**GPU Nuclear**

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November 21, 1984

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5211-84-2284

Mr. Harold Denton, Director
Office of Nuclear Reactor Regulation
Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Denton:

SUBJECT: DOCKET NO. 50-289 - BEYEA REPORT

As you know in August, 1984, a report entitled "A Review of Dose Assessments at Three Mile Island and Recommendations for Future Research," prepared by Dr. Jan Beyea, under contract with the TMI Public Health Fund, was made available to us. The GPU companies had nothing to do with the undertaking and preparation of the Beyea Report; however, it was referred to during a Commission meeting on TMI, and so I provided it to you.

We asked Drs. Jacob I. Fabrikant and Merril Eisenbud, two experts in the field, to advise us of their views with respect to the "Beyea Report." I enclose a copy of letters dated October 6 and October 7, 1984, to me and dated November 3, 1984, to Mr. Heward, GPUN Vice President, and of the attachments to those letters in response to our request.

It would not do justice to the comments of Drs. Fabrikant and Eisenbud for me to attempt to summarize their views, and I shall not do so. I do, however, suggest that they deserve careful study by you and your staff.

Sincerely,

P. R. Clark
P. R. Clark

PRC/agh

Enclosures

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GPU Nuclear Corporation is a subsidiary of General Public Utilities Corporation

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NOV 6 - 1989

November 3rd, 1984

Mr. Richard W. Heward, Jr., Vice President
Radiological and Environmental Controls
G P U Nuclear Corporation
100 Interpace Parkway
Parsippany, New Jersey 07054

Re: The 1984 Beyea Report

Dear Dick,

I am enclosing my written response to the August 15th, 1984 Beyea Report, as you requested. My response is both general and specific, but I have not attempted to take on the Beyea Report on a point-by-point basis. That would require a committee of scientific experts and a great deal of time and effort.

As my two letters to Phil Clark (enclosed) point out, Merril Eisenbud and I are in full agreement as regards what should be considered to be done, if anything. It would appear that the estensive investigations conducted by and the reports of the Nuclear Regulatory Commission, the Department of Energy, the Environmental Protection Agency, the Food and Drug Administration, the General Public Utilities, the President's Commission, and others, concerning the dosimetry of the accident at Three Mile Island, together with the implications for potential delayed health effects, are being questioned by the current Beyea Report. Therefore, in view of the circumstances, a special expert scientific committee knowledgeable in the nuclear aciences and engineering, radiation dosimetry, radiation epidemiology and statistics, and risk analysis and decision-making, should be assembled to examine all these key investigations, including the Beyea Report, and provide a comprehensive report and evaluation which will assess the credibility, validity, and degree of certainty associated with each of these investigations and reports.

There are at least three types of uncertainties which must be evaluated. (1) Uncertainties in data, arising from an inability to make very precise measurements, either because of inaccuracies in instruments or because of inherent variability in processes. (2) Uncertainties in assumptions and models used to analyze data. And (3) uncertainties that are intrinsically not estimable because important phenomena or principle have not yet been discovered.

It would appear that Governor Richard Thornburgh might best be in the position to request perhaps the National Academy of Sciences-National Research Council to appoint members to a committee responsible for the study and the report chosen for their special competences and with regard for appropriate balance.

continued...

Finally, Supplement No. 1 of the Beyea Report, dated October 1984, has just arrived on my desk, kindly sent by Mr. Thomas Murphy. Constraints on my time imposed by a very demanding schedule simply does not permit me an extended review and commentary before I leave for Washington, D.C. early on Tuesday morning, the 6th of November 1984, to join Messrs. Kuhns, Clark, Kintner, Fletcher, Rasmussen, et al at the Nuclear Regulatory Commission. However, a brief glance at Beyea's Supplement No. 1 provides no surprises, and suggests to me, at least, that my enclosed commentary on the August Beyea Report extends to the October Beyea Supplement.

I hope I have helped. Please keep me informed on the progress and the position of GPU concerning the Beyea Report. With all good wishes and with my warmest personal regards, I am

Very sincerely yours,

Jack

Jacob I. Fabrikant

JIF:ib
cc: Mr. Philip R. Clark
Mr. E. E. Kintner
Dr. James C. Fletcher
Dr. Merril Eisenbud

JACOB I. FABRIKANT, M.D., PH.D.

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October 6th, 1984

Mr. Philip R. Clark, President
G P U Nuclear Corporation
100 Interpace Parkway
Parsippany, New Jersey 07054

Re: The Beyea Report

Dear ~~Mr. Clark~~ Phil,

I have attached a brief statement concerning the findings and recommendations of the President's Commission on the Accident at Three Mile Island. The statement is based on the report of the Public Health and Safety Task Force; I have modified it from the original, which I wrote, and which I prepared for testimony before Congress.

The President's Commission reviewed, in great detail, the nuclear accident radiation dosimetry. Its assessment found sufficient scientific evidence for estimating with considerable precision the collective dose equivalent and average or individual doses to the general population and the workers. Accordingly, using epidemiological and statistical methods evolved over more than two decades by national and international scientific bodies concerned with radiation and health, and based on current and conservative radiation protection philosophy, the President's Commission could estimate quite reliably the potential delayed health effects in the general population and in the worker population of exposure to low levels of ionizing radiation released during the accident. The evidence compelled the conclusion that no detectable delayed health effects will occur in the general population, the worker population, or their progeny.

The recommendations of the President's Commission, therefore, were not directed to assessing potential delayed health effects in exposed populations in and around Three Mile Island, or in their progeny. On the contrary, since it was concluded that no detectable health effects will occur, the recommendations emphasized those general conditions that would have wide application to all potential nuclear accidents, viz., research, education, radiation monitoring and surveillance, and improved emergency planning and response by Federal, State, and local agencies.

The recently released August 15, 1984 Beyea Report appears to be in direct conflict with the findings and recommendations of the President's Commission on the Accident at Three Mile Island.

Very sincerely yours,

Jacob I. Fabrikant

JIF:ib

# BRIEF STATEMENT ON FINDINGS AND RECOMMENDATIONS OF THE PUBLIC HEALTH AND SAFETY TASK FORCE OF THE PRESIDENT'S COMMISSION ON THE ACCIDENT AT THREE MILE ISLAND

The President's Commission on the Accident at Three Mile Island estimated that between March 28th and April 15th, 1979, the collective dose of radiation resulting from the radioactivity released at TMI to more than 2 million people living within 50 miles of the nuclear plant was approximately 2,000 person-rem. This represented an average increase of about 1% of the natural background radiation level each person living in that area normally receives each year. Within 5 (10) miles, it was calculated to be an average increase of about 10% (5%) of the annual background radiation. On the basis of present scientific knowledge, the radiation doses received by the general population exposed during that period were so small that there will be no detectable additional cases of cancer, developmental abnormalities (i.e., birth defects) or genetically-related ill-health (i.e., inherited disease) as a consequence of the accident at Three Mile Island.

During the period from March 28th to June 30th, 1979 only, three out of approximately 1,000 workers were exposed to measurable low-level radiation received doses of 3 to 5 rem; these levels just exceeded the NRC maximum permissible quarterly dose of 3 rem.

The major health effect of the accident was on the mental health of the people living in the region of Three Mile Island and of the workers at the Three Mile Island nuclear plant. High levels of mental distress occurred in household heads living within 5 miles of TMI; mothers with pre-school age children; teenagers living within 5 miles of TMI, with pre-school age brothers or sisters and whose families left the area; and the workers at TMI.

The Commission recognized that although the radiation dose levels due to the accident were very low, nevertheless, not enough was known about the potential health effects of low-level radiation of a few rem or less. It therefore recommended increased emphasis on better coordinated and expanded health-related radiation effects research, particularly on the biological effects of low-level radiation, and on the development of methods of monitoring and surveillance, and of mitigating adverse health effects due to radiation. It further recommended educational programs for the public on how nuclear power plants operate, on radiation and its health effects, and on protective measures against radiation.

The Commission noted with concern that while Federal, State, and local agencies all responded to the emergency, there was, however, confusion over definition of responsibilities and a notable absence of designated authority responsible for protecting and insuring the public health and safety. Emergency plans were either incomplete or were not designed to meet the demands of a protracted crisis. Federal and State officials disagreed about the nature of the information on which to base emergency preparedness decisions, such as evacuation of vulnerable populations, and other protective actions during the emergency. The Commission therefore recommended that there be significant involvement by Federal and State health agencies into emergency planning and response to a nuclear reactor accident. Emergency plans must detail clearly and consistently the actions public officials and utilities should take in the event of a radiological emergency to protect the public health and safety. Specifically, they must insure the feasibility and effectiveness of evacuation plans, requirements for protective measures against radiation, adequacy of plans for enviornmental radiological monitoring, and adequacy and availability of health professionals and facilities for protecting public health and worker health and safety.

Jacob I. Fabrikant, M.D., Ph.D.
formerly, Director, Public Health and Safety
The President's Commission on the
Accident at Three Mile Island
October 3, 1984

**JACOB I. FABRIKANT, M.D., PH.D.**

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October 7th, 1984

Mr. Philip R. Clark, President
G P U Nuclear Corporation
100 Interpace Parkway
Parsippany, New Jersey 07054

Re: The Beyea Report

Dear ~~Mr. Clark~~ Phil,

I have enclosed a very rough working draft, prepared hurriedly for your review, that you may wish to use in part or completely to respond to the August 15, 1984 Beyea Report. It is written to serve as a framework only, but to have sufficient information for your staff to prepare a position paper for the public record. There is still much to do, particularly matters of verification, editing, corrections, and references cited.

The draft addresses three issues: (1) the findings of the President's Commission on the Accident at Three Mile Island, concerning the radiation dosimetry of the accident and the potential delayed health effects in the general population and the workers; (2) the krypton-85 venting dosimetry in June-July 1980 and its potential health effects; (3) the assessment of the Safety Advisory Board, TMI-2, of the NRC Supplement No. 1 to the PEIS concerning the worker collective dose equivalent during the TMI-2 recovery program. All three issues are a matter of record in the public sector.

These three areas are those addressed in the recently released August 15, 1984 Beyea Report. There are notable disagreements between the Beyea Report concerning dosimetry of the accident, the krypton venting to the atmosphere, and the worker collective dose equivalent during the recovery program, and the reports extant concerning these areas of investigation. These disagreements are particularly evident in the findings, the implications for potential delayed health effects, and the recommendations that flow from them.

