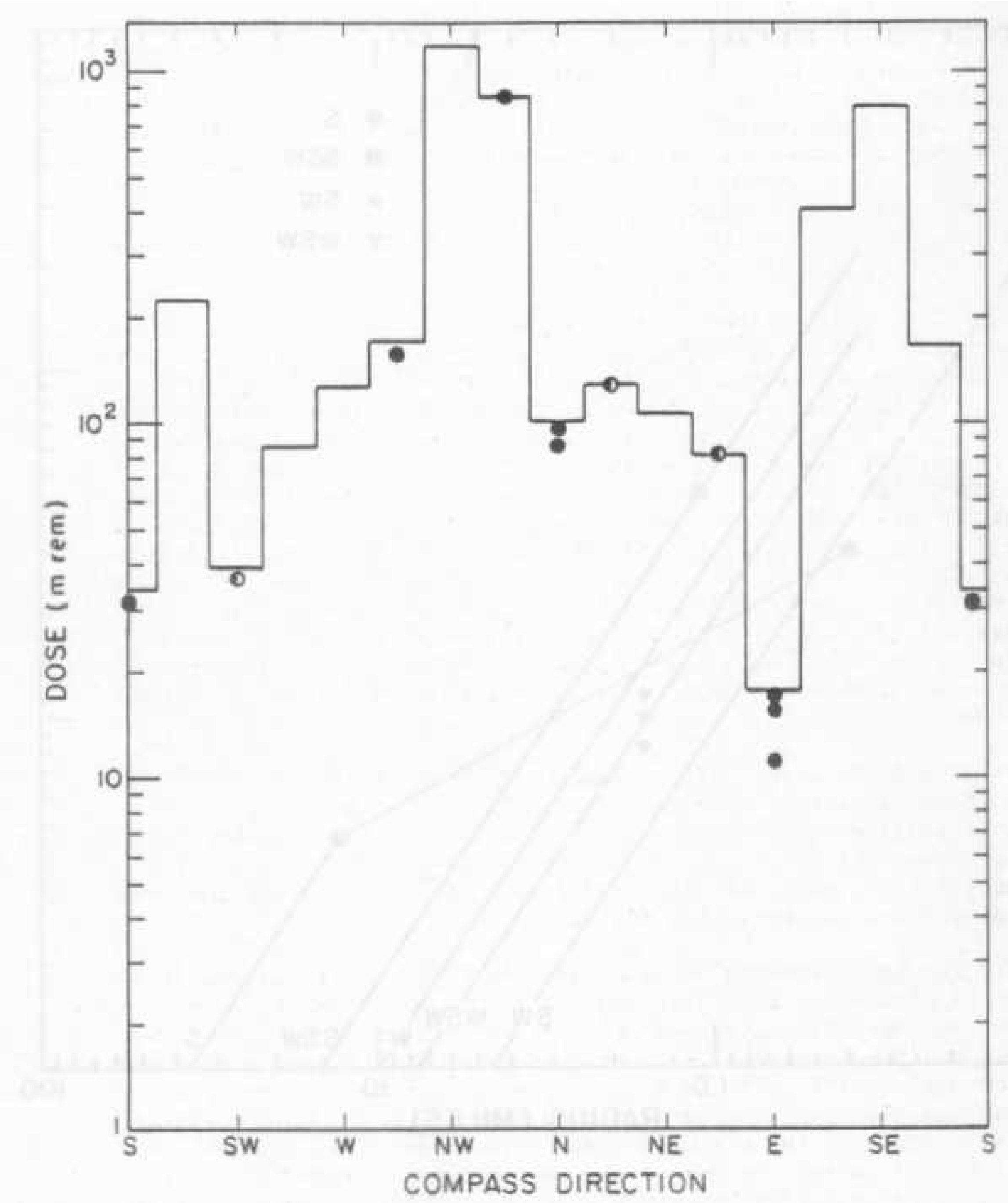
Symbols indicate measured values; straight lines indicate values calculated by interpolation or extrapolation from measured values.

FIGURE B-4: Calculated and Measured Doses as a Function of Radial Distance From TMI



Symbols indicate measured values; straight lines indicate values calculated by interpolation or extrapolation from measured values.

FIGURE B-5: Calculated and Measured Doses as a Function of Direction at a Radial Distance of 0.4 Miles From the TMI Reactor



Solid black circles indicate values measured at 0.4 miles; half-black circles indicate values extrapolated from measurements at distances between 0.1 and 0.7 miles; the histogram indicates doses inferred from measurements at all available distances.

from the measured data. On the figures, a straight line with a slope of (-n) corresponds to a decrease of r^{n} with distance. In particular, a line at 45 degrees with slope of -1 corresponds to r^{-1}.

These figures show that except for the three directions mentioned above, either one or two measured values exist for each of the 16 directions. Figure B-1 shows dose values for directions near the northwest direction, for which the highest doses ark istimated. Measured points in the north direction indicate that the r 'assumption is reasonable. Figure B-1 also shows that the estimated dose in the northwest direction is based on only one measurement taken at a distance of 15 miles. The values inferred at distances of less than 2 miles are sensitive to the assumed exponent in the power-law distribution.

The direction in which the next-highest doses are predicted is the southeast direction shown in Figure B-2. Here again, the dose close-in is determined by measurements at great distances -- in this case, 9 and 15 miles. In this direction, however, the neighboring east-southeast direction contains no measurements, and the south-southeast contains only a relatively low-dose measurement at 2.3 miles. Therefore, the extrapolated high-dose values within a few miles of TMI in the southeast and east southeast directions may be spurious. Figures B-3 and B-4 show measured interpolated doses in the other directions. In Figyrg B-3 the measured doses in the north direction are consistent with r , although the spread in measured values at 2.5 miles does not preclude other exponents. Figure B-3 also shows that the combination of the measured value in the east-northeast direction at 0.5 miles and the average of the measured yajues at 10 miles leads to a predicted variation that is lower than r- .

Figure B-4 shows the same phenomenon for the south direction. Because the uncertainty in the measured values is of the order of 2 mrem, uncertainties in measured values at distances greater than 5 miles are large. Uncertainties such as these are probably responsible for some incorrect estimates of slope; a slope of r^{-n} with n less than one in all directions is physically impossible.

In order to assess the adequacy of radial interpolation, doses as a function of direction, at a **fixed** radius of 0.4 miles, where several measurements exist, are compared with predicted values in Figure B-5. The black circles represent measured points and the histogram represents predicted doses. The half-black circle in the southwest direction represents an extrapolation outward from a measurement at 0.1 miles; the half-black circle in the north-northeast direction is an extrapolation inward from 0.7 miles; the one in the east-northeast direction is interpolated from measurements between 0.3 and 0.5 miles. The main feature of this figure is that peak values are predicted in three directions for which there are no close-in measurements. The highest peak is in the northwest direction and, as mentioned earlier, its estimated value is quite sensitive to the assumed power-law distribution. The peak predicted in the southeast and east-southeast directions is based on only one measured point at 9 miles and may be spurious. The peak in the south southwest direction is based on a measurement at 1.1 miles and is probably real. It is possible that dose-rates derived from air monitoring, combined with meteorological data, can be used to determine whether these peaks are realistic. For the present, it is assumed that they are all real.

Predicted dose-versus-distance relationships shown in Figures B-1, B-2, B-3, and B-4 were used to calculate average doses in each radial and directional sector. These were then multiplied by the population in each sector to obtain collective doses in units of person-rems. Calculated collective doses summed over all directions for 10 different radial intervals are shown in Table B-1.

Average doses per individual also are given. Average doses beyond 50 miles are less than one-half background (background is about 0.7 for the 4-day period when most of the dose was received) and comparable to variations in background from one geographical area to another. The total collective dose is within the range predicted in the Ad Hoc Committee Report (reference 1).

It is important to look at possible locations where individuals may have received the greatest doses. Table B-2 shows sectors in which the predicted dose exceeds 30 mrem. Parentheses indicate uncertain or conservative values.

For example, the doses in the east-southeast and southeast directions, as already discussed, are based on extrapolation of measurements at a radial distance of 9 miles. The population values in parentheses represent people on the various islands in the Susquehanna River west of the TMI plant. According to the Ad Hoc Committee Report, only one person is known to have been on those islands during the period of the accident -- on Hill Island in the north-northwest direction, radius 1-2 miles, for 9-1/2 hours (reference 1). No evidence to the contrary has been presented since publication of that report on May 10, 1979. Questionnaires distributed by the Center for Disease Control should determine if there was anyone else on the islands during the period of the accident. Until these data become available, a conservative assumption is made that there might have been one individual in each of the sectors within which the islands lie. However, the most probable number of people on these islands was zero, except for the individual on Hill Island.

Table B-3 summarizes the probable and possible number of people who were exposed to three ranges of dose. This table requires careful interpretation. The most probable situation is that no one received more than 300 mrem. For the individual on Hill Island listed in the 300-100 mrem dose interval in the table, an occupancy factor must be applied to account for his being on the island for only 9-1/2 hours. A detailed analysis reduces his probable dose to 48 mrem. The number of people who may have received between 30 and 100 mrem, if outdoors the entire time, is 262. However, allowing for an average shelter factor of 1.36 (see Appendix C), they probably received between 20 and 70 mrem. They were located mainly in the populated areas east of the TMI plant. Finally, the possible number of people receiving these doses is also indicated. Except for possible campers, the shelter factor would lower these doses. These numbers should be interpreted only as a possibility until the results of the census become available.

TABLE B-1: Collective Dose to Population 0-50 Miles from Three Mile Island March 28 through April 15, 1979

Radius (mi)	Population	Collective Dose (person-rem)	Average Dose (mrem)
0.4-1.0	324	19	58.6
1-2	1,816	36	19.8
2-3	7,579	120	15.8
3-4	9,676	78	8.1
4-5	8,891	102	11.5
5-10	137,474	720	5.2
10-20	577,288	1,173	2.0
20-30	433,001	240	0.55
30-40	273,860	95	0.35
40-50	713,210	202	0.28
Total	2,163,579	2,786	1.3

TABLE B-2: Location of Areas in Which Dose May Have Exceeded 30 mrem

Direction	0.4-1.0 Miles Dose (mrem)	0.4-1.0 Miles Population	1.0-2.0 Miles Dose (mrem)	1.0-2.0 Miles Population
N	43	19		
NNE	54	55		
NE	48	42		
ENE	43	58		
E				
ESE	(170)	6	(52)	36
SE	(330)	6	(102)	94
SSE	68	88		
S				
SSW	93	(1)		
SW				
WSW	36	(1)		
W	54	(1)		
WNW	71	(1)		
NW	501	(1)	154	(1)
NNW	360	(1)	114	1

TABLE B-3: Analysis of Individual Doses

Dose Interval (mrem)	Probable No. of People	Possible No. of People*
500-300	0	8
300-100	1	102
100-30	262	302

*See text for interpretation

ANALYSIS OF UNCERTAINTY

In order to estimate the uncertainty in the collective dose, several parameters were varied. In the Ad Hoc Committee report, it is shown that the estimated collective dose was 60 percent to 80 percent higher if the TLDs deployed by NRC from March 31 through April 7 were included in the analysis. However, it was pointed out that possible difficulties in background estimates could lead to severe overestimates of dose. In the present analysis we have explored the impact of including results from one set of NRC TLDs, which were in the field for one day (March 31-April 1), and another set which were in the field for the full month of April. Revised estimates of background for these TLD measurements are discussed in Appendix A. In Table B-4 the columns denoted Run/18c and Run/19c show the impact of including data from NRC TLDs.

In Run 18c the Met Ed doses were accumulated from readings measured during two or three intervals from March 28 through April 15. The collective doses are somewhat different from those in Table B-1 because interpolation on the time-dependent data may be different for each time period. In Run/19c, the Met Ed doses through March 31 were combined with NRC measurements during the period from March 31 through May.

Most of the increase in collective dose indicated by the NRC dosimeters is due to one-day measurements taken from about noon on March 31 until noon on April 1. Readings from these TLDs included exposure during a 12-hour transit time during which they were being distributed or collected. During this period, the TLDs were stored in a trailer for 2-1/2 hours near the station with the highest dose-rate or were moved in and out of areas with variations of a factor of 10 in dose-rate, shielded only by the trailer or the auto in which they were distributed. In the next

TABLE B-4: Comparison of Collective Doses With and Without NRC TLD Data

Radius (miles)	Collective Dose (person-rems) Run/18c (Met Ed only)	Run/19c (Met Ed & NRC)
0.4-1	18	24
1-2	38	48
2-3	133	145
3-4	88	99
4-5	106	114
5-10	758	943
10-20	1,248	1,792
20-30	281	382
30-40	106	143
40-50	221	260
Total	2,997	3,950

section, it is shown that the spurious transit dose could exceed the in-place dose for TLDs located more than a mile or two from TMI. Therefore, the NRC data have been excluded from our evaluation of the most probable dose. However, these data have been included when estimating an upper bound on the collective dose.

Inclusion of the four TLD dosimeters read out by RMC for the state of Pennsylvania and the four TLDs read out by DOE personnel at Idaho Falls has a negligible effect on the collective dose. Removal of these readings decreases the estimated collective dose by 2 percent. Inclusion of 11 TLD readings from the on-site personnel dosimetry system decreases the collective dose by 4 percent.

Figures B-1, B-2, B-3, and B-4 show that the assumption of $r^{-1.5}$ decrease of dose with distance is not always borne out by two or more readings in the same direction. This is not surprising, because vertical plume movement and changes in wind direction can distort any idealized power-law distribution. Because many of the estimated doses, particularly beyond 10 miles, are obtained by extrapolation, it is important to look at the sensitivity of the results_r tq the exponent in the power law. Computer calculations in which r was assumed y}e3ded 3,464 person-rems, a change of +24 percent; calculations for r yielded 2,430 person-rems, a change of -13 percent.

The largest single source of uncertainty in the estimated collective dose is associated with the exclusion of the NRC TLD data. In estimating an upper bound for the collective dose, the NRC data was included and every measurement was increased by the (2 a deviation estimated for the TLD reading. The latter is extreme, because it assumes that all deviations will be positive. Calculation of the collective dose under these conditions yielded 5,748 person-rems. A 15-percent estimated systematic error was added to the TLD readings to obtain an upper bound of 6,610.

To estimate the lower bound, the NRC data was excluded and every other measurement was decreased by the (2Q) deviation estimated for the TLD. RMC dosimeters were further decreased by about 2 mrems per month to account for a possible spurious background. Again, this assumption is extreme. Calculation of the collective dose under these conditions yielded 1,201 person-rems. From this was subtracted the estimated systematic error of 15 percent to obtain a lower bound of 1,021 person-rems.

TABLE B-5: Estimated Collective Dose

	Most Probable	Upper Bound	Lower Bound
Outdoor Dose	2,784	6,610	1,021
Indoor Dose	2,047	6,480	601
(-1.36 + 25%)			
	(2,000)	(6,500)	(600)

Table B-5 summarizes the collective doses calculated from TLD measurements (outdoor dose) and collective doses reduced because of shielding of houses or offices (indoor dose). The upper and lower bounds are extreme limits because all uncertainties, such as those due to TLD measurements, have been combined with the same arithmetic sign. The most probable collective dose estimated from TLD data, however, is 2,000 person-rems.

REASONS FOR REJECTING NRC TLD READINGS
DURING THE PERIOD MARCH 31 TO APRIL 1, 1979

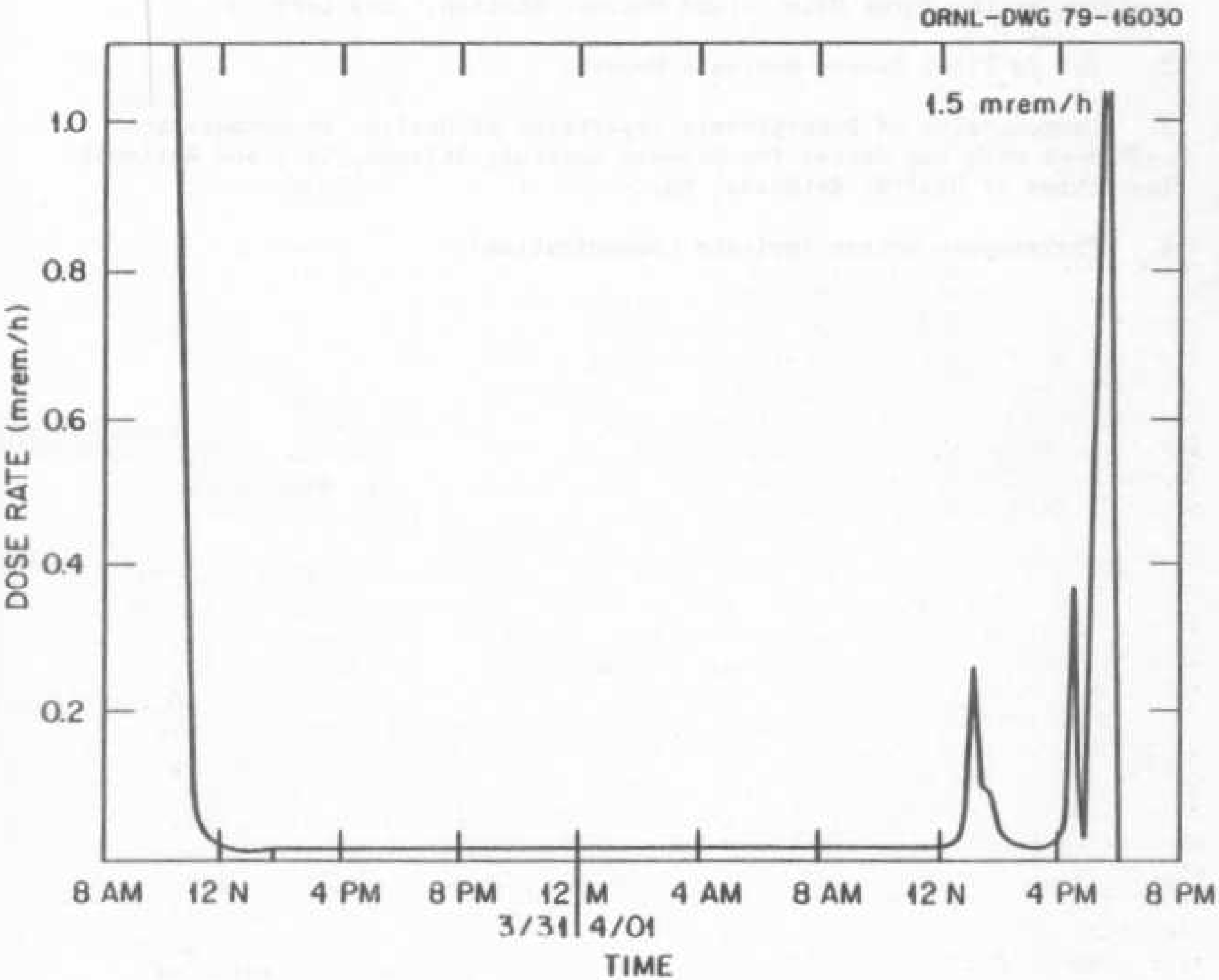
In the preliminary report, attention was called to high doses predicted by NRC TLDs placed from March 31 to April 1, compared with estimates from the TLDs placed by Met Ed. Re-evaluation of the calibration and processing of these TLDs did not eliminate the inconsistency. However, review of the procedures for the placement and the collection of the NRC TLDs raised the possibility that considerable exposure was received by these TLDs during the placement and collection periods.

The high collective doses predicted by the NRC measurements are due mainly to readings at locations of 8 to 15 miles from the plant. In several directions, these readings are higher than those closer in -- a situation which, though not impossible, is highly improbable. The TLD readings at 9.6 and 13.8 miles in the northwest direction have the greatest impact on the estimate of collective dose. These high readings were referred to as the "northwest anomaly" in hearings before the House Committee on Science and Technology on June 13, 1979. Procedures for deploying and collecting one of these (Station NW-4) were examined in order to determine possible reasons for spuriously high readings.

The reading from the Station NW-4 TLD exposed at 9.6 miles from TMI for 22 hours included exposure over a 12-hour transit time during which it was being distributed or collected. The TLDs were stored beforehand in a trailer for 2-1/2 hours near the station with the highest dose rate, and moved in and out of areas with variations of a factor of 10 in dose-rate, shielded only by the trailer or the auto in which they were distributed. An estimated irradiation history for this TLD, assuming no shielding, is shown in Figufe $_5$ B-6. Exposure rates at each time were estimated by assuming an r decrease with distance and calculating the radial distance of the automobile at that time. The intended exposure period was from 1:45 p.m. on March 31 to 12:04 p.m. on April 1. From about 8:00 a.m. to 10:30 a.m., the TLDs were stored in a trailer near the site, with no special precautions to shield them. The average dose-rate a short distance away was 1.11 mrem per hour. Even if a factor of two or three reduction due to shielding in the trailer is assumed, the dose accumulated during this period, as estimated from the area under that portion of the curve, could be several times the dose accumulated at Station NW-4 during the intended exposure period. Additional doses could also have been accumulated during the collection period from 12:00 noon to 6:00 p.m. on April 1, when the TLDs were on the front seat of the automobile.

No control dosimeters were used to estimate the dose received during the distribution and collection periods. No precautions were taken to shield the TLDs with, say, lead during these periods. It therefore seems highly likely that some of the dose received by TLDs at low dose-rate locations, such as Station NW-4, was received during transit periods through high dose-rate areas. Consequently, these measurements have been rejected in the evaluation of the collective dose.

FIGURE B-6: Irradiation History of NRC TLD NW-4 Exposed on March 31 and April 1, 1979, Assuming No Shielding During Periods of Distribution and Collection



APPENDIX B REFERENCES

1. Battist, L., et al., "Population Dose and Health Impact of the Accident at the Three Mile Island Nuclear Station," May 1979.

2. Met Ed Final Safety Analysis Report.

3. Commonwealth of Pennsylvania Department of Health, in cooperative agreement with the Center for Disease Control, Atlanta, Ga., and National Institutes of Health, Bethesda, Md.,

4. Christopher Nelson (private communication).

APPENDIX C

SHELTER FACTOR

The doses measured by TLDs would be applicable to a person who was outdoors during all of the first few days of the accident. Because most people spent a good deal of that time indoors, some protection can be assumed due to absorption of the gamma radiation in the structural materials of a house. Measured dose rates reported by A. P. Hull indicate a uniformly exponential decrease with time (reference 1). Therefore, it is probable that releases occurred frequently enough so that the time indoors must be averaged over a 24-hour period.

It must be assumed that the radioactive plume from the reactor was sufficiently dispersed by the time it reached most residential areas that it resembled an infinite cloud. However, due to absorption of the gamma rays in air, only sources within about 500 feet of a structure contribute to the dose in that structure. The main point here is that most of the dose comes from sources in a volume of air that is large, compared to the volume of the house. Therefore, the external gamma-ray dose is not critically dependent on whether windows were open or closed. Doses due to inhalation or ingestion of radioactivity, on the other hand, would be strongly dependent on the contamination existing within the house.

The following analysis is based on the assumption the Xe-133 was the predominant source*/ of radiation in the cloud during the first few days (reference 2). Gamma-rays emitted by radioactive Xe-133 have an energy of 81 KeV. If such a source is uniformly distributed in an infinite medium of air, an equilibrium spectrum of air-scattered gamma rays is generated. Extrapolation of calculations by L. D. Gates and C. M. Eisenhauer (reference 2) gives an estimate that 90 percent of the dose is delivered by scattered radiation. More recent data reported by A. B. Chilton, et al. (reference 3), and fit to a buildup factor of the form $(1 + au_o r e^{bu_o r})$ yield a value of 88 percent. Spectra calculated by L. Thomas Dillman (reference 4) for four monoenergetic sources are shown in Figure C-1, where the single scatter cutoff for each source is indicated. This figure shows that the spectrum of scattered photons below the source energy is almost independent of the source energy, except for details of the single scatter distribution.

The attenuation data for 81 KeV radiation at various angles of incidence on concrete, as shown in Figure C-2, were obtained by interpolation of calculations by L. V. Spencer and J. C. Lamkin (reference 5). Attenuation of 57 KeV radiation, which is near the peak of the

---

There is evidence that other short-lived radioactive gases were present during the first two days of the accident. Their presence is taken into account when estimating the attenuation of the radiation.

FIGURE C-1: Scattered Photon Spectrum From Four Monenergetic Sources

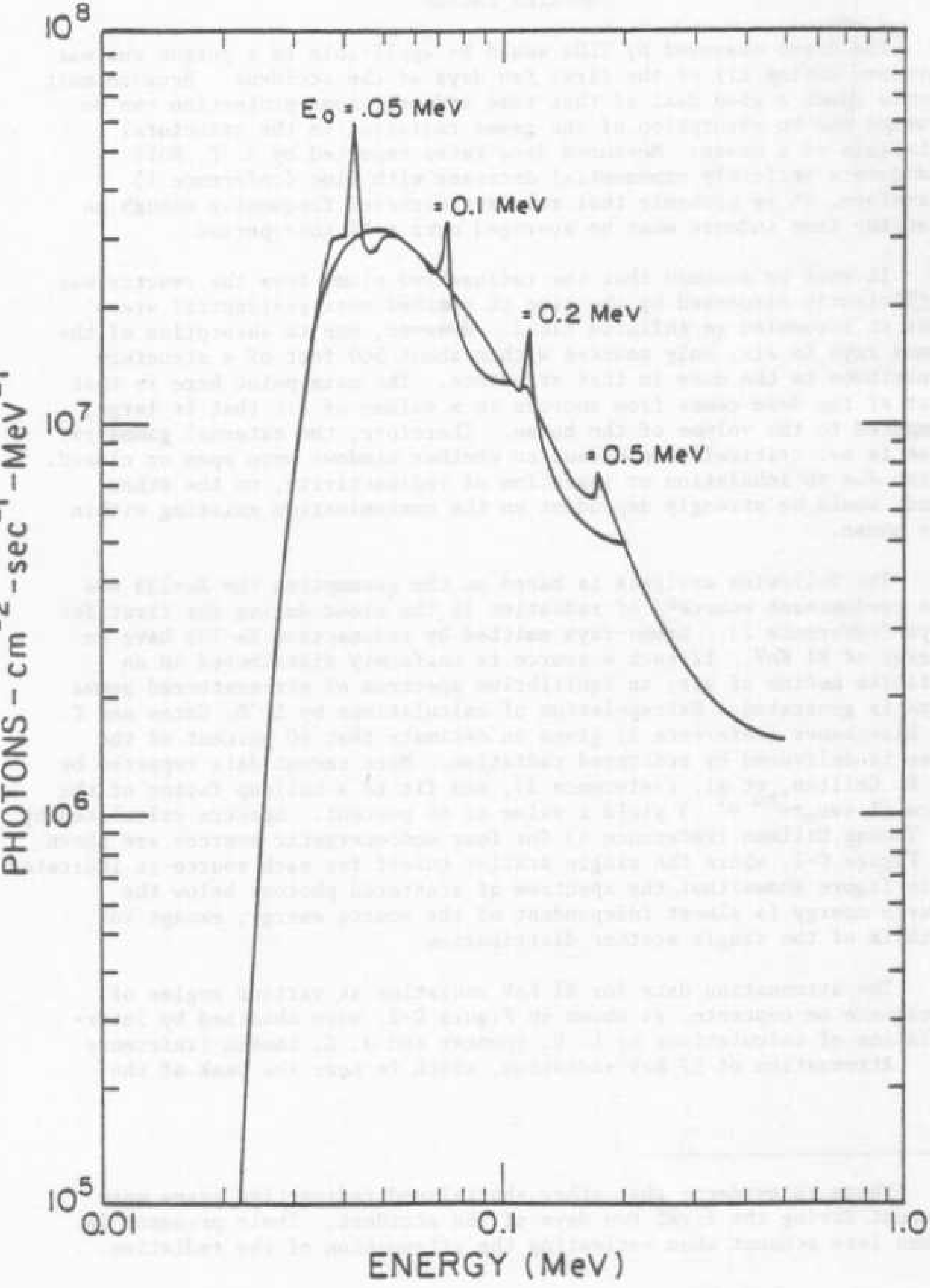
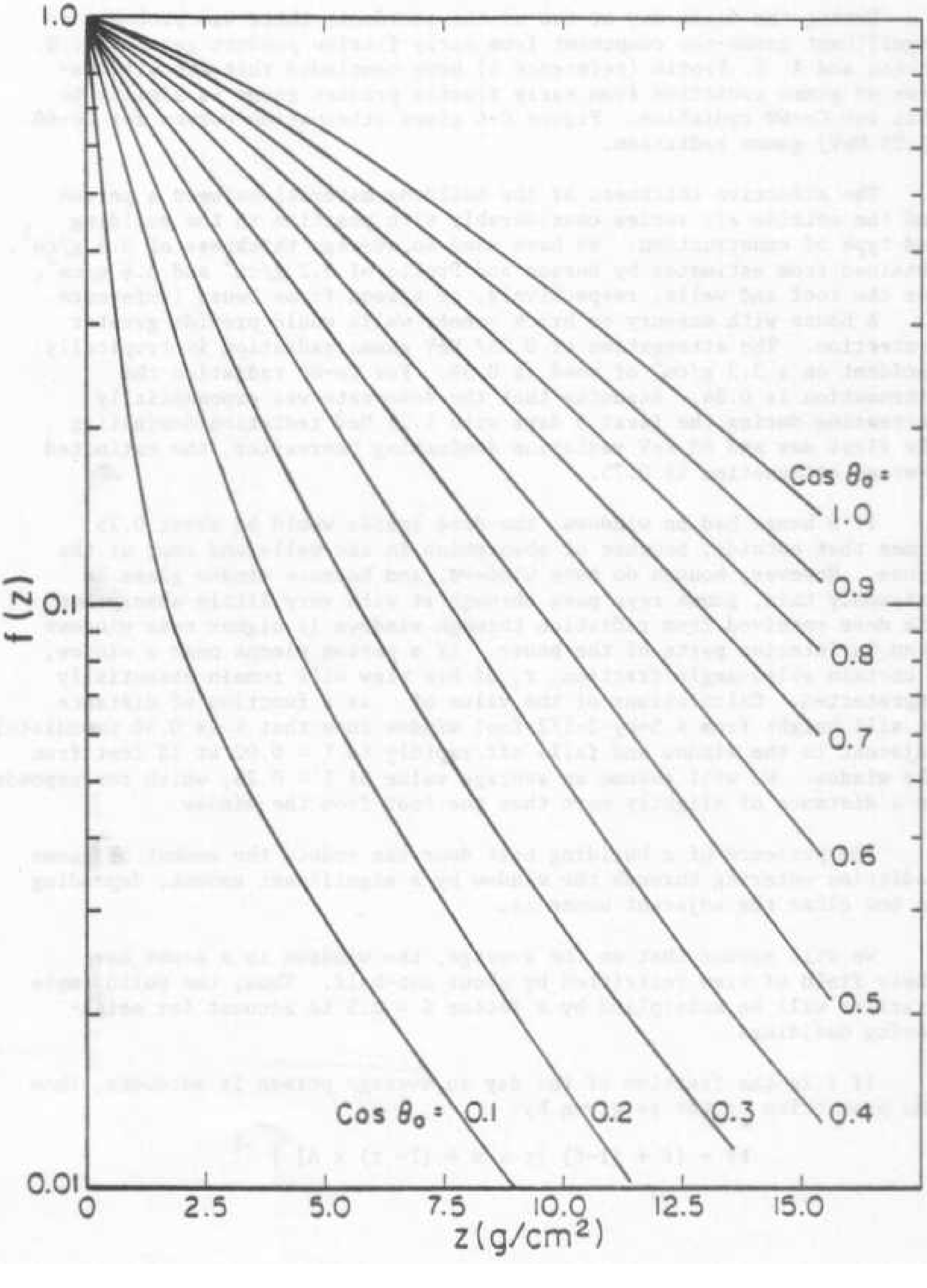


FIGURE C-2: Attenuation Curves for 81 KeV Photons Incident at Various Angles 9_0 on Concrete



spectrum of scattered photons, is shown in Figure C-3. It is assumed that the structure does not disturb the isotropic nature of the flux in an infinite cloud.

During the first day or two of the accident, there was probably a significant gamma-ray component from early fission product gases. Z. G. Burson and A. E. Profio (reference 6) have concluded that the attenuation of gamma radiation from early fission product gases is similar to that for Co-60 radiation. Figure C-4 gives attenuation curves for Co-60 (1.25 MeV) gamma radiation.

The effective thickness of the building material between a person and the outside air varies considerably with position in the building and type of construction. We have used an average thickness of 3.3 g/5m^2, obtained from estimates by Burson and Profio of 3.2 g/cm and 3.4 g/cm , for the roof and walls, respectively, of a wood frame house (reference 6). A house with masonry or brick veneer walls would provide greater protection. The attenuation of 0.057 MeV gamma radiation isotropically incident on a 3.3 g/cm of wood is 0.59. For Co-60 radiation the attenuation is 0.84. Assuming that the dose-rate was exponentially decreasing during the first 4 days with 1.25 MeV radiation dominating the first day and 80 KeV radiation dominating thereafter, the estimated average attenuation is 0.75.

If a house had no windows, the dose inside would be about 0.75 times that outside, because of absorption in the walls and roof of the house. However, houses do have windows, and because window glass is extremely thin, gamma rays pass through it with very little absorption. The dose received from radiation through windows is higher near windows than in interior parts of the house. If a person sleeps near a window, a certain solid-angle fraction, T, of his view will remain essentially unprotected. Calculations of the value of as a function of distance at sill height from a 5-by-2-1/2-foot window show that T is 0.50 immediately adjacent to the window and falls off rapidly to T = 0.02 at 10 feet from the window. We will assume an average value of T = 0.25, which corresponds to a distance of slightly more than one foot from the window.

The presence of a building next door can reduce the amount of gamma radiation entering through the window by a significant amount, depending on how close the adjacent house is.

We will assume that on the average, the windows in a house have their field of view restricted by about one-half. Thus, the solid angle fraction will be multiplied by a factor S = 0.5 to account for neighboring buildings.

If f is the fraction of the day an average person is outdoors, then the protection factor is given by:

$$PF = \{f + (1-f)\ [T \times S + (1-T) \times A]\}^{-1}$$

FIGURE C-3: Attenuation Curves for 57 KeV Photons Incident at Various Angles A_o on Concrete

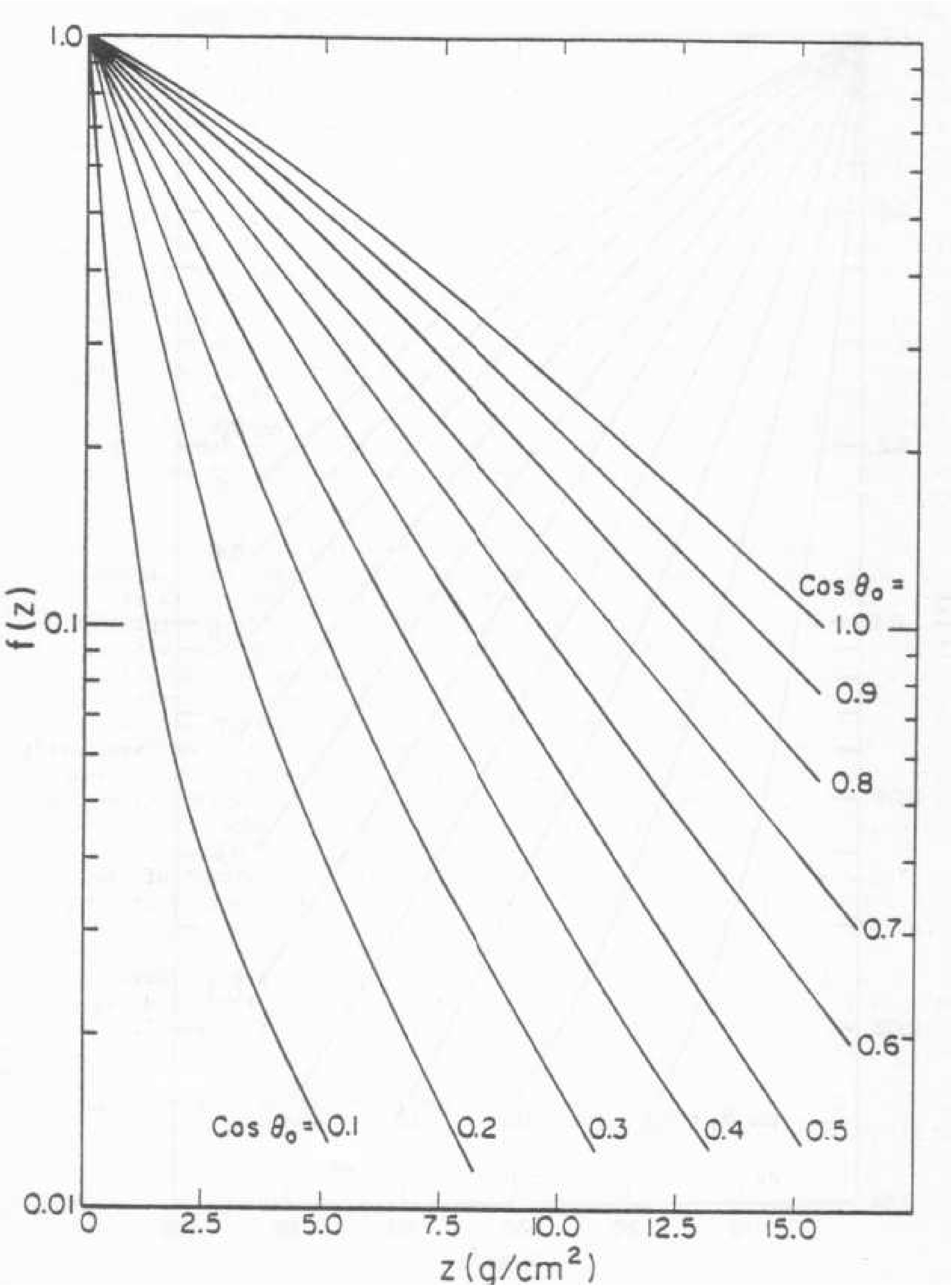
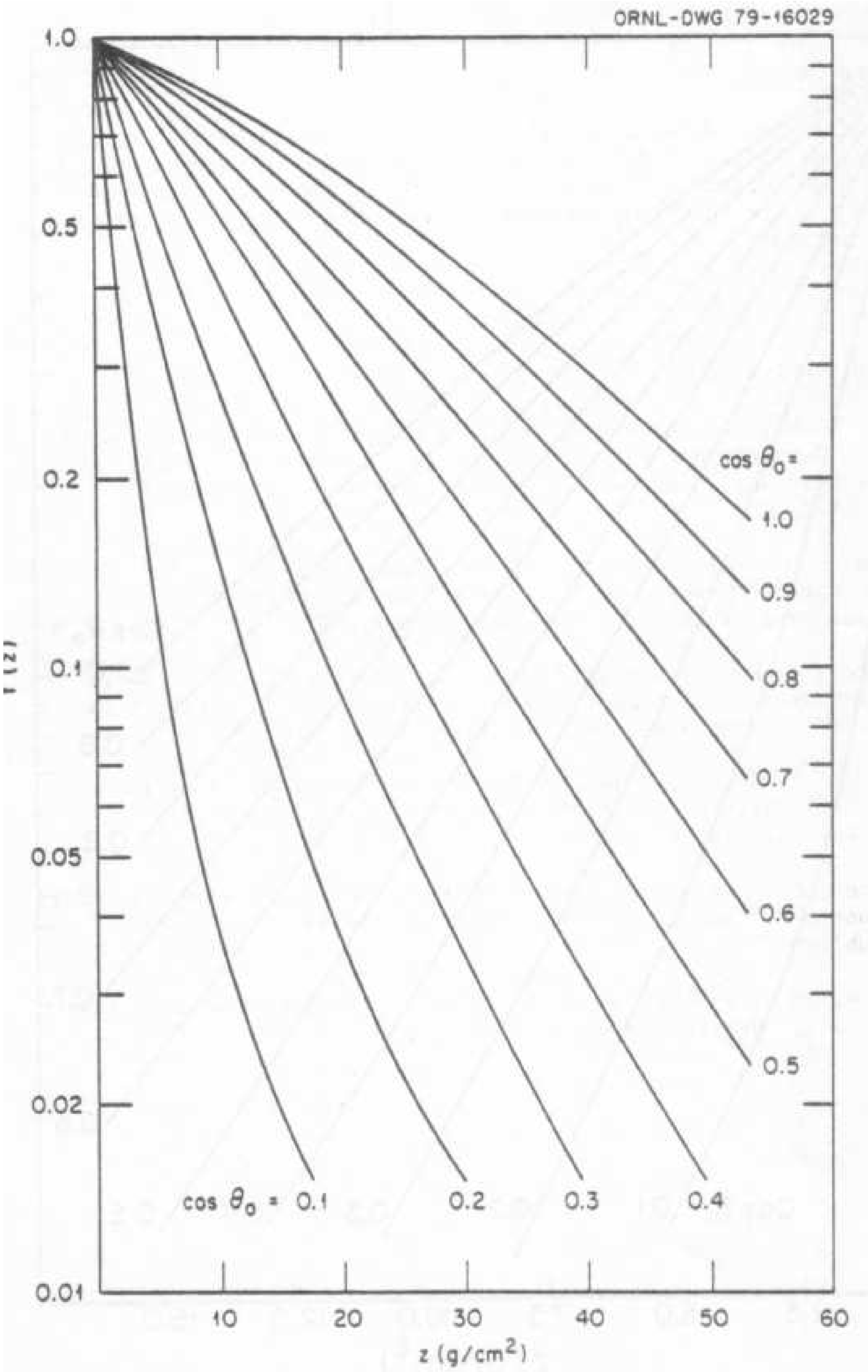


FIGURE C-4: Attenuation Curves for 1.28 MeV Photons Incident at Various Ankles 8 on Concrete



Assuming an average of four hours outdoors (f = 1/6) we have:

$$PF = \left\{ \frac{1}{6} + \frac{5}{6} \left[\frac{1}{4} \cdot \frac{1}{2} + \frac{3}{4} \times .75 \right] \right\}^{-1}$$

$$PF = 1.36$$

ESTIMATE OF UNCERTAINTY

The effective values of T and (1 - T) must be regarded to be an uncertainty of about + 0.25. Further, it is estimated that an uncertainty of + 30 percent in the value of A and an uncertainty of ± 100 percent in f. The resultant uncertainty in the protection factor is then + 25 percent.

APPENDIX C REFERENCES

1. Hull, S. P., "Estimate of External Whole-Body Radiation Exposure to the Population Around the Three Mile Island (TMI) Nuclear Power Station," Brookhaven National Laboratory, draft report, July 1979.

2. Gates, L. D. and Eisenhauer, C. M., "Spectral Distribution of Gamma Rays Propagated in Air," AFSWP, No. 502A, Armed Forces Special Weapons Project (now DNA), January 1954.

3. Chilton, A. B., Eisenhauer, C. M., and Simmons, G. L., "Photon Point-Source Buildup Factors for Air, Water, Iron," (submitted to Nuclear Science and Engineer, July 1979).

4. Dillman, L. Thomas, "Absorbed Gamma Dose Rate from Immersion in a Semi-Infinite Radioactive Cloud," Health Physics 27, December 1974, p. 571.

5. Spencer, L. V. and Lamkin, J. C., "Slant Penetration of Gamma-Rays in Concrete," NBS Report 6591, National Bureau of Standards (unpublished).

6. Burson, Z. G. and Profio, A. E., "Structure Shielding in Reactor Accidents," Health Physics 33 (1977), p. 287.

APPENDIX D

CALCULATION OF POPULATION DOSE FROM SOURCE TERM AT TMI

Collective dose estimates to the general population within 50 miles of Three Mile Island have been made from various approaches, as reported previously by this task group and by other organizations. It is the goal of this task group to arrive at a similar estimation by a method that is independent of the others. The approach chosen was to calculate a source term, from March 28, 1979, to April 15, 1979, that is independent of TLD and "in-plume" helicopter measurements, and then incorporate that source term into a plume-modeling computer program capable of calculating collective dose.

The radiation monitor that was situated within the auxiliary building stack at TMI (which would have given the best estimate of real-time releases) went off-scale by 8:00 a.m. on March 28, 1979. There was another gamma monitor, located about 40 feet from the stack and less than 15 feet from the vent duct that "fed" the stack, which did not go off-scale. Careful graphical analysis of both the stack monitor (HPR-219) and the external gamma monitor (HPR-3236) strip charts showed that the count rate from both detectors rose from 7:00 a.m. to 7:45 a.m. on March 28, 1979, at approximately the same rate. The stack monitor was then used to calibrate the external gamma monitor, along with the known flow-rate in the stack; the integrated source term subsequently was calculated from the external gamma monitor readout. Due to several uncertainties, some of which cannot yet be quantified, the calibration value may be in error by as much as a factor of two. A check on this value was performed by looking at an air sample (grab sample) that was obtained on March 31, 1979, between 12:00 noon and 2:00 p.m. from the stack itself, and comparing it to the external gamma monitor readout during this same time period. These two values were within 10 percent of each other, and thus sufficed as a means of confirming the calibration value of the external gamma monitor.

It must be repeated here that a direct measurement of stack release was not performed. Stack release rate was inferred from the readout of the external gamma monitor. This monitor did not "see" everything that went up the stack. But analysis of strip chart records from all the surrounding monitors, as well as visual confirmation of the locations of each by a member of this task group, has given the task group confidence in the fact that the external gamma monitor responded proportionally to the actual releases. It was, therefore, chosen as the best source of information for calculation of source term.

Numerical integration of the real-time release rate was done by using a trapezoid method:

$$S = \int^{t} Q(t)\,dt \qquad \text{Equation 1}$$

where S = source term and Q(t) = activity per unit time. For calculational purposes,

$$S_i = \frac{t_i - t_{i-1}}{2}\left(Q(t_{i-1}) + Q(t_i)\right) \qquad \text{Equation 2}$$

which, when summed from 6:00 a.m. on March 28, 1979, to April 15, 1979, yields a source term estimation of 2.37 million curies (2.37×10^6 Ci), which again could be in error of not more than a factor of two. This incorporates the short-lived fission products that were present during the early hours of the incident, as well as the longer lived Xe-133. Estimation of the relative concentrations of the isotopes released was performed by taking the core inventory, as calculated by the ORIGEN code (a computer technique), and making appropriate decay corrections to include the approximately 2-hour transfer time of the iodines, xenons, and kryptons from the core to the release point. It was assumed that the above isotopes traveled in the same manner and that there was no holdup time.

The next task is to turn the above source-term value, along with meteorological and population distribution data, into an estimation of dose to the general population. To do this, computer techniques were employed. It must be stressed that computer modeling is only an approximation of real events. There is a degree of uncertainty associated with its use. In this task group's efforts to arrive at the "most probable" dose to the population from the release at TMI, rather than the "most conservative" dose, there is a risk of under or overestimating actual dose values if a single computer-modeling technique is employed. Therefore, help from several types of computer codes was solicited and statistical analyses were performed on their results to arrive at the best estimation of population dose. Short descriptions of each of these codes, and a summary of their results, are as follows.

The AIRDOS-EPA computer code was developed at Oak Ridge National Laboratory (ORNL) as part of a methodology to evaluate health risks to people from atmospheric radionuclide releases. Both point sources and uniform area sources of atmospheric releases of radionuclides can be evaluated by AIRDOS-EPA, which estimates concentrations in air, rates of deposition on ground surfaces, ground surface concentrations, and radiation doses received by people.

The equation used by AIRDOS-EPA to estimate the movement of the plume when airborne (as it blows downwind from the auxiliary building stack) is the standard Gaussian plume equation given as follows (references 1 and 2):

$$\chi = \frac{Q}{2\pi\sigma_y\sigma_z u}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} \qquad \text{Equation 3}$$

where X = concentration in air at X meters downwind, y meters crosswind, and z meters above the ground (ci/m^3),

Q = uniform emission rate from the stack (ci/sec),

P = mean wind speed (m/sec),

Q_y = horizontal dispersion coefficient (m),

az = vertical dispersion coefficient (m),

H = effective stack height (physical stack height, h, plus the plume rise, (A h) (m),

y = crosswind distance (m),

a = vertical distance

The downwind distance (x) enters the above equation through Q_y and a_s which are functions of both X, and of whichever Pasquill atmospheric stability category is applicable during emission from the auxiliary building stack.

The source term, as described previously, was submitted to an IBM-360 computer. Meteorological data for the area surrounding TMI were supplied as input to the code. These data were then used to estimate air and ground concentrations and intake by people based on various parameters for each radionuclide released at various distances and directions from the auxiliary building stack release point. From these values, collective dose at various distances and directions was estimated. (A detailed discussion of the AIRDOS-EPA atmospheric and terrestrial transport models and the code use can be found on ORNL-5532 report.) Results are summarized in Table D-1.

The second atmospheric dispersion modeling code that was used to estimate population dose was developed by the Tennessee Valley Authority (TVA) Environmental Laboratory. This code, like that of ORNL, is a Gaussian plume dispersion model which uses source-term, meteorological, and population distribution data to calculate collective dose to the general population within 50 miles of TMI. These calculations were made using four release/dispersion options:

- point source, ground-level release,
  - -- sector-averaged dispersion,
  - -- short-term dispersion.
- stack release at 182 feet,
  - -- sector-averaged dispersion,
  - -- short-term dispersions.

In the judgment of the TVA staff, the best estimate of the population dose employed the ground-level, sector-averaged dispersion. This option varies from the standard Gaussian plume equation, described previously, as stated below.

TABLE D-1: Collective Dose to Population 0-50 Miles from TMI
March 28 - April 15, 1979

Radius (mi)	Population	Collective Dose (person-rem)
0-1	324	.372
1-2	1,816	3.1
2-3	7,579	21.2
3-4	9,676	15.2
4-5	8,891	14.0
5-10	137,474	113.0
10-20	577,748	144.0
20-30	433,001	33.5
30-40	273,860	16.5
40-50	713,210	31.3
Total	2,163,579	ti 390

The average ground-level concentration in air (X ave) over a given sector of 22.5 degrees can be approximated by setting y = 0 and a = 0 in equation 3. Therefore:

$$\chi_{ave} = f\chi \qquad \text{Equation 4}$$

where f is found after mathematical manipulations by:

$$f = \frac{\int_0^{\infty} \exp\left[-\left(\frac{0.5}{\sigma_y}\right) y^2\right] dy}{y_s} \qquad \text{Equation 5}$$

In this case, ys is the value of y at the edge of the 22.5-degree sector. The final equation used for plume dispersion in the TVA calculational code is *therefore:*

$$\chi = \frac{Q}{0.15871\pi x \sigma_z \mu} \exp\left[\frac{-1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \qquad \text{Equation 6}$$

One must bear in mind that this is not a precise method due to the fact that the integration over the Y-axis (crosswind), which is perpendicular to the downwind direction (x) involves increasing value for x as y is increased from zero to infinity.

Using equation 6 plus various other parameters, the TVA code, designated as TMIDOSE, calculated collective population dose at various distances and directions. Results are summarized in Table D-2.

TABLE D-2: Collective Dose to Population 0-50 Miles from TMI
March 28 - April 15, 1979

Radius (mi)	Population	Collective Dose (person-rem)
0.4-1	324	12.73
1-2	1,816	30.27
2-3	7,579	105.46
3-4	9,676	46.02
4-5	8,891	41.12
5-10	137,474	261.97
10-20	577,748	290.33
20-30	433,001	87.74
30-40	273,860	32.95
40-50	713,210	60.70
Total	2,163,579	- 970

Further discussion of the TMIDOSE code can be obtained at: TVA Environmental Lab, River Oaks Building, Muscle Shoals, Ala., 35660.

There are certain aspects of both AIRDOS-EPA (ORNL) and TMIDOSE (TVA) that make them other than ideally suited to handle the conditions encountered at TMI, even though both were modified from their normal operational code. Because these were not taken into consideration as basic assumptions, both the 390 person-rems and the 970 person-rems fall within large limits of error. In an effort to narrow the range of error, the same source term and meteorological data were submitted to Lawrence Livermore Laboratory (ARAC) for analysis.

The ARAC group uses a series of computer models that calculate three-dimensional transport and diffusion of the particles released from the stack at TMI. This series of codes is quite complex; therefore, no attempt is made to describe specific techniques and capabilities. The reader is referred to articles by the authors of the codes for detailed information (references 3 and 4).

One of the most important considerations of the ARCA codes series (ADPIK) is topography of the Till area. This factor is not incorporated in either AIRDOS-EPA or TMIDOSE, or the population dose estimate based on TLD measurements discussed in a previous appendix. The effects of topography on dispersal of the source term appear to play a significant part. Summary of the ADPIK-estimated collective population dose, with distance, is given in Table D-3.

TABLES D-3: Collective Dose to Population 0-50 Miles From TMI, March 28 - April 7, 1979

Radius (mi)	Collective Dose (person-rems)
0 - 10	253.84
10 - 20	20.49
20 - 30	1.60
30 - 40	.17
40 - 50	4.01×10^{-3}
Total	', 276

To summarize, if all three calculated values of population dose are assumed to be correct within themselves, and the ADPIK code is adjusted for the same parameters as the others, the value this task group would assign to collective dose to the population within 50 miles of TMI would be 559 $\pm$ 366 person-rems. However, in the task group's judgment, the region of error is probably much higher due to numerous factors. The calculated source term alone could interject an error of as high as a factor or two. Meteorological data were found to be sketchy in some regions, and assumptions had to be made. It would be difficult, if not impossible, to determine how much error they introduced into the task group's final results. The Gaussian plume programs did not include such aspects as terrain effects or modeling perturbations on the dispersion of the source term caused by upwind or downwind proximity of large structures, such as the cooling towers or the reactor containment building. Again, quantification of the range or error this would introduce is at best difficult, but would ultimately lower the collective dose somewhat.

In essence, with the data as supplied to each of the three computer models, the task group would not be out of line in stating that the collective dose could be in error as high as an order of magnitude. The following is therefore presented:

- most likely collective dose: 500 person-rems
- highest likely collective dose: 5,000 person-rems
- lowest likely collective dose: < 50 person-rems

APPENDIX D REFERENCES

1. Sherman, C., "A Mass-Consistent Model for Wind Fields Over Complex Terrain," JAM, 17 (3), March 1978.

2. Lange, R., "ADPIK - A Three Dimensional Particle-in-Cell Model for the Dispersal of Atmospheric Pollutants and Its Comparison to Regional Tracer Studies," JAM, 17 (3), March 1978.

3. Gifford, F.A., Jr., "Use of Routine Meteorological Observations for Estimating Atmospheric Dispersion," Nuclear Safety, 2 (4), 1961, pp. 45-57.

4. Pasquill, F., "The Estimation of the Dispersal of Windborne Material," Meteorological Magazine, 90 (33), 1961.

APPENDIX E

DISCUSSION AND REPORT OF WHOLE-BODY COUNTING AS A TECHNIQUE TO DETERMINE INTERNAL DOSE

Whole-body counting is a standard technique used to determine the qualitative and quantitative aspects of radionuclides deposited within the body. Determination of a body burden can be done in a short time and, depending on the radionuclide, with good detection sensitivity. If the energies of the photons emitted from the internally deposited isotope are low, whole-body counting becomes a difficult task. But for higher-energy photons, determination of results can be simple if proper equipment and analysis techniques are used.

In a nuclear power facility such as TMI, the most likely isotopes to be found within the body emit photons of high energy and, therefore, are relatively easy to detect, even in small quantities. Of the isotopes released during the incident at TMI, Table E-1 shows those most likely to be found.

TABLE E-1: Isotopes Likely to be Found During Operation of a Nuclear Reactor

Isotope	Half-life	Energy of Photon (KeV)
1-131	8d	364,637
Co-60	5.3y	1170,1320
Cs-137	30y	662
Xe-133	5.3d	81
Cs-134	2y	796,1038
1-135	6.7	850,890
1-133	21h	530

Some of these, as well as other radioactive elements found around the TMI nuclear plant before and during the incident, are generally of such short half-life or show such poor bodily uptake from inhalation, absorption, or ingestion that they are not likely to be seen by a whole-body counter's detector, except in the case of surface deposition. (The actual electronics and physics of whole-body counting and gamma spectrometry will not be discussed here, but are thoroughly covered in many texts and reference sources (see references 1 and 2).)

Within the plant, subjects are chosen to be whole-body counted if they spend a significant amount of time in an area that is radioactively contaminated. (For example, inhalation in that area could lead to deposition of radioisotopes within the body.) This is standard practice for a radiation facility, but it is unclear whether routine whole-body counting was done at TMI before the incident. During the incident, more people were counted than would be usual because there were more regions around the plant designated as radiation areas and, therefore, there were higher risks of internal contamination. Off the site, the general population could possibly have been exposed to airborne fission products (either through inhalation, a minor pathway, or ingestion of food contaminated with radionuclides); therefore, a sample of 760 residents within 3 miles of TMI also was counted.

On-site, Met Ed subcontracted with RMC and contracted with Helgeson Nuclear Services to perform whole-body counting. Off-site, NRC contracted Helgeson to count the general population.

SUMMARY OF RESULTS

As stated above, 760 residents within 3 miles of TMI were whole-body counted. Children and adults were surveyed by the private company contracted by the NRC. Counting took place over a period of 8 days ending at about 7:00 p.m. on Wednesday, April 18, 1979.

Examination of the spectral and numerical results for these subjects revealed none of the radioactive elements associated with the fission process, other than trace amounts of cesium-137. (These low levels of cesium-137 are commonly found in most people due to fallout from atmospheric weapon tests.) Another isotope found was potassium-40. A small percentage of all potassium is radioactive potassium-40; normally, humans have quite a bit of body potassium, about 140 grams, or 0.2 percent of total body weight. Therefore, the potassium-40, as well as the cesium-137 found in these subjects, is considered to be a normally occurring background isotope.

In quite a few of the spectra examined, there were detectable amounts of radon "daughters" noted. These elements are not related to the Three Mile Island incident, and it has been postulated that the source of internal deposition is the natural release of radon gas from building materials used in homes and places of work, as well as emanations from the ground. Even though this situation is not related to the TMI incident, it deserves some discussion here as it sheds some light on the techniques of the subcontracted counting facilities.

These body burdens of radon were carefully tabulated by sequence of count. The average amount found in the 760 subjects was 6.48 + 4.7 nanocuries, with the highest subject having 32 + 9 nanocuries. Inspection of the tabulated results revealed some interesting trends. There appeared to be no correlation between body burden of radium and age. If actual "uptake" was observed, one should see less in a small child, as compared to what would be incorporated in a large adult. Also, at certain times of the day, everyone counted showed some of the radon daughters. At other times of the day, no one did. The reason for this is hypothesized as follows.

A large detector, such as that used to count the 760 subjects, is plagued with quite a bit of background interference. In other words, it "sees" a relatively high percentage of the radioisotopes in the environment around the detector, as well as those originating from the body of the subject being counted. To eliminate this interference, a "background" count is taken with no subject under the detector; this count is then subtracted from the subject's count. This gives a "net" spectrum showing just the count emanating from the subject's body. The 760 residents around TMI were counted within just a few days; therefore, counts were performed literally back-to-back, with no time in between to obtain an up-to-date background spectrum for subtraction. This led the task group to the belief that the radon daughters seen in the 760 residents during certain times of the day could have been due to fluctuations in the higher radon background of the area that were not subtracted out. This hypothesis is given strength due to the fact that a few of the subjects with higher radium body burdens were recounted the next day, and results showed no internally deposited radium or radon daughters. (Radium is not eliminated from the body very rapidly.) Also, correlation of the meteorological data over these time periods with the trends in radon seen in whole-body counts reveals decreased numbers of counts with radon background when wind speeds were high and weather conditions unstable. When weather conditions were stable, there was an increase in subject counts showing professed body burdens of radon.

This problem with adequate background subtraction becomes more critical when analyzing the whole-body counts of the TMI plant personnel. It must be noted here that no radon was found in plant workers. A multitude of data was obtained -- in excess of 7,000 counts which, if handled properly, could give very accurate estimates of internal dose to workers.

Again, these spectra were tabulated and closely examined for errors in analysis. The nuclides found (from both the Helgeson and RMC facilities) are listed in Table E-2.

The amounts of Cs-137 found in quite a few of the workers were in excess of the amounts normally found due to fallout. Levels of 1-131 ranged from trace amounts to in excess of 23,000 nanocuries (in one subject). The other isotopes listed were found in small but detectable amounts.

TABLE E-2: Nuclides Identified From Whole-Body Counts

Nuclides
K-40
Cs-137
Cs-134
1-131
1-133
1-135
Xe-135
Co-60
Co-58
Mn-54
Ba-La-140

In going through these tabulated results, trends were noted similar to the off-site whole-body counts. For example, a subject was counted and found to have a certain level of Mn-54. The next six or seven counts performed also showed detectable, but decreasing, amounts of Mn-54. Bearing in mind the previously discussed problem with adequate background subtraction, the task group hypothesized that the first subject could have been externally contaminated with radioisotopes in his clothes, hair, etc. This in itself is not a radiological health problem, but leads to the high probability of cross-contaminating the whole-body count apparatus or vault. If this was the case, and an up-to-date background spectrum was not obtained, the next person to be counted would also show low levels of the same isotopes.

This theory gained credibility when a tour of the whole-body counting facilities revealed a state of poor housekeeping. A whole-body counter, by definition, requires a very clean environment to prevent cross-examination and high atmospheric fluctuations of radionuclides from interfering with analyses of a subject's count. An unclean situation would raise the minimum detectable levels of some important isotopes.

The two trailers containing the whole-body count apparatus were stationed very near the dusty TMI plant entrance at the time of the visit. The doors to both trailers were propped open, allowing dust and airborne radionuclides to blow in and out. (Dust is a major carrier of charged particles.) One trailer did not have carpeting on the floor near the door to prevent the tracking in of more dust and dirt. One can see that due to this situation alone, if up-to-date background subtractions are not performed, the fluctuations in background readings can contribute to enormous errors in identification and quantification of isotopes within each subject's body.

According to representatives of both counting facilities, each subject to be counted must first remove his/her clothes and shoes, then don a disposable gown before entering the whole-body counter vault. Requiring a shower before the count is not assumed to be the responsibility of either contractor. At the time a visit was made to each of these facilities, not one person counted removed his/her street clothes. Any surface contamination they had deposited on their garments was brought with them into the whole-body counter vault where, more likely than not, some of it was left inside to contribute to erroneous analysis of the next subject's count.

This task group was given, after a series of unexplained delays, all of the whole-body count results from the two contractors, in the hopes of assessing internal dose to the plant workers. Due to the situation described above, it became impossible to accomplish this task. There was no way to be sure whether a given subject's results were accurate determinations of internal deposition or merely the result of surface contamination, cross-contamination from the previous count, or atmospheric background fluctuations.

Both of the contracted whole-body count facilities are computer-based. In other words, a few commands are typed into a computer by a technician, and the computer handles it from there. In the case of RMC, full analysis is done in the trailer where its computer is located. Helgeson, on the other hand, has all data transmitted by telephone lines to its computer in California, where they are analyzed. Both systems have adequate analysis techniques and fairly complete nuclide libraries for the commercial power industry, although inspection of some of the subjects' results showed that the computer missed some isotopes, most probably due to shifting amplifier gains. Some question is raised as to the appropriateness of the electronics settings. The gain of the signal amplifiers from the detector should be adjusted so that the energy region of the net spectra best incorporates all of the isotopes likely to be found. In the case of a nuclear plant, a key one is 1-131 with its primary photon energy of 364 KeV. Both of the subcontracters have set the gain of their amplifiers in such a way that the 1-131 photopeak is very close to the low end of the spectrum. This is certainly not the most optimum setting. The energy region that these spectra are suited to is the K-40 region, which although beautifully centered in the middle of the page, is not an isotope of any concern at TMI or any other nuclear facility. Other difficulties encountered with both of these whole-body count systems involve geometry problems that could lead to significant errors in quantifying any given isotope. However, these problems are inherent in "shadow-shield" type whole-body counters, such as those employed by RMC and Helgeson.

To summarize, it was impossible for this task group to assess internal dose based on in-vivo measurement, even though there was a multitude of data available for analysis. As stated above, there were a large number of on-site whole-body counts that revealed isotopes other than those found in normal background. Most of the levels were very low. But a few on-site personnel showed very high levels of 1-131 and Cs-137, which justify considerable concern. Because access to individual names on the data sheets was not allowed (due to privacy acts), it was impossible to trace these subjects' subsequent counts to see if, after a shower and change of clothes, the levels decreased (verifying external contamination), or whether there really were significant amounts of internal deposition. This is particularly important in the case of I-131, which has a relatively low maximum permissible body burden due to its ability to concentrate primarily within a single organ.

APPENDIX E REFERENCES

1. Hine, G. J. and Brownell, G. L., Radiation Dosimetry, Academic Press, Inc., New York, N.Y. (1956).

2. Heath, R. L., Scintillation Spectrometry, Phillips Petroleum Company, Atomic Energy Division, USAEC, Idaho Operations Office (1964).

APPENDIX F

THE DOSE TO ORGANS AND TOTAL BODY DUE TO INTERNAL DEPOSITION OF RADIONUCLIDES RELEASED DURING THE ACCIDENT AT THREE MILE ISLAND

In the preceding sections of this report, exposure to the population due to external gamma irradiation has been treated. In addition to this mode of exposure, the population dose due to radioactive isotopes that are internally deposited in the human body deserves consideration. The mechanisms of entry of radionuclides into the body include ingestion, inhalation, and skin absorption. The degree of systemic uptake and incorporation depends upon the isotope, its chemical form, and the body structure and metabolism of the person involved. The wide variability of biological half-lives among individuals makes it very difficult to assess internal dose to any one person with accuracy; however, by assuming rates associated with the average normal individual, a useful estimate of average dose due to internalized radionuclides can be obtained.

