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HEALTH EFFECTS OF THE NUCLEAR ACCIDENT AT THREE MILE ISLAND

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THREE MILE ISLAND<sup>1,2</sup>

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## INTRODUCTION

My assignment this morning is to try to provide some understanding of the real and potential health effects of the nuclear reactor accident at Three Mile Island. This task is not an easy one, since it involves two very complex areas of scientific enquiry--the biological effects of low-level radiation, and the behavioral response of populations and individuals under stress. I think the best thing for me to do is to discuss our current knowledge of the health effects of low-level radiation--what we know and what we do not know--and the potential risks to health of such radiation in exposed human populations. To place this into perspective, I shall describe very briefly what the major sources of ionizing radiations are, and how we are exposed to these natural background and man-made radiations. I shall also try to discuss the scientific basis of the delayed or late biological effects of ionizing radiations, primarily carcinogenesis, teratogenesis and mutagenesis. To do this, I shall cite some numbers to provide a limited understanding of quantitative risk estimation of the potential health effects--radiation-induced cancer, developmental abnormalities in the newborn, and genetically-related ill-health--and what such risk estimation may have to do with the affairs of mice, men, and nuclear energy. To make this current and relevant to today's discussion, I shall place all this in the framework of the events of the nuclear accident at Three Mile Island.

However, at that point my task is not completed until I discuss with you some understanding of the most important health effect of the accident at Three Mile Island, that of the mental stress and behavioral responses of the individuals and the special populations living in the area. To accomplish all this in the limited time available, I have chosen to draw heavily from my personal scientific experiences as Director of the Public Health and Safety Task Force

of the President's Commission on the Accident at Three Mile Island, and as a Member of the Committee on the Biological Effects of Ionizing Radiations of the National Academy of Sciences-National Research Council.

#### WHAT ARE THE SOURCES OF IONIZING RADIATIONS?

The major sources of ionizing radiations to which the general population is exposed in the United States are natural background and medical applications of radiation (1). Natural background radiation consists primarily of galactic cosmic radiation from outer space, from terrestrial radiation in the rocks and soils, and our own internal radioactivity. In all, the average whole-body dose rate received by each American annually is about 100 mrem/year. For a given person, the dose rate from natural background varies with altitude and geographic location, as well as with living habits. Medical applications of radiation contribute similar doses each year to the various tissues of the body. Workers in nuclear and other industrial activities in which radioactive materials or x-ray equipment are used are occupationally exposed to levels of radiation that may exceed background severalfold, and the number of such workers is increasing.

#### WHAT DO WE KNOW ABOUT THE HEALTH EFFECTS OF LOW-LEVEL RADIATION?

Low-level ionizing radiation can affect the cells and tissues of the body in three important ways (2,3). First, if the macromolecular lesion occurs in one or a few cells, such as those of the hematopoietic tissues, the irradiated cell can occasionally transform into a cancer cell, and after a period of time there is an increased risk of cancer developing in the exposed individual. This biological effect is called carcinogenesis, and the health effect, cancer.

Second, if the embryo or fetus are exposed during gestation, injury can occur to the proliferating and differentiating cells and tissues, leading to abnormal growth. This biological effect is called teratogenesis, and the health effect, developmental abnormality of the newborn.

Third, if the macromolecular lesion occurs in the reproductive cell of the testis or of the ovary, the hereditary genome of the germ cell can be altered, and the injury can be expressed in the descendants of the exposed individual. This biological effect is called mutagenesis, and the health effect, genetically-related ill-health.

There are a number of other biological and related health effects of ionizing radiation, such as cataract of the lens of the eye, or impairment of fertility, but these three important delayed or late effects--carcinogenesis, teratogenesis, and mutagenesis--stand out as those of greatest concern. This is because a considerable amount of scientific information is known from epidemiological studies of exposed human populations and from laboratory animal experiments. Furthermore, we believe that any exposure to radiation, even at very low levels of dose, may carry some increase in the risk of such deleterious effects. And as the dose of radiation increases above very low levels, the risk of these health effects increases in exposed human populations. It is these latter observations that have been central to the public concern about the potential health effects of low-level radiation, and to the need of establishing standards for the protection of the health of exposed populations.

WHAT DO WE KNOW ABOUT RADIATION CARCINOGENESIS?