At present, the Beyea Report appears at odds with the scientific evidence and the conclusions of investigations of recognized scientific bodies and groups who have been dealing with matters of radiation dosimetry and epidemiology at the national and international levels. Accordingly, GPU Nuclear Corporation may wish to chart a course of action that places on the public record---perhaps prior to the "Fund" meeting in Philadelphia in November---its own position concerning the Beyea Report.

Please keep me informed of any decisions in this matter, where they appear appropriate and I can assist. I am asking Dr. John Auxier to review the draft, to provide corrections and comments, and to pass them on to you. With my best wishes and with my kindest personal regards, I am

Very sincerely yours,

Jacob I. Fabrikant

JIF:ib
cc: Dr. John Auxier
Dr. James Fletcher

# AN ASSESSMENT OF THE AUGUST 15, 1984 BEYEA REPORT, "A REVIEW OF DOSE ASSESSMENTS AT THREE MILE ISLAND AND RECOMMENDATIONS FOR FUTURE RESEARCH", WITH SOME COMMENTS ON THE RADIATION DOSIMETRY OF THE ACCIDENT AT THREE MILE ISLAND, THE KRYPTON-85 VENTING FROM CONTAINMENT TO THE ATMOSPHERE, AND THE PROJECTED WORKER COLLECTIVE DOSE EQUIVALENT DURING THE TMI-2 RECOVERY PROGRAM

Jacob I. Fabrikant

November 1st, 1984

The following report is in five parts: (1) the radiation dosimetry of the accident at Three Mile Island derived from the 1979 President's Commission Report; (2) the estimation of the potential delayed health effects of the accident at Three Mile Island derived from the President's Commission Report; (3) the dosimetry and potential health effects of the releases of krypton-85 vented from the TMI-2 containment building in June-July, 1980; (4) the worker exposure experience during the clean-up of the damaged TMI-2 nuclear power plant; and (5) an assessment of the credibility, validity, and degree of certainty of the 1984 Beyea Report, "A Review of Dose Assessments at Three Mile Island and Recommendations for Future Research," by Jan Beyea, Principal Investigator, August 15, 1984.

## 1.0 Radiation Dosimetry of the Accident at Three Mile Island

### 1.1 The Radiation Doses During Normal Operating Conditions

Under Normal conditions, the 2,163,000 persons living in the 50-mile area surrounding Three Mile Island would receive an annual collective dose of about 440,000 person-rem; about 240,000 person-rem would come from natural background radiation, and the rest primarily from medical and dental radiation. The average dose-rate from natural background exposure to the individual living in the Harrisburg, Pennsylvania area is about 116 mrem per year. This comes primarily from cosmic radiation from outer space, terrestial radioactivity in the soil and in building materials, and the radioactivity within the human body.

Under normal operating conditions of the Three Mile Island Nuclear Generating Plant, based on the Final Environmental Statement, for the almost 2 million persons living in the 50-mile area, the radiation dose was estimated to be 31 person-rem per year whole-body collective dose, and 0.017 mrem per year average whole-body dose to the individual. From gaseous effluents from the Three Mile Island Plant these values were estimated to be 2.05 person-rem per year whole-body collective dose, and 0.0011 mrem per year average whole-body dose to the individual, respectively. Over a 30-year operation, the total collective dose predicted was 930 person-rem, and the individual dose was 0.51 mrem.

### 1.2 The Radiation Doses During the Accident at Three Mile Island

During the accident at Three Mile Island, considerable effort by Federal Agencies of the United States, and by foreign groups, went into the accurate assessment of the radiation exposures received by the general population living in south central Pennsylvania. There are quite accurate estimates of the collective radiation dose received by the approximately 2 million people residing within 50 miles of the Three Mile Island Nuclear Station resulting from the accident. The initial estimates were mainly for the period from March 28 through April 15, 1979, during which accidental releases occurred that resulted in exposure to the offsite population. These measurements are continuing to the present. Nuclear radiation doses were measured with instruments or detectors called thermoluminescent dosimeters (TLD). The principal dose estimates were based upon ground-level radiation measurements from thermoluminescent dosimeters located within 15 miles of the TMI site. These estimates assumed that the accumulated exposure recorded by the dosimeters was from gamma radiation (that is, penetrating radiation that contributes dose to the internal body organs). The data were obtained from dosimeters placed by Metropolitan Edison Company after the accident and covering the period to April 15, and from dosimeters placed by the Nuclear Regulatory Commission from noon of March 31 through the afternoon of April 7, 1979. Additional determinations provided by the Department of Energy using aerial monitoring that commenced about 4 p.m. on March 28, 1979 is also included. Further data were collected by the Environmental Protection Agency and the United States Public Health Service. There is also available equivalent accuracy on possible internal exposure doses received by ingestion or inhalation of radionuclides, particularly iodine-131.

### 1.2.1 TLD Measurements

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 instruments were located within a 15-mile distance of the plant. Radiation doses to individuals living 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 and 70 mrem. One person on a nearby island for 9 1/2 hours during the day of the accident received about 50 mrem. All other persons living outside a 1-mile radius and within 10 miles from the plant could have received an average dose of less than 20 mrem. Almost all recorded excess exposure above background levels occurred within a 10-mile radius. There was no recordable radiation levels above natural background at a distance greater than 10 miles from the nuclear plant at any time during the accident.

### 1.2.2 Radioactivity Released: Source Term

The total amount of radioactivity released into the atmosphere from the damaged power plant during the period of March 28 to April 15, 1979 was calculated to be about 2.4 million curies, primarily consisting of the radioactive noble gas xenon-133. Approximately 10-15 curies of radioactive iodine as iodine-131 was released into the environment. 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. (In recent reports there are references to 10,000 curies used by C. Berger in the 1980 ORNL Report. The number was "pulled out of the air" by W.K. Stratton as a source term to provide a value for comparing doses calculated by the relatively simple code used by C. Berger with the huge code used by J. Knox at LLNL. W.K. Stratton, and those associated with the effort, recognized that any value would do, but that a big number would provide good statistical results in less computer time. The 10,000 curies was never contemplated to be the real release. This is an example wherein the basis of the number can be misrepresented by those desirous of discrediting the TMI-II accident dosimetry.) This total release of radioactivity, known as the source term, was one way to determine the radiation dose to the entire population (collective dose) and to the individual in the population (average dose), taking into account meterological conditions and population distribution of the population at the time of the nuclear accident. Another way to determine the collective dose was by use of the TLD radiation dose measurements.

### 1.2.3 Collective Dose and Average Dose in the General Population

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 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 rem, received by each person in the affected area, the collective dose unit is the person-rem. The collective dose to all persons living within a 50-mile radius of TMI and outdoors based on the TLD radiation dosimetry was estimated to be about 2800 person-rem. Since most people spent a large amount of their time indoors and were therefore partially shielded by buildings, and since the radiation dose indoors was about three-quarters of that outdoors, a more accurate collective dose to this exposed population was estimated to be about 2000 person-rem. The average dose to any individual in the population living within 50 miles of the nuclear reactor, therefore, was estimated to be about 1 mrem. The average dose to an individual living within 10 miles of the plant was estimated to be about 1mrem. The average dose to an individual living within 10 miles of the plant was estimated to be about 6.5 mrem.

There were 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 mrem, this could 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 was that this dose was equivalent to the difference between annual background radiation exposure in Harrisburg, Pennsylvania and Denver, Colorado. An average dose of 6.5 mrem is about 5 percent of the exposure from natural background annually in Harrisburg, and equivalent to the difference of living 2 weeks in Denver. The 2 mrem average exposure to persons living within 50 miles of the nuclear reactor is far less than each person would receive over many years from color television, or about the exposure from cosmic radiation during a few round-trip transcontinental commercial jet airplane trips between San Francisco and Washington, D.C.

### 1.2.4 Internal Dose

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 it in, swallowing it, and absorbing it through the skin. This could result in an internal radiation dose to the tissues of the body. 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 air. The highest doses due to ingestion and inhalation of iodine-131 would occur in the thyroid gland, since iodine concentrates in that gland. However, whole body 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 to the lung, was only a small fraction of that of the external dose. Overall, the internal doses due to the radioisotopes released at Three Mile Island 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.

There has been criticism that the environmental monitoring done during the accident could have been inaccurate and incomplete. The President's

Commission reviewed all the available dosimetry with great care and in great detail and there was little doubt that the extensive environmental monitoring based on thermoluminescent dosimetry measurements and food sampling were adequate to characterize the nature and extent of the radionuclides released and the concentrations of radionuclides in those media. The measurements performed by the Department of Energy (aerial surveys), by the Metropolitan Edison Company, by the Nuclear Regulatory Commission (ground level dosimeters), by the Environmental Protection Agency, and by the Food and Drug Administration were extensive and sufficient to characterize the magnitude of the collective dose and therefore to assess and estimate any possible or potential long-term health effects (see below).

### 1.3 The Maximum Radiation Dose Received by an Individual

The maximum dose that an individual locatee offsite in the populated area could receive was less than 70 mrem. This estimate was based on the cumulative dose (83 mrem) recorded by an offsite dosimeter at 0.5 mile east-northeast of the nuclear reactor site and assumed that the individual remained outdoors at that location for the entire period from March 28 through April 15. The estimated dose could apply only to individuals in the immediate vicinity of the dosimeter site.

An individual was identified who had been on an island (Hill Island) 1.1 miles north-northwest of the site during a part of the period of higher exposure. The best estimate of the dose to this individual for the 9 1/2 hour period he was on Hill Island (March 28 to March 29, 1979) was about 50 mrem.

### 1.4 The Highest Radiation Doses Outside the Nuclear Plant

Some of the Metropolitan Edison Company TLDs located on or near the Three Mile Island Nuclear Station site during the first day of the accident recorded net cumulative doses as high as 1000 mrem. These recorded readings did not apply directly to any persons located offsite.

### 1.5 The Principal Radionuclides Released to the Environment

The principal radionuclides released to the environment were the radioactive xenons and iodine-131. Aerial survey measurements made by the Department of Energy in the environment, measurement of the contents of the waste gas tanks, of the gases in the containment Building and the actual gas released to the environment confirmed that the principal radionuclide released was xenon-133. Xenon-133 is a noble gas, is chemically nonreactive in the body, and does not persist in the environment after it disperses in the air. It has a short half-life of 5.3 days and produces both gamma and beta radiation. The risk to people from xenon-133 is primarily from external exposure to the gamma radiation.