To determine the type of quantity of radionuclide releases that could be internalized by the on- and off-site populations during the accident, reliance has been placed on data from environmental samples collected in the vicinity of Three Mile Island. At the time of this report, data have been made available to the Commission staff by the organizations listed in Table F-1. In the case of radioactive noble gases known to be released to the atmoshpere, only one agency, EPA, reported ground-level data on 35 samples collected from April 4 to April 25. Given the limited number of samples and the fact that no data were collected during the initial week of the accident, the calculation of internal doses due to noble gases cannot be based on environmental sampling data. Instead, an estimate has been made based on the known ratios between internal dose and external gamma dose for the noble gases released.

TABLE F-1: Organizations Supplying Data Used in Estimating Internal Dose

Radiation Management Corp. (RMC)
Teledyne Isotopes, Inc.
Nuclear Regulatory Commission (NRC)
Environmental Protection Agency (EPA)
Bureau of Radiological Health of the U.S. Department of Health, Education, and Welfare (HEW)
U.S. Department of Energy (DOE)

DATA ANALYSIS

Format of Data

The data consist of measurements of radionuclide concentrations in environmental samples from TMI and the surrounding area during the accident, which began on March 28, 1979. These data were obtained from the commercial and governmental organizations listed in Table F-1.

The data from each organization were separated according to sample type, radionuclide being analyzed, and site-of-sampling (on-site versus, off-site). On-site is defined as the area of restricted access controlled by Met Ed: It is roughly a circle with a radius of about 0.4 miles centered on the nuclear station grounds, including the Observation Center. The types of environmental samples considered are listed in Table F-2. The radionuclides considered are listed in Table F-3. Not all radionuclides were measured for each sample type.

TABLE F-2: The Types of Environmental Samples Considered In Estimating Internal Dose

Cows' milk
Goats' milk
Drinking water
Air
Food, including unprepared food products such as eggs, poultry, pork, beef, fruits, and vegetables, and prepared food products such as baked goods, cheese, and candy
Fish
River sediment and silt
Grass
Nondrinking water
Precipitation

TABLE F-3: Radionuclides Considered in Estimating Internal Dose

Iodine-131 (^{131}I)
Cesium-137 (^{137}Cs)
Tritium (^{3}H)
Krypton-85 (^{85}Kr)
Xenon-133 (^{133}Xe)
Strontium-90 (^{90}Sr)

The collection of data from all organizations concerning a given radionuclide and a given sample type shall be considered a group of data -- the data concerning 1-131 in cows' milk, for instance. The data compiled by a single organization concerning a given radionuclide and a given sample type shall be considered a subgroup of data -- the data compiled by RMC concerning 1-131 in cows' milk is an example.

Statistical Analysis

The mean, the standard deviation, the minimum value, and the maximum value for all positive results -- samples exhibiting a measured activity above the minimum detectable level (MDL) -- were calculated for each subgroup. These values appear in Attachment 1.

Because a positive result was reported as a measurement of activity greater than two standard deviations above the mean background activity (reference 1), one expects 2.5 percent of the number of samples for which the activities are actually below the MDL to register as positive results (2.5 percent of a normal distribution lies more than two standard deviations above the mean). Consequently, in order to determine if the observed number of positive results was significantly greater than 2.5 percent of the number of samples analyzed, hypothesis testing was performed, assuming a binomial distribution (below MDL versus above MDL), or the normal approximation thereof, for radionuclide concentrations in environmental samples. The level of significance was set at 5 percent. If the observed number of positive results was significantly greater than the expected number of positive results due to statistical variation -- false positive results -- the number of positive results was considered significant.

Hypothesis testing was performed first for a group of data. If the number of positive results was significant, the overall mean and standard deviation were calculated by considering all positive results in the group. If this were not the case, hypothesis testing was performed for each subgroup. The overall mean and standard deviation were then calculated by considering only those subgroups having a significant number of positive results. These values are reported in Attachment 2. The absolute minimum and maximum positive results for each group have been reported in Attachment 2, whether or not each of these respective quantities came from a subgroup having a significant number of positive results.

Comparison of Pre- and Post-Accident Environmental Radionuclide Concentrations

In 1978, Teledyne provided radiological monitoring services for Met Ed in the area of TMI (reference 2). The statistical analysis described above was applied to these 1978 data, and the results are given in Attachment 3. Using the one-tailed test (55 percent level of significance), the post-accident data were compared with the 1978 data to determine if a significant increase had occurred. Pre-accident radionuclide concentrations were compared only with post-accident data compiled by Teledyne, where possible. In the absence of Teledyne post-accident data, the post-accident data in that subgroup having an MDL closest to that used by Teledyne in 1978 were used in this comparison.

It should be noted that pre-accident radionuclide concentrations include environmental contamination resulting from the Chinese atmospheric nuclear test of March 14, 1978.

Based on this comparison, it has been concluded that the accident has resulted in the increases in environmental radionuclide concentrations as indicated in Table F-4.

TABLE F-4: Increases in Environmental Radionuclide Concentrations Following the Accident at TMI

1311 in cows' milk
1311 in goats' milk
1311 in nondrinking water on-site
131I in air on- and off-site
137 Cs in fish

No pre-accident data were available concerning Kr-85 and Xe-133 concentrations in the air and, therefore, it was assumed that post-accident activities of these radionuclides were attributable to the accident. This assumption is supported by the knowledge that relatively large amounts of Kr-85 and Xe-133 were released during the accident.

INTERNAL DOSE CALCULATIONS

Internal Dose Due to Iodine-131

Iodine-131 can enter the human body primarily through inhalation and ingestion. It has been shown that inhaled radioiodine is completely deposited and absorbed by either of two routes (reference 3). It deposits primarily in the oro- and naso-pharynx, and is subseqently carried by saliva to the gastrointestinal (GI) tract, where it is absorbed into the bloodstream. Alternatively, it can be transported into the pulmonary system and absorbed through the lungs.

The ingestion of radioiodine is associated largely with the intake of milk. Cows and goats foraging on contaminated pastures concentrate some radioiodine in their milk. When the milk is consumed by a normal (euthyroid) person, the amount of uptake of radioiodine depends on the person's dietary intake of nonradioactive iodine (references 4 and 5). For the purposes of this report, 100 percent absorption of radioiodine by the GI system has been assumed. This, of course, is a conservative assumption. It should be noted that the goats' milk in the vicinity of TMI was not used for human consumption. Therefore, although the highest levels of 1-131 in milk were detected in the milk of a single goat, this was not considered in internal dose calculations.

Compared to inhalation, the absorption of 1-131, whether aqueous or gaseous, through intact skin ~'s very small (reference 6). At the most, approximately 0.08 percent/cm /hr of 1-131 deposited on the skin is absorbed. Coupled with the large 2 difference in surface area between the lungs (60 m) and the skin (1.8 m), skin absorption of 1-131 is considered negligible (reference 7 and 8).

Once radioiodine has entered the bloodstream, a large fraction of the ingested or inhaled radionuclide is retained in the thyroid. The body iodine occurs in several chemically different forms, forming separate "pools," each with a particular turnover rate. An established mathematical treatment (reference 9) of the relatively complex biological distribution of iodine in the normal human body has been applied for the determination of internal dose due to absorbed radioiodine.

To perform the calculations, a series of assumptions is necessary. The mean concentrations of 1-131 determined from the number of positive environmental samples of cows' milk and air are assumed. It should be noted from Appendix A, however, that only 8 percent of the milk samples analyzed and 13 percent of the air samples analyzed were positive for I-131 -- that is, above minimum detectable levels. The actual concentrations of radioiodine in the large number of negative samples is not known. Calculations based on the mean of positive results, therefore, are likely to overestimate the actual dose. A milk intake rate of one liter per day for persons in all age groups is assumed. The assumed inhalation intake rates are based on data from the International Commission of Radiological Protection (ICRP) Report 23 (reference 8).

In these calculations, the duration of exposure to iodine in the air is assumed to be from March 28 until the date of the last positive sample reading. NRC measured its last positive off-site reading on April 18, and its last positive on-site reading on April 29. Recently reported air data from EPA (received too late to be included in the tables) extend their sampling date to [4] June 28. These data show no positive off-site data after April 23, and no positive on-site data after April 30. Therefore, the duration of exposure off-site is taken to be 27 days, while for on-site it is 34 days. In the case of milk data, the Bureau of Radiological Health, HEW, reports its last positive value on April 20, while RMC and Teledyne continued to measure positive readings through their last sample collection date, April 30. This is not unexpected, based on the low MDLs for RMC and Teledyne. Based on the air data (on-site being negative after April 30) and based on knowledge of the sequence of events, it is inferred that no significant iodine releases occurred after April 30. Therefore, the duration of exposure to milk iodine it taken to be from March 28 to April 30 plus one mean life (= 1.44 x 1/2) for 1-131, or 46 days. The results of these calculations of dose to various organs due to 1-131 ingestion and inhalation are given in Table F-5.

In the case of inhalation of iodine-131 off-site, evaluation of the locations of the air sampling sites used by Met Ed, EPA, and NRC shows that, of the 94 sites used, 77 percent were within 5 miles of the plant, 93 percent were within 10 miles, 98 percent were within 20 miles, and all were within 26 miles. Therefore, the average positive levels given for 1-131 in air certainly cannot be used to estimate the exposure to the population beyond 26 miles of TMI, and probably should only be applied to the population within 10 miles of the plant. (The projected 1980 population within 10 miles of the plant is 166,295; within 30 miles, it is 1,176,584; and from 30 to 50 miles, 987,070.)

Without sufficient data, it is difficult to estimate the dose to the population beyond 10 miles. However, based on the concept of atmospheric dispersion, it is reasonable to assume that the dose to this population was, at least, somewhat lower.

Internal Dose Due to Cesium-137 in Fish

Environmental Cs-137, whether inhaled or taken orally, is almost completely absorbed (reference 10). Being an analogue of potassium, it distributes almost uniformly throughout the human body (reference 11). Its decay scheme includes a rather energetic (661 KeV) -- and therefore

TABLE F-5: Internal Dose due to Iodine-131

Intake Mode	Concentration	Intake Rate	Duration	Organ	Dose (mrem)
Cows' Milk Ingestion	Av: 9.4 pCi/l	1 1/days	46 days	new-born thyroid	6.5
				1-yr.-old thyroid	4.7
				adult thyroid	0.6
				ovaries	0.00002
				testes	0.00002
				red marrow	0.00009
				total body	0.0003
Inhalation (off-site)	Av: 5.8 pCi/m^3	0.8m^3/days	27 days	new born thyroid	2.0
		3.81^3/days		1-yr.-old thyroid	6.5
		23m /days		adult thyroid	5.4
				ovaries	0.0002
				testes	0.0001
				red marrow	0.0007
				total body	0.003
Inhalation (on-site)	Av: 45 pCi/m^3	23m^3/days	34 days	adult thyroid	52.8
				ovaries	0.002
				testes	0.001
				red marrow	0.007
				total body	0.03

penetrating -- gamma ray. Coupled with the relatively long biological half-life of the radionuclide (135 days), this suggests that the radiation hazard associated with internalized Cs-137 can be particularly serious. Fortunately, the accident at TMI resulted in no significant increases in environmental concentrations of Cs-137, with the exception of an increase in Cs-137 concentration in fish. Such findings are not unexpected in view of evidence of concentration of Cs-137 in freshwater ecosystems (reference 13). (It should be noted that above-ground Chinese weapons testing contributed to environmental levels of Cs-137.)

Assuming that an adult consumed one kilogram of fish having a concentration of Cs-137 equal to the mean positive sample result (0.35 pCi/g), a total-body dose of 0.02 mrem would result (reference 12). The dose to children and pregnant women is substantially smaller than 0.02 mrem because their metabolism results in more rapid elimination of Cs-137 (references 14 and 15) and because for children, there is an increased probability of escape from their smaller bodies of the Cs gamma rays.

Internal Dose Due to Noble Gases

Radioactive noble gases such as xenon and krypton, although inert, are internalized in an individual immersed in a cloud of radioactive gas. The whole-body dose from gas absorbed in body tissues, following inhalation and some skin absorption, adds to the dose from the radiations external to the body. However, although external gamma irradiation takes place whether the radioactive cloud is overhead or at ground level, internal dose results only when the cloud envelopes an individual.

A person immersed in a noble gas atmosphere reaches equilibrium with it rather quickly. The amount of internalized activity at equilibrium depends on the solubilities of the noble gas in adipose and soft tissue (given by Ostwald coefficients) and on the amounts of adipose and soft tissue in the individual's body. In addition to gamma rays, the radioactive gases under consideration emit electrons or beta particles in their decay that do not penetrate very far into tissue. Therefore, the lungs -- the surfaces of which are irradiated not only by gases dissolved in body tissues, but also by the volume of gas in the pulmonary airways -- receive a higher dose than other tissues. In this report, internal dose to lung includes both contributions from noble gases dissolved in the body and undissolved in the air passages of the lung.

Only one agency (EPA) performed measurements of noble gas concentrations in air during the accident. Unfortunately, their earliest measurement was made on April 4. Based on the TLD data and knowledge of the sequence of events, one can infer that the significant noble gas releases occurred prior to April 4. Therefore, sufficient environmental sampling data do not exist on which to base an estimate of internal dose due to inhalation of noble gases.

However, based on worst-case assumptions, an estimate can be made of the percent of increase in total-body dose when internal dose is included over the dose due to external gamma radiation only as measured by thermoluminescent dosimeters. This approach was previously taken in the report of L. Battist, et al. (reference 15).

The ratio -- internal dose divided by external photon dose -- for immersion in radioactive clouds of noble gases is given in Table F-6. From the EPA noble gas concentration data, xenon-133 was the predominant noble gas released -- a fact consistent with knowledge of the reactor core inventory. If all of the dose delivered to an individual during the accident were due to plume touchdown and continuous total immersion in the cloud, then Table F-6 can be used to determine internal dose. For example, if the off-site individual receiving the highest dose received 50 mrems total body due to external photons from xenon-133, then he received an additional 50 times 0.057, or 3 mrems total body. Similar low numbers are obtained for the other isotopes of xenon listed in Table F-6. The dose to the lungs due to inhalation of krypton-85 is a factor of 1.5 to 2.5 times greater than the dose due to external photons, because Kr-85 is almost a pure beta (electron) emitter. A photon (514 KeV) is emitted with a probability of only 0.41 percent per disintegration. Some bremsstrahlung is created in the air by the electrons, but overall, less than half of the dose delivered to the lungs by krypton is due to photons. However, based on results from the ORNL ORIGEN code, only 7.7 percent of the noble gases in the core was Kr-85, while 41.2 percent was Xe-133, 6.2 percent Xe-133m, and 9.8 percent Xe-135 at the time of shutdown.

Overall, then, the internal dose due to noble gases released at Three Mile Island is small, compared with the external gamma dose.

DOSES DUE TO NATURALLY OCCURRING, INTERNALLY DEPOSITED RADIONUCLIDES

In order to gain some perspective on the doses due to internalization of radionuclides released during the accident at TMI, one may compare these doses with those due to naturally occurring, internally deposited radionuclides. The average annual dose to a man in the United States due to internal radiation is approximately 27 mrems to soft tissue -- including thyroid and gonads -- 60 mrems to bone surfaces, 24 mrems to red bone marrow, and 124 mrems to the lungs (reference 18).

TABLE F-6: Ratio of Internal Dose to External Gamma Ray Total-Body Dose for Immersion in a Radioactive Cloud of Noble Gas

Isotope	Organ	Internal Dose / External Gamma Dose	Reference
^{133}Xe	total body	0.006	(16) [a]
	lung	0.057	(16) [b]
^{133m}Xe	total body	0.009	(16) [a]
	lung	0.073	(16) [b]
^{135}Xe	total body	0.004	(16) [a]
	lung	0.029	(16) [b]
^{135m}Xe	total body	0.001	(16) [a]
	lung	0.006	(16) [b]
^{85}Kr	total body	0.094 0.061	(16) [a] (17) [c]
	lung	2.50 1.53	(16) [b] (17) [d]

a. Determined total body activity based on average Ostwald coefficient.

b. Assumed lung volume of 5.6 liters.

c. Treated individual tissues and their associated Ostwald coefficients separately.

d. Assumed lung volume of 4 liters.

APPENDIX F REFERENCES

1. Harley, J. (Ed.), "EML Procedures Manual," USDOE Report, HASL-300 (1972, revised annually).

2. Teledyne Isotopes, Inc., "Metropolitan Edison Company, Radiological Environmental Monitoring Report, 1978 Annual Report, Prepared for the Three Mile Island Nuclear Station," IWL-5590-443 (1978).

3. Morgan, A., Morgan, D. J., and Black, A., "A Study of the Deposition Translocation and Excretion of Radioiodine Inhaled as Iodine Vapour," Health Physics 15 (1968), p. 313.

4. Pochin, E. E. and Barnaby, C. F., "The Effect of Pharmacological Doses of Non-radioactive Iodide on the Course of Radioiodine Uptake by the Thyroid," Health Physics 7 (1962), p. 125.

5. Adams, C. A. and Bonnell, J. A., "Administration of Stable Iodide as a Means of Reducing Thyroid Irradiation Resulting from the Inhalation of Radioactive Iodine," Health Physics 7 (1962), p. 127.

6. Harrison, J., "The Fate of Radioiodine Applied to the Skin," Health Physics 9 (1963), p. 993.

7. Altman, P. L. and Wittmer, D. S., Biology Data Book, Vol. III, Federation of American Societies for Experimental Biology, Bethesda, Md. (1974).

8. ICRP, International Commission of Radiological Protection, Report of the Task Group on Reference Man, ICRP Report No. 23, Pergamon Press, N.Y. (1974).

9. Wellman, H. N. and Anger, R. T., "Radioiodine Dosimetry and the Use of Radioiodines Other Than 1-131 in Thyroid Diagnosis," Seminars in Nuclear Medicine, Vol. 1, No. 3 (1971).

10. Stara, J. F., Nelson, N. S., Dells Rosa, R. J., and Bustad, L. K., "Comparative Metabolism of Radionuclides in Mammals: A Review," Health Physics 20 (1971), p. 1130.

11. Yamagata, N. and Yamagata, T., "The Concentration of Cesium-137 in Human Tissues and Organs," Bull. Inst. Public Health (Tokyo) 9, No. 2 (1960), p. 720.

12. National Council on Radiation Protection and Measurements, "Cesium-137 from the Environmental to Man: Metabolism and Dose," NCRP Report No. 52, National Council on Radiation Protection and Measurements, Washington (1977).

13. Pendleton, R. C. and Hanson, W. C., "Absorption of Cesium-137 by Components of an Aquatic Community," in Proceedings of the Second United Nations International Congress on the Peaceful Uses of Atomic Energy, Vol. 18, United Nations, New York (1968), p. 419.

14. Zundel, W. S., Tyler, F. H., Mays, C. W., Lloyd, R. D., Wagner, W. W., and Pendleton, R. C., "Short Half-Times of Cesium-137 in Pregnant Women," Nature 221 (1969), p. 89.

15. Battist, L., Buchanan, J., et al., "Population Dose and Health Impact of the Accident at the Three Mile Island Nuclear Station (A preliminary assessment for the period March 28 through April 7, 1979)," U.S. Government Printing Office, No. 017-001-00408-1 (1979).

16. Russell, J. L. and Galpin, F. L., "Comparison of Techniques for Calculating Doses to the Whole Body and to the Lungs from Radioactive Noble Gases," in Radiation Protection Standards: Quo Vadis, Howell, V. P. and Corley, J. P. (Eds.), Proceedings of the Sixth Annual Health Physics Society Topical Symposium, Columbia Chapter, Health Physics Society, Richland, Wash., February 1972 (1972), p. 286

17. Snyder, W. S., Dillman, L. T., Ford, M. R., and Postin, J. W., "Calculations of the Absorbed Dose to a Man Immersed in an Infinite Cloud of Krypton-85," in Noble Gases, Stanley, R. E. and Moghissi, **A. A. (Eds.)**, Proceedings of the Noble Gases Symposium, Las Vegas, Nevada, Sept. 24-28, 1973 (1973), p. 420.

18. National Council on Radiation Protection and Measurements, Natural Background Radiation in the United States, NCRP Report No. 45, National Council on Radiation Protection and Measurements, Washington (1975).

ATTACHMENT 1

SUMMARY OF **RADIONUCLIDE CONCENTRATIONS** IN **ENVIRONMENTAL SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION AFTER** THE ACCIDENT OF MARCH 28, 1979

COW'S MILK

ISOTOPE	ORGANIZATION	DATES OF SAMPLING	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	MEAN POSITIVE RESULT (pCi/R)	STANDARD DEVIATION OF POSITIVE RESULTS (pCi/R)	MINIMUM POSITIVE RESULT (pCi/R)	MAXIMUM POSITIVE RESULT Ci/R)	MEAN MINIMUM DETECTABLE LEVEL (MDL) (pCi/R)
LHc	RMC	3/29-	ON-SITE	0	-	-	-			
		4/30	OFF-SITE	30	23	3.8	4.2	0.5	19	0.8
	Teledyne	3/29-	ON-SITE	0		-	-	-		
		4/30	OFF-SITE	122	60	2.5	3.8	0.24	21	0.5
	NRC	4/3-	ON-SITE	0						
		5/27	OFF-SITE	112	0					20
	EPA	4/5-	ON-SITE	0						-
		4/25	OFF-SITE	158	0					N.A.
	HEW	3/30-	ON-SITE	0					-	-
		6/21	OFF-SITE	1259	51	20	20	13	36	N.A.
	DOE	3/29-	ON-SITE	0						-
		4/16	OFF-SITE	7	0					48

N.A. The relevant data (i.e., minimum detectable levels) are not available.

ATTACHMENT 1 (continued)

SUMMARY OF RADIONUCLIDE CONCENTRATIONS IN ENVIRONMENTAL SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION AFTER THE ACCIDENT OF MARCH 28, 1979

COW'S MILK

ISOTOPE	ORGANIZATION	DATES OF SAMPLING	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	MEAN POSITIVE RESULT (pCi/R)	STANDARD DEVIATION OF POSITIVE RESULTS (pCi/L)	MINIMUM POSITIVE RESULT (pCi/2)	MAXIMUM POSITIVE RESULT (pCi/Q)	MEAN MINIMUM DETECTABLE LEVEL (MDL) (pCi/Q)
^{137}Cs	RMC	3/29-	ON-SITE	0		-	-			
		5/1	OFF-SITE	29	10	4.7	2.9	1.6	11	1.1
	EPA	4/5	ON-SITE	0		-		-	-	-
		4/25	OFF-SITE	**158**	**1(N.S.)**	6.7	0	6.7	6.7	N.A.
	HEW	3/30	ON-SITE	0					-	-
		6/21	OFF-SITE	1295	34(N.S.)	18	19	11	37	**N.A.**
	DOE	**3/29**	**ON-SITE**	0						
		4/16	**OFF-SITE**	1	0					
^{90}Sr	HEW	3/29-	ON-SITE	0						
		4/15	OFF-SITE	375	0					**N. A.**

N. S. The observed number of positive results is not significant for the subgroup. (See text).
N.A. The relevant data (i.e., minimum detectable levels) are not available.

ATTACHMENT 1 (continued)

SUMMARY OF RADIONUCLIDE CONCENTRATIONS IN ENVIRONMENTAL SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION AFTER THE ACCIDENT OF MARCH 28, 1979

GOAT'S MILK

ISOTOPE	**ORGANIZATION**	DATES OF SAMPLING	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	MEAN POSITIVE RESULT (pCi/Z)	STANDARD DEVIATION OF POSITIVE RESULTS (pCi/2)	MINIMUM POSITIVE RESULT (pCi/L)	MAXIMUM POSITIVE RESULT (pCi/k)	MEAN MINIMUM DETECTABLE LEVEL (MDL) (pCi/2)
^{131}I	Teledyne	3/29-	ON-SITE	0			-			
		4/30	OFF-SITE	36	35	31	25	1.1	110	40
	NRC	4/29-	ON-SITE	0		-		-	-	
		5/27	OFF-SITE	11	5	22	11	8.5	36	11
	HEW	4/13-	ON-SITE	0						-
		4/15	OFF-SITE	5	0					N.A.
^{137}Cs	HEW	4/13-	ON-SITE	0						-
		4/15	OFF-SITE	5	0					N.A.
^{90}Sr	HEW	4/13-	ON-SITE	0						
		4/15	OFF-SITE	5	0					**N. A.**

N.A. The relevant data (i.e., minimum detectable levels) are not available.

ATTACHMENT 1 (continued)

SUMMARY OF RADIONUCLIDE CONCENTRATIONS IN ENVIRONMENTAL
SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION AFTER THE ACCIDENT
OF MARCH 28, 1979

AIR

ISOTOPE	ORGANIZATION	DATES OF SAMPLING	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	MEAN POSITIVE RESULTS (pCi/m)	STANDARD DEVIATION OF POSITIVE R5SULTS (pCi/m)	MINIMUM POSITIVE RESULJ (pCi/m)	MAXIMUM POSITIVE RESULJ (Ci/m	MEAN MINIMUM DETECTABLE LEVEL (MRL) (pCi/m)
131 1	RMC	3/29-	ON-SITE	0			-		-	
		4/30	OFF-SITE	20	11	1.0	2.9	0.08	9.8	0.07
	Teledyne	3/24-	ON-SITE	20	18	3.4	6.9	0.082	22.6	0.05
		4/30	OFF-SITE	48	32	2.1	5.7	0.049	23.9	0.05
	NRC	4/1-	ON-SITE	240	32	68	70	0.7	250	44
		5/21	OFF-SITE	102	3(N.S.)	40	12	27.0	50	68
	EPA	4/1-	ON-SITE	0					-	
		4/24	OFF-SITE	1247	106	0.5	0.5	0.0023	2.3	0.2
	DOE	3/29-	ON-SITE	0	-	-				-
		4/16	OFF-SITE	59	24	32	41	2	119	82

N.S. The observed number of positive results is not significant for the subgroup. (See text).

ATTACHMENT 1 (continued)

SUMMARY OF **RADIONUCLIDE CONCENTRATIONS** IN ENVIRONMENTAL
SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION AFTER THE ACCIDENT
OF MARCH 28, 1979

AIR

ISOTOPE	ORGANIZATION	DATES OF SAMPLING	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	MEAN POSITIVE RESULI (pCi/m)	STANDARD DEVIATION OF POSITIVE R SULTS (pCi/m)	MINIMUM POSITIVE RESUL (pCi/m)	MAXIMUM POSITIVE RESUL (Ci/m	MEAN MINIMUM DETECTABLE LEVEL (L) (pCi/m)
^{85}Kr	EPA	4/4-	ON-SITE	1	1	20	0	20.0	20.0	N.A.
		4/25	OFF-SITE	34	34	70	250	11.0	1500.0	N.A.
^{133}Xe	EPA	4/4-	ON-SITE	1	1	25	0	25	25	N.A.
		4/25	OFF-SITE	34	32	4900	25000	9	140000	6.1
^{3}H	EPA	4/4-	ON-SITE	1	0				-	1.0
		4/20	OFF-SITE	9	4	1.5	1.2	0.6	3.3	1.5

N.A. The relevant data (i.e., minimum detectable levels) are not available.

ATTACHMENT 1 (continued)

SUMMARY OF RADIONUCLIDE CONCENTRATIONS IN ENVIRONMENTAL SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION AFTER THE ACCIDENT OF MARCH 28, 1979

DRINKING WATER

ISOTOPE	**ORGANIZATION**	**DATES** OF SAMPLING	**SITE** OF SAMPLING	**NO. SAMPLES** ANALYZED	**NO. POSITIVE** RESULTS	**MEAN POSITIVE RESULT** (pCi/i)	**STANDARD DEVIATION** OF **POSITIVE** RESULTS (pCi/k)	MINIMUM POSITIVE RESULT (Ci/i	MAXIMUM POSITIVE RESULT Ci/i)	MEAN MINIMUM DETECTABLE LEVEL (MDL) (pCi/£)
^{131}I	RMC	4/5	ON-SITE	0						-
			OFF-SITE	1	0				0	7.8
	Teledyne	4/5	ON-SITE	0				-	-	
			OFF-SITE	214	8(N.S.)	0.6	0.1	0.37	0.72	0.4
	HEW	3/30-	ON-SITE	0						-
		6/21	OFF-SITE	109	0					N.A.
^{137}Cs	RMC	4/5	ON-SITE	0						
			OFF-SITE	1	0					7.8
	Teledyne	3/29-	ON-SITE	0						
		4/5	OFF-SITE	37	0					6.5
	HEW	3/30	ON-SITE	0						
		6/21	OFF-SITE	109	0					N.A.
^{3}H	RMC	4/5	ON-SITE	1	1	243	0	243	243	**N.A.**
			OFF-SITE	0		-		-	-	-
	Teledyne	3/29-	ON-SITE	0						-
		4/19	OFF-SITE	126	103	180	110	100	810	**N.A.**
^{90}Sr	HEW	3/29-	ON-SITE	0						-
		4/15	OFF-SITE	43	0					N.A.

N. S. **The observed number** of **positive results** is **not significant for the subgroup. (See text).**

N.A. **The relevant data (i.e., minimum detectable levels) are not available.**

ATTACHMENT 1 (continued)

SUMMARY OF RADIONUCLIDE CONCENTRATIONS IN ENVIRONMENTAL
SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION AFTER THE ACCIDENT
OF MARCH 28, 1979

FOOD

ISOTOPE	ORGANIZATION	DATES OF SAMPLING	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	MEAN POSITIVE RESULT (pCi/g WET)	STANDARD DEVIATION OF POSITIVE RESULTS (pCi/g WET)	MINIMUM POSITIVE RESULT (pCi/g WET)	MAXIMUM POSITIVE RESULT (pCi/g WET)	MEAN MINIMUM DETECTABLE LEVEL (MDL) (pCi/gWET)
^{131}I	RMC	4/13-	ON-SITE	0						
		4/16	OFF-SITE	8	0					0.09
	Teledyne	3/30-	ON-SITE	0						
		4/8	OFF-SITE	3	0					0.08
	HEW	3/30-	ON-SITE	0						-
		6/21	OFF-SITE	541	0					N.A.
^{137}Cs	HEW	3/30-	ON-SITE	0						-
		6/21	OFF-SITE	541	0					N.A.
^{90}Sr	HEW	3/29-	ON-SITE	0						
		4/15	OFF-SITE	225	0					N. A.

N.A. The relevant data (i.e., minimum detectable levels) are not available.

ATTACHMENT 1 (continued)

SUMMARY OF RADIONUCLIDE CONCENTRATIONS IN ENVIRONMENTAL
SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION AFTER THE ACCIDENT
OF MARCH 28, 1979

FISH

ISOTOPE	ORGANIZATION	DATES OF SAMPLING	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	MEAN POSITIVE RESULT (pCi/g WET)	STANDARD DEVIATION OF POSITIVE RESULTS (pCi/g WET)	MINIMUM POSITIVE RESULT (pCi/g WET)	MAXIMUM POSITIVE RESULT (pCi/g WET)	MEAN MINIMUM DETECTABLE LEVEL (MDL) (pCi/gWET)
1311	Teledyne	4/10- 4/26	ON-SITE OFF-SITE	0 16	0					– N.A.
137 Ca	Teledyne	4/10- 4/26	ON-SITE OFF-SITE	0 16	7	– 0.35	0.30	0.11	- 0.778	– N.A.
90Sr	HEW	3/29- 4/15	ON-SITE OFF-SITE	0 5	0					- N.A.

N.A. The relevant data (i.e., minimum detectable levels) are not available.

ATTACHMENT 1 (continued)

SUMMARY OF RADIONUCLIDE CONCENTRATIONS IN ENVIRONMENTAL
SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION AFTER THE ACCIDENT
OF MARCH 28, 1979

GRASS

ISOTOPE	ORGANIZATION	DATES OF SAMPLING	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	MEAN POSITIVE RESULT (pCi/g DRY)	STANDARD DEVIATION OF POSITIVE RESULTS (pCi/g DRY)	MINIMUM POSITIVE RESULT (pCi/g DRY)	MAXIMUM POSITIVE RESULT (pCi/g DRY)	MEAN MINIMUM DETECTABLE LEVEL (MDL) (pCi/g DRY)
131_{I}	RMC	4/5	ON-SITE	0						
			OFF-SITE	3	0					0.15
	Teledyne	4/5	ON-SITE	0						
			OFF-SITE	3	2	0.05	0.02	0.033	0.063	0.01
137_{Ca}	RMC	4/5	ON-SITE	0		-			-	-
			OFF-SITE	2	2	0.25	0.1	0.18	0.32	N.A.

N.A. The relevant data (i.e., minimum detectable levels) are not available.

ATTACHMENT 1 (continued)

SUMMARY OF RADIONUCLIDE CONCENTRATIONS IN ENVIRONMENTAL
SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION AFTER THE ACCIDENT
OF MARCH 28, 1979

RIVER SEDIMENT AND SILT

ISOTOPE	**ORGANIZATION**	**DATES** OF **SAMPLING**	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	MEAN POSITIVE RESULT (pCi/g DRY)	STANDARD **DEVIATION** OF **POSITIVE RESULTS** (pCi/g DRY)	**MINIMUM POSITIVE RESULT** (pCi/g DRY)	**MAXIMUM POSITIVE RESULT** (pCi/g DRY)	**MEAN MINIMUM DETECTABLE LEVEL (MDL)** (pCi/g DRY)
^{131}I	Teledyne	4/5-	ON-SITE	0						-
		4/23	OFF-SITE	18	0					**N.A.**
	EPA	3/30-	ON-SITE	0						-
		4/2	OFF-SITE	10	0					**N.A.**
^{137}Ca	Teledyne	4/5-	ON-SITE	0					-	-
		4/23	OFF-SITE	18	18	0.3	0.1	0.066	0.52	N.A.
	EPA	3/30-	ON-SITE	0						
		4/2	OFF-SITE	10	1	0.35	0	0.35	0.35	**N.A.**

N.A. The relevant data (i.e., minimum detectable levels) are not available.

ATTACHMENT 1 (continued)

SUMMARY OF RADIONUCLIDE CONCENTRATIONS IN ENVIRONMENTAL
SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION AFTER THE ACCIDENT
OF MARCH 28, 1979

SOIL

ISOTOPE	**ORGANIZATION**	DATES OF SAMPLING	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	MEAN POSITIVE RESULT (pCi/g DRY)	STANDARD DEVIATION OF POSITIVE RESULTS (pCi/g DRY)	MINIMUM POSITIVE RESULT (pCi/g DRY)	MAXIMUM POSITIVE RESULT (pCi/g DRY)	MEAN MINIMUM DETECTABLE LEVEL (MDL) (pCi/g DRY)
^{131}I	RMC	4/5	ON-SITE	0						
			OFF-SITE	3	0					0.07
	Teledyne	4/5	ON-SITE	0						-
			OFF-SITE	3	0					0.27
	EPA	4/2-	ON-SITE	0						-
		4/13	OFF-SITE	53	0					N.A.
^{137}Cs	RMC	4/2	ON-SITE	0				-		-
			OFF-SITE	3	3	0.8	0.2	0.58	1.0	N.A.
	Teledyne	4/5	ON-SITE	0				-	-	-
			OFF-SITE	3	3	0.4	0.3	0.456	1.38	**N.A.**
	EPA	4/2-	ON-SITE	0				-		-
		4/13	OFF-SITE	53	11	0.6	0.3	0.22	1.1	N.A.

N.A. The relevant data (i.e., minimum detectable levels) are not available.

ATTACHMENT 1 (continued)

SUMMARY OF RADIONUCLIDE CONCENTRATIONS IN ENVIRONMENTAL SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION AFTER THE ACCIDENT OF MARCH 28, 1979

NON-DRINKING **WATER**

ISOTOPE	**ORGANIZATION**	DATES OF SAMPLING	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	MEAN POSITIVE RESULT (pCi/f,)	STANDARD DEVIATION OF POSITIVE RESULTS (pCi/f,)	MINIMUM POSITIVE RESULT (pCi/i)	MAXIMUM POSITIVE RESULT (pCi/£)	MEAN MINIMUM DETECTABLE LEVEL (MDL) (pCi/i)
131 1	RMC	3/29-	ON-SITE	44	41	9.6	16	0.62	71	0.6
		4/30	OFF-SITE	153	3(N.S.)	0.7	0.2	0.57	0.72	0.4
	Teledyne	3/29-	ON-SITE	38	30	11	21	0.54	73	0.3
		4/30	OFF-SITE	231	4(N.S.)	0.5	0.2	0.37	0.72	0.3
	NRC	4/3	ON-SITE	0						-
		5/20	OFF-SITE	5	0					N.A.
	EPA	3/30-	ON-SITE	13	0					N.A.
		5/15	OFF-SITE	191	0					**N.A.**
	HEW	3/30-	ON-SITE	0						
		6/21	OFF-SITE	41	0					**N.A.**
	DOE	3/29-	ON-SITE	0		-			-	-
		4/16	OFF-SITE	322	8(N.S.)	330	140	50	555	340

N.S. The observed number of positive results is not significant for the subgroup. (See teat).

N.A. The relevant data (i.e., minimum **detectable levels) are** not available.

ATTACHMENT 1 (continued)

SUMMARY OF **RADIONUCLIDE CONCENTRATIONS** IN **ENVIRONMENTAL**
SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION AFTER THE ACCIDENT
OF MARCH 28, 1979

NON-DRINKING WATER

ISOTOPE	ORGANIZATION	DATES OF SAMPLING	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	MEAN POSITIVE RESULT (pCi/i)	STANDARD DEVIATION OF POSITIVE RESULTS (pCi/i)	MINIMUM POSITIVE RESULT (pCi/i)	MAXIMUM POSITIVE RESULT (pCi/i)	MEAN MINIMUM DETECTABLE LEVEL (MDL) (pCi/i)
137 Ca	RMC	3/29-	ON-SITE	0						-
		5/1	OFF-SITE	100	0					3.6
	Teledyne	3/31-	ON-SITE	0						
		4/5	OFF-SITE	2						7.0
	HEW	3/30-	ON-SITE	0						-
		6/21	OFF-SITE	41	0					N.A.
	DOE	3/31-	ON-SITE	0						
		4/16	OFF-SITE	5	0					61
^{3}H	RMC	3/29-	ON-SITE	30	14	1500	1200	181	2880	270
		4/30	OFF-SITE	153	19	250	120	180	578	260
	Teledyne	3/29-	ON-SITE	19	17	740	1100	100	3690	130
		4/30	OFF-SITE	141	117	180	110	100	810	120
^{90}Sr	HEW	3/29-	ON-SITE	0						-
		4/15	OFF-SITE	35	0					N.A.

N.A. The relevant data (i.e., minimum detectable levels) are not available.

ATTACHMENT 1 (continued)

SUMMARY OF **RADIONUCLIDE CONCENTRATIONS IN ENVIRONMENTAL**
SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION AFTER THE ACCIDENT
OF MARCH 28, 1979

PRECIPITATION

ISOTOPE	ORGANIZATION	DATES OF SAMPLING	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	MEAN POSITIVE RESULT (pCi/i)	STANDARD DEVIATION OF POSITIVE RESULTS (pCi/Q,)	MINIMUM POSITIVE RESULT (pCi/R)	MAXIMUM POSITIVE RESULT (pCi/R)	MEAN MINIMUM DETECTABLE LEVEL (MDL) (pCi/i)
^{131}I	RMC	3/29-	ON-SITE	0						
		4/5	OFF-SITE	2	0					1.0
	Teledyne	3/29-	ON-SITE	1	1	1.2	0	1.2	1.2	N.A.
		4/5	OFF-SITE	3	1(N.S.)	2.1	0	2.1	2.1	0.2
	NRC	4/5-	ON-SITE	2	0					20
		5/26	OFF-SITE	2	0					17
^{137}Cs	RMC	3/31-	ON-SITE	0						-
		4/5	OFF-SITE	2	0					7.8
	Teledyne	3/31-	ON-SITE	1	0					9
		4/5	OFF-SITE	3	0					7.3

N.S. The observed number of positive results **is** not significant for the subgroup. (See text).

N.A. The relevant data (i.e., minimum detectable levels) are not available.

ATTACHMENT 2

SUMMARY OF SIGNIFICANT RADIONUCLIDE CONCENTRATION IN
ENVIRONMENTAL SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION
AFTER THE ACCIDENT OF MARCH 28, 1979

SAMPLE TYPE	ISOTOPE	DATE OF SAMPLING	SITE OF SAMPLING	TOTAL NO. SAMPLES ANALYZED	TOTAL NO. POSITIVE RESULTS	NO. OF SIGNIFICANT POSITIVE RESULTS*	MEAN OF SIGNIFICANT POSITIVE RESULTS*	STANDARD DEVIATION OF SIGNIFICANT POSITIVE RESULTS*	ABSOLUTE MINIMUM POSITIVE RESULTS*	ABSOLUTE MAXIMUM POSITIVE RESULTS	UNITS
COW'S MILK	^{131}I	3/29-	ON-SITE	0	-	-	-				
		5/27	OFF-SITE	1724	134	134	9.4	14.7	0.24	21	pCi/1
	^{137}Ca	3/29-	ON-SITE	0			-	-		-	
		6/21	OFF-SITE	1483	45(N.S.)	10	4.7	2.9	1.6	37	pCi/1
	^{90}Sr	3/29-	ON-SITE	0							
		4/15	OFF-SITE	375	0	0					pCi/1
GOAT'S MILK	^{131}I	3/29-	ON-SITE	0							
		5/27	OFF-SITE	52	40	40	30	24	1.1	110	pCi/1
	137 Cs	4/13-	ON-SITE	0							
		4/15	OFF-SITE	5	0	0					pCi/1
	^{90}Sr	4/13-	ON-SITE	0							
		4/15	OFF-SITE	5	0						pCi/1
DRINKING WATER	^{131}I	3/30-	ON-SITE	0							
		6/21	OFF-SITE	324	8(N.S.)	0			0.37	0.72	pCi/ i
	137 Cs	3/29-	ON-SITE	0							
		6/21	OFF-SITE	147	0	0					pCi/1
	^{3}H	3/29-	ON-SITE	0							
		4/19	OFF-SITE	127	104	104	180	110	100	810	pCi/ 1
	^{90}Sr	3/29-	ON-SITE	0							
		4/15	OFF-SITE	43	0						pCi/ 1

* The values of these quantities are determined by considering the entire group of data. If the total number of positive results is not significant.

r
00

SUMMARY OF SIGNIFICANT RADIONUCLIDE CONCENTRATION IN
ENVIRONMENTAL SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION
AFTER THE ACCIDENT OF MARCH 28, 1979

these values are determined by considering only those sub-groups for which the observed number of positive results is significant. (See text).

** The values of these quantities are determined by considering the entire group of data. (See text).

N.S. The total number of positive results is not significant for the group. However, an individual subgroup may contain a significant number of positive results. (See text).

ATTACHMENT 2 (continued)

SUMMARY OF **SIGNIFICANT RADIONUCLIDE CONCENTRATION** IN
ENVIRONMENTAL SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION
AFTER THE ACCIDENT OF MARCH 28, 1979

SAMPLE TYPE	ISOTOPE	DATE OF SAMPLING	SITE OF SAMPLING	TOTAL NO. SAMPLES ANALYZED	TOTAL NO. POSITIVE RESULTS	NO. OF SIGNIFICANT POSITIVE RESULTS*	MEAN OF SIGNIFICANT POSITIVE RESULTS*	STANDARD DEVIATION OF SIGNIFICANT POSITIVE RESULTS*	ABSOLUTE MINIMUM POSITIVE RESULTS**	ABSOLUTE MAXIMUM POSITIVE RESULTS**	UNITS
AIR	131 1	3/29-	ON-SITE	268	50	50	45	72	0.082	246	pCi/m 3
		5/21	OFF-SITE	1476	176	176	5.8	20	0.0023	119	
	85 Kr	4/4-	ON-SITE	1	1	1	20	0	20.0	20.0	pCi/m
		4/25	OFF-SITE	34	34	34	70	250	11.0	1500.0	pCi/m3
	133 Xe	4/4-	ON-SITE	1	1	1	25	0	25	25	pCi/m3
		4/25	OFF-SITE	34	32	32	4900	25000	9	140,000	pCi/m
	3 H	4/4-	ON-SITE	1	0					-	
		4/20	OFF-SITE	9	4	4	1.5	1.2	0.6	3.3	pCi/m 3
FOOD	131 1	4/3-	ON-SITE	0							
		6/21	OFF-SITE	552	0						pCi/g WET
	137 Cs	3/30	ON-SITE	0							
		6/21	OFF-SITE	541	0						pCi/g WET
	90 Sr	3/29-	ON-SITE	0							
		4/15	OFF-SITE	225	0						pCi/g WET

* The values of these quantities are determined by considering the entire group of data. If the total number of positive results is not significant, these values are determined by considering only those sub-groups for which the observed number of positive results is significant. (See text).

** The values of these quantities are determined by considering the entire group of data. (See text).

r
V

ATTACHMENT 2 (continued)

SUMMARY OF **SIGNIFICANT** RADIONUCLIDE CONCENTRATION IN ENVIRONMENTAL SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION AFTER THE ACCIDENT OF MARCH 28, 1979

SAMPLE TYPE	ISOTOPE	DATE OF SAMPLING	SITE OF SAMPLING	TOTAL NO. SAMPLES ANALYZED	TOTAL NO. POSITIVE RESULTS	NO. OF SIGNIFICANT POSITIVE RESULTS*	MEAN OF SIGNIFICANT POSITIVE RESULTS*	STANDARD DEVIATION OF **SIGNIFICANT** POSITIVE RESULTS*	ABSOLUTE MINIMUM POSITIVE RESULTS**	ABSOLUTE MAXIMUM POSITIVE RESULTS**	UNITS
FISH	^{131}I	4/10-	ON-SITE	0							
		4/26	OFF-SITE	16	0						pCi/g WET
	^{137}Cs	4/10-	ON-SITE	0			-			-	
		4/26	OFF-SITE	16	7	7	0.35	0.30	0.11	0.778	pCi/g WET
	^{90}Sr	3/29-	ON-SITE	0							
		4/15	OFF-SITE	5	0						pCi/g WET
RIVER SEDIMENT AND	^{131}I	4/5-	ON-SITE	0							
		4/23	OFF-SITE	28	0						pCi/g DRY
SILT	^{137}Cs	3/30-	ON-SITE	0						-	
		4/23	OFF-SITE	28	19	19	0.3	0.1	0.066	0.52	pCi/g DRY
SOIL	^{131}I	4/2-	ON-SITE	0							
		4/13	OFF-SITE	59	0						pCi/g DRY
	^{137}Cs	4/2-	ON-SITE	0							
		4/13	OFF-SITE	59	17	0.6	0.6	0.4	0.22	1.39	pCi/g DRY

* The value of these quantities are determined by considering the entire group of data. If the total number of positive results is not significant, these values are determined by considering only those sub-groups for which the observed number of positive results is significant. (See text).

** The values of these quantities are determined by considering the entire group of data. (See text).

ATTACHMENT 2 (continued)

SUMMARY OF **SIGNIFICANT RADIONUCLIDE CONCENTRATION** IN
ENVIRONMENTAL SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION
AFTER THE ACCIDENT OF MARCH 28, 1979

SAMPLE TYPE	ISOTOPE	DATE OF SAMPLING	SITE OF SAMPLING	TOTAL NO. SAMPLES ANALYZED	TOTAL NO. POSITIVE RESULTS	NO. OF SIGNIFICANT POSITIVE RESULTS*	MEAN OF SIGNIFICANT POSITIVE RESULTS*	STANDARD DEVIATION OF SIGNIFICANT POSITIVE RESULTS*	ABSOLUTE MINIMUM POSITIVE RESULTS**	ABSOLUTE MAXIMUM POSITIVE RESULT**	UNITS
GRASS	^{131}I	4/5	ON-SITE	0						-	
			OFF-SITE	6	2(N.S.)	2	0.05	0.02	0.033	0.063	pCi/g DRY
	^{137}Cs	4/5	ON-SITE	0						-	
			OFF-SITE	2	2	2	0.3	0.1	0.18	0.32	pCi/g DRY
NON-DRINKING WATER	^{131}I	3/29-6/21	ON-SITE	95	71	71	10.2	18.2	0.54	73	pCi/k
			OFF-SITE	943	15(N.S.)	0		-	0.37	0.72	
	^{137}Cs	3/29-6/21	ON-SITE	0							
			OFF-SITE	148	0						pCi/k
	^{3}H	3/29-4/30	ON-SITE	49	31	31	1100	1200	100	3690	pCi/k
			OFF-SITE	294	136	136	190	130	100	810	pCi/k
	^{90}Sr	3/29-4/15	ON-SITE	0							
			OFF-SITE	35	0						pCi/k
PRE-CIPITATION	^{131}I	3/29-5/26	ON-SITE	3	1(N.S.)	1	1.2	0	1.2	1.2	pCi/k
			OFF-SITE	7	1(N.S.)	0			2.1	2.1	pCi/k
	^{137}Cs	3/31-4/5	ON-SITE	1	0	0					pCi/k
			OFF-SITE	5	0	0					pCi/k

* The values of these quantities are determined by considering the entire group of data. If the total number of positive results is not significant, these values are determined by considering only those sub-groups for which the observed number of positive results is significant. (See text).

ATTACHMENT 2 (continued)

SUMMARY OF SIGNIFICANT RADIONUCLIDE CONCENTRATION IN
ENVIRONMENTAL SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION
AFTER THE ACCIDENT OF MARCH 28, 1979

SAMPLE TYPE	ISOTOPE	DATE OF SAMPLING	SITE OF SAMPLING	TOTAL NO. SAMPLES ANALYZED	TOTAL NO. POSITIVE RESULTS	NO. OF SIGNIFICANT POSITIVE RESULTS*	MEAN OF SIGNIFICANT POSITIVE RESULTS*	STANDARD DEVIATION OF SIGNIFICANT POSITIVE RESULTS*	ABSOLUTE MINIMUM POSITIVE RESULTS**	ABSOLUTE MAXIMUM POSITIVE RESULT**	UNITS
GRASS	^{131}I	4/5	ON-SITE	0							
			OFF-SITE	6	2(N.S.)	2	0.05	0.02	0.033	0.063	pCi/g DRY
	^{137}Cs	4/5	ON-SITE	0						-	
			OFF-SITE	2	2	2	0.3	0.1	0.18	0.32	pCi/g DRY
NON-DRINKING WATER	^{131}I	3/29-6/21	ON-SITE	95	71	71	10.2	18.2	0.54	73	pCi/k
			OFF-SITE	943	15(N.S.)	0			0.37	0.72	-
	^{137}Cs	3/29-6/21	ON-SITE	0							
			OFF-SITE	148	0						pCi/k
	^{3}H	3/29-4/30	ON-SITE	49	31	31	1100	1200	100	3690	pCi/k
			OFF-SITE	294	136	136	190	130	100	810	pCi/9
PRE-CIPITATION	^{131}I	3/29-5/26	ON-SITE	3	1(N.S.)	1	1.2	0	1.2	1.2	pCi/k
			OFF-SITE	7	1(N.S.)	0			2.1	2.1	pCi/k
	^{137}Cs	3/31-4/5	ON-SITE	1	0	0					pCi/k
			OFF-SITE	5	0	0					pCi/k

* The values of these quantities are determined by considering the entire group of data. If the total number of positive results is not significant, these values are determined by considering only those sub-groups for which the observed number of positive results is significant. (See text).

** The values of these quantities are determined by considering the entire group of data. (See text).

N.S. The total number of positive results is not significant for the group. However, an individual subgroup may contain a significant number of positive results. (See text).

ATTACHMENT 3

SUMMARY OF RADIONUCLIDE CONCENTRATIONS IN ENVIRONMENTAL SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION PRIOR TO THE ACCIDENT (JANUARY 1 THROUGH DECEMBER 31, 1978)

SAMPLE TYPE	ISOTOPE	COLLECTION FREQUENCY	ANALYSIS FREQUENCY	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	MEAN POSITIVE RESULTS	MINIMUM POSITIVE RESULTS	MAXIMUM POSITIVE RESULTS	TYPICAL MINIMUM DETECTABLE LEVEL (MDL)	UNITS
GOAT'A MILK	^{131}I	MONTHLY	MONTHLY,	ON-SITE	0			-	-		
			BI-MONTHLY	OFF-SITE	75	2(N.S.)	14	0.28	28	0.3	pCi/A,
	^{137}Cs	MONTHLY	MONTHLY	ON-SITE	0				-	-	
			BI-MONTHLY	OFF-SITE	77	11	12	8	22	7.7	pCi/A,
GOAT'S MILK	^{131}I	MONTHLY	MONTHLY	ON-SITE	0						
			BI-MONTHLY	OFF-SITE	17	1(N.S.)	0.72	0.72	0.72	0.30	pCi/R
	^{137}Cs	MONTHLY	MONTHLY	ON-SITE	0				-		
			BI-MONTHLY	OFF-SITE	17	12	15	8	22	9	pCi/R
DRINKING/ NON-**DRINKING** WATER	**131** I	MONTHLY	MONTHLY	ON-SITE	0						
				OFF-SITE	47	1(N.S.)	0.26	0.26	0.26	0.5	pCi/R
	137 Cs	MONTHLY	MONTHLY	ON-SITE	0						
				OFF-SITE	81	1(N.S.)	12	12	12	6	pCi/R
	^{3}H	**MONTHLY**	QUARTERLY	ON-SITE	0	-	-				
				OFF-SITE	28	26	380	120	200	210	pCi/R

N. S. The observed number of positive results is not significant. (See text).

r
r

ATTACHMENT 3 (continued)

SUMMARY OF **RADIONUCLIDE CONCENTRATIONS** IN **ENVIRONMENTAL**
SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION PRIOR TO THE ACCIDENT
(JANUARY 1 THROUGH DECEMBER 31, 1978)

SAMPLE TYPE	ISOTOPE	COLLECTION FREQUENCY	ANALYSIS FREQUENCY	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	**MEAN** POSITIVE RESULTS	MINIMUM POSITIVE RESULTS	MAXIMUM POSITIVE RESULTS	TYPICAL MINIMUM DETECTABLE LEVEL (MDL)	UNITS
AIR PARTICULATES	^{131}I	WEEKLY	QUARTERLY	ON-SITE	4	0				**N.A.**	pCi/3
				OFF-SITE	28	0				N.A.	pCi/m^3
	^{137}Cs	WEEKLY	QUARTERLY	ON-SITE	4	3	.0025	.0017	.0039	.0006	pCi/3
				OFF-SITE	28	19	.0017	.00059	.0025	.0006	pCi/m^3
FILTERED AIR	^{131}I	WEEKLY	WEEKLY	ON-SITE	40	2(N.S.)	.26	.018	.501	.052	pCi/3
				OFF-SITE	157	5(N.S.)	.64	.036	.119	.052	pCi/m^3
FISH	131_1	SEMI-ANNUALLY	SEMI-ANNUALLY	ON-SITE	0						
				OFF-SITE	8	0				0.01	pCi/g WET
	^{137}Cs	SEMI-ANNUALLY	SEMI-ANNUALLY	ON-SITE	0		-				
				OFF-SITE	8	4	.067	.061	.081	0.030	pCi/g WET
SEDIMENT	131_1	SEMI-ANNUALLY	SEMI-ANNUALLY	ON-SITE	0						
				OFF-SITE	6	0				0.01	pCi/g DRY
	^{137}Cs	SEMI-ANNUALLY	SEMI-ANNUALLY	ON-SITE	0						
				OFF-SITE	6	6	.51	.19	.90	0.02	pCi/g DRY

N.S. The observed number of positive results is not significant. (See text).
N.A. The relevant data (i.e., minimum detectable levels) are not available.

ATTACHMENT 3 (continued)

SUMMARY OF RADIONUCLIDE CONCENTRATIONS IN ENVIRONMENTAL
SAMPLES FROM THREE MILE ISLAND NUCLEAR STATION PRIOR TO THE ACCIDENT
(JANUARY 1 THROUGH DECEMBER 31, 1978)

SAMPLE TYPE	ISOTOPE	COLLECTION FREQUENCY	ANALYSIS FREQUENCY	SITE OF SAMPLING	NO. SAMPLES ANALYZED	NO. POSITIVE RESULTS	MEAN POSITIVE RESULTS	MINIMUM POSITIVE RESULTS	MAXIMUM POSITIVE RESULTS	TYPICAL MINIMUM DETECTABLE LEVEL (MDL)	UNITS
GREEN LEAFY VEGETABLES (i.e., CABBAGE)	^{131}I	ANNUALLY	ANNUALLY	ON-SITE	0						
				OFF-SITE	6	0				.008	pCi/g WET
	^{137}Cs	ANNUALLY	ANNUALLY	ON-SITE	0						
				OFF-SITE	6	0				0.02	pCi/g WET
PRECIPI-TATION	^{131}I	MONTHLY	QUARTERLY	ON-SITE	0						
				OFF-SITE	16	0				0.01	pCi/2
	137Cs	MONTHLY	QUARTERLY	ON-SITE	0						
				OFF-SITE	16	0				0.02	pCi/Q,
	^{3}H	MONTHLY	QUARTERLY	ON-SITE	0		-		-		
				OFF-SITE	16	14	230	100	370	110	pCi/Z

REPORT OF THE PUBLIC HEALTH AND SAFETY TASK FORCE

ON

RADIATION HEALTH EFFECTS

BY

RADIATION HEALTH EFFECTS TASK GROUP

George W. Casarett
(Task Group Leader)
School of Medicine and Dentistry
University of Rochester

Seymour Abrahamson
University of Wisconsin
Madison, Wisconsin

William J. Blair
Battelle Pacific Northwest
Richland, Washington

Michael A. Bender
Brookhaven National Laboratory
Upton, New York

Arthur D. Bloom
College of Physicians and Surgeons
Columbia University
New York, New York

Victor P. Bond
Brookhaven National Laboratory
Upton, New York

Jacob I. Fabrikant
University of California Berkeley
Berkeley, California

October 1979
Washington, D. C.

TABLE OF CONTENTS

I. SUMMARY AND CONCLUSIONS

This report presents assessments of the potential health impact on the approximately 2 million off-site residents within 50 miles of the Three Mile Island (TMI) nuclear station and on workers on-site from collective and individual ionizing radiation exposure doses received as a consequence of the nuclear plant accident on March 28, 1979.

It was the intent of the Radiation Health Effects Task Group to make these assessments as realistically as possible within the constraints of the uncertainties of dose estimates and health risk estimation models. Assumptions selected to deal with uncertainties of dose estimates or health risk estimation models were intentionally conservative, i.e., chosen from widely accepted radiation protection practices and/or scientific principles such that errors which might result would be errors tending to overestimate the doses and/or the health risks.

The radiation exposure doses used in these assessments were based upon the estimates presented and described in detail in the report of the Health Physics and Dosimetry (HP&D) Task Group (reference 1). That report concluded that the best estimate of the actual total collective whole-body radiation exposure dose from external sources to the approximately 2,164,000 off-site residents within a 50-mile radius of the TMI plant was about 2,000 person-rems, with an average individual dose of about one millirem (0.001 rem) and a maximum individual dose of about 70 millirems (mrem). The exposure dose is assumed to be the whole-body dose without correction for the reduction of dose to internal organs from shielding and absorption of radiation by more superficial body tissues.

In the present report, the total collective absorbed radiation dose to the gonads (testes and ovaries) was taken to be 2,000 person-rems for purposes of estimating genetic risks, and 3,000 person-rems (average individual about 1.4 mrem) to the whole body was assumed for estimating cancer development risks, with the intent of conservatively erring on the side of overestimation of risks.

The HP&D Task Group (reference 1) estimated the collective whole-body external gamma radiation exposure dose to the workers (on-site) from the TMI accident, to the end of June 1979, to be about 1,000 person-rems, with individual doses ranging as high as 4 rems. Although there will be additional exposure to on-site personnel associated with the cleanup and recovery operations at TMI-2, the Public Health and Safety Task Force has not attempted to estimate the magnitude of that exposure at the present.

Radiation exposures from the TMI accident were largely or solely from gamma and beta radiations, principally from radioactive noble gases, especially xenon-133 and a smaller amount of krypton-85, and in some locations from small amounts of iodine-131 and traces of cesium-137. The biological effectiveness of these radiations per unit dose tends to decrease with decrease in dose size and/or dose rate owing to decreasing radiation damage and increasingly greater effectiveness of repair and recovery from radiation damage. However, in the present report conclusions concerning the potential radiation cancer risks at the low doses and dose rates involved were made largely on the basis of the conservative assumption that these risks are proportional to those observed at high doses and dose rates.

This report considers the only potential health effects that might be of concern at the very low levels of radiation exposure dose involved -- the genetic effects and two of the somatic health effects, i.e., cancer development and the abnormal development of individuals irradiated as embryos in the womb.

Somatic health effects of ionizing radiation are those that become manifest in irradiated individuals, as contrasted with genetic (heritable) effects that become manifest in offspring of irradiated individuals. Health effects are defined here as specific disease entities, abnormalities, or decrements of development, structure, or function of body organs which result in significant illness or disability or reduction of quality or length of life. As such, health effects are to be distinguished from effects such as changes in relatively small numbers of cells which may be repaired -- eliminated by cell death and normal replacement -- or, if permanent, are not sufficient to cause significant health detriment.

Many types of somatic health effects of ionizing radiation, as defined, are dose-threshold effects, i.e., radiation doses above certain levels of magnitude (threshold), which vary for different kinds of health effects, must be exceeded to produce the effects and the severity as well as the incidence (frequency) of such effects in individuals increases with increasing dose above threshold to a maximum. These threshold effects have dose thresholds for intensive (high dose rate) irradiation which vary roughly from a few rems, for development of a small increase in frequency of severe developmental effects of irradiation at critical stages in organogenesis *in utero,* to tens, hundreds, or thousands of rems for the production of significant incidence and degrees of nontumorous degeneration in various body organs or subacute or acute whole-body radiation syndromes.

In the case of radiation induction of genetic effects or cancer, however, although there is considerable uncertainty and no direct conclusive evidence as to whether or not, or to what extent, low-level radiation (e.g., a few rems or less) can cause or contribute to increased incidence or temporal advancement (earlier development), theoretical considerations cannot now exclude the possibility such effects may have no dose threshold. Therefore, it is currently assumed that ionizing radiation at any level of dose and dose rate may potentially contribute to an increase, however small, in the incidence of genetic effects or cancer in human populations. As such, the radiation induction of these effects is regarded as a stochastic (probabilistic or chance) effect in which the incidence may be increased by increase in dose, but not the severity of individual effects.

On the basis of these considerations of dose threshold and of the very low levels of radiation exposure, and even lower levels of internal absorbed doses, associated with the TMI accident, the only factors of concern in this report are the risks of development of cancer, genetic effects, and the low-threshold developmental effects.

In the past two decades or so, because of the paucity of human data on genetic effects of radiation, the human radiation genetic effects risk estimates for radiations such as gamma, X, and beta radiations have been based primarily on experimental mouse data, particularly at the lower dose rates used in such experiments in order to take some, but still radioprotectively conservative, account of the decreasing radiation effectiveness with decreasing dose rate. The resulting dose-effect relationship is extrapolated to lower levels of dose and/or dose rate on the assumption of proportionality and no threshold.

In the case of radiation-related cancer development, human data have been available and increasing during the past 25 years and have been used as the basis for human risk estimates, not withstanding the limitations and many deficiencies of these data as compared with the extensive data and principles available from experimental research. Because of the deficiencies in available human data and the lack of knowledge of the dose-effect relationships over the whole practical range of doses and dose rates, especially at low radiation levels, the usual approach to estimation of radiogenic cancer risks at low radiation levels has been to extrapolate (interpolate) proportionally from data at high doses and dose rates down to zero effect at zero dose, on the assumption of no dose threshold.

This approach has been chosen by various national and international risk assessment bodies for pragmatic rather than strictly scientific reasons, because of the ease involved and the great difficulty of doing otherwise with the uncertain human data, and for radioprotective purposes, to ensure that errors that may be involved are on the side of over-estimation of risks. Usually the risk assessment bodies have emphatically indicated that such an approach for radiations such as gamma, X, and beta radiations tends to overestimate the risks, and they have acknowledged or explicated the reasons for doubting the scientific validity of the approach and realities of the estimates for such radiations. More recently, on the basis of extensive experimental information, some risk assessment groups have recommended the application of still conservative effectiveness reduction factors for low levels of low linear energy transfer (low-LET) radiation to the risk estimates computed on the basis of the proportional interpolation from high doses and dose rates, to take some account of the influence of dose size and dose rate.

Because single or multiple, absolute and/or relative, radiogenic cancer risk estimation models have been used by these various risk assessment bodies and these have varied in regard to assumptions, risk duration parameters, relative biological effectiveness values, account taken of dose size and dose rates influences, inclusion of age-distribution and susceptibility factors, and other aspects, this task force has applied the various cancer risk estimation models to the TMI dose estimates to obtain ranges of projected potential lifetime numbers of radiogenic cancers and individual cancer risk estimates from which to make conclusions.

On the basis of the conditions described above and in greater detail in the body of this report, the following conclusions were reached concerning the potential health impact f radiation exposures from the TMI accident.

A. CANCER

1. The projected number of fatal cancers or nonfatal cancers potentially induced or temporally advanced over the remaining lifetime off-site population within 50 miles of the TMI plant site from whole-body gamma radiation exposure is less than one, and the total number less than 1.5, with zero or near-zero not excluded.

These numbers can be contrasted with numbers that could be similarly projected for various periods of natural background radiation, i.e., approximately 7 to 8 times as large from one month, 90 times as large for one year, or 3,150 times as large for 35 years (half the average life expectancy) of average natural background radiation exposure.

The estimated number of cancer cases from all causes that would ordinarily (normally) develop in the TMI off-site population over its remaining lifetime, even if the TMI accident had not occurred, is approximately 541,000 (325,000 fatal and 216,000 nonfatal).