Cancers arising in a variety of organs and tissues of the body are the principal late somatic effects of radiation exposure at low-dose levels (1). Organs and tissues appear to differ greatly in their susceptibility to cancer induction by radiation. Induction of leukemia by radiation stands out because of the natural rarity of the disease, the relative ease of its induction by radiation, and its short latent period. When the total risk of radiation-induced cancer is considered, however, it is now clear that the risk of induced solid tumors (such as breast, thyroid, and lung cancers) exceeds that of leukemia. This may not be the case for the fetus and embryo, however.

There is great uncertainty in regard to the shape of the dose-response relationships for cancer-induction by radiation, especially at low doses. Estimates of any excess cancer risk from radiation at low doses depend more on what is assumed about the mathematical form of the dose-response relationship than on the epidemiological or radiobiological data themselves. There is now emerging among radiation scientists some general agreement that estimating the cancer risk from low doses of low-LET radiation, such as x-rays and gamma rays, can be approached by using dose-response models that are felt to be consistent with the vast amount of epidemiological and radiobiological data. However, it is this uncertainty, probably more than any other, that is central to the controversy which has emerged over the potential health effects of low-level radiation exposure.

There is now considerable evidence from human studies that age, both at exposure to radiation and at appearance of cancer, and sex, are major determinants of radiation-induced cancer risk (1). Furthermore, there is increasing recognition of human genotypes that confer increased cancer risk after exposure to carcinogenic agents, including ionizing radiations.

However, we do not know the role of constitutional susceptibility to cancer-induction by environmental mutagens. Nor do we know the extent to which the cells and tissues of the body can and do repair sublethal radiation damage. We are aware that reduction in dose rate may decrease the observed radiation effect per unit dose, and that this dose rate effect affects the risk of cancer induction. This observation is well recognized in mammalian radiobiology, but the information available on man is insufficient to adjust estimation of risk for it.

There are a number of ways of deriving quantitative estimates of excess cancer risk from radiation (1-9). Among the most appropriate for epidemiological studies of exposed human populations is the relative risk model. The relative risk is a measure of the change in incidence of a disease caused by an etiologic agent in a population. It is the ratio of the risk in those persons exposed to the risk in those not exposed, or it is the ratio of the incidence of a disease, say, cancer, in the exposed population to the incidence in a suitable unirradiated control population.

In any task to estimate the carcinogenic risk of low-dose, low-LFT (i.e., x-rays and gamma rays) whole-body radiation, it must be recognized that the scientific basis for making such estimates, in spite of all that is known, remains inadequate. Accordingly, there is justifiable reason to place emphasis on the assumptions, procedures, and uncertainties involved in the estimation process, and not on specific numerical estimates. This is necessary, since it must be recognized that policy decisions and the exercise of regulatory authority require a position on the probable risks to health from low-dose radiation exposure. Since the epidemiological surveys on exposures to whole-body radiation at dose levels below 10 rads lack reliable data bases and dose-effect information to derive quantitative estimation of cancer risk with any certainty, it may be considered appropriate to limit such risk estimation to whole-body doses of 10 rads or higher. Thus, on the basis of the available epidemiological studies and extensive radiobiological data, for the lifetime risk of cancer mortality induced by low-LFT radiation from a single whole-body exposure to 10 rads, the estimate of increase in cancer risk is about 0.5% to 1.4% of the naturally-occurring cancer mortality (1). For example, if the naturally-occurring lifetime cancer risk is about 160,000 cases per million persons, in the general population, the rate is 16%. An increase in the

cancer rate due to radiation of 10 rads of whole-body exposure equal to 0.5% of the natural rate will result in an increase of 160,000 cases  $\times$  0.5%, or 800 cases--that is, 160,800 total cancer cases will occur. This now represents a cancer rate of 16.08% after radiation. For continuous lifetime exposure to 1 rad per year, the estimate of increase in cancer risk is about 3%-8%.