### 1.6 The Beta Radiation Dose from Xenon-133

Beta radiation contributes to radiation dose in an individual by inhalation and by skin absorption. The total beta plus gamma radiation dose to the skin from xenon-133 is estimated to be about 4 times the dose to the internal body organs from gamma radiation. This contribution would be considerably decreased by clothing. The total beta plus gamma radiation dose to the lungs from inhalation of xenon-133 increased the dose to the lungs by 6 percent over that received by external gamma exposure.

### 1.7 Radionuclides Found in Milk and Food

Iodine-131 was detected in milk samples during the period March 31 through April 4, 1979. The maximum concentration measured in milk (41 mCi/liter in goat's milk, 35 pCi/liter in cow's milk) was 300 times lower than the level at which the Food and Drug Administration (FDA) would recommend that cows be removed from contaminated pasture. Cesium-137 was also detected in milk, but at concentrations expected from residual fallout from previous atmospheric atomic weapons testing, particularly the previous Chinese atomic weapons testing. No reactor-produced radioactivity was found in any of the 377 food samples collected between March 29 and April 30, 1979 by the Food and Drug Administration.

## 1.8 The Important Biological Differences Among the Different Radionuclides of a Nuclear Reactor Accident

### 1.8.1 The Noble Gases: Xenon and Krypton

Xenon-133 and krypton-85 are noble gases. Xenon-133 has a half-life of 5.3 days, and krypton-85, about 10.7 years. Other forms of these radionuclides include xenon-135 and krypton-84m, krypton-87, and krypton-88. Xenon-133 is among the isotopes having the largest radioactive inventories in the nuclear reactor core; krypton-85 is also present in large amounts. However, the noble gases are chemically and biologically inert. The noble gases rapidly diffuse through the atmosphere worldwide, and have very limited health effects. Xenon-133 and krypton-85 both emit beta and gamma radiation. The only health effect to be expected would be primarily through direct exposure to high levels to the skin from beta radiation.

### 1.8.2 Iodine

Iodine-131 (half-life, 8.1 days), cesium-137 (half-life, 30 years) and strontium-90 (half-life, 28 years) are also radionuclides in the nuclear reactor core which can be released in the event of a nuclear reactor accident. There are a number of radioisotopes of iodine, cesium, and strontium. These radionuclides, however, are all chemically active, and therefore biologically active, and they become incorporated in the body tissues at specific sites. Iodine is a functional part of the thyroid gland; iodine-131 when ingested or inhaled into the body, is transported by the blood stream directly to the thyroid gland, and is incorporated into the cells of the gland. The gland cannot differentiate between radioactive and non-radioactive iodine. Iodine-131 has a short half-life, but when fixed in the gland, its beta and gamma radiation can injure the cells of the gland, leading to diseases of the thyroid, including cancer.

### 1.8.3 Cesium

Cesium-137 disperses itself in the various tissues of the entire body, entering the water inside and around the cells. It is therefore most commonly found in the muscles of the body, which have the greatest amount of tissue bulk, as well as in the gonads. It emits primarily gamma radiation.

### 1.8.4 Strontium

Strontium-90 and strontium 89 (half-life, 52 days) have a special affinity for substituting for calcium in the body, and they are therefore readily found not only in the growing bones and teeth of young people, but also in the bones of adults. These primarily emit beta radiation. Thus, the tissues or organs that are irradiated include both bone and bone marrow, and can cause diseases of these tissues, including cancer.

## 2.0 Health Effects of the Accident at Three Mile Island

## 2.1 The Health Effects on the General Population Due to the Radiation Released During the Three Mile Island Nuclear Accident

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 Three Mile Island set off a series of events that raised the threat of risks to health of much higher levels of radiation exposure of the public to uncontrolled releases of radioactivity. Low-level ionizing radiations (e.g., radiation doses of a few rem 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 of fetus is exposed during pregnancy, sufficient radiation damage in developing cells and tissues may lead to developmental abnormalities of 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 effects. There are other health effects of ionizing radiations, but these three important health effects---carcinogenesis, teratogenesis, and genetic mutagenesis---stand out because it is possible that low levels of radiation may increase the risk of these delayed health effects. These 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.

## 2.2 Cancer

The estimated number of cancer cases from all causes normally occurring in the population living within 50 miles of Three Mile Island of about 2,163,000 people over their remaining lifetime is 541,000 (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 TMI nuclear accident based on a collective dose of 2000 person-rem to the population was extremely low, and could be zero, and it would not be possible to detect or to distinguish this 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 over more than half a million cancers that would occur in the population even if the Three Mile Island 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 additional radiation-induced risk of cancer due to beta radiation and internally-deposited radioisotopes were estimated to be extremely small, and may be regarded as encompassed within the cancer risk values expressed for whole-body radiation exposure. The conclusion, therefore, was that there may be no additional cancers resulting from the radiation released during the accident. If there are any additional cancer cases, however, 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 (in the 2 million population) living within a 50-mile radius of Three Mile Island, who would for other reasons develop cancer during the course of their lifetime.

### 2.3 Genetically-Related Ill-Health

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-rem, with an average individual dose of 1 mrem. In this population, assuming a 30 year generation time, there would be expected 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 1 mrem above natural background radiation, there would be expected about 0.0001 to about 0.002 additional radiation-induced cases of genetically-related ill-health, representing less than 1 in 10 million live births. This may result ultimately in no more than 1 additional case of genetically-related ill-health in 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 spontaneously-occurring (in the absence of any added radiation exposure) cases of genetically-related ill-health in each generation during all future human existence. The conclusion, therefore, was that 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.

### 2.4 Developmental Abnormalities of the Newborn

To the approximately 2 million people who live within a 50 mile radius of Three Mile Island, it was estimated that about 28,000 children would 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 was below any threshold dose level known to cause detectable cases of developmental abnormality in the human embryo of fetus. The conclusion was that no case of developmental abnormality may 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.

### 2.5 Behavioral Effects

The most important health effect of concern that occurred at Three Mile Island was not directly due to radiation exposure. This was the mental health andbehavioral effects on the general public and the nuclear power plant workers. Studies by the behavioral scientists of the President's Commission revealed significant mental health and behavioral effects both in the general population and in the workers. The Three Mile Island nuclear accident had a pronounced demoralizing effect on the general population living in the Three Mile Island area, including its teenagers and mothers of preschool-age children. However, this effect proved transient in all groups studied except the workers, who continued to show relatively high levels of demoralization four months after the accident. Moreover, the groups in the general population and the workers, in their different ways, had continuing problems of trust of authorities that stem directly from the nuclear accident. For both the workers and the general population, the mental health and behavioral effects were understandable in terms of the objective realities of the threats they faced during the accident at Three Mile Island.

## 3.0 Krypton-85

### 3.1 Preparatory Studies

The initial step of decontamination of the containment building was the removal of radioactive krypton-85 required for cleaning up after the accident. It was necessary to remove 44,000 Ci of krypton-85 from the containment building atmosphere to permit sufficiently safe conditions in the environment in which the recovery could proceed. Metropolitan Edison Company proposed a plan in November 1979 to remove the krypton-85 by venting it to the atmosphere under controlled conditions. This was followed by the Nuclear Regulatory Commission study submitted as an environmental impact study. Subsequently, Governor Thornburg of Pennsylvania had two studies carried out, one by the Union of Concerned Scientists, and the second by the National Council of Radiation Protection and Measurements, assessing the radiation dosimetry of krypton venting into the atmosphere, and hence, the potential delayed health effects. Hearings were held on methods and alternative approaches, such as cryogenic trapping. The extensive studies in preparation for the krypton venting to the atmosphere indicated that release under carefully defined and controlled conditions involving specific meterological conditions could be designed to achieve maximum atmospheric dispersion with minimum radiation exposure to the general population living within the vicinity of Three Mile Island.

### 3.2 Radiation Doses

The krypton-85 venting from the Containment Building to the atmosphere occurred during a two-week period, from June 28 to July 11, 1980. Over this period, measured radiation doses at all defined locations were substantially below projected doses derived from computer-generated models. The radiation dose to the population living in the immediate area was estimated to be 4.5 mrem to the skin and 0.0045 mrem whole-body dose. From cryogenic samples taken at 0.5 mile from the nuclear plant an actual integrated beta dose to the skin of about 1.8 mrem was computed; an integrated population collective dose equivalent to the whole-body (gamma dose) of less than 0.03 person-rem was also calculated. These doses were quite small, with no potential health impact to the general population or the workers. The venting made possible the decrease in radiation dose concentration within the containment building with which the workers would come in contact as they began to remove the radioactive waste water, i.e., a decrease in dose rate by about 200 rems per hour beta radiation to the skin, and about 1600 mrems per hour gamma radiation to the whole body.

## 4.0 Worker Exposure During the Clean-up of the Damaged Three Mile Island-2 Nuclear Power Plant

The Safety Advisory Board of TMI-2, was constituted early in 1980 to provide expert scientific, engineering, and medical advice for guidance for the safe clean-up and recovery of the damaged TMI-2 nuclear power plant. The scientific advisors reviewed the Nuclear Regulatory Commission's December 1983 draft of Supplement No. 1 to the Programmatic Environmental Impact Statement (PEIS) (NUREG 0683). The Safety Advisory Board of TMI-2 submitted a number of comments to the Nuclear Regulatory Commission concerning the Report in general, and Supplement No. 1 in particular.

### 4.1 Collective Dose Equivalentfor TMI-2 Workers

The range given in the PEIS Supplement No. 1 of the estimate of the collective dose equivalent for workers expected to occur in the course of the TMI-2 recovery operations of 13,000 to 46,000 person-rem appeared to represent a more realistic assessment than the estimates proposed in the original PEIS, particularly since so much more data on the status of the damaged plant were available. As the clean-up progresses, the ranges of uncertainties will narrow depending on the engineering technologies developed and applied to the tasks, and as additional data become available to define subsequent tasks. These will impact the proposed collective dose equivalent assigned to each subsequent of concurrent major activity. Thus, while the estimates proposed reflect the current status, it may be necessary to revise of at best narrow the range of estimates as the clean-up of the plant progresses safely to completion.

### 4.2 Potential Delayed Health Effects

The conservative estimates of potential delayed health effects by the Nuclear Regulatory Commission Staff were in accord with current scientific and medical knowledge, and were consonant with the methods of risk assessment used by the International Commission on Radiological Protection, the United Nations Scientific Committee on the Effects of Atomic Radiation, the National Council on Radiation Protection and Measurements, and the National Academy of Sciences-National Research Council. The Nuclear Regulatory Commission Staff estimates were statistically-derived numerical values and were conservative within the prudent philosophy of radiological protection of the workers and the general public. Based on current radiobiological knowledge and theory the numberical values could be considered as an upper bound, and the uncertainties associated with such risk estimates, derived by linear extrapolation from radioepidemiologic data at high doses, include the statistical probability that no delayed health effects could occur.