2. The average individual lifetime radiogenic cancer risk from the whole-body gamma radiation exposure dose to the maximally exposed off-site individual (approximately 70 mrems) is about one (0.17-1.6) in 100,000 for fatal cancer and a like risk for nonfatal cancer, for a total cancer risk of about two (0.34-3.2) in 100,000 with zero risk not excluded.

The average individual lifetime radiogenic cancer risk from the average off-site individual exposure (about 1.4 mrem) would be about 0.02 of these values, or about one in 5 million for either fatal or nonfatal cancer, for a total cancer risk of about two in 5 million.

These risks for the average individual can be contrasted with a normal risk of about one in 7 for either a fatal cancer or a nonfatal cancer from all causes, or a total normal cancer risk of about one in 4.

3. The additional potential radiogenic cancer contributions and risks to the TMI off-site population associated with beta radiation doses to skin from external sources, beta and gamma radiation doses to lungs from inhaled radionuclides, beta radiation doses to the thyroid gland from inhaled or ingested iodine-131, and doses from cesium-137 are very small in comparison with the projected numbers of cancers and year exposure doses, and can be regarded as encompassed within the values expressed above for whole-body gamma radiation exposure doses.

4. The projected potential lifetime numbers of radiogenic cancers in the TMI off-site population associated with radiation exposure are very low, if not zero, and would not be possible to detect in the population.

5. The whole-body external gamma radiation exposure of the on-site workers is about 1,000 person-rems accident-related collective dose through June 1979 -- about one-third as large as the collective dose value of 3,000 person-rems used above for the off-site population. Furthermore, radiogenic cancer projections per unit dose are less for the on-site workers than for the general population because these workers are all adults. No worker received more than 5 rems. Therefore, the projected number of cancers would be less than one-third of that projected for the off-site population, i.e., less than 0.5 cancer, if any, with zero not excluded.

6. The maximum individual whole-body dose among on-site workers (about 4 rems) would carry with it an average individual lifetime risk of cancer development of approximately 1.2 (0.8 - 1.6) in 1,000, presumably with about half that risk for fatal cancer and half for nonfatal cancer.

7. The additional potential radiogenic cancer contributions and risks to the TMI on-site workers from beta radiation doses to skin from external sources, beta and gamma radiation doses to lung from inhaled radionuclides, beta radiation doses to the thyroid gland from inhaled or ingested iodine-131, and doses from cesium-137 are small in comparison with those from the whole-body gamma radiation exposure doses and can be regarded as encompassed within the values expressed above for whole-body gamma radiation exposure doses.

8. The projected potential lifetime number of radiogenic cancers in the TMI on-site (worker) population associated with radiation exposure from the TMI accident, as presented above, are very low, if not zero, and would be impossible to detect in that population against the background of general occupational and natural background doses.

B. GENETIC EFFECTS

9. On the reasonable and conservative assumption that the collective dose to the testes and ovaries of the approximately 2 million persons in the off-site population (within 50 miles of TMI) is equal to the best estimate (reference 1) for the actual collective whole-body exposure dose (2,000 person-rems), with an average individual dose of about one mrem, it is estimated that between about 0.0001 and about 0.002 induced case of genetically related ill health would be added to the expected 3,000 cases of genetically related ill health per year, among the expected 28,000 births per year averaged over future time in that population (assuming population stability). The 0.002 case represents less than one in 10 million live births. In other words, the incidence of genetically related ill health in that off-site population is estimated to increase as a result of radiation exposure from the accident by no more than 0.00007 percent of the spontaneous ("normal") incidence prior to the accident.

10. The average gonadal exposure of one mrem to the 2 million off-site population within 50 miles of the TMI plant may result ultimately in a total of no more than about one additional case of genetically related ill health per million live births during all future human existence.

11. As a hypothetical extreme "worst case" or maximum credible risk to an individual in the TMI off-site population, assuming that a male-female couple each received a dose of 100 mrems to their gonads from the TMI accident and subsequently have a child, the added risk (attributable to this radiation) that the child will experience genetically related ill health at some time in its life is 0.00005 - 0.00075 percent. In other words, since the "normal" risk (without the TMI accident) for the average case in this respect is about 10.7 percent, the risk would be increased in this "worst case" example from the normal 10.7 percent to a maximum of 10.70075 percent.

12. For the occupationally exposed on-site workers, definitive assessment of the genetic risks can be made only when additional information on the numbers, ages, sexes, and occupational doses become available, as susceptibility differs with sex and the gonadal dose for each individual must be weighted by the number of future children expected for that person's age and sex. Althouth the average individual gonadal dose for the on-site personnel may be found to be higher than that for the off-site population (within 50 miles), there are differences in population characteristics which tend to reduce the potential genetic effect of the on-site TMI radiation doses relative to that which might pertain to the off-site population. These differences, aside from any difference in sex distribution, include the relatively small number of people involved and the fact that they are all adults, some of whom partially or fully completed the conception and production of their children before the accident occurred.

13. In view of the very small numbers of cases of genetically related ill health to be expected as a consequence of the radiation from the TMI accident, even under "worst case" assumptions, and the fact that such cases could not be distinquished qualitatively from the more than 100,000 cases per million births that will unavoidably results from other causes, clearly it will be impossible to attribute any increase in incidence or a case to the TMI accident radiation exposures.

C. TERATOGENIC (DEVELOPMENTAL) EFFECTS

14. The maximum individual whole-body radiation exposure dose in the off-site population was well below the apparent dose thresholds for the radiation induction of congenital malformation as a consequence of irradiation of the embryo or fetus. The maximum individual embryo-fetal dose associated with the maximum individual gamma radiation exposure dose on-site, if that dose were received by a pregnant woman, probably did not exceed a practical dose threshold.

In addition, on the assumption of a linear nonthreshold dose-effect relationship for interpolation from a risk coefficient based on data at high doses and dose rates, and using other extraordinarily conservative assumptions to err on the side of overestimation of risk, only 0.015 case was estimated.

Therefore, no case of developmental abnormality may reasonably be expected as a result of the radiation exposure from the TMI accident.

D. DETECTABILITY OF EFFECTS

15. **Radiation-induced cancers, genetic effects, and teratogenic effects** cannot be distinguished qualitatively from those resulting from other cases. Therefore their detection with confidence becomes a matter of ascertainment of statistically significant increase in irradiated populations compared with valid control populations in appropriately designed and thorough epidemiological studies which take due account of measurements, influences, and uncertainties of pertinent variables and of scientific interpretations.

It will not be possible for such epidemiological studies to detect unequivocally, and with a high degree of statistical confidence or significance, the very small numbers (if any) of cases of cancer, genetic effect, and teratogenic effect projected above in relation to the radiation exposures from the TMI accident, in view of the size of the population involved, the small radiation doses involved (even in comparison with annual natural background radiation exposure), the high "normal" or background incidences of such diseases, and the difficulty of establishing an appropriate control population. The population sample sizes required for comparison groups, in order to detect such small effects at such low dose levels unequivocally and with high statistical confidence, are much greater than those available.

II. INTRODUCTION

The principal charge to the Radiation Health Effects Task Group of the President's Commission on the Accident at Three Mile Island (TMI) was to assess the potential health effects from ionizing radiation exposure in the general off-site population within 50 miles of the TMI nuclear reactor plant site and in the on-site workers as a consequence of radiation exposures related to the nuclear reactor accident.

Because of the low radiation doses involved, the health effects of concern here are limited to cancer induction, genetic effect, and teratogenic or developmental effect (from irradiation of embryo or fetus). Cancer induction and teratogenic effect are somatic health effects in that they are caused in individuals receiving the radiation exposures, as contrasted with the genetic (hereditary) effects which occur in future offspring of irradiated individuals.

Radiation cancer induction and genetic health effects are regarded as "stochastic" (probabilistic) effects in that the probability (chance) of occurrence, but not the severity of the individual effect, is dependent upon radiation dose size (and other factors). These effects are also regarded theoretically as having no dose threshold, i.e., no dose that must be exceeded for the causation of some increase in the frequency (incidence) of the effect in a population. Teratogenic health effects, on the other hand, are apparently dose-threshold effects, i.e., various dose levels must be exceeded to cause various teratogenic health effects and the severity of such effects in individuals increases with increasing dose. Teratogenic health effects are regarded as non-stochastic effects. Teratogenic effect has been included for consideration in this health assessment, along with cancer induction and genetic effect, because of the public concern and because some degrees of certain types of teratogenic effects apparently may have relatively low dose thresholds (e.g., a few rem) when the embryo is irradiated at high dose rate in certain brief, critical, radiosensitive stages of organ formation. Other somatic health effects of radiation are not considered in this report because they have dose thresholds ranging far above the doses involved in the Till accident.

Although there is considerable uncertainty, and no direct unequivocal evidence, as to whether or not, or to what extent, low-level radiation, i.e., very low doses (e.g., less than 10 rems) at low dose rates (e.g., less than one rem per day), can cause or contribute significantly to cancer induction or to clinically significant genetic health effects in human populations, it is assumed conservatively (to avoid underestimation of risk) on theoretical grounds that these potential effects have no dose threshold. That is, it is assumed that ionizing radiation in any amount or rate may potentially contribute to increase, however small, in the incidence (frequency) of such effects in a population of exposed (irradiated) people and that the increase in incidence is greater the greater the dose, within certain limits at very high doses.

In view of the wide ranges of uncertainty or variation in estimates of risks of radiation induction of cancer or genetic health effects in human populations, the risk rates, risk estimation models and assumptions, and dose values used in this report have been reasonably conservative, i.e., chosen to ensure within reasonably realistic limits that risk estimates are likely to err in the direction of overestimation.

Attempts to estimate health risks in advance of the accumulation of additional knowledge needed to dispel uncertainties are usually made because of compelling societal needs for immediate guidance in matters such as safety or benefit-risk considerations for purposes of decision-making concerning alternative means to needed ends. A most pertinent example has been the societal need for estimates of risk of radiogenic health effects at low radiation levels, where no unequivocal concrete data exist, and for which risk estimation for stochastic effects (cancer induction and genetic effect) depends upon some form(s) of mathematical interpolation and/or extrapolation from uncertain and incomplete data at high radiation levels and assumptions concerning dose-effect relationships, dose threshold, and pathologic mechanisms involved.

Under these circumstances, there have been understandably various viewpoints among scientists of different experience in regard to analysis and interpretation of available data, dose-effect relationships, mechanisms of effects, absolute or practical dose thresholds, and appropriate methods of extrapolation or interpolation.

Most radiobiological scientists and national and international bodies who are well informed in these matters both scientifically and also in their application to health risk estimation for purposes of developing radiation protection standards and guidelines are acutely aware of the difference between the arbitrary application of the linear (proportional) nonthreshold hypothesis for pragmatic and radioprotective reasons in estimating low radiation level cancer induction and genetic effects risks from high radiation level data, on one hand, and the cogent scientific evidence that this practice tends to systematically overestimate the risk at low levels of low linear energy transfer (low-LET) radiations (e.g., X, gamma, and beta radiation). Unfortunately, despite the explication of this distinction in the reports of various national and international radiation risk assessment and radioprotection bodies, the distinction has all too often been overlooked and this arbitrary procedure has often been erroneously invested with scientific validity and reality for low-LET radiations. A minority of scientists have claimed, with little and equivocal support, that the use of the linear hypothesis, as described above, does not overestimate the radiogenic cancer risk at low levels of low-LET radiation, and a few have claimed, on highly equivocal bases, that such extrapolation may underestimate the radiogenic cancer risk at low levels of low-LET radiation.

In view of these variations in viewpoints and in the radiogenic cancer risk estimation models, parameters and assumptions which have been used by various national and international risk assessment groups, it was decided to apply these various models to the TMI dose estimates in order to display an array of values for the radiogenic cancer impact of the TMI accident, from which to derive reasonably realistic values.

Benefit-risk-cost consideration for societal decision-making and choices of alternative methods or activities for needed ends requires reasonable perception and perspective concerning benefits, risks, and costs on the part of the public in order to avoid invitation of health hazards and economic dislocations that may be greater than others unreasonably feared. For these reasons, it was decided to include in this report, for perspective, comparisons of the radiation health effects risks and impact related to the TMI accident radiation doses with those for the same health effects related to natural background radiation levels and their variation and with those for the same health effects from all "natural" causes combined.

III. RADIATION EXPOSURE DOSES

A. BACKGROUND RADIATION

It should be noted, for perspective, that everyone is unavoidably and normally subject to exposure to normal background radiation, which varies in amount with location.

The normal background radiation consists of the natural solar and galactic cosmic radiation, radiation from cosmogenic radionuclides formed in the upper atmosphere, and terrestrial radiation from radionuclides in the earth's crust, together with technologically enhanced background radiation, such as that from radionuclides in building materials, fallout radionuclides from atmospheric bomb testing, and other sources.

In addition to external source irradiation from these background radiations, all individuals are irradiated from radionuclides that are normally deposited internally within their bodies.

Presented in Table 1 are estimated total annual average whole-body doses from natural background radiation in the United States (reference 2).

The term "rem" is the dose-equivalent unit used in radiation protection practice. A rem is equal to the absorbed dose (rad) multiplied by a quality factor (Q) which is related to linear energy transfer and ultimately to considerations of relative biological effectiveness of various radiations. The Q factor for radiations of concern in the TMI accident is one. For convenience in this report, the term "dose" is used to represent dose-equivalent in rem or millirem (mrem). A millirem is one-thousandth of a rem.

TABLE 1: Estimated Total Annual Average Whole-Body Doses from Natural Radiation*

Source	Annual Dose (mrem)
Cosmic Radiation	44
Terrestrial Radiation	
External Sources	40
Internal Sources	18
Total	102

* Reference 2.

The annual average whole-body dose from various components of natural radiation varies with geographic location, altitude, and terrestrial radioactivity. For example, the average annual dose from cosmic radiation ranges from about 38 mrem in Florida to 75 mrem in Wyoming, and the average annual dose from terrestrial gamma radiation ranges from about 15 to 35 mrem in the Atlantic and Gulf Coast plains to 75 to 140 mrem on the Colorado Plateau. The average annual gonadal (testes and ovaries) dose in the United States from natural radiation has been calculated to be about 90 mrem, taking into account shielding by overlying tissue and by building structures (reference 2). Shown in Table 2 are estimates of average annual whole-body doses from natural background radiation in several geographic locations in the United States which are generally and approximately consistent with reported measurements (references 2,3)

According to the report of the Health Physics and Dosimetry (HP&D) Task Group (reference 1), the increases in radionuclide concentrations in the environment as a result of the TMI accident were as follows: xenon-133 in air on-site and off-site; krypton-85 in air on-site and off-site; iodine-131 in air on-site and off-site; in nondrinking water on-site, and in cows' milk and goats' milk; and cesium-137 in fish.

B. <u>OFF-SITE POPULATION DOSES FROM THE TMI ACCIDENT</u>

Collective dose (person-rem) is the total radiation dose received by the population in question from the source specified, and is obtained by adding the individual doses received by members of the population or, as in the present case, by multiplying the number of people in given areas by doses estimated for those areas and adding all of these contributions. The average individual dose is the collective dose divided by the number of people involved in the collective dose. The maximum individual dose is the highest dose measured or estimated for an individual in the population.

The Health Physics and Dosimetry (HP&D) Task Group (reference 1) reported the following estimates of radiation exposures and doses in the off-site population within 50 miles of Till as a consequence of the TMI accident.

1. The best estimate of the total (collective) whole-body gamma radiation exposure dose (from the noble gases, mainly xenon-133) was derived from the results of two calculational approaches. One (based on thermoluminescent dosimeter measurement) yielded a collective dose of 2,800 person-rems, and the other (based on computer technique using a calculated source term) yielded a value of 500 person-rem. The 2,800 person-rems exposure dose is an outdoors dose which was reduced to 2,000 person-rems by correction for time indoors and shielding.

In the present report, for the purposes of assessment of radiation health effects risks, however, a value of 3,000 person-rems collective exposure dose is used conservatively, i.e., in the attempt to ensure that potential error will be in the direction of overestimation of the health risks. Furthermore, this value does not take into account the

TABLE 2: Estimates of Average Annual Whole-Body Doses From Natural Background Radiation In The United States

Approximate Average Annual Whole-Body Doses (mrem)

Location	Cosmic Rad.(a)	Terrestrial Rad.(a)	Internal Rad.(b)	Total
Atlanta, Ga.	45	57	28	130
Denver, Co.	75	90	28	193
Harrisburg, Pa.	42	46	28	116
Las Vegas, Nev.	50	20	28	98
New York, N.Y.	41	46	28	115
Pennsylvania	43(c)	36	28	107
Washington, D.C.	41	35	28	104
United States(a)	40-160	0-120	28	70-310

a. Reference 2.
b. Reference 3.
c. Reference 10.

shielding of internal organs by external tissues, which would result in substantial reduction of actual doses to internal organs.

2. An average individual dose of about 1.4 mrem is indicated by the collective dose of 3,000 person-rems to the 2,164,000 people within 50 miles. Those individuals within about 2 miles from the plant probably received the highest doses. The dose to the one person known to have been on one of the nearby islands for about 9-1/2 hours during the first few days after the accident is estimated to have been about 50 mrem. In addition, about 260 people may have received doses somewhere between 20 and 70 mrem. All other people probably received less than 20 mrem.

3. Calculations performed to determine the dose due to ingestion (in milk) and inhalation of iodine-131 yielded the following dose values for thyroid gland in which iodine concentrates, based on the mean values of only the positive measurements. The radioiodine released was too low to be detectable in most areas, and it was not possible to determine collective doses.

Intake Mode	Thyroid Age	Thyroid Dose (mrem)
Cows' milk ingestion (1 liter per day)	Newborn	6.9
	One year	4.7
	Adult	0.6
Inhalation (off-site)	Newborn	2.0
	One year	6.5
	Adult	5.4

4. A person eating one kilogram (2.2 pounds) of river fish containing cesium-137 at the average concentration measured would receive a whole-body dose of 0.02 mrem.

5. Internal dose due to inhalation of xenon is small compared to the external whole-body dose. For example, if a person were immersed in a cloud of xenon-133, the internalization of some xenon would increase the total body gamma radiation dose above that from the external xenon-133 by 0.6 percent, and the dose to the lungs would be increased by 6 percent.

6. For perspective on the doses due to internalization of radionuclides, the doses indicated in items 3-5 above can be compared with doses due to naturally occurring internally deposited radionuclides. The average annual radiation doses to a human in the United States due to internalized radionuclides consist of approximately 27 mrem to soft tissues (including thyroid and gonads), 60 mrem to bone surfaces, 24 mrem to red bone marrow, and 124 to lungs.

C. ON-SITE POPULATION DOSES FROM THE TMI ACCIDENT

The Health Physics and Dosimetry (HP&D) Task Group (reference 1) also reported the following estimates of radiation exposures and doses in the on-site (worker) personnel (all adults) at the TMI plant as a consequence of the accident.

1. The sum of the collective whole-body gamma exposure doses to the end of June 1979 was about 1,000 person-rems. Individual doses ranged up to 4.2 rems. In addition, two workers received overexposures of their hands (50 and 150 rems).

Although the total collective dose to on-site workers will continue to grow as the decontamination process proceeds, it is difficult to predict the eventual total because this will depend upon decisions to be made about decontamination of the containment building and the reactor vessel. The Public Health and Safety Task Force has not attempted to estimate the magnitude of that exposure in this report.

2. The estimated radiation dose to the thyroid gland of workers from inhaled iodine-131 was 54 mrems.

IV. RADIOGENIC CANCER RISKS

A. GENERAL CONSIDERATIONS

As it is conservatively assumed, in the absence of conclusive human data, that any dose of ionizing radiation, however small, can cause some increase in incidence of cancer in exposed populations (i.e., there is no dose threshold), the cancer risks estimated in this section are potential risks in the sense that there is no conclusive evidence that risks estimated by hypothetical extrapolation or interpolation are real at the dose levels involved in the TMI accident. The individual whole-body dose levels are within the maximum permissible annual dose equivalent limits for whole-body irradiation of members of the public or of radiation workers (references 4,5).

The health risks from low-level radiation for effects which are assumed to have no dose threshold, i.e., induction of cancer or hereditary effects, must be derived by extrapolation or interpolation from observed data at high doses and dose rates on the basis of additional assumptions concerning the dose-effect relationships over the whole range of dose and dose rate (high to low) and the inductive mechanisms involved.

Often the choice of the relationship used for such extrapolation or interpolation has been made in the conservative direction, i.e., in the direction of overestimation of risks or estimation of so-called upper limits of risks, for prudence in radiation protection, as well as for convenience in the face of the difficulty of doing otherwise with the sets of data. For these reasons, the linear (proportional) dose-effect relationship has often been assumed for the purpose of extrapolation or interpolation to zero dose-effect. This involves the assumptions that in the rising portion of the dose-effect curve for either or both low-LET and high-LET radiations, the effects of very low doses, where no data exist, are directly proportional to the observed effects at high doses, the effectiveness per unit dose is the same over the whole range of dose, and there is no influence of dose rate.

This linear hypothesis, although relatively compatible with the radiobiologic information on effects of the high-LET radiations (e.g., neutrons, alpha-particles), which are more effective than low-LET radiations, is not compatible with the radiobiologic information on effects of low-LET radiations. This use of the linear hypothesis is generally believed by national and international risk agreement bodies to overestimate the health risk from low-level low-LET radiations (references 4 to 11). A wealth of data on the effects of low-LET radiations (gamma radiation, X-rays, beta particles) for many biopathologic endpoints and in many living species indicate that the effectiveness of the radiation per unit dose decreases with decreasing dose size and dose rate. It would be highly improbable for cancer induction in man to be an exception. The radiations of concern in the Three Mile Island accident are low-LET radiations.

It is important, not only for scientific reasons and radioprotective purposes, but also for prudence in weighing the risks versus benefits among important alternatives and choices in societal decision-making within limited resources, that radiation and other health risks be estimated with both reasonable prudence and realism and placed in realistic perspective (references 4,9).

Although cancer risk may be incurred at the time of irradiation, the cancers induced may not begin to appear until after some minimal latent period has passed. The minimal latent period appears to vary from a year or two (possibly less for embryos or fetuses irradiated _in utero)_ to 20 years or more, depending on the type of cancer and age at the time of irradiation. The average time of appearance of radiation-induced cancers in individuals after irradiation is considerably longer and depends on the type of cancer and age at the time of irradiation. There is also a strong tendency for the latent period for most if not all radiation-induced cancers to vary inversely with dose size, i.e., increasing latent period (and decreasing life span lost from induced cancer) with decreasing dose size or dose rate. This also means that radiation-inducible cancers that have long minimal or average latency periods even after high doses and dose rates may not have enough time to appear in individuals irradiated with low doses and/or dose rates at ages (potential after-survival times) that will not accommodate these latent periods.

The duration of apparent radiation-induced increase in incidence of cancers of types that have long latency in man are not yet known exactly, even in ongoing studies involving high doses and dose rates and in which such cancers have been observed to have been increased in incidence. The duration of apparent radiation induced increase in incidence of leukemia, which has a relatively short modal or average latency, is better known.

Cancers induced by radiation are not specific or pathognomonic for radiation and cannot be distinguished from cancers resulting from other causes. Therefore, the detection of radiation-induced cancer is a problem of proper statistical detection of increased incidence, taking account of such factors as other potential competing or contributing causes, latency in relation to age at time of irradiation, age and sex susceptibility, and other factors. Ongoing human studies suffer from many deficiencies such as those concerning numbers of subjects in samples, imperfect controls over many factors, imprecise dose determinations, limited knowledge of competing risks, and, importantly, as yet incomplete followup and ascertainment. Incomplete followup and ascertainment limits estimates of risk to consideration of age-specific differences in incidences (with relative neglect of dose-latency relationships), which falls short of ascertainment of absolute lifetime differences in incidence between irradiated and control populations.

Some individuals who develop cancer, whether from radiation or other causes, may die as a result ("cancer death", "fatal cancer") while others may not die from their cancer ("nonfatal cancer") because of successful therapy and/or the nature and behavior of the cancer, competing causes of death, or other reasons. Theoretically and logically, an individual who develops fatal cancer caused either partly by radiation (e.g., where low dose contributes a part of the mechanism) or wholly by radiation (e.g., where high dose contributes all of the mechanism), either:

a. dies of the same kind of cancer that would have caused his death if he had not been irradiated but dies earlier (temporal advancement of cancer);

b. dies of a cancer different in type from a cancer that would have caused his death if he had not been irradiated, with or without loss of life span; or

c. dies of cancer instead of a noncancerous disease which would have caused his death if he had not been irradiated, presumably but not necessarily in every case with loss of life span

The risk of radiogenic cancer or cancer mortality per unit dose can be expressed in absolute or relative (comparative) terms. Absolute risk represents the statistical difference in incidence between an irradiated population and a control (nonirradiated) population that preferably has similar characteristics.

In the unlikely situation where the doses (and dose rates) to individuals of the population are the same, or when the linear dose-effect hypothesis is invoked permitting averaging of varying doses and the use of collective doses (person-rem) with neglect of dose rate, the absolute risk coefficient or rate in a population may be expressed as the increased (excess) number of radiation-related cases of cancer or deaths from cancer per number of irradiated population per unit of time per unit of dose, e.g., 10 cases (or deaths per million irradiated people per year per rem (10/10^6 /yr/rem or 10/10^6 person-rem/yr). Absolute risk may also be expressed with time factors other than one year, including remaining life span, or in reference to the actual number of people in a particular population of interest.

The relative risk is the ratio of the incidence or risk in the irradiated population to that in the nonirradiated (control) population and is expressed essentially as a fraction or multiple of the "natural" risk in the nonirradiated population, e.g., 0.01 or one percent per year per rem. Conversion of relative risk to units comparable to absolute risk, for any particular type of cancer in a population, involves multiplication of the relative risk per rem by the gatural risk or rate, e.g., 0.01 (i.e., 1 percent)/yr/rem x 1,000/10^6 person-yrs. = 10/10^6 person-rem/yr.

B. EXISTING "NATURAL" RATES (RISKS) FROM ALL CAUSES

Given in Table 3 are estimates of the numbers of new cancer cases, cancer deaths, and deaths/cases in the U.S. population for 1979 for several specific types of cancer (reference 12), selected on the basis of importance in consideration of radiation induction of cancer, for other cancers, and for all cancers.

Next to heart disease, cancer is the second leading cause of death in the United States. The American Cancer Society (reference 12) estimates that about 25 percent of people in the United States will eventually develop cancer (lifetime risk 0.25) and that about 15 percent of the

TABLE 3: Estimated New Cancer Cases and Deaths in United States for 1979 Based on Existing Rates

Specific Cancers	New Cases[(a)]	Deaths[(a)]	Deaths/Cases	Cases/10^6[(b)]	Deaths/10^6[(b)]
Bone	1,900	1,750	0.92	9	8
Breast[c]	106,900	34,500	0.32	509	164
Digestive Organs	182,900	105,150	0.57	871	501
Genital Organs	143,500	44,800	0.31	683	213
Leukemia	21,500	[illegible]	0.72	102	73
Lung	112,000	97,500	0.87	533	464
Skin (Melanoma)	13,600	4,300	0.32	65	21
Thyroid	9,000	1,000	0.11	43	5
Other	173,700	90,000	0.52	827	429
TOTAL	765,000	395,000	0.52	3,643	1,881

[a] Estimates from reference 12, American Cancer Society, "Facts and Figures-1979."

[b] Calculations using the American Cancer Society (reference 12) estimates of new cancer cases and deaths for 1979 and assuming a U.S. population of 210 million people, the approximate population for 1976.

[c] Breast cancer largely in women, and therefore the rates (per 10^6 people) for females would be about twice those given for the population as a whole.

U.S. people (60 percent of those who develop cancer) will eventually die of cancer (lifetime risk 0.15). Estimates of the lifetime risk of cancer death in the United States range between about 15 and 17 percent depending upon the source of data and the year. In 1976, the U.S. Vital Statistics showed 377,312 cancer deaths in the United States, representing about 1,800 cancer deaths per million people and about 20 percent of all deaths in the United States that year among the approximately 210 million people. The estimated cancer death rate for the state of Pennsylvania is 2,080 per million people per year, and for the state of Maryland $1{,}790/10^6$ people per year.

On the basis of these U.S. or Pennsylvania cancer death rates, the cancer death rate existing "naturally" among the 2,164,000 people estimated to dwell within 50 miles of the TMI plant site can be calculated to be approximately 3,895 (according to the U.S. rate) to 4,500 (according to the Pennsylvania rate). Applying the approximate lifetime risks (cited above) of developing cancer (0.25) and dying of cancer (0.15) to the estimated population within 50 miles of the TMI plant (2,164,000) gives normal expectations of about 541,000 cancer cases -- about 325,000 cancer deaths and 216,000 nonfatal cancers in that population.

As neither the existing cancer rates nor the U.S. or Pennsylvania populations and their age and sex distributions are constant, the ratios of cancer deaths to cancer cases, e.g., as given in Table 3, provide only approximate indications of the severity of specific or all cancers, or of the probability of death from them.

C. RADIOGENIC CANCER RISKS TO OFF-SITE TMI POPULATION

1. General Considerations

It should be reemphasized here that the external gamma radiation whole-body doses used in this section are exposure doses uncorrected for shielding by buildings and for occupancy and uncorrected to account for the associated lesser doses absorbed internally in the body, which are reduced by attenuation of the radiation, i.e., by the body's own shielding of its internal organs. For example, the Health Physics and Dosimetry Task Group has indicated that the rib bone marrow doses are about 0.25 to 0.35 of the exposure doses measured in air. This correspondingly has important implications for the risk of radiogenic leukemia for which the tissue at risk is red bone marrow. Furthermore, although the HP&D task group concluded that the most probable value of the actual collective dose to the off-site population is around 2,000 person-rems, the collective exposure dose chosen here for prudent health risk assessment is 3,000 person-rems.

In the subsections below, various radiogenic cancer risk coefficients and risk estimation models employed by various national and international radiation risk assessment bodies (reference 13) are applied to the radiation dose estimates used in this report for the off-site population exposed as a consequence of the TMI accident.

2. <u>Whole-Body, Gamma Radiation (External Source)</u>

a. Risk Estimates According to Various Models

1. Ad Hoc Population Dose Assessment Group. The assessment by this Ad Hoc Group (reference 14) of the radiogenic cancer risk to the off-site TMI population as a consequence of the TMI accident was based largely on the 1972 Report of the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiations (the BEIR I report) (reference 8).

The Ad Hoc Group report (reference 14) indicated that, although the BEIR I Committee developed its illustration in terms of annual excess numbers of cancer deaths in the U.S. population from continual, repeated, annual doses, these estimates can be translated roughly into estimates of excess cancer death risk rates from a short-term exposure, which is more meaningful for the assessment of radiogenic cancer death risk from the TMI accident.

This translation was made, using the assumptions employed by the BEIR I Committee, and the results of the translation are shown in Table 4. Here, the annual numbers of excess leukemia or other cancer deaths in the U.S. population from 0.1 rem per year, as estimated and given in the BEIR I report (reference 8) according to the absolute risk model and the relative risk model, were divided by the collective annual dose (1967 U.S. population of about 198 million people x 0.1 rem/year = 19.8×10^6 person-regs) to derive risk estimates in terms of numbers of cancer deaths/10 person-rem, on the basis of the assumption of the overall linear dose-effect relationship.

On this basis, the Ad Hoc Group (reference 14) estimated the potential cancerogenic effects (fatal and nonfatal cancers) from radiation from the TMI nuclear plant accident in the off-site population within 50 miles, as shown in Table 5. The central estimates in Table 5 are associated with the Ad Hoc Group's mean value of collective dose (3,300 person-rems) to the off-site population, or an average individual dose of approximately 1.5 mrems (reference 14). On the basis of this central estimate of collective dose and the risk estimation model used, the projected total number of fatal radiogenic cancers is less than one (0.7) and of nonfatal radiogenic cancers is also less than one (0.7), for a total of 1.4 radiogenic cancers according to the overall linear hypothesis. The ranges given in Table 5 represent extreme values based on both the range of the Ad Hoc Group's estimates of collective dose (1,600 to 5,300 person-rems) and the range of risk coefficients given in the 1972 BEIR report (reference 14, 8).

Using the linear (proportional) hypothesis further, the projected numbers of cancers obtained with this risk estimation model can be translated simply into projected numbers for the collective dose (3,000 person-rems) chosen for use in the present report. This translation yields a projected potential lifetime (remainder of life) total number of 1.2 cancer cases, 0.6 fatal, and 0.6 nonfatal in the TMI off-site polulation.

TABLE 4: Radiogenic Cancer Death Risk Rates
Derived From 1972 BEIR Report

Estimates of Annual Excess Cancer Deaths
in U.S. Population From 0.1 Rem/Yr.

Rates	1972 BEIR Report Estimates (Cancer deaths/yr in [1] U.S. from 0.1 rem/yr) Risk Model		Derived Risk (Cancer deaths ~10 [6] person-rem) Risk Model	
	Absolute	Relative	Absolute	Relative
Leukemia	516	738	26	37
Other Cancers				
Assumption A [3]	1,210	2,436	61	123
Assumption B [4]	1,485	8,340	75	421
Total (Range) [5]	1,726 - 2,001	3,174 - 9,078	87 - 101	160 - 458

Geometric Mean $(95 \times 310)^{1/2} = 172$

[1] 1967 U.S. population = 197,883,000. Collective annual dose = 198 million people x 0.1 rem = 19.8 x 10 person-rem. Excess annual cancer deaths from 1972 BEIR Report (8), Table 3-3 (Relative Risk) and Table 3-4 (Absolute Risk).

[2] 1972 BEIR values (annual cancer deaths in U.S. from 0.1 rem/yr) divided by annual collective dose of 19.8×10^6 person-rem.

[3] Assumption A: 30-year period of elevated risk.

[4] Assumption B: Elevated risk for remainder of life after latent period.

[5] Low-estimate in range = leukemia risk + risk based on Assumption A for other cancers. High estimate in range = leukemia risk + risk based on Assumption B for other cancers.

TABLE 5: Potential Lifetime Cancerogenic Impact of Population Radiation Dose (3/28-4/7/79) From Three Mile Island Accident to Off-Site Population Within 50 Miles*

	Potential Lifetime Numbers in Population (2,164,000)	
Cancers	Range[a]	Central Estimate[b]
Fatal Cancers	0.15 - 2.4 [c]	0.7
Nonfatal Cancers	0.15 - 2.4d e	0.7
Total		1.4

[a] Represents extreme range of health effects estimates considering both the range of collective dose estimates (1,600-5,300 person-rem) (14) and the range of estimates of risks of low-level ionizing radiation as estimated in 1972 BEIR report (reference 8).

[b] Central estimate based on multiplying the mean estimate of the population dose (3,300 rems) (reference 14) by the geometric mean (square root of produce) of upper and lower bounds of dose-to-health-risk conversion factors (as shown in Table 4 of the present report).

[c] Based on multiplication of the lower range estimate of population dose (1,600 person-remsa by the lower range estimate of absolute radiogenic cancer risk (90/10), and the upper range estimate of population dose (5,300 person-reins) by thg upper range estimate of the relative radiogenic cancer risk (460/10).

[d] Based on American Cancer Society projection that risk of cancer death is 0.15.

[e] Based on difference between American Cancer Society projection of risk of getting cancer (0.25) and risk of dying of cancer (0.15). Value given is based on product of this difference (0.25-0.15 = 0.10) and size of population.

* Reference 14.

The Ad Hoc Group estimated a lifetime risk of fatal radiogenic cancer from the accident to the hypothetical maximally exposed off-site individual as being one change in 50,000 based on an assumed dose of 100 mrem rather than the lower estimated value. Again, using the linear (proportional) hypothesis, the lifetime risk of fatal radiogenic cancer to the hypothetical maximally exposed off-site individual estimated by this model (reference 14) can be translated into an estimate of about 1.4 chances in 100,000 for the approximately 70 mrem dose estimated by the Health Physics and Dosimetry Task Group (reference 1).

2. EPA Office of Radiation Programs, Criteria, and Standards Division Bioeffects Analysis Branch Report. The report of the Ad Hoc Population Dose Assessment Group (reference 13) also contains an independent (U.S. Environmental Protection Agency) assessment of potential radiation health effects from the TIM accident corresponding to an earlier collective dose estimate of 2,000 (actually 1,800) person-rems.

The radiation-rleated cancer risk coefficients were derived from the 1972 BEIR I report (reference 8) using a modified version of the CAIRD computer code which makes it possible to perform individual analysis of each cohort in an exposed population. Each cohort is followed to its extinction, all deaths associated with radiation exposure are enumerated, and a weighted sum of the deaths from each analysis is calculated using weights determined by the age distribution of the exposed population at the time of exposure. The risk estimates were based on the overall linear nonthreshold assumption for dose-effect relationship.

In this particular analysis, each of the individuals in every cohort was assumed to have received a single dose of one rem, and the total exposed population was assumed to be 100,000 persons distributed in age like the 1970 U.S. population.

In terms of radiogenic cancer risk associated with the population age groups, this analyses indicated that for the average adult individual a whole-body dose of one rem is associated with a lifetime risk of between 10 and 20 fatal cancers per 100,000.adults exposed, i.e. 100 to 200 fatal cancers/10 /rem, and an equivalent level of gisk for nonfatal cancer, for a total cancer risk of about 200 to 400/10 /rem. For children less than 10 years of age, the lifetime cancer risk from a dose of one rem was said to be highly uncertain, ranging from lg to 200 fatal cancers per 100,000 children exposed, i.e., 100 to 2,000/10 /rem. According to the 1970 U.S. population statistics, about 20 percent of the general population is less than 10 years of age.

For internal organs other than than thyroid, one rem of organ exposure was reported to h8ve a potential lifetime cancer risk of about 4 per 100,000, i.e., 40/10 /rem.

These radiogenic cancer risks also represent the chance that a cancer may occur in the individual's lifetime.

This EPA analysis (in reference 14), based on the risk coefficients developed by the 1972 BEIR Committee (reference 8), was applied to the estimate of no more than 2,000 person-rems (0.9 mrem average individual dose) received by the off-site residents within 50 miles of the TMI site as of April 3, 1979. The lifetime risk of fatal radiation-related cancer among the exposed adults was estimated to range from 0.16 to 0.32 cancer, depending on the specifics of the risk model used. For children less than 10 years of age, the risk estimates were more uncertain and ranged from 0.04 to 0.8 fatal cancer. Simple addition of the low ends and of the high ends of these ranges for adults and children yields a combined range of 0.2 to 1.1 cancer death. This EPA report also states that, in addition, the incidence of nonfatal cancer would be increased by a like amount.

Using the linear (proportional) hypothesis further, the projected numbers of cancers obtained with this risk estimation model can be translated simply into projected numbers of the collective dose (3,000 person-rems) chosen for use in the present report. This translation yields a projected potential lifetime (remainder of life) total number of 0.6 - 3.3 cancer cases, 0.3 - 1.6 fatal, and 0.3 - 1.6 nonfatal in the TMI off-site population.

Linearly applying this EPA report's lifetime risk estimate ranges for fatal radiogenic cancer following whole-body irrgdiation (i.e., 10 to 20/10 /rem for the average adult and 10 to 200/10 /rem for children less than 10 years of age), one can estimate that the hypothetical maximally exposed off-site (TMI) individual receiving a dose of approximately 70 mrem (according to the report of the Health Physics and Dosimetry Task Group) would have a lifetime risk of fatal radiogenic cancer ranging from $0.7 - 1.4/10^{5}$, or 0.7 to 1.4 chances in 100,000 if the person were an average adult, or ranging from about 0.7 to 14.10^{8}, or 0.7 to 14 chances in 100,000, if the person were an average child under 10 years of age, all depending on the specifics of the risk model used.

3. <u>1975 Reactor Safety Study.</u> The three risk estimation models (upper bound, central, and non-zero lower bound) in the 1975 Reactor Safety Study Report (reference 7) use as a starting point the absolute risk coefficients for radiogenic cancer stated in the 1972 BEIR Committee report (reference 8), with small changes reflecting more recent data on leukemia and cancers of the gastrointestinal tract, bone, and thyroid gland. The upper bound estimate is based on the 1972 BEIR report with such changes; the central estimate is the upper bound estimate modified by dose-effectiveness factors which reduce the expected incidence of cancers for small doses and/or low dose rates of low-LET radiation as compared with the incidence expected from linear interpolation; and the non-zero lower bound estimate is derived as an approximate indication by applying the incidence rate used for the upper bound estimate to doses received by individuals in excess of a threshold dose of 10 or 25 rems.

The total risk values estimated in that report (reference 7) consist of the weighted sum of the risk for leukemia and for each specified cancer type adjusted for the then-current age distribution in the population, age-specific sensitivities, estimated latencies, risk plateaus, and life expectancies. In the analysis of absolute risk factors, age intervals include the fetal period, 0 to 0.99 year, one to 10 years, and each succeeding decade, and more than 80 years of age. Risk factors were derived from calculations of doses to specific organs and the risks of death from cancer induced in those organs per unit dose, such that the sum of these represents the total risk to the individual. The thyroid gland was treated separately from other organs because it concentrates radioiodine.

According to the upper bound risk estimation model, the expected number of latent cancer deaths (excluding thyroid cancer, with its low mortality rate) per million person-rems of whole-body dose from external radiation source is about 122 (see Table 6).

On the basis of the linear (proportional) nonthreshold hypothesis, the upper bound value can be translated simply into projected numbers for the off-site collective dose (3,000 person-rems) chosen for use in the present report. This translation yields a projected potential lifetime (remainder of life) total number of 0.6 cancer, 0.3 fatal, and 0.3 nonfatal in the TMI off-site population, based on the assumption that the number of nonfatal radiogenic cancers would be approximately equal to the number of fatal radiogenic cancers.

According to the central risk estimation model (reference 7), the dose-effectiveness factor which would be applied to doses less than 10 rems (at any dose rate) would be 0.2. Since the maximum off-site individual dose from the TMI accident was less than 0.1 rem, it is appropriate to apply this factor in applying this central risk estimation model to the collective dose for the TMI off-site population (3,000 person-rems). Thus, according to the central risk estimation model (reference 7), the projected lifetime number of radiogenic cancers in the off-site TMI population for this collective dose would be 0.12, half fatal and half nonfatal, on the assumption that the number of nonfatal radiogenic cancers would be approximately equal to the number of fatal radiogenic cancers.

According to the "non-zero" lower bound risk estimation model (reference 7), in which the incidence rate used for the upper bound estimate is applied to doses received by individuals in excess of a threshhold dose of 10 or 25 rems, the lifetime numbers of cancers to be expected in the population within 50 miles of the TMI nuclear plant site as a consequence of radiation exposure related to the accident would be zero.

Proportionally applying this Reactor Safety Study report's (reference 7) risk estimation models and upper bond lifetime radiogenic cancer death risk coefficient (about 122/10 person-rems) for whole-body irradiation, one can estimate that the hypothetical maximally exposed off-site (TMI) individual receiving a dose of approximately 70 mrem (reference 1) would have an average lifetime risk of fatal radiogenic cancer of about 0.9 chance in 100,000 according to the upper bound risk estimation model, about 1.7 chances in one million according to the central risk estimation model, or zero according to the "non-zero" lower bound risk estimation model.

4. UNSCEAR 1977 Report. Based on data presented in the 1977 report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (reference 6), the Ad Hoc Group made the estimates of radiogenic cancer risks for various ages and sexes given in

TABLE 6: Expected Latent Cancer (Excluding Thyroid) Deaths Per Million Person-Rems of External Exposure*

Type of Cancer	Expected Deaths per 10 person-rem
Leukemia	28.4
Lung	22.2
Stomach	10.2
Alimentary canal	3.4
Pancreas	3.4
Breast	25.6
Bone	6.9
All other	21.6
Total (excluding thyroid)	121.6

* Table VI 9-4 from Reactor Safety Study (reference 7).

Table 7 (reference 94). The UNSCEAR itself, however, regarded the average lifetime risk of radiogenic fatal cancer in general populations as being about 1/10 /rad, with a similar risk for nonfatal radiogenic cancer, at moderately low whole-body doses of low-LET radiation. These latter risk values are used in the present report (reference 6). The UNSCEAR cautions that the radiogenic cancer risk from whole-body irradiation at low radiation levels cannot be derived appropriately by adding the separate risk estimates for all body organs and subpopulations.

On the basis of the linear (proportional) nonthreshold hypothesis, these values can be translated into the expected numbers of cancer cases and cancer deaths associated with the TMI off-site population collective dose (3,000 person-rems) chosen for use in the present report. This translation yields a projected potential lifetime number of 0.6 radiogenic cancers, 0.3 fatal, and 0.3 nonfatal in the TMI off-site population.

Similarly, from the risk coefficients above, one can estimate that the hypothetical maximally exposed TMI off-site individual receiving a dose of approximately 70 mrems would have an average lifetime risk of fatal radiogenic cancer of about 0.7 chance in 100,000, a like risk of nonfatal radiogenic cancer, and a lifetime risk of radiogenic cancer of about 1.4 chances in 100,000 (reference 1).

5. ICRP 1977 Report. The International Commission on Radiological Protection (ICRP), in its 1977 Publication No. 26, has presented the radiogenic fatal cancer risk coefficients assumed by the ICRP for radiation protection purposes (reference 4) (see Table 8) -- a total lifetime risk in irradiated populations no greater than 125 cases/10^6 /rem; the value of about 100 cancer deaths/10^6 /rem was concluded to be the average for both sexes and all ages.

On the basis of the linear (proportional) nonthreshold hypothesis, this value can be translated into the expected numbers of cancer cases and cancer deaths associated with the TMI off-site population collective dose (3,000 person-rems) chosen for use in the present report. This translation yields a projected potential lifetime number of 0.3 fatal radiogenic cancer and, presumably, about 0.3 nonfatal cancer, for a total of about 0.6 radiogenic cancer in the TMI off-site population.

Similarly, from the risk coefficients above, one can estimate that the hypothetical maximally exposed off-site (TMI) individual receiving a dose of approximately 70 mrem (reference 1) would have an average lifetime risk of fatal radiogenic cancer of about 0.7 chance in 100,000 and, presumably, a like risk of nonfatal cancer, for a total radiogenic cancer risk of about 1.4 chances in 100,000.

6. NCRP Scientific Committee 40 Report. The 1979 Report (reference 11) of Scientific Committee 40 of the National Council on Radiation Protection and Measurements (NCRP) on the influence of dose and its distribution in time on dose-effect relationships for low-LET radiation presents extensive information strongly supporting the concept of application of an effectiveness reduction factor for low doses and dose rates of low-LET radiation to radiogenic cancer risk coefficients derived from data at high doses and dose rates, such as those derived in the 1972

TABLE 7: Estimates of Radiogenic Cancer Mortality Risks Based On 1977 UNSCEAR Report*

Cancer Type	Irradiated Population	Estimated Absolute Risk Cases/10^6 person-rem	Estimated General Population Death Risk Deaths/10^6 person-rem
Breast	Adolescent Women	440 (36-1500)	30.0 (20-35) [a]
	Women (all ages)	180 (140-230)	
Lung	Adult Males	50 (20-150)	50.0 (20-150) [b]
Skin	Adults	5 (2-10)	0.5 (0.2-1.0) [c]
Thyroid		100 (50-150)	10.0 (5-15) [d]
Leukemia	Adults	25 (15-30)	25.0 (15-30) [e]
Bone	Adults	3 (2-5)	3.0 (2-5) [e]
Brain	Fetus	50 (neg.-145)	
	Children	20 (9-39)	20.0 (9-39) [e]
Salivary	Children	10 (5-20)	5.0 (3-10) [f]
Sinus Mucosa		3 (2-5)	3.0 (3-5) [e]
Digestive Organs			12.0 (10-15) [e]
	Estimated Total Risks	450 (400-500) [f]	230 (200-250) [f]

[a] Assumes 30% of mortality and 50% of general population is female.

[b] Assumes 100% mortality and equal risk for women.

[c] Assumes 10% mortality (UNSCEAR assumes 6%).

[d] Assumes 10% mortality.

[e] Assumes 100% mortality.

[f] Assumes 50% mortality.

* References 6, 14.

TABLE 8: Radiogenic Cancer Risk Estimates Assumed By The ICRP For Radiation Protection Purposes*

Type of Cancer	Tissue At Risk	Total Risk Factor (per Sv) [a]	Total Risk/10^6 (Cases/10 /rem)
Leukemia	Red bone marrow	$2/10^3$/Sv	20
Bone	Cells on bone surfaces	$5/10^4$/Sv	5
Lung	Tracheal, bronchial, pulmonary, lymphoid	$2/10^3$/Sv	20
Thyroid [c]	Follicular epithelium	$5/10^4$/Sv	5
Breast	Breast tissues	$2.5/10^3$/Sv	25
All Other Combined [d]	---	< $5/10^3$/Sv	< 50
Total		< $125/10^4$/Sv	< 125
Total Cancer Mortality (Ave) [e]		$1/10^2$/Sv	100

[a] The ICRP uses the Sievert (Sv) dose-equivalent unit. One Sv = 100 rems.

[b] Calculated from Total Risk Factors assumed in ICRP Publication 26.

[c] Values given for thyroid are for thyroid cancer mortality, assuming mortality risk factor about 1/4 that for leukemia.

[d] For "All Other Combined" the ICRP further assumed that cancer of no single tissue in that category is responsible for more than one-fifth of the risk factor value assumed for that category.

[e] For purposes of radiation protection involving individuals, the ICRP assumed that the mortality risk factor for radiation-induced cancers for whole-body irradiation is that given above for average total cancer mortality risk (1/10 /Sv or 100/10$_6$ h/rem or 1/10 /rem), as an average for both sexes and all ages.

* Reference 4.

BEIR report (reference 8) and other reports, to take account of the influence of dose size and dose rate which are otherwise neglected in linear interpolation from high to low radiation levels.

This NCRP report also considers some claims suggesting that extrapolation according to the linear, nonthreshold hypothesis may not be conservative and may even underestimate effect at low doses and dose rates, in relation to its extensive review of relevant data, and concludes that these claims individually or collectively are not convincing enough to argue effectively against the existence of dose size and dose rate effectiveness factors for low-LET radiation for radiation effects in human beings.

b. Summary

Summarized in Table 9 are the various projected potential lifetime cancer risk estimates for the collective and maximum individual whole-body external gamma radiation doses in the off-site population within 50 miles of the TMI nuclear plant as a consequence of the TMI accident. These values were obtained by applying the cancer risk coefficients and risk estimation models represented in reports discussed above to the TMI dose estimates provided by or based on the report of the Health Physics and Dosimetry Task Group (reference 1).

It should be reemphasized that the values in Table 9 were based initially on the linear (proportional) nonthreshold extrapolation (interpolation) from data at high doses and/or dose rates, and that these assumptions permit the neglect of the influence of dose size and dose rate on effect and allow the use of the collective dose (person-rem). With these assumptions and the associated linear method of extrapolation (interpolation) to zero dose-effect, which, as discussed earlier, overestimate the effects of low-LET radiation at low radiation levels, it becomes unnecessary to deal with doses to each individual or separate collective doses at various distances from the TMI site for purposes of risk estimations. Otherwise, without such assumptions, and therefore with recognition of the influence of dose size and dose rate on the effect of low-LET radiation and the associated nonvalidity of collective dose derived linearly from data at high doses and dose rates, there would be a greater scientific requirement to deal with individual doses or at least different doses at different distances from the TMI plant. However, since all of the TMI accident-related off-site individual doses were very low and likely to be associated with a dose-effect relationship (low-LET radiation) which is fairly linear, but at a substantially lower slope (rate of increase with dose) than that used for extrapolation from high doses and/or dose rates, it is still practically and scientifically reasonable to use a single collective dose (within 50 miles) in this case, as long as the actual risk coefficients at such low radiation levels of low-LET radiation are recognized to be substantially lower than those derived by linear extrapolation from high doses and/or dose rates.

In regard to the EPA's risk coefficients for adults and for children less than 10 years of age, and the projected values and risk estimates derived from them (see Table 9), it should be noted that for purposes of

TABLE 9: Summary of Various Projected Lifetime Cancer Numbers Or Risk Estimates for Whole-Body External Gamma Radiation Doses to Off-Site TMI Population (Within 50 Miles) [a]

Source Of Estimates Or Risk Factors	Projected Numbers Of Cancers At 3,000 Person-Rem			Cancer Risk Max. Expose Person (approx. 70 mrem)		
	Fatal	Nonfatal	Total	Fatal	Nonfatal	Total
Ad Hoc Group*	0.6	0.6	1.2	$1.4/10^{5}$	$1.4/10^{5}$	$2.8/10^{5}$
EPA[c]*						
General Pop.	0.3-1.6	0.3-1.6	0.6-3.3	--	--	--
Adults	0.24-0.5	0.24-0.5	0.5-1.0	$0.7\text{-}1.4/10^{5}$	$0.7\text{-}1.4/10^{5}$	$1.4\text{-}2.8/10^{5}$
Children < 10 yrs.	0.06-1.2	0.06-1.2	0.12-2.4	$0.7\text{-}14/10^{5}$	$0.7\text{-}14/10^{5}$	$1.4\text{-}2.8/10^{5}$
Reactor Safety Study**						
Upper Bound Model	0.3	0.3	0.6	$0.9/10^{5}$	$0.9/10^{5}$	$1.8/10^{5}$
Central Model	0.06	0.06	0.12	$0.17/10^{5}$	$0.17/10^{5}$	$0.34/10^{5}$
Lower Bound Model	0.0	0.0	0.0	0.0	0.0	0.0
UNSCEAR 1977***	0.3	0.3	0.6	$0.7/10^{5}$	$0.5/10^{5}$	$1.4/10^{5}$
ICRP 1977 ^	0.3	0.3	0.6	$0.7/10^{5}$	$0.7/10^{5}$	$1.4/10^{5}$

[a] Values obtained by applying projections or risk coefficients yielded by models in listed reports to TMI dose estimates used in this report.

[b] 3,000 person-reins 50 percent higher than most probable actual total collective dose, and 70 mrem the dose for maximally exposed individual estimated by HP&D Task Group (reference 1).

[c] Range for general population the sums of lower range values and upper range values for adults and children<10 yrs. Extraordinarily high upper range values for children and general population due to inclusion of causally questionable association of high risk of childhood cancer with *in utero* diagnostic irradiation and to projection of the assumed high relative risk of radiogenic cancer in children (0-9 yrs.) to the 50+ age group in the BEIR 1972 relative risk model (reference 8) used.

* Reference 14.

* Reference 7.

* Reference 6.

^` ^^ Reference 4.

the present report the range values for the general population were taken to be the sums of the lower range end values and of the upper range end values for adults and children less than 10 years of age. It should also be noted that the extraordinarily high upper range end values for children and for the general population are due to the inclusion of the casually questionable association of high risk of childhood cancer with *in utero* diagnostic irradiation and to the projection of the assumed high relative risk of radiogenic cancer in children (zero to 9 years of age) all the way to the 50+ years age group in the BEIR I 1972 relative risk model (reference 8) which was used and which therefore yielded much higher risk estimates than did the absolute risk model. The other values in Table 9 were obtained from risk estimation models which were less heavily weighted by these inclusions, usually absolute risk models which are preferable to relative risk models.

In Table 9, with the exception of the upper range values for children less than 10 years of age and for the general population derived from the EPA Report's risk coefficients (from the 1972 BEIR report) and TMI cancer projections, it is evident that the projected lifetime numbers of cancers associated with the TMI off-site collective dose of 3,000 person-rems, derived from all indicated sources of estimates or risk factors, including those for adults derived from the EPA report, are all less than one for fatal cancer, less than one for nonfatal cancer, and less than 1.5 for cancer (fatal and non-fatal combined). With the same exceptions, the estimated lifetime radiogenic cancer risks (chances in 100,000) for the maximally exposed individual (approximately 70 mrem dose) range from approximately 0.17 to 1.4 for fatal cancer or for nonfatal cancer, and from 0.34 to 2.8 for cancer (fatal and nonfatal combined). Correspondingly, on a linear (proportional) basis, the lifetime radiogenic cancer risk (chances in 5 million) for the average whole-body dose in the off-site population (1.4 mrem) would range from approximately 0.17 to 1.4 for fatal cancer or for nonfatal cancer, and from 0.34 to 2.8 for cancer (fatal and nonfatal combined).

With the same exceptions as those noted in the previous paragraph, the Reactor Safety Study report's upper bound estimate model yielded values for the general population in reasonable agreement with those derived from the other sources, but the central estimate model with application of the dose size-rate effect modifying factor of 0.2 yielded the lowest non-zero projected values, and the lower bound (threshold) model yielded projections of zero cancers and cancer risks, a possibility that is not excluded by data. For fatal cancer, nonfatal cancer, and fatal and nonfatal cancer combined, the central estimate model yielded projections of 0.06, 0.06, and 0.12 cancer, respectively, at the 3,000 person-rem level, and cancer risks to the maximally exposed individual (70 mrem), in terms of chances in 1 million of 1.7, 1.7, and 3.4, respectively. For the average individual whole-body dose (about 1.4 mrem) the cancer risks would be (in terms of chances in 50 million) approximately 1.7, 1.7, and 3.4 (fatal + nonfatal).

3. <u>Skin, Beta Radiation (External Source)</u>

The Health Physics and Dosimetry and Dosimetry Task Group did not attempt to assess the contribution of beta irradiation to the skin dose, since (a) there were no reported measurements of integrated beta dose from thermoluminescent dosimetry (TLD); (b) there was no accurate method of determining points of plume "touchdown;" and (c) clothing would presumably have provided shielding from the poorly penetrating beta radiation. Therefore, the estimated skin doses to the off-site population as a consequence of the TMI nuclear plant accident, which are used in this section, are those presented in the report of the Ad Hoc Population Dose Assessment Group (reference 14), for the period March 28 through April 7, 1979.

The total beta plus gamma radiation dose to skin from xenon-133 was estimated to be about four times the dose to the internal organs from gamma radiation. The estimated increase in total fatal cancers over that estimated for external gamma radiation alone (3,300 person-rem exposure dose) was about 0.01 fatal skin cancer from the beta irradiation. This number would be considerably decreased if account could be taken of the shielding of the skin from the poorly penetrating beta radiation by clothing as well as other shielding materials and structures.

Skin cancer is not a prominent type of fatal radiogenic cancer and is particularly rare at low radiation levels. The 1972 BEIR Committee (reference 8) reported skin cancers associated with doses above 230 rem in rats and above 450 rem in humans. A dose of 450 rem can cause visible damage of the human skin and is more than 1,000 times greater than the estimated total (beta and gamma radiation) skin dose (380 mrem) to any individual exposed to radiation from the TMI accident (reference 14), even without correction for shielding by clothing, buildings, or other structures.

The International Commission on Radiological Protection's (ICRP) Publication No. 26 (reference 4) regards skin as being less likely to develop fatal radiogenic cancer than other tissues, and recommends a lifetime occupational dose limit for skin of 2,000 rems, and 5 rems per year for members of the ggneral public. The ICRP has recommended a risk coefficient of one per 10 person-rem for fatal skin cancer, which is in reasonably good agreement with the risk coefficient of 0.5 per 10 person-rem for fatal skin cancer presented in the 1977 United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) report (reference 6).

The 1977 UNSCEAR report (reference 6) indicates that the ratio of fatal skin cancers to all skin cancers is approximately 0.06. Assuming that this ratio also holds for radiogenic skin cancers, the total number of skin cancers associated with 3,300 person-rems might then be 0.01/0.06 = 0.17 (or approximately 0.2) (reference 14). These values (0.01 fatal skin cancer, 0.06 nonfatal skin cancer, and 0.17 skin cancers combined) at 3,300 person-rems would be only 10 percent higher than those which would apply to the collective dose of 3,000 person-rems chosen for use in the present report.

4. Lung, Beta and Gamma Radiations (Internal Source)

The radioactive noble gases, such as xenon-133, contribute to irradiation of the lung by the beta and gamma radiations emitted from the gas which is inhaled by individuals located within the radioactive plume, as well as by the penetrating gamma radiation from the gas outside the body (external source). The external gamma radiation contribution to the lung radiation dose has been included in the estimates of whole-body radiation doses and their potential cancerogenic consequences in previous sections of this report. In those risk estimations it was assumed that the lung dose from external gamma radiation was equal to the whole-body dose, which, in turn, was assumed to be the dose as measured in air outside the body. It should be reemphasized here that refined calculations have shown that for xenon-133, the lung dose from external gamma radiation is about 25 percent less than the whole-body exposure dose as measured externally.

The report of the Health Physics and Dosimetry Task Group (reference 1) indicates that the internal dose due to inhalation of xenon-133 is small compared to the external whole body dose. For example, if a person were immersed in a cloud of xenon-133, internalization of xenon would increase the whole-body gamma radiation dose above that from the external xenon-133 by 0.6 percent and the dose to the lungs would be increased by 6 percent. It has not been possible to determine whether or not or how long anyone in the vicinity of the TMI accident was actually breathing radioactive xenon gas.

The risk estimates presented in the 1977 UNSCEAR report (reference 6) indicate that the risk of fatal lung cancer per unit radiation dose is about one-fifth (0.22) of the total fatal cancer risk.

On the basis of the considerations above, the total number of cancers, fatal or nonfatal, that potentially could be associated with the small contribution to whole-body or lung doses by internalized xenon-133 would be very small compared with the numbers of cancers estimated for external whole-body gamma irradiation, of the order of one percent.

5. Thyroid, Beta Radiation (Internal Iodine-131)

The radioiodine released in the TMI accident was too low to be detected in most of the off-site areas, and it was not possible to determine collective thyroid doses from radioiodine.

The estimates of potential radiation doses on the high side to some individuals in the off-site TMI population from accident-released iodine-131 are about 10 mrem total for the new-born thyroid, 12 mrem for the one year old thyroid, and 6 mrem for the adult thyroid, for combined inhalation and ingestion (one liter cow's milk per day) (reference 1).

Applying the risk coefficients for thyroid cancer as a consequence of bgta irradiation of thyroid from iodine-A31 in the gland (14), i.e., 2/10 /rem for infants and children and 1/10 /rem for adults, to these 7 dose estimates yields average risks for individual cases of about 2/10

(2 in 10 million) for the newborn and the one year old, and about $1/10^7$ for the adult. Possibly 10 percent to 20 percent of the thyroid cancers would be fatal.

The projected numbers of thyroid cancers in the TMI off-site population, based on these low specific risk values and appropriate age distribution fractions, would probably be very small, in view of the fact that radioiodine was too low to be detected in most off-site areas and in comparison with the small numbers of cancers projected for the whole-body external gamma radiation doses.

6. Total

In view of the very small potential additional contributions of skin cancer from external beta irradiation, lung cancer from internal beta and gamma radiations, and thyroid cancer from radioiodine to the potential numbers of fatal and nonfatal cancers projected for the TMI off-site population for whole-body gamma radiation doses from external source, the overall total potential numbers of cancers for that population as a consequence of the TMI accident radiation is fairly represented by the total for the external whole-body gamma radiation dose, considering the uncertainties involved (see Table 9 and subsection 2.b. above).

The potential numbers of fatal and nonfatal cancers projected here for the TMI off-site population, based on absolute risk estimates, are concluded to be less than one in either case and less than 1.5 for cancer (fatal + nonfatal), if any, with zero not excluded.

D. RADIOGENIC CANCER RISKS TO ON-SITE POPULATION (OCCUPATIONAL EXPOSURE)

1. Whole-Body, Gamma Radiation (External Source)

According to the report of the task group on Health Physics and Dosimetry (reference 1), the sum of the collective whole-body external gamma radiation exposure doses to the on-site personnel to the end of June 1979 was 1,000 person-rems, with individual doses ranging as high as about 4 rems. This total value for the on-site personnel is one-third as large as the collective exposure dose (3,000 person-rems) chosen for use in the present report for the off-site population. Furthermore, radiogenic cancer projections per unit dose are less for on-site workers than for the general population because the on-site workers are all adults. On this basis, the projected potential number of cancers would be less than one-third of that projected for the off-site population, i.e., less than 0.5 cancer, if any, with zero not excluded.

Although the total collective dose to on-site workers will continue to grow as the decontamination process proceeds, it is difficult to predict the eventual total because this will depend upon decisions to be made about decontamination of the containment building and reactor vessel. The Public Health and Safety Task Force has not attempted to estimate the magnitude of that exposure in this report.

On the basis of the linear hypothesis, the maximal individual dose of 4 rems would carry with it a risk of cancer development of approximately 1.2 (0.8 to 1.6) chances in a thousand, presumably consisting of about half of that risk for fatal cancer and a like risk for nonfatal cancer.

2. <u>Thyroid, Beta Radiation (Internal Source)</u>

The report of the task group on Health Physics and Dosimetry (reference 1) also provided estimates of 54 mrem dose to thyroid and 0.03 mrem whole-body dose from inhaled iodine-131 in on-site personnel.

[5]Applying the EPA's (reference 1) thyroid cancer risk coefficient of 1/10 /rem, for adult thyroid exposed to radiation from internalized iodine-131, to this individual dose of 54 mrem yields a risk for this dose of one chance in 2 million with about 10 to 20 percent of this risk for fatal thyroid cancer.

Although an estimate of collective dose to thyroid from internalized radioiodine in the on-site population is not yet available, conservative assumptions concerning the likely number of people who may have received thyroid doses as high as 54 mrem would yield an estimate of a small fraction of a thyroid case in the population.

3. <u>Skin, Beta Radiation (External Source)</u>

As in the case of the off-site population, the beta radiation dose to skin, even taking into account the relatively high radiation exposure of the hands of two workers, would add only a very small fraction to the projected number of cases in on-site personnel for the collective whole-body gamma radiation exposure dose.

4. <u>Lung, Beta and Gamma Radiations (Internal Source)</u>

As in the case of the off-site population, the beta and gamma radiation doses to lung from internalized (inhaled) radionuclides would add only a small fraction to the projected number of cases in on-site personnel for the collective whole-body gamma radiation exposure dose.