It is not known whether dose rates of x-rays or gamma rays of about 100 mrad per year, the range of natural background radiation, are detrimental to human health. Any somatic effects, if they do occur, at these dose rates would be masked by environmental or other competing factors--physical, chemical, or biological factors--that produce the same types of health effects as does ionizing radiation. It is unlikely that carcinogenic effects of doses of low-LET radiation administered at a dose rate of about 100 mrad per year will be demonstrable in the foreseeable future, indeed, if ever. The problem is, at the present time, too complex for our methods of epidemiology, radiobiology, and mathematics and statistics to decipher. However, for higher dose rates--e.g., a few rads per year over a long period--a discernible carcinogenic effect could become manifest in exposed human populations; and this appears relevant to problems of occupational exposure and the nuclear power industry.

#### WHAT DO WE KNOW ABOUT RADIATION TERATOGENESIS?

There is ample evidence from laboratory experiments, and to a limited extent in man, that the developmental effects of radiation in the embryo and fetus are strongly related to the gestational stage at which the radiation exposure occurs (1,11). Most information on such teratogenic effects is derived from laboratory animal studies, mainly from the laboratory mouse, but the human data are sufficient to indicate important qualitative correspondence for developmentally equivalent stages of embryogenesis in mouse and man. In laboratory animals, some developmental abnormalities have been observed at



dose levels just below 10 rads. The most extensive study available in the human experience is that of the atomic bomb data for Hiroshima, which show that the frequency of small head size was significantly increased by acute air doses in the range of 10-19 rads kerma (the average fetal dose would be the equivalent of about 10 rads of gamma radiation) received during the most sensitive period of gestation (11). At Hiroshima, about 20% of the radiation dose was from highly damaging neutron radiation. At Nagasaki, on the other hand, where almost the entire radiation was due to gamma rays, there was no significant increase in the frequency of small head size at air doses below 150 rads; the average fetal dose would have been about half of this value.

Because a given gross malformation or functional impairment probably results from damage to more than a single sensitive target, e.g., more than a single cell or a clone of cells with a common progenitor, we can predict that a threshold radiation dose exists below which that effect will not be observed. There is evidence of such dose thresholds for radiation-induced teratogenesis, but the dose levels vary widely depending on the developmental abnormality (1). Observed dose rate effects may also be the result of multitarget or multicellular causation of these developmental abnormalities; that is, cells can repair the damage either by intracellular mechanisms or cellular proliferation, provided the dose rate is low enough. Furthermore, protraction of the radiation dose over a long period can reduce the teratogenic effectiveness of any radiation dose by decreasing to below the threshold level the portion of the dose received during a particular radiosensitive period of gestation.

#### WHAT DO WE KNOW ABOUT OTHER SOMATIC EFFECTS OF RADIATION?

For somatic effects other than cancer and developmental abnormalities (e.g., cataracts, aging, and infertility), the available epidemiological and laboratory experimental data do not suggest any increased risk of low-dose

low-LET radiation exposure (i.e., x-rays and gamma rays) in human populations (1-9).

#### WHAT DO WE KNOW ABOUT RADIATION MUTAGENESIS?

Radiation-induced transmitted genetic effects have not been demonstrated in man, and it appears likely that adequate information on radiation-mutagenesis in man will not soon be forthcoming (1). Thus, estimation of the genetic risk of radiation must be based on laboratory animal data, and in recent years almost exclusively on laboratory mouse experiments. This necessarily entails the uncertainty of extrapolation from the laboratory mouse to man. However, there is information on the nature of the basic genetic lesions, which are believed to be similar in all organisms; and several physical and biological variables of radiation mutagenesis have been experimentally examined in considerable detail. For these reasons, some of the uncertainties arising in the evaluation of somatic risks--carcinogenesis and teratogenesis--are absent in the estimation of genetic risk.

The current estimate of the incidence of serious human disorders of genetic origin is about 10.7%, or about 107,000 cases per million liveborn offspring (1). Estimation of the genetic effects of radiation must take into account those which are expressed in the first generation, and those expressed in future generations at the time genetic equilibrium is reached and the effect is disseminated throughout the population. In the first generation, it is estimated that 1 rad of low-LET radiation exposure to the parents throughout the general population will result in an increase of about 5 to 75 additional serious genetic disorders per million liveborn offspring. Such an exposure of 1 rad received in each generation is estimated to result, at genetic equilibrium, in an increase of about 60 to 1,100 serious genetic disorders per million liveborn offspring (1). These wide ranges of risk estimates emphasize

the limitations of our current understanding of the genetic effects of radiation on human populations. However, even within this range of uncertainty, the genetic risk of radiation is nevertheless very small in relation to the naturally occurring 107,000 cases of serious human disorders of genetic origin, perhaps an increase due to radiation equal to much less than 0.1% of the natural rate.