This information can be used as a basis for radiation protection guidance in the special situation of the TMI-2 clean-up; the guidance or standard should be related to risk. Whether the magnitude of the risk should be considered acceptable or not depends largely on how avoidable it is, and to the extent not avoidable, how it compares with the risks of alternative options and those normally accepted by the individual or by society in everyday life. Evaluation of the adequacy of an occupational health standard, regulation, or guideline must consider whether the potential incremental risk imposed is regarded as acceptable to the worker, both in the workplace and in his way of life. Such judgements are necessarily subjective; the currently proposed estimates of collective dose equivalent are believed to impose potential health risks to the workforce that should be acceptable to them, and to society in general, since the risks, in perspective, are extremely small in comparison to other risks that are now readily accepted.

### 4.3 Radiological Protection Data for the Clean-up, 1979-1983

Recently available radiological protection data for the clean-up, 1979-1983, indicated that during the five-year period since the accident, approximately 16,750 worker-years were involved in the clean-up process resulting in a collective dose equivalent of less than 1700 person-rem. Of the 16,750 worker-years, two-thirds recorded no measurable radiation exposure, and 85% involved doses of less than 0.1 rem per year, that is, less than the average annual whole-body dose received by all persons from natural sources of ionizing radiation. Moreover, a dose rate of 0.1 rem per year is considerably less than that received from all sources (including natural background radiation, medical and dental radiation, commercial air travel, etc.) other than occupational exposure.

Occupational exposure levels in the range of natural background radiation are considered to represent negligible risks to individual workers. For example, a dose rate of 0.1 rem per year is only one-fiftieth of the annual maximum permissible dose for occupational exposure recommended by national and international standard-setting bodies, including the Nuclear Regulatory Commission. The annual collective dose equivalent to the TMI-2 workers (1979-1983) consisted primarily of values considerably less than 0.1 rem. The risk of developing a delayed health effect, such as cancer, from a dose of 0.1 rem is considered to be about 1 in 100,000 (or about $10^{-4}$per rem) and this order of risk is generally considered by society as a negligible incremental risk to the individual.

The recorded radiation monitoring data demonstrated that approximately 96% of all TMI-2 clean-up workers received less than 0.5 rem per year, or less than 10% of the annual permissible dose. Of the remaining 4% of the worker-years of exposure, no worker received more than the maximum permissible dose. This record is an excellent achievement considering the immense engineering problems encountered and the unique nature of the work involved in the clean-up process.

## 4.4 Precision of Estimates of Delayed Health Effects

The Nuclear Regulatory Commission PEIS Supplement No. 1 determined that the revised estimates of worker exposure necessary for the clean-up process (range 13,000 to 46,000 person-rem for a population of some 10,000 workers) would result in "from 2 to 6 additional deaths among these workers due to cancer and from 3 to 12 additional genetic defects among their offspring." Over the entire period of the clean-up process, the dose commitments associated with the recovery will be no greater than those stated, and the numerical values for potential health risks estimated most likely represent an upper bound, and will be less. The statistically-derived values presented by the Nuclear Regulatory Commission Staff denoted a level or precision that was not warranted; while the estimates are conservative, they are also extremely small. Furthermore, the estimates must not be taken to represent more than crude estimates of risk, based on the incomplete nature of the data at present available.

Several factors, not taken into account in the calculation of those estimates, exist which compound the uncertainty of the members. First, the scientific evidence indicates, for experimental animal and human data, as well as theoretical considerations, that for exposure to low-LET radiation at low doses, the linear dose-response model probably leads to overestimates of the risk of most cancers, but can be used to define the upper limits of risk. Second, in these calculations, no allowance was made for the likelihood that the carcinogenic ormutagenic effectiveness of low-LET radiation was reduced at low dose rates through the action of biological repair processes. Third, the individual cancer risks used in the derivation of these numbers may rise of fall as the follow-up of the radioepidemiological study groups from which they are ultimately derived is extended to longer periods. Fourth, the risks have been derived for the most part at high total doses (which may have been sufficient to inactivate potentially susceptible cells from which a cancer might result), and linear extrapolation could tend to overestimate risk of low-LET radiation. Fifth, the numerical values of the risk estimates derived from radioepidemiological surveys are themselves crude and uncertain and often have wide statistical confidence limits. These uncertainties are made even wider by uncertainty about the dose-response relationship and the risk projection model.

However, the uncertainties tend in the main to emphasize the conservatism of the risk estimates as presented by the Nuclear Regulatory Commission Staff. This is clearly the situation where the linear hypothesis is applied and no allowance is made for biological repair processes; where age-distribution relative to potential reproductive performance is not considered; and where upper-bound uncertainties derived from high-dose and high dose-rate data and extrapolated to the region of low doses and low dose-rates tend to a multiplicative effect in the calculation of risk estimates. These overestimates may serve to offset any calculations that argue that these numbers reflect cancer deaths, and do not therefore represent the number of individuals affected, or that they are based on absolute risk projection models rather than relative risk projection models for predicting future risks to an exposed worker population. If expressed in terms of cancer incidence, including non-fatal cancers, estimates of risk could be higher by a factor of roughly 1.5 considering the predominance of men in the workforce. And whereas within a particular homogenous population the protection of future risk may probably best be done on a relative risk basis, as yet no firm conclusions can be drawn as to the appropriateness of either model for projection forward in time wihtout further years of observation of irradiated populations. However, the current evidence indicates that estimates of lifetime excess cancer risk may vary only by a factor of 2 or 3, depending on which projection model is chosen.

### 4.5 Other Reports of Record

Differing viewpoints may exist to those of the Nuclear Regulatory Commission which oppose the PEIS Supplement No. 1 in an effort to challenge the range of the calculated estimates of the worker collective dose equivalents or the potential delayed health effects that could occur. These positions are not unique to the clean-up of TMI-2, but rather tend to apply to many of the societal activities involving the use of ionizing radiation. Frequently these viewpoints are not predicated on sound scientific evidence, but rather on controversial or incomplete reports or personal statements, either that are in conflict with the preponderance of scientific evidence on radiation dosimetry or on existing methods for estimating the delayed health effects on populations of exposure to low levels of ionizing radiation. Several such reports have been published some recently, seeming to claim degrees of carcinogenic radiation effects at low doses in humans that would be incompatible with the linear hypothesis being conservative, and may even underestimate the effects at low doses and dose-rates. Many of these studies are limited due to incomplete data bases, inadequate dosimetry, confounding factors, unconventional statistical methods, or unconfirmed results. The situations individually or collectively are not convincing enough to argue against the conservatism associated with the linear hypothesis, nor do they provide evidence that the risk of cancer from low-dose radiation is greater than indicated by conventional estimates. These claims compel no scientific reason for national and international standard-setting groups to abandon the body of epidemiologic evidence on radiation-induced cancer that, although based on greater exposures, yields consistent and statistically stable risk estimates.

## 5.0 An Assessment of the 1984 Beyea Report

### 5.1 Introduction

Any evaluation which will assess the credibility, validity, and degree of certainty associated with the findings and conclusions of the 1984 Beyea Report can be misinterpreted depending, in large measure, on the position of the reader. Although undoubtedly other interpretations of these three concepts are reasonable, we see them as representing the following questions:

1. Credibility: Does the report as a whole portray to the scientific community a consistent, believable picture of the dosimetry of the accident and of our understanding of the risks of radiogenic cancer? Do the various assumptions required seem to fit together and relate easily to plausible mechanisms of the radiation releases, of the radiation exposures impacting the general population and workers, and of radiogenic cancer induction in exposed human populations?

2. Validity: Does the analysis of the radiation dosimetry conform with recorded data where it is possible to observe them? Do the cancer risk estimates in the Beyea Report conform with observed risks of radiogenic and nonradiogenic cancer where it is possible to observe them? Do any properties of the methods used seem to violate fundamental principles or empirical observations?

3. Degree of Certainty: How good are the numbers in the risk estimates in the Beyea Report? Are they biased in one direction or the other? What are the consequences of the likely differences between the true estimates and those estimated in the Beyea Report? Where do the uncertainties come from, and how could they be reduced? What are the uncertainties in the information needed to assess potential cancer risk estimates in the Beyea

Report?

The following is an overview assessment of the 1984 Beyea Report from the point of view of the radiation dosimetry of the accident at Three Mile Island, and the potential delayed or late health effects which could result in the general population and the worker population from exposure to the low level radiation releases at the time of the accident.

## 5.2 The Radiation Dosimetry of the Accident at Three Mile Island

Section 1 of this report provides a synopsis of the dosimetry of the accident at Three Mile Island. It is derived completely from the Staff Reports (see summaries, Appendix A and Appendix B) of the Health Physics Task Group of the Public Health and Safety Task Force Report of the Staff Reports to The President's Commission on the Accident at Three Mile Island. The "Summary of the Health Physics and Dosimetry Task Group Report" taken from the Reports of the Public Health andSafety Task Force is attached (Appendix A). On pages 8, 9, and 10, a number of important statements are made, e.g.,

- 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 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, primarily consisting of radioactive noble gases. 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 meterological 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.

- A more accurate collective dose to this (2,163,000 persons living within a 50-mile radius of the TMI stie) exposed population is estimated to be about 2,000 person-rems above normal background levels.
- Overall, the internal (radiation ) doses due to radioisotopes released at TMI were negligible, and would only have been a minute fraction of the average annual dose received due to naturally occurring, internally deposited radioisotopes in the body.
- The collective dose for these 1,000 (TMI) workers from the time of the accident on March 28, 1979, through June 30, 1979, was about 1,000 person-rems.

These findings were based on analyses of all available relevant and reliable data of record from the public and private sectors by August 31, 1979. The analyses were carried out by a team of six internationally known radiation physicists from national laboratories (from the United States and Canada) and University centers, in conjunction with 25 scientific colleagues, consultants, and advisors from the major national laboratories and universities in the United States and Great Britain.

### 5.3 The 1984 Beyea Report Criticisms of Reports of Record

The 1984 Beyea Report, with a team of six unknown (and with no university or research laboratory affiliations cited) persons attempts to criticize the President's Commission Report, and reports by the Nuclear Regulatory Commission, Department of Energy, Environmental Protection Agency, and scientific papers of record on the dosimetry of the accident at TMI. The Beyea Report states repeatedly that there are gaps in the published data and large uncertainties, and concludes that the missing data results in serious underestimates of the collective dose to the population. While these uncertainties could very well result in the conclusion that the doses were, as all studies concluded, extremely low, the Beyea Report prefers to conclude the contrary, viz., large radiation releases went undetected. By compounding uncertainties, preliminary assertions, and examples of data admittedly uncorroborated or unsubstantiated, Beyea concludes that all the low-dose estimates are incorrect, and all the high-dose estimates appear reasonable, if not correct.