5. <u>Total</u>

The total projected numbers of cancers in the on-site population (workers) from the TMI accident radiation, based on absolute risk estimates, is fairly represented by the value expressed above for the collective whole-body external gamma radiation exposure dose of 1,000 person-rems, i.e., less than 0.5 cancer, if any, with zero not excluded. The projected number tends to accommodate the possibility of somewhat higher additional risks from higher additional doses to thyroid and possibly skin and lung in the on-site population.

E. COMPARISON OF RADIOGENIC CANCER RISKS FROM TMI ACCIDENT WITH OTHER RADIOGENIC AND NONRADIOGENIC CANCER RISKS

According to the American Cancer Society's "Cancer Facts and Figures-1979" (reference 12), cancer is the second leading cause of death (second to heart disease) in the United States. According to the U.S. Vital Statistics for 1976, there were 377,312 deaths in the United States from cancer, i.e., cancer deaths were approximately one-fifth (0.198) of all deaths for that year. This corresponds to a rate of about 180 cancer deaths per 100,000 people per year (reference 12), i.e., 180 cancer deaths/10^5/year. The cancer death rate in the state of Pennsylvania has been estimated (reference 12) to be 208/10^5/year. The state of Maryland, part of which is within 50 miles of the Three Mile Island plant, has an estimated cancer death rate of 179/10^5/year.

Applying the various annual cancer death rates given above to the estimated 2,164,000 people residing off-site within 50 miles of the TMI site gives the following approximate estimates of existing cancer deaths per year in that off-site population: 3,900 (for U.S. or Maryland rate) to 4,500 (for Pennsylvania rate).

Given in Table 3 are estimated numbers of new cancer cases (765,000) and deaths (395,000, 52 percent of cases), in the United States for 1979 (existing rates), provided by the American Cancer Society (ACS) (reference 12). The ACS estimates that approximately 25,000 per 100,000 people (25 percent) will eventually develop cancer and about 15,000 (15 percent) will eventually die of cancer (range 0.15 to 0.17 depending on sources of data and years). The ordinary risk to the individual of developing cancer (from "all causes") is one in 4, and of dying of cancer is about one in 6 to 7. Application of these values to the estimated 2,164,000 people residing off-site within 50 miles of the TMI site indicates that in that population, 541,000 people would ordinarily develop cancer (25 percent rate) and that about 325,000 (15 percent rate) to 370,000 (17 percent rate) would ordinarily die of cancer.

The annual collective dose from natural background radiation to the off-site population within 50 miles of the TMI site has been estimated to be about 270,000 person-rems (2,164,000 persons x 0.125 rem per year) (reference 14). The total collective dose from natural background radiation to the off-site population over a period of 35 years, i.e., about half the average life expectancy, would be about 9,450,000 person-rems at the same background radiation level. Compared with the collective dose (3,000 person-rems) chosen for this report for the TMI off-site (within 50 miles) population as a consequence of the nuclear plant accident, the annual collective dose and the 35-year collective dose from natural background radiation to that off-site population would be 90 and 3,150 times greater, respectively, as would the associated projections of potential numbers of radiogenic cancer cases and deaths on the basis of the linear, nonthreshold hypothesis for dose-effect relationship.

The average individual dose for the off-site TMI population (within 50 miles) as a consequence of the TMI nuclear plant accident can be estimated to be about 1.4 mrem (3,000 person-rems divided by 2,164,000 persons). For further perspective in relation to natural background radiation, see Table 2 (Chapter III) for estimates of average annual individual whole-body doses from natural background radiation in the United States (range 70 to 310 mrem/year). It should also be noted, for example, that living in Denver, Colo., as compared with Harrisburg, Pa., adds a dose of about 80 mrem per year (average) from natural background radiation; living in a brick house instead of a wood frame house adds a dose of about 14 mrem per year (average); and the fact of being male instead of female adds a natural background dose of about 5 mrem per year (average) from potassium-40 within the body (reference 14).

The Ad Hoc Population Dose Assessment Group (reference 14) estimated that the existing natural rate for fatal cancers in the off-site TMI population (within 50 miles) is about 3,900 per year. On the basis of the 1972 BEIR Committee's (reference 8) extreme range of radiogenic cancer mortality risk estimates, from its various absolute and relative risk models, the Ad Hoc Group estimated that the annual number of fatal cancers potentially caused by background radiation (125 mrem/yr. to 2,163,654 people = 270,500 person-rem/yr.) would be 24 to 27 (0.6 to 0.7 percent of normal rate) for the absolute risk models; 43 to 124 (1.1 to 3.2 percent of normal rate) for the relative risk models; and 54 (1.4 percent of normal rate) for the Ad Hoc Group's central risk estimate (geometric mean of the absolute and relative risk estimates).

The Ad Hoc Group also estimated that the total potential numbers of cancers in the TMI off-site population (annual rates x 70 years mean life span) due to natural background radiation would be 1,700-9,000 (fatal cancers) and an equal range for nonfatal cancers (assuming twice as many cancers as cancer fatalities). This is to be compared with their estimates of 325,000 fatal cancers and 216,000 nonfatal cancers to be expected ordinarily (from all causes).

Further, the Ad Hoc Group estimated on the same basis that the lifetime risk of fatal cancer ~o an individual as a consequence of a dose of 100 mrem is about 2/10 , i.e., about one in 50,000, with presumably a similar risk for nonfatal cancer. This risk is extremely small compared with the normal risk of fatal cancer (0.15), and it is only slightly more than one percent of the potential lifetime risk of fatal cancer associated with continuous average natural background radiation year after year, based on the same dose-effect relationship assumptions.

Comparing the various projected potential lifetime cancer numbers or risk estimates, obtained by various risk estimation models, for the off-site TMI population as a consequence of the radiation doses from the TMI nuclear plant accident, as presented above in this chapter and summarized in Table 9, it is clear that all of these values are small compared with either the existing annual or lifetime incidence or risks of naturally occurring cancer or of cancers estimated to be potential effects of natural background radiation on the average or in relation to its variation. Such comparisons also lead to the conclusion that the potential cancerogenic impact of the TMI accident, if any, would not be detectable and that the existing degree of uncertainty concerning cancerogenic risk from low-level ionizing radiation would not be sufficient to affect that conclusion.

F. CONCLUSIONS

1. The projected number of fatal cancers or nonfatal cancers potentially induced or temporally advanced over the remaining lifetime of the off-site population within 50 miles of the TMI plant site from whole-body gamma radiation exposure is less than one and the total number less than 1.5, with zero or near-zero not excluded.

These numbers can be contrasted with numbers that could be similarly projected for various periods of natural background radiation, i.e., approximately 7 to 8 times as large for one month, 90 times as large for one year, or 3,150 times as large for 35 years (half the average life expectancy) of average natural background radiation exposure.

The estimated number of cancer cases from all causes that would ordinarily (normally) develop in the TMI off-site population over its remaining lifetime, even if the TMI accident had not occurred, is approximately 541,000 (325,000 fatal and 216,000 nonfatal).

2. The average individual lifetime radiogenic cancer risk from the whole-body gamma radiation exposure dose to the maximally exposed off-site individual (approximately 70 mrem) is about one (0.17 to 1.6) in 100,000 for fatal cancer and a like risk for nonfatal cancer, for a total cancer risk of about 2 (0.34 to 3.2) in 100,000, with zero risk not excluded.

The average individual lifetime radiogenic cancer risk from the average off-site individual exposure (about 1.4 mrem) would be about 0.02 of these values, or about one (0.17 to 1.6) in 5 million for either fatal or nonfatal cancer, for a total cancer risk of about 2 (0.34 to 3.2) in 5 million.

These risks for the average individual can be contrasted with a normal risk of about one in 7 for either a fatal cancer or a nonfatal cancer from all causes, or a total normal cancer risk of about one in 4.

3. The additional potential radiogenic cancer contributions and risks to the TMI off-site population associated with beta radiation doses to skin from external sources, beta and gamma radiation doses to lung from inhaled radionuclides, beta radiation doses to the thyroid gland from inhaled or ingested iodine-131, and doses from cesium-137 are very small in comparison with the projected numbers of cancers and radiogenic cancer risks from the whole-body gamma radiation exposure doses and can be regarded as emcompassed within the values expressed above for whole-body gamma radiation exposure doses.

4. The projected potential lifetime numbers of radiogenic cancers in the TMI off-site population associated with radiation exposure from the Till accident, as presented above, are very low, if not zero, and would not be possible to detect in the population.

5. The collective exposure dose from whole-body external gamma radiation in the on-site workers (1,000 person-rems) through June 1979 is one-third as large as the collective dose value of 3,000 person-rems used for the off-site population. Furthermore, radiogenic cancer projections per unit dose are less for on-site workers than for the general population because the on-site workers are all adults. No worker received more than 5 rems. Therefore, the projected number of cancers would be less than 0.5 cancer, if any, with zero not excluded.

6. The maximum individual whole-body dose among on-site workers (about 4 rems) would carry with it an average individual lifetime risk of cancer development of approximately 1.2 (0.8 to 1.6) in 1,000, presumably with about half that risk for fatal cancer and half for nonfatal cancer.

7. The additional potential radiogenic cancer contributions and risks to the TMI on-site workers from beta radiation doses to skin from external sources, beta and gamma radiation doses to lung from inhaled radionuclides, beta radiation doses to the thyroid gland from inhaled or ingested iodine-131, and doses from cesium-137 are small in comparison with those from the whole-body gamma radiation exposure doses and can be regarded as encompassed within the values expressed above for whole-body gamma radiation exposure doses.

8. The projected potential lifetime number of radiogenic cancers in the TMI on-site (worker) population associated with radiation exposure from the TMI accident, as presented above, are very low, if not zero, and would be impossible to detect in the population against the background of general occupational and natural background doses.

V. RADIATION GENETIC RISKS

A. INTRODUCTION

Genetic health effects are those resulting from heritable changes in the germ cells or their precursors of one generation but expressed only in the following or subsequent generations. They result from alterations, called mutations, in the genetic material (deoxyribose nucleic acid, or DNA) or from aberrations (changes in number or form) of the microscopic structures, called chromosomes, that contain the cell's DNA. It has long been known that ionizing radiation is capable of inducing such changes, but it is important to recognize that radiation is only one among a large number of chemical and physical agents that can do so.

Unlike the case for the induction of cancer by radiation, there is virtually no evidence available demonstrating the induction of any genetic effects in human populations exposed to ionizing radiation. Nevertheless, the experimental evidence from other organisms is overwhelming, and in view of the striking similarities between the genetic apparatus of all organisms including man, it seems certain that human radiation exposure must also produce such effects.

Because of the lack of human data, estimates of the risk of radiationinduced human genetic health effects must be based upon data from experimental animals, and all recent estimates of national and international advisory groups have rested very heavily upon the large body of data now available on the laboratory mouse. The negative data from human studies, most importantly from study of the offspring of Hiroshima and Nagaski atomic bomb survivors, is consistent with the mouse data. Thus, though there do exist many uncertainties, we may at least be confident that the extrapolation from mouse to man does not greatly underestimate the genetic health effects of human radiation exposure.

As for cancer induction, there is no direct evidence for the induction of genetic effects in animals by doses as low as those of interest in connection with the accident at Three Mile Island. The effects of doses below of the order of a few tens of rems are simply too small to be detected statistically. However, both theoretical considerations and indirect experimental evidence strongly indicate that genetic effects are indeed induced by even very low doses of ionizing radiation and that in the range of dose and dose rate of interest the numbers of effects produced is a simple linear function of dose.

Genetically related ill health is ubiquitous in human populations, some 10 percent of live borns being affected. Such ill health spans the entire range from major congenital defects incompatible with continued life to relatively trivial conditions that, while eventually requiring medical attention, are of minor consequence in the lives of the affected person. It is important to recognize that ionizing radiation produces only the same kinds of genetic changes as occur spontaneously. Consequently, any genetically related ill health that might arise as a result of human radiation exposure would be qualitatively indistinguishable from that which already occurs spontaneously. Thus, as with cancer, no genetic ill health in any particular individual can be attributed definitely to parental radiation exposure, and the smaller the dose, the less likely it is that parental irradiation was the cause.

The consequences of mutation, that is, alteration of the genetic information encoded in the DNA of genes and the chromosomes which contain them, are generally recognized to be detrimental to the health of individuals carrying them. The degree of harm varies from mutation to mutation, and a few might even be beneficial under certain circumstances, but it is widely agreed that any increase in the human mutation rate may be expected to result in some net increase in human ill health.

Generally speaking, deleterious mutations will tend to be eliminated from the population through effects ranging from slightly impaired fertility, through partial or complete sterility, to death prior to reproduction of the individuals in whom they are expressed. However, in certain apparently unusual situations, even very detrimental mutations may be maintained in populations as a result of beneficial effects expressed in carriers (i.e., in individuals receiving the mutant gene from one parent but not the other). For example, in the case of sickle cell anemia, the carriers are resistant to the malarial parasite and thus enjoy better health in populations at risk of contracting malaria than their genetically normal contemporaries, even though the anemic offspring they may produce (the "affected," who inherit the mutant gene from both parents) suffer severe ill health. Obviously, then, the degree of detriment varies not only from mutation to mutation, but according to environmental and other factors as well.

Mutations may be induced in almost any type of cell in the body. However, most of these cells (the so-called somatic cells) cannot contribute any genetic material to the next generation: mutations occurring in them cannot contribute to heritable ill health (though some scientists do feel that they may result in ill health in the individual in whom they occur). Defining genetic effects as only those that arise in germ cells (or their precursors) that contribute to the next generation, it follows that the doses of concern are only those actually received by these cells, or, for practical purposes, by the gonads.

In the female, the germ cells persist as immature oocytes from birth till shortly before ovulation. In the male, most of the mature sperm that will ever be produced will arise from precursor cells called spermatogonia. It is consequently the immature oocytes and the spermatogonia that are of primary concern in genetic hazard evaluation, and these two cell types in the mouse, and presumably in humans, differ greatly in their susceptibility to the induction of genetic effects by ionizing radiation.

B. PRINCIPLES OF GENETIC RISK ESTIMATION

There is general agreement within the scientific community involved in genetic hazards evaluation that a few principles are of particular relevance to risk estimates for humans. These have been recently stated by the National Research Council Safe Drinking Water Committee in a chapter of its report entitled "Radioactivity in Drinking Water" (reference 15) and are repeated here.

1. Radiation or other mutagens appear to produce genetic changes that are qualitatively the same as those that occur naturally. Different mutagens, however, may not increase all types of mutations in quantitatively the same manner.

2. At low doses and low dose rates of low-LET radiation, mutations are induced in direct proportion to the dose. No threshold dose is evident in the experiments testing this (with a few experiments that are presently the subject of reevaluation).

3. In the low dose range of irradiation to which human populations are normally exposed from natural background or man-made sources, the manner in which the dose is received will not affect the yield of induced mutations. The same number will result if 100 millirem are received at once or spread out over weeks, months, or even years.

These points are especially important and applicable to our analysis of the accident at Three Mile Island since all general population doses were well below 100 millirems, and the doses to the gonads consisted exclusively of low-LET gamma rays.

For over 20 years, various national and international committees, including the BEAR and BEIR committees of the National Academy of Sciences (references 8, 16, 17), the United Nations Scientific Committee on the Effects of Atomic Radiation (references 6, 10), and the International Commission on Radiological Protection (reference 4) have periodically analyzed the available data and developed updated formulations of risk and radiation. The most recent effort in this area is the report of the 1979 BEIR III Committee's Genetic Effects Subcommittee (references 16). Their findings and methodologies will be adopted as the basis of the present analysis of genetic risk for the Three Mile Island population. It should be noted, however, that adoption of those used in earlier reports would not result in any dramatic change in our numerical assessment.

Because of the differences in the circumstances under which different mutations are expressed as ill health, two types of risk estimates are required. Some mutations, called dominant, as well as some chromosomal aberrations, are expressed in the first generation following exposure of the parental generation. Other mutations, called recessives, are not expressed in carrier individuals who inherit them from only one parent. In this case expression does not occur in the first generation, but only in later generations when two carriers mate and produce an affected child who receives the mutant gene from both parents. Thus, different estimates must be made for the expression of dominant genetic effects in the first generation and for the ultimate expression of both surviving dominant mutations and of recessive mutations.

The BEIR III Committee (reference 16) used two separate approaches to making these kinds of risk estimates, both based very largely upon experimental data for the laboratory mouse, and only to a limited extent upon pertinent human information. For estimation of effects in the first generation following parental exposure a so-called "direct" method was used which depends upon observations of induced heritable skeletal abnormalities in mice after irradiation of their sires' spermatogonial cells. The frequency of such serious skeletal abnormalities per rem of exposure was adjusted for all organ system abnormalities to include the estimated frequency for both sexes. This approach provided the estimate that 5 to 65 induced dominant disorders would be expected during the lifetime of one million live-born children following parental exposure to one rem of radiation. Based largely on information from human spermatogonial irradiations and the observed frequency of chromosome abnormality, it was possible to develop, in addition, an estimate of the number of offspring of irradiated parents who would manifest a genetic disorder as a result of some induced chromosomal anomaly. This estimate ranged from zero to 10 affected per million offspring per rem of parental exposure. Thus, by these direct methods the total number of cases estimated to occur in the first generation ranged from 5 to 75 per million offspring per rem of parental radiation.

The second risk estimate methodology employed by the BEIR III Committee (reference 16), as well as the previous BEIR I Committee (reference 8), is called the "indirect" method. This procedure permits an estimate of the number of genetic disorders to be expected in each generation after many generations of parental radiation, when an equilibrium has been reached between the rates at which new genetic ill health is induced in each generation and the rate of elimination in each generation through its expression in affected individuals. By definition, this equilibrium estimate is numerically the same as the total number of affected individuals to be expected over all future generations following a single exposure of one generation. Estimates by this method integrate the number of additional disorders over literally hundreds or thousands of generations into the future. We believe the method has considerably less pertinence to the specific problem of human ill health as a consequence of the Three Mile Island accident because inherent in this procedure is the assumption that the medical sciences hundreds or thousands of years from now will be no more advanced in the treatment, amelioration, or elimination of genetic disease than they are today. Clearly, the strides made in medical genetics and allied sciences over the past decade belie such an attitude. However, with this caveat, the method does provide some idea of the maximum total of the eventual health impact of the Three Mile Island Accident.

The indirect equilibrium genetic effects estimate made by the BEIR III Committee (reference 16) is based largely upon extensive data on the induction of recessive mutations in mouse spermatogonia and immature oocytes. From these induced and spontaneous mutation rates, a relative mutation risk (i.e., the reciprocal of the so-called "doubling dose," or amount of radiation exposure required to double the spontaneous mutation rate) is derived. The relative mutation risk factor was used together with estimates of the degree to which the frequency of human ill health is responsive to mutation frequency to derive an equilibrium estimate of from about 60 to possibly as many as about 1,100 affected individuals per million live-born per generation per rem of parental exposure in each generation.

It is exceedingly important that the BEIR III Committee's numerical genetic risk estimates, and indeed any such risk estimates, be placed in proper perspective by comparison with the incidence of such effects to be expected in the same population spontaneously in the absence of any added radiation exposure. The estimate of current incidence given in their report is 107,000 per million live births; that is, 10.7 percent of all human live births. Thus the first generation increase of between 5 and 75 cases per million live births per rem of parental exposure (i.e., 0.0005-0.0075 percent) is more meaningfully expressed as an increase from 10.7 percent to somewhere between 10.7005 percent and 10.7075 percent per rem parental exposures. The "all time" (i.e., equilibrium) estimate of from 60 to 1,100 cases per million per rem of parental exposure is more difficult to put in perspective, simply because neither the total number of human generations nor the future population dynamics are known. However, the BEIR III estimate of from 60 to 1,100 cases per million per rem of parental exposure may be expressed as an increase from 10.7 percent to an average of 10.7 plus (60-1,000/N x 100) percent, where N is a very large number of generations. If we assume N = 1,000, for example, the current incidence would rise from 10.7 percent to 10.700006 percent to 10.70011 percent averaged over the one thousand generations (with most of the expression, obviously, in the first few generations).

The estimates above are estimates of effects to be anticipated among live-born individuals. In addition, there would also be expected some mutations that would result in prenatal lethality. However, such effects would be infrequent, and those that did occur would have little human impact as most such losses occur prior to the time the mothers even suspect they might be pregnant. In the absence of any numerical estimates of the frequency of such effects and of the probable lack of any awareness of any that might occur, we shall not attempt to consider them further here.

C. SPECIFIC ESTIMATES OF RADIATION GENETIC RISKS FROM THE TMI ACCIDENT

1. General Population (Off-Site)

The collective gonadal (testes and ovaries) dose to the general population of about 2 milion persons living within a 50-mile radius of the Three Mile Island facility is estimated to have been about 2,000 person-rems, i.e., about two-thirds of the 3,000 person-rems whole body gamma radiation exposure dose chosen for the off-site population for this report. This assumed 2,000 person-rems gonadal dose errs on the high side for the energy of the gamma radiation involved. This gives an average of about one mrem per person in the exposed population. The highest gonadal dose to any individual is taken here to be 100 mrem, in order to err on the high side. Since in the range of dose below 100 mrem its distribution among the population is of no consequence, the number of genetic effects to be anticipated may be calculated from the BEIR III (reference 16) estimates by simple dose proportionality. Thus, the BEIR III first generation estimate of between 5 and 75 cases becomes 5-75/1,000, or 0.005 to 0.075 cases per million live births.

If it is assumed for simplicity that the present off-site population of about 2 million will be stable in the future and if the generation time of populations is taken to be 30 years as an approximation, then we would expect about 28,000 births per year, of which about 3,000 (28,000 x 0.107) would have been affected at some time in life by genetically related ill health had the accident at Three Mile Island not happened. To this the estimated one mrem average exposure in consequence of the accident would add between about 0.0001 (0.005 cases per million births x 28,000/1,000,000) and about 0.002 induced cases. Expressed another way, the incidence of genetically related ill health in the 50-mile population is estimated to increase as a result of radiation exposure from the accident by no more than 0.00007 percent (0.002 case/3,000 x 100) of the spontaneous incidence prior to the accident.

In addition to the total population risk, we may also consider the maximum credible risk to any individual. As an extreme "worst case," it might be assumed that a couple who each received an individual gonadal dose of 100 mrem subsequently have a child. In the absence of their radiation exposure, the risk that that child will experience genetically related ill health at some time in its life is 10.7 percent. From the BEIR III genetic effect estimates (references 16) of 5 to 75 per million per rem, we may calculate the added risk attributable to the Three Mile Island accident as 0.00005 to 0.00075 percent (5-75 x 10^{6} x 0.1 rem x 100). In other words, the risk is increased in this "worst case" example from the normal 10.7 percent to a maximum of 10.70075 percent.

From the BEIR III equilibrium estimate of between 60 and 1,100 cases per million live births per rem of parental exposure, we may further conclude that the average parental exposure of one mrem to the approximately 2 million population within 50 miles of the Three Mile Island facility may result ultimately in a total of no more than about one additional case of genetically related ill health per million live births during all future human existence.

2. The Occupationally Exposed Population (On-Site)

The collective whole-body external gamma radiation exposure doses to the on-site population of about 1,000 workers who had measurable doses was about 1,000 person-rems through June 30, 1979 (reference 1). It appears that the total population of workers numbered about 5,000. In order to estimate properly the possible genetic effect of this exposure, it would be necessary to know the age, sex, and marital status of these people (reference 7), but unfortunately the task group has been unable to obtain this information. (As stated previously in this report, although there will be additional exposure to on-site personnel associated with the cleanup and recovery operations at TMI-2, the Public Health and Safety Task Force has not attempted to estimate the magnitude of that exposure.)

One way of looking at the genetic effects that the occupational exposure dose mentioned above might cause is simply to consider the occupationally exposed to be a part of the general 50-mile population (even though many probably do not permanently reside in this area.) The total dose (on-site plus off-site) would then become about 3,000 person-rems -- about half again the off-site dose. The risk of future genetic ill health in this population (workers plus general population) would then be approximately 1.5 times that for the population when only the off-site dose is considered.

However, there are likely to be differences in population characteristics which would largely tend to reduce the potential genetic effect of the on-site TMI radiation doses relative to the potential genetic effect of the doses to the off-site population. These differences, aside from the probable differences in sex distribution, include the relatively small number of people involved and the fact that they are all adults, some of whom undoubtedly had partially or fully completed their families before the accident occurred.

Another way of considering the possible genetic effects of the occupational exposures is to calculate the risk for an individual child conceived some time after the accident. As has been said previously, the average dose received by workers who had measurable doses up to June 30, 1979, was about one rem (reference 1). If we arbitrarily assume, for convenience, that this dose might be doubled for at least a few workers during subsequent decontamination, we would then have a dose of 2 rems, but experienced by only one of the two potential parents. Since the parent will have been male, and since the contribution of parental irradiation is about 70 percent of the total when both parents are equally irradiated (reference 16), the effective dose would be 1.4 rems. Since the upper bound first generation genetic effect estimate from the BEIR III Report is 75 per million live births per rem (to both parents), a conservative estimate for a birth to a parent exposed on-site at TMI would be (75 x 10   x 1.4 rem x 100) = 0.01 percent. That is, the normal risk of 10.70 percent would be increased to 10.71 percent.

D. SOMATIC CHROMOSOME ABERRATIONS

As noted earlier, genetic effects may be induced in the somatic cells of the body as well as in germ line cells by exposure to ionizing radiation. Though not a genetic effect in the context of genetic hazard evaluation, the frequency of chromosomal aberrations in peripheral blood lymphocytes has long been used as a sensitive indicator of human radiation exposure. A study of aberration levels in blood samples from persons exposed as a consequence of the accident at Three Mile Island is among the health research studies already proposed and/or accepted. There are several technical considerations that bear on the feasibility and merit of such a cytogenetic study.

Under some circumstances chromosome aberration analyses may provide estimates of the radiation dose received, and thus constitute a "biological dosimeter." It must be recognized, however, that the technique is laborious and relatively imprecise and insensitive compared to physical dosimetry. It is generally recognized to be of value only in cases where physical dosimetry is impossible for one reason or another, or where the physical evidence is conflicting.

Several factors limit the ability of the cytogenetic method to detect and quantify radiation exposure. Chromosomal aberrations occur spontaneously, and this "noise" sets a practical lower bound on the minimum dose that can be detected even under the most favorable circumstances. Various studies agree that the lowest doses of low-LET, acute, whole-body irradiation that can be measured in a peripheral blood sample obtained promptly after the exposure are in the range of a few rads. To establish the effect of such a low dose, however, requires the study of many thousands of individual cells, and the practical lower limit of dose is generally considered to be of the order of a few tens of rads.

The aberrations induced in peripheral lymphocytes are largely of types that tend to be lost for mechanical reasons during cell division. While the human peripheral blood lymphocyte does not normally divide while in the circulation, they are ultimately replaced in the blood by cells arising in the solid lymphoid tissues by cell division. Thus, within a few weeks after a radiation exposure the initial frequency of chromosomal aberrations begins to fall. This not only makes the minimum detectable dose increase as the interval between radiation exposure and sampling for chromosomal aberrations increases, but also introduces greater uncertainty and imprecision into measurements made many weeks or months after an exposure.

Finally, there exist several recent technical advances that may be used to reduce some of the uncertainties inherent in chromosomal aberration frequency measurements on human peripheral blood lymphocytes. These, however, have not yet come into general use. Furthermore, as with mutations in general, there are many environmental agents and health factors that can increase peripheral lymphocyte aberration frequencies, among which radiation exposure is only one. There are differences in the types of aberrations induced by radiation and by many other agents, but distinction between them becomes less easy as time elapses between exposure and sampling. Thus, protocols for attempts to detect radiation exposures by peripheral lymphocyte chromosomal aberration measurements need to be carefully designed even for the case of relatively large radiation doses and prompt blood sampling, and this requirement becomes even more stringent for low doses and delayed sampling.

E. SUMMARY AND CONCLUSIONS

Despite the lack of positive human data on the induction of genetic effects by ionizing radiation, estimation of the numbers of such effects to be anticipated as a consequence of human population exposure to low doses of radiation, such as those that actually occurred at Three Mile Island, rests upon a relatively firm scientific foundation. The estimates of genetic risk presented in the reports of various national and international committees, such as the U.S. National Research Council's Biological Effects of Atomic Radiation (BEAR) and BEIR Reports (references 8, 16, 17) and the United Nations UNSCEAR Reports (reference

6, 10) are in reasonably close agreement. Thus, while this task group has adopted the most recent BEIR III risk estimates as the basis for its calculations of the numbers of cases of genetically related ill health that might occur as a result of the accident at Three Mile Island, adoption of the risk estimates in any of the other reports would result in only inconsequential numberical changes.

The number of cases of genetically related ill health to be expected as a consequence of the accident at Three Mile Island are very small even under worst case assumptions: a tiny fraction of a case in the first generation, and no more than a few cases over all future human existence. Any cases that do occur will be indistinguishable from the more than 100,000 per million births that will unavoidably occur for other reasons. Clearly it will be impossible to detect any increase that does occur by any available scientific test or method, nor will it be possible to attribute any individual case of genetically related ill health to radiation exposures from the accident.

In the light of the very small doses involved and the impossibility of detecting any genetic effects that might actually occur against the enormously larger background of indistinguishable cases that presently exists, there appears to be no scientific justification whatever for any clinical or epidemiologic study of genetic effects in the population around the Three Mile Island facility. This conclusion is reinforced by consideration that the doses received in connection with the accident amount to only a fraction of the natural background radiation exposure to which the population is unavoidably exposed each year, and by the negative results of a very large scale, long-term study of the offspring of Hiroshima and Nagasaki survivors, despite the fact that this population received radiation doses many orders of magnitude larger.

Though not properly a genetic effect in the present context, the possibility of a cytogenetic study of peripheral blood lymphocyte chromosome aberrations in the populations exposed during the Three Mile Island accident has been considered. Technical considerations lead to the conclusion that the doses involved could not produce any detectable cytogenetic effect. At best, such a study could only be expected to provide reassurance that the radiation doses were not enormously greater than estimated. Moreover, the technical complexities involved in such a study are large, so it would be extremely important that the protocol, should a cytogenetic study be initiated, be very carefully designed.

VI. RADIATION TERATOGENIC EFFECTS

A. INTRODUCTION

This chapter contains a brief summary review of the general state of knowledge concerning the teratogenicity of low dose levels of ionizing radiations, followed by a consideration of the possible teratogenic effects of the radiation exposures of the pregnant women residing in the vicinity of Three Mile Island at the time of the 1979 accident.

The reader interested in comprehensive reviews of the scientific literature on this subject is referred to the 1979 Report (reference 16) of the National Academy of Sciences Advisory Committee on Biological Effects of Ionizing Radiations (the BEIR III report) and the 1977 Report (reference 6) of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), which have provided much of the background information below.

B. BACKGROUND INFORMATION

Intra-uterine mammalian development is a highly complex process, involving, among other aspects, rapid cell division and differentiation of cells into tissues and vital organs of the body. Actively dividing cells are generally more radiosensitive than nondividing cells and damage to them in critical phases of embryonic or fetal development may result in malformations or developmental deficiencies.

Most of the available knowledge of teratogenic effects of radiation in mammals, particularly at low-dose levels, has come from experimental animal studies, mostly on mice and rats and to a lesser extent on other mammalian species. However, certain important qualitative generalizations may be regarded reasonably as applicable to man as well.

Radiation-induced defects in development range widely in type and severity. Some may cause death of the animal in the uterus, others are structural abnormalities manifest and recognizable at birth, and still others are manifest only as functional deficiencies after birth. The types of developmental changes caused and their susceptibility to induction by radiation differ considerably at different stages of prenatal development, i.e., before implantation of the conceptus, during the subsequent stage of major organogenesis, or during the subsequent stage of fetal growth.

Although similar types of effects may be caused in man by prenatal radiation exposure at corresponding developmental stages, available human data are not sufficient for quantitative estimation of radiation risks for these effects at these developmental stages, and values derived from animal studies cannot be applied directly to man.

The UNSCEAR in its 1977 Report (reference 6) reviewed the reported radiation effects on prenatal development in several mammalian species irradiated experimentally at various developmental stages and attempted to correlate them with changes observed in man at corresponding stages, when known. Radiation exposure before implantation (in mouse, rat, hamster, rabbit, and dog) may cause do th of the embryo and failure of implantation, the frequency varying with species. Surviving embryos which become implanted appear to develop normally. Irradiation after implantation but during the period of major organogenesis causes broadly similar types of effects in various mammalian species if they are irradiated at comparable developmental phases.

Experimental animal studies (largely on rats and mice) have shown three categories of radiation effects. Relatively high doses, especially if given early in the period of organogenesis, cause death of the conceptus either in the uterus or soon after birth, with the absorbed dose for 50 percent lethality being about 100 rads or more. Growth of surviving embryos may be impaired at these or lower doses and impairment of growth may persist postnatally. More localized developmental effects may result, which cause malformations or functional defects in particular body structures.

Typical malformations resulting from irradiation during the period or organogenesis include malformations of eye, brain and nervous system, or head, skeleton and extremities, with the most likely particular malformation depending very critically upon the developmental phase within the period of organogenesis at the time of radiation exposure.

There is little available information on frequency-dose relationship for particular or all malformations. Slightly increased incidence of some malformations has been reported in some experiments at absorbed doses as low as 5 rads in the mouse and 5 to 10 rads in the rat, for exposures at high dose rate at developmental phases highly susceptible for induction of these malformations. Animal experiments have shown that several types of malformations may be caused by absorbed doses of 10 to 100 rads, each with a frequency of about 1/1,000/rads or more. However, available data generally do not reveal increased frequencies at lower doses.

In its 1977 report (reference 6), the UNSCEAR indicated that it had previously estimated a possible incidence of mental retardation, associated with reduced head size (microcephaly), for man in the region of 1/1,000/rads for absorbed doses greater than 50 rads at high dose rates, and referred to data on Nagasaki atomic bomb survivors which have shown an increased incidence of these effects following low-LET (gamma) radiation exposures within 3 to 17 weeks in the gestation period. Comparable incidence was observed in Hiroshima atomic bomb survivors but at lower doses owing to the much greater neutron (high-LET) component of the radiation. However, as the UNSCEAR report points out, various studies of the effects of human embryonic exposure during radiological procedures, usually in the region of a few rad, have failed to show a significantly increased incidence of malformation.

The frequently observed sigmoid (S-shaped) dose-effect relationships for radiation damage of the embryo and fetus, the involvement of repair systems at the subcellular and tissue levels and the reduction of effect by reduction of dose rate for low-LET radiation, and theoretical considerations strongly support the existence of nonlinear (nonproportional) components in the dose-effect relationships and the existence of true dose thresholds (reference 6).

In regard to the question of potential contribution of background radiation to the "normal" incidence of effects under consideration here, the 1979 BEIR III Committee report (reference 16) concluded:

> The natural and man-made background radiation during gestation is so low in total magnitude and dose rate that it is not thought to be a factor in the normal incidence of congenital malformations, intrauterine or extrauterine growth retardation, or embryonic death.

C. RADIATION TERATOGENIC RISK FROM THE TMI ACCIDENT

The reporting of some small increase in incidence of a particular developmental abnormality in mice after an absorbed radiation dose (to embryo) of 5 rads delivered at high intensity during a developmental phase that is highly susceptible for induction of the malformation raises some question as to the magnitude of the absolute dose threshold, if any, for radiation induction of teratogenic health effect, at least for mice.

Because of this, two different approaches are used here in the assessment of potential teratogenic effect risk in the populations (off-site and on-site combined) within 50 miles of the TMI accident site -- the dose threshold approach and the nonthreshold ("stochastic") approach.

1. Risks According to Dose-Threshold Approach

Here it is assumed that the absolute dose threshold for radiation induction of increased frequency of any clinically significant teratogenic health effect in man is 2 rads absorbed dose to the embryo or fetus, regardless of the developmental stage and regardless of the dose rate. It should be noted that there are several highly conservative assumptions (erring in the direction of overestimation of risk) within that statement, given the assumption of a threshold in the first place.

For the energy of the gamma radiation involved in the TMI exposures, the internal dose to the embryo or fetus is taken to be one-half the external exposure dose (a conservative estimate of attenuation). Taking the maximum off-site individual external exposure dose to be either 100 mrem or 70 mrem, assuming the dose was received by a pregnant woman, the dose to embryo or fetus (50 or 35 mrem) would be well below the threshold dose of 2 rads. Similarly, taking the maximum on-site individual external exposure dose of 4 rems, assuming the dose was received by a pregnant woman, the dose to the embryo or fetus (2 rems) would be about equal to but not in excess of the dose threshold assumed.

On this basis, no case of clinically significant developmental abnormality may reasonably be expected as a result of the radiation exposure from the TMI accident.

2. Risks According to Nonthreshold ("Stochastic") Approach

In this approach, which may be regarded as an illustrative exercise, the risk is assessed in a manner similar to that applied in the assessment of radiogenic cancer risks. In view of the limitations of human data and the many assumptions which must necessarily be made, the risk estimate below is crude. In the attempt to ensure that error will be in the direction of overestimation of risk, extraordinarily conservative assumptions have been made.

It is assumed that the risk coefficient 1/1,000 live births/rad (or rem) to embryo or fetus, based on data at high doses and dose rates and for effects relatively susceptible to radiation induction, applies linearly (proportionally) and without dose threshold to any and all teratogenic effects and to any dose size and dose rate, regardless of the stage of embryonic or fetal development at the time of irradiation (i.e., as if susceptibility in all stages was equal to that in the stage of highest susceptibility). This assumed rate (1/1000) is roughly equal to approximately one-fifteenth of the "natural" incidence from all causes (1.5 percent).

On the basis of the assumed linear nonthreshold hypothesis the collective dose (person-rem) to the embryos and fetuses of pregnant women may be used to estimate the risk of teratogenic effect. Since the number of pregnant women, if any, in the on-site population (workers) is not likely to contribute significantly to the collective embryo-fetal dose calculated for the off-site population, the risk estimate based on the conservative collective exposure dose chosen for the off-site population can be taken to represent the total population (off-site and on-site combined) within 50 miles of the TMI accident site.

On the assumption of the 1.3 percent annual birth rate in the state of Pennsylvania (reference 18), approximately 28,000 births would be expected within a year after the TMI accident in the population of approximately 2,164,000 within 50 miles of the TMI plant site. The number of births of concern iri this assessment are those occurring within approximately 9 months (gestation time) after the TMI accident, i.e., 28,000 x 3/4 = 21,000 births (pregnant women).

The collective whole body external gamma radiation exposure dose of 3,000 person-rems to the off-site population, chosen for use in risk assessment in this report, is 50 percent greater than the 2,000 person-rems regarded as the best estimate of the actual collective dose by the Health Physics and Dosimetry (HP&D) Task Group. On the basis of 3,000 person-rems, the average individual exposure dose is 3,000 divided by 2,164,000 people equals 1.4 mrem. Applying the estimate of 50 percent attenuation, the average individual embryo-fetal dose would be 0.7 mrem. The collective embryo-fetal dose for the 21,000 pregnant women irradiated as a result of the TMI accident would then be 21,000 x 0.7 = about 14.7 rems. Applying the 14.7 rems to the risk coefficient 1/1000 births/rem (1/1000 person-rem) yields .001 x 14.7 = 0.015 case of developmental abnormality in the population (off-site and on-site) within 50 miles of the TMI accident site.

This value is very small despite the extraordinarily conservative assumptions made to err in the direction of overestimation.

On this basis, far less than one case, virtually no case, of developmental abnormality is reasonably expected in the population within 50 miles of TMI as a consequence of the TMI accident radiation.

In 1978, in Pennsylvania, 1.6 percent of newborns (2,395 of the 151,438 live births) were affected with congenital malformations or birth injuries. In those counties and localities within a 10-mile radius of Three Mile Island, 1.3 percent of newborns (178 of the 13,884 births) were so affected. These two figures are compatible with the generally accepted estimate that 1 to 2 percent of all newborns have a congenital malformation.

On this basis, the normally expected number of cases of congenital malformation in the population within 50 miles of the TMI plant within 9 months after the accident would be about 21,000 x 0.015 (0.01 - 0.02), or 315 (210 to 420).

Based on the conservative assumptions given above, and assuming that the risk coefficient 1/1000 rad (or rem) is indicative of average individual risk, the average individual risk of radiogenic developmental abnormality associated with the maximum on-site individual whole body gamma radiation exposure dose of 4 rems (2 rems to embryo-fetus) would be one chance in 500; that risk associated with the maximum off-site individual exposure dose of either 70 or 100 mrem (35 or 50 mrem to embryo-fetus) would be one chance in 30,000 or one in 20,000, respectively; that risk associated with the average off-site individual exposure dose of 1.4 mrem (0.7 mrem to embryo-fetus) would be about 1.4 chances in about one million.

In view of the risk estimates derived above for the TMI population, it will not be possible to detect qualitatively or quantitatively any teratogenic effect attributable to the radiation from the TMI accident.

REFERENCES

1. "Health Physics and Dosimetry," President's Commission on the Accident at Three Mile Island, October 1979.

2. Oakley, D.T., "Natural Radiation Exposure in the United States," EPA Report ORP/S1D 72-1, U.S. Environmental Protection Agency, Washington, D.C., 1972.

3. National Council on Radiation Protection and Measurements (NCRP), "Natural Background Radiation in the United States," NCRP Report No. 45, NCRP, Washington, D.C., 1975.

4. International Commission on Radiological Protection (ICRP), "Recommendations of the International Commission on Radiological Protection," ICRP Publication 26, Annals of the ICRP, Vol. 1, No. 3, 1977.

5. National Council on Radiation Protection and Measurements (NCRP), "Basic Radiation Protection Criteria," NCRP Report No. 39, NCRP, Washington, D.C., 1971.

6. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), "Sources and Effects of Ionizing Radiation-1977 Report," UNSCEAR, United Nations, N.Y., 1977.

7. Nuclear Regulatory Commission (NRC), "Reactor Safety Study. An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," Appendix VI, WASH-1400 (NUREG-75/014), NRC, Washington, D.C., 1975.

8. National Academy of Sciences (NAS) Advisory Committee on the Biological Effects of Ionizing Radiations (BEIR I Committee), "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," NAS, Washington, D.C., 1972.

9. National Council on Radiation Protection and Measurements (NCRP), "Review of the Current State of Radiation Protection Philosophy," NCRP Report No. 43, NCRP, Washington, D.C., 1975.

10. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), "Ionizing Radiation: Levels and Effects." Report E-72-IX 18), Vol. 11: Effects, United Nations, N.Y., 1972.

11. National Council on Radiation Protection and Measurement (NCRP), Draft report, "Influence of Dose and Its Distribution in Time on Dose-Effect Relationships for Low-LET Radiation," NCRP, Washington, D.C., 1979.

12. American Cancer Society (ACS), "Cancer Facts and Figures - 1979," American Cancer Society, N.Y., 1979.

13. Casarett, G.W., "Radiogenic Cancer Risk Estimation Models," Prepared for the Archives of the President's Commission on the Accident at Three Mile Island, 1979.

14. NRC-EPA-HEW Ad Hoc Population Dose Assessment Group. "Population Dose and Health Impact of the Accident at the Three Mile Island Nuclear Station. (A preliminary assessment for the period March 28 through April 7, 1979)," U.S. Government Printing Office, Washington, D.C., May 10, 1979.

15. National Research Council Safe Drinking Water Committee, "Radioactivity in Drinking Water," Chapter VII in Drinking Water And Health, National Research Council, Washington, D.C., 1977.

16. National Research Council Advisory Committee on the Biological Effects of Ionizing Radiations (BEIR III Committee), draft report, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiations," National Research Council, National Academy of Sciences, Washington, D.C., 1979.

17. National Academy of Sciences Advisory Committee on the Biological Effects of Atomic Radiation (BEAR Committee), "Report on Genetic Effects of Atomic Radiation," National Academy of Sciences, Washington, D.C., 1956.

18. Health Statistics Division, Department of Health, State of Pennsylvania, personal communication, 1979.

REPORT OF THE PUBLIC HEALTH AND SAFETY TASK FORCE

ON

BEHAVIORAL EFFECTS

BY

BEHAVIORAL EFFECTS TASK GROUP

Task Group:

Bruce P. Dohrenwend
(Task Group Head)
Department of Psychiatry
Columbia University

Barbara Snell Dohrenwend
School of Public Health
Columbia University

Jacob I. Fabrikant
University of California, Berkeley

Stanislav V. Kasl
Department of Epidemiology and Public Health
Yale University

George J. Warheit
Departments of Psychiatry and Sociology
University of Florida at Gainesville

Collaborating Researchers:

Glen S. Bartlett
The Milton S. Hershey Medical Center
The Pennsylvania State University

Rupert F. Chisholm
Graduate Program of Public Administration
The Pennsylvania State University Capitol Campus

Raymond L. Goldsteen
School of Public Health
Columbia University

Karen Goldsteen
Capitol Area Health Research, Inc.

John L. Martin
Program in Personality and Social Psychology
Graduate Center, City University of New York

October 1979
Washington, D.C.

TABLE OF CONTENTS

I. INTRODUCTION AND SUMMARY

The Charter for the President's Commission on the Accident at Three Mile Island states that, as part of its comprehensive study and investigation, it shall include, "an evaluation of the actual and potential impact of the events on the public health and safety and on the health and safety of the workers . . ." (Section 3 of the Charter).

The overall objective of the Behavioral Effects Task Group was to examine the effects on the mental health of the public and the workers directly involved in the accident at TMI-2. Of particular interest were the behavioral response of the workers and the population under stress during the accident. In examining effects on mental health, a distinction has to be made between short-term and long-term effects. Attention also has to be paid to the possible impact on the affected populations and workers of a variety of studies, either underway or planned.

The Behavioral Effects Task Group was created on June 18, 1979, and met for the first time as a group on July 23, 1979. The accident at TMI, however, took place between March 28 and April 10, 1979. Fortunately, during or shortly after the accident, several researchers from colleges and universities near the TMI site began sample surveys of the approximately 744,000 people living within 20 miles of TMI. Most of these studies employed reliable measures of psychological effects with small but carefully drawn samples of the general population and/or high-risk groups, such as mothers of preschool children within the general population. Each study represented the work of a single investigator or a small team of investigators who financed the undertakings mainly out of their own pockets or, occasionally, with the help of small sums from their college or university departments. These studies held out the best hope for identifying the immediate and short-term behavioral effects of the accident on the general population and several important groups within it.

To be of use for purposes of the Commission, the studies being conducted by local researchers had to be suitably focused and expanded. The general strategy of the task group was to locate studies of high-risk groups in the general population and to seek control groups from whom comparable data could be collected. Each comparison was selected in such a way as to provide strong clues about the mental health and behavioral effects of groups between the time of the accident in late March and early April and the time of the last data collection in July and August. No systematic research had been begun, however, with regard to the behavioral effects and mental health of the nuclear workers -- a group specifically mentioned in the charge to the task group as appropriate for study. We were able to add a study of the workers. The task group also was able to help expand data collection in ongoing studies of the general population and of mothers of preschool children, and to process the data for these studies and for a study of 7th, 9th, and 11th grade students.

"Mental health" is a broad topic, and the data and time available for our analyses made it possible to cover only narrow aspects.

Fortunately, although narrow, these aspects -- centering on measures of psychological distress, upset, and demoralization -- are important and appropriate to what is known about the most characteristic responses to stress situations. Moreover, the task group was able to construct reasonably reliable measures of several other important behavioral effects.

The report is based on surveys of about 2,500 persons from four different groups:

1. The general population of male and female heads of households located within 20 miles of TMI.

2. Mothers of preschool children from the same area and similarly drawn control sample from Wilkes-Barre, Pa., which is about 90 miles away.

3. Teenagers in the 7th, 9th, and 11th grades from a school district within the 20-mile radius of TMI.

4. Workers employed at TMI at the time of the accident and a control group of workers from the Peach Bottom nuclear power plant about 40 miles away.

In addition, an interview study was conducted of a sample of clients at community mental health centers. These individuals, most of whom were suffering from chronic mental disorders, provided valuable criterion information that could be used to identify unusually high scores on a measure of demoralization.

The study of household heads in the general population consisted of surveys of three different samples ranging in size from 50 to 380 persons. The first sample was drawn in April, directly following the accident; the second was drawn in May; and the third and largest in July. The mothers of preschool children from the TMI area were studied initially in a sampling in May and in an additional sampling in July, when a control sample of Wilkes-Barre, Pa., mothers with preschool children was added. The study of the teenagers was completed in May, just before the Memorial Day weekend. The last study -- that of the workers -- was begun in August.

The usual procedure in these studies was to draw strict probability samples of households and to conduct structured, half-hour interviews by telephone. The April and May studies of household heads, however, were conducted by mail questionnaires, and the study of the teenagers was conducted by questionnaires distributed in classrooms.

A core of similar measures of mental health, attitudes, and behavior were used in each study except for that of teenagers, which was limited to specific measures of distress developed for the study. The areas covered by measures in the other three studies were:

- living within versus outside the 5-mile radius of TMI;
- having preschool age children in one's family;

- recall of immediate upset at the time of the accident;
- staying in or leaving the TMI area at the time of the accident;
- demoralization since the accident;
- perceived threat to physical health;
- attitude toward continuing to live in the TMI area;
- attitude toward nuclear power, including TMI; and
- trust in authorities.

In addition, the study of the workers included measures of their concern about the future of their occupation, and their perceptions of hostility from the wider community. The large majority of the measures used in all studies were scales composed of multiple items and demonstrating satisfactory internal consistency reliabilities.

In all studies, the major measures of objective threat stemming from the accident were:

- living within versus outside the 5-mile radius of TMI; and
- having preschool age children in one's family.

For the workers, an added measure of objective threat was whether they worked at TMI rather than Peach Bottom at the time of the accident. For teenagers, the task group added whether or not their families left the area during the accident, because this was a factor outside their control.

In analyzing the results, a series of regression analyses were designed and conducted to assess the effect of each threat factor, while holding constant other threat factors and relevant variables, such as sex, age, and educational level. All of the effects reported were found in these analyses to be statistically significant at the 0.05 level or better using one-tailed tests.

Demoralization was sharply elevated immediately after the accident but dissipated rapidly among most groups. The task group estimated that a substantial minority -- about 10 percent of the household heads -- showed severe demoralization immediately after the accident that was directly attributable to the accident itself. These 10 percent are an increase of about two-thirds over the 15 percent or so who would ordinarily show such a high level of demoralization for a variety of reasons other than the accident. The most demoralized persons were household heads, teenagers living within 5 miles of TMI, and mothers and teenage siblings of preschool children. Teenagers who left the area temporarily were more distressed than those who did not. Levels of demoralization among workers at TMI were high in comparison to Peach Bottom workers and with males in the general population several months after the accident.

Although the perceived threat to physical health from the TMI accident was higher in the general population immediately after the accident than later, by July most people were reassured considerably. Workers at both TMI and Peach Bottom also expressed a fairly low level of concern about the threat in their work situation to their physical health. However, workers at TMI were more uncertain about health effects than those employed at Peach Botton. Households heads living within 5 miles of TMI were more uncertain than those living outside this range, and mothers of preschool children near TMI felt more uncertain than their counterparts in Wilkes-Barre, Pa.

Feelings of the population living within 20 miles of TMI about continuing to reside in the area were mixed and uncertain. Relatively unfavorable attitudes -- although still generally uncertain rather than negative -- were expressed by people living within 5 miles of TMI and by mothers of preschool children. The only group with somewhat negative attitudes were those at risk on two counts -- mothers of preschool children who live within 5 miles of TMI.

Attitudes toward nuclear power and reactivation of TMI-1 and -2 held by the general population living within 20 miles of the plant showed uncertainty, with a leaning toward negative feelings. Mothers of preschool children expressed the most negative attitudes.

Among people living in the 20-mile area around TMI, distrust of federal and state authorities and the utilities was high immediately following the accident. Although it was somewhat lower by May as nearly as can be estimated, it continued to be higher than the national average throughout the period of the study. Workers at both TMI and Peach Bottom, like the general population, expressed considerable distrust of federal and state authorities. They diverged from the general population, however, in expressing generally trusting attitudes toward the utilities.

Workers at both TMI and Peach Bottom expressed fairly low levels of concern about the future of their occupation. Similarly, both groups perceived that the people in their communities held less than positive attitudes toward them. Because there was no evidence of a difference between TMI and Peach Bottom on these matters, neither finding contributes to our understanding of the basis for the elevated level of demoralization among TMI workers that continued to be evident in August and through September, when the study ended.

In brief, the TMI accident had a pronounced demoralizing effect on the general population of the TMI area, including its teenagers and mothers of preschool children. However, this effect proved transient in all groups studied except the workers, who continued to show relatively high levels of demoralization. Moreover, the general population groups and the workers, in their different ways, showed continuing problems of trust that stem directly from the accident. For both the workers and the general population, the mental health and behavioral effects are comprehensible in terms of the objective realities of the threats they faced.

II. OVERVIEW OF PEOPLE, PLACES, AND TIMES

Table 1 presents a summary description of the people and places studied and times of the various data collection operations. The samples of male and female household heads from the general population and the special samples of mothers of preschool children were drawn at different times following the accident, starting with a small sample from the general population in April. They also were selected in such a way that the effects of distance from Three Mile Island could be analyzed. Within the TMI areas, the population within a 20-mile radius of TMI was sampled. The sample from the Wilkes-Barre area was about 90 miles away.

Strict probability sampling procedures were used in the Study of the general population to select households at random (April and May samples), or by place-stratified random sampling from telephone directories (July-August sample). In Pennsylvania, a minimum of 90 percent of the population have telephones; therefore, no marked bias should have been introduced by this procedure (see Appendix D on telephone interviewing). Unfortunately, in the telephone sample, there was no prior designation of whether the male or the female head of the household was to be interviewed, and as a consequence females are over-represented in the resulting sample.

The mothers of preschool children also were selected by strict probability sampling procedures. This time, however, the source was listings of birth announcements in the Harrrisburg and Wilkes-Barre, Pa., newspapers dating back to February 1977 and continuing through June 1979. The first sample from the TMI area was drawn in May, and interviewed by telephone. Later samples were similarly selected and interviewed during July and August in both the TMI and Wilkes-Barre areas.

The procedures for selecting respondents were different in the other studies. The study of teenagers involved pupils in the 7th, 9th, and 11th grades of the Lower Dauphin School District, which is in the vicinity of Middletown and Harrisburg, Pa. All classrooms participated in the study, which was conducted just before the Memorial Day weekend.

Similarly, the aim was to interview all of the workers at TMI and at the control plant, Peach Bottom, who were permanent employees at the time of the accident. However, this study was the last to be implemented in the field; interviewing, again by telephone, began late in August and was completed, for the most part, by the end of September. As Table 1 shows, the response rates were lower in this study, reflecting the limited time the task group had to make a sustained effort to reach all workers who were not readily available and/or willing to cooperate in an interview.

Although the response rates were lower for the study of the workers, they were quite similar for the TMI facility and for the Peach Bottom control facility. As Table 2 shows, the workers interviewed at both

TABLE 1: Completed Sample Sizes and Completion Rates According to Time of Study, Place of Study, and Type of Respondent

Dates in 1979	General Population: Male and Female Heads of Household within 20-mile Radius of TMI	Mothers of Preschool Children Sampled from Birth Announcements in Harrisburg Newspapers	Mothers of Preschool Children Sample from Birth Announcements in Wilkes-Barre Newspapers	TMI Workers	Peach Bottom Workers	7th, 9th, 11th Graders in Lower Dauphin	Clients of Community Mental Health Centers
Prior to 3/28	No studies in this period						
3/28 Accident - 4/10 Reopening of Schools	No studies in this period						
4/10-4/30	50 (.67)		--				
5/1-5/31	54 (.67)*	165 (.79)x''			--	632 (.91)	
6/1-6/30			--				
7/1-9/5	380 (.65)	260 (.79)^^	328 (.66)				198 (Sample of convenience)
8/20-9129			--	305+ (.57)+	258++ (.53)++		

*Overall completion rate for April and May combined.
**Overall completion rate for May, July, and August combined.
+Does not include 28 workers interviewed between 10/1 and 10/10 in a special followup study of a subsample of nonrespondents (see p. 15).
++Does not include 30 workers interviewed between 10/1 and 10/10 in a special followup study of a subsample of nonrespondents (see pp. 15, 50-51).
(Percents in parentheses indicate completion rates for each sample; usually about half to two-thirds of those not obtained were refusals, except among the nuclear workers, where refusals constituted 40 to 45 percent of the total number of persons with whom interviews were not obtained.)

N

TABLE 2: Comparison of Workers Interviewed and Not Interviewed by September 29, 1979

Worker Characteristic	Site			
	TMI		Peach Bottom	
	Interviewed (%)	Not Interviewed (%)	Interviewed (%)	Not Interviewed (%)
Supervisory Status				
Supervisor	35.0	25.9	39.5	16.3
Nonsupervisor	65.0	74.1	60.5	83.7
College Graduate	23.7	Not obtained	23.8	Not obtained
Sex				
Male	89.7	90.4	97.6	97.8
Female	10.3	9.6	2.4	2.2
Married	82.8	Not obtained	85.2	Not obtained
Age				
Less than 30	29.9	29.3	21.8	25.0
30-39	50.3	46.8	46.7	46.0
40-49	13.5	12.2	12.5	19.6
50 or more	6.3	11.7	12.1	9.4
Preschool Children	29.2	Not available	33.7	Not available
Distance of home from TMI				
5 miles or less	35.6	50.0	0.4	Not obtained
Located at TMI at time of accident	73.0	Not obtained	22.0	Not obtained
Total respondents*	(305)	(228)	(258)	(232)

*Bases for percents vary somewhat from totals shown because of missing data for some respondents for some variables.

facilities have quite similar demographic characteristics, except for expected differing variables -- distance of home from TMI and presence at the plant at the time of the accident. (Note that 22 percent of the Peach Bottom workers who were interviewed reported being at TMI during the accident. This was consistent with reports that some were called in to help in the crisis.) It is unlikely, therefore, that differences in mental health and behavioral effects between the two samples of workers can be explained by the problem of nonresponse.

There are, however, clear differences shown in Table 2 between those interviewed at either plant and those with whom interviews were not obtained by the cutoff date of September 29. Supervisors, for example, were considerably more likely to be interviewed than other workers in both plants. To investigate the problem further, a separate study of nonrespondents was conducted from October 1 to October 10, 1979, after the field work on which this report is based was completed. Small, representative samples of workers at TMI and Peach Bottom who refused or were not interviewed for some other reason in the main study were approached again and asked for an interview. The results from interwiews with 28 our of 50 former nonrespondents at TMI, and 30 out of 75 former nonrespondents at Peach Bottom, suggest that even if more time and money were available to raise the completion rates for the workers up to between 70 and 80 percent, the main findings presented herein would not be altered substantially.

The procedure for selecting the clients at community mental health centers was again different. The task group did not focus on either a whole population of patients or a strict probability sample of such a population. Rather, the clients interviewed were a "sample of convenience," consisting for the most part of persons with chronic mental disorders who were available, willing, and able to be interviewed by telephone (see Appendix D on telephone interviewing) or in person. They provide a criterion group whose responses indicate which scores show a high degree of demoralization.

HOUSEHOLD HEADS IN THE GENERAL POPULATION

The typical member of the large, general population sample interviewed in July and August was female, married, and a high school graduate who has not gone on to finish a 4-year college education. Less than 15 percent of this sample had not finished high school, and only slightly over this percent had finished 4 years of college or more. About one-third lived within 5 miles of TMI and 14 percent had preschool children.

This July-August sample was stratified in such a way as to over-represent lower educated households and households within a 5-mile radius of TMI. The smaller samples drawn in April and May were random samples, and males systematically were alternated with females in the households selected. The result was that males and females were almost equally represented. The educational level was considerably higher, because 49 percent of the April sample and 40 percent of the May sample were college graduates, and smaller proportions (16 percent in the April sample and 13 percent in the May sample) were living within 5 miles of TMI. Slightly older on the average than the July-August sample, these earlier samples of household heads had slightly smaller proportions of preschool children. In general, the April and May samples were highly similar to each other in demographic characteristics but showed differences of the types indicated with the larger samples of household heads interviewed in July-August.

MOTHERS OF PRESCHOOL CHILDREN

The samples of mothers of preschool children were, of course, much younger than the samples of household heads from the general population. The main difference from the Wilkes-Barre mothers, which is similarly self-evident, was that they lived roughly 80 miles nearer to TMI. The TMI mothers of preschool children had somewhat higher proportions of graduates of 4-year colleges than the Wilkes-Barre sample. There appeared to be little difference in the demographic characteristics of the TMI mothers of preschool children interviewed in May and those interviewed in July-August.

SEVENTH, NINTH, AND ELEVENTH GRADE STUDENTS

The sample of junior high and high school students ranges from 12 through 18 years of age. The sample of 632 students included 27 percent 7th graders, 36 percent 9th graders, and 37 percent 11th graders. The sample was fairly well balanced for sex, with 56 percent females and 44 percent males responding to the classroom-administered questionnaire. Over half of these students came from households in which the father had completed high school. About a third had fathers who had not completed high school, and about 20 percent had fathers who had had one or more years of college. About one-third of the students lived within 5 miles of the TMI plant, one-half lived between 6 and 10 miles of the plant, while the remaining 20 percent lived within 11 to 30 miles of the plant.

WORKERS

The survey of workers aimed to include all employees on the payroll of the Metropolitan Edison Company (Met Ed) when the TMI incident began on March 28, 1979. This group included all employees who were on permanent assignment at the Three Mile Island location when the accident occurred. The survey group did not include employees who were assigned temporarily to TMI during or following the accident. Contractor personnel also were not covered by the survey.

Permanent employees at the TMI plant fell into three categories: (1) bargaining unit employees; (2) supervisory employees; and (3) nonexempt employees. Names of employees in these three categories were arranged in a combined alphabetical list, and employees were contacted according to a number system designed to assure randomness in the order of initial contact attempts and equivalence of initial interviewer assignments.

Nuclear workers at the Peach Bottom Plant of Philadelphia Electric Company served as a comparison group. All employees permanently assigned to the Peach Bottom Plant comprised the study group. The same randomization procedure as that applied to the TMI employee list was used to determine the order of contact attempts with Peach Bottom workers, and equivalence of initial interviewer assignments.

As described earlier, and shown in Table 2, the demographic characteristics of the workers who were interviewed were similar. Note, however, that of the employees interviewed, less than 10 percent were women, disproportionately so at TMI. Because tests indicated that the exclusion of women did not change the results, they were included in all analyses.

III. STRATEGY OF DATA ANALYSIS

The task group was concerned with assessing mental health and behavioral effects as they varied with the threat factors at the time of the accident and during the course of the following five months. The task group did not have an ideal situation for doing so, because there was no pre-accident baseline on any of the measures of effect, and there were no perfectly matched control groups that were not exposed to the threat. Moreover, there were no repeated post-measures on the same respondents at various times during the months following the accident. Fortunately, however, meaningful comparison groups were selected, such as the Wilkes-Barre mothers of preschool children and the workers at Peach Bottom -- places quite far away from TMI. In addition, the investigations that were relied on were conducted at different times since the accident so that the task group could begin to piece together which effects were immediate, which had begun to dissipate, and which remained strong.

To conduct the statistical analyses, a general linear model was used which allowed the assessment of the effect of one factor while holding the other relevant factors constant. Thus, for example, when reporting on an effect due to distance of a person's home from TMI, the task group controlled for having a preschool child in the family and various characteristics of the person, such as age, sex, marital status, and level of education, which might have been confounded with distance of the person's home from TMI. The particular procedure variously has been called "dummy variable multiple regression analysis" and "non-orthogonal fixed effects analysis of variance."

All of the effects reported were found to be significant statistically at the 0.05 level or better using one-tailed tests. Because of the large number of tests that were conducted and the lack of independence of the behaviors and attitudes being studied, the true probability of type one errors -- that is, falsely rejecting the null hypothesis -- may be somewhat greater than 0.05.

IV. THE GENERAL POPULATION AND MOTHERS OF PRESCHOOL CHILDREN

MEASURES

The Main Measures of Threat

At 12:30 noon Friday, March 30, Gov. Richard Thornburgh advised pregnant women and preschool age children to leave the area within 5 miles of TMI. He reaffirmed this advice at a press conference later that evening. No comparably authoritative definition of the chief targets of the threat was made before or after this message. Accordingly, the two major measures of threat that were emphasized were:

1. living within 5 miles of TMI; and

2. having one or more preschool children.

In so doing, the task group did not wish to imply that Governor Thornburgh created a threatening situation; rather, it was suggested that his statement narrowed and focused it.

Note that the task group accepted the respondent's report of the distance of his or her home from TMI. A survey conducted for the Nuclear Regulatory Commission (NRC) found that some people who lived more than 5 miles from TMI reported themselves as living within 5 miles (reference 8). If this error occurred in the survey, it could inflate relations between distance from TMI and mental health effects if, in addition, those who were most upset and otherwise affected were also most likely to underestimate the distance of their home from TMI. This information was not available for the task group to check whether there were errors in the respondents' estimates of the distance of their homes from TMI. At the same time, a consistency between the NRC results and the task group's concerning the proportion of people living within 5 miles of TMI who left the area argues against assuming gross misreporting by our respondents.

The Main Measures of Mental Health and Behavioral Effects

One of the most prominent behavioral effects was leaving the area. The task group was able to develop other measures as well from the interview and questionnaire material gathered in the studies of the general population and mothers of preschool children:

- recall of the personal "upsettingness" of the accident at the time it occurred;

- demoralization;

- perception of the threat to physical health;

- attitude toward continuing to live in the TMI area;

- attitude toward nuclear power, in general, and TMI, in particular; and

- attitude of trust or distrust toward authorities.