#### HOW CAN WE APPLY THIS INFORMATION TO THE THREE MILE ISLAND EXPERIENCE?

The heightened concern over the health effects of low-level radiation has been closely linked to the political developments of nuclear proliferation and to the parallel commercial development of nuclear energy. There is no doubt that the events of the nuclear accident at Three Mile Island have added enormously to a public awareness of the potential health effects of low-level radiation. What happened at Three Mile Island? What were the radiation levels? And what are the health implications, the radiation health effects, to be expected in the population living in and around the area of Three Mile Island?

Under normal conditions, and in the absence of any additional nuclear radiation, the 2,163,000 persons living within a 50-mile radius surrounding Three Mile Island would each receive about 116 mrem year, or an annual collective dose (i.e., the average yearly dose summed up for the entire population) of about 440,000 person-rem; about 240,000 person-rem would come from natural background radiation. In contrast, the collective dose to that population resulting from the radioactive releases during the Three Mile Island nuclear accident was approximately 0.5% of the normal annual exposure rate, or about 1% of natural background radiation (12-14).

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 Three Mile Island experience, the population living within the 50-mile radius of the nuclear reactor site, approximately 2,163,000 persons, were included in the collective dose estimate calculations. Since this value is obtained by summing the estimated radiation doses, measured in rem, received by each person living within the affected area, the collective dose unit is the person-rem. The collective dose to all persons within a 50-mile radius of Three Mile Island during the first 10 days and outdoors based on the reliable thermoluminescent dosimetry available was estimated to be 2,800 person-rem. 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-rem. The average dose to any individual in the population living within 50 miles of the nuclear reactor plant, therefore, is estimated to be about 1 mrem (11). The average dose to an individual living within 10 miles of the plant is estimated to be about 6.5 mrem. Almost all recorded excess exposure above background levels occurred within a 10-mile radius. There was no recordable radiation at levels above natural background at a distance greater than 10 miles from the nuclear plant at any time during the accident. Thus, an average dose of 6.5 mrem to individuals living within 10 miles of the nuclear plant is about 5% of the exposure from natural background radiation annually in Harrisburg, Pennsylvania, and equivalent to that difference of living 2 weeks in Denver, Colorado. The average dose of about 1 mrem to individuals being within 50 miles of the nuclear plant is less than 1% of the exposure from natural background radiation annually in Harrisburg, and equivalent to the difference of living about four-and-a-half days in Denver (12,13).

What does this mean in regard to the estimation of the potential delayed or late health effects of low-level radiation exposure and the population exposed at Three Mile Island. There are three radiation health effects to consider--radiation-induced cancer, genetically-related ill-health, and developmental abnormalities in the newborn.

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 Three Mile Island nuclear plant and exposed to an average whole body dose of about 1 mrem is much less than 1, if any at all; a similar number could be estimated for excess non-fatal cancers (15). 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 (i.e., 325,000 fatal cancers and 216,000 non-fatal cancers). The estimated excess number of fatal and non-fatal cancers associated with the increase in radiation exposure due to the nuclear accident is extremely low, probably cannot be measured, and could be zero, and 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 did occur, and probably none will, would be so small that it would not be possible to detect such an increase statistically in over half a million cancers that would occur in the population even if the Three Mile Island accident had not happened (15). 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.

Based on this information, we can conclude, therefore, that since the total amount of radioactivity released during the nuclear reactor accident at Three Mile Island was so small, and the total population exposed so limited, that there may be no additional detectable cancers resulting from the radiation (15). If there are any additional cancer cases, however, the number would 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 Three Mile Island, who for other reasons will normally develop cancer during the course of their lifetimes.

There is persuasive scientific evidence which suggests that if an average human population were exposed to 1 rem (or 1,000 mrem) of irradiation during their reproductive life span when they can produce children, about 5 to 75 cases of additional genetically-related diseases (such as mental retardation or diabetes) might be expected in 1 million children born to the irradiated parents (1). Genetically-related ill-health is extremely common in humans under normal conditions; about 10.7% of all live births are affected. Therefore, the increase due to 1,000 mrem 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 1/1000th of 1 percent) of genetic disorders expected to develop in that newborn population.