The Beyea Report is not a scientific report on the dosimetry of the accident. On the contrary, it is an overt attempt to find the limitations---both ommissions and commissions---which lead to "official" estimates of doses of radiation released during the TMI accident. It demonstrates profound bias in failing to address the strengths of the methods, and the reliability and credibility of the observed or calculated data. The Report lacks scholarship, is poorly balanced, and is frequently pejorative. Statements made are incompletely referenced, and frequently not supported at all by the literature. Conclusions are drawn that are frequently uncritical.

The Report does not identify the faults in dosimetry estimates of the President's Commission Report, the Regovin Report, or others, but prefers to argue that the gaps in data were incorrectly reconstructed. It is clear, the Beyea group has difficulties with dosimetry terminology and units: it refers to"population doses" rather than the correct unit, "collective dose", and such uncritical terms and units "a 300-rem thyroid population dose" and a "delayed radiation dose" are used.

The President's Commission assessment of the radiation dosimetry of the accident at Three Mile Island is among the most complete and scholarly of all the reports extant. Its staff of scientists and expert consultants with access to the most extensive network of reliable scientific groups, methods and technologies in radiation dosimetry, demographic and dosimetric data, computational mathematics and computer sciences, both in the United States and abroad, insured the completion of a comprehensive and scholarly report to the Commission in a timely fashion. The 1984 Beyea Report places emphasis on uncritical remarks of the Commission's report, as it does on other official (NRC, DOE, Rogovin) reports, with unfounded and frequently pejorative statements, e.g., in its Introduction, p.1:

> "Because the major studies on the subject were undertaken in the months soon after the March 28, 1979 accident, and completed under considerable pressure for immediate findings and reassurances, it is not surprising that these official studies cannot provide complete, scientifically justifiable answers. Subsequent studies in the scientific and engineering literature have not resolved the residual uncertainties."

And further, on p.2:

> "On the contrary, the investigators reviewed in this (Beyea) study were found to have been extremely clever in using a combination of inference and science to extract information from limited data. Problems remain because a great deal of crucial data does not exist, or is unreliable. Researchers have been forced to replace the missing information with assumptions and to manipulate, as best they can, the unreliable data."

Such statements are unsupported, uncritical, unsubstantiated, and uncorroborated. They cannot, and should not, be considered scientific, credible, valid or reliable.

### 5.4 The Beyea Report and "Doses to the Whole Body"

The Beyea Report, in its Tables 1, 2, and 3 lists a number of reports, and concludes, "The TMI literature contains a substantial range of whole-body population dose estimates from the noble gases released in the initial accident---from 276 to 63,000 person-rem delivered to the general population within 50 miles (see Table 1, column 1). Such a divergence is sufficient to indicate the degree of uncertainty on the question." This statement is misleading and leads the reader to assume that there is a very wide spectrum of collective dose estimates, all troubled by great uncertainty. However, Beyea is uncritical and biased: he fails to point out that all the "official" estimates---the President's Commission, Lawrence Livermore National Laboratory, Oak Ridge National Laboratory, Environmental Protection Agency, Nuclear Regulatory Commission, Nuclear Safety Analysis Center (EPRI), and Woodyard (Pickard, Lowe, and Garrick, Inc.)---all fall roughly within 1 order of magnitude, a factor of 10. In view of the circumstances and data, this must be considered reliable and reproducible. However, Beyea dismisses this observation resulting from the nation's (and international) outstanding scientific communities, and scientific resources, as uncertain and displaying discordant results, in spite of the extensive scientific documentation extant.

On the other hand, two whole-body collective dose estimates, one by Takeshi and one by Kepford, 16,200 person-rems and 63,000 person-rems respectively, are not only given equal weight by Beyea, but are applauded as being more reliable, and are subsequently used to project health consequences or as a basis for future scientific research. Each estimate was derived by one man, whose scientific credentials are suspect, whose material has not been critically reviewed, nor published in the peer-reviewed literature, and who did not have access to the original data. Mr. Seo Takeshi is listed, on p. A45 as "associated with the Kyoto Nuclear Reactor Laboratory", and his reference is cited as: "S.Takeshi, "Excerpts from the author's review published in the Japanese journal Nuclear Engineering, Vol 26, No. 3," (unpublished mimeographed notes, Kyoto University Nuclear Reactor Laboratory, Kyoto, Japan, not dated)."

Mr. Chauncey Kepford is listed on the same page, as, "a nuclear critic, associated at the time with the Environmental Coalition on Nuclear Power," and his reference is cited, on the same page, as, "Chauncey Kepford, "Testimony before the NRC Atomic Safety and Licensing Board, August 20, 1979, in the matter of Public Service Electric & Gas Co., Salem Generating Station Unit #1, Dockett #50-272,"(1979)."

The conclusions are evident; Beyea has placed undue emphasis on two single-authored personal statements, uncritically reviewed, unsubstantiated and unpublished; one is undated and the other calculated and stated in August 1979, within perhaps 1 month of the availability of data on the dosimetry of the accident, and months before the "official" reports on the accident were completed and available. He has rejected the "official" reports as incomplete and unreliable, and therefore suspect.

## 5.5 The Beyea Report and the Radioiodine Releases

Perhaps no section of the Beyea Report is as confusing and redundant as is the inordinate emphasis placed on the radioiodine releases during the accident, and the unaccounted or "missing" radioiodine. Dr. Merril Eisenbud addresses the question directly and compels the conclusion that (1) if the excessive radioiodine was released, it would have been readily detected and accurately measured by the experienced governmental agency teams, (2) that whatever remained isnot "missing", but was contained and not released from the damaged core and has subsequently decayed, and (3) the 11,000,000 curies (still unaccounted for) was calculated from source term data and codes developed prior to the 1975 WASH-1400 Report, and which may very well be inaccurate and a considerable overestimate. Dr. Eisenbud's conclusions need no additional supportive evidence; his analysis is cogent and compelling (see Appendix C).

There is additional information now available that makes much of Beyea's analyses of the radioiodine releases irrelevant, and therefore spurious. This is the "Review of Recent Source Term Investigations", presented by William R. Stratton, Ph.D., formerly of the Los Alamos National Laboratory and chairman of the NRC Advisory Committee on Reactor Safeguards. The "Review" was presented in July 1984, and announces the forthcoming report of the American Nuclear Society's Special Committee on Source Terms. It is presently before the Nuclear Regulatory Commission for evaluation, and a committee of The American Physical Society is presently assessing its methodology and calculations.

In veiw of the present August 15, 1984 release of the 1984 Beyea Report, it is appropriate to quote directly from sections of the July 1984 Stratton ANS Report.

From page 1 of the Stratton ANS Report, concerning the complete ANS study:

> "This review is based largely on the study recently completed by the American Nuclear Society's Special Committee on Source Terms. committee members are: M Christian Devillers, France; M. Sergio Finzi, CEC (alternates, M. William Vinck, M. Anesto Della Loggia, M. Brian Tolley); Dr. Mario Fontana, U.S.A.; Mr. Michael Hayns, United Kingdom; Dr. Hans H. Hennies, F.R.G. (alternative, Mr. Peter Hosman); Dr. Herbert J.C. Kouts, U.S.A.; Mr. Saul Levine, U.S.A.; Dr. A.P. Malinauskas, U.S.A.; Mr. James F. Mallay, U.S.A.; Mr. Andrew Millunzi, U.S.A.; Mr. Masao Nozawa, Japan (alternate, Dr. Ryohei Kiyose); Dr. Walter Pasedag, U.S.A.; Mr. A. Schuerenkaemper, JRC-Euratom; Dr. Robert L. Seale, U.S.A. (Vice Chairman); Dr. William R. Stratton, U.S.A. (Chairman);

Dr. Richard C. Vogel, U.S.A.; Mr. Edward A. Warman, U.S.A. Individuals who contributed significantly to the report are: Mr. Andrew Pressesky, U.S.A.: Dr. Walton Rodger, U.S.A.; Dr. Thomas Kress, U.S.A.: Dr. Robert Burns, U.S.A."

From p.1, ABSTRACT:

"The state of knowledge relative to the evaluation of source terms subsequent to a severe reactor accident is examined. The following matters are assessed: the methods and assumptions used to describe fission product behaveior and retention associated with various phenomena, response of plant systems and structures, and a summary of source term results obtained by various investigators. These are compared to results quoted in WASH-1400."

From pp. 1 and 2, INTRODUCTION:

"The source term means that amount and type of radioactive materials which would be available for escape to the environment from a reactor which has undergone a severe accident. This is an accident in which fuel is damaged by overheating to the point of allowing substantial escape of fission products to the containment from the fuel and the containment may not have functioned adequately to prevent the escape of significant amounts of radioactivity to the environment.

Source terms have been recognized form the early days of nuclear energy development as the important factor of risk. Because the technology for making accurate and valid estimates of the source term was not available at that time, the conservative, non-mechanistic assumption was made that essentially all of the fission products could be released from a severely damaged reactor. This conservative assumption was later slightly modified and incorporated into regulations which are still in force at this time.

This early assumption and the subsequent regulations focussed on radioiodine as the principal substance of concern. This was because of its relative abundance, its high biological activity (iodine is known to concentrate in the thyroid), and its assumed elemental gaseous form, which provided ready transportability.

During the Three Mile Island accident in 1979, a surprisingly small amount of iodine escaped to the environment, contrary to expectations based on regulatory prescriptions. It was then theorized that the iodine, escaping from the fuel into a chemically reducing atmosphere (due to the presence of water and hydrogen) became an iodide, was readily dissolved in the water, and so became unavailable for escape. Thus, chemistry, which previously had been largely neglected, was seen to play an important role in severe accidents. Other aspects of severe accident considerations were identified at that time. As a result, large programs to investigate source terms, with the objective of providing a more realistic and accurate estimate, were undertaken by government agencies and industry, both in the U.S.and abroad.

The principal focus of this work was the analysis of severe accident sequences chosen because they represented the upper range of consequences and/or exemplified phenomena believed to be important in understanding the chemical and physicalprocesses that determine fission product behavior in severe accidents. This work is an extension of the methodology brought to a considerable stage of maturity by WASH-1400 (The Reactor Safety Study, 1975), an earlier effort to quantify the risk from nuclear energy.