A full description of these scales is provided in Appendix A, which includes the internal consistency reliabilities of the five, multiquestion scales for which they could be calculated in the various samples from the general population, the mothers of preschool children, and the clients of community mental health centers. All reliabilities were adequate for research purposes and some were more than adequate.

RESULTS

The scores on the demoralization scale of community mental health centers clients were used as an indicator of the points at which that scale indicated severe demoralization. Because of differences in the way men and women express their feelings, our procedure was to call scores above the mean for male mental health center clients as an indication of ***severe*** demoralization in male respondents in general, and scores above the mean for female clients as an indication of severe demoralization in females in general.

How Upset Were People at the Time of the TMI Accident?

On the average, people living in the 20-mile area around TMI rated the accident fairly high on an 11-point scale of least to most upsetting at the time. The midpoint on this scale was 5, and the average rating by these respondents was 7.4. As would be expected if people were indeed rating the extent to which they were upset at the time of the accident rather than their then-current level of upset, there was no change in this average between earlier and later interviews.

Women were found to be more upset than men, and people under 65 years of age were more upset than older people. However, all groups averaged above the midpoint on the scale.

Over and above these differences related to personal characteristics, people with a preschool child living in the area around TMI were more upset than mothers living at a greater distance in Wilkes-Barre. In general, although people in the area found TMI a relatively upsetting event no matter what their circumstances, the most upset were those who could infer from advice given about evacuation and safety precautions that they were in danger on two counts -- living relatively close to TMI and having a child in the vulnerable age range.

Who Left the TMI Area at the Time of the Accident?

On the basis of our study of the general population, the task group estimated that 52 percent of the people living within 20 miles of TMI left the area at the time of the accident -- the majority of them on Friday, March 30. As shown in Table 3, the proportion who left differed between men and women, and by marital status, age, and education. Table 3 also shows that, over and above these differences related to personal characteristics, the decision to leave was influenced by the distance of the person's home from TMI. Although the basis for the estimation

TABLE 3: Estimates of Proportions of Persons in the Population Living Around Three Mile Island Who Left the Area at the Time of the Accident

Type of Person	Percent Who Left
Men	41
Women	57
Married	57
Not Married	38
Less than 65 years old	53
65 or older	42
Not a college graduate	59
College graduate	50
Condition Related to TMI	
Home 5 miles or less from TMI	62
Home more than 5 miles from TMI	48
Preschool child in family	77
No preschool child in family	48

differs, our finding that 62 percent of those living within 5 miles of TMI left was consistent with the estimate in the study done for the NRC that 66 percent of households within a 5-mile radius of TMI contained at least one evacuee; the same study found that the proportion of households in which some members evacuated and others did not was small.

The decision to leave was influenced not only by distances of the person's home from TMI, but also by whether there was a preschool child in the family -- presumably as a consequence of Governor Thornburgh's advice on March 30 that preschool children within 5 miles of TMI should leave the area. Further evidence of the impact of this advice is shown in Table 4. Of those in the general population who left, less than 5 percent left before March 30 and the majority (59.5 percent) left on that day. Table 4 also shows that among the 72 percent in the sample of mothers of preschool children who left the TMI area, almost two-thirds left on March 30.

How Demoralized Were People in the TMI Area?

Demoralization is a common distress response when people find themselves in a serious predicament and can see no way out (reference 9). Sometimes, this level of distress can approach that shown by persons suffering form mental disorders (reference 5). On our measures of demoralization, the overall mean was 28.3 for clients of community mental health centers, most of whom were suffering from chronic mental disorders. For the female clients in our sample, the mean was about 30; for the males, about 25.

On the average, demoralization in the community never reached the level of severity of the clients of the community mental health centers. It was, however, far higher on the average in the sample interviewed in April, closely following the accident, than in the samples interviewed in later months.

Moreover, 26 percent of those interviewed in April showed severe demoralization (scores above 30.46 for females and above 25.56 for males). These scores were similar to the scores of the more demoralized clients in the sample from mental health centers. In view of the stringency of the definition of what constitutes severe demoralization, the estimate should be regarded as conservative. In contrast to April, during May and later months, 15 percent or fewer persons in the general population group scored above the means for the male and female mental health center clients. This difference between April and later months suggests that a substantial minority -- perhaps 10 percent -- experienced severe demoralization by the above definition at the time of and in the 2 or 3 weeks following the accident that was directly attributable to the accident itself.

Combining interviews across the entire period of the study, it was found that the level of demoralization was higher among those living within the 5 miles of TMI than among those living at the greater 20-mile distance covered by the general population study. Almost a quarter (22 percent) of those living within 5 miles of Till scored above the mental health center clients' mean, whereas only 15 percent of persons living at a greater distance had demoralization scores that high.

TABLE 4: Estimates of Proportions of General Population Sample and of Sample of Mothers of Preschool Children Living within 20 Miles of TMI who left on Each Day during the Accident

Day	General Population Sample (13% have preschool children)	Sample of Mothers of Preschool Children
	(%)	(%)
3/28	2.4	2.0
3/29	2.4	6.2
3/30	59.5	65.8
3/31	17.0	14.0
4/1	10.5	7.8
4/2	4.9	3.6
4/3	3.2	0.7
Percent who left	51.8	72.4
Percent who stayed	48.2	27.6

Consistent with findings of previous studies, it also was found that men and people who were currently married scored lower on the demoralization scale than women and those not currently married.

Was the TMI Accident Perceived as a Threat to Physical Health?

Scores on the multiquestion measure of perceived threat to physical health from the TMI accident and radiation ranged from 1 to 3, with 2 the midpoint, indicating uncertainty about the matter. For the general population sample intervimed in April shortly after the accident, the mean was 1.85. This level of perceived threat declined fairly steadily over the interview time to 1.68. Although some uncertainty remained, people were becoming more reassured.

Men and women differed, with women perceiving more threat to their health than men. People in different age groups also differed, with the perception of threat generally declining with age. However, on the average, both women and younger people scored below the uncertainty point on the scale.

Over and above sex and age differences, those living within 5 miles of TMI were less certain that their physical health was not affected by the accident than those living at a greater distance. This difference in opinions held by those living within 5 miles and those living further away was found both in the general population and among mothers of young children living in the area of TMI. Realistically, mothers living still further away in Wilkes-Barre felt even less threatened on this count than mothers living around TMI.

Attitude Toward Continuing to Live in the TMI Area

In the general population, the average score on a measure of whether the individual devalues the area as a result of the TMI accident and would like to move away was just on the side of the uncertainty point, favoring to remain in the area. Scores on this multiquestion scale ranged from 1 to 3, with an uncertainty point of 2, and the average score in the general population sample was 1.90.

Men and women differed, with women holding more unfavorable attitudes, although still, on average, favorable toward continuing to live in the TMI area. The attitudes of people in different age groups also differed. The youngest people, in their 20s, were the least favorable; the oldest, those 75 years or older, were the most favorable; in between, there was a fairly regular increase in favorability with age. All but the youngest group -- whose average was just above the uncertainty point -- were generally favorable toward continuing to live in the TMI area.

People in the general population sample who had a preschool child in the family held more unfavorable attitudes toward continuing to live in the area than those without a child in this age range. Their average score was near the uncertainty point, rather than favorable. Reflecting the effect of having a preschool child found within the general population, the mothers of preschool children in the TMI area who were sampled separately also had an average score near the uncertainty point -- at 2.03.

Within the sample of mothers, those who had not graduated from college had a less favorable attitude (an average score of 2.10) than college graduates whose attitude on the average was favorable. In addition, mothers living within 5 miles of TMI had a more unfavorable attitude than those living further away. The average score in the latter group was at the uncertainty point, but the average in the former groups was in the unfavorable range -- at 2.37. In contrast with this difference, distance from TMI had a negligible influence on attitudes toward living in the area in the general population sample. Thus, the only people whose attitudes toward continuing to live in the TMI area tended to be negative were those who could infer from advice given at the time of the accident about evacuation and safety precautions that they were in danger on two counts -- living relatively close to TMI and having a child in the vulnerable age range.

Attitude Toward Nuclear Power Including TMI

In the general population living in the TMI area, the average score on the multiquestion measures of attitude toward nuclear power and restarting of TMI-1 and -2 was in the unfavorable range. Scores on this scale ranged from 1 to 3, with 2 being the uncertainty point; the average score in the general population sample was 2.23. Although comparisons from surveys using somewhat different questions can be hazardous, the results of a national poll summarized by Mitchell (reference 13) suggest that on the issue of nuclear power, people in the TMI area did not differ from the rest of the country in being uncertain and divided. In the national poll (taken in May), 38 percent reported that they had not made up their minds, 36 percent described themselves as supporters, and 26 percent as opponents of nuclear power.

On the average, women in the TMI area reported more negative attitudes than men. Attitudes in the general population in the area also varied, depending on whether the person had a preschool child; those with children in this age range had more negative attitudes on the average. Furthermore, in a sample of women with preschool children, those who did not graduate from college had more negative attitudes than those who did. Among the relatively favorable groups -- men, people without preschool children, and mothers of preschool children who were college graduates -- only men had an average score indicating a leaning toward favorable rather than unfavorable attitudes toward nuclear power.

Trust in Authorities

Individual responses to the scale of trust in authorities, including federal and state officials and utility companies, covered the full range -- from complete trust (score of 1) to total distrust (score of 3).

For the sample interviewed in April, the tendency was to lean strongly toward distrust. This level of distrust appears to be higher than that found in national polls taken in April and early May (reference 13). Although the questions on this topic in the two pools were not identical to the task group's, questions somewhere between nearly one-half and a substantial majority of respondents gave the trusting rather than the distrustful response.

The level of distrust in the TMI area declined after April, but the decline was very gradual. The tendency as of July and August was for opinions to lean, on the average, toward distrust. Insofar as these results can be compared with the responses to somewhat different questions asked on the national polls, distrust in the TMI area seems to have remained above the national level. Elevation of distrust in authorities among people in the TMI area is also suggested by the differing scores between the mothers of preschool children interviewed in the TMI area and those in Wilkes-Barre, with the TMI-area mothers significantly higher on this measure.

Distrust was greater among women than among men. Comparing age groups, it was the strongest among people in their thirties, declining steadily with increasing age, but also lower among people under thirty. However, both sexes and all age groups scored, on the average, above the uncertainty point on the measure, indicating a tendency to distrust authorities.

MAIN CONCLUSIONS

The amount of immediate and, fortunately, short-lived demoralization produced by the accident among household heads, in general, and mothers of preschool children, in particular, in the TMI area should not be underestimated. The increase in demoralization at the time of, an in the month following, the accident initiated on March 28 was sharp.

The task group estimates that, as a direct effect of the accident, approximately 10 percent of the April general population sample experienced demoralization as severe as that reported by persons suffering from chronic mental disorders. Note that this is not to say that 10 percent of the sample became mentally ill as a result of the accident. Rather, their demoralization at the time was analogous to a short elevation in body temperature; such an elevation is a clear sign that something is wrong. Persons with psyahiatric disorders frequently show such elevations on measures of demoralization. So do psychiatrically normal people caught in situations of extreme stress.

Note that the decline over time in symptoms indicating demoralization was inconsistent with one explanation of elevation of symptoms among people in the TMI area -- that symptoms developed as a secondary effect of the filing of law suits claiming that people's health was damaged by the TMI accident. If this were so, symptoms should have remained high or even have increased after April, when such suits began to be filed in connection with the TMI accident.

On the contrary, the reality of the objective stress situation in which people found themselves must be underlined. They were reacting to uncontrollable circumstances that posed a clear and major threat so far as the available information indicated. This is evident in the higher levels of demoralization shown by persons living within 5 miles of TMI or having preschoool children. They were told that their situation was more threatening by a respected source of information, the governor, who advised them to leave the area. Sharp elevation of demoralization in situations of severe objective threat and its rapid dissipation when the threat diminishes was consistent with most of the firm findings in reactions of previously normal persons to extreme situations such as combat during wartime and natural disasters (e.g., references 3, 4).

Although the unusually high levels of psychological demoralization apparently subsided after April 1, some of the other behavioral effects of the accident did not dissipate so rapidly. People gradually became more reassured about the threat of this accident to their physical health. Distrust of authorities, however, although declining sharply after April, remained relatively constant from May on. It still is at a level that shows, on balance, more distrust than trust of government and utility companies so far as information about and policy toward the safety of nuclear energy are concerned.

V. THE STUDY OF SEVENTH, NINTH, AND ELEVENTH GRADE STUDENTS

MEASURES

The Main Measures of Threat

With regard to 7th, 9th, and 11th grade students, three main threat factors were identified as having potential for elevating psychological distress and physical symptoms. Two of these threat factors are the same as those identified in the previous samples: (1) living within 5 miles of the power plant; and (2) having one or more preschool children in the household. The third threat factor is whether or not they left the area during the accident.

In the studies of the general population and mothers of preschool children, the task group's approach was to examine the factors that influenced whether or not they left the area. However, in studying the effects of the accident on these adolescents, leaving or staying in the area was largely a matter over which they had little influence. Therefore, the act of leaving or staying in the area was taken as an additional characteristic of the TMI incident for these young people. The question posed was whether or not temporarily leaving their homes served to increase or decrease the amount of stress these young people experienced; conceivably, it could go either way.

The Main Measures of Mental Health and Behavioral Effects

Toward the end of the questionnaire, students were asked to rate each of the following on a five-point scale: (1) worry, (2) concern, (3) disturbed, and (4) anxious. They first rated how they felt at the time of the accident and, on the next page, how they had felt since the accident. Thus, a self-perceived distress measure was obtained.

Students also were provided with a list of 10 physical symptoms, such as sore throat and sleep problems, and were asked to check any symptoms they may have had during the time of the accident -- March 28th through April 11th. The number of checks were added together to arrive at a symptom score for each student. (A full description of these scales is provided in Appendix B. The first is a measure of psychological distress, the second a measure of psychosomatic distress.)

RESULTS

The teenagers in the 7th, 9th, and 11th grades in lower Dauphin County were studied at the end of May, as indicated in Table 1. No surveys were conducted with samples of these students either before or after that date. It was necessary, therefore, to rely more on the students recall of their distress and symptoms at the time of the accident in contrast with how they had felt since the accident than was the case for the studies of adults in the general population. Nor were contrast groups available, as in the study of mothers of preschool children and the workers. Focus, therefore, was solely on contrasts in threat associated with living within 5 miles of TMI or further away, having preschool siblings or not, and being in a family that left the TMI area during the crisis or in one that stayed.

<u>How Much Psychological Distress did the Students Experience During the TMI accident?</u>

On the scale combining reports of worry, concern, disturbance, and anxiety, scores ranged from 1 signifying psychological well-being, to 5, indicating maximum psychological distress, with 3 as the neutral mid-point. The students on the average reported a score of about 3.25 for the time of the accident. Moreover, a quarter of them scored 4 or more on this scale.

There was no difference between 7th, 9th, or 11th graders in the level of psychological distress during the accident. However, somewhat higher levels of distress were reported by students living within 5 miles of the power plant. An even higher level of distress was found in students who had a preschool sibling; they averaged around 3.75, in comparison to those who did not have a preschooler in the home, who averaged around 3.12.

It also was found that there was an increase in level of psychological distress for those students whose families left the area. They averaged around 3.50 in comparison to 3.0 (the neutral point) for those who did not evacuate the area. In addition, it was found that females reported higher levels of concern in comparison to males -- 3.50 and 2.75, respectively. Hence, during the accident, students in general tended to experience some psychological distress, and distress tended to be more pronounced for students in the more threatening circumstances.

<u>How Distressed Have the Students Felt Since TMI?</u>

Students also were asked about their level of worry, concern, disturbance, and anxiety since the TMI accident. This second measure of psychological distress had identical scale properties as the first, with a neutral point of 3 in a range from 1 to 5.

Overall, the average level of distress since the accident was approximately 2. This value did not differ across the three grade levels. There was a sharp drop in the level of distress within 2 months of the occurrence of the accident for students in all three grades. The assurances that have come from authorities apparently had helped in reducing these teenagers' psychological distress over the accident.

However, there are two groups of students from whom this dissipation of distress was not quite so clear. When we compare the group of students who have a preschool sibling with those who do not, it was found that their level of distress had not decreased to the student average of 2. Instead, they scored just over 2.25. Similarly, it was found that having left the area during the accident reduced the dissipation effect, such that for those who left, their average concern since the accident was also at 2.25 compared with those who did not leave, whose average score was 1.75. It is interesting to note that those who stayed in a potentially hazardous area showed significantly lower levels of psychological distress both during the accident and in the 2 months following the accident, compared with those who left the area. The sex difference noted earlier continued to emerge, with females scoring higher in levels of distress since TMI, compared with males.

Was Distress Accompanied By Somatic Symptoms?

The students were asked to report the occurrence of any 10 possible symptoms commonly associated with stress in youngsters. An additional category of "other" was included in case they had experienced a somatic problem not included in the list. They were asked to report the occurrence of these symptoms during the period from March 28 to April 9. The number of symptoms checked were summed to compute a scale score for each student. Thus, the scale values could range from zero to 11. In fact, no student had a somatic symptom score above 8.

The average number of symptoms reported by the entire sample was one. This small average value is characteristic for all group comparisons that were made. Correlations do indicate, however, that as psychological distress increases, so does the number of somatic symptoms experienced, but that high levels of somatic symptomatology are relatively uncommon. Small but significant increases were found in the number of symptoms reported by two of the high-risk groups: students living within 5 miles of the TMI plant and those who left the area reported more symptoms compared with those who live further away and who did not leave the area. Somatic symptoms were especially prevalent in females and in youngsters in the lower grades.

MAIN CONCLUSIONS

The youth studied appeared to have reacted to the accident in ways remarkably similar to the adults. They were psychologically distressed by the accident at the TMI plant. Their distress was acute and diminished rapidly within 2 months of the accident. The groups who experienced the highest levels of distress were those who had preschool siblings, who live within 5 miles of the plant, and whose families left the area. For those who had a preschool sibling and those who left the area, the level of psychological distress had not dissipated to the neutral level after 2 months, as it had for the other groups. The point to be emphasized, as in the studies of adults, is that the reactions of distress were related to the realistic threat that the youngsters faced. These reactions tended to disappear as the threat receded in time.

VI. THE STUDY OF THE WORKERS

MEASURES

The Main Measures of Threat

The primary indicator of threat to the workers was the contrast between being employed at TMI, as opposed to being employed at Peach Bottom. Note also was taken of whether TMI workers reported being at TMI-2 during the accident between March 28 and April 11. In addition, the task group included the two conditions outside of the work situation that had been included in all other studies: living within 5 miles of TMI; and having a preschool child.

The Main Measures of Mental Health and Behavorial Effects

The measures were designed to parallel those used in the studies of the general population living around TMI and the mothers of preschool children, insofar as possible. Therefore, they included a measure of upset at the time of the accident, as well as before and currently -- the same measure of demoralization as used in other studies, a measure of perceived threat to physical health, and questions about trust in authorities.

In addition, two measures suited to the workers' situation were included: (1) certainty about the future of their occupation; and (2) perception of hostility from the community. A full description of these scales is provided in Appendix C.

RESULTS

How Upset Were the Workers?

The workers were asked whether they had had any periods of extreme upset during three periods: 6 months before the accident; the crisis from March 28 through April 11; and currently. Before the accident, there was no difference between workers at TMI and those at Peach Bottom. In contrast, for the period of the accident, a higher proportion of TMI than Peach Bottom workers reported being extremely upset. As shown in Table 5, however, this difference between workers at the two sites had largely disappeared by the time they were interviewed.

How Demoralized Were the Workers?

Demoralization is common distress response when people find themselves in a serious predicament and can see no way out. On this measure, the average score of TMI workers (12.7) was higher than the average of 10.9 among Peach Bottom workers. By comparison, it was found that the average score on this measure for men in the general population around TMI was 9.7, and that after early elevation, demoralization appeared to be largely dissipated by July and August, when most of the interviews were conducted in the general population. This comparison indicates that Peach Bottom workers may have been slightly demoralized but that TMI workers were clearly still more demoralized than men in the

TABLE 5: Percents of Workers at TMI and at Peach Bottom Reported Periods of Extreme Upset Before and During the Accident and at Present

Location of Plant	Time of Periods of Extreme Upset		
	During the 6 Months Before 3/28/79 (X)	Anytime During Crisis (3/28-4/11/79) (X)	At the Present Time (X)
TMI	10	28	16
Peach Bottom	11	17	13

general population in late August and September, when they were interviewed.

There also were differences in the level of demoralization between supervisors and nonsupervisors at TMI. The average level of demoralization of supervisors was 10.6 -- only slightly higher than the average of males in the general population in the area. Nonsupervisors at TMI were more demoralized than their supervisors, with an average score of 13.8. By contrast, the average score of nonsupervisors at Peach Bottom was significantly lower -- 11.1.

Over and above the differences between supervisors and nonsupervisors, education, age, sex, and marital status influenced the level of demoralization. Workers who were college graduates were less demoralized than those who had not graduated from college. In terms of age, workers under 40 were the most demoralized and those over 50 the least, with those in their forties in the intermediate range. Consistent with findings from other comparisons, women were more demoralized than men, and people not married were more demoralized than those who were currently married.

Was the TMI Accident Perceived as a Threat to Physical Health?

This scale was designed to indicate the extent to which the workers felt that their health was endangered by the TMI accident. Scores on this measure ranged from 1, **indicating** low concern, to 3, indicating high concern, with an uncertainty point of 2. Realistically, TMI workers reported more concern than Peach Bottom workers about work-related threats to their health, and those who were at TMI during the accident reported more concern than those who were not. However, the means of workers at both TMI and Peach Bottom -- 1.59 and 1.32, respectively -- were below the uncertainty point, indicating that on the average, the workers were not seriously concerned about their health. In this respect, they were like the general population, where scores on an indicator of concern about the accident as a threat to physical health were also in the low range.

Within this range -- between feeling safe or uncertain -- non-supervisors were more threatened than supervisors, and younger workers were more threatened than older ones. However, even the most threatened group -- workers under 30 at TMI -- had an average score of 1.66, which was below the uncertainty level.

Were the Workers Uncertain About the Future of Their Occupation?

This measure was designed to assess the extent of the workers' insecurity about the future of their occupation in nuclear power plants. A high level of insecurity might be one basis for demoralization. However, although workers at TMI felt less certain than workers at Peach Bottom about the future of their occupation, responses in both groups indicated that there was little feeling of insecurity on this count among the workers at either site. The scale ranged from 5, indicating most uncertain, to 1, indicating certainty about the future; the average score of Peach Bottom workers was 1.62, and the average of TMI workers was 2.19.

How Hostile Does the Community Seem to the Workers?

This scale was designed to describe the extent to which the workers believed that the public was critical and unappreciative of their work. There was no evidence of a difference on this measure between workers at TMI and those at Peach Bottom, with both groups indicating that they perceived some hostility in the community. Specifically, the scale ranged from 1, indicating perception of greatest appreciation, to 10, indicating perception of greatest hostility, with a neutral point of 5.50. The average score of TMI workers was 6.60 and of Peach Bottom workers 6.26. However, within both sites, the extent to which the community was perceived as hostile decreased with the increasing age of the worker.

Trust in Authorities

An attempt was made to construct a scale for the workers that would be comparable to the trust of authorities scale used for the studies of the general population and mothers of preschool children. The two questions in the workers' interview -- whether they felt information from state and federal officials was truthful, and whether they thought their employer kept them fully informed about risks and unhealthful conditions of their job -- were uncorrelated.

Responses to the question concerning state and federal officials suggest that the workers' attitude was similar to that found in the general population and among mothers of preschool children. Slightly less than half said that they did not trust the information from state and federal officials, about a quarter were uncertain, and less than one-third expressed trust.

On the other hand, when asked whether their employers were keeping them fully informed about the risks involved in their job, the overwhelming majority of both TMI and Peach Bottom workers responded positively. Although this proportion was lower at TMI (73 percent) than at Peach Bottom (85 percent) the sharpest contrast is between the trust expressed by most of the workers and the distrust expressed by the general population in relation to the utility companies.

The Problem of Nonresponse

A separate study was conducted of small subsamples of nonrespondents at TMI and Peach Bottom following the completion of the main interview study reported above. These subsamples were drawn from the groups of workers who previously had refused or were otherwise not available for an interview. The results of the study of nonresponse indicate that the main findings presented above would not be changed substantially even if the task group had been able to improve the completion rates. For example, it was found that prior nonrespondents who were interviewed in this special study did not have lower scores on the demoralization scale than those previously interviewed. If contrary to the actual finding that the previous nonrespondents had had lower scores, this fact could have called into question the conclusion that levels of demoralization had remained high among the workers by comparison with men in the general population.

A comparison of results obtained in interviews conducted before September 15, results obtained in interviews between September 15 and September 30, and results from the study of previous nonrespondents in October did reveal an interesting difference. There was a tendency in Peach Bottom, especially marked for supervisors, to score higher on the demoralization scale in the more recent interviews. Whether this was simply a sampling fluctuation, or, instead, represented a real change at Peach Bottom is unclear from the data. To the extent that the difference represented a real change, the result suggests that the predicament of nuclear workers in general had begun to affect the supervisors at Peach Bottom.

MAIN CONCLUSIONS

One of the most important findings with regard to the workers was that two factors that affected the morale of other adults and teenagers in the TMI area did not show independent effects on the morale of the workers. These were living within 5 miles of TMI and having preschool children. Moreover, the workers did not show distrusting attitudes toward plant authorities. Clearly, they were not threatened in the same way as most groups in the general population. Yet, these workers at TMI, especially the large majority who were nonsupervisory, were showing higher levels of demoralization in September than their counterparts at Peach Bottom and than male household heads in general in the TMI area. Like Peach Bottom workers, TMI workers believed that less than positive attitudes were held toward them by people in the wider communities. This belief was not unrealistic if attitudes in communities around TMI were like those reported in a national poll conducted in April, when 55 percent of respondents blamed the accident on human error rather than on government or the power industry (reference 13).

The salient fact was that the TMI workers' predicament had not been resolved. Their level of demoralization had not returned to normal following the accident, as had been the case with other samples of adults in the general population of the TMI area.

VII. FURTHER RESEARCH

One of the charges to this task group was to evaluate the possible impact on the affected populations and the workers in the TMI area of a variety of studies either under way or planned. This charge stemmed, in part, from the concern that the people being studied would come to feel that they were being used for psychological research. Available evidence indicates that this was not the case with the samples of persons who participated in the studies on which this report has relied. Questioning by the field supervisor of the interviewers involved in these studies about the reactions of those who participated failed to yield a single mention of such a response. Rather, the participants often expressed appreciation at being contacted for the interview and given a change to express their feelings and attitudes.

The charge also asked that a distinction be made between short-term and long-term mental health and behavioral effects. Given the timeframe for this research, it was obvious that the task group could not evaluate how long some effects will persist, nor what levels of upset, distress, and demoralization could recur should another threat appear. In addition, given the brief time for this research, it was not possible to follow up the assessments of some aspects of the mental health and behavioral effects with more intensive study of the consequences to the groups and individuals at highest risk of upset, distress, and demoralization. Moreover, a number of groups -- the decision-makers, for example, and persons who left the area as a result of the accident and have not returned -- were not studied.

The present report by necessity has had limited goals and scope. There do remain important areas deserving further study, which touch on vital concerns regarding trust, vulnerability, and institutional capabilities for identifying and dealing with the psychological and behavioral consequences of situations such as that associated with the TMI-2 accident.

APPENDIX A

DESCRIPTION OF SIX MEASURES OF MENTAL HEALTH AND BEHAVIORAL EFFECTS USED IN THE STUDIES OF THE GENERAL POPULATION, MOTHERS OF PRESCHOOL CHILDREN, AND CLIENTS OF COMMUNITY MENTAL HEALTH CENTERS

RATING OF IMMEDIATE UPSET

How upsetting was the TMI incident? Please rate it on the 0-10 scale. 0 means least upsetting and 10 means most upsetting.

0 1 2 3 4 5 6 7 8 9 10

Scoring note: This item is scored just as the subject was asked to score it.

Reliability: Since this is a single item scale, we cannot check its internal consistency reliability. Nor were data collected on its test-retest reliability.

Interpretation: This scale is an attempt to measure the subjectively experienced immediate "upset" resulting from the accident. It is unfortunate that it consists of only one item. However, this item was preceded by the question: "In the last two years, have you experienced any major life changes?" Please put a check beside all of the following experiences which have occurred to you in the last two years." A list of 10 events including "Job change (what?)," "Death in the Family (relationship to you," "Serious Illness (heart attack, etc.)." The individual was asked to rate the upsettingness of each of the events he or she experienced on the ten-point scale later used to rate the upsettingness of the TMI accident. Each person therefore had context for the TMI upsettingness rating. This should markedly increase the validity of the TMI rating of upset. If so, it could provide a useful measure of immediate distress to contrast with the demoralization items that followed it in the questionnaire and that refer to longer term effects in the period since TMI and the time of the interview.

DEMORALIZATION

1. How often since TMI have you had times when you couldn't help wondering if anything was worthwhile any more? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

2. Since TMI, how often have you felt that nothing turns out for you the way you want it to, would you say (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

3. Since TMI, how often have you felt completely helpless? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

4. Since TMI, how often have you felt completely hopeless about everything, would you say? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

5. Since TMI, how often have you feared going crazy, losing your mind? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

6. Since TMI, how often have you had attacks of sudden fear or panic? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

7. Since TMI, how often have you feared something terrible would happen to you? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

8. Since TMI, how often have you felt confused and had trouble thinking? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

9. Since TMI, how often have you had trouble concentrating or keeping your mind on what you were doing? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

10. Since TMI, how often have you been bothered by feelings of sadness or depression, feeling blue? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

11. Since TMI, how often have you been in very low or low spirits? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

12. Since TMI, how often have you felt like crying? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

13. Since TMI, how often have you felt lonely? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

14. Since TMI, how often have you had frightening dreams? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

15. Since TMI, how often have you feared getting physically sick? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

16. Since TMI, how often have you felt anxious? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

17. Since TMI, how often have you been bothered by feelings of restlessness? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

18. Since TMI, how often have you feared being left all alone or abandoned? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

19. Since TMI, how often have you been bothered by acid or sour stomach several times a week, would you say (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

20. Think of a person who is the worrying type, a worrier. Is this person (4 very much like you; 3 much like you; 2 somewhat like you; 1 very little like you; 0 not all like you)

21. Since TMI, how often has your appetite been poor? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

22. Since TMI, how often have you been bothered by cold sweats? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

23. Since TMI, how often did your hands ever tremble enough to bother you, would you say? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

24. Since TMI, how often have you had trouble with headaches or pains in the head? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

25. Since TMI, how often have you had trouble with constipation? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

26. Since TMI, how often have you felt you were bothered by all different kinds of ailments in different parts of your body? (4 very often; 3 fairly often; 2 sometimes; 1 almost never; 0 never)

<u>Scoring notes:</u> All items are scored in the same direction on a five-point scale.

<u>Internal consistency reliability:</u> Above 0.90 in all samples.

<u>Interpretation:</u> These 26 items are a sample from a larger set of items that have been developed in the Social Psychiatry Research Unit, Department of Psychiatry, Columbia University, to measure demoralization (Dohrenwend, et al., in press-a; Dohrenwend, et al., in press-b; Dohrenwend, et al., unpublished). The 26 items correlate 0.98 with a composite scale formed from the larger set of demoralization scales.

Interpretation: "Demoralization" is the term used by Jerome Frank to describe the psychological symptoms and reactions a person is likely to develop ". . . when he finds that he cannot meet the demands placed on him by his environment, and cannot extricate himself from his predicament" (1973). Demoralization can coincide with diagnosable psychiatric disorders but may also occur in the absence of such disorders. The various sources of the intractable predicaments include, for example, situations of extreme environmental stress such as combat or natural disasters; physical illnesses, especially those that are chronic; and crippling psychiatric symptoms of, for example, the kinds associated with severe psychotic episodes. Hence, an elevated score on a scale measuring demoralization is something like elevated physical temperature; it tells us that there is something wrong; it does not in and of itself tell us what is wrong.

PERCEIVED THREAT TO PHYSICAL HEALTH

1. Are you satisfied that you are now safe and not contaminated by radiation from the TMI incident?

   1 yes
   3 no
   2 maybe
   2 don't know

2. Do you think your chances of getting cancer have changed because of the TMI incident?

   3 increased
   1 decreased
   1 remained the same
   2 don't know

3. Since the TMI incident, has your health changed?

   1 much better
   1 better
   1 same
   3 worse
   3 much worse

4. Do you think your health will deteriorate in the future because of the TMI incident?

   3 yes
   1 no
   2 maybe
   2 don't know

Scoring notes: All items are scored on a three-point scale with the highest scores assigned to perception of threat. Note that there is balanced keying of the items in this scale, so that for two items a positive response indicates the highest threat while in the other two a negative response indicates highest threat. Item scores were added and divided by 4 to obtain scale scores.

Internal consistency reliability: From .66 to .69 in general population, TMI mothers, and Wilkes-Barre mothers; .70 in clients of mental health centers.

Interpretation: These 4 items represent an attempt to measure perceived threats to physical health from the TMI accident. The threats described come from radiation contamination, increased chances of cancer, and the actual or expected likelihood of unspecified deterioration.

ATTITUDE TOWARD CONTINUING TO LIVE IN TMI AREA

1. If you or your spouse were offered a job in another area containing no nuclear plants, assuming the pay and benefits to be comparable, would you want to take it?

   1 yes
   3 no
   2 maybe
   2 don't know

2. If you could, would you move to another house which was located farther away from a nuclear power plant?

   3 yes
   1 no
   2 maybe
   2 don't know

3. Do you think the quality of life in this region has been permanently altered by the incident at TMI?

   3 yes
   1 no
   2 maybe
   2 don't know

Scoring notes: All items are scored on a three-point scale with the highest scores assigned to desire to move. Item scores were added and divided by 3 to obtain scale scores.

Internal consistency reliability: From .79 to .81 in general population, TMI mothers, and Wilkes-Barre mothers; .83 in clients of community mental health centers.

Interpretation: These 3 items represent an attempt to measure whether the individual devalues the area as a result of the accident and would prefer to leave it, other things (e.g. economic considerations) being equal.

ATTITUDE TOWARD NUCLEAR POWER, INCLUDING TMI

1. Do you want to ban all nuclear-powered, electric generating plants?

   3 yes
   1 no
   2 maybe
   2 don't know

2. Are you in favor of Unit 1 at TMI restarting?

   1 yes
   3 no
   2 maybe
   2 don't know

3. Are you in favor of Unit 2 at TMI restarting?

   1 yes
   3 no
   2 maybe
   2 don't know

Scoring notes: All items are scored on a three-point scale with the highest scores assigned to con attitudes. Note, however, that the first item unlike the other two is keyed negatively. Item scores were added and divided by 3 to obtain scale scores.

Internal consistency reliability: From .54 to .70 in general population, TMI mothers and Wilkes-Barre mothers; .46 in clients of community mental health centers

Interpretation: These three items are an attempt to measure whether attitudes are favorable or unfavorable toward nuclear power in general and towards the resumption of TMI as a nuclear power facility.

TRUST IN AUTHORITIES

1. Do you feel the information you were getting from state and federal officials during the TMI crisis was truthful?

   1 yes
   3 no
   2 sometimes
   2 don't know

2. Do you trust utility companies regarding the safety of nuclear energy?

   1 yes
   3 no
   2 maybe
   2 don't know

3. Do you think federal officials have been truthful regarding the radiation dangers of the TMI incident?

   1 yes
   3 no
   2 maybe
   2 don't know

4. Do you trust the federal government regarding the safety of nuclear energy?

   1 yes
   3 no
   2 maybe
   2 don't know

Scoring notes: All items are scored on a three-point scale with the highest scores assigned to distrust. Item scores were added and divided by 3 to obtain scale scores.

Internal consistency reliability: From .64 to .75 in general population, TMI mothers and Wilkes-Barre mothers; .82 in clients of community mental health centers.

Interpretation: This 4-item scale is an attempt to measure an attitude of distrust towards authorities responsible for the public health and safety with reference to the plants at TMI. The authorities referred to in the items are state and federal officials and the utility companies.

APPENDIX B

DESCRIPTION OF THREE MEASURES OF MENTAL HEALTH AND BEHAVIORAL EFFECTS USED IN THE STUDY OF THE 7th, 9th, AND 11th GRADE PUPILS IN LOWER DAUPHIN SCHOOL DISTRICT

PSYCHOLOGICAL DISTRESS

1. How did you feel when you were most concerned about the Three Mile Island incident? (Please put one check for each item).

Worried ___ ___ ___ ___ ___ Not worried
1 2 3 4 5

Concerned ___ ___ ___ ___ ___ Not concerned
1 2 3 4 5

Disturbed ___ ___ ___ ___ ___ Undisturbed
1 2 3 4 5

2. How do you feel now about the current situation at Three Mile Island? (Please put one check for each item).

Worried ___ ___ ___ ___ ___ Not worried
1 2 3 4 5

Concerned ___ ___ ___ ___ ___ Not concerned
1 2 3 4 5

Disturbed ___ ___ ___ ___ ___ Undisturbed
1 2 3 4 5

Anxious ___ ___ ___ ___ ___ Calm
1 2 3 4 5

Scoring note: The direction of scoring was reversed such that on both questions, for each of the four items, a high score, 5, indicated distress, (i.e. worried, concerned, disturbed, anxious), and a low score, 1, indicated the absence of distress. Item scores were added and divided by 4 to obtain scale scores.

Internal consistency reliability:

.84 for question 1. .86 for question 2. These figures indicate a very high level of internal consistency reliability of both scales for the entire sample.

Interpretation: These items were designed to assess the degree of emotional distress experienced by each respondent at two points in time. Each scale is based on self-reports. The first scale is based on recall, whereas the second scale is based on current state.

PSYCHOSOMATIC DISTRESS

3. Did any of the following tangs happen to you during the time from March 28 to April 9? (Check all that happened.)

Stomach Ache	Nightmares
Sick to Stomach	Bed Wetting
Headache	Sleep Problems
Sore throat	Loss of appetite
High Temperature	Eating more than usual

Other ______________________________

Scoring note: A check was assigned a 1, a blank assigned a 0. The score on this scale for each subject was simply the sum of the 11 possible symptoms. Scores could range from 0 to 11.

Internal consistency reliability: .66 for the entire sample. This internal consistency coeffecent was computed using the Kuder-Richardson formula 20, a special case of Cronbach's alpha, for dichotomous data. The level of reliability indicates an acceptable degree of consistency of responding for use as a scale.

Interpretation: These are symptoms commonly experienced by youngsters under stress. Some of them such as bed wetting would be unusual among teenagers.

APPENDIX C

DESCRIPTION OF SIX MEASURES OF MENTAL HEALTH AND BEHAVIORAL EFFECTS USED IN THE STUDY OF THE WORKERS AT TMI AND PEACH BOTTOM

UPSET

I am going to list some problems which people experience from time to time. Please tell me if any of them have bothered you at the times indicated.

	During the 6 mos. before 3/28/79		Anytime during crisis (3/28-4/11/79)		At the present time	
	yes	no	yes	no	yes	no
Periods of extreme upset	1	2	1	2	1	2

Scoring notes: Yes was scored 1 and negative response 0 for each period.

Reliability: No information. Each is treated as a single item index.

Interpretation: The middle item is as near as we could come to a measure for the workers that may be comparable to the ratings of upsettingness on a ten-point scale that we used in analyses of the data from the general population and the mothers of preschool children.

DEMORALIZATION

This 26-item scale is identical to the one used in the studies of the general population and of mothers of preschool children. See Appendix A.

Reliability: The internal consistency reliability of this scale is .90 in TMI and .91 in Peach Bottom.

THREAT TO PHYSICAL HEALTH

During the TMI incident (3/28/79-4/11/79) did your job expose you to:	no problem at all	slight problem	sizeable problem	great problem

1. Radiation?
   Yes
   No

2. Risk of catching diseases?
   - Yes
   - No

3. Even if your employer kept you fully informed [about any dangers or unhealthful conditions that you may have been exposed to on your job], do you feel that your health was endangered more than usual during the TMI incident due to hazards in the workplace?
   - Yes
   - No

4. Are you satified that you are now safe and not contaminated by radiation from the TMI incident?
   - Yes
   - Maybe
   - Don't know
   - No

Scoring notes: Question 1: No or No problem = 1
Slight problem = 2
Sizeable problem or Great problem = 3

Question 2: No or No problem = 1
Slight problem, Sizeable problem, or Great problem = 3

Question 3: No = 1
Yes = 3

Question 4: Yes = 1
Maybe or Don't know = 2
No =3

Item scores were added and divided by 4 to obtain scale scores.

Internal consistency reliability: .53 in two samples combined; .48 in TMI and .54 in Peach Bottom sample.

Interpretation: This scale is intended to measure the extent to which the workers felt that their health was endangered by the TMI accident.

PERCEPTION OF HOSTILITY FROM COMMUNITY

1. How do you think the performance of nuclear workers such as yourself was seen by people in the community during the TMI incident (3/28/79-4/11/79)? Please indicate on a scale of 1 to 10: 1 = made serious errors; 10 = performed very capably.

2. To what degree do you feel this view was justified? Please indicate on a scale of 1 to 10: 1 = completely unjustified; 10 = completely justified.

3. How much do you feel the general public appreciated the work of nuclear workers such as you during the TMI incident (3/28/79-4/11/79)? Please indicate on a scale of 1 to 10: 1 = very little appreciation; 10 = very great appreciation.

Scoring notes: As noted, each item is scored on a scale from 1 to 10. Item scores were reversed so that the higher the score the greater the perception of hostility. They were added and divided by 3 to obtain scale scores.

Internal consistency reliability: .71 in two samples combined; .72 in TMI and .69 in Peach Bottom.

Interpretation: This scale was designed to describe the extent to which the workers felt that the public is critical and unappreciative of their work.

TRUST IN AUTHORITIES

1. Do you feel that the information you were getting from state and federal officials during the TMI incident was truthful?

2. During the TMI incident (3/28/79-4/11/79), do you think your employer kept you fully informed about the dangers or unhealthful conditions that you may have been exposed to on your job?

Scoring notes: Question 1: Yes = 1
Maybe or Don't know = 2
No =3

Question 2: Yes = 1
No =3

Reliability: There was no relation between these two items. Therefore, they were not combined to make a scale, but were analyzed separately.

Interpretation: Each item is treated as a separate index with no interpretation beyond the working of each question.

CERTAINTY ABOUT FUTURE OF OCCUPATION

I would now like to ask you how you see the future of your occupation. For each of the following questions, please indicate how certain/uncertain you feel. Possible responses include:

somewhat uncertain	a little uncertain	somewhat certain	fairly certain	very certain
1	2	3	4	5

1. How certain are you about what your future career picture looks like? Are you ... (repeat response categories)?

2. How certain are you of the opportunity for promotion and advancement which will exist in the next few years? Are you ... (repeat response categories)?

3. How certain are you about whether your job skills will be of use and value five years from now? Are you ... (repeat response categories)?

4. How certain are you about what your responsibilities will be six months from now? Are you ... (repeat response categories)?

Scoring notes: All items are scored on a scale from 1 to 5 as indicated. Item scores were reversed so that 5 indicated most uncertain. Item scores were added and divided by 4 to obtain scale scores.

Internal consistency reliability: .65 in combined samples; .72 in TMI sample; and .36 in Peach Bottom. The low figure for Peach Bottom is probably due to the lack of variability in responses to these items in this sample, where the majority responded "very certain" to three of the four questions. This figure cannot therefore be interpreted as indicating that this scale is necessarily an unreliable measure in this sample.

Interpretation: These questions were designed to assess the workers' feelings of security or insecurity about their occupation without an indication of the basis for their feelings.

APPENDIX D

THE USE OF TELEPHONE SURVEYS

Market researchers have reported the successful use of telephone interviews to obtain data regarding a variety of subjects, e.g., the effectiveness of advertising campaigns, products being used in the home, and so forth. By and large, however, social scientists have been skeptical of the telephone as a device for securing information from the population at large for a number of reasons. It has been argued that telephone surveys would provide a biased sample because not all persons have access to telephones in their homes, and not all who have phones have them listed. It has been hypothesized further that respondents could not respond to complex questions over the telephone and/or they would not be willing to answer inquiries of a personal nature. The respondents have been viewed as more shy, cautious, and unwilling to offer information over the telephone than in face-to-face situations. There is, however, a growing body of information that refutes this commonly held conception.

BIAS DUE TO UNDERREPRESENTATION

Issues associated with underrenumeration and other biases related to representativeness have been extensively studied by the Rand Corporation (reference 12). The results of this National Science Foundation-supported study, which was conducted in several Pennsylvania communities, offer the following conclusions:

1. Research shows that by 1976, saturation was so high that the exclusion of nontelephone households is no longer a liability for telephone survey sampling in most parts of the country (p. v).

TABLE D-1: Percent of Telephones per Occupied Housing Unit, 1970

Adams	88.45%
Cumberland	93.50
Dauphin	91.40
Lancaster	90.93
Lebanon	92.64
Perry	89.10
York	91.42
State of Pennsylvania	91.74

Source: Socioeconomic Patterns of Pennsylvania: An Atlas

2. Available techniques of random-digit and added-digit dialing are shown to provide representative samples of telephone households (p. V).

3. Estimates of population characteristics obtained by telephone or personal surveys in seven Pennsylvania cities were acceptable representations of the adult populations. This judgment was made after careful comparisons between census data, voter registrations and turnouts, and other available data (p. v).

4. Data from two Pennsylvania communities where comparative telephone and personal interviews were collected support the view that respondents are willing to provide detailed and complex information on a variety of personal topics over the telephone and that it is comparable to that obtained in person. In addition, telephone interviewing may lead to slight reductions in bias toward socially desirable and presumably less distorted answers, although the effects are fairly subtle (p. v).

5. Further comparative analysis of the personal and telephone interviews found a few differences that appeared to be associated with the complexity of the questions and the pacing of the interviews. The matters of complexity and fast pacing of the interviews appear to be more important issues than subject matter sensitivity (p. v).

The Rand report concludes as follows:

> Findings from the Pennsylvania surveys were consistent with a growing body of research which supports the conclusion that telephone surveys can provide representative samples of the general population and can obtain reliable answers on sensitive as well as factual subjects. The telephone survey does as well as the personal survey for most purposes and has greater potential for quality and flexibility at lower cost (pp. V, vi).

HEALTH-RELATED STUDIES CONDUCTED BY TELEPHONE

A growing body of empirical research suggests that health-related interviews conducted by telephone are as effective as those obtained in face-to-face settings. Josephson (reference 11) in a telephone interview that screened for visual difficulties (N=2,000) concluded that little or no underreporting of problems occurred. This judgment was based on a followup in a face-to-face, personal situation. Hochstein (reference 10) compared data from two California health studies. One consisted of 977 mailed questionnaires, 518 telephone, and 183 face-to-face interviews. The second consisted of 524 mailed questionnaires, 285 telephone, and 137 face-to-face interviews. The findings showed few differences across all three methods, in spite of the fact that the questionnaires/schedules included sensitive issues. The author concluded that the data were virtually interchangeable among approaches on most substantive questions. In fact, on questions related to alcohol use, the women were slightly more likely to acknowledge drinking habits over the phone than by mailed questionnaire or face-to-face interviews.

Although not corroborated by face-to-face interviews, Mooney, et al., (reference 14) successfully interviewed women over the telephone regarding menstrual cycles, pregnancies, illnesses, and related subjects of a highly personal nature. And, the well-known longitudinal fertility studies of Freedman, et al., successfully used telephone surveys in a number of instances (reference 2).

Overall, there is a growing body of evidence that indicates that telephone interviews can provide as valid and reliable data as those obtained in personal face-to-face situations. In addition, the evidence indicates that the techniques (based on the Rand-developed million random digits) used to select samples from the general population for the report to the Commission yield representative samples. We can, therefore, conclude that the use of telephone interviews to gather data for the studies of behavioral effects of the TMI accident gives them scientific value and utility.

The only possible major exception to this general conclusion involves persons of the Amish religion who live in the area. They do not have telephones in their homes. But, they would not, in all probability, provide information in a personal interview.

There are many people whose efforts, taken together, were essential in making it possible for the task group and the collaborating researchers to do the work that has provided the basis for this report. These include Dr. Joseph Adelstein, Ms. Joanne M. Buhl, Mr. Shields Daltroff, Mr. Allen Danfield, Dr. Victor Fongemie, Mr. Joseph Gallagher, Dr. Wayne Guymon, Dr. Henry R. Hoerner, Ms. Janet Kelley, Mr. James Kimmey, Mr. Ralph A. Moyer, Jr., Mr. Vincent O'Reilly, Mr. Charles H. Pillard, Dr. Harold Proshansky, Mr. Robert R. Saylor, Dr. Patrick E. Shrout, Dr. Peter Campbell-Smith, Ms. Judy Vercher, and Mr. John F. Wilson. We gratefully acknowledge their contributions.

REFERENCES

1. Ad Hoc Population Dose Assessment Group, "Population Dose and Health Impact of the Accident at the Three Mile Island Nuclear Station," (Preliminary Assessment for the Period March 28 through April 7, 1979), U.S. Food and Drug Administration, Bureau of Radiological Health, Rockville, Md., Table 3-2.

2. L. Coombs, R. Freedman, "Use of the Telephone Interview in a Longitudinal Fertility Study," Public Opinion Quarterly, Vol. 28, Spring 1964, pp. 112-117.

3. Bruce P. Dohrenwend, "Stressful Life Events and Psychopathology. Some Issues of Theory and Method," in J.F. Barrett, R.M. Rose, and G.L. Klerman (Editors), Stress and Mental Disorder, New York: Raven Press, 1979, pp. 1-15.

4. Bruce P. Dohrenwend and Barbara Snell Dohrenwend, Social Status and Psychological Disorder: A Causal Inquiry, New York: Wiley, 1969.

5. Bruce P. Dohrenwend, Barbara S. Dohrenwend, M.S. Gould, B. Link, R. Neugebauer, and R. Wunsch-Hitzig, Mental Illness in the United States: Epidemiologic Estimates of the Scope of the Problems, New York: Praeger, in press.

6. Bruce P. Dohrenwend, L. Oksenberg, P.E. Shrout, B.S. Dohrenwend, and D. Cook, "What Brief Psychiatric Screening Scales Measure," in S. Sudman (Editor), Proceedings of the Third Biennial Conference on Health Survey Research Methods, Washington, D.C.: National Center for Health Statistics and National Center for Health Services Research.

7. Bruce P. Dohrenwend, P.E. Shrout, G. Egri, & F.S. Mendelsohn, "What Psychiatric Screening Scales Measure in the General Population Part II: The Components of Demoralization by Contrast with other Dimensions of Psychopathology." Unpublished manuscript.

8. Cynthia Bullock Flynn, "Three Mile Island Telephone Survey: Preliminary Report on Procedures and Findings," Mountain West Research, Inc., September 1979.

9. Jerome D. Frank, Persuasion and Healing, Baltimore: Johns Hopkins University Press, 1973.

10. J.R. Hochstein, "A Critical Comparison of Three Strategies of Collecting Data from Households," American Statistical Journal, Vol. 62, September 1967, pp. 967-989.

11. Eric Josephson, "Screening for Visual Impairment," Public Health Reports, Vol. 80, January 1965, pp. 47-54.

12. William Lucas and William Adams, "An Assessment of Telephone Survey Methods," October 1977, The Rand Corporation, Santa Monica, Calif.

13. Robert C. Mitchell, "Public Opinion about Nuclear Power and the Accident at Three Mile Island," in D.L. Sills, C.P. Wolf, and V.B. Shelanski (Editors), Social Science Aspects of the Accident at Three Mile Island, New York: Social Science Research Council, 1979.

14. W.H. Mooney, B. Pollack, and L. Corsa, "Use of Telephone Interviewing to Study Human Reproduction," Public Health Reports, Vol, 83, December 1968, pp. 1049-1060.

15. George G. Warheit, "General Characteristics of Counties and Places Located Within a 20-Mile Radius of the Three Mile Island Nuclear Power Plant, Pennsylvania," Prepared for the President's Commission on the Accident at Three Mile Island, September 1979 (Commission Document Control Accession #9210004).

REPORT OF THE
PUBLIC HEALTH AND SAFETY TASK FORCE

ON

PUBLIC HEALTH AND EPIDEMIGLOGY

BY

PUBLIC HEALTH AND EPIDEMIOLOGY TASK GROUP

Paul M. Densen
(Task Group Leader)
Center for Community Health and Medical Care
Harvard University Medical School
Boston, Massachusetts

David Axelrod
Department of Health
State of New York
New York, New York

Maura Bluestone
Health Services Consultant
Washington, D.C.

Jacob I. Fabrikant
University of California
Berkeley, California

Eugene W. Fowinkle
Department of Health
State of Tennessee
Nashville, Tennessee

Kenneth G. Johnson
Department of Community Medicine
Mt. Sinai School of Medicine
New York, New York

Ellen W. Jones
Center for Community Health and Medical Care
Harvard University Medical School
Boston, Massachusetts

Raymond Seltser
Johns Hopkins Comprehensive Cancer Center
Baltimore, Maryland

October 1979
Washington, D.C.

NOTE

Many of the health and safety issues examined by the Public Health and Epidemiology Task Group also are addressed from different perspectives in other Commission staff reports. In order to obtain the full range of information available from the Three Mile Island investigation on health and safety issues, it is advisable to read the reports:

"Behavioral Effects"

"Health Physics and Dosimetry"

"Radiation Health Effects"

"Report of the Emergency Preparedness and Response Task Force"

"Report of the Public's Right to Information Task Force"

"Emergency Preparedness, Emergency Response"

In addition, although the Public Health and Epidemiology Task Group did not deal with technical aspects of the TMI nuclear reactor and its operation, the group did note, from other staff investigations, that the NRC does not systematically examine the performance history of nuclear power plants to detect possible problems that ultimately could affect the health and safety of the general population and nuclear workers. This lack of an epidemiological orientation to data in the nuclear power industry raises serious concerns about the attitude and attention paid to safety issues. Discussion of this problem is contained in the legal staff report, "The Nuclear Regulatory Commission."

TABLE OF CONTENTS

SUMMARY

The Public Health and Epidemiology Task Group conducted one of a set of inquiries into the actual and potential impact of the accident at Three Mile Island (TMI) on the public health and safety, and on the health and safety of TMI workers. Other inquiries contributed to assessment of the magnitude of the actual radiation exposures produced by the accident (see the report "Health Physics and Dosimetry") and the apparent and potential health effects resulting from the accident (see the reports "Behavioral Effects" and "Radiation Health Effects").

The Public Health and Epidemiology inquiry addressed a broad range of issues encompassing health and safety policies, practices, and procedures in place during the development and operation of a nuclear power plant as well as during response to an accident. The task group report thus discusses:

- measures taken to prevent or minimize public and worker exposure to radioactivity emitted by commercial nuclear power plants, and to prepare for appropriate response to the health hazards posed by a radiological emergency;
- authorities and responsibilities for these radiological health and safety measures;
- the ways in which those responsibilities are implemented -- regulation, guidance, administrative procedure; and
- the response of federal and state health agencies to the accident at TMI.

A. GENERAL ISSUES

The Nuclear Regulatory Commission (NRC) has primary responsibility for, and virtually exclusive regulatory authority over, health and safety measures as they relate to the operation of commercial nuclear power plants.

The Environmental Protection Agency (EPA) has jurisdiction over standards of radiation exposure for populations outside the boundaries of NRC-licensed facilities; NRC off-site radiation protection standards, therefore, must be consistent with EPA standards. The NRC, however, retains sole authority to determine and enforce occupational radiation protection standards in the commercial nuclear power industry. The NRC, as a matter of policy, has followed the guidance of the EPA on these standards, but is not compelled to do so.

In relation to radiological emergencies, the EPA has responsibility for providing (1) guidance to states on planning for protective actions; and (2) assistance to states in monitoring the environmental radiation exposures resulting from nuclear power plant accidents.

The Public Health Service (PHS) of the Department of Health, Education, and Welfare (HEW), whose primary institutional mission is the protection and promotion of the public health, also has some limited responsibilities in matters relating to planning for and responding to a radiological emergency. The PHS does not, however, have specific authority or significant involvement in radiological health matters related to the location, construction, and routine operation to nuclear power plant.

Activities specifically oriented toward protection of the public and nuclear workers from exposure to radioactivity emitted by commercial nuclear power plants include: (1) the promulgation, implementation (such as monitoring and surveillance), and enforcement of radiation protection standards; (2) the siting of plants in areas of low population density; (3) the surveillance of radiation-related health effects; and (4) preparation for response to radiological accidents through emergency planning, education, and resource readiness.

1. <u>Radiation Protection Standards</u>

Standards for protection against exposure to radioactivity emitted by NRC-licensed nuclear power plants take the form of (a) maximum permissible dose levels for individuals on-site (workers) and off-site (the public); and (b) design objectives for exposure levels which are as low as is reasonably achievable (ALARA). Numerical levels are prescribed for maximum permissible dose levels to individuals; no numerical levels are indicated for collective -- total person-rems -- dose, or for ALARA design objectives. The maximum permissible dose levels have remained unchanged since they were adopted in 1960.

Maximum permissible doses (whole-body) to workers are limited by the NRC to 1-3/4 rems per quarter and 5 rems per year. Under certain circumstances, however, the standards permit exposure of individual workers to a maximum of 3 rems per quarter and 12 rems per year. In 1977, the average exposure of those workers in the nuclear power industry who had measurable doses was 740 millirems. Fewer than one percent of such workers received an annual dose in excess of 5 rems, and no workers had doses in excess of 10 rems.

There is no requirement for direct measurement of off-site individual doses -- personal dosimetry. Rather, off-site exposure levels are monitored by means of calculational models applied to radioactive emmissions, and verified by environmental radiological measurements, such as sampling of air, soil, and water. NRC regulations for environmental radiological monitoring leave the details and methods of how these requirements are to be implemented to the discretion of the licensee subject to NRC inspection. Licensees are required to report to the NRC instances of off-site exposure levels which exceed background levels by a specified amount beyond the prescribed maximum permissible limits.

A cost-benefit approach is prescribed by the NRC in applying the ALARA concept to off-site exposure reduction efforts. In deciding whether to invest during construction of a nuclear power plant in safety features that would reduce off-site exposures below the maximum permissible levels, licensees are instructed to weigh the cost of installing the safety feature against the benefit of exposure reduction valued by the NRC at $1,000 per person-rem.

Personnel dosimetry is required by NRC for specified classes of nuclear power plant workers, and licensees are required to report to NRC summary statistics on worker exposure, cases of individual worker overexposure, and individual accumulated occupational exposure upon termination of employment. The NRC does not require licensees to obtain information on nonoccupational radiation exposures of workers, such as medical X-rays. A cost-benefit approach is neither prescribed nor endorsed by the NRC for determining investment in safety features intended to reduce occupational exposures.

2. Siting of Nuclear Power Plants

In addition to physical suitability of a proposed nuclear power plant site -- such as geology, seismology, and hydrology -- NRC site selection criteria, established by regulation, require consideration of current and projected population density in the surrounding area.

Site suitability is also a function of estimated radiological consequences of a nuclear reactor accident. The applicant for an NRC license must assess the proposed nuclear reactor's "design basis accident," and the releases of radioactivity produced by that postulated accident. The magnitude of these potential releases is determined by the engineered safeguards designed into the plant. The calculated emissions are converted into projected whole-body exposures to which individuals would be subjected at specific distances from the reactor over specified periods of time. These calculations are then used to specify the "exclusion area" -- the licensee's property; the "low population zone" (LPZ) -- the area surrounding the exclusion area in which the population size and distribution is such that "there is a reasonable probability that appropriate measures could be taken in their behalf in the event of a serious accident;" 1/ and the "population center distance" -- the distance to the boundary of the nearest densely populated area.

The actual radial distance of the low population zone is thus dependent on the number and type of engineered safeguards designed into the proposed plant, and the capability to take protective action in the area affected by the radiological consequences of the design basis accident. Given this relationship to the capability to take protective action (such as evacuation), the LPZ siting concept is incorporated into the NRC's guidance to licensees on emergency planning. This requires that the licensee arrange for protective action on behalf of the LPZ in the event of an accident with releases of radioactive materials that threaten to exceed population exposure limits. The NRC guidance document states that a 3-mile radius is generally an acceptable LPZ.

The role played by the NRC in siting of nuclear power plants is limited to the constraints placed on the applicant in conforming to NRC site selection criteria. Primary responsibility for siting remains with state and local authorities which maintain control over land-use decisions. A growing number of states have been legislating establishment of siting boards or commissions to review and approve proposed nuclear power plant sites. In states that lack such an authority, siting decisions remain under the jurisdiction of local zoning boards and/or public utility commissions.

3. Surveillance of Radiation-Related Health Effects

A considerable amount of scientific information on the biological effects of ionizing radiation has been developed over recent years from epidemiological studies of exposed human populations and from laboratory animal experiments. The results of these studies have been examined by various scientific groups in an effort to understand the relationship between radiation exposure, particularly exposure to low levels of radioactivity, and health effects. Although there is a consensus on the effects of high doses, there are limited understanding and competing theories within the scientific community about low dose effects.

A variety of federal agencies fund such research. In fiscal year 1978, over 60 percent of the $76.5 million spent by the federal government was provided by the Department of Energy (DOE), 20 percent by the Department of Health, Education, and Welfare (HEW), and the balance by the Departments of Agriculture and Defense, the NRC, EPA, Veterans' Administration, and the National Aeronautic and Space Administration.

The NRC requires a medical examination of all applicants for initial or renewal nuclear reactor operator licenses to ensure that "the physical condition and general health of the applicant are not such as might cause operational errors endangering public health and safety" (10 CFR Part 55). There is no indication in the regulation or its accompanying guide that the NRC uses the information gathered in the required medical examinations to detect possible radiation-related health effects in the applicants. The NRC does not require medical examinations of radiation workers other than licensed reactor operators; nor does it require reporting of nonoccupational radiation exposure of nuclear workers.

No other federal agency, including the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA), has regulatory authority over radiological health matters related to commercial nuclear power plant workers.

4. Preparation for Response to Radiological Accidents

Preparedness to respond to the health and safety hazards posed by a nuclear power plant accident encompasses a number of activities authorized or conducted by a wide variety of federal, state, and local agencies. Major efforts include the following:

a. The NRC requires its licensees to maintain site emergency plans which include: (i) procedures for on-site management of an emergency situation; (ii) protective actions, including evacuation of nonessential personnel, to be taken on behalf of the on-site population; (iii) arrangements for on-site and off-site emergency medical care to handle injured workers with or without contamination; (iv) arrangements for notifying appropriate off-site emergency preparedness agencies of an incident at the reactor site; and (v) assurance of the ability and readiness of off-site agencies to take protective action on behalf of the LPZ population. The licensee is required to have annual drills of the site emergency plan, and to make appropriate alterations to that plan based on critiques of the drill.

The NRC also offers a program that provides guidance, review, and concurrence on emergency plans developed by states to respond to radiological emergencies. There are no regulatory requirements placed on states by the NRC or any other agency to prepare and maintain such plans, and the NRC has not made concurrence of state plans a condition of nuclear power plant licensing.

b. Protective Action Guides (PAGs) are provided by different federal agencies to assist states in developing emergency plans and responding to radiological emergencies. The EPA PAGs indicate levels of airborne radioactivity at which protective action such as evacuation should be considered. The HEW PAGs indicate levels of food and animal feed contamination at which protective action should be considered. The DREW PAGs also are intended to assist states in developing plans for prevention of adverse effects of radiation exposure including the use of prophylactic drugs such as potassium iodide.

c. The Interagency Radiological Assistance Plan (IRAP) is an agreement among 13 federal agencies, maintained by the Department of Energy, to provide a variety of assistance activities to states in the event of a peacetime nuclear emergency.

B. TMI SPECIFIC ISSUES

1. Metropolitan Edison

An extensive series of administrative, health physics, and prrsonnel policy procedures at Metropolitan Edison (Met Ed) outline the health and safety practices in effect during routine and emergency operations of the plant.

Routine monitoring for exposure to radioactivity follows requirements outlined in NRC regulations. At the time of the accident at TMI, thermoluminescent dosimeters (TLDs) were in place at 20 locations around the site monitor airborne radioactivity. Sampling of various media (air, soil, river and rain water, etc.) was also conducted routinely, with those measurements compared to background levels determined during a 3-year period prior to operation of TMI-1. In addition to reporting to NRC any excess environmental exposures as required by regulation, Met Ed reports annually to the NRC on all environmental monitoring results through General Public Utilities Corporation (GPU).

The personnel dosimetry program at Met Ed is designed to conform with NRC regulations. The medical surveillance program at Met Ed, however, contains features that exceed those required by the NRC. For example, in addition to the NRC-required medical examinations for reactor operator license applicants, Met Ed requires pre-employment and biannual medical examinations of all radiation workers in jobs which could expose them to 300 millirems or more in a quarter for the purpose of detecting "radiation-related bodily changes" and providing baseline health status measures for evaluation of the effects of any accidental overexposures. Met Ed, however, does not retrieve past medical records on new employees and does not require reporting of prior or current nonoccupational, such as medical, radiation exposure.

Met Ed conducts two types of drills during routine operations to prepare for possible emergency situations. The first type is designed to test the site emergency plan. This drill is not to disturb normal operation of the plant. In order to involve all employees, therefore, a series of such drills is conducted once a year. Representatives from off-site agencies are invited to observe and critique the on-site drill. Actual participation of off-site agencies, however, is limited to establishing telephone communication in order to test the notification system.

The second type of drill is designed to test the on-site emergency medical care procedures. This annual drill involves simulation of a worker injury, presumably involving contamination, which requires on-site emergency treatment, decontamination, and transport to the Hershey Medical Center with which Met Ed has a contract to care for injured contaminated TMI workers. Two community physicians are retained by Met Ed to provide such emergency care as well as to conduct some of the routine medical examinations. Neither of these physicians reported ever participating in a drill as more than an observer, and neither has been called upon to practice administering emergency care in either a simulated or real contaminated environment.