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 nuclear power plant was estimated to be about 2,000 person-rem, with an average individual dose of about 1 mrem (14). In this population, assuming a 30-year generation time, we would normally expect about 3,000 cases of genetically-related ill-health among the approximately 29,000 live children born each year. These cases would occur in the absence

of any additional radiation exposure and would be unrelated to the radiation from the nuclear power plant accident. From an additional radiation dose of 1 mrem above natural background radiation resulting from the nuclear accident, we would expect about 0.0001 to about 0.002 (i.e., about 1/10,000th to 2/1000th) additional radiation-induced cases of genetically-related ill-health. This additional 2/1000th case is an average number and is miniscule, representing less than 1 in 10,000,000 live births. Furthermore, this may result ultimately in a total of no more than about 1 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 can 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 (15).

In the approximately 2,160,000 people who live within the 50-mile radius of Three Mile Island, it was estimated, based on vital statistics data, about 28,000 children were 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 Three Mile Island. The estimated average individual radiation dose (perhaps only 1/2 of 1 mrem) to the fetus of pregnant women exposed during the nuclear reactor accident 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, this estimated dose may still be too high, since many pregnant women left the area within the 5-mile vicinity of the nuclear plant. We can conclude, therefore, that no case of

developmental abnormality can be expected to occur in a newborn child as a result of radiation exposure of a pregnant woman from the accident at Three Mile Island (15).

#### WHAT WAS THE MAJOR HEALTH EFFECT OF THE THREE MILE ISLAND ACCIDENT?

Although no radiation health effects occurred during the nuclear accident, and probably no delayed or late radiation health effects are to be expected, what emerged from this experience was that the major health effect of the accident appears to have been on the mental health of the people living in the region of Three Mile Island and of the workers at the nuclear reactor plant (16). There was immediate, short-lived mental distress produced by the accident among certain groups of the general population living within 20 miles of Three Mile Island. The highest levels of distress were found among adults living within 5 miles of Three Mile Island, or with preschool children; and among teenagers living within 5 miles of Three Mile Island, with preschool siblings, or whose families left the area. Workers at the Three Mile Island nuclear plant experienced more distress than workers at the Peach Bottom nuclear plant in Pennsylvania which was studied for comparison purposes. This distress was higher among the nonsupervisory employees and continued in the months following the accident.

But, surprisingly, the main threat was not the fear of radiation exposure nor the dangers of radiation to health--not how one was threatened, but who was threatened. We have found, in all the behavioral studies, that the major measures of objective threat stemming from the accident were whether a person was living within or living outside the 5-mile radius of Three Mile Island; and 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 the Three Mile Island nuclear plant, rather than at the Peach Bottom plant, at the



time of the accident. For teenagers, an added measure of objective threat was whether their families left the area or not following the accident, because this was a factor outside the control of the teenagers themselves.

Demoralization is a term used 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. Such sources of intractable predicaments include, for example, situations of extreme environmental stress, such as combat or natural disasters, and physical illnesses, especially those that are chronic. Demoralization is something like an elevated temperature of the body; it tells us that there is something wrong, but it does not in itself tell us what is wrong.

Demoralization was sharply elevated immediately after the nuclear accident, but dissipated rapidly among most groups. A substantial minority, about 10% of the heads of households showed severe demoralization right after the accident that was directly attributable to the accident itself. The most demoralized persons were heads of households and teenagers living within 5 miles of Three Mile Island, 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 the Three Mile Island nuclear plant were high in comparison to the Peach Bottom nuclear plant workers, and in males in the general population, several months after the accident.

Although the perceived threat to physical health from the nuclear accident was higher in the general population immediately after the accident than later on, most people were considerably reassured by July. Workers at both the Three Mile Island and Peach Bottom plants also expressed a fairly low level of

concern about the threat of their work situation to their physical health. However, workers at the Three Mile Island plant were more uncertain about health effects than workers at Peach Bottom plant. Household heads living within 5 miles of Three Mile Island were more uncertain than those living outside the area. And mothers of preschool children in the Three Mile Island area felt more uncertain than mothers of preschool children in Wilkes-Barre, the city studied for comparison.