The American Nuclear Society chartered the Special Committee on Source Terms to examine the state of knowledge relative to the source term, and the methods and assumptions used to describe fission product behavior and retention associated with various phenomena, plant systems, and structures in a severe reactor accident. The Committee was also to provide a summary of source term results obtained by various investigators, and to compare these data to those presented in WASH-1400.

The Committee recognized that both probability and consequences are intrinsic elements of risk; however, the Committee's charge included only an examination of consequences as predicted by analyses, and these only up to the point of potential escape of radioactivity to the environment. The probability of occurrence was examined in a general way to show that severe accidents are predicted to be exceedingly rare."

From p. 3, IMPORTANT RADIONUCLIDES:

"Typically, a large number of fission product species exist in the fuel in a nuclear reactor. Radionuclides escaping into the environment in the unlikely event of a severe reactor accident vary in their importance as to potential consequences. The factors determining the importance of a radionuclide in this regard are: 1) its total inventory in the reactor; 2) its physical and chemical properties which determine its behavior in the plant and the environment; and 3) its biological characteristics. Some of these factors are inherent, and others depend on feqtures of the accident and plant design; thus, the importance of a radionuclide depends to a significant extent on specific aspects of the hypothetical accident sequence being considered.

Radioiodine has long been and still is considered to be a very important radionuclide. However, it is clear that its treatment has been significantly over-conservative, and even historically incorrect. Other important radionuclides include cesium, tellurium, and, of much lesser importance, some of the alkaline earths and noble metals. Like iodine, the importance of cesium also has been previously overstated.

The noble gases, though very volatile, are chemically inert, and thus have a low importance in severe accidents."

From pp. 12 and 13, FINDINGS, OBSERVATIONS, AND RECOMMENDATIONS OF THE COMMITTEE

"Major Finding

The Committee has concluded that the state of knowledge and the analytical methods and assumptions on which current calculations of the source term are based have progressed far beyond those on which WASH-1400 (The Reactor Safety Study, 1975) was based. In general, an ample foundation has been provided to warrant reductions of the source term estimates in WASH-1400 by more than an order of magnitude to as much as several orders of magnitude. This major conclusion is based on reviews of chemical and physical processes relevant to severe accident analysis; severe accident sequences which bound risk from nuclear power plants and represent the ranges of phenomena involved; the status of severe accident modeling and calculational codes; containment capability; and the results of a number of source term studies performed both here and abroad. In addition, the committee has considered studies performed on its behalf of a number of important parameters and phenomena which had not previously been given adequate emphasis. The noble gases are exceptions because of their chemically inert character, and because they do not undergo the wide range of chemical and physical interactions which are the fundamental cause of the reduced release of most fission products; however, the very fact that they are inert also leads to low radiological consequences.

### Findings Supporting or Qualifying the Major Finding

a) Iodine will be released and transported predominantly as cesium iodide and cesium as cesium hydroxide. These species will form aerosols and be subject to aerosol depletion processes, are highly soluble in water, which will be present, and can be irreversibly adsorbed onto metal survaces, resulting in greatly reduced releases compared to WASH-1400. This finding holds for all light water reactors and all accident sequences.

b) The more severe accident sequences developed in WASH-1400 and more recent Probabilistic Risk Assessment studies provide a sufficiently complete basis for in-depth analyses of source terms. These sequences cover the high end of the release spectrum and involve the phenomena and processes that are considered to affect the escape and transport of fission products.

c) Sequences and plant details are important in estimating plant-specific source terms.

d) If there is no breach of containment, there is essentially no release of fission products; if containment breach is delayed more than a few hours after core degradation, the source term is greatly reduced, independent of the final size of containment breach. Containment is less susceptible to early breaching than previously believed.

e) A substantial basis exists for knowledgeable analysts to calculate LWR source terms with a high degree of confidence in the results."

In <u>conclusion</u>, the July 1984 Stratton ANS Report (American Nuclear Society's Special Committee on Source Terms" makes the August 1984 Bayea Report and its Appendices A through E obsolete, inaccurate, and irrelevant, thereby vitiating its credibility, its validity, and its certainties.

### 5.6 The 1984 Beyea Report and Health Impacts

On p. 2 of the Introduction, Beyea states: "It should be noted that this report does not critically examine the quantitative connection that is made in the TMI literature between radiation doses and projected health effects." Then, Section 6.9, pp 32 to 34, the Report provides a naive "A Summary of Health Impacts Described or Implicit in the Literature." Here, Beyea makes error after error in his approach, takes liberties with the established and conservative approaches of radiation protection philosophy and risk estimation, and tries to simplify, as he sees fit, a very complex scientific literature of cancer-induction in human populations exposed to low-level ionizing radiation.

Without justification, Beyea chooses as the upper-bound collective dose estimate of 63,000 person-rems (based soley on the Kepford testimony) to the general population of over 2 million persons living within 50 miles of Three Mile Island at the time of the accident, and based on the National Academy of Sciences-National Research Council's BEIR III Report, projects a maximum life-time cancer risk of 12.6 excess cancer deaths. He cites the President's Commission Report, the Rogovin Report, and Secretary Califano's press conference statement.

In two-and-a-half pages he makes numerous errors of fact, and by compounding uncertainties, preliminary assertions, and examples of data that Beyea admits to be uncorroborated and unsubstantiated, Beyea hypothesizes a very large estimate of excess cancer deaths from the radiation releases of the accident.

Some obvious errors are worth citing; however, the greatest error is his simplistic approach to a very complex science. For example, Beyea states: "Although uncertainty exists about such low-level radiation risks, the (National) Academy (of Sciences 1980 BEIR III Report) projects 0.6 to 2.0 delayed cancer deaths per 10,000 person-rem. That is incorrect. First, the cancer risk estimates for the President's Commission Report, the Rogovin Report, and Secretary Califano's statement were derived from the NAS 1972 BEIR-I Report, not from the 1980 BEIR III Report. The risk coefficients in the two reports are different.

Second, the BEIR-III Report does not present absolute risk estimates as probabilities per rad; rather, from p. 194 of the BEIR-III Report: "The final estimates are expressed as the numbers of excess cancers or of excess cancer deaths in an exposed population of 1 million people followed from the onset of exposure to the end of life. These numbers may also be expressed as percentages of the numbers of cancers normally expected for a population cohort of that size over the period under consideration and in the absence of the additional radiation exposure. Their expression per rad is generally avoided in the final tables, because it would suggest a commitment to the linear hypothesis that some members of the Committee wished to avoid, believing that the effect per rad is most probably variable, an increasing function of dose in the region from zero rads up to a point where cell-killing becomes important."

Third, Beyea cites "official dose-response coefficients" and "conventional dose/response coefficients" as the basis of his calculation. This is wrong. He probably means "age- and sex-specific regression coefficients or risk coefficients."

Fourth, even if he choses a collective dose of 63,000 person-rems for 2.3 million persons, the individual doses (average of 27 mrems) would still be too small to justify calculation. The BEIR-III Committee chose whole-body doses of 10 rads administered acutely, or 13 to 14 rads administered continuously (at 1 rad/yr for males and females, ages 50 to 65 years) as the lowest doses because "Below these doses, the uncertainties of extrapolation of risk were believed by some members of the (BEIR-III) Committee to be too great to justify calculation." (p. 144, BEIR-III Report) Furthermore, the Committee stated (p. 139) that "It is by no means clear whether dose rates of gamma or x-radiation of about 100 mrads/yr (of background radiation levels) are in any way detrimental to exposed people."

Fifth, the BEIR-III Report chose specific dose-increments for computation of excess cancer risk as follows: "Selection of dose increments for which cancer risk estimates are made was guided by existing maximal permissible dose limits, information on occupational exposure recorded in recent surveys (cf. Chapter III) concern for a hypothetical situation in which some part of the general population might be exposed to a single dose of 10 rads, and uncertainty as to whether a total dose of, say, 1 rad would have any effect at all." (p. 193, the 1980 BEIR-III Report.)

Therefore, the Beyea calculations based on BEIR-III risk coefficients that are not considered either age-or sex-specific regression coefficients, are spurious and irrelevant.

### 5.6.1. The Reasons Why the 1984 Beyea Report Calculations on Health Impacts are Spurious and Irrelevant

The 1984 Beyea Report attempts the estimation of carcinogenic risk from whole-body exposure to ionizing radiation released during the accident at Three Mile Island. In doing so, the report makes a number of assumptions concerning the latent period (or induction period), selection of a projection model (e.g., absolute risk or relative risk), and the need for adjusting for competing causes, as by life-table methods. However, the single assumption that weakens the position taken is the tissue doses absorbed resulting from the accident. In any scientific endeavor that attempts to organize information for a practical purpose, there are at least three types of uncertainties which the authors have failed to recognize: uncertainties in data; uncertainties in assumptions and models; and uncertainties that are intrinsically not estimable.

1. Uncertainties in data; these uncertainties arise from an inability to make very precise measurements, either because of inaccuracies in instruments or because of inherent variability in processes. The measurement or calculation of doses is an example of the former; counting the number of cancers in a cohort population exemplifies both uncertainties.

2. Uncertainties in assumptions and models used to analyze data. A model may fit the observed data in a narrow range, but could be substantially in error elsewhere, either because of inability to estimate risk coefficients precisely or misunderstandings about the nature of the physical, chemical, and biological processes involved. The models for projecting and extrapolating risks associated with radiation are all subject to such uncertainties.

3. Uncertainties that are intrinsically not estimable; these uncertainties arise because important phenomena or principles have not yet been discovered. For example, before the discovery that high-LET radiation was more damaging per unit dose than low-LET radiation, it might easily have been assumed without question that only the dose was important.

The 1984 Beyea Report assumes that the calculation of probability of cancer induction at low doses and low dose rates is a straight forward exercise of the application of simple formulae, taken, for example, from such reports as the National Research Council's 1980 BEIR-III Report. This is simply not the case.

There is a great deal more to the estimation of risk than size of the population at risk, time since exposure or latency interval, dose, and dose-response function. Other influential factors include demographic characteristics such as age and sex, quality of radiation, perhaps dose-rate, perhaps host factors that are yet to be identified, e.g., hormonal state, genetic make-up, immune competence, etc., and other enviornmental factors also yet to be identified, e.g., chemical carcinogens. In listing these factors we cannot ignore the problem of bias, such as may arise in the comparison of exposed and controls when ascertainment is incomplete or differs in its completeness. If ascertainment, i.e., the gathering of information on the events of interest, is equally incomplete in both the exposed and the control samples (or other source of expected values), relative risk estimates will not be affected, but absolute risk estimates will be reduced and by the degree of incompleteness. But if ascertainment is differentially incomplete, then both the relative and the absolute risk estimates will be biased. This we know is precisely the case at Three Mile Island, where large numbers of persons left the area during the first week of the accident. Thus, ascertainment is incomplete, the population at risk is smaller than previously considered, perhaps by a half or more, and the absolute risk estimates will be increased by the substantial degree of incompleteness.