NRC requirements for health physics training of nuclear reactor workers are broadly stated regulations which leave the content, frequency, attendance, and other features of such training to the discretion of the licensee. Met Ed has a series of such health physics training courses required of different levels and types of personnel.

During the accident at TMI, a number of health-related problems arose on-site:

- There was an inadequate number of operating respirators available. Some personnel who were respirator-qualified had to use types of respirators for which they had not been fitted or tested. Respirators were also issued to some employees who were not respirator-qualified since their need for a respirator was never anticipated.

- Some essential dosimetry instruments were inaccessible due to high radiation levels in the area adjoining the health physics laboratory in which the instruments were stored.

- There was no supply of potassium iodide available on-site in the event of radioiodine exposure of workers. The drug was obtained on the first day of the accident and stored for possible future use.

- Neither of the radiation emergency medical services designated by Met Ed -- community physicians and the Hershey Medical Center -- was officially notified by the utility of the accident to assure their readiness to respond if needed.

2. <u>State Response to the Accident</u>

States traditionally have had primary responsibility for protection of the health and safety of members of the public. The response to the accident at TMI by state health and health-related agencies and TMI-area health care providers, however, revealed insufficient resources to respond adequately to the actual and potential public health consequences of the accident.

- Responsibility for radiological protection, both environmental and medical, in the Commonwealth of Pennsylvania rests with the Department of Environmental Resources. At the time of the accident, the Department of Health had no specific authority or capability to exercise its responsibility for protection of the public health. In addition, no formal liaison existed between the Department of Health and the Department of Environmental Resources for matters relating to radiological health.

- The Department of Environmental Resources' environmental radiological monitoring program in place around TMI at the time of the accident consisted of a few dosimeters placed alongside utility dosimeters for purposes of verifying measurement of routine radiation levels. Once higher off-site exposures were detected during the accident, state officials called upon the U.S. Department of Energy to assist in environmental monitoring.

- The Commonwealth of Pennsylvania had required emergency planning for areas within 5 miles of a nuclear power plant. This area around TMI does not include any hospitals. The hospitals within a 10-mile radius did not have any evacuation plans at the time of the TMI accident.

- There were no directives given by the governor's office or the secretary of health on appropriate protective actions to be taken during the accident. Decisions on whether and how to evacuate hospitals and nursing homes in the area, for example, were left to the administrators of those facilities. Similarly, when the emergency appeared to be subsiding, no directives were given on when and how to terminate protective actions which had been voluntarily taken by institutions and individuals.

- The Commonwealth of Pennsylvania had no plans at the time of the accident for the procurement, distribution, or use of potassium iodide as a thyroid-blocking agent. After receiving potassium iodide supplied from HEW during the accident, the Department of Health maintained central storage of the drug. Distribution was not made to local areas.

- Few hospitals were prepared as to space, equipment, personnel, and established procedures to receive and treat members of the public who might have suffered radiation injuries or contamination.

3. <u>HEW Response to the Accident</u>

There were two levels of response to the accident at TMI from HEW: (1) the on-the-scene provision of direct assistance in Pennsylvania; and (2) the deliberations and recommendations of Washington-based officials.

Direct assistance to Pennsylvania involved a variety of activities including: (1) placement of a large number of dosimeters in the TMI area to supplement environmental dosimetric measurements being taken by other agencies; (2) continuous sampling of food, milk, and water for radioactive contamination; (3) procurement and delivery of sufficient supplies of potassium iodide to cover the population living within 20 miles of the plant; (4) arrangements for assistance from radiation physicians, if needed; and (5) investigation of the adequacy of personnel dosimetry and recordkeeping at the TMI site in the event that followup studies of the workers would be indicated.

The potassium iodide "story," in particular, became a matter of some controversy. The use of potassium iodide as a blocking agent to prevent accumulation of radioiodine in the thyroid gland has been known for more than 15 years. The effectiveness of potassium iodide administration to large populations in the event of a radiological emergency such as the accident at TMI was recognized by the National Council on Radiation Protection and Measurement in mid-1977. The Food and Drug Administraton (FDA) approved potassium iodide for this use in December 1978. At the time of the accident at TMI, however, potassium iodide for this use was not commercially available in the United States, and supplies of the drug for other clinical applications were not readily available in sufficient quantity for the population within a 20-mile radius of TMI. HEW decided on Friday, March 30, to obtain supplies of the drug for possible use in Pennsylvania. A crash effort by the FDA and private industry resulted in initial delivery of potassium iodide to Harrisburg within 2 days of the HEW decision. Distribution and use of the drug later became a subject of deliberation and decision among the Washington-based HEW officials.

During the accident at TMI, HEW officials in Washington repeatedly expressed their desire to consult with NRC officials concerning NRC decisions related to evacuation and the public health implication of actions taken to bring the reactor to a safe condition. Meetings were held between representatives of HEW and NRC, but they were informational rather than consultative. Existence of the Interagency Radiological Assistance Plan was apparently not known to the high-level Washington officials, and the DOE, custodian of the plan, assumed NRC would take responsibility for notifying and involving other federal agencies since the accident involved an NRC-licensed facility. Initial and continuing notification of HEW and actions taken by the agency in responding to the accident were therefore generally arranged on an ad hoc basis.

Among other things, HEW officials based in Washington made two decisions, each of which could have or did produce misunderstandings and conflict. One, based on uncertainties as to the status of the reactor and the lead time potentially available to evacuate the area, the Washington-based officials suggested to the White House that consideration be given to evacuation of the area within 20 miles of the plant and that residents of the area be notified of a possible evacuation. Two, in response to a request from the White House, Public Health Service officials recommended that potassium iodide be administered immediately to TMI workers and be distributed to residents within the 20-mile area around the plant for possible future use.

Both the evacuation and potassium iodide decisions were made without consultation with state officials, and apparently with limited information as to the status of the accident, the emergency response, and the activities of other federal and state agencies. It is unclear whether the evacuation recommendation was transmitted beyond the White House. The potassium iodide recommendations were transmitted to the state, however, despite being in direct conflict with the decisions on distribution and use arrived at by the Pennsylvania secretary of health and other officials.

FINDINGS

The major findings of the inquiry of the Public Health and Epidemiology Task Group are organized according to six general topics:

1. Locus of responsibility for health and safety.

2. Siting of nuclear power plants.

3. Monitoring and surveillance.

4. Education and training in radiological health issues.

5. Emergency preparedness and health care.

6. **Epidemiological studies** of long-term health effects.

A. LOCUS OF RESPONSIBILITY FOR HEALTH AND SAFETY

1. The Nuclear Regulatory Commission has virtually exclusive authority over radiological health and safety factors associated with development and routine operations of commercial nuclear power plants. This authority takes a number of forms, including the following:

a. The NRC is responsible for enforcing radiation protection standards for the general population which are consistent with maximum permissible dose levels promulgated by the Environmental Protection Agency. The NRC, However, retains exclusive authority to set radiation protection standards for workers in NRC-licensed facilities. The NRC has chosen to follow EPA guidance on occupational exposure standards, but is not required to do so.

b. The NRC has exclusive regulatory authority over occupational radiological health matters in commercial nuclear power plants; the Occupational Safety and Health Administration regulates only conventional industrial health and safety matters in these plants. The NRC has no standard procedure for involving other federal agencies -- for example, HEW or EPA -- directly in the occupational radiation protection standards-setting process.

c. The NRC requires its licensees to develop and maintain site emergency plans which include arrangements with off-site agencies for notification of a radiological emergency and implementation of protective action on behalf of the population living close to the reactor. There are no federal requirements placed on state, county, or local authorities to develop and maintain such emergency plans, and approval of existing plans is not an NRC condition of license approval.

d. The NRC retains, by law, exclusive authority to determine whether a nuclear power plant accident is an "extraordinary occurrence."

2. The Public Health Service (PHS) of the Department of Health, Education, and Welfare, whose mission is the protection and promotion of public health, has some limited responsibilities to take action in the event of a nuclear power plant accident. The PHS has no specific authority in radiological health matters related to location, construction, and routine operation of commercial nuclear power plants.

3. Federal funding of research on the biological effects of ionizing radiation is distributed among a number of agencies. In Fiscal Year 1978, more than 60 percent of the $76.5 million spent by the federal government on such research was provided by the Department of Energy.

4. Although there were designated channels of communication and specific responsibilities assigned for federal agencies responding to the radiological emergency at TMI -- for example, the Interagency Radiological Assistance Plan -- the existence of these channels and responsibilities was generally unknown to many high-level federal officials. In several instances, during the course of the accident, some federal agencies were unaware of what other federal agencies were doing in providing support personnel and resources.

5. The Department of Energy responded promptly to the nuclear accident under its Radiological Assistance Program (RAP). However, DOE, assuming NRC had responsibility for coordinating assistance, did not notify other agencies, and none was aware in the early days of the accident of DOE's activity in the TMI area.

6. Coordination of radiological monitoring data during the TMI accident was initially assigned to NRC by the White House. The DOE, with its comprehensive monitoring system, became the de facto coordinator. The DHEW and EPA, preferring such data to be collected by a health agency, convinced the White House to assign EPA as lead agency for coordination of all radiological monitoring data.

7. Responsibility for radiological health, both environmental and medical radiation control, in the state of Pennsylvania rests with the Department of Environmental Resources (Bureau of Radiation Protection or BRP), not the Department of Health. Only an informal liaison relationship exists between the two departments.

8. During the accident, Pennsylvania Secretary of Health Gordon MacLeod called Secretary Joseph Califano in HEW to request physician advice on medical aspects of radiation exposure. The call was referred to Arthur Upton, director of the National Cancer Institute, who recommended several non-HEW physician-scientists. MacLeod has submitted a reorganization proposal to the executive branch of Pennsylvania government that would, among other changes, create Divisions of Radiation and Occupational Health in the Department of Health.

9. Hospital administrators found no one at the state level with authorit to instruct them on when to evacuate patients and when to resume normal admitting procedures. MacLeod viewed the role of the Department of Health vis-a-vis area hospitals as informational, not advisory.

10. Governor Richard Thornburgh received conflicting advice from a number of sources during the accident regarding whether there should be an evacuation and, if so, how large an area and which population groups should be involved.

a. As of Thursday, Health Secretary MacLeod began to suggest that consideration be given to advising pregnant women and children under age 2 to leave the 5-mile area around TMI. MacLeod strengthened the urgency of his suggestion on Friday morning based on his assumption that the discharge of industrial wastes from TMI into the Susquehanna River on Thursday night represented human error, compounding the already established mechanical problems in the reactor.

b. On Friday morning (9:15 a.m.), senior NRC staff in Bethesda, Md., recommended a 10-mile evacuation based on erroneous interpretation by NRC officials of a 1,200 millirem reading.

c. Oran Henderson, director of the Pennsylvania Emergency Management Agency (PEMA), received the Friday 9:15 a.m. telephone call from NRC recommending evacuation, and requested verification from the Bureau of Radiation Protection. When BRP had not returned his call within a half hour, Henderson advised the governor to begin evacuation out to 5 miles while emergency preparedness agencies began drafting 10-mile evacuation plans.

d. The BRP informed the governor that evacuation was not justified on the basis of radiation levels that had been monitored.

e. The governor chose not to follow the 9:15 a.m. NRC evacuation recommendation. NRC Chairman Joseph Hendrie endorsed the advisability of pregnant women and preschool children leaving the 5-mile area around TMI. Thornburgh announced that advisory at 12:30 p.m. on Friday, March 30.

B. SITING OF NUCLEAR POWER PLANTS

1. The Commonwealth of Pennsylvania did not have nuclear power plant siting authority at the time the TMI nuclear station was under consideration. An interagency state commission was legislated in early 1978; the Department of Health is not included on that commission.

2. The low population zone (LPZ) identified in the siting of nuclear power plants and incorporated in emergency planning is defined, in part, by projected exposures of individuals to radioactivity released as a result of a postulated design basis accident. On the basis of this analysis, the LPZ accepted by the NRC for TMI was only a 2-mile radius. The potential consequences of the actual accident at TMI, however, led NRC officials to consider evacuation of the population within 5-, 10-, and 20-mile areas around the site.

C. MONITORING AND SURVEILLANCE

1. Environmental monitoring of radiation levels is currently the responsibility of NRC licensees (nuclear power plants) and the EPA. The only direct involvement of HEW in radiation monitoring and surveillance

related to nuclear power plants is monitoring of radioactive contamination of food and animal feed, and identifying dose levels of such contamination at which protective action should be considered.

2. NRC requirements for off-site monitoring are directed solely at detection and measurement of low-level radiation from nuclear power plants during routine operations.

3. The NRC requires licensees to collect at least 2 years of off-site normal background radiation level data prior to operation of the nuclear power plant in order to establish a baseline for comparison with future radiation levels measured under normal plant operations.

4. The NRC monitoring requirements leave details and methods on implementation of the requirements (media to be sampled, dosimetry instrumentation to be used, etc.) to the discretion of the licensee. Monitoring practices therefore may vary among nuclear power plants throughout the country.

5. The NRC applies a "dollar value per person-rem" concept to calculate the relationship of the cost of safety to the benefit derived in terms of reduced radiation exposure to the general population. No such cost-benefit approach is provided or endorsed by the NRC for evaluating safety features intended to reduce occupational exposure.

6. NRC radiation protection standards specify individual worker dose limits but no limits for collective (population) dose. Maximum permissible doses (whole-body) to workers are limited by the NRC to 5 rems per year. Under certain circumstances, however, the standards permit exposure of individual workers to a maximum of 12 rems per year. In 1977, the average exposure of those workers in the nuclear power industry who had measurable doses was 740 millirems. Fewer than one percent of such workers received an annual dose in excess of 5 rems.

7. Personnel monitoring, recording, and reporting of radiation exposures are only required by the NRC for workers who, in the utility's view, are likely to receive doses beyond NRC specified levels. The NRC requires its licensees to report (a) annual statistical summaries of worker exposure, (b) any worker exposure in excess of maximum permissible levels, and (c) accumulated occupational exposure upon termination of employment. There is no requirement by NRC to obtain information on nonoccupational radiation exposure to combine with information on occupational exposures for purposes of monitoring total accumulated radiation exposure of nuclear workers.

8. The NRC has no requirements for medical examination of workers other than licensed reactor operators, and even those examinations are performed only to ensure that the operators do not have physical or mental conditions that might impair their ability to perform their jobs safely. Met Ed administrative procedures go beyond this NRC requirement to provide routine medical examinations for all radiation workers for the purpose of detecting "radiation-related bodily changes."

9. Met Ed retains management right to set all safety standards, practices, and procedures (company-based as well as implementation of federal requirements) at TMI. The right to negotiate such standards, practices, and procedures has been a demand of the union (International Brotherhood of Electrical Workers) in past collective bargaining; to date, however, such matters are not open to negotiation.

10. Despite a 1974 Shippingport study recommendation for comprehensive state monitoring programs around nuclear reactor sites in Pennsylvania, the state Bureau of Radiation Protection had a limited environmental radiation monitoring capacity at TMI directed solely to verifying the utility's program for monitoring routine releases of radioactivity. This program met the minimum capacity for which the NRC provided funds to the state for reporting monitoring data to the NRC. A variety of federal resources are available to assist the state in responding to the need to monitor radiation releases resulting from an accident. The state BRP, because of lack of equipment and manpower to monitor radiation levels during the accident at TMI, requested radiological monitoring assistance offered by the DOE under its Radiological Assistance Program.

11. The only personal dosimetry performed by federal agencies on TMI area residents during the accident was bioassay urine sampling conducted by the National Institutes of Health on 38 individuals. These examinations were negative for excess radioactivity.

12. Decontamination of the auxiliary and fuel handling buildings at TMI is being conducted by outside contractors and volunteer non-nuclear workers from other Met Ed utility plants. The decontamination workers are given radiation work permits and respirator training as well as a 5-hour indoctrination course. Their maximum permissible exposure is 1,250 millirems per quarter. Emphasis is placed on ALARA design of decontamination tasks; as of mid-July, no decontamination worker had received a full quarterly dose.

D. <u>TRAINING AND EDUCATION IN RADIOLOGICAL HEALTH ISSUES</u>

1. The ongoing public education provided by the utility consists only of rudimentary training of off-site emergency response personnel, and provision of public relations information at the observation center near the reactor site.

2. The state Department of Health has no specifically defined responsibility for providing radiological health education to the public, or to health care professionals.

3. NRC radiation health training requirements for workers leave details of program content and design to the discretion of the licensee.

4. Training of community physicians who have been retained by Met Ed to provide emergency medical care to contaminated workers is marginal.

5. Since the accident, few initiatives have been taken to improve public and professional education in Pennsylvania with regard to radiation, radiation hazards, and protective actions.

6. Met Ed has cut back, temporarily, on some health physics training and routine company-sponsored physical examinations for older employees due to financial constraints following the accident.

E. EMERGENCY PREPAREDNESS AND HEALTH CARE

1. Pennsylvania did not have an NRC-concurred state emergency plan at the time of the TMI accident. Only 9 of 25 states that have operating reactors currently have state emergency plans in which NRC has concurred. NRC has not made approval of state emergency plans a condition of nuclear power plant operation.

2. Met Ed, state, and county emergency plans for responding to a nuclear reactor accident lacked provisions for (a) evacuating beyond the state-designated 5-mile radius, (b) evacuating area hospitals, nursing homes, and infirm people, (c) medical care for members of the public who might become contaminated or suffer radiation injuries, (d) inventories of facilities or personnel equipped and trained to handle radiation injuries, or provide advice and information on radiological health, and (e) possible procurement, distribution, and/or use of potassium iodide as a radioiodine thyroid-blocking agent.

3. Physician participation in Met Ed emergency medical drills has involved observation only. Although these physicians are expected to render emergency treatment to contaminated injured workers on-site, the drills have never involved decontamination procedures.

4. Off-site state and county agencies are invited to observe Met Ed site emergency drills. Participation of these agencies is limited to receiving and acknowledging notification to test the communication procedures.

5. Few of the area hospitals, including the Hershey Medical Center, were prepared to provide medical care to members of the public who might have suffered acute radiation injury or radioactive contamination.

6. HEW did not recommend that the population in the TMI area be evacuated. It did, however, recommend to the White House that the population within 20 miles of the plant be notified of the need for a possible evacuation.

7. The use of blocking agents such as potassium iodide to prevent the accumulation of radioiodine in the thyroid gland has been known for over 15 years. The effectiveness of potassium iodide administration for thyroid gland protection in the event of releases of radioiodine was recognized by the National Council on Radiation Protection and Measurement in 1977. The Food and Drug Administration authorized use of potassium iodide as a thyroid-blocking agent for the general public in December 1978. However, at the time of the TMI accident, potassium iodide for this use was not commercially available in the United States in sufficient quantities for the population within a 20-mile radius of TMI. A crash effort by the federal government and private industry resulted in delivery of substantial supplies of potassium iodide to Pennsylvania within 2 days of the decision to obtain such supplies. At

the time of the accident, Met Ed had no supply of potassium iodide on-site. Supplies were subsequently obtained and stored for possible future use.

8. During the accident, HEW and DOE were unaware that each agency had trained radiation physicians prepared to assist in Pennsylvania if needed.

9. One result of the evacuation advisory was a staff shortage at the two nursing homes within the 5-mile radius of the plant. Administrators of those health facilities, with the help of county emergency personnel, relocated these patients over the weekend of March 31 - April 1.

10. Emergency planning for nuclear reactor accidents in Pennsylvania is required only for the area within 5 miles of the site. This area around TMI includes no hospitals. There were therefore no evacuation plans for the hospitals within a 10-mile radius. The NRC estimated that it could give officials a few hours "lead time" for evacuation, but hospital adminstrators estimated they needed substantially more time to evacuate their patients.

11. Met Ed experienced several radiation protection problems during the accident: (a) lack of access to non-mobile dosimetry instruments due to high levels of radioactivity in the areas in which the instruments were stored; (b) shortage of respirators; (c) inadequate supply of piped air; and (d) over-exposure of three workers.

12. Neither of the radiation emergency medical services designated by Met Ed -- community physicians and Hershey Medical Center -- were officially notified by the utility of the accident to ensure their readiness to respond if needed.

13. There was confusion among state officials and the NRC over when to terminate the advisory to pregnant women and preschool children. The NRC commissioners insisted on voting on the issue before Harold Denton could advise the governor. As with the initial recommendation to evacuate, the NRC acted unilaterally on this decision.

F. EPIDEMIOLOGICAL STUDIES OF LONG-TERM HEALTH EFFECTS

The Pennsylvania Department of Health is pursuing several epidemiological studies of long-term radiation health effects, some of which -- such as chromosome analysis -- have been judged of limited or negligible scientific value by a federal interagency subcommittee. Population census, pregnancy outcome, and long-term behavioral effects studies are being funded by HEW. Most funding for other studies in Pennsylvania is being provided by the Electric Power Research Institute.

I. INTRODUCTION

The Public Health and Epidemiology Task Group conducted one of a set of inquiries into the actual and potential impact of the accident at Three Mile Island on the health and safety of the general population and TMI workers. Other inquiries contributed to assessment of the magnitude of the actual radiation exposures produced by the accident (see the report on "Health Physics and Dosimetry"), and the apparent and potential health effects resulting from the accident (see the reports on "Behavioral Effects" and "Radiation Health Effects").

The Public Health and Epidemiology inquiry addressed issues which encompass the health and safety policies, practices, and procedures in place during the development and operation of a nuclear power plant as well as during response to an accident. The task group report thus discusses:

1. measures taken to prevent or minimize public and worker exposure to radioactivity emitted by commercial nuclear power plants, and to prepare for appropriate response to the health hazards posed by a radiological emergency;

2. authorities and responsibilities for these radiological health and safety considerations;

3. the ways in which those responsibilities are developed and implemented -- regulation, guidance, administrative procedures; and

4. the response of federal and state health agencies to the accident at TMI.

II. APPROACH AND METHODS OF THE INQUIRY

A. APPROACH

The task group first developed a classification scheme by which to identify the health and safety issues associated with the production of nuclear energy. This scheme had two dimensions. One represented the populations at risk, i.e., the general population living in the TMI area and the population of TMI workers. The second represented the time frame of TMI-2 existence. It was clear to the task group that health and safety concerns associated with nuclear power plants are not confined to emergency situations. Rather, the capacity and readiness to respond to health and safety threats in an emergency reflect the amount and type of attention paid to such concerns during the development and routine operation of a nuclear reactor. The task group inquiry thus attempted to encompass health and safety concerns throughout the lifetime of TMI-2 from its siting and construction through its routine operations to the accident and its aftermath.

Major health issues relating to (1) physical protections (such as plant siting, protective clothing, etc.), (2) protective procedures (such as radiological monitoring, health surveillance, and emergency services), and (3) educational programs were identified for each of the two populations at risk during each major stage of TMI-2 existence. Specific questions to be addressed within each issue and the sources from which such information was to be obtained were then outlined; this matrix produced a comprehensive work plan for the task group inquiry. Due to time and resource constraints, some lines of inquiry were either deleted or abbreviated. For example, despite its critical importance to public health, the health and safety issues associated with transport and disposal of radioactive materials could not be dealt with during the time span of the present inquiry. Similarly, the health hazards of occupational exposure associated with decontamination of TMI-2 were not adequately defined at this time to permit detailed analysis. Discussion of the decontamination effort in this report is therefore confined to some basic information about the recruitment, training, and health physics procedures for decontamination workers at TMI-2.

B. METHODOLOGY

For each health issue identified in the work plan, the task group examined (a) who has authority over the issue, (b) the requirements for protecting health and safety developed by that authority, (c) the breadth or specificity of those requirements and their implementation, (d) contingency plans which had been made to deal with emergency situations, and (e) the history of health and safety policies and practices relative to TMI, prior to and during the accident.

The task group inquiry was conducted by development and analysis of information from four major sources:

1. document review (see Appendix A);

2. interviews and depositions (see Appendix B);

3. Commission hearings; and

4. review of other health and safety staff reports.

C. STRUCTURE OF THE REPORT

The sections of this report fall into two distinct categories of discussion, the first representing generic health and safety issues, industry-wide and at TMI, and the second summarizing the response of public health agencies to the accident at TMI. Sections III through VIII cover the generic issues of health authorities and responsibilities (III), radiation protection standards (IV), health and safety issues in the siting and construction of nuclear power plants (V), monitoring and surveillance (VI), training, education, and information exchange (VII), and emergency preparedness and health care (VIII). Sections IX and X discuss the actual response of agencies and individuals to the health and safety problems posed by the TMI accident, and related activities in the aftermath of the accident.

III. OVERVIEW AND HISTORY OF FEDERAL AND STATE HEALTH RESPONSIBILITIES REGARDING NUCLEAR POWER PLANTS

A. OFF-SITE CONSIDERATIONS -- HEALTH AND SAFETY OF THE PUBLIC

Primary responsibility for the radiological health and safety of populations living in the vicinity of a nuclear power plant rests with the utility, pursuant to NRC regulations. This is particularly true during routine operation of the plant. During emergency situations, responsibility for action is diffused among a number of federal and state agencies. The following discussion summarizes briefly the distribution of responsibilities among these agencies. More specific discussion of these responsibilities and their implementation is provided in later sections of the report.

1. Federal Agencies

a. The Nuclear Regulatory Commission (NRC)

The Atomic Energy Act of 1954, as amended, contains frequent reference to health and safety considerations in the development and use of atomic energy. The basic declaration of findings and purpose repeatedly states that regulation of atomic energy is necessary "to protect the health and safety of the public." (Section 2(d)(e).)

> (Section 161) In the performance of its functions, the Commission is authorized to . . .
>
> b. establish by rule, regulation or order, such standards and instructions to govern the possession and use of special nuclear material, source material and byproduct material as the Commission may deem necessary or desireable to promote the common defense and security or <u>to protect health or to minimize danger to life or property.</u> (emphasis added)

In many respects, the act assigns exclusive authority to the NRC for regulation of health and safety standards associated with nuclear power plants. For example, the act outlines areas of cooperation between NRC and states to control radiation hazards associated with byproduct, source, and special nuclear materials (Section 274(a)). Under these provisions "the Commission is authorized to enter into agreements with the Governor of any State providing for discontinuance of the regulatory authority of the Commission" as it relates to the referenced materials for purposes of protecting "the public health and safety from radiation hazards" (Section 274(b)). It is under this provision that so-called "agreement" states regulate transport of radioactive materials within their boundaries. The section goes on to say, however, that:

> (Section 274(c)) No agreement entered into pursuant to subsection b. shall provide for discontinuance of any authority and the Commission shall retain authority and responsibility with respect to regulation of --

> (1) the construction and operation of any production or utilization facility . . .

This issue of federal (NRC) preemption of state authority to regulate nuclear power plants for purposes of protection of public health and safety has been the subject of litigation.

> Accordingly, for the reasons stated, we hold that the Federal government has exclusive authority under the doctrine of preemption to regulate the construction and operation of nuclear power plants, which necessarily includes regulation of the levels of radioactive effluents discharged from the plant.2/

Another indication of NRC exclusive authority over health and safety matters related to production of nuclear energy is the provision for classification of a nuclear incident as an extraordinary occurrence.

> (Section 11(j)) The term "extraordinary nuclear occurrence" means any event causing a discharge or dispersal of source, special nuclear, or byproduct material from its intended place of confinement in amounts offsite, or causing radiation levels offsite, which the Commission determines has resulted or will probably result in substantial damages to persons offsite or property offsite. Any determination by the Commission that such an event has, or has not, occurred shall be final and conclusive, and no other official or any court shall have power or jurisdiction to review any such determination. (emphasis added)

An exception to an exclusive health and safety authority was provided by the Atomic Energy Act of 1954 in the form of an interagency Federal Radiation Council (FRC) to address issues of radiological health and radiation protection.

> (Section 274(h)) There is hereby established a Federal Radiation Council, consisting of the Secretary of Health, Education and Welfare, the Chairman of the Atomic Energy Commission, the Secretary of Defense, the Secretary of Commerce, the Secretary of Labor, or their designees, and such other members as shall be appointed by the President. The Council shall consult qualified scientists and experts in radiation matters, including the President of the National Academy of Sciences, the Chairman of the National Committee on Radiation Protection and Measurement, and qualified experts in the field of biology and medicine and in the field of health physics . . . The Council shall advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all Federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with States.

In 1970, the Federal Radiation Council was dissolved, and the authority to issue guidance on radiation protection and exposure limits was transferred to the newly created Environmental Protection Agency (EPA). The radiation exposure guides promulgated by the FRC in 1960 constitute the guidance currently provided by the EPA.3/

Actual EPA jurisdiction over Atomic Energy Act materials, however, is limited to releases of radioactivity into areas outside the boundaries of NRC-regulated facilities. 4/ NRC standards for the maximum exposures allowed to individuals in the general population from radioactive emissions from nuclear power plants must therefore be consistent with EPA standards.

The EPA does not have authority over occupational radiation exposure levels although their FRC-assumed functions permit issuance of guidance on such levels.5/ Federal user agencies -- such as DOE, DOD, HEW, and Veterans' Administration, which have facilities in which workers are exposed to radiation -- must enforce occupational exposure standards consistent with that guidance. Regulation of occupational exposures in the private sector, including commercial nuclear power plants, however, rests with the relevant regulatory agency. The NRC thus retains authority to set standards for permissible radiation dose levels to nuclear power plant workers.6/

Although not compelled to follow EPA guidance on occupational exposures, it has been the policy of the NRC, and the AEC before it, to follow such guidance.7/ The NRC has not had a standard procedure for involving other agencies directly in its occupational radiation protection standards-setting process other than inviting comment, along with that of the general public, on proposed rulemaking. 8/ (See section IV of this report for a discussion of NRC radiation protection standards.)

Much of the NRC responsibility for protection of public health and safety is implemented through environmental monitoring and emergency planning regulations.

As discussed in section VI of this report, NRC licensees are required to conduct ongoing monitoring of off-site environmental radiation levels during normal plant operations. These levels are routinely compared with natural background levels measured prior to and during the period of plant operations in order to detect increases in low-level environmental radiation. This monitoring system is not designed to provide comprehensive measurement of releases of radioactivity which could result from a nuclear reactor accident. During an emergency, however, the licensee is required to determine the magnitude of off-site radiation levels by deployment of radiological monitoring teams to off-site locations where such radiation exposure is suspected. The emergency plan required of NRC licensees must contain arrangements for the utility operator to notify off-site authorities of the need for protective action such as evacuation, and indication, through letters of agreement, of the off-site authority's capability to implement such an action. These NRC emergency preparedness requirements apply only to the licensee, not to any state or local agencies (see sections VI and VIII for further discussion).

b. Other Federal Agencies

Responsibilities of other federal agencies for off-site radiological monitoring and protection have changed considerably during the last decade. Up until the mid-1960s, the Atomic Energy Commission (AEC) was responsible for virtually all radiological matters related to nuclear energy and nuclear weapons. From the mid-1960s and the 1970s, off-site radiological surveillance of nuclear power plants and weapons testing facilities of the AEC and Department of Defense (DOD) was conducted by the Bureau of Radiological Health (BRH) in the Public Health Service (PHS), Department of Health, Education, and Welfare (HEW).9/

With creation of the Environmental Protection Agency (EPA) in 1970, responsibility for radiation surveillance was divided between environmental and medical activities. All personnel and facilities for surveillance of environmental hazards, including radiation, were assigned to the EPA. Regulation and radiological surveillance of electronic product radiation, both medical and dental radiation as well as non-ionizing radiation, remained in the BRH. As discussed in Section VIII, however, each agency is authorized to provide guidance, training, and assistance to states in developing and implementing health and safety protective actions in the event of a peacetime nuclear emergency. 10/ The EPA protective action guides (PAGs) deal primarily with levels of airborne radio-iodine and noble gases at which protective action, such as evacuation, should be considered. The BRH guides deal primarily with monitoring for radioactive contamination of food and animal feeds during a radiation emergency.

The Department of Energy (DOE) maintains a Radiological Assistance Program (RAP) whereby states can request assistance from the DOE and its network of national laboratories to assist in management of radiological emergencies.

Federal assistance in the event of a peacetime nuclear emergency is also available through the Interagency Radiological Assistance Plan (IRAP) which was developed in 1961. DOE is responsible for administering and implementing the plan, and has available, on request, the resources of IRAP signatory agencies, namely the Defense Civil Preparedness Agency; Departments of Agriculture, Commerce, Defense, HEW, Labor, and Transportation; the EPA; Interstate Commerce Commission; National Aeronautics and Space Administration; NRC; and the Postal Service. 11/ By marshalling the capabilities of these various agencies through TRAP, the federal government can provide assistance to state and local authorities in the form of (1) evaluating radiological health hazards, (2) minimizing personnel exposure, (3) minimizing the spread of radioactive contamination, (4) minimizing property damage, (5) performing rescue and first aid, (6) providing technical information and medical advice on the treatment of injuries complicated by radioactive contamination, and (7) providing information to the public to minimize undue alarm and assist in orderly conduct of emergency procedures.12/

2. <u>State Agencies</u>

At the state level in the Commonwealth of Pennsylvania, reponsibility for radiation health concerns is housed in the Bureau of Radiation Protection (BRP) of the Department of Environmental Resources (DER).

Prior to 1970, the state's radiological health capability was part of the Department of Health. Following creation of the EPA at the federal level, however, the state reorganized its agency structure, transferring radiological monitoring and surveillance to a counterpart environmental agency. Unlike the federal model, however, the BRP retained responsibility for surveillance of medical radiation as well. 13/ In fact, most of the BRP's staff and time has been devoted to licensing and inspection of non-NRC licensed users of radioactive material and X-ray equipment. 14/ The Pennsylvania Department of Health currently has no responsibility in radiological health, and therefore no authority or capability to respond to a radiological emergency.15/

B. ON-SITE CONSIDERATIONS -- HEALTH AND SAFETY OF THE WORKERS

Federal radiological health and safety requirements are dealt with separately from conventional industrial health and safety concerns in the nuclear power industry. The NRC issues all regulations dealing with radiological health and safety such as exposure limits for workers, health physics training, physical and"technical qualifications for radiation work permits, and response to radiation emergencies, including arrangements for medical care of workers who become contaminated and/or suffer radiation injuries. All other conventional industrial health and safety practices, ranging from housekeeping to procedures for working with high voltage electrical equipment, are subject to regulations issued by the Occupational Safety and Health Administration (OSHA) of the Department of Labor.

NRC and OSHA receive guidance from different agencies in developing their occupational health standards. The EPA is charged with providing "guidance for all Federal agencies in the formulation of radiation standards." 16/ This provision includes guidance for limiting the exposure of workers to ionizing radiation in the nuclear power industry (see section IV).

OSHA receives its guidance from the National Institute for Occupational Safety and Health (NIOSH) in HEW. NIOSH is not a regulatory agency, but it does conduct research and recommend regulatory standards to OSHA and the Mine Safety and Health Administration on protection of workers' health and safety.

Since NRC has primary regulatory responsibility in the nuclear power industry, OSHA has, in effect, delegated enforcement of its health and safety regulations to NRC. Although not an official arrangement, it is understood that NRC Inspection and Enforcement personnel will check for compliance with OSHA safety requirements when they perform NRC plant safety inspections. 17/ According to spokesmen for the International Brotherhood of Electrical Workers, OSHA apparently has not inspected operating nuclear power plants in the United States, although OSHA inspections have occurred during construction of such plants.18/

At Three Mile Island, Met Ed has organized its staff to relate to the requirements of the regulatory agencies which govern occupational health and safety practices in a nuclear power plant. A health physics staff manages all radiation protection matters including compliance with NRC health and safety regulations. A separate site safety staff is responsible for compliance with OSHA industrial health and safety standards. Although these organizational units are distinct, their activities overlap and interrelate, especially in certifying workers' physical health qualifications and in the content of health and safety training programs.19/

C. RESEARCH ON THE BIOLOGICAL EFFECTS OF IONIZING RADIATION

A considerable amount of scientific information on the biological effects of ionizing radiation has been developed from epidemiological studies of exposed human populations and laboratory animal experiments. The results of these studies have been reviewed and analyzed by a variety of scientific groups such as the Committee on the Biological Effects of Ionizing Radiation (BEIR) of the National Research Council; the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR); the National Council of Radiation Protection and Measurement (NCRP); and the International Commission on Radiological Protection (ICRP).

The objective of these groups has been to identify the relationship between radiation exposure and health effects. Two assumptions underlie the analyses: (1) any exposure to radiation, no matter how low the dose, carries some risk of deleterious health effects; and (2) as the radiation dose increases above very low levels, the risk of deleterious effects increases in exposed human populations. To date, there is general agreement in the scientific community on the effects of relatively high radiation dose levels. There is insufficient knowledge of the dose-response relationship at low levels of exposure to radioactivity. Scientists therefore differ in their estimates of the risks to health associated with low exposures.

Federally funded research on the biological effects of ionizing radiation is sponsored by a number of agencies. In fiscal year 1978, the federal government spent over $76 million on such research. About 63 percent was provided by DOE, another 20 percent by HEW, and the balance supported by the Departments of Agriculture and Defense, the NRC, EPA, Veterans' Administration, and the National Aeronautic and Space Administration. No formal interagency organization exists to coordinate these federal research programs.20/

The Atomic Energy Act of 1954, as amended, authorized the AEC to arrange for research and development activities (Section 31). Most of the substantive areas listed under this section relate to research into the technologies of nuclear energy generation. Item 5, however, relates to "the protection of health and the promotion of safety during research and production activities."

In Title II of the Energy Reorganization Act of 1974, which created the NRC, provisions were made to establish an Office of Nuclear Regulatory Research. Section 205(b) of this act states that this research office

> ....shall perform such functions as the Commission shall delegate including:
>
> (1) Developing recommendations for research deemed necessary for performance by the Commission of its licensing and related regulatory functions.
>
> (2) Engaging in or contracting for research which the Commission deems necessary for the performance of its licensing and related regulatory functions.

IV. RADIATION PROTECTION STANDARDS

The NRC has implemented its general authority and responsibility for health and safety in its licensed facilities in part by means of regulations entitled "Radiation Protection Standards" (10 CFR Part 20). It is in these regulations that permissible radiation exposure levels for both off-site and on-site populations are found. These regulations, and accompanying regulatory guides, therefore represent the basic framework of radiological health considerations established and enforced by the NRC.

The radiation protection standards have two distinct components. First, the Part 20 regulations establish maximum permissible exposure levels for individual nuclear workers and members of the general public (Sections 20.101 and 20.105). NRC-licensed facilities (all types of facilities, including nuclear power plants) must be designed and operated so as to prevent emissions of radioactivity which would result in radiation exposures that exceed the maximum permissible levels. These standards are health-based, i.e., their formulation has been based on what is presently theorized about the biological effects of ionizing radiation.

Second, the regulations stress that licensees should develop systems to assure that radiation exposures are kept at levels which are "as low as is reasonably achievable" (Section 20.1(c)). This approach, referred to as ALARA, is technology-based rather than health-based in that it relies on considerations of technological and economic feasibility for reducing radiation exposures below the maximum permissible levels.

This section of the report will discuss briefly this dual regulatory approach to radiological protection. For a more complete discussion of this subject as well as the relationships of the governmental authorities involved in radiation protection, see the report of the Advisory Committee on the Biological Effects of Ionizing Radiation, "Considerations of Health Benefit-Cost Analysis for Activities Involving Radiation Exposure and Alternatives" (Chapter IV, EPA 520/4-77-003, April 1977).

A. MAXIMUM PERMISSIBLE DOSE LEVELS

Acting under its broad statutory authority, the AEC developed the numerical standards currently in use for maximum permissible individual radiation exposure levels in 1957 (10 CFR Part 20). These standards were established in conformance with two health effects studies: the Medical Research Council's "The Hazards to Man of Nuclear and Allied Radiation" (HMS Office, Great Britain, 1956) and the National Research Council's "The Biological Effects of Atomic Radiation -- Summary Reports" (1956). The reports contended that radiation represented a health risk at any level of exposure, a risk that increased cumulatively with each increment of exposure. The reports marked a turning point in the growing public awareness of radiation hazards. Whereas, in the previous 30 years, the "acceptable" exposure levels had gradually fallen from 1.4

rads per week to 0.3 rads per week, after these reports, the now-termed "permissible" levels were set at the much lower level of 5 reins per year.

The 1957 AEC standards found their basis in these studies. Those standards refer to levels of radioactivity in the environment (e.g., the air and water) under normal conditions, i.e., natural radiation as well as radiation due to routine operation of nuclear facilities. The standards vary depending upon three factors: (1) whether the person who is exposed is in a restricted area or an unrestricted area;* (2) whether the danger is caused by radiation or by radioactive material;** and (3) whether the person who would be exposed is under 18 years of age (Section 20.104(a)).

Doses of radiation to individuals in unrestricted areas (i.e., off-site) are not to exceed 2 millirems in any one hour or 100 millirems in any period of 7 consecutive days (Section 20.105). NRC permits an exception to this requirement, however, if the applicant can demonstrate that an alternative proposal will not result in individual whole-body doses in excess of 0.5 rem ner calendar year (Section 20.105(a)).

The Part 20 regulations also establish maximum exposure levels for airborne and waterborne radioactive materials released in effluents to unrestricted areas (Appendix B, Table II). These levels are lower than those for such exposures in restricted areas. A licensee is permitted to exceed the off-site levels if it can demonstrate that no individual person would be exposed to levels exceeding the standards (Section 20.106(b)(1)), and that a "reasonable effort" has been made "to minimize the radioactivity contained in effluent to unrestricted areas" (Section 20.106(b)(2)).

---

* A "restricted area" is "any area access to which is controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials. 'Restricted area' shall not include any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area." (10 CFR Section 20.3(14)) An "unrestricted area" is "any area access to which is not controlled by the licensee for purpose of protection of individuals from exposure to radiation and radioactive materials, and any area used for residential quarters." (10 CFR Section 20.3(17)) As a general matter, the restricted area would be the exclusion zone established in accordance with 10 CFR Part 100 ("Reactor Site Criteria"). The unrestricted area would include the low population zone and areas more distant from the plant.

*- "Radiation" is defined as "any or all of the following: alpha rays, beta rays, gamma rays, X-rays, neutrons, high-speed electrons, high-speed protons, and other atomic particles; but not sound or radio waves, or visible, infrared, or ultra-violet light." (10 CFR Section 20.3(12)) "Radioactive material" includes "any such material whether or not subject to licensing control by the Commission." (10 CFR Section 20.3(13))

Programs for monitoring off-site exposures are discussed in section VI of this report.

Maximum permissible radiation doses to individuals in restricted areas (i.e., on-site) are not to exceed quarterly levels of 1-3/4 rems whole-body, 18-3/4 rems extremities, and 7-1/2 rems to skin of whole body (Section 20.101(a)). Like the off-site limits, NRC permits the licensee to increase the whole-body dose level to 3 reins per quarter if (1) the individual worker is over 18 years of age; (2) the licensee tracks that individual's lifetime accumulated occupational whole-body dose; and (3) that accumulated dose does not exceed 5(N - 18) rems where "N" equals the worker's age as of his last birthday (Section 20.101(b)). If these three requirements are satisfied, the licensee, in effect, may expose a worker to a maximum of 12 rems per year (3 rems per quarter for 4 quarters).21/

In contrast, the exposures permitted for workers in DOE nuclear facilities may not reach these levels; although 3 rems quarterly exposure is permitted, annual doses may not exceed 5 rems. Given the age-related formula which NRC requires to restrict lifetime occupational dose, however, maximum individual exposures would be 5 rems per year after an initial period during which doses up to 12 rems per year may be permissible.*

---

* For example, as illustrated in the following table, a new nuclear power plant worker, age 22, with no prior occupational exposure, could be permitted to receive the maximum 12 rems per year dose in his first 2 years of employment. By his third year, the maximum annual exposure he could receive would be 6 rems, and, from his fourth year onward, his annual exposure could not exceed 5 rems. The older the worker is when he enters the industry with no prior occupational exposure, the more years he can be exposed in excess of 5 rems.

New worker, age 22; accumulated occupational exposure = 0
(column (e) may not exceed column (c))

Year of work (a)	A e (b)	Permissible Accumulated Exposure 5 (Age-18) (c)	Exposure Permitted This Year (d)	Accumulated Occupational Exposure (e)
1	22	20	12	12
2	23	25	12	24
3	24	30	6	30
4	25	35	5	35
5	26	40	5	40
etc.				

It is important to emphasize that these radiation exposure standards are maximum levels. As discussed in the next subsection (section IV), the NRC, following FRC/EPA guidance, urges licensees to design and conduct their radiation protection programs to reduce actual exposures to levels as low as are reasonably achievable. In fact, occupational exposures in the commercial nuclear power industry are much lower than the maximum levels permitted by the Part 20 standards.

In 1977, there were 71,904 workers monitored in commercial nuclear power plants; 44,233 (61.5 percent) of these workers had measurable doses. 22/ The average annual exposure in 1977 of the workers who had measurable doses was 740 millirems. Over half of these workers had exposures under 250 millirems, 75 percent under one rem, and 95 percent of these workers had annual exposures less than 3 rems. Only 0.6 percent of all such workers, 270 of the 44,233, exceeded a 5-rem dose in 1977. No individuals exceeded a 10-rem annual dose.23/

The average dose per worker with measurable exposure has remained relatively constant (between 640 and 970 millirems) since 1973 when data for the commercial nuclear power industry were available separate from that of all nuclear power facilities.24/ (Programs for monitoring worker exposures to radiation are discussed in section VI.)

Licensees must also assure that individual workers will not inhale, or absorb through their skin, quantities of radioactive material in excess of levels specified in Part 20 regulations (Section 20.103(a)(1)); levels in Appendix B, Table I, Column 1). Licensees are directed to "use process or other engineering controls, to the extent practicable" to limit concentrations of airborne radioactive material (Section 20.103(b)(1)). If such measures are "impracticable," licensees are to use other precautionary measures to reduce worker exposures (Section 20.103(b)(2)). Such measures may include increased surveillance, limitation on the amount of time a worker spends in the radioactive environment and use of respiratory protective equipment. If the licensee chooses to use respirators which comply with NRC standards,25/ adjustments may be made to the estimates of airborne radioactive exposures to account for the protective factor afforded by the respirator (Section 20.103(c)). (Programs for monitoring airborne radioactivity, and requirements for respiratory protection are discussed in section VI of this report.)

The application to construct a nuclear power plant must demonstrate adequate structural design and engineered safeguards to assure prevention of exposures to radiation and radioactive materials during normal plant operations beyond the maximum off-site and on-site permissible dose levels. (See section V of this report for discussion of the construction permit phase at TMI-2.)

In the years since their original promulgation, the Part 20 numerical standards have not been changed. The NRC asserts that the present occupational standards "seem to be working, creating a safe occupation." 26/ The EPA, with interagency advice, currently is reviewing their occupational health standards; it is speculated that external dose levels will remain essentially unchanged, while internal dose levels may be lowered.27/

With respect to worker health, the NRC also contends that the nuclear industry is safer than many other industries. This NRC contention, however, is based upon assumptions of comparability among various industries and occupational health hazards.

> What we try to do is select (a dose level) which, if received year in and year out by a worker, would create for that worker a risk similar to the risk accepted in the safer industries in the United States, such as manufacturing.
>
> Now this attempt suffers somewhat from the fact that radiation-induced cancer and genetic effects are not directly comparable with accidental death. For one thing, in industry the accidental deaths occur to people much younger than the radiation-induced cancers. Because of the latent effect, it can be 20 years or more for cancer to appear at the advanced state, whereas these accidental deaths tend to occur to younger people, to younger men.
>
> So the number of years of life lost is much greater in industry than it is for the radiation-induced cancers. That's not true of other industrial diseases, but we simply don't have the data for other industrial diseases on which to make our comparison. So we're almost limited by circumstance to making our comparison with accidental deaths, and that's what we do.28/

B. THE ALARA CONCEPT

In determining its radiation protection standards, the NRC has adopted the hypothesis of the linear non-threshold dose response relationship (risk is proportional to dose). The NRC therefore assumes: (1) there is no exposure level below which there is no hazard; and (2) the risk of adverse health effects increases linearly with dose. Although Part 20 regulations specify permissible dose levels, the NRC stresses development of programs to reduce exposures to "as low as is reasonably achievable" (ALARA) in order to reduce the risk of adverse health effects.

> . . persons engaged in activities under licenses issued by the Nuclear Regulatory Commission. . . should, in addition to complying with the requirements set forth in this part, make every reasonable effort to maintain radiation exposures, and releases of radioactive materials in effluents to unrestricted areas (off-site) as low as is reasonably achievable. The term "as low as is reasonably achievable" means as low as is reasonably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to the utilization of atomic energy in the public interest.29/

There are economic trade-offs in efforts to reduce exposure. Insertion of ALARA into the NRC regulatory system thus introduces cost-benefit analysis as a decision-making tool. Under ALARA (10 CFR Part 50, Appendix I), the construction application for a nuclear power plant should include description of the equipment to be installed which will control the radionuclide concentrations of liquid, gaseous, and particulate effluents within numerical limits -- the so-called "design objectives." Cost-benefit analysis is used to determine whether investment should actually be made in such equipment. In other words, the benefits of reduced radiation exposure resulting from installation of a piece of equipment must be weighed against the financial outlay required to purchase, install, and operate that equipment. Even though the precise cost of that additional equipment may be demonstrable, quantification of the benefits of exposure reduction is inherently difficult since it involves placing a value on that exposure reduction and its associated reduced risk of ill health effects. Some persons contend that the difficulty in quantifying health benefits renders futile the use of cost-benefit analysis in these circumstances.30/

The NRC does, however, place a dollar value on exposure reductions in 10 CFR Part 50, Appendix I:

> If the dose to the population, in the design stage, can be calculated to be reduced by an increment which is less than $1,000 per man-rem, then it's recommended. . that that particular piece of equipment, or whatever, be installed in the plant. Let's say that a piece of equipment cost $2 million, and reduces the exposure -- population exposure -- by 20 man-rem. Twenty man-rem times $1,000, that's $20,000 -- they would not put in that piece of equipment to reduce the population exposure.31/

Appendix I, however, has narrow applicability. First, it is directed only at nuclear power plants, not all NRC-licensed facilities. Second, it applies only to reduction of radiation exposure to off-site populations; a dollar value on exposure reduction is not prescribed by the NRC for use in assessing the value of installing equipment or introducing procedures which might reduce occupational exposures.

The NRC assumes that increases in the collective dose translate into higher risks of adverse health effects for individuals within the exposed population. 32/ Staff of the NRC Occupational Health Standards Branch thus stress that reductions in individual dose not be made in exchange for increases in collective dose (total person-rems) when considering occupational ALARA decisions.

NRC Part 20 regulations currently specify only individual dose limits. The regulations on permissible exposure limits (10 CFR Part 20), however, do stress that licensees make every reasonable effort to minimize both individual and collective exposures. Unlike the Appendix I application of ALARA to off-site populations which deals with initial design and construction of the plant, the on-site ALARA program is a continuous effort to reduce exposures during operation of the nuclear power plant.

To that end, ALARA guidance is provided in two forms. One is a regulatory guide which describes an acceptable general operating philosophy for achievement of ALARA objectives. 33/ This guide outlines the types of policies expected of a licensee to demonstrate management commitment to ALARA concepts and vigilance on the part of radiation protection staff.

A second regulatory guide provides information on the factors which should be examined in setting ALARA goals and objectives, and in developing a program geared towards their achievement. 34/ This guide states clearly an NRC concern for growth in the industry-wide collective dose, and related economic considerations.

> The radiation protection community (applied health physics) has recognized for many years that it is prudent to avoid unnecessary exposure to radiation and to maintain doses ALARA. In addition to reduced biological risks, the benefits of such practices may include avoidance of costs for extra personnel to perform maintenance activities and avoidance of nonproductive station shutdown time caused by restrictions on station personnel working in radiation areas. . .
>
> In view of the anticipated growth of nuclear power stations over the next few decades and the radiation exposure experience to date, additional efforts to reduce radiation doses to nuclear power station personnel are warranted.35/

The guide goes on to outline major factors to be considered in designing an operating ALARA program. Specific attention is drawn to those activities which are known to account for a major portion of radiation exposure to station personnel, namely, maintenance, rad-waste handling, inservice inspection, refueling, and nonroutine operations such as decontamination. 36/ ALARA objectives are to be considered in factors such as station design, choice and use of equipment, shielding, radiation protection program procedures, and training.

The ALARA guidance documents do not embody specific numerical values (dose limits). As noted, the guides do, however, stress the need to conserve dose, whether it be collective or individual. In order to strengthen this guidance program, the staff of the NRC Occupational Health Standards Branch is encouraging development of an "inspectable and enforceable" ALARA program. 37/ For each type of nuclear facility, appropriate equipment and radiation control practices and procedures would be outlined, based on the most effective ALARA programs existing in the industry. Although adoption of such programs would not be required by regulation, efforts of individual companies to achieve those ALARA objectives would be subject to NRC inspection. Collective dose limits would be part of this guidance.38/

V. SITING AND CONSTRUCTION OF NUCLEAR PLANTS

A. THE NUCLEAR REGULATORY COMMISSION -- SITING

Prevention of high level releases of radioactive materials and adequate protection of the public and workers in the event of such releases are first addressed in the siting and construction of nuclear reactors. The NRC Regulatory Guide on site selection states that "the safety requirements are primary determinants of the suitability of a site for nuclear power stations, but considerations of environmental impacts and public acceptance of nuclear power stations are also important and need to be evaluated." 39/ Specific criteria listed in the site selection regulations (10 CFR Part 100) include: (1) physical suitability (geology/ seismology; atmospheric extremes and dispersion; hydrology; ecological systems; land use and aesthetics; industrial, military, and transportation facilities; and noise); and (2) population considerations (density and socioeconomics).

Three types of populated areas must be defined and considered in the site selection process:

1. The "exclusion area" is basically the licensee's property (the area over which the licensee has controlling authority). Maximum radiation doses of 25 rems whole-body and 300 rems thyroid radioiodine to the on-site worker population from a postulated accident are considered in determining this area. Based on experience, the NRC has found a minimum distance of 0.4 miles around the reactor an adequate exclusion area. 40/ The TMI exclusion area is 2,000 feet, around 0.4 miles.

2. The "low population zone" (LPZ) is that area surrounding the exclusion area in which the population size and distribution is such that "there is a reasonable probability that appropriate measures could be taken in their behalf in the event of a serious accident." 41/ This concept of LPZ incorporates two considerations -- population density and potential population exposure resulting from a postulated "design basis" reactor accident (a loss-of-coolant-accident, or LOCA). NRC guidance specifies a population density factor based on permanent and weighted transient populations averaged over a 30-mile radial distance; population projections over the lifetime of the facility are also considered. Maximum population exposures of 25 rems whole-body and 300 rems thyroid radioiodine per individual received during the course of the design basis accident determine the outer boundary of the LPZ. The magnitude of exposures resulting from such an accident is determined by the engineered safeguards designed into the nuclear reactor.

The LPZ siting concept is incorporated into NRC guidance on emergency planning 42/ which directs licensees to develop and maintain site emergency plans that include arrangements to initiate protective action within the LPZ in the event of an accident with releases of radioactive materials which threaten to exceed population exposure limits. The actual radial distance of the LPZ is thus dependent on the number and type of engineered safeguards designed into the plant, and the capability to take protective action on behalf of the population in the area.

The NRC guide indicates that a 3-mile distance usually is an adequate LPZ.43/ The LPZ at TMI is 2 miles and encompasses about 3,000 people. Some nuclear power plants have even smaller LPZs; for example, the LPZ at the Indian Point in New York is only 0.6 mile. As mentioned in section X of this report, efforts are underway, both within and outside the NRC, to change the geographic focus of emergency planning. Consequently, the LPZ concept in plant siting criteria may also change.

3. The "population center distance" is defined as the distance from the reactor to the nearest boundary of a densely populated center having more than 25,000 residents. The NRC Regulatory Guide specifies that this distance should be at least 1-1/3 the distance from the reactor to the outer boundary of the LPZ. Harrisburg, the population center closest to TMI, lies about 10 miles from the site with a population of close to 70,000. Since the 10-mile distance lies beyond the 1-1/3 factor (the TMI LPZ is just 2 miles), Harrisburg was, in effect, not a constraint on siting of the TMI nuclear station.

B. COMMONWEALTH OF PENNSYLVANIA -- SITING

In addition to the NRC site criteria which applicants must address, a variety of siting requirements are imposed by states and local authorities. As of January 1978, 25 states had facility-siting legislation. All but two of these states had a single designated agency, acting on behalf of all state government concerns, empowered to grant or deny a utility request to site a nuclear reactor. The remaining two states used a multiple agency review process requiring approvals from several state and local boards and agencies. The provisions of these 25 state laws varied not only in method of review, but in composition and size of the siting authority, agency designation, method of site acquisition, application fees, and required utility forecasts as well.44/

No such siting authority existed in Pennsylvania when the TNT site was under consideration for a nuclear power plant. The review process at that time had two features: (1) if the proposed site was in an area already zoned for such a use or if a variance had been granted by the local zoning board, no state approval was needed; and (2) if there was no such local zoning or variance, the applicant could turn to the state public utility commission for a certificate of convenience permitting the utility to exercise the power of eminent domain.45/

Three Mile Island was selected for a GPU nuclear station in January 1967, and construction began on TMI-1 in the Spring of 1968. In 1968, GPU also applied to build a second unit on the Island using plans originally developed for an additional unit at their Oyster Creek station in New Jersey. The TMI site was judged suitable by the NRC for a second unit at that time.

In late 1977 and early 1978, legislation to establish an Energy Facility Siting Interagency Commission was approved by the General Assembly of Pennsylvania. This legislation ruled that no utility could begin construction or operation of a "bulk power facility without obtaining a certificate of public need, social, economic and environmental compatability from the Commission." 46/

The commission is to include seven state departments, two municipal governments, and the general public. The state Department of Health is not included in this interagency commission.47/

C. CONSTRUCTION

After having received approval of the site, the applicant must next obtain a permit to construct the nuclear plant. The major health and safety consideration at this point is containment of routine radioactive emissions within the limits prescribed by the NRC in its radiation protection standards.48/

1. Construction Permit Hearing for TMI-2

A mandatory public hearing by the Atomic Safety and Licensing Board was held in October 1969 to review the TMI-2 application for a construction permit. At that hearing, both the applicant (Met Ed) and NRC staff testified to the adequacy of site, structural, and engineered safety features. Hazardous releases of radiation were considered preventable based on:

a. the plant's capability to withstand extreme acts of nature, such as floods, tornadoes, and earthquakes;

b. the self-contained features of the fuel and primary coolant systems;

c. the design and strength of the reactor vessel; and

d. automatic safeguards (system redundancy and multiple on-site power sources) built into the system.49/

The design basis loss-of-coolant accident (LOCA) and other system failures used as the postulated accidents for designation of the LPZ and other site safety considerations for TMI were similar to those used in other nuclear power plant applications. 50/ Both the Advisory Committee on Reactor Safeguards and the AEC licensing staff had previously reviewed the application and testified that:

> In the unlikely event of various postulated accidents, including loss of normal reactor coolant, engineered safety features will provide core protection, and confine radioactivity released from damaged fuel to the containment building. We have considered the radiological effects on the environment and conclude that the off-site radiation levels resulting from normal plant operations, as well as from postulated accidents, are within established regulations or site criteria guidelines.51/

There were no petitions filed to intervene in the construction permit process for TMI-2. Representatives from the state Bureau of Radiation Health (which was then part of the Department of Health) testified as to their satisfaction with the safety features of the proposed TMI-2 facility. Only one member of the public, a private citizen not representing any group or groups, requested a limited appearance at the hearing to question what provisions had been made to avoid aircraft approaching the nearby airport from crashing into the cooling towers and, in the event of such a collision, to contain potential radiation releases. The Met Ed response to this one public inquiry included analysis of the probability of such an occurrence, stress tests of the power plant structure to withstand such a collision, and indication of precautionary measures taken, such as lighting of the cooling towers. The NRC considered this response adequate.52/

A construction permit was awarded for TMI-2. Almost 10 years later, in February of 1978, TMI-2 received its operating license after a set of hearings which included a challenge to the emergency planning conducted by Met Ed pursuant to NRC regulations. (Discussion of this contention is available in the reports of the Office of Chief Counsel on "Emergency Preparedness" and "Emergency Response.")

2. Application of the ALARA Concept to Design Considerations at TMI-2

The means by which the ALARA concept (see section IV) was applied to design considerations at TMI-2 is summarized in the NRC staff Safety Evaluation Report filed during the operating license stage of TMI-2 development.53/

Met Ed had applied cost-benefit analysis as outlined in 10 CFR Part 50, Appendix I, to evaluation of augmentation of the proposed system for processing radioactive wastes. The NRC staff reviewed that analysis and concluded that the costs of the additional systems exceeded the $1,000 per person-rem valuation of the benefits of consequent radiation exposure reductions.

VI. MONITORING AND SURVEILLANCE

A. ENVIRONMENTAL MONITORING -- NRC

Monitoring and surveillance for protection of the public health in the nucear power industry refers exclusively to detection and analysis of environmental radioactivity; there is no direct measurement of individual exposure. In order to enforce the off-site radiation exposure levels required by 10 CFR Part 20 and to assess achievement of ALARA objectives (as discussed in section IV), the NRC requires an on-going environmental monitoring program throughout the lifetime of a nuclear power plant. At least 2 years of monitoring background radiation levels prior to operation of a plant is required of the licensee in order to establish the baseline levels to which the population is exposed in the absence of the nuclear reactor. During operation of the nuclear power plant, data on radioactive releases monitored at the reactor stack are fed into calculational models to estimate resulting environmental doses. Actual environmental monitoring by sampling of various media (air, water, soil, etc.) is conducted to confirm the estimated exposures.

As with many NRC regulations and regulatory guides, design of the detailed characteristics of the environmental monitoring program is left to the licensee. Only general guidance is given by the NRC as to the types of media to be sampled, the sampling frequency, the measurement methods, and equipment used, including their detection capabilities, quality controls, and analytical methods. This information, as well as the environmental dosimetry itself, is to be retained by the licensee, subject to NRC inspection.

Exposure estimates made throughout the operational lifetime of the plant are compared to the known background levels to determine whether exposures resulting from normal plant operations are within established limits, and to ensure that long-term buildup of specific radionuclides in the environment will not be significant.54/

> If the quantity of radioactive material actually released in effluents to unrestricted areas from a light-water-cooled nuclear power reactor during any calendar quarter is such that the resulting radiation exposure calculated on the same basis as the respective design objective exposure, would exceed one-half the design objective annual exposure. . . the licensee shall:
>
> 1. Make an investigation to identify the causes for such release rates;
>
> 2. Define and initiate a program of corrective action; and
>
> 3. Report these actions to the appropriate NRC Regional Office. . . within 30 days from the quarter during which the release occurred.55/

In its second report to the National Research Council, the Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR) expressed concern about the implications of this regulatory language:

> Two features stand out, emphasizing the broad scope of NRC enforcement discretion:
>
> (1) By implication, the licensee will be allowed to exceed the emission standards by a substantial amount indefinitely, without even calling the NRC's attention to the matter.
>
> (2) If the licensee exceeds the exposure limit, and sets to work on a program of corrective action, there is no indication of the time-scale on which the licensee will be required to act.
>
> Both these situations are governed at the discretion of the NRC.56/

B. ENVIRONMENTAL MONITORING -- METROPOLITAN EDISON

The background environmental radiation levels for the TMI nuclear station were established during a 3-year period prior to operation of TMI-1. The continuing operational program for TMI-1 served as the pre-operational program for TMI-2. Met Ed conducts continuous monitoring of (1) direct radiation, (2) air particulate and iodine in air samples, (3) river water, (4) milk samples for iodine, (5) green leafy vegetables in season, (6) rain water, and (7) fish and sediment. Daily, monthly, or quarterly measurements are made depending on the type of device applied to various samples. Technical specifications approved by NRC define the scope of this program, analyses to be performed, and lower levels of detection required. All monitoring records are reported through GPU to NRC annually.57/

The required environmental monitoring program is designed to measure low-level releases of radioactivity associated with normal plant operations. At the time of the accident at TMI, TLDs were in place at 20 locations around the site. The measurement reliability of these dosimeters, and actions taken in the first few days of the accident to supplement this system, are discussed in the report of the Health Physics and Dosimetry Task Group.

C. ENVIRONMENTAL MONITORING -- STATE OF PENNSYLVANIA

The issue of state environmental radiological monitoring capability gained some prominence in Pennsylvania in 1974 with investigation of allegations of excessive emissions of radioactivity from the Shippingport Nuclear Power Station. Since Shippingport is a U.S. Department of Energy, rather than commercial, facility, the state had not developed an environmental monitoring program around the site. In the investigation, it thus became exceedingly difficult to validate or reject the alleged exposure levels.58/ It was therefore recommended:

> In order to determine radiation exposure of the public to determine compliance with applicable requlations, to verify results of the facility environmental monitoring program, and to assure citizens living near nuclear facilities of adequate protection from radiation exposure, the Commonwealth Department of Environmental Resources should immediately begin an independent comprehensive environmental radiation monitoring program in the vicinity of all nuclear reactors within the State or near the State's borders.59/

Following this recommendation, legislation was introduced in the state legislature to fund additional environmental monitoring capacity, including an emergency response program. The legislation, however, failed to pass both the House and Senate. 60/ As a result, prior to the accident at TMI, the BRP had a limited environmental monitoring program around the site designed solely to check the monitoring program of the utility. The NRC provides funds to the BRP to report monitoring data based on minimum NRC reporting requirements. It is this "minimum program" which the BRP had in place at TMI at the time of the accident.61/

> We had one air sampling station located at the observation building . . . four thermoluminescent dosimeters in locations that were the same as the utility locations . . . water, milk, the nearest cow, was sampled . . . again, the same locations as the utility.
>
> If the utility did not find something in a sample where we were at the same location, there would be a way to verify.62/

D. MONITORING AND SURVEILLANCE OF WORKERS

Monitoring and surveillance of the worker population includes: (1) medical evaluation of workers, and (2) detection, analysis, and reporting of on-site environmental and individual radiation exposures.