Feelings in the population within 20 miles of Three Mile Island 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 Three Mile Island, and by mothers of preschool children. The only group with somewhat negative attitudes was those at risk on two counts; the mothers of preschool children who lived within 5 miles of Three Mile Island.

Attitudes toward nuclear power and reactivation of the Three Mile Island nuclear power plants No. 1 and No. 2 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 Three Mile Island distrust of federal and state authorities and of the utilities was high immediately after the accident. Although it was somewhat lower in 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 the Three Mile Island and the Peach Bottom nuclear power plants, 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 the Three Mile Island and the Peach Bottom nuclear

plants 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 the workers at the Three Mile Island and Peach Bottom nuclear plants on these matters, neither of these findings contributes to understanding the basis for the elevated level of demoralization among the Three Mile Island nuclear workers that continued to be evident in August, 1979 and through September, 1979 when the study ended.

#### WHAT CAN WE CONCLUDE ON THE HEALTH EFFECTS OF THE ACCIDENT AT THREE MILE ISLAND?

Based on the best available dosimetric and demographic information, it is estimated that between March 28 and April 15, 1979 the collective dose resulting from the radioactivity released to the population living within a 50-mile radius of the Three Mile Island nuclear plant was approximately 2,000 person-rems. The estimated annual collective dose to this population from natural background radiation is about 240,000 person-rems. Thus, the increment of radiation dose to persons living within a 50-mile radius due to the accident was somewhat less than 1% of the annual natural background level. The average dose to a person living within 5 miles of the nuclear plant was calculated to be about 10 percent of annual background radiation and probably was less. The maximum estimated radiation dose received by any one individual in the general population (excluding the nuclear plant workers) during the accident was 70 mrem. On the basis of present scientific knowledge, the radiation doses received by the general population as a result of exposure to the radioactivity released during the accident were so small that there will be no detectable additional cases of cancer, developmental abnormalities, or genetic ill-health as a consequence of the nuclear reactor accident at Three Mile Island (15).

During the period from March 28 to June 30 three Three Mile Island nuclear workers received radiation doses of about 3 to 4 rem; these levels exceeded the Nuclear Regulatory Commission's maximum permissible quarterly dose of 3 rem (14). The process of cleanup and recovery presents a special situation with regard to potential health effects, since these activities present additional sources of possible radiation exposure to the nuclear workers and to the general population living in the area.

The major health effect of the accident at Three Mile Island was that of a pronounced demoralizing effect on the general population in the Three Mile Island area, including teenagers and mothers of preschool children and the nuclear plant workers (16). However, this effect proved transient in all groups studied except the nuclear workers, who continue to show relatively high levels of demoralization months after the accident. Moreover, the groups in the general population and the workers, in their different ways, have continuing problems of trust that stem directly from the Three Mile Island accident. For both the nuclear 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 nuclear accident at Three Mile Island.

But what have we learned about nuclear reactor safety and health from the experience of Three Mile Island? The present scientific evidence and the interpretation of the available human data from epidemiological surveys can draw very few firm conclusions on which to base scientific public health policy for protection standards for low-level radiation in the nuclear industry. However, even in the normal operation of nuclear reactor plants for the generation of electricity, based on the radiation risk estimates we have been able to ascertain with reasonable reliability, any lack of precision does not

minimize the need to limit radiation exposure in all societal activities involving ionizing radiations to levels at which the risk to health are acceptable. Nor does it minimize the conclusion that such risks to health are extremely small when compared with those available from alternative options, and those normally accepted by society as the hazards of everyday life.

But nuclear reactor accidents are not normal societal activities. Radiation is different. It is gratuitous and self-serving to conclude that more people die in coal-mining and oil-drilling accidents than in the nuclear energy activities. And it is not enough to conclude that no one died at Three Mile Island. The matters are complex and the solutions are elusive. When compared with the benefits that society has established as goals derived from the necessary activities of energy production, it is now both apparent and imperative that society must establish and maintain appropriate standards and seek appropriate procedures which continue to assure that its needs and services are met with the lowest possible risks, both to the individual and to society.

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I am indebted to my scientific colleagues who shared in the work of the President's Commission on the Accident at Three Mile Island and of the National Academy of Sciences-National Research Council Committee on the Biological Effects of Ionizing Radiations. It is from their labors that I have drawn freely for the preparation of this presentation.

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