It is important that estimates be sex-specific not only for tumors peculiar to one sex or the other, but also for leukemia, thyroid cancer, probably lung cancer, and perhaps other sites as well. Until we know more about the comparative performance of relative and absolute risk estimates weshould think that any site of cancer for which male and female incidence rates differ would require that estimates of risk be made in sex-specific fashion.

Age at exposure is being recognized as having a major influence on risk, but without our understanding why. In part its influence may reflect hormonal status or other physiological state dependent on age, as in breast cancer, or the time-dependent accumulation of tissue changes induced by cocarcinogens.

Quality of radiation has long been recognized as a major factor in the risk or radiogenic disease, and the related concepts of quality factor and relative biological effectiveness (RBE) are used in expressing risk estimates in rems rather than rads. Unfortunately, there are only very approximate estimates of the RBE ratios for radiation of various qualities and for different end-points.

Dose-rate becomes important if we are using high dose and high dose-rate data to estimate low dose and low dose-rate effects, as the BEIR III Committee has done in relying on the experience of the A-Bomb survivors. At Three Mile Island, the ameliorating effect of dose-reduction due to protection of dose administered at low dose rate would serve to reduce the risk estimates substantially. Although the BEIR III Committee reached the conclusion that the dose-rate effect on human tumor incidence was too uncertain to justify a quantitative adjustment for its magnitude, committee 40, working concurrently on NCRP Report #64, decided to recommend a reduction factor of between 2 and 10 when high dose and high dose-rate observations are used with a linear dose-response function to estimate low dose and low dose-rate effects of low-LET radiation. The UNSCEAR 1977 Report used a factor of 2.

With respect to host factors other than age and sex, and carcinogens other than radiation, little can be said except that investigators reporting their results, and those who depend on those results, should be aware of the possibility that such factors may be present and may influence the results in some unexpected way. This might come about because of host or environmental factors that interact with radiation to exaggerate or minimize the effect of radiation, or because of some characteristic associated with exposure to radiation that independently affects the normal expectation of teh effect under study.

Other factors influencing estimates of radiogenic risk are inherent in the various limitations of the underlying observations, e.g., their precision as to diagnosis and dose, but such factors are not peculiar to the estimation of radiogenic risks. A related point concerns the translation of external dose to tissue dose. If comparable estimates are to be obtained from different human series, reliable tissue-dose estimates must be available. During the Three Mile Island Nuclear accident, estimates of external doses indicated that only extremely low-level exposure could have impacted a small population during the initial days of the accident. When transformed to tissue doses, for the majority of the population that could have been potentially exposed, the actual absorbed doses would prove to be negligible tissue doses.

Some reference should be made to specific statistical methods. In statistics we regard risk estimates as members of a larger set, perhaps an infinite set, of similar estimates and we have ways of placing them within a specific range of values with a pre-determined level of confidence that, it we could repeat indefinitely the experiment or survey leading to the estimate, the proportion of such estimates lying within the specified range, or confidence interval, would correspond to the pre-determined level of confidence. Thus we calculate, for example, 95 percent confidence intervals, or 80 percent confidence intervals, at will, and these estimates are often the most useful ones we can make, far more informative than estimates that do not carry a measure of their inherent variability. When factors other than numbers of subjects and events, time following exposure and dose must be taken into account, as is usually the case, they must be adjusted for in some fashion or other.

The 1984 Beyea Report fails to recognize that its concern with uncertainties regarding very low doses following the Three Mile Island Accident precludes estimation of the carcinogenic risk to the exposed populations. In studies of animal or human populations, the shape of a dose-response relationship at low doses may be practically impossible to ascertain statistically. This is because the sample sizes required to estimate or test a small absolute cancer excess are extremely large; specifically, the required sample sizes are approximately inversely proportional to the square of the excesses. For example, if the excess is truly proportional to dose and if 1,000 exposed and 1,000 control subjects are required to test the cancer excess adequately for 100 rads, then about 100,000 in each group are required for 10 rads; and about 10,000,000 in each group are required for 1 rad. Thus, risk coefficients based on a knowledge of dose-response relationships can never be estimated for the dose ranges of concern at Three Mile Island.

The BEIR Committee of the National Research Council concluded that it is not known whether dose rates of gamma or x-rays of about 100 mrads/yr are detrimental to man. Any somatic effects at these dose rates would be masked by environmental or other 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 this dose rate will be demonstrable in the foreseeable future. For higher dose rates, e.g., a few rads per year over a long period i.e., far in excess of the levels determined during the Three Mile Island accident-a discernible carcinogenic effect could become manifest.

Furthermore, the 1984 Beyea Report assumes that the precision of such cancer risk coefficients as estimated in the BEIR-III Report are precise and certain. However, it failed to recognize that the BEIR-III Committee's most difficult task has been to estimate the carcinogenic risk of low-dose, low-LET, whole-body radiation. BEIR-III recognized that the scientific basis for making such estimates is inadequate, but it also recognized that policy decisions and the exercise of regulatory authority require a position on the probable cancer risk from low-dose, low-LET radiation. Accordingly, the Committee decided that emphasis should be placed on the assumptions, procedures, and uncertainties involved in the estimation process, and not on specific numerical estimates.

In other words, the BEIR-III Committee recognizes that policy decisions cannot be reached or regulatory authority exercised without someone's taking a position on the probable cancer risk associated with such radiation. Because critical analysis of the different data bases disclosed major inadequacies, however, the Committee decided to emphasize the assumptions, procedures, and uncertainties involved in the estimation process, and not specific numerical estimates. The variety of mathematical functions that could be used to express dose-response relationships reflects additional uncertainty. Therefore, the Committee concluded that the best method of expressing the range of uncertainty associated with these problems would be to present an envelope of risk estimates.

The probabilities of cancer induction following exposure to low-dose radiation presents formidable problems. Even for its illustrative computations of the lifetime risk from whole-body exposure, the Committee chose three situations: a single exposure of a representative (life-table) population to 10 rads; a continuous, lifetime exposure of a representative (life-table) population to 1 rad/yr, and an exposure to 1 rad/yr over several age intervals exemplifying conditions of occupational exposure. The three exposure situations do not reflect any circumstances that would normally occur, but embrace the areas of concern-general population and occupational exposure and single and continuous exposure. Below these doses, the uncertainties of extrapolation of risk were believed by some members of the Committee to be too great to justify calculation. Thus, the uncertainties were considered too great to justify calculation of risk below dose levels of 10 rads (whole body) administered acutely or about 75 rads (whole body) administered chronically over a lifetime.

And finally, any attempt to use epidemiological surveys that challenge the conservatism of the linear hypothesis for low-LET radiation exposure would be fraught with failure.

Studies by a number of scientists who have claimed a greater carcinogenic effect due to exposure to low-dose ionizing radiation than generally accepted are reviewed in detail in Appendix B of the BEIR-III Report. None of these studies was considered by the Committee to constitute reliable evidence at present for use in risk estimation, for various reasons, including inadequate sample size in some instances, inadequate statistical analysis, and unconfirmed results. Published criticisms of these various study findings have suggested alternative explanations for the observed dose associations, including confounding of radiation exposure with exposures to other carcinogens and inadequate dosimetry. In some instances, only further study can determine the validity of these suggestions. Further followup of the studies of nuclear workers, for example, workers and of other groups occupationally exposed to similar quantities of highly fractionated radiation may eventually tell us whether the risks and the spectrum of affected cancer sites differ markedly from what would be expected from studies of more heavily exposed populations. At present, however, there seems to be no reason to abandon the body of epidemiologic evidence on radiation-induced cancer that, although based on greater exposures, yields consistent and statistically stable estimates.

### 5.7 The Krypton-85 Releases

The Beyea Report addresses the June-July 1980 venting of noble gases from TMI-2 containment only occasionally and indirectly. Section 3.0 of this analysis provides the currently known information correctly.

### 5.8 The Beyea Report Appendix F: A Review of the Cleanup of Three Mile Island Unit 2.

The Beyea Report, in this section, demonstrates a naive approach to a very complex problem. This section, prepared by one private consultant and a part-time graduate student provides "too little, too late." Not only was there an interim NRC NUREG-0683 Supplement No. 1 draft report PEIS dealing with the occupational radiation dose available in February 1984 before the release of the August 15, 1984 Beyea Report, but the Final Report, NUREG-9683, Supplement No. 1, PEIS is available at the beginning of October 1984. While the Beyea Report recognized that this made its Appendix F outdated and irrelevant it nevertheless published it as part of its own report. The response of this review to the Draft Report, and hence to the Beyea Report is included as Section 4.0 (supra), and is included (on pp. A26-A29) of NRC's NUREG-9683, Supplement No. 1, Final Report.

## CONCLUSIONS

It would be redundant and time-consuming to review and criticize in detail the 1984 Beyea Report section-by-section. That is not the purpose of this review. The illustrations outlined are sufficient to respond to my introductory remarks concerning an assessment of the credibility, validity, and the degree of certainty associated with the findings and conclusions of the 1984 Beyea Report.

1. Credibility. The evidence is that the Beyea Report as a whole does not portray to the scientific community a consistent, believeable picture of the dosimetry of the accident and of our scientific and medical understanding of radiogenic cancer. The various assumptions required do not seem to fit together and relate easily to plausible mechanisms of the radiation releases, the radiation doses, or of radiogenic cancer in exposed human populations.

2. Validity. The analysis of the radiation dosimetry in the Beyea Report does not conform with recorded data where it is possible to observe them. The cancer risk estimates in the Beyea Report do not conform with observed risks of radiogenic and nonradiogenic cancer where it is possible to observe them. In the Beyea Report, the properties of the methods used clearly violate fundamental principles and empirical observations.