1. Medical Examinations

The NRC requires a medical examination of all applicants for initial or renewal operator licenses to assure that "the physical condition and general health of the applicant are not such as might cause operational errors endangering public health and safety."63/

The NRC examination form (Form NRC-396), which is submitted for inclusion in the worker's application, includes a history of physical and emotional conditions completed by the applicant, and a brief medical examination completed by a licensed physician.

The NRC regulation lists several medical conditions which may disqualify an applicant for an operator's license. These include epilepsy, insanity, diabetes, hypertension, cardiac disease, fainting spells, defective hearing or vision, or any other physical or mental condition which might impair judgment or motor coordination. 64/ Any potentially disqualifying mental condition listed in the applicant's history is to be evaluated by a licensed psychologist, psychiatrist, or physician trained to identify such a condition.65/

The examining physician is encouraged to use criteria developed by the American National Standards Institute (ANSI) in **identifying the** health qualifications of the worker. 66/ The ANSI guide also requires the employer to submit a report to the examining physician on the applicant's work performance, attendance, and behavioral changes noted since the previous medical evaluation. It continues with the proviso that nothing in the guide "should be construed to mean that the reading habits, political or religious beliefs, or attitudes on social, economic, or political issues of an individual should be investigated or judged." 67/ Dr. Miles Newman, one of the community physicians who is retained by Met Ed to conduct many of these medical examinations, reported he had never heard of the ANSI guide.68/

Although the NRC only requires medical examinations for those nuclear workers who are licensed reactor operators (10 CFR Part 55), it is Met Ed company policy that all radiation workers (those in jobs which could expose them to 300 millirem or more in a quarter) receive periodic medical examination. The purpose of these examinations is "to ensure that no radiation related bodily changes go unnoticed, and that baseline data are available for evaluation of any accidental overexposures."69/

Pre-employment examinations outlined in Met Ed Health Physics Pror'r1ure 1628 include:

a. general medical examination of reactor operators and senior operators, and "if the last examination before employment at TMI has not included blood analysis, eye examination and an evaluation of the hearing function, the operator will receive an ophthalmologic examination with special reference to lens opacities and visual acuity (to be corrected before the employment), an audiometric investigation, and a complete blood cell count (with platelet count), hemoglobin, hematocrit and differential,"70/ plus whole-body counting and radiobioassay of excreta;

b. general medical examinations of other radiation workers including hematological, audiometric, eye, and bioassay examinations;

c. general medical examinations of all TMI non-radiation workers with "no special requirements (e.g., related to radiation protection)" and "if no previous exposure to radioactive products has occurred, this personnel will not receive any bioassay examinations. If such exposure has occurred, bioassay requirements are the same as those given for radiation workers."71/

Any disqualifying abnormality found in the pre-employment physical is referred for a second opinion. Since August 1978, Met Ed also has required psychological evaluation (Minnesota Multiphasic Personality Inventory, and psychological interviews) of all applicants for jobs which permit unescorted entry to controlled areas of the facility. Personnel records of those already employed as of August 1978 were reviewed for aberrant behavior.72/

Prior medical records, including medical radiation, are not requested for a new employee. The written medical record developed by Met Ed is treated as the property of the company, available to the worker only upon written request that such records be sent to his private physician.73/

According to Health Physics Procedure 1628, medical examinations to be performed during employment at TMI include:

a. general examinations of all radiation workers every 2 years including blood analysis (blood count, hemoglobin, hematocrit, and differential), ophthalmologic examinations including visual acuity checks and correction, if needed, whole-body counting after refueling and/or as required, and urinalysis about 6 months after the last whole-body count;74/

b. whole-body counts or radiobioassay of urine after major maintenance outages and refueling for all personnel involved in those actions; and

c. special examinations, determined in consultation with Radiation Management Corporation, of any employee who receives any accidental overexposure to radiation or radioactive materials.

Termination physicals are required for all personnel at TMI. For radiation workers, this general medical examination includes blood analysis, audiometric and ophthalmologic examinations, and urinalysis.75/

2. <u>Radiological Monitoring and Surveillance</u>

a. NRC Requirements

Like the off-site environmental radiological monitoring program, monitoring and surveillance of worker radiation exposures are regulated by the NRC (10 CFR Part 20).

Quarterly, annual, and accumulated occupational lifetime maximum permissible dose levels are specified (see section IV). Protective procedures include required personnel dosimetry, an optional respiratory protection program, health physics training (described elsewhere), and placement of appropriate cautionary signs and labels throughout the facility.

The NRC does not require licensees to monitor and maintain records on radiation exposure for all workers. Rather, regulations on personnel monitoring apply only to:

1. Each individual who enters a restricted area under circumstances that he receives, or is likely to receive, a dose in any calendar quarter in excess of 25 percent of the applicable value (as specified in Section 20.101).

2. Each individual who enters a restricted area under circumstances that he receives, or is likely to receive a dose in any calendar quarter in excess of 25 percent of the applicable value (as specified in Section 20.101.)

3. Each individual who enters a high radiation area. 76/ [NOTE: A high radiation area is one in which there exists radiation "at such levels that a major portion of the body could receive in any one hour a dose in excess of 100 millirem."]

Licensees are required to notify individual workers of their radiation exposure under three circumstances: (1) annual exposure only upon request by the affected worker; 77/ (2) over-exposures within 30 days of occurrence; 78/ and (3) accumulated occupational exposure upon termination of employment. 79/ The licensee is only required to maintain records, and therefore be able to report, on workers for whom personnel monitoring is required, as specified in 10 CFR Part 20, Section 20.202.

The NRC must also be informed by the licensee of individual over-exposures and accumulated occupational exposures on termination of employment for workers for whom personnel monitoring is required. In addition, the licensee must supply to the NRC, within the first quarter of each calendar year, reports on: (1) the total number of employees for whom personnel monitoring was required during the calendar year as specified in 20.202, or the total number of employees for which the licensee provided personnel monitoring (that is, those monitored in addition to workers for whom monitoring is required); and (2) a statistical summary on those for whom monitoring was required and/or provided, including a distribution of such workers by exposure level, and, in separate reports, by job category.80/

With the exception of overexposures, these requirements limit the licensee's obligation for monitoring and maintaining radiation records only to those employees which the licensee determines are likely to receive the doses specified in Section 20.202. This implies that the NRC is confident that: (a) the licensee can identify accurately which employees are likely to receive such doses, and (b) radiation standards and protective procedures required and used in nuclear facilities are adequate to control who is exposed as well as the magnitude of the exposure.

It is questionable whether this regulatory approach to personnel monitoring and recordkeeping adequately accommodates emergency situations in which employees for whom radiation exposures were not anticipated may indeed receive doses from accidental releases bf radioactivity. Since dosimetry would not have been routinely required for such employees, they would not have been equipped with personnel dosimeters at the time the accidental releases first occurred. Similarly, there would not have been established records on these employees in the radiation exposure recordkeeping system maintained by the licensee.

Monitoring and surveillance of on-site airborne radioactive materials required by the NRC to assure compliance with Part 20 standards (see section IV) include: (1) measurement of air samples in restricted areas, and (2) individual measurements including bioassay examinations. 81/ For purposes of estimating individual exposures to such airborne materials based on air samples, it is assumed that the individual worker inhales the materials at the airborne concentrations in which he is present unless he is wearing a respirator which meets the criteria set by the NRC for an acceptable respiratory protective program. That program must include, among other features, a written company policy on respiratory usage, procedures for monitoring, training, testing and fitting of respirator equipment, and annual respiratory examination of the individual worker by a physician to certify the worker's physical ability to perform work while using a respirator. 82/ The NRC leaves details of the physical examination to the discretion of the physician.83/ Respiratory equipment is to be selected to provide protection factors indicated in the Part 20 regulations which then may be used to adjust the estimates of environmental airborne radioactivity measured by the licensee. Bioassay and other surveys are to be used to evaluate the actual individual exposures -- that is, actual inhalation of radioactivity while using the respirator -- to assess the protection actually afforded by the device and, consequently, to verify or modify the adjusted estimates of environmental exposure.84/

b. Met Ed Practices and Procedures

The radiation protection policies and practices at TMI are incorporated in a series of administrative procedures. Detailed procedures are summarized in a Radiation Protection Manual (Administrative Procedure 1003) which applies to both TMI-1 and -2. The manual enunciates a company policy "to keep personnel radiation exposure within the Nuclear Regulatory Commission . . . regulations, and beyond that, to keep the exposures as low as reasonably achievable."85/

The manual covers all areas of radiation protection from permissible exposure limits, including allowable exceptions during emergency situations, through training in radiation protection, recordkeeping, and reporting requirements. Provisions are made for prompt investigation of any situation in which excess exposure of a worker is suspected or known. As noted in the previous section, in any case where an individual exposure must be reported to NRC (e.g., overexposure), the worker involved is also to be notified of the extent and nature of the exposure and the report is to be entered in the worker's personnel file. This written notification applies specifically to any exposure which exceeds the radiation protection standards in 10 CFR Part 20. Also in keeping with regulatory requirements, Met Ed has procedures for informing workers for whom personnel monitoring is required of their annual exposure, if requested. Within 90 days of termination, the company supplies a report to NRC and the individual worker of accumulated occupational exposure during employment at TMI.

Upon initial employment at TMI, nuclear workers are to report past occupational exposures to radioactivity, and, as required by NRC regulation (Section 20.101), Met Ed must contact previous employers to verify the reported exposure. The reporting procedure does not include nonoccupational (medical) sources of radiation exposure.86/

All workers at TMI whose jobs may require them to enter an area with potential radiation exposure must have a Radiation Work Permit (RWP). A major part of this permit process is qualification in the use of a respirator. The worker must first be examined by a licensed physician to certify his physical capability to use a respirator. The respiratory examination conducted by company physicians at TMI includes: (1) a short pulmonary screening history designed by the American Lung Association, (2) a brief physical examination to screen for any cardiac, circulatory, or pulmonary problems, and (3) a pulmonary function test. 87/ Having passed this examination, the worker is then fitted for the respirator appropriate to his facial size and shape, trained in proper use of the respirator, and finally subjected to a "booth" test -- a drill in a simulated contaminated environment -- for final certification. The examination process is repeated annually. At TMI, approximately 80 percent of all employees have respirator classifications.88/

The personnel monitoring program at TMI is designed to comply with NRC requirements (10 CFR Part 20, Section 20.202). All employees in any control area must wear a film badge and carry a pocket dosimeter which has a full-scale reading of 200 millirems. 89/ The personnel dosimeters are read and recorded by health physics personnel once monthly.90/

The most recent occupational exposure summary data from NRC are for 1977, the year prior to operation of TMI-2. Data for TMI-1, however, indicate that no worker had exceeded a 3-rem annual dose throughout the history of that reactor's commercial operation.91/

3. Management-Labor Relations Regarding Worker Health and Safety

Given the NRC-regulated worker exposure limits and regulatory guidance on ALARA programs (see section IV), the International Brotherhood of Electrical Workers (IBEW), which represents about 300 workers at TMI (and workers at 32 other nuclear power generating stations), does not consider radiation exposure standards in collective bargaining. In addition, setting of all safety standards, rules, and practices at TMI have been regarded by Met Ed as a management right, and therefore have not been open to negotiation. Management claims this right based on their liability -- "We call the shots. We don't negotiate safety rules. We accept full responsibility and, along that line, we direct the safety rules." 92/ Union spokesmen, on the other hand, claim that economic factors account in large part for management's unwillingness to negotiate safety -- the safety standards which would be demanded by workers could be costly to management either in terms of equipment that might be required and/or staffing and job preparation which might compromise productivity.93/

The current contract between the IBEW and Met Ed therefore addresses general safety matters. Met Ed retains the right to set working conditions, e.g., determination of the number and class of employees to be employed and assigned to a given task. Management, however, cannot require an employee "to perform any hazardous task with which he/she is not familiar, without proper instruction and close supervision," and "no employee shall be required to work alone on jobs of hazardous or complex nature, without qualified helpers."94/

Section 2.7 of the agreement sets out the respective responsibilities of the parties to adhere to safety rules and regulations:

> In the interest of safety, continuity of service, and efficient and orderly operation, the Brotherhood agrees that its members will abide by the Company's rules and regulations. Accordingly, it is understood by both the Brotherhood and the Company, that all rules and regulations now in effect or as adopted or changed in the future shall be strictly enforced and observed at all times. However, no rule or regulation shall be adopted which is contrary to the law, or to the terms of this agreement, except at a legally enforceable order of an agency of the Government.95/

Situations do arise in which a worker is directed to perform a task which the worker feels is unsafe or for which he feels he is either not classified or not trained. Met Ed management decisions have priority in these conflicts; ". . . that's the way the company feels, that you are not to hold up a job because you, the employee, say it's unsafe, that if the foreman says it's safe, it's safe."96/

Some of these conflicts are resolved immediately by intervention of a union steward. If there is no resolution, however, the union suggests the worker do the task, unless it is jeopardizing "health or limb," and then file a grievance to protest the assignment. 97/ If the worker refuses to do the assigned task, he is usually disciplined by being sent home for a number of days thus losing pay.98/

The federal agencies which have jurisdiction over worker health and safety in the nuclear power industry are OSHA and NRC (see section III of this report). According to Fred Grice, supervisor of generation safety for all GPU sites, OSHA has never inspected any Met Ed facility.99/

IBEW spokesmen at TMI also reported that they rarely consider turning to OSHA for resolution of a safety complaint. A task which workers regard as unsafe is generally completed by the time an OSHA inspector would respond to a complaint. Furthermore, it is felt that OSHA should only be approached if there is an indisputable complaint on the part of the worker.

> If you're talking about OSHA, you got to be pretty sure that anybody else in their right mind would not do that job. If you can substantiate that, then you're on pretty solid ground, but if it's a little wishy-washy, then I would say you're in trouble 100

Most safety issues are not of a clearly hazardous nature, however, thus leading to worker reluctance to pursue them with OSHA.101/ Complaints about radiation protection practices and procedures are occasionally referred to NRC for inspection and comment. This tends not to be an official avenue of complaint, however. In sum, the IBEW spokesmen claimed that they do not rely on federal agencies to respond to their health and safety concerns or disputes.

Matters of dispute between the IBEW workers and management at TMI are generally handled either through management-labor safety committees which meet regularly, or through the grievance procedure. Grievances work their way up through a system of higher and higher level personnel in search of resolution. Only if no resolution can be found between management and labor is the matter referred to arbitration. An estimated 10 percent or less of all grievances at TMI are characterized as safety-related by IBEW spokesmen. The union has always demanded negotiable safety regulations in its past contract talks, and intends to continue to make such demands in the future. It is unlikely, however, that they would ever strike on the sole issue of retrieving safety from the unilateral control of management.102/

VII. TRAINING, EDUCATION, AND INFORMATION EXCHANGE

A. PUBLIC EDUCATION

Although education or information programs for the public in health matters is a recognized function of government health agencies, education of the public specifically about nuclear reactors and radiological health concerns is not a required activity of any federal, state, or local authority. Most information received by the public about these matters stems from: (1) public hearings at various stages in the NRC licensing process, (2) press releases describing routine activities as well as events of particular public interest, (3) involvement of community service organizations such as emergency preparedness agencies and police and fire departments in emergency response training and drills, and (4) conventional public relations activities conducted by the utility including public speaking engagements on request by community groups and speaking programs in area high schools.

1. NRC Public Hearings Process

There are two main stages to NRC review of an application to develop, build, and operate a nuclear power plant which may require public hearings. The first stage, application for a construction permit, requires review by NRC staff and the Advisory Committee on Reactor Safeguards (ACRS) followed by a mandatory public hearing. Members of the public may appear at the hearing in a formal intervention, filing an objection to the application, or in a limited appearance for the purpose of making a position statement and/or requesting further information from the applicant.

The second stage, application for an operating license, requires only NRC staff and ACRS review. A public hearing is only held if there is an intervenor.

As noted earlier, there were no intervenors in the TMI-2 construction permit hearings, and only one member of the public who appeared to question Met Ed about safety hazards associated with landing patterns at nearby Harrisburg International Airport. Several intervenors did appear at the operating license application stage, thus producing a second series of public hearings.

2. The Press and Public Relations -- Met Ed

The NRC provides some guidance to its licensees in identifying events of potential public interest.103/ Such events include:

a. damage to property or equipment which affects power generation;

b. public or worker radiation exposures which exceed the standards provided in NRC regulations;

c. natural or man-made conditions which result in a plant shutdown and/or protective measures;

d. a radiological event resulting from transport of materials;

e. an unscheduled plant shutdown in excess of one week's duration; and

f. failure of or damage to safety-related equipment.

Met Ed has a history of weekly press releases on these as well as many other events and conditions at TMI. (Detailed discussion and evaluation of Met Ed's public relations activities, including press coverage, are provided in the "Report of the Public Information Task Force.")

3. <u>Educational Programs -- Met Ed</u>

The obligation of the company to educate members of the public is generally confined to emergency response training of fire, police, and other emergency personnel. TMI training requirements (Administrative Procedure 1690) outline a course for the police, fire, and civil defense organizations in surrounding communities which includes: (1) fundamentals of radioactivity, (2) personnel monitoring, (3) exposure controls and limits, (4) protective clothing, (5) emergency plans, (6) plant layout, (7) on-site fire-fighting procedures, and (8) shipping requirements for radioactive materials. At their operating license hearings in 1977, spokesmen for Met Ed characterized the content of such training as rudimentary, and expressed the belief that more extensive knowledge of radiological matters was not needed by these community agencies in order for them to fulfill their responsibilities during an emergency.104/

Furthermore, Met Ed spokesmen felt there was no need to educate the general public as to radiation effects in order for them to exercise their responsibility, namely to evacuate the area safely and effectively when so ordered.

> We have no reason to believe that the effects of radiation would cause some response from the general public at five miles that is any different from the kind of response we could expect in the event of a natural disaster, a bomb fallout, being told to wash your fruit and keep your windows closed. I think they are one and the same in that there are those that would follow the advice and guidance of the experts and a very minimal number'of individuals who would not. And it is my opinion that the numbers of those who would not are of such small magnitude as to be insignificant.105/

> You make the supposition that the general public knows nothing about radiation, or you appear to be making that supposition. I would disagree with that. The atomic bomb has been with us for some time. There has been a lot published on the subject. It is discussed in schools, so to assume the general public has no knowledge at all of radiation is wrong.106/

4. The State

The state authorities who are ultimately responsible for the public's health also have no specifically defined responsibility for education of the public. As mentioned earlier, the Department of Health in Pennsylvania is not responsible for radiological matters and has virtually no staff expertise in radiation health. Consequently, no such public education programs have been available from this department.

B. EDUCATION OF AREA HEALTH CARE PROFESSIONALS

Various courses exist in radiological health and the management of radiation emergencies for health care professionals. One example of such training is a set of courses conducted by the Radiation Emergency Assistance Center/Training Site (REAC/TS) of the Oak Ridge Associated Universities in Oak Ridge, Tenn. Courses are offered, tuition free, several times a year on: (1) medical planning and care in radiation accidents, (2) health physics in radiation accidents, and (3) handling of radiation accidents by emergency personnel. The first two are one-week courses, the third is of 2-1/2 days' duration.

The Oak Ridge courses meet NRC requirements for training emergency personnel, have been endorsed for credit by the American Medical Association, the Tennessee Nurses' Association, the American College of Emergency Physicians, and the American Board of Health Physics, and endorsement is under consideration by the Technology Section of the Society of Nuclear Medicine (course brochure).

The federal government (AEC, ERDA, DOE) has also produced over the years a series of pamphlets on radiological health and management of radiation injuries for physicians, nurses, and other health and emergency care personnel. It is questionable, however, if these written materials have been widely sought by professionals. Courses like the Oak Ridge series are also not utilized by all relevant personnel. For example, one of the two TMI physicians requested Met Ed sponsorship to attend; arrangements never were made to permit his attendance.107/

It has been reported that many people in the TMI area called their personal physicians for advice during the accident. 108/ There is no evidence, however, of any efforts having been made before or since the accident to assure that these physicians were adequately informed to provide reliable advice to their patients during a radiation emergency.

Gordon MacLeod, Pennsylvania secretary of health, has reported some limited effort since the accident to speak to physician groups and provide articles to professional journals. At the moment, however, limited resources within the department and limited authority in the area of radiation health constrain the extent of such educational efforts.109/

The Pennsylvania Bureau of Radiation Protection (BRP) also has had no planned or formal program for public education or education of health professionals in the area of radiological health. Although staff members have responded to infrequent invitations to speak at a variety of scientific or public meetings, there has been no concerted effort to devote limited staff to development and conduct of a public education program. Although the need for public information on nuclear reactors, radiation hazards, and potential emergency situations has been recognized, the BRP and other agencies, notably the Pennsylvania Emergency Management Agency (PEMA), havp been unable to agree on the substance of such information.110/

C. WORKER EDUCATION AND TRAINING IN RADIOLOGICAL HEALTH

1. Education and Training

In contrast to the lack of public educational programs, some effort is made to educate workers and related personnel in radiological health and safety. The NRC has a broadly stated requirement that "all individuals working in or frequenting any portion of a restricted area shall . . . be instructed in the health protection problems associated with exposure to. . radioactive materials or radiation, in precautions or procedures to minimize exposure, and in the purposes and functions of protective devices employed."111/ Such instruction includes reporting requirements and emergency response procedures.

Each licensee develops training programs in health physics and emergency response to comply with the NRC regulations. The health physics training requirements at TMI are outlined in Administrative Procedure 1690. Different courses on "Radiation Protection Training" are required for different levels of personnel.

a. Basic I is provided to temporary personnel who will be on-site for less than one day. It consists mainly of reading material on personnel monitoring devices, the meaning of precautionary signs, emergency procedures, and exposure controls and limits. Such personnel must be escorted in all controlled areas.

b. Basic II is required of all personnel who will be working in the controlled area for no more than one day and may be on-site outside that area for more than one day. This one-hour orientation program includes a health physics briefing and review of emergency, industrial safety, and security procedures. These individuals must also be escorted in all controlled areas.

c. Basic III is a 3-hour program for temporary personnel who will be working in a controlled area for more than one day, and for permanent employees who work outside such areas, such as offices or warehouses. The content is an expansion of Basic II.

d. Intermediate I is a 3-hour course required of all Met Ed and contractor personnel who apply for a radiation work permit allowing them unescorted entry to controlled areas. Subjects covered include basics of radioactivity, radiation effects, and radiation monitoring and control procedures. Individuals must have a minimum of 2 years experience in a nuclear reactor facility (commercial, research, or military) to qualify for a radiation work permit.

e. Intermediate II is a full-day course for maintenance personnel, engineers, supervisors, and other radiation workers which expands on material covered in Intermediate I.

f. Advanced training is a 2-week course for auxiliary operators, control room operators, and radiation protection personnel. The course covers health physics methods and techniques as well as general procedures.

g. A comprehensive training program of 3 months duration is required for radiation chemistry technicians covering all aspects of their technical responsibilities.

Annual recertification of personnel in these courses is required by the utility to retain authorization to enter controlled areas of the plant.

Although the course descriptions appear to be comprehensive in radiological health content, spokesmen for the workers claim that such training is inadequate. The courses are said to be too short in duration, thus limiting the thoroughness with which any topic can be treated. Written exams are given the same day as the course, rather than at some later point to determine whether the material was retained. Furthermore, workers have been pulled out of courses to work on a job. Union spokesmen noted that this practice has ceased recently. It appears that management is placing a higher priority on training to the extent that they now seek alternative workers to complete a task rather than excuse a worker from his required training.112/

Questions also still remain regarding the adequacy and appropriateness of course content. For example, each higher level course is apparently an expansion of the content of the previous course. It is unclear, however, if merely expanding content adequately addresses the different radiation risks encountered in different jobs.

2. <u>Emergency Drills</u>

The health physics staff at TMI works with the training staff to develop and conduct emergency drills. As required by NRC, a series of drills are carried out over a period of several weeks once a year at TMI. This permits participation by each worker in a 2- to 4-hour drill without disruption of normal plant operations. The training staff, which includes three licensed reactor operators, develops the scenarios for these drills. The health physics staff develops the radiological sequence of events indicated by a given scenario. Off-site agencies, such as county emergency preparedness agencies, are invited to observe the drills but their only active participation is in receiving and acknowledging telephone contact from TMI through the planned emergency notification procedure. Observers are asked to submit critiques for use in evaluating the drills. NRC inspectors observe at least one drill per year. The plans tested in these drills were designed to manage a 12- to 14-hour emergency, not the long-term situation which actually occurred at TMI. As a result, the health physics staff has found itself in need of additional support during the long-term response to the accident.113/

3. Other Training for Health and Safety

OSHA has no requirements for training in industrial health and safety procedures. Met Ed, however, does provide a variety of such programs related to switching and tagging of equipment, fire, rescue and life-support first aid, and general safety practices.

Met Ed also requires training for the community physicians with which it contracts to provide medical examinations and emergency medical care. As discussed in section VIII on emergency preparedness, however, this training is considered totally inadequate by the physicians involved.

VIII. EMERGENCY PREPAREDNESS AND HEALTH CARE

A. PROTECTION OF THE PUBLIC

1. NRC Programs and Requirements

The NRC requires an applicant for a nuclear reactor operating license to include an emergency plan in its Final Safety Analysis Report (FSAR). In addition to provisions for on-site emergency response to protect the health and safety of workers, that plan must include procedures to notify appropriate off-site agencies of an emergency, and to determine when actions such as evacuation should be considered to protect public health and safety and prevent property damage. 114/ The off-site consideration applies to the low population zone identified in the siting of plant.

The licensee's plan must include letters of agreement from appropriate off-site agencies indicating their concurrence in the proposed plan and their willingness and capability to perform the required protective actions, namely evacuation. In this indirect way, one might construe a requirement for off-site agencies to develop and maintain radiological emergency plans. There is no direct requirement for such plans placed on any off-site agency, however, and NRC has not made approval of state or local emergency plans a condition of nuclear power plant operation.

The NRC, however, does encourage the development of state radiological emergency plans, and provides guidance and a concurrence mechanism for their development. 115/ This voluntary concurrence program has been available since 1975. Of the 25 states which currently have operating commercial nuclear reactors, only nine have radiological emergency plans in which NRC has concurred. An additional three states have such plans although they contain no operating reactors, a precaution taken either because of the presence of noncommercial reactors, transport of radioactive materials through the state, or reactors in contiguous states.

Lack of NRC concurrence, of course, does not mean that a state has no emergency plan which can be used to respond to nuclear reactor accidents. According to a report of the House Committee on Government Operations issued on Aug. 8, 1979, only 10 states in the country have no radiological emergency plan of any sort. Two of those, Michigan and Ohio, currently have operating nuclear reactors. 116/ At the time of the TMI accident, the Commonwealth of Pennsylvania did not have an NRC concurred state emergency plan; plans did exist, however, which were designed to deal with a TMI emergency. The adequacy of these plans is discussed in the report of the Emergency Preparedness and Response Task Force of the President's Commission.

It also is not clear that NRC concurrence is an effective device for assuring a state's emergency preparedness. The House report found "startling deficiencies." An overall concern was with the absence of plans at the local government level where most emergency response activities must take place. Plans were also found to be lengthy, cumbersome documents which would not lend themselves to easy implementation. Inaccuracies were frequent. In sum, the House committee concluded that "there ... is serious doubt whether the standards against which the NRC measures these plans are meaningful -- doubt, in fact, whether NRC concurrence really means anything at all from a public health and safety standpoint."117/

2. <u>Other Federal Agencies -- HEW</u>

A variety of federal guidance, training, and assistance programs is also available to states in developing their emergency response capacity. A federal interagency agreement published by the Federal Preparedness Agency (formerly the Office of Emergency Preparedness) in 1975 assigns such responsibilities to eight agencies including the NRC, EPA, HEW, and DOE. The EPA and HEW provide so-called "protective action guides" (PAGs) pursuant to this notice. The EPA guides identify the environmental exposure levels for airborne radioactivity at which emergency actions such as evacuation should be considered, while the HEW guides define contamination levels for food and animal feeds. The EPA published partial guides in 1975; complete PAGs are still not available. HEW published its PAGs in December 1978.118/

In addition to these federal efforts to assist in development of state emergency plans, a number of federal agencies claim some authority to respond to an actual radiological emergency in a state. As indicated in section III of this report, 13 agencies agree to provide various types of assistance on request under the IRAP agreement.

In terms of health agency response, HEW claims several legal authorities and responsibilities for acting on behalf of the public's health.

a. The Public Health Service Act provides broad authority to the Secretary to assist state and local governments and the general public in the event of a health-threatening emergency. Such assistance may range from emergency medical care at PHS facilities to followup and/or research on persons exposed to low-level radiation.

Specifically, under this act, the secretary is authorized to (i) provide medical groups advice and recommendations with respect to public health impacts of an incident; (ii) train medical personnel for state and local work; (iii) provide trained personnel as well as equipment, medical supplies, and other resources for a limited period at the request of the state or local authority; (iv) conduct research and studies related to diagnosis, treatment, control, and prevention of radiation injuries, and to the biological effects of ionizing radiation; and (v) implement communicable disease control measures in situations such as evacuation centers.

b. The Disaster Relief Act of 1974 authorizes mental health assistance -- counseling, financial aid to public or private mental health organizations -- requested by a state following Presidential declaration of a major disaster.

c. The 1975 Federal Preparedness Agency notice of interagency assistance assigns to HEW responsibility to (i) assist state health departments, hospitals, and other professional organizations in developing emergency plans for the prevention of adverse erects of radiation exposure, including the use of prophylactic drugs; (ii) provide protective action guidance with respect to contamination of food and animal feeds; (iii) work with EPA on guidelines for emergency radiation doses related to the health and safety of ambulance, hospital, and other health care personnel; and (iv) work with NRC on guidelines for radiation detection and measurement related to health care facilities and personnel.

Assistance in emergency planning, response, and recovery is also available through the network of agencies which have grown out of the civil defense program (the Defense Civil Preparedness Agency, FPA, and Federal Disaster Assistance Agency, all three of which have recently integrated to form the Federal Emergency Management Agency (FEMA)). Discussion of the role, responsibilities, and relationships of these agencies is available in the report of the Emergency Preparedness and Response Task Force.

It is clear that a multitude of resources are available from the federal government to assist state and local authorities in preparing for, responding to, and recovering from the public health and safety impacts of a nuclear reactor accident. Effective use of these resources, however, depends on the ease with which they can be accessed and coordinated. Section IX of report, which summarizes the response of health agencies to the accident at TMI, examines these issues of accessibility and coordination.

3. <u>State and Local Agencies</u>

Preparation at the state and local level to deal with health and safety problems resulting from a nuclear reactor accident is the responsibility of emergency preparedness, health, and environmental protection agencies. In Pennsylvania, state (PEMA) and county agencies had, prior to the accident, emergency plans for the 5-mile radius. The history and content of those plans are described in the reports of the Emergency Preparedness and Response Task Force and the Emergency Preparedness legal staff. Several features of those plans are of particular relevance to public health concerns.

a. No provisions were made for possible evacuation of the population beyond a 5-mile radius from the reactor -- although the LPZ for which NRC requires planning is only 2 miles, Pennsylvania requires 5-mile plans from county agencies to achieve uniformity throughout the state. At public hearings in May 1977 before the Atomic Safety and Licensing Board concerning the TMI-2 operating license application, the 5-mile plan was defended by both Met Ed and Pennsylvania attorneys as more than adequate since it went beyond the required LPZ.

b. Since there are no hospitals within the 5-mile planning area, there had never been any requirement or directive to the hospitals within a 10- and 20-mile area to develop plans for evacuating their patients.

c. There were no provisions for medical care of members of the general public who might become contaminated or suffer radiation injuries in the event of a nuclear reactor accident. This omission reflected a belief that such casualties would not occur and therefore required no preparation.

In the May 1977 public hearings, witnesses were questioned as to arrangements made for such medical care for members of the public. A Met Ed spokesman testified:

> Well, it was certainly our testimony that both effects of radiation doses received, and effects of contamination to which members of the public would be subject through the maximum hypothetical accident, through the consequences of the maximum hypothetical accident, and I would further say "accidents of less consequence," would not require immediate medical attention.119/

d. County emergency preparedness agencies maintained no inventories of facilities and personnel in the area equipped or trained to treat contaminated persons or those suffering radiation injuries, or to provide advice and information on radiological health concerns and appropriate public response during a radiation emergency. In repeated statements by emergency preparedness personnel, it was clear that radiation as a public safety hazard was not regarded any differently than floods, and other natural disasters. As a result, few "special" arrangements were considered necessary.120/

e. The emergency plans contained no reference to the possible procurement, distribution, and/or use of potassium iodide as a thyroid-blocking agent in the event of radioiodine releases during a nuclear reactor accident, as discussed by the National Council on Radiation Protection and Measurement.121/

B. PROTECTION OF NUCLEAR WORKERS

In contrast to the plans for public emergency preparedness, the TMI site plan contains, by regulation, provisions for: (1) training of workers and other personnel in emergency response procedures (as described earlier); and (2) emergency medical care of workers who may suffer injuries, including those involving radioactive contamination.122/

1. On-Site Medical Response

The first level of response to contamination or injury of a worker is the plant facilities and personnel. Decontamination areas and methods are thoroughly outlined in administrative procedures at TMI, and, unless a worker has suffered a severe injury requiring immediate off-site attention, decontamination procedures are generally undertaken in the plant.123/

The only in-plant medical facilities at TMI are first aid stations in both TMI-1 and -2, and a first aid trailer on the site grounds. The unit stations stock basic first aid supplies such as bandages, and are open to direct use by any worker. Senior bargaining unit and management personnel at TMI receive Red Cross life support first aid training in order to provide initial response to an injured or ill worker. A registered nurse, who is employed to conduct site safety reviews and to oversee the medical surveillance program, is available in case of emergency. In addition, two community physicians are retained by Met Ed to provide emergency care to injured workers who are contaminated.124/

Each of the two physicians, William Albright and Miles Newman, has been associated with Met Ed for a number of years. In addition to conducting many of the various physical exams required for Met Ed employees (pre-employment, termination, respiratory, audiometry), these physicians are on call to attend radiation injuries on-site. In case of such an injury, the physician is expected to administer initial first aid to the injured worker, assist in on-site decontamination, and then accompany the worker in an ambulance to the Hershey Medical Center (HMC) where further decontamination and treatment of injuries takes place.125/

Met Ed contracts with the Radiation Management Corporation (RMC) in Philadelphia to provide training to these physicians. According to Albright and Newman, this "training" amounts to: (1) a one-day course held annually, or less frequently, to review written emergency management procedures, tour RMC facilities in Philadelphia, and observe a demonstration of decontamination techniques; and (2) an annual medical emergency drill conducted at TMI in which an "injured" worker is provided first aid at the site of the accident, removed to an ambulance, and transported to HMC. The physicians' participation in these drills has involved observation only. The drills have never involved decontamination of an injured worker; participants therefore have never practiced administering emergency treatment in a simulated contaminated environment in which suits and respirators are used. According to Newman, these drills are not adequate for practicing emergency response to conventional serious injury, let alone one in which radioactive contamination is involved.126/

The first aid trailer was initially brought in by a construction contractor, Catalytic Corporation, and remains for use by all contractor and Met Ed employees. Until recently, the trailer was staffed 24 hours a day by certified emergency medical technicians who rendered emergency first aid, arranged for transport of injured workers to area hospitals, and provided some routine health assessment procedures such as blood pressure checks of workers with known hypertension. Met Ed has reduced staffing to one daytime technician only, citing financial constraints and reductions in the number of workers on-site. According to those who work in the trailer, including Dr. Newman who conducts some physical and respiratory exams there, the facility is totally inadequate to provide medical attention to the number of workers at TMI. The trailer has one examination/treatment room in which staff often find themselves conducting an exam of one worker while another is being treated for an injury.

2. Off-Site Medical Response

Workers with injuries or sudden illnesses which require off-site medical attention are transported to any of several area hospitals. Most injuries which involve no radiation are sent to the Harrisburg General Hospital. All contaminated injuries, however, must be sent to HMC, the only area facility which is prepared to manage radioactive contamination. The HMC contract provides for:

a. advance telephone notification of the status of an injured worker being transported to HMC by Met Ed, accompanied by Met Ed personnel;

b. adherence to HMC patient admission procedures;

c. payment by Met Ed for use of all normal services (emergency room, supplies, etc.) and any materials or equipment either consumed or destroyed by exposure to the contaminted patient;

d. indemnification of HMC against claims other than those resulting from HMC negligence; and

e. decontamination by Met Ed of HMC equipment and property.

HMC has developed a procedures manual for handling a contaminated, injured worker from TMI, and participates in the annual on-site medical emergency drill at TMI. Given the availability of RMC clinical facilities at the University of Pennsylvania in Philadelphia and the assumed low probability of a major radiation accident at TMI, the HMC has prepared to care for no more than three contaminated, injured workers from TMI at a given time.

IX. THE RESPONSE OF HEALTH AGENCIES TO THE ACCIDENT AT TMI

The following discussion of the accident at TMI focuses primarily on the response of HEW at the federal level, and the Department of Health in Pennsylvania. Significant relationships with other agencies are covered, but only as they represent efforts to protect the health and safety of the general public and TMI workers. Issues and problems of worker health and safety encountered by Met Ed during the first few days of the accident are also discussed.

A. THE HEW RESPONSE

The HEW response involved two different arenas of activity: (1) the deliberations and recommendations of senior officials in Washington, D.C., and (2) the direct provision of support services and assistance in Pennsylvania. These activities were based on legal authorities described earlier, but were implemented in an ad hoc manner rather than in accordance with established plans.

1. Notification

HEW Secretary Joseph Califano was notified of the accident by General Counsel Peter Libassi, midafternoon on Wednesday, March 28. Libassi had been called by NRC staff who had served on the Interagency Task Force on the Health Effects of Ionizing Radiation which Libassi had chaired. Califano's reaction was to call William Foege, director of the Center for Disease Control (CDC) with instructions to contact Pennsylvania state health authorities and offer assistance. Califano apparently did not turn to CDC because of any particular radiation health capability or responsibility in that agency. Rather, CDC, with its state network of PHS officers available to assist in disease surveillance and control, was recognized as the primary agency within HEW which had a working relationship with the Pennsylvania Health Department through which assistance could be offered. Foege's staff promptly contacted Beauford Washington, deputy secretary of health in Pennsylvania, and was informed that the state Bureau of Radiation Protection (BRP) in the Department of Environmental Resources was handling the situation rather than the Health Department.127/

For the first two days of the accident, the only information available to the HEW secretary's office came from CDC and the media. No official communications channel had been established with the NRC or any other federal or state agency or office. Some activity had begun within HEW, but not in response to Secretarial directive or request from Califano. For example, on Thursday morning, March 29, Anthony Robbins, director of NIOSH, had spoken to Richard Cotton, executive secretary to HEW, expressing concern about the uncertainty of the situation, and the locus of public health response.128/ On Thursday, Robbins also placed a personal call to Gordon MacLeod, Pennsylvania secretary of health, to inquire about the situation and offer help. MacLeod informed Robbins that the Department of Environmental Resources, not his health department, had responsibility in radiological matters such as the TMI accident. The Bureau of

Radiological Health (BRH) in the FDA had also begun by Thursday to sample food and water in the TMI area for radioactive contamination without having informed the Secretary's office.129/

2. Initial Meetings and Task Assignments

HEW, through the Secretary's office, became involved on Friday, March 30, following a call to Califano from an unidentified Senator inquiring how HEW was responding to the TMI situation. 130/ Two major meetings were held late that day to make assignments for agency response.

The first meeting involved Califano, EPA Administrator Douglas Costle, NRC Commissioners Victor Gilinsky and Peter Bradford, and Jessica Mathews of the National Security Council. Review of the situation at TMI at that time led to the conclusion that circumstances were possibly worse than originally understood. HEW and EPA arranged to place representatives in the NRC Incident Response Center in Bethesda in order to share data and information. Califano and Costle expressed concern about minimizing radiation releases of any type from the reactor (the previous night, TMI had discharged liquid industrial wastes into the Susquehanna River), and the need to evaluate the evacuation implications of various potential developments in the reactor systems. 131/ Califano also expressed concern for the adequacy of data which would be available for use in possible long-term followup studies.132/

The second meeting was the first in a series of meetings held by Califano with PHS senior officials who were to advise him throughout the duration of the accident. Over the course of the weekend, this group included Julius Richmond, Surgeon General and assistant secretary for health, HEW; Donald Frederickson, director of the National Institutes of Health: Donald Kennedy, FDA administrator; William Foege, CDC director; Arthur Upton, director of the National Cancer Institute; Anthony Robbins, NIOSH director; and various assistants and experts from those agencies.

Two major items were covered at the initial Friday meeting. First, there was considerable discussion whether evacuation should be recommended. The group felt unable to make a definitive recommendation on evacuation, however, because of the paucity of information available from NRC; the PHS officials felt that they "simply did not have a full understanding or indeed almost any understanding of what the situation was with respect to the reactor."133/ There was consensus, however, that the population should be notified of the nature of the problem and the possible need to evacuate, especially if NRC could not give assurances either that no further significant radiation releases would occur or warning could be given at least 6 hours prior to such a release. 134/ The thinking of the group was summarized by Upton, a proponent of such protective action.

> It was evident to us that people need some time to evacuate. There are inevitably preparations to be made, suitcases to be packed, arrangements to be made with the household and so on, household pets; and that precious time could be lost if such arrangements were left to the last minute; that the population around the plant could be well served by adequate information as to the nature of (the) radiation emergency and warning that they should be prepared and ready to move if it should be necessary to do so.135/

Second, assignments were made for departmental activities. Cotton was named overall coordinator; John Villforth, director of the BRH in FDA, was named operational coordinator; and Charles Cox, Villforth's assistant, was sent to Harrisburg to act as the HEW on-the-scene coordinator. Specific assignments, summarized in a March 31 memorandum from Califano to agency heads, outlined the direct assistance level of HEW response:

a. BRH/FDA sampling of food and water, and communication of that monitoring data to the NRC command center and Secretary Califano;

b. placement of FDA staff on a 24-hour basis in the NRC command center to gather monitoring and reactor status information for communication to PHS scientists who were analyzing public health implications and protective actions to be recommended;

c. procurement by FDA of adequate supplies of potassium iodide for emergency use by persons living within a 10-mile radius of TMI;

d. collaboration of FDA with White House and Pennsylvania authorities in making arrangements for distribution of potassium iodide;

e. review of the PHS readiness to provide the emergency assistance authorized in the PHS Act;

f. arrangements to train PHS hospital personnel in the treatment of radiation injuries in case such assistance is requested by the state; and

g. assessment of the adequacy of data collection efforts by all federal agencies in anticipation of information needs of future epidemiological studies.

3. Evacuation Considerations

Meeting of the PHS officials with Secretary Califano continued through the weekend. On Saturday, March 31, the group discussed further not just the possibility of evacuation, but the appropriate geographic area to be evacuated. A 5-mile radius was considered too small; there was debate over the adequacy of a 10- versus 20-mile radius. Upton was recommending a 20-mile radius based on his recollection of evacuation speed and radiation casualties analyzed in the WASH 1400 report.136/ The group accepted Upton's advice. Consideration was also given to precautionary evacuation of special populations such as hospital and nursing home patients, and prison inmates. All of these discussions, however, led only to recommendations to consider evacuation; no actual evacuation recommendation was made. The deliberations of the group were summarized in a noon, March 31 memorandum from Califano to Jack Watson of the White House staff.

4. White House Meeting -- Relationship to NRC

Late Saturday afternoon, Cotton, Villforth, Upton, and Robbins attended an interagency White House meeting convened by Watson. The PHS evacuation considerations summarized in the earlier memorandum were again expressed by Cotton to Watson. Cotton never gained an understanding of what the White House did with the HEW recommendations. 137/ At the Saturday meeting, Cotton also reiterated concern that NRC was not consulting adequately with HEW and EPA with respect to appropriate health and safety protective measures and evacuation planning.138/

This concern had been growing since the first quasi-official NRC notification of HEW. The two NRC Commissioners who attended the HEW/EPA meeting, convened by Secretary Califano on Friday afternoon, had come only in response to an explicit invitation. The NRC had not initiated any communication. Califano and PHS officials were disturbed by this lack of involvement.

> . . .to the extent the NRC had put on the table the fact it was going to be making decisions in the future with respect to what to do with the reactor that involved very perceptible, very real risks, there was clearly a desire on the part of the Public Health Service scientists and medical officials to be consulted in that process; to be able to offer to the NRC their judgement as to the best way to protect the public health, the amount of exposure that in their judgment represented an acceptable public health risk, the nature of an evacuation. . . So that for a whole variety of reasons and on a whole variety of subjects the Public Health Service people wanted to be able to offer advice as the NRC considered future courses of action.139/

Watson's reaction to the concern expressed by Cotton was "to turn to Victor Gilinsky and say 'Please take care of that."' 140/ It was HEW, however, which pursued that directive. Cotton continued to call NRC throughout Saturday evening, and did succeed in arranging HEW briefings by Brian Grimes of the NRC on Sunday morning and Tuesday of that week. These briefings, however, were always informational rather than consultative.

> . . . the impetus always, in my opinion, came from HEW; it never came the other way. That's not to say that there was antagonism. It was simply that there was never the impetus to seek out either advice, information or consultation. . . . I think one has to remember that the statutory responsibility specifically with respect to the operation of a nuclear power plant rests with the Nuclear Regulatory Commission. I don't think there is a statutory obligation or any other kind of obligation on the Commission that I am aware of to consult with anyone. . . . I think it is understandable why they operated the way they did. I don't think anyone at HEW agreed that that was the best way to proceed.141/

5. HEW Activities in Pennsylvania

While the HEW officials were discussing evacuation considerations and seeking to obtain information in Washington on Saturday and Sunday, other PHS personnel were busy carrying out the operational assignments made Friday evening.

FDA was involved in two types of monitoring activity in the TMI area. The first was the continuous sampling of food, water, and milk; the second was placement of approximately 250 thermoluminescent dosimeters (TLDs) for environmental monitoring. The former activity was based on established authority to monitor for contamination of foods and food products which might be subject to interstate commerce. Such monitoring was also consistent with HEW protective action guidance on contamination of food and animal feeds resulting from a radiation emergency.

The latter activity (environmental monitoring), however, was not an official responsibility of HEW. By coincidence, the supply of TLDs was available from the FDA/BRH X-ray mammography monitoring program. Knowing the limited monitoring capacity of Pennsylvania BRP, the FDA/BRH offered to place the TLDs for collection of additional environmental data.142/ CDC sent two Epidemic Intelligence Service officers, neither of whom was experienced in radiation health, to the scene to assist in developing the protocol for TLD placement and in identifying data which might be needed for later studies. HEW personnel in the area also began attending a series of Department of Energy (DOE) briefings at their command center in the Capital City Airport near TMI to share information being collected by the various agencies involved in monitoring (DOE, EPA, HEW, NRC).

Full-scale efforts to obtain supersaturated potassium iodide supplies also began in the early hours of Saturday, March 31. Over 15 years ago, potassium iodide was identified as an effective pharmacologic agent for blocking absorption of radioactive iodine by the thyroid gland. Although approved and available as a prescription drug for treatment of several medical conditions, use of potassium iodide as a protective measure for large populations in the event a radiological emergency was not recognized until mid-1977 with release of a report by the National Council on Radiation Protection and Measurement. 143/ Furthermore, the drug was not officially approved for such use by the FDA until publication of a New Drug Application notice in the Federal Register in December 1978.144/ At the time of the accident at TMI, no pharmaceutical or chemical company had responded to the notice, presumably because there was no perceived market for the drug.145/ As a result, it was quickly apparent on Friday, March 30, when the decision was made to obtain potassium iodide for possible use in Pennsylvania, that the large quantity of potassium iodide needed, even considering that used in other clinical situations, was not available.

Jerome Halperin and colleagues at the FDA Bureau of Drugs thus began seeking a possible manufacturer of the drug, finally reaching agreement with the Mallinckrodt Chemical Company at approximately

3:00 a.m. on Saturday, March 31. An around-the-clock effort ensued involving Mallinckrodt in St. Louis, Mo., Parke-Davis in Detroit, Mich., and a dropper manufacturer in New Jersey to produce approximately 250,000 one-ounce bottles of potassium iodide solution with accompanying medicinal droppers. The FDA in Rockville, Md., began to print patient information leaflets and wrote labeling instructions to be placed on the bottles. The first shipment of bottled potassium iodide arrived in Harrisburg about 1:30 a.m. Sunday; by Wednesday, April 4, the full supply of 237,013 bottles had been delivered to Pennsylvania.146/

It should be noted that, according to the Federal Preparedness Agency, Federal Register notices assigning radiation emergency responsibilities to various agencies,147/ the official HEW responsibility regarding potassium iodide is to assist state authorities in developing plans for the prevention of adverse effects of radiation exposure, including the use of prophylactic drugs.148/ The actual procurement of the drug by FDA for use in Pennsylvania was an ad hoc decision in response to the realization that none was available on the open market for direct purchase by the state.149/

Arrangements also were made during the weekend to locate and train about 30 Public Health Service physicians in the treatment of radioactive contamination and injuries, if needed. Gordon MacLeod, in the Pennsylvania Health Department, was notified of the availability of this clinical assistance. No effort was made by HEW, however, to evaluate the local capacity to treat such patients,150/ nor was HEW aware that DOE also had physician radiation specialists on alert if needed by the State of Pennsylvania. 151/ None of the HEW or DOE physicians were called in to assist the state during the accident.

Over the weekend, NIOSH also initiated efforts to obtain information on the availability of data identifying all persons on the Island during the episode and their individual exposure in case followup studies of workers would be warranted. NRC explained that such recordkeeping was the responsibility of Met Ed, but that NRC would assist NIOSH in identifying needed data. Problems began to emerge later in the week when NIOSH personnel appeared at TMI to "investigate" data availability.152)

On Monday, the potassium iodide story developed further with the involvement of Washington-based officials. When the FDA first became involved in this issue, there was an understanding that the federal agency would only be involved in arranging for production and treatment of the drug to Pennsylvania; they would not give directions on its distribution or use. "We felt it would be not only presumptuous, but ineffective for us to discuss distribution with the state. We didn't know the layout of the area there, how they wanted to handle it, stockpile it where. And we understoond and indeed saw later that the State was working on a distribution plan."153/ This position reflected that discussed by the National Council on Radiation Protection and Measurement in its report on potassium iodide (NCRP #55), and summarized by the FDA in its New Drug Application Notice.

> The report discusses stockpiling thyroid-blocking agents at appropriate outlets for ease of distribution in the event their use is necessary in a radiation emergency. The report concludes, however, that the details of stockpiling, if this method is to be used, and of distribution would be determined best at the state and local levels.154/

On Monday, April 2, however, Califano's office received from Jack Watson in the White House a request for HEW recommendations on distribution and use of the potassium iodide supplies in Pennsylvania. It was implied that the request was initiated by Governor Thornburgh. 155/ The request was forwarded to Julius Richmond for PHS response. Frederickson director of the National Institutes of Health (NIH) had begun collecting information on the use of potassium iodide as a thyroid-blocking agent following the Friday evening meeting at which the decision was made to secure supplies for Pennsylvania. On Monday, he gathered a number of NIH scientists together to discuss possible administration of the drug.

> I believe by that time we knew there were many curies of 1-131 in the containment vessel. . .it was after assessing the information available to us there and almost unanimous opinion on part of all the people attending that the risks of giving potassium iodide were so minimal, that, that all of us felt that were there to occur a serious release of 1-131 from the containment vessel, the workers on the site would certainly not have sufficient time to effectively block their thyroid glands from taking up radioactivity. . . . we still felt that the briefing, we had had, I guess the last by Grimes on Sunday, had led us to believe there still was some contributing risk of release.156/

Several recommendations emerged from this meeting and were incorporated in a memo from Richmond to Califano on April 2. The signficant recommendations were to:

a. administer potassium iodide immediately to workers on the Island;

b. have potassium iodide personally available to all people who would have less than 30 minutes warning of an iodine release (perhaps a 10-mile distance from TMI); and

c. have local authorities assess the recommendations in light of their first-hand knowledge of the situation.

HEW spokesmen insist that the last recommendation was genuinely intended to leave acceptance or rejection of each recommendation to the discretion of state authorities.

> . . .the actual decision as to whether to follow these recommendations depended very importantly on the particular circumstances at the scene. . . . The HEW people made no effort to attempt by long distance to consult with state officials and try to understand exactly what the circumstances were, their judgments about circumstances.

> Rather what they tried to do was base their recommendations a general assessment of the type of circumstances that existed at the plant and their understanding of the risks and benefits in terms of possible exposure to radioactive iodine and a general set of recommendations. Those general. . . recommendations were made always with the understanding that they might have to be adapted or modified based on decisions taking into account the particular circumstances on scene at the time.157/

> I have the. . attitude. . . that then, and I retain it now, that MacLeod and those on the site had the final call and they had the right to make that decision. . . If on the site they were convinced that there was not going to be any breach or one chance in a thousand, they had the right to make that call and they were certainly closer to it than we were.158/

Gordon MacLeod, however, interpreted the White House letter containing recommendations from the Secretary of HEW to be a set of directives. MacLeod did not agree with the recommendations, and chose not to accept them. In so doing, he provoked a confrontation with PHS officials which will be described in later discussion of the response of the state Health Department.

One other direct service initiated by HEW at this time was an offer made on Monday by an NIH Radiation Advisory Group chaired by Frederickson to conduct whole-body counting and urine sampling on members of the worker and general populations to provide both diagnostic and epidemiologic data.

> . . . we felt that clearly none of us could tell. . . from the information available then, whether or not some individuals might have been exposed more than was suspected. And this was the most direct way of doing that. We also were cognizant of the fact that in very few accidents have accurate monitoring records been made at the very time until it is too late. So that is why we offered to do this service. 159/

Frederickson was informed by Roger Linneman of the Radiation Management Corporation (RMC) that whole-body counting and urine sampling of workers were being conducted under their contract with Met Ed. Between March 29 and May 1, RMC conducted over 1,000 whole-body counts at TMI as well as providing a variety of other services, including respirator fittings, film badge processing and bioassay analyses. 160/ Pennsylvania Health authorities were informed of the availability of NIH services to the general population. Ultimately, no patients reported to NIH for the whole-body counting, but CDC officers on the scene did collect urine samples from 38 area residents, all of which tested negative for radioactive contamination.

This urine sampling program was the only attempt made to determine actual individual exposures. There was some discussion among PHS officials as to the feasibility of distributing film badges to members of the public to assure individuals of the level of their personal exposure. The notion was rejected.

> . . . you don't know whether the person actually wears the badge at all times, and since people drift in and out of the area, determine someone else's dosage, plus there is no way of being able to separate out Three Mile Island from other exposures that the person would, in fact, get an X-ray or separate it out from other background exposures. So we decided it would be better to get good environmental data and then take histories on people on how much time they spent in different areas to determine their individual doses.161/

During the balance of the week, as the acute phase of the accident subsided, the attention of HEW officials in Washington turned to reasserting the Department's leadership in response to possible health consequences of the accident, and intervening in the assignment of TMI-related responsibilities among various federal agencies.

On Tuesday, April 4, Califano, Richmond, Kennedy, Robbins, and Upton appeared with other witnesses before the Senate Subcommittee on Health and Scientific Research of the Committee on Labor and Human Resources to testify on the health implications of the accident. The HEW testimony included: (1) explanation of the current state of knowledge about the health effects of low-level radiation exposure; (2) projections of "excess" cancer deaths anticipated given exposure data then available from NRC and other agencies monitoring in the TMI area; (3) discussion of efforts already initiated to establish a worker registry and data on the general population, specifically pregnant women and young children, for possible followup studies; and (4) discussion of the status of ongoing radiation effects studies (i.e., Portsmouth Naval Yard) and the need for continuing research.

In addition, the Surgeon General, speaking as chief health officer of the country, offered reassurance of protection of the public's health:

> I think that on the basis of the monitoring that has been done thus far and the data which have been made available to us, the population in general seems to be at no significant risk. In other words, we think their health has not been endangered.
>
> We, of course, feel that that population can be reassured by virtue of the continuity of monitoring in some sense. They will have known quantities of radiation around them. Most of us go about our daily lives without (knowledge) precisely what is around them. So I think there is some reason for them to feel reassured.162/

6. Relationships to other Agencies -- EPA, DOE

HEW also became entangled in the politics of agency responsibilities for TMI-related activities. In initial interagency and White House meetings on March 30-31, it had been understood that NRC was lead agency for coordination and collation of monitoring data being collected by various agencies (NRC, DOE, EPA, HEW, state BRP). This was one of the reasons for assigning EPA and HEW coverage to the NRC command center in Bethesda. By the end of the week of April 1st, however, it became apparent to Washington-based officials that DOE, not NRC, was the de facto lead for data collection, coordination, and dissemantion.163/

The DOE, and its contractor from Brookhaven National Laboratory, had arrived on the scene Wednesday after being summoned under its Radiological Assistance Program (RAP). They immediately established an elaborate monitoring operation, complete with such features as continually updated meteorology, aerial crews, and a DOE historian recording events. A command center was set up at the Capital City Airport where daily briefings were held for all agencies involved on the scene. All of this activity, although consistent with established Interagency RAP procedures (IRAP), was apparently unknown to IRAP signatory agencies, such as HEW and EPA, and the White House.

> I don't think that the Department Heads, whether it is the Secretary and the Assistant Secretary for Health and all of the other senior health staff, understood about the IRAP plan. I suspect I was the only one. . . that understood that an IRAP plan existed and I didn't think it was really instituted and that DOE had the lead role.
>
> I don't think this was understood. . .by the 31st when we met at the White House with Jack Watson of the White House staff because there was no representative from the Department of Energy at that meeting.
>
> So whereas this accident was being managed to a large extent by the White House or by the meetings on the 30th with the heads of EPA and Gilinsky and Secretary Califano, it was operated without the benefit of the principal group, the Department of Energy, participating on the site.164/

The DOE had apparently assumed that the NRC was responsible for requesting assistance from other federal agencies since the accident involved an NRC-licensed nuclear power plant. The DOE thus responded under its own RAP procedures but had not activated other agencies under the IRAP agreement.

> In this situation. . .with this particular incident, TMI, we assumed. . . rightly or wrongly. . . that NRC would ask for whatever other Federal agencies it needed. And we did not, at that time, I'm sure, take responsibility for notifying other agencies ourselves.
>
> ' . we thought if we had had a more clear cut license to respond without the, if you want to call it, waiting. . .to be invited in, we would have been there faster. In this case, we would have made our response differently, there is a -- there is a charter problem here in the sense of possibly even some legal legislation may be needed, I don't know.
>
> ' . .to move into an area that was where clearly another federal agency had jurisdiction over the situation is not. . . clear cut. . . .165/

Once the DOE activities became known, HEW officials began expressing concern about the appropriateness of the DOE role.

> I thought that the purpose of collecting that data was to get an accurate understanding of the potential public health and environmental impact of any releases of radioactivity. From that point of view, I thought it appropriate for either an agency with a public health mission or an environmental protection mission to be coordinator and overseer of the collection of that data and the presentation of that data.
>
> I was told quite directly that the Department of Energy was in the possession of many of the most sophisticated monitoring instruments and technical expertise in the field. And I had no doubt that that technical expertise and those instruments had to be available to monitor the releases.
>
> But I thought it was a very bad decision to place the Department of Energy, who is charged with the development of and promotion of nuclear power, in the position of coordinating and being in charge of the federal government's monitoring of the releases from a nuclear power plant where there could be serious public health and environmental consequences.166/

Steve Gage of the EPA shared this concern with Cotton, and indicated EPA's ability to perform the data coordinating role. After receiving endorsement from HEW Secretary Califano, Cotton discussed the issue with Gene Eidenberg of the White House staff. Eidenberg was unaware of the DOE role, understood the concern, and suggested that the EPA and HEW draft a memorandum for Jack Watson to officially designate responsibility for the data collection/coordination role.167/ The result was an April 13 memorandum from Watson to the HEW, DOE, and EPA naming the EPA lead agency for environmental monitoring efforts at TMI, and specifying the monitoring responsibilities of each agency in relation to EPA.

7. Worker Registry -- NIOSH and NRC

HEW officials also continued to seek information from the NRC on identification of and access to worker registry data. On Sunday, April 1, Secretary Califano had written to Chairman Hendrie of the NRC requesting establishment of an exposure registry of all persons, workers, and temporary personnel, on the Island. NIOSH staff also went to TMI early in the week of April 2 to check first-hand on the availability of such data. By Wednesday, NIOSH had established that Met Ed had an adequate film badging procedure in effect, and did have a worker registry system. The only information reported to NRC at that point, however, was the number of workers having received in excess of the 3 rem quarterly limit. The NIOSH site visit concluded with questioning of: (1) the adequacy of whole-body counting at TMI, and (2) the merging of internal and external dose data to determine workers' total doses.168/

B. THE STATE RESPONSE

1. Notification and Initial response

Notification of state agencies of the accident at TMI on the morning of March 28 went according to the established Met Ed emergency plan. Shortly after 7:00 a.m., the shift supervisor at TMI notified the duty officer at PEMA of a "site emergency." PEMA, in turn, called BRP in the state Department of Environmental Resources. The BRP is responsible for recommending to PEMA whether or not radiation levels warrant action to protect the public. Within an hour, BRP staff had established communications with the TMI control room and were actively engaged in gathering information to assess potential off-site consequences of the accident.169/

Shortly after 7:30 a.m., TMI declared a "general emergency"; the situation had escalated from a site-contained emergency to one in which there was a potential for off-site releases. The immediate concern was a reading of 800 rems per hour on the dome monitor of the containment building which, given prevailing weather conditions and assumptions about the leak rate from containment, translated into a 10 rem per hour exposure in Goldsboro, directly west of the Island. 170/ Met Ed immediately sent a monitoring team to Goldsboro, and the BRP told PEMA to put the York County Emergency Preparedness Agency on alert for a possible evacuation. By 8:15 a.m., it had been confirmed that the releases were contained, and "excess radiation" had not been detected in Goldsboro; the alert in York County was relaxed.171/

Later in the morning, TMI reported to BRP increased radiation levels around the area of the plant. After verifying the readings, BRP recognizing its limited monitoring capacity, requested DOE and National Laboratory assistance under the DOE Radiological Assistance Program.172/

Although excess radiation levels continued to be read periodically throughout the day, few were off-site and those did not approach levels for which BRP considered protective action. Monitoring continued through Thursday without significant readings; the situation appeared stable and returning to normal.173/

Spokesmen for the PEMA and BRP agree that, on Wednesday and Thursday, all notifications and responses occurred as planned. 174/ Those plans did not include direct notification or involvement of the Secretary of Health, Gordon MacLeod. MacLeod was first told of the accident at TMI around 8:00 to 8:30 in the morning of March 28 by Joe Romano, director of the department's Health Communications Office; MacLeod was in Pittsburgh at the time.175/ Romano reported that "there was a technical problem at Three Mile Island and it was of an engineering nature. . . . [T]here was concern that radioactivity had been released. . .but that the problem didn't seem severe."176/

MacLeod had only been secretary for 12 days and was unfamiliar with the resources and responsibilities of his department in regard to radiation emergencies. In response to his inquiries, he was told that: (a) there was no bureau or office of radiation health in the department since that responsibility was assigned to BRP in the Department of Environmental Resources, (b) there was no official liaison person between the Health Department and BRP, and (c) there was no library within the department and therefore no ready source of information on radiation health to which MacLeod could turn.177/ In sum, the Department of Health had no responsibility nor capability to respond to a radiation emergency.

MacLeod remained in Pittsburgh for the day, communicating primarily with Health Department staff (except for informational calls from Lt. Gov. Scranton's office) and offering no recommendations on public health protective actions.

> I remained in touch with the office and with the staff and paid particular attention to the media, as announcements were made over the course of the day. I had planned to spend the day in Pittsburgh and did so. The events of the day did not indicate that there had been, that there was any major problem with respect to the accident at Three Mile Island.178/

2. Evacuation Considerations

On Thursday morning, MacLeod went to Philadelphia to fulfill a speaking engagement and returned to his office in Harrisburg around 1:00 p.m. in the afternoon. Shortly thereafter he received a call from Anthony Robbins, director of NIOSH, with whom he had had a professional acquaintance for many years. Robbins told MacLeod of his concern about the accident at Till and "based upon his experience as health commissioner in Colorado and prior to that as health commissioner in Vermont ... he urged me to consider recommending evacuation of the population around Three Mile Island."179/

> Well, my response to him was that the radiation levels at that time were not sufficiently high to warrant evacuation, and he advised me that it was not his concern about the radiation levels, but about his concern about the inability to shut down the reactor.180/

Robbins has testified that his call to MacLeod was a purely personal, not official, gesture intended to express his concern and offer assistance. Although he discussed his prior experience with evacuation related to an alleged nuclear accident in Colorado, Robbins has denied having discussed or suggested to MacLeod evacuation of the TMI area.181/

The conflict between these two sets of testimony may never be completely resolved. What is significant, however, is that MacLeod, who to this point had taken no action nor offered any recommendations regarding protective actions, immediately arranged a conference call with other state officials to inform them of Robbins' alleged recommendation. In this call to PEMA director Oran Henderson, BRP director Thomas Gerusky, and John Pierce of Lieutenant Governor Scranton's office, MacLeod identified Robbins not as a personal friend, but as director of NIOSH and therefore a high-level official in HEW. He characterized Robbins' advice as a strong recommendation to evacuate because of the experimental mode of the reactor shutdown.182/

It is impossible to assess the sense of import with which this message may have been regarded by the group. Their reaction was to reject the alleged recommendation, since there was insufficient information available to say that the reactor was in an experimental mode. They did agree, however, to reconsider evacuation if and when it was established that the reactor was in such a mode.183/

MacLeod then, on his own initiative, questioned whether the group would consider it desirable to have pregnant women and children under the ages of 2 leave the area around TMI.