3. Degree of Certainty. The doses estimated and the cancer risk estimates supported by the Beyea Report are uncertain at best and unreliable and unsubstantiated assertions at worst. They are biased in the most conservative direction only---to high doses and high mortality estimates---without considering the preponderance of the scientific evidence. By compounding these uncertainties, preliminary assertions, and examples

of data that Beyea admits to be uncorroborated and unsubstantiated, the Beyea Report attempts to conclude that the dosimetry has been inadequate and analys s misguided and incorrect, and that the implications for delayed health effects would be much greater numbers of cancers in the general population. On this basis, by simply declaring that much research must be done to reduce these uncertainties, Beyea proposes a series of research projects, most of which appear irrelevant, unnecessary, and frequently trivial. In areas where research has been needed, e.g., source term investigations and the dosimetry of the cleanup of TMI-2, much has already been done by competent scientists, has been published, and has become available. This makes the 1984 Beyea Report obsolete <u>before</u> the meetings planned to discuss it can take place, thereby invalidating it and discrediting its findings and conclusions.

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November 1, 1984

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APPENDIX A

# REPORT OF THE
# PUBLIC HEALTH AND SAFETY TASK FORCE

ON

# HEALTH PHYSICS AND DOSIMETRY

BY

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# 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.

APPENDIX B

# REPORT OF THE
# PUBLIC HEALTH AND SAFETY TASK FORCE

ON

# PUBLIC HEALTH AND SAFETY SUMMARY

BY

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# 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 TMI 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 air. 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 TMI 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 tential 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.

### Comments by Merril Eisenbud on "A Review of Dose Assessments at Three Mile Island and Recommendations for Future Research," by Jan Beyea, dated August 15, 1984

On page 15, the statement is made that "There is evidence in the literature that the original TLD's left significant angular gaps through which bursts of radioactivity might have passed entirely undetected or only partially detected." This is an uncritical statement. They don't document the evidence except by reference to the Thomas report (AIF/NESP-023) from which they have taken their Figure 1 on page 16. The figure they present is for stability Class F (moderately stable) which was not typical of conditions that existed during most of the accident. This part of their argument requires critical review by somebody more familiar with the post-accident meteorology. I would think that Pickard, Lowe, and Garrick would have the information right at their fingertips.

Para. 3.2, Doses from Radioiodine: The amount of iodine released is very important and has been thoroughly investigated. The Beyea report tries to cast doubt on the validity of the estimates but it succeeds only by innuendo and not with hard facts.

The subject is discussed extensively in Appendix C, which starts out by saying there are three "major puzzles associated with the behavior of radioiodine at Three Mile Island."

The first puzzle presented is that 11 million curies of the core's radioiodine inventory is unaccounted for. But if even a small fraction of the radioiodine escaped, it would be easily detectable by a variety of means. Only 20,000 curies escaped during the Windscale accident in

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1957, and except for a minor amount of cesium, no other radionuclide was deposited downwind of the Windscale reactor. As a result of that accident, there were large downwind areas in which the gamma radiation levels due to I-131 deposition were in excess of 150 μr, which is about 20 times normal. The milk in these areas contained radioiodine in concentrations greater than 500,000 pCi/liter.

In the post-accident gamma surveys around TMI, a 20% increase could have been easily detected. Assuming the relationship between the source strength and deposition were comparable at Windscale and TMI (though only to a first approximation), a 20% increase in the gamma background at TMI would have been attributable to a release of 200 curies. If you think it worthwhile, this approximation can be refined by taking micrometeorological factors into consideration. Beyea (page C-39) uses Windscale in a similar way and estimates that the TMI emission was actually 4 Ci! All things seem to point in the right direction: I-131 in grass, human measurements, etc. lead one to conclude the I-131 release was miniscule.

One would not expect to see an elevation in the gamma background unless the emission was more than 10 times higher than estimated. It is not "puzzling" that most of the radioiodine inventory is unaccounted for: it remained within the reactor building and has long since decayed.

We learned from the Windscale accident that when radioiodine is released in quantities significant to health, it can be readily detected not only by the increase in ambient gamma radiation, but also by high concentrations of radioiodine in grass and cow's milk, as well as human thyroids.

Incidentally, one cow we were monitoring in Pennsylvania after a Chinese weapons test in 1980 delivered milk containing 1000 pCi/liter! In the early 1960's, the milk from some of major eastern milksheds frequently contained radioiodine in concentrations greater than 100 pCi/liter during periods of many days. The methods for radioiodine detection are very sensitive and, when present, it is one of the easiest radionuclides to find in the environment.

The lengthy discussion in Appendix C of the various pathways by which radioiodine may have escaped is of no importance insofar as public health is concerned. Had the I-131 escaped in significant quantities, it would have been detected in the environment.

On page C-27, they propose a search for residual I-129 in the reactor building. One of the problems is that the reactor operated for such a short period of time that there was very little build-up of I-129. In any case, I doubt that the sampling and analytical methods would permit developing useful information. A basic problem is that it would be necessary to obtain a small number by subtracting two large numbers (the I-129 estimated to have been present originally, and the 129 estimated to be present at the time of measurement). This is always a risky procedure where one or both of the large numbers are subject to uncertainty.

The second "puzzle" identified in the report is that airborne radioactivity, inferred from milk measurements, is much higher than the amount inferred from other environmental measurements. It is proposed that there be research to reconcile the data. What's the point of all this? Surely we want to improve our I-131 models, and perhaps some of the information that could be obtained will be useful from this point of view, although I doubt it. If the milk concentrations were lower than expected, then people received lower doses. They make reference to the peak concentration of 900 pCi/m$^2$ on April 15. They then use the Windscale information and conclude that if the radioiodine at TMI behaved the way the Windscale iodine behaved, the TMI release would be 4 Ci, "number which is not wildly inconsistent with the official TMI estimate of 15 Ci." As a matter of fact, all things considered, it is excellent agreement and shows that the TMI estimate of 15 Ci was arrived at in a conservative manner.

The third "major puzzle" is that it is not clear what percentage of the radioiodine was organic. I don't see what difference this would make. The iodine retention system might be less efficient for methylated I-131, but once it entered the environment it should behave the same. My recollection is that the various biological uptake factors are no different for organic iodine than they are for inorganic. This, however, should be checked by someone.

The discussion of radioiodine then goes on to comment on measurements that were made of voles. Some may find this interesting radioecology, but I don't see how the information can affect the estimates of the doses received by people. This is also true of measurements made in rabbits, goats and sheep.

The review of the cow's milk studies, beginning on page C-51, is mainly concerned with the question of whether the cows absorbed radioiodine from the air or from grass. I don't think it matters as long as the milk concentrations assure that the dose to children's thyroids, even with the assumption of the highest radioiodine concentrations in milk, were less than about 10 mrem. This is brought out very well in the report of the Ad Hoc Population Dose Assessment group (Battist, 1979).

I have even more trouble understanding Beyea's reasoning concerning radiocesium. Considering the fact that so little radioiodine was emitted, I don't understand why anyone would suspect that cesium-137 would be a problem. The xenons have short half-lives and blow out of the area in a matter of hours after release. I-131 has a 8-day half-life, so that measurements might be possible for many days after the accident. Cesium-137, with its 30-year half-life, remains near the surface of soils for long periods of time and can be measured easily. Most of the background described by Beyea as being due to residual fallout from nuclear weapons tests has been in the soil since 1962! On the other hand, as pointed out by Beyea, Cs-134 with a 2.1-year half-life is associated with the cesium-137 and can be used to differentiate fallout from reactors and weapons because Cs-137 is not present in weapons fallout. The amount of cesium-137 reported (100 nCi/m$^2$) is consistent with what would be expected to be present from weapons fallout and the absence of cesium-134 can be taken as a definite indication that there was no contamination by reactor material.

On page 23, Beyea says "In the absence of confirmation of this presumption (which could have been checked by testing for the ratio of cesium-134 to cesium-137), it is not scientifically valid to conclude that no radiocesium from the accident was present." The DOE Environmental Measurements Laboratory is highly skilled in cesium measurements and found no cesium-134 and reported their findings to the EPA. I have not had an opportunity to check this in the EPA report, but the information comes from Harold Beck at EML, who made the measurements. Beyea should have known that these measurements were made.

On page 57 the report "assumes" that 25% of the measured cesium contamination (25 $nCi/m^2$) could have originated from the accident. This is not possible because cesium-134 was not detected.

Beyea's general conclusion, given in the second paragraph on page 25, is that "For all these reasons, it appears that the official estimates for whole-body and thyroid population doses should not be regarded as final at this time. Such a statement is not meant to imply that, in fact, the official dose estimates have been proven wrong, but only to judge that much greater uncertainty than heretofore acknowledged should have been assigned to the doses delivered to the population and, as a result, to the estimated health effects projected from the doses." I believe the GPU position should be: 1) that the dose estimates were made by some of the best teams in the country, operating independently, and that they agreed within a reasonable factor; and 2) that the uncertainty in the dose estimates is well within the uncertainties accepted by public health authorities in risk assessment when low levels of risk are involved. The highest credible estimates place the individual population doses at less than would be received by the population due to natural sources of radiation in one year.

The report suggests that the Public Health Fund should support a comprehensive research program to improve the dosimetry. In support of their recommendations, the report states on page 29 "It has already become clear from this preliminary study of the dosimetry that in order to minimize radioiodine in milk, not only should cows be kept indoors after a release of radioactivity and kept from grazing, but they should be shifted to feed that has been stored indoors or brought from distant locations..." Here the author displays his ignorance of the subject. The Federal Radiation Council discussed countermeasures against I-131 in its reports in the early 1960's, and identified all of the options mentioned by Beyea. The FRC recommendations were at that time incorporated into state emergency plans to deal with contamination of the milksheds by I-131. This subject is also covered in the 1977 report by NCRP, "Protection of the Thyroid Gland in the Event of Releases of Radioiodine."

In Section 6 the report considers the health impacts of the Three Mile Island accident and states "The conversion of population dose to health impacts for low-level radiation is conventionally accomplished by applying dose response estimates research and published by the National Academy of Sciences." The report then goes on to give the range of risk coefficients used by the Academy. Beyea fails to point out that the Academy was careful to note that the risk coefficients are derived from high doses at high dose rates, and that there is some question about their applicability to exposures less than about 1 rad. As a matter of fact, the BEIR III report states (page 3) that "The Committee does not know whether dose rates of gamma or X rays of about 100 mR/yr are detrimental to man." Because of this position, the Committee would not make risk estimates for single exposures to less than 10 rads, or to continuous lifetime exposure to 1 R/yr.

A fundamental problem with the report is that it attaches equal weight to the Takeshi and Kepford estimates as it does to the more thorough studies of others listed in the report's Table 3. This, despite the fact that the Takeshi and Kepford reports were critically reviewed.

I am sure you will ask Pickard-Lowe to deal with the 12,000 prem estimate Beyea derived from the Woodard report.