> ... it is my understanding from my somewhat limited knowledge of the field of radiation health, radiation protection, that the population most at risk is the developing embryo fetus and the young child during his early developmental growth period. And so therefore, there would be a higher risk to that population if a serious accident were to occur. That is not to exclude the population also at risk by virtue of being a pubescent male or even others in the population who would have had procreational activities by virtue of being an adult or at least pubescent.184/

> I was really trying to suggest that this would be the least active but most -- most least active thing we could do for the most vulnerable population. And so I was focusing the question in a somewhat perhaps academic fashion.185/

The group's response was the same; there was no reason at that point in time, Thursday afternoon, to advise pregnant women and small children to move out of the area.186/

The events of Friday, March 30, have been well documented in the legal staff report on "Emergency Response." Several points are important to note.

a. The NRC senior management in Bethesda, Md., acted unilaterally in recommending evacuation to Governor Thornburgh. No radiation protection, public health, or emergency preparedness authorities were consulted at either the federal or state level. The recommendation was also not discussed with NRC personnel at TMI.187/

Furthermore, Harold Collins, who transmitted the NRC recommendation to evacuate people for a distance of 10 miles in the direction of the plume, bypassed the established notification procedure by calling Henderson at PEMA, rather than Gerusky at the BRP.188/ Henderson compounded the problem by endorsing the recommendation in a conversation with Governor Thornburgh although the BRP had not yet advised PEMA on the necessity of such action.189/ The BRP saw no need to evacuate and so advised the governor.190/

One result of these actions was to elevate decision-making regarding evacuation to the level of the governor's office, senior NRC management, and ultimately, the NRC commissioners themselves.

b. MacLeod had gone to Philadelphia Thursday night in preparation for meetings unrelated to TMI on Friday morning. MacLeod heard reports of the dumping of industrial wastes from TMI into the Susquehanna on Thursday night and assumed that it represented human error resulting in dumping of contaminated water. MacLeod thus instructed his deputy, Emmet Welch, to urge the governor on Friday morning to consider advising departure of pregnant women and children under the age of 2 from the 5-mile radius.191/

After the NRC had withdrawn the general evacuation recommendation later on Friday morning, Governor Thornburgh raised the question about evacuation of pregnant women and young children being forwarded by MacLeod.

> ...Hendrie's response, I think, was, "If my wife were pregnant and I had small children in the area, I would get them out because we don't know what is going to happen." He said, "I go along with you on that, Governor, and I think there ought to be an evacuation."192/

The evacuation radius was discussed in a rather off-hand manner, ultimately settling on 5 miles from TMI since it coincided with available plans.193/ Upon hearing the governor's 12:30 p.m. advisory regarding pregnant women and preschool children on the radio, Secretary MacLeod, assuming his suggestion had been accepted, decided to cancel plans to go to Pittsburgh and, instead, returned to Harrisburg.194/

c. Within the course of the day, NRC recommendations for possible evacuation extended from a 5- to a 10- and, ultimately to a 20-mile radius from TMI.195/ Even the 5-mile recommendation exceeded the limits of the 2-mile LPZ, thus demonstrating the inadequacy of the LPZ concept as a basis for emergency planning.

The NRC recommendations were made with little, if any, regard for the fact that only 5-mile plans were available in Pennsylvania, and that expansion to 10, and then 20 miles, involved evacuation of an area with up to 700,000 people, 13 hospitals, and several nursing homes. None of the hospitals in the area had evacuation plans. While the NRC was claiming they could give 4 to 8 hours to evacuate the area in anticipation of a major radiation release, the hospitals estimated at least 2 days were needed to evacuate medical facilities.196/

d. With the advisory for pregnant women and preschool children to leave the area, many other people chose to depart as well. It is estimated that 40 percent of the Dauphin County population alone left the area.197/

To some extent, this led to staffing shortages at area hospitals and nursing homes. Due to intentionally reduced patient census, the reduced staffing did not cause a major problem at the hospitals. These shortages, however, combined with general uncertainty about the ability to evacuate on short notice, led administrators of two area nursing homes to relocate their patients over the weekend. Since an official emergency had not been declared and no evacuation had been ordered, the nursing homes, with some assistance from the county, had to make their own arrangements for host facilities and transport of their patients. This was all done at their own expense.198/

3. Response to Public Health and Safety Concerns

The weekend witnessed a flurry of activity. State and county emergency preparedness agencies were busy writing 10- and 20-mile evacuation plans. Area hospitals continued to reduce their census by discharging less seriously ill patients and cancellation of elective admissions. The Frye Village Retirement Center and Odd Fellows Home relocated over 370 residents. 199/ Shipments of potassium iodide solution were being received, sampled, and stored in a warehouse in Harrisburg; on Saturday morning, responsibility for handling the potassium iodide was transferred from the BRP, which had originally consented to the FDA offer of potassium iodide supplies, to the Department of Health.200/

Throughout this period, decisions were being made in an atmosphere of uncertainty and inadequate information. From Friday on, the established communications system broke down as authority rose from the state agency level -- PEMA and BRP -- to the governor's office and NRC management represented by Harold Denton. Local agencies could no longer rely on PEMA as the information source on which to base their actions. To some extent, they turned to the media. In addition, they sought response from any state authority, ultimately attempting to get guidance from the governor's office. The situation of area hospitals is illustrative.

As noted earlier, area hospitals began voluntarily reducing their patient census on Friday in anticipation of the need to evacuate entirely. Given the considerable advance time needed to relocate patients, particularly those who are gravely ill and dependent on life support equipment, hospital administrators vigorously sought information on which to decide whether or not to begin such protective action. They were repeatedly frustrated in their attempts to get information from PEMA or the governor's office, even when they worked through state legislators. By Sunday afternoon, a meeting of virtually all area hospital and nursing home representatives had been arranged with Secretary MacLeod to inform him of the status of the facilities and to request his guidance on how to proceed.

> Basically, prior to the meeting... [we] pigeon-holed Secretary MacLeod and Secretary [for administration/budget] and tried to identify, briefly, what the meeting was about and the type of information that we had hoped that they would be passing on to all the area hospital administrators and representatives from the nursing homes. And, I believe it was Secretary Wilburn that said something to the effect, "we'll all fill everybody in when its up-to-date because I've been just with the Governor." And we took that to mean that we, maybe we were going to get some definitive information. And that's when we opened up the meeting for everybody.
>
> I guess the only thing that I would say is that I -- I'm not sure that I learned anything more from that meeting that I didn't already know beforehand.201/

In the midst of concern over evacuating hospitals, little attention was paid to the possible need to provide medical attention to people suffering radiation injuries or sickness.

> <u>QUESTION:</u> . . .by this time, down at the plant, we've identified the bubble, and we're all waiting for the place to blow up, perhaps, depending on what Harold Denton says, anything was to happen next. So, was there any movement within any of the hospitals that you were aware of to staff up for radiation injuries, to hit the books to prepare for radiation injuries, treatment or diagnosing radiation sickness? Any kind of activity like that?
>
> <u>ANSWER:</u> None whatsoever. All the hospitals ... were just trying to insure enough staffing to take care of the patients that were there, and were strictly concerned about evacuating the hospitals and taking care of the patients. We did touch upon ... the idea ... if there is a mass evacuation, two of the emergency departments in the county would have to stay open ... to take care of all the citizens who were evacuating, in case somebody had a heart attack ... in case a firefighter or an emergency worker was injured, and we had to give treatment.
>
> Had an incident occurred, it would not have been a localized incident. It would have been, you know, massive radiation. We would have been caught in -- the hospitals would have been caught right in the middle of trying to get their patients out, and yet, patients wanting to get in the doors.... Could we have dealt with it? I don't think we could have.202/

The foregoing description of the response of area hospitals was provided by spokesmen for the Harrisburg General Hospital and Emergency Health Services Federation of South Central Pennsylvania (Semanko, Fisher, et al.) who were involved in coordinating information and action among area hospitals.

Some facilities were better prepared than others to deal with a radiation emergency. For example, the chairman of disaster planning at the Memorial Osteopathic Hospital in York reported that a radiation emergency procedure based on the Hershey Medical Center manual did exist in his institution at the time of the TMI accident, and that treatment rooms and nuclear medicine and health physics personnel were available throughout the first week of the accident to receive and treat members of the public who might suffer radiation injuries or contamination. This hospital also reported having an established training program in treatment of radiation injuries for its staff. Reasons suggested for this greater degree of activity and readiness to deal with radiation emergencies in contrast to other area hospitals included the fact that: (1) the chairman of disaster planning is also a radiologist and nuclear medicine specialist, and (2) the hospital is located midway between the TMI and Peach Bottom nuclear stations.203/

While the governor's evacuation advisory on Friday seemed to creat greater uncertainties for groups such as hospital administrators, it seemed to resolve some public concern. Prior to the advisory, all agencies, including the Health Department, were deluged with calls from people seeking information and advice on what to do. Like others, MacLeod has testified that "...with the governor's announcement, I was informed that the calls, the number of calls, dropped precipitously."204/

4. Relationships with HEW

The first few days of the week of April 2 were marked by clashes and confusion over health-related decisions. As mentioned in the discussion of HEW activities, a confrontation developed between MacLeod and PHS officials over distribution and use of the potassium iodide provided by the FDA. MacLeod had assumed responsibility for the supply of drugs on Saturday morning. He then called the FDA Bureau of Drugs to consult with an endocrinologist about the process by which the drug had been manufactured, and possible adverse side effects from its administration. 205/ MacLeod also placed a call to Secretary Califano, his "counterpart at DREW," in search of advice on medical aspects of radiation exposure. Although Califano could not be reached, Arthur Upton of the National Cancer Institute did return the call later with several suggestions of physicians knowledgeable in the field of radiation health to whom MacLeod could turn for advice. 206/ It is notable that there was no immediately identifiable unit within HEW to which the state health officer could turn for such assistance, and that, once contact was made, the advice given was to consult several physicians and scientists in academic institutions across the country rather than within the department itself. MacLeod hired Neil Wald from the University of Pittsburgh to advise him on radiation health matters, including the use of potassium iodide.207/

As the potassium iodide arrived in Harrisburg, it was stored under armed guard in a central warehouse. No plans had been made for distribution of the drug on Saturday because none had yet arrived. 208/ Local deployment sites were identified on Sunday. On Monday, April 2, following discussion with outside consultants, MacLeod decided to maintain the potassium iodide at the central warehouse because he was told that several "civil defense people had fled the area" thus hampering security coverage if the drug were stored at the local distribution points.209/

Also on Monday, April 2, MacLeod heard that a memorandum was being prepared by HEW advising distribution and use of potassium iodide. MacLeod, Wald, Denton and the governor's office had already agreed to withhold distribution and use, and communicated their thinking on the matter in a phone conversation with the White House.210/

Nevertheless, the White House letter containing HEW recommendations to administer potassium iodide immediately to all workers at TMI and distribute the drug to all persons within a 10-mile radius was sent to Governor Thornburgh on Tuesday. Harold Denton had already rejected the idea of administering it to the workers since there had been no radioiodide exposures to indicate such use.211/ MacLeod rejected the second recommendation on the basis of prior considerations: 212/

a. radioiodine levels were far below that for which such protective action was indicated;

b. public anxiety would increase and people might administer the drug without being so advised;

c. by Monday, the likelihood of a high-level release from the damaged reactor was diminishing rapidly;

d. the possibility of adverse side effects presented a potential public health problem; and

e. inappropriate dropper sizes, questionable quality of the drug supplies, and conflicting recommendations over the length of administration could lead to inappropriate or harmful use of the drug.

Neil Wald, Chairman of the Department of Radiation Health at the University of Pittsburgh School of Public Health and consultant to MacLeod during the accident, agreed with MacLeod's rejection of the HEW recommendations.

> The showed me the memorandum [containing the HEW/White House recommendations] and I was definitely surprised and didn't feel that it was medically sound or even an acceptable course of action from the standpoint of the public health.... It didn't make sense. The first item, for example, would have the workers ... begin taking doses now which would be in complete conflict with the NCRP [National Council on Radiation Protection and Measurement] which says you don't unless there is a significant buildup in the thyroid gland, and to do that you have to have a release; and one of the tenets in any occupational health situation is you don't treat in advance and give workers a basis for being careless about how they do their job.
>
> ...as far as the population, it was even more of a concern.... [T]he radioiodine levels which were being reported to the public were well below an action level of any sort... [to] make the material personally available to all persons perhaps up to ten miles distance, to hand them KI [potassium iodide] personally available in their hands at the time when the State is pointing out that these are very low iodine levels in the milk and are not an action level and represent no hazard, would be... authority figures saying conflicting things at the same time, and the psychological stress of that just made it bad medicine to do that. So that these recommendations just created a problem rather than helping with a problem.... 213/

Although the White House/HEW letter had included the qualification that local authorities should assess the recommendations in light of first-hand knowledge of the situation, MacLeod concluded that "because the 'recommendations' were couched more in the language of a directive, there appeared to be only minimal leeway available to accommodate [sic] the judgment of the health and nuclear officials who were actually on the scene and presumably in the best position to evaluate the danger."214/

> ...if I recommend to you that you take digitalis because you've got heart failure are you gonna take digitalis because you have heart failure? I think you are. It ; basically that kind of thing. I read the recommendations as something that comes on the HEW stationary via the White House after we have asked them, we've advised them that, that this in fact is not appropriate... There was a two-way conversation but it still arrived and the events proceeded from there.215/

On Wednesday, Surgeon General Richmond arranged a conference call between several PHS officials and MacLeod to address the apparent conflict.

> So we called and again, I just reinforced the notion that we had always said that the people who were on the scene ought to make the judgment as to whether it should be utilized and he also seemed to think that somehow or other that we were being critical of them. And I said, well, in the testimony that we had given that morning [Senate Subcommittee hearings of April 4, 19791 I had occasion to commend the Governor and all of the state officials for the way in which they had been handling the situation and that's in the testimony. ...So he seemed to be somewhat reassured that we were not being critical, and rather being supportive.216/

The potassium iodide supplies remained in the central warehouse. By midsummer, the FDA had relocated the drugs to a repository in Little Rock, Ark. to be maintained as a national stockpile.

5. <u>Concern Over When to Terminate Protective Actions</u>

Other conflicts with health authorities emerged during the week around the issue of when to terminate various protective actions. Although there had been consensus among area hospital personnel on the need to reduce census over the weekend, there was no consensus on when to return to normal operations.

> The financial people were saying, hey, we'd better get that census back up, we can't meet the payroll this week. The administrative people were saying, well, we've got to be able to react if we have to evacuate and the medical people are sort of siding with the administrative people saying we've got to be cautious here on what we do. 217/

To resolve the issue, hospital administrators, working through the Pennsylvania Hospital Association, turned to Secretary MacLeod for clearance to begin admitting patients. MacLeod viewed the role of the Health Department vis-a-vis area hospitals as purely informational, not advisory. In response to the request for guidance, therefore, MacLeod's office merely described the latest reports from the governor's office which indicated that conditions were improving.218/

> I think it was implicit in my telephone calls what action they might wish to take, but we were not -- as we had not closed down the hospitals or asked people to leave the hospitals or leave the

area, neither did we give them specific instructions to return to a prior state of activity.219/

Hospital authorities finally decided on their own that the governor's decision to reopen schools outside the 5-mile zone on Monday, April 2, signaled the end of the emergency. Normal operations then were resumed.220/

Beyond the hospitals, there was confusion over when to lift the evacuation advisory for pregnant women and preschool children. Governor Thornburgh asked Denton daily when to lift the advisory, and was repeatedly told that they should wait for the reactor to achieve cold shutdown. After a week, it was still uncertain when cold shutdown would occur. People had started to return home; Gerusky was convinced that nothing could cause an unexpected massive release. The NRC commissioners insisted on voting on the issue of lifting the advisory, and, having finally done so, Governor Thornburgh announced termination of the advisory and reopening of schools within the 5-mile radius as of April 9.221/ As with the initial recommendation to evacuate, the NRC acted unilaterally on this decision affecting the health and safety of the public.

C. WORKER HEALTH AND SAFETY CONCERNS DURING THE ACCIDENT

1. Notification and Site Evacuation

As the site emergency developed early in the morning of March 28, the TMI staff implemented on-site emergency procedures. Workers reporting for the 7:00 a.m. shift were sent to the off-site Observation Center rather than permitted on the Island. As the emergency escalated, all non-essential personnel were evacuated from the site. Many of those workers who were kept off the Island were assigned to the TMI communications network or off-site radiological monitoring teams.

2. Health and Safety Problems

With high radiation levels in various parts of the facility, safety procedures and practices were followed by all personnel. A number of health and safety problems were nevertheless encountered.

a. Despite having about 80 percent of the work force certified to use a respirator, a shortage of respirators developed for the limited number of personnel retained on-site. Some persons ended up using a type of respirator for which they were not qualified, that is, they had not been fitted nor subjected to a booth test for that particular brand. Respirators were also issued to people who were not respirator-qualified.222/

b. The health physics lab was inaccessible due to high radiation levels emitted from the nearby TMI-2 primary sample room. As a result, nonportable dosimetry instruments could not be retrieved for use. Samples initially had to be sent to state laboratories in Harrisburg, and, subsequently, were analyzed in mobile units brought in by the NRC and various contractors. 223/ In addition, there was no whole-body counter on site prior to March 28 to evaluate internal contamination. That service had been provided by an NRC mobile unit in cases of worker overexposure.224/

c. There was a problem supplying air through piped systems so self-contained breathing apparatus, which was cumbersome, had to be used.

d. Three workers received overexposures at levels ranging from around 3 to 5 rems. Bioassays were taken and analyzed, and whole-body counts administered. It was reported that these workers were sent to Hershey Medical Center (HMC) for observation and examination. There apparently has been no further followup of these workers. 225/ HMC spokesmen, however, claimed that no workers were referred to them during the accident.226/

e. A few workers revealed acute anxiety when faced with apparently dangerous tasks during the accident.

> And during this time, a man looks at himself and he's in a big yellow bag and he can't help but wonder why. Now, my background is nuclear; I can relate to that bag and why it's there. Some of these individuals are very good mechanics and electricians and instrument technicians, but their nuclear background is only what we've taught them since they've been here. And it can be frightening, I'm afraid.227/

By and large, however, the workers expressed more concern over their job security than their health during the incident. No one refused to work.

> ...I think that they had an inherent feeling of safety. Safety in a nuclear facility is foremost, now by safety... I mean radiological safety, core safety. I think that they were enough convinced that it was safe that it wasn't foremost, that they had the faith in that.228/

f. Neither of the community physicians retained to provide emergency care of radiation injuries on-site was notified of the accident by Met Ed until 5 days after the incident began. They then were called to perform respiratory physicals on temporary personnel such as NRC staff on-site.229/

g. Prior to March 28, 1979, there was no potassium iodide on-site for use in the event of a potential or actual release of radioiodine.230/ A supply was immediately procured and stored on the Island. The drug was not administered to workers during the acute phase of the accident since Met Ed officials and Denton of NRC never felt it was warranted by radioiodine levels in the plant.

In ensuing weeks, two Met Ed contractors, Porter-Gertz Associates (health physics) and Radiation Management Corporation (radiation health), suggested administration of prophylactic potassium iodide to workers before they entered a highly contaminated area. The Met Ed policy has been to take every precaution -- protective clothing, well-designed equipment, adequate training in safety practices -- to avoid worker exposure; only if radioiodine exposure actually occurs should potassium iodide be administered. Much of the debate between Met Ed and its advisors centers on the time frame in which the drug has to be administered to prove effective, and the possibility of adverse health effects. Met Ed states they could administer the drug within minutes of an exposure, thus providing effective intervention. Furthermore, Met Ed assumes "serious side effects" may occur from the use of potassium iodide, a risk they are unwilling to take without the obvious benefit of blocking the thyroid from a known radiation exposure.231/

3. Hershey Medical Center

In addition to these various problems on-site, there was little involvement of Hershey Medical Center (HMC), the off-site facility contracted to provide medical backup to TMI in the event of a radiation accident.

Members of the HMC staff, including the division of health physics, learned of the accident at TMI from media reports early on the morning of March 28. No formal notification came from the utility, the state Department of Health, or the Radiation Management Corporation of Philadelphia, with which HMC has a contract to provide medical support in the event of a radiation accident involving TMI personnel.232/

HMC began conducting its own emergency response. Health physics began monitoring the environment around the Medical Center on March 29, but no increase in radiation levels was detected. On March 30, PEMA called the hospital administrator, who in turn declared an emergency. The Emergency Care Unit began preparing for a large number of contaminated, injured workers from TMI. On the morning of March 31 a hospital meeting was held with Beauford Washington from the state Health Department, who indicated that a possible meltdown nuclear accident was imminent. On that evening, an emergency meeting was called by the dean of the medical school and emergency plans were discussed for possible patient evacuation of the hospital to be coordinated by H. Arnold Muller, director of the Department of Emergency Medicine.

From April 1 to 3, evacuation plans were still in place; the hospital census was minimized (no new patients were admitted, all patients who could be safely sent out of the hospital were discharged, and incubator babies were sent to the Children's Hospital in Philadelphia), but no actual evacuation took place.233/ By Wednesday, April 4, work returned to normal; the emergency had subsided and Governor Thornburgh had told state employees to return to work.

Throughout the period of the acute accident, Met Ed never apprised HMC of the number of workers on the Island, the status of the reactor, or the types of safety hazards confronted. HMC, therefore, never knew how many injured workers might need care.234/

X. HEALTH AND SAFETY CONSIDERATIONS: THE AFTERMATH

The TMI accident has not ended. Concern exists as to the long-term effects -- physical and psychological -- of the general public and TMI workers. Inadequacies in emergency preparedness, public and professional awareness of radiological matters, and organizational responsibilities for radiation-related health and safety have not been remedied. In addition, decontamination and recovery of TMI-2 presents a new set of health hazards. This section reviews some of the activities initiated to date to address these continuing health and safety considerations.

A. LONG-TERM HEALTH EFFECTS

Estimates of population and worker radiation exposures and discussion of the potential health effects -- carcinogenic, teratogenic, genetic --resulting from those exposures are presented in the reports of the Health Physics and Dosimetry Task Group and the Radiation Health Effects Task Group of the President's Commission. In anticipation of the need to document such effects, health officials at both the federal and state levels began early in the accident to prepare for possible epidemiological studies. Efforts were made to identify the data which would be needed, and to assure its collection.

In early June, the Pennsylvania Health Department formed a panel of doctors and scientists to oversee TMI-related research efforts being coordinated by the department. Planned studies include various aspects of radiation health effects (pregnancy outcomes, congenital and postnatal thyroid disease, dose assessment, cytogenetics, long-term disease surveillance), social and psychological effects (health behavior, mental health, drug and alcohol abuse), and related health economics. Most funding is to be provided by the Electric Power Research Institute (EPRI).235/

Gordon MacLeod, state secretary of health, has endorsed the conduct of "controlled" studies of the TMI area population, in which the long-term health status of the TMI population will be contrasted with that of similar populations in other parts of the state which did not receive radiation exposure from the TMI accident. Development of tumor registries in those areas has been recommended to provide comparable data on cancer rates. Despite the apparent low levels of radiation to which the population was actually exposed, MacLeod feels the studies are justifiable but is hesitant to state his expectations of the outcomes.236/

At the federal level, Arthur Upton, director of the National Cancer Institute, HEW, was asked to chair an interagency subcommittee concerned with research relating to followup of the TMI accident. That subcommittee reviewed and endorsed three studies. One, a census of the population residing within 5 miles of TMI at the time of the accident, was conducted in June and July 1979 to determine how many people were in the area on each day from March 28 through April 6, the history of cancer, thyroid disease, radiation therapy, occupational radiation exposure, and cigarette smoking in that population, and the number of women pregnant at the time of the accident. Information was also gathered to assist in locating the respondents in the future if followup of their health status is pursued. The second study will analyze pregnancy outcomes of the women identified in the census, and the third will examine long-term behavioral effects.

Serious reservations were expressed about the other avenues of research to be pursued by the Department of Health in Pennsylvania.

> In my view, because . . . the dose is unquestionably very small, the studies that one knows how to design and conduct now can be expected to yield virtually no useful scientific information and may simply exacerbate the anxiety that exists in the population.
>
> They will also require time, energy, resources that could be used to better advantage on real research or real care. You are not really going to care for the population. You are not going to get any scientific information of value. 237/

NIOSH has established the availability of TMI worker exposure data needed for any potential followup studies. In addition, the NRC has contracted with a research firm to identify populations of nuclear workers or communities on which epidemiological studies of the long-term effects of radiation exposure are feasible. 238/

B. EMERGENCY PREPAREDNESS

An NRC/EPA task force had published a report for comment prior to the accident at TMI which recommended planning for two emergency zones around nuclear power plants: (1) a 10-mile plume exposure pathway; and (2) a 50-mile ingestion exposure pathway. 239/

On the basis of this report and other critiques of the existing requirements, NRC published an Advance Notice of Proposed Rulemaking on July 17, 1979, soliciting public comment on "The Adequacy and Acceptance of Emergency Planning Around Nuclear Facilities."

Several congressional inquiries also have been undertaken which point the way towards requirement of NRC concurrence on state emergency preparedness plans as a condition of nuclear power plant licensure.

Apparently little has been done so far to improve emergency preparedness at the state and county level in Pennsylvania. In response to questions raised at the Aug. 2, 1979, Commission hearings, Kevin Molloy, director of the Dauphin County Emergency Preparedness Agency, has stated that: (1) no effort has yet been made to develop a registry of area health facilities and personnel available to respond in a radiation emergency, and (2) only brief discussions have been held with the Pennsylvania Emergency Management Agency (PEMA) and Bureau of Radiation Protection (BRP) to improve the procedures and plans by which they are to interrelate during a radiation emergency. Reasons given for this lack of activity include limited resources and limited responsibilities.240/

Following the accident at TMI, however, state authorities did act to enhance the environmental radiological monitoring capacity of the Bureau of Radiation Health. As in past years, legislation was being considered in Pennsylvania in the months before the accident to appropriate additional funds to the Bureau to develop an emergency response capacity in their monitoring program. 241/ After the accident at TMI, the funding provision was removed from the proposed legislative appropriations and placed, instead, in the general fund budget. As a result, additional funds will now be available to the BRP to upgrade the environmental surveillance and emergency monitoring capacity around nuclear power sites. 242/

C. PUBLIC AND PROFESSIONAL EDUCATION

Efforts to improve public and professional awareness of radiological matters have been slow to develop since the accident at TMI. As of August 1979, the Pennsylvania Emergency Management Agency (PEMA) was printing up a booklet entitled "What You Should Know About Radiation" for public distribution. The booklet had been proposed prior to the TMI accident, but its distribution was opposed then by a council of the state Bureau of Radiation Protection.

> ...several of the members were concerned that it appeared that we might be highlighting the hazards associated with fixed nuclear sites unfairly, and that the document could more appropriately be included in an overall document treating all kinds of disasters, and therefore they withheld their concurrence. I am not certain they withheld their concurrence, or at least they would rather we would not publish it, and as a consequence we did not.
>
> I think it would have been a good public service to have had such a document out, and that the document, although it is not in great detail, it is a very brief treatment of the various areas of what radiation is. I personally feel that people would have been perhaps less concerned, and a lot of the questions that we were receiving during the incident would have been answered, assuming that people had held on to copies of it or had read it. 243/

Henderson has outlined a variety of other public education programs which should be developed to increase awareness and understanding of radiological matters. These include programs for: (a) students in school systems from ninth grade through college level courses, (b) emergency response organizations such as fire, police, and emergency care personnel, (c) the general public, and (d) federal, state, county, and local authorities who must manage radiation emergencies. Limitations on resources and authority to pursue certain activities are given as reasons for lack of activity in this area by PEMA. 244/

The Pennsylvania State Department of Health and the Bureau of Radiation Protection have reported no established educational programs for professionals such as area physicians. Health Secretary MacLeod, however, is attempting to develop an organizational basis for conducting such programs. Some area physicians have shown interest in learning more about radiation health. As an example, the Pennsylvania State

University Colleges of Medicine and Engineering joined with the State Medical Society in sponsoring a 2-day seminar in September 1979 on "Radiation and Health." The purpose of this seminar was to provide interdisciplinary knowledge of the complexities of radiation hazards and emergencies. It was directed at those who would respond professionally to a radiation emergency such as federal, state, and local authorities, educators, health professionals, and those with social and environmental interests.

D. ORGANIZATIONAL CHANGE

Pennsylvania Secretary of Health MacLeod has proposed a total reorganization of his department which would include creation of divisions of radiation and occupational health. Responsibility for those two areas now rests within the state Department of Environmental Resources (DER). Some radiation protection activities would remain in the DER under this arrangement.

> ...they [DER] will be more concerned with the hardware and the mechnical engineering aspects of the radiation protection and we should be concerned with the preventive end and management of disease processes that could relate to the health aspects of radiation; so we would be a division of radiation health and they would be a division of radiation protection....
>
> We would certainly have to also have the capabilities of responding within that unit or having enough opportunity to reach out into the community, the state, the nation, for the management of the consequences of a radiation accident.
>
> ... We would be concerned with the information and knowledge that would relate to the health aspects and those programmatic aspects that would relate to prevention and early detection. Of course on the therapeutic side, we would be necessarily concerned with the disease processes that would occur after the accident. The primary emphasis would be directed ... through ... professional education and training, identification of resources in the community at large and elsewhere to take care of the consequences of a nuclear accident.245/

E. RECOVERY OPERATIONS AT TMI

Of the many adjustments made at TMI in the wake of the March accident, three are of particular significance to worker health and safety considerations.

1. Decontamination

In order to conserve the individual exposures of permanent TMI workers, Met Ed is engaging in a common industry practice of using temporary workers to decontaminate TMI-2 facilities. Non-nuclear utility workers from other parts of the Met Ed system are being hired, on a voluntary basis, to perform decontamination. Most of these workers are linemen, many of whom had recently been laid off due to financial cutbacks in Met Ed utilities. They are all members of local unions of the International Brotherhood of Electrical Workers (IBEW) and their working conditions, rights, and benefits are governed by union contracts with Met Ed. Other non-Met Ed workers, primarily from the building trades, also are being employed in a transient capacity. To date, however, they have not been involved in decontamination work. 246/

Most of the decontamination work is being conducted by Met Ed contractors, Chem Nuclear and Vykem, with NRC oversight. The decontamination workers are given radiation work permits and respirator training, and a 5-hour indoctrination course in which exposure is explained to them "very thoroughly" and tasks and safety practices are discussed. This is followed by simulation exercises. 247/ IBEW spokesmen expressed the view that utility workers often work in high risk situations and therefore understand risk-taking in jobs; the decontamination workers are considered adequately informed of the risks taken in that work as well. Decontamination work, with its potential exposure to high levels of radiation, is not considered high risk for purposes of premium pay. Such pay, however, is negotiated in some utilities for high risk jobs such as checking power line insulators from a helicopter. 248/

Decontamination work at Met Ed is conducted by crews of 15 to 18 workers, 7 days a week, with three 10-hour shifts each day; the overlap allows for briefing of incoming workers by those who have just been involved in a particular task. One-half of each crew is rotated every 2 weeks, thus allowing, once again, for overlap of experienced and inexperienced workers. All decontamination workers are to be escorted in contaminated areas by a qualified health physicist. 249/

Health and safety standards set for these workers are:

a. a quarterly maximum exposure limit of 1,250 millirem;

b. weekly whole-body counts;

c. use of pocket dosimeters read by the workers themselves, and thermoluminescent dosimeters (TLDs) and film badges read by Met Ed health physics personnel; and

d. continuous use of portable air monitors to detect any change in environmental radiation in the work area. 250/

As of July 11, 1979, when the decontamination supervisor was interviewed, decontamination work had been underway in the auxiliary and fuel handling buildings for 2 months. Work planning has been done on the basis of ALARA considerations to keep exposures as low as is reasonably achievable. 251/

> ...as far as reaching their quarterly limit, we do everything: time, distance and shielding, of course, is the three important things. And we use...tools which keep us away from hot areas. And in the last quarter, of...all the people that we had working down in there, nobody got anywhere near their quarterly limit. We get whole-body counts every week, to see if they have any problems internally. We have had no problems with the way it's going right now. 252/

Safety is claimed to be the foremost consideration in designing and conducting decontamination.

> The most important element to us is not to get anybody hurt, overexposed. To this date, and we've done one heck of a lot of deconning in there so far, nobody had had this happen to them in a decon group. So, we're pretty well pleased with the operation. When we leave, we ought to leave proud.
>
> We've had no plant schedule forced on us. We're in the decontaminating ... and we're going to go about it a safe way. Nobody's pushed us on timeframes or anything. We tell them how long it's going to take. We have a very good working agreement. 253

2. Radiation Protection Manual

In August 1979, the health physics staff at TMI issued revisions to the Radiation Protection Manual and health physics program. 254/ Additional monitoring activities and safety procedures were outlined to accommodate the contaminated conditions at TMI-2. These included procedures for (a) internal dosimetry/bioassay and air sampling designed to monitor specifically for strontium-89 and strontium-90; (b) care, use, and cleaning of respiratory protection devices; (c) revised respirator booth testing; and (d) a training program for health physics foremen and technicians to conduct the bioassay program. Met Ed also claims to be developing additional procedures for ALARA review and evaluation of potential exposures of workers to concentrations of airborne radioactive materials.

3. Training and Physical Exams

Some routine training courses and physical examinations have been cut back since the accident. The Basic III course on radiation protection has not been conducted since the accident because of time constraints and inaccessibility of contaminated areas of the plant previously used for such training. 255/

Routine physical examinations provided older employees every 2 years have also been suspended since the accident due to financial cutbacks. Safety meetings previously held for the entire staff six times a year will now be held quarterly. 256/

NOTES

1/ Regulatory Guide 4.7, p. 16.

2/ Northern States Power Company v. Minnesota, 447 F. 2d 1143, 1154 (8th Cir. 1971) Affirmed 405 U.S. 1035 (1972).

3/ Department of Health, Education, and Welfare, Interagency Task Force on the Health Effects of Ionizing Radiation, "Report of the Work Group on Exposure Reduction," June 1979, pp. 14-15.

4/ Department of Health, Education, and Welfare, Interagency Task Force on the Health Effects of Ionizing Radiation, "Report on Institutional Arrangements," June 1979, pp. 22-23.

5/ Ibid., p. 24.

6/ Ibid.

7/ Alexander deposition, Aug. 13, 1979, p. 30.

8/ Ibid., p. 39.

9/ Villforth interview, pp. 10, 13-14.

10/ 40 Fed. Reg. 59494, Dec. 23, 1975.

11/ Interagency Radiological Assistance Plan, 1961, Annex IV.

12/ Ibid., p. 2.

13/ Gerusky deposition, July 24, 1979, pp. 4-7.

14/ Ibid., p. 3.

15/ MacLeod deposition, July 23, 1979, p. 5.

16/ Executive Order 10831 and Public Law 86-373, 42 U.S.C. 2021(h).

17/ Shoop interview, p. 2.

18/ Ibid.

19/ Gee interview, pp. 2-7, 38-39.

20/ HEW, "Report of the Interagency Task Force on the Health Effects of Ionizing Radiation," June 1979, p. 97.

21/ HEW, "Report Of the Work Group On Exposure Reduction," June 1979, p. 119.

22/ NUREG-0463, "Occupational Radiation Exposure," Tenth Annual Report, 1977, Table 1, p. 4.

23/ Ibid.

24/ Ibid., Table 3, p. 8.

25/ Regulatory Guide 8.15, "Acceptable Programs for Respiratory Protection."

26/ Alexander deposition, p. 29.

27/ Ibid., p. 31.

28/ Ibid., pp. 26-27.

29/ 10 CFR Part 20, Section 20.1(c).

30/ National Research Council, National Academy of Sciences, Advisory Committee on the Biological Effects of Ionizing Radiation, "Considerations of Health Benefit-Cost Analysis for Activities Involving Ionizing Radiation Exposure and Alternatives," 1977.

31/ Parsont deposition, Aug. 13, 1979, p. 27.

32/ Alexander deposition, pp. 18-20.

33/ Regulatory Guide 8.10, "Operating Philosophy for Maintaining Occupational Radiation Exposures as Low as Is Reasonable Achievable."

34/ Regulatory Guide 8.8, "Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations Will Be as Low as Is Reasonably Achievable."

35/ Ibid., p. 2.

36/ Ibid.

37/ Alexander deposition, p. 35.

38/ Ibid.

39/ Regulatory Guide 4.7, "General Site Suitability Criteria for Nuclear Power Stations," p. 2.

40/ Regulatory Guide 4.7, p. 16.

41/ Ibid.

42/ Regulatory Guide 1.101, "Emergency Planning for Nuclear Power Plants."

43/ Regulatory Guide 4.7, p. 16.

44/ Southern States Energy Board, "Energy Facility Siting in the U.S.," Vol. 1, February 1978, pp. ix-xiii.

45/ Ibid., p. 97.

46/ Southern States Energy Board, "Energy Facility Siting in the U.S.,". Vol. II, February 1978, p. 312.

47/ Ibid., p. 309.

48/ 10 CFR Part 20.

49/ Atomic Safety and Licensing Board hearings, Docket #50-520, Oct. 6, 1969, pp. 82-85.

50/ Safety Evaluation Report (SER) for TMI, AEC Division of Licensing, September 5, 1979, pp. 54-57.

51/ Atomic Safety and Licensing Board hearings, Docket #50-520, Oct. 6, 1969; Testimony of Raymond Powell, AEC, p. 96.

52/ Atomic Safety and Licensing Board hearings, Docket #50-520.

53/ NUREG-0107, "Safety Evaluation Report Related to Operation of the Three Mile Island Nuclear Station, Unit 2," Docket #50-320, Supplement 1, Section 11.7, September 1976.

54/ Regulatory Guide 4.1, "Programs for Monitoring Radioactivity in the Environs of Nuclear Power Plants."

55/ 10 CFR 10, Appendix I.

56/ National Research Council, National Academy of Sciences, Advisory Committee on the Biological Effects of Ionizing Radiation, "Considerations of Health Benefit-Cost Analysis for Activities Involving Ionizing Radiation Exposure and Alternatives," 1977, p. 97.

57/ Dubiel deposition, July 20, 1979, 42-49.

58/ Gerusky deposition, p. 17.

59/ Governor's Fact-Finding Committee, Commonwealth of Pennsylvania, "Shippingport Nuclear Power Station, Alleged Health Effects," 1974, p. 3.

60/ Gerusky deposition, pp. 18-19.

61/ Ibid., p. 18.

62/ Ibid., pp. 16-17.

63/ 10 CFR Part 55, Operator Licenses; Regulatory Guide 1.134, "Medical Evaluation of Nuclear Power Plant Personnel Requiring Operator Licenses," P. 1.

64/ 10 CFR Part 55, p. 2.

65/ Regulatory Guide 1.134, p. 2.

66/ American National Standards Institute (ANSI), N546-1976, "Medical Certification and Monitoring of Personnel Requiring Operator Licenses for Nuclear Power Plants."

67/ Regulatory Guide 1.134, p. 2.

68/ Newman interview, Aug. 23, 1979.

69/ Health Physics Procedure 1628, "Program for Medical and Bioassay Examinations," p. 1.0.

70/ Ibid., p. 2.0.

71/ Ibid., p. 3.0.

72/ Personnel Policy Procedure, "Procedure for Employee Screening for Protected Areas at TMI."

73/ Grice interview, p. 15.

74/ Health Physics Procedure 1628, p. 40.

75/ Ibid., p. 50.

76/ 10 CFR Part 20, Section 20.202(a).

77/ 10 CFR Part 19, Section 19.15.

78/ 10 CFR Part 20, Section 20.409.

79/ 10 CFR Part 20, Section 20.408.

80/ 10 CFR Part 20, Section 20.407; Regulatory Guide 1.16, "Reporting of Operating Information -- Appendix A, Technical Specifications."

81/ 10 CFR Part 20, Section 20.103(a)(3).

82/ Regulatory Guide 8.15, "Acceptable Programs for Respiratory Protection."

83/ NUREG-0041, "Manual of Respiratory Protection Against Airborne Radioactive Materials."

84/ Regulatory Guide 8.15, pp. 1-2.

85/ Administrative Procedure 1003, Radiation Protection Manual, p. 6.0.

86/ Health Physics Procedure 1640, "Personnel Dosimetry, Issuance, Administration and Record Keeping."

87/ Newman interview, pp. 40-44.

88/ Gee interview, pp. 36-37.

89/ Dubiel deposition, p. 96.

90/ Ibid., p. 97.

91/ NUREG-0463, "Occupational Radiation Exposure," Tenth Annual Report, Appendix A, 1977, p. 39.

92/ Gee interview, p. 8-

93/ Dietrich interview, pp. 8-9.

94/ Agreement between Metropolitan Edison Company and Local Unions 563, 603, 1261, and 1482 of the IBEW, AFL-CIO, effective May 1, 1978, Article V, Section 5.2(a).

95/ Ibid.

96/ Interview, Kimmey, et. al., p. 40.

97/ Parks interview, p. 26.

98/ Kimmey interview, p. 25.

99/ Grice interview, p. 40.

100/ IBEW interview, J. Parks, p. 25.

101/ Interview, Kimmey, et. al., ibid.

102/ Dietrich interview, pp. 10-11.

103/ Regulatory Guide 1.16, "Reporting of Operating Information -- Appendix A, Technical Specifications."

104/ NRC Docket #50-320, May 1977, pp. 1640-1642.

105/ NRC Docket #50-320, May 1977; Testimony of J.G. Herbein, pp. 1653-1654.

106/ Ibid., pp. 1961-1962.

107/ Albright interview, p. 25.

108/ Albright interview, p. 32; Barnowski testimony, May 19, 1979, public hearings of the President's Commission on the Accident at Three Mile Island.

109/ Testimony of Gordon MacLeod, public hearing of the President's Commission on the Accident at Three Mile Island, Aug. 2, 1979, pp. 162-166.

110/ Testimony of Thomas Gerusky, public hearing of the President's Commission on the Accident at Three Mile Island, Aug. 2, 1979, pp. 65-68.

111/ 10 CFR Part 19, "Notices, Instructions, and Reports to Workers; Inspections," Section 19.12.

112/ Kemmey interview, pp. 57-60.

113/ Dubiel deposition, pp. 56-94.

114/ 10 CFR Part 50, Appendix E, "Emergency Plans for Production and Utilization Facilities."

115/ NUREG-75/111, "Guide and Checklist for the Development and Evaluation of State and Local Government Radiological Emergency Response Plans in Support of Fixed Nuclear Facilities."

116/ U.S. House of Representatives, Report No. 96-413, "Emergency Planning Around U.S. Nuclear Powerplants: Nuclear Regulatory Commission Oversight."

117/ Ibid., p. 35.

118/ Federal Register, Vol. 43, No. 242.

119/ Testimony of Thomas E. Potter, NRC Docket #50-320, May 1977, pp. 1683-1684.

120/ Molloy testimony during operating license hearings on Contention 8, NRC Docket #50-320.

121/ National Council on Radiation Protection and Measurement, Report 55, July 1977.

122/ TMI Administrative Procedure 1004, "Three Mile Island Site Emergency Plan."

123/ TMI Administrative Procedure 1670.11, "On-Site Medical Emergency."

124/ Gee interview, pp. 11-12, 19-21.

125/ Newman interview, p. 2.

126/ Albright interview, p. 27, Newman interview, pp. 24-29, 55.

127/ Cotton deposition, August 16, 1979, pp. 4-7; Foege deposition, Aug. 17, 1979, pp. 6-10.

128/ Robbins deposition, July 27, 1979, p. 31.

129/ Cotton deposition, p. 6.

130/ Ibid., p. 7.

131/ Ibid., p. 22.

132/ Ibid., p. 13.

133/ Ibid., p. 18.

134/ Ibid., p. 28.

135/ Upton deposition, p. 8.

136/ Ibid., pp. 9-10.

137/ Cotton deposition, p. 81.

138/ Ibid., pp. 56-57.

139/ Ibid., pp. 35-36.

140/ Ibid., p. 57.

141/ Ibid., pp. 62-64.

142/ Villforth interview, pp. 21-29.

143/ National Council on Radiation Protection and Measurement, Report 55, "Protection of the Thyroid Gland in the Event of Releases of Radioiodine."

144/ Federal Register, Vol. 43, No. 242, Dec. 15, 1978, pp. 58798-58800.

145/ Halperin interview.

146/ "Chronology of Events at HEW Regarding Three Mile Island, March 28, 1979, through April 30, 1979," submitted by HEW, PHS, FDA, to the President's Commission on the Accident at Three Mile Island, June 28, 1979.

147/ 40 FR 59494, December 24, 1975.

148/ Memorandum to Peter Libassi, HEW General Counsel, dated April 2, 1979, re: "Radiological Incident Emergencies -- Legal Authorities and Responsibilities of the Secretary Under the Public Health Service Act and Related Programs."

149/ Villforth interview, pp. 19-20.

150/ Robbins deposition, p. 47.

151/ Robbins interview, p. 26.

152/ Robbins deposition, pp. 73-87.

153/ Halperin interview, p. 8.

154/ "Potassium Iodide as a Thyroid-Blocking Agent in a Radiation Emergency," Federal Register, Vol. 43, No. 242, Dec. 15, 1978, p. 58798.

155/ Cotton deposition, p. 84.

156/ Frederickson deposition, Aug. 15, 1979, p. 55.

157/ Cotton deposition, pp. 85A-86.

158/ Frederickson deposition, pp. 64-65.

159/ Ibid., p. 49.

160/ R. Linneman, "A Chronology of RMC's Participation in Events at Three Mile Island," memorandum to RMC Board of Directors, May 9, 1979.

161/ Foege deposition, pp. 69-70.

162/ Testimony of D. Julius Richmond, Hearings of the Senate Subcommittee on Health and Scientific Research, Committee on Human Resources, April 4, 1979, pp. 122-123.

163/ Cotton deposition, p. 99.

164/ Villforth deposition, pp. 42-43.

165/ Deal interview, pp. 36-38.

166/ Cotton deposition, pp. 99-100.

167/ Ibid., pp. 105-107.

168/ Robbins deposition, pp. 81-86.

169/ Gerusky deposition, pp. 29-30.

170/ Ibid., pp. 30-31.

171/ Ibid., pp. 131-32.

172/ Ibid., p. 34.

173/ Ibid., pp. 35-41.

174/ Ibid., p. 34.

175/ MacLeod deposition, p. 12.

176/ Ibid.

177/ Ibid., pp. 12-13.

178/ MacLeod Testimony, Hearings of the President's Commission, August 2, 1979, p. 135.

179/ MacLeod deposition, p. 21.

180/ Ibid., p. 138.

181/ Robbins deposition, p. 34.

182/ MacLeod deposition, pp. 26-29.

183/ Ibid., p. 30.

184/ Ibid., pp. 35-36.

185/ Ibid., p. 33.

186/ Ibid., pp. 35-36.

187/ Gerusky deposition, pp. 53-54.

188/ Ibid., pp. 52-54.

189/ Henderson deposition, July 30, 1979, pp. 56-57.

190/ Gerusky deposition, p. 56.

191/ MacLeod deposition, pp. 42-43.

192/ Ibid., p. 64.

193/ Gerusky deposition, p. 67.

194/ MacLeod deposition, pp. 52-56.

195/ Henderson testimony, public hearing of the President's Commission on the Accident at Three Mile Island, Aug. 2, 1979, p. 45.

196/ Interview, Semanko, Fisher, et. al., p. 69.

197/ Molloy deposition, July 26, 1979, p. 113.

198/ Interview, Semanko, Fisher, pp. 76-80.

199/ Ibid., p. 80.

200/ MacLeod deposition, p. 61.

201/ Semanko, Fisher interview, p. 98.

202/ Ibid., p. 85.

203/ Telephone conversation with D. Trachtenberg, Sep. 6, 1979.

204/ MacLeod deposition, p. 58.

205/ Trachtenberg, pp. 65-66.

206/ Ibid., p. 65.

207/ Ward deposition, Aug. 28, 1979, p. 39.

208/ MacLeod deposition, p. 64.

209/ Ibid., pp. 76-77.

210/ MacLeod interview, pp. 77-78.

211/ MacLeod deposition, pp. 77-78.

212/ MacLeod, "The Decision to Withhold Distribution of Potassium Iodide During the Three Mile Island Event: Internal Working Document," undated, pp. 16-19.

213/ Wald deposition, pp. 100-103.

214/ MacLeod, p. 21.

215/ MacLeod interview, p. 80.

216/ Richmond deposition, Aug. 21, 1979, pp. 40-41.

217/ Semanko, Fisher interview, p. 110.

218/ MacLeod deposition, pp. 91-93.

219/ MacLeod deposition, p. 93.

220/ Interview, Semanko, Fisher, p. 115.

221/ Gerusky deposition, pp. 82-85.

222/ Gee interview, p. 37.

223/ Dubiel deposition, pp. 100-101.

224/ Ibid., pp. 9-11.

225/ Grice interview, p. 29.

226/ Miller interview.

227/ Gee interview, p. 27.

228/ Ibid., p. 31.

229/ Albright interview; Newman interview.

230/ Grice interview, p. 19.

231/ Ibid., pp. 19-26.

232/ Miller interview.

233/ Interview, Hershey Medical Center staff, July 16, 1979.

234/ Miller interview.

235/ Pennsylvania Department of Health, "TMI Health Research Program: Summary and Status," June 12, 1979.

236/ MacLeod testimony, public hearing of the President's Commission on the Accident at Three Mile Island, Aug. 2, 1979, p. 161.

237/ Upton deposition, Aug. 22, 1979, p. 37.

238/ Parsont deposition, Aug. 13, 1979, p. 49.

239/ NUREG-0396, "Planning Basis for Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants," December 1978.

240/ Letter dated Aug. 14, 1979, Kevin Molloy to Barbara Jorgenson, Director of Public Information, President's Commission on the Accident at Three Mile Island.

241/ Gerusky deposition, pp. 19-20.

242/ Ibid.

243/ Testimony of Oran Henderson, Aug. 2, 1979, hearings of the President's Commission, pp. 67-68.

244/ Letter from Henderson to Jorgenson, Aug. 15, 1979.

245/ MacLeod deposition, pp. 7-10.

246/ Interviews, O'Reilly, Shoop, Kimmey.

247/ Block interview, pp. 3-4, 7-8.

248/ O'Reilly, Shoop meeting summary, p. 5.

249/ Block interview, pp. 5-6.

250/ Ibid., pp. 8-10.

251/ Ibid., pp. 16-17.

252/ Block interview, p. 8.

253/ Ibid., pp. 23-24.

254/ Letter from Herbein to Grier, Aug. 13, 1979.

255/ McCormick interview, pp. 4-5.

256/ Grice interview, pp. 9-10.

APPENDIX A

DOCUMENTS REVIEWED

I. NRC

A. <u>Legislation</u>

1. Atomic Energy Act of 1954, as amended (Public Law 83-703).

2. Energy Reorganization Act of 1974, as amended (Public Law 93-438).

B. <u>Regulations</u>

1. 10 CFR Part 19, "Notices, Instructions, and Reports to Workers: Inspections."

2. 10 CFR Part 20, "Standards for Protection Against Radiation."

3. 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities."

   Appendix E, "Emergency Plans for Production and Utilization Facilities."

   Appendix I, "Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion." (ALARA)

4. 10 CFR Part 55, "Operators' Licenses."

5. 10 CFR Part 100, "Reactor Site Criteria."

C. <u>Regulatory Guides and Guidance Documents</u>

1. Reg. Guide 1.8, "Personnel Selection and Training."

2. Reg. Guide 1.16, "Reporting of Operating Information -- Appendix A, Technical Specifications."

3. Reg. Guide 1.101, "Emergency Planning for Nuclear Power Plants."

4. Reg. Guide 1.134, "Medical Evaluation of Nuclear Power Plant Personnel Requiring Operator Licenses."

5. Reg. Guide 4.1, "Programs for **Monitoring Radioactivity in the** Environs of Nuclear Power Plants."

6. Reg. Guide 4.7, "General Site Suitability Criteria for Nuclear Power Stations."

7. Reg. Guide 8.8, "Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations will be as Low as is Reasonably Achievable."

8. Reg. Guide 8.10, "Operating Philosophy for Maintaining Occupational Radiation Exposures as Low as is Reasonably Achievable."

9. Reg. Guide 8.15, "Acceptable Programs for Respiratory Protection."

10. NUREG-75/111, "Guide and Checklist for Development and Evaluation of State and Local Government Radiological Emergency Response Plans in Support of Fixed Nuclear Facilities," March 1977.

11. NUREG-0041, "Manual of Respiratory Protection Against Airborne Radioactive Material."

12. NUREG-0195, "Improving Regulatory Effectiveness in Federal/State Siting Actions," May 1977.

13. NUREG-0348, "Demographic Statistics Pertaining to Nuclear Power Reactor Sites," October 1977.

14. NUREG-0463, "Occupational Radiation Exposure," Tenth Annual Report, 1977.

D. Hearings

1. Atomic Safety and Licensing Board, Docket #50-520, TMI-2 Construction Permit Hearings, October 1969.

2. Atomic Safety and Licensing Board, Docket #50-320, TMI-2 Operating License Hearings, 1977.

II. CONGRESSIONAL, AGENCY, AND INTERAGENCY REPORTS, PLANS, AND GUIDANCE DOCUMENTS

1. U.S. Senate Committee on Governmental Affairs, "Federal Regulation of Radiation Health and Safety: Organizational Problems and Possible Remedies," August 1978.

2. U.S. Department of Health, Education, and Welfare, "Report of the Interagency Task Force on the Health Effects of Ionizing Radiation," June 1979.

3. Southern States Energy Board, "Energy Facility Siting in the U.S.," Vols. I and II, February 1978.

4. Commonwealth of Pennsylvania, Governor's Fact-Finding Committee, "Shippingport Nuclear Power Station Alleged Health Effects," 1974.

5. DOE, "Interagency Radiological Assistance Plan" (IRAP), DOE/EV-0010, March 1978.

6. NRC-EPA, "Planning Basis for the Development of State and Local Government Radiolocial Emergency Response Plans in Support of Light Water Nuclear Power Plants," NUREG-0396, EPA 520/1-78-016.

7. U.S. General Accounting Office, "Areas Around Nuclear Facilities Should be Better Prepared for Radiological Emergencies," EMD-78-110, March 30, 1979.

8. U.S. House of Representatives Committee on Government Operations, "Emergency Planning Around U.S. Nuclear Power Plants: Nuclear Regulatory Commission Oversight," Aug. 8, 1979.

9. Commonwealth of Pennsylvania, "Three Mile Island Nuclear Station Annex to the Pennsylvania Plan for the Implementation of Protective Action Guides."

10. Food and Drug Administration, HEW, "Accidental Radioactive Contamination of Human Food and Animal Feeds," Federal Register, Part VII, Dec. 15, 1978.

11. National Council on Radiation Protection, "Protection of the Thyroid Gland in the Event of Releases of Radioiodine," NCRP #55, 1977.

12. Food and Drug Administration, HEW, "Potassium Iodide as a Thyroid-Blocking Agent in a Radiation Emergency," Federal Register, Part VII, Dec. 15, 1978.

13. Advisory Committee on the Biological Effects of Ionizing Radiations, "Considerations of Health Benefit-Cost Analysis for Activities Involving Ionizing Radiation Exposure and Alternatives," EPA 520/4-77-003, 1977.

14. Michael S. Baram, "Radiation from Nuclear Power Plants: The Need for Congressional Directives," Harvard Journal on Legislation, Vol. 14, No. 4, June 1977, pp. 905-977.

15. Elaine Hallmark, "Radiation Protection Standards and the Administrative Decision Making Process," Environmental Law, Vol. 8, Sep. 1978, pp. 785-825.

III. MET ED AND MET ED-RELATED ADMINISTRATIVE PROCEDURES AND REPORTS

1. NRC, "Safety Evaluation Report Related to Operation of Three Mile Island Nuclear Station, Unit 2," NUREG-0107, Docket No. 50-320.

2. Agreement between Metropolitan Edison Company and Local Unions Nos. 563, 603, 803, 1261, and 1482 of the International Brotherhood of Electrical Workers (AFL-CIO), May 1, 1978.

3. Administrative Procedure 1003, "Radiation Protection Manual."

4. Administrative Procedure 1004, "Three Mile Island Site Emergency Plan," Revision 1, January 1978.

5. Health Physics Procedure 1628, "Program for Medical and Bioassay Examinations."

6. Health Physics Procedure 1640, "Personnel Dosimetry, Issuance, Administration and Record-Keeping."

7. Health Physics Procedure 1670.11, "On-Site Medical Emergency (Injured and Contaminated)."

8. Health Physics Procedure 1686, "Use of Protective Clothing."

9. Health Physics Procedure 1690, "Training Requirements."

10. Personnel Policy Procedure, "Procedure for Employee Screening for Protected Areas at TMI."

11. Hershey Medical Center, "Decontamination and Treatment of the Radioactively Contaminated Patient at Milton S. Hershey Medical Center," June 1978.

12. NUREG-0107, "Safety Evaluation Report Related to Operation of Three Mile Island Nuclear Station, Unit 2," NRC, Docket No. 50-320, September 1976.

IV. CORRESPONDENCE AND MEMORANDA

Document requests produced an extensive set of memoranda, letters, progress reports, and notes generated by White House, federal, and state officials during the accident at TMI. The following list includes only major documents referenced in preparation for interviews, depositions, and report writing.

1. HEW

a. "Chronology of Events at HEW Regarding Three Mile Island, March 28, 1979 through April 30, 1979," prepared for the President's Commission on the Accident at Three Mile Island by the HEW, Public Health Service, FDA/BRH.

b. March 31, 1979, memorandum from Secretary Joseph Califano to Heads, Principal Operating Components, Staff Offices and Assistant Secretaries re: Three Mile Island Nuclear Power Plants.

c. April 7, 1979, memorandum from Assistant General Counsel for Public Health to Peter Libassi, General Counsel re: Radiological incident emergencies -- legal authorities and responsibilities of the Secretary under the Public Health Service Act and related programs.

d. April 1, 1979, memorandum from Secretary Califano to NRD Chairman Hendrie re: Workers at TMI.

e. April 14, 1979, letter from Secretary Califano to NRC Chairman Hendrie re: Studies of worker radiation exposure at TMI.

f. May 23, 1979, letter from NRC Chairman Hendrie to Secretary Califano re: Response to April 14th letter (#3).

g. April 2, 1979, summary of briefing by NRC, Brian Grimes.

h. April 3, 1979, memorandum from Secretary Califano to Jack Watson re: Recommendations for distribution and use of potassium iodide.

i. April 13, 1979, memorandum from J. Robbins and J. Wolff to D. Fredrickson re: NIH urine sampling at TMI.

j. April 9, 1979, memorandum from William Foege to J. Richmond re: Long-term health studies relating to the TMI accident.

2. <u>White House</u>

a. April 13, 1979, memorandum from Jack Watson to Secretary Califano, James Schlesinger (DOE), and Douglas Costle (EPA) re: Long-term environmental radiation monitoring at Three Mile Island.

3. <u>Commonwealth of Pennsylvania</u>

a. Aug. 14, 1979, letter from Kevin Molloy to Barbara Jorgenson re: Post-TMI registry of health care professionals in Dauphin County.

b. Aug. 15, 1979, letter from Oran Henderson to Barbara Jorgensen re: Post-TMI public education programs recommended by PEMA.

4. <u>Metropolitan Edison and Contractors</u>

a. Sept. 10, 1979, letter from J.G. Herbein to B.H. Grier (NRC) re: Post-TMI alterations in radiation protection program.

b. May 9, 1979, memorandum from Roger Linneman to Board of Directors, Radiation Management Corporation, "A Chronology of RMC's Participation in Events at Three Mile Island."

APPENDIX B

INTERVIEWEES AND DEPONENTS

(I = Interviewee; D = Deponent)

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

1. Richard Cotton, Executive Secretary to the Department (D)
2. Charles Cox, Assistant to the Director, Bureau of Radiological Health, Food and Drug Administration (I)
3. William Foege, Director, Center for Disease Control (D)
4. Donald Frederickson, Director, National Institutes of Health (D)
5. Jerome Halperin, Deputy Director, Bureau of Drugs, Food and Drug Administration (I)
6. Clark Heath, Director, Chronic Diseases Division, Bureau of Epidemiology, Center for Disease Control (I)
7. Julius Richmond, Assistant Secretary for Health and Surgeon General (D)
8. Anthony Robbins, Director, National Institute for Occupational Safety and Health, Center for Disease Control (I, D)
9. Arthur Upton, Director, National Cancer Institute (I, D)
10. John Villforth, Director, Bureau of Radiological Health, Food and Drug Administration (I, D)

NUCLEAR REGULATORY COMMISSION

1. Robert Alexander, Chief, Occupational Health Standards Branch, Office of Standards Development (D)
2. Harold Collins, Assistant Director for Emergency Preparedness, Office of State Programs (I, D)
3. Michael Parsont, Chief, Radiological Health Standards Branch, Office of Standards Development (D)

DEPARTMENT OF ENERGY

1. L. Joe Deal, Chief, Environment and Public Safety Branch, Office of the Assistant Secretary for Environment (I, D)

COMMONWEALTH OF PENNSYLVANIA

1. William Dornsife, Nuclear Engineer, Bureau of Radiation Protection, Department of Environmental Resources (I)

2. Thomas Gerusky, Director, Bureau of Radiation Protection, Department of Environmental Resources (I, D)

3. Oran Henderson, Director, Pennsylvania Emergency Management Agency (I, D)

4. Gordon MacLeod, Secretary, Department of Health (I, D)

5. Margaret Reilly, Chief, Division of Environmental Radiation, Department of Environmental Resources (I)

6. George Tokuhata, Director of Research, Department of Health (I)

7. Neil Wald, Chairman, Department of Radiation Health, University of Pittsburgh School of Public Health; Consultant to the State Department of Public Health (D)

METROPOLITAN EDISON MANAGEMENT

1. Thomas Block, Decontamination Supervisor (I)

2. Richard Dubiel, Supervisor, Radiation Detection and Chemistry (D)

3. Earl Gee, Site Safety Representative (I)

4. Fred Grice, Supervisor of Generation Safety/GPU (I)

5. Frank McCormick, Supervisor of Training (I)

INTERNATIONAL BROTHERHOOD OF ELECTRICAL WORKERS

International Staff

1. Vincent O'Reilly, Director, Utility Department (I)

2. Paul Shoop, Nuclear Power Staff, Utility Department (I)

IBEW Regional and Local Staff

1. J. Cody, Executive Board Chairman, Local 563, TMI (I)

2. T. Dougherty, Head Steward, Operations, Local 563, TMI-2 (I)

3. R. Dietrich, International Representative, Third District, IBEW (I)

4. M. Janouski, Head Steward, Health Physics Department, Local 653, TMI (I)

5. J. Kimmey, President, Local 563, TMI (I)

6. J. Parks, President, Local 603, and President, System Council (I)

7. L. Wright, Steward, Operations, Local 563, TMI-2, Shift A (I)

TMI AREA HEALTH CARE PROVIDERS

Community Physicians on Retainer to Met Ed

1. William Albright, Highspire, Pennsylvania (I)

2. Miles Newman, Elizabethtown, Pennsylvania (I)

Harrisburg General Hospital

1. Warren Prelesnik, Executive Vice-President (I)

2. Jack Semanko, Director, Ambulatory Care Services (I)

3. James Fisher, Executive Director, Emergency Health Services Federation of South Central Pennsylvania (assisted in coordination of hospital emergency response) (I)

Hershey Medical Center

1. Ward Donovan, Staff Physician, Emergency Medicine (I)

2. Kenneth Miller, Director, Division of Health Physics (I)

3. H. Arnold Muller, Chief, Emergency Medicine (I)

4. Al Vastyon, Chairman, Department of Behavioral Sciences (I)

5. William Weidner, Chairman, Radiology Department (I)

0 U. 9. GOVERNMENT PRINTING OFFICE : 1990 307-684/6797

Staff Reports To

THE PRESIDENT'S COMMISSION ON
THE ACCIDENT AT
THREE MILE ISLAND

The Nuclear Regulatory Commission, Report of the Office of Chief Counsel

The Role of the Managing Utility and Its Suppliers, Report of the. Office of Chief Counsel

Emergency Preparedness, Emergency Response, Reports of the Office of Chief Counsel

Reports of the Technical Assessment Task Force, Vol. I
- "Technical Staff Analysis Reports Summary"
- "Summary Sequence of Events"

Reports of the Technical Assessment Task Force, Vol. II
- "Chemistry"
- "Thermal Hydraulics"
- "Core Damage"
- "WASH 1400 -- Reactor Safety Study"
- "Alternative Event Sequences"

Reports of the Technical Assessment Task Force, Vol. III
- "Selection, Training, Qualification, and Licensing of Three Mile Island Reactor Operating Personnel"
- "Technical Assessment of Operating, Abnormal, and Emergency Procedures"
- "Control Room Design and Performance"

Reports of the Technical Assessment Task Force, Vol. IV
- "Quality Assurance" ~~
- "Condensate Polishing System"
- "Closed Emergency Feedwater Valves"
- "Pilot-Operated Relief Valve Design and Performance"
- "Containment: Transport of Radioactivity from the TMI-2 Core to the Environs"
- "Iodine Filter Performance"
- "Recovery: TMI-2 Cleanup and Decontamination"

Reports of the Public Health and Safety Task Force
- "Public Health and Safety Summary"
- "Health Physics and Dosimetry"
- "Radiation Health Effects"
- "Behavioral Effects"
- "Public Health and Epidemiology"

Report of the Emergency Preparedness and Response Task Force

Report of the Public's Right to Information Task Force