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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

JUN 6 1979

Dr. Aubrey V. Godwin, Director
Division of Radiological Health
Department of Public Health
State of Alabama
State Office Building
Montgomery, Alabama 36130

Dear Dr. Godwin:

I have been asked by Chairman Hendrie to respond to your letter of May 3, 1979. In reviewing your questions, I find they can be answered by providing you with two sets of documents. The first is a set of questions asked by Senator Hart's Committee, which address nearly the same questions you asked. The answers provided by myself and the NRC staff follow each question.

Regarding offsite doses, I have provided a copy of an interagency document that describes the bases on which offsite doses have been calculated after the event. During the accident, NRC staff in our incident response center were attempting to turn the early monitoring data into dose rate estimates, and it was on the basis of that activity that our early recommendations were made.

As you are probably aware, there are several studies currently underway on various aspects of the accident. I expect that an outcome of these studies will be new perspectives in such areas as our incident response mechanisms. Therefore, some of the answers that are given in the enclosures may well change as we further explore the issues involved. Nevertheless, the information I have provided as attachments represents my current thinking on the matters addressed.

Sincerely,

Original Signed by
H. R. Denton

Harold R. Denton, Director
Office of Nuclear Reactor Regulation

Enclosure:
1. Senator Hart's Committee Questions
2. Interagency Document

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QUESTION 14: Mr. Denton, the morning of March 30 you stated you had advised the state police to evacuate out to five miles. On what information did you base that recommendation for evacuation? Did you make the same recommendation to the Governor at that time?

ANSWER:

At that time I had been advised that a helicopter had flown into the plume near the plant and had measured radioactivity levels of 1200 mr/hr. There was some indication that additional releases could occur. Given the relatively high levels of radiation reported and concerns about the ability to control or prevent further releases, I concluded that evacuation was a prudent course of action. I so advised other members of the NRC staff and suggested that the Governor of the State of Pennsylvania be notified by the NRC's Office of State Programs.

QUESTION 16: Did you feel you had adequate information during the initial stages of the Three Mile Island incident to advise the Governor on an evacuation decision? If not, at what point do you feel you had adequate information to give advice on this decision?

ANSWER:

No, I don't feel the NRC had adequate information concerning the accident during the early stages. I didn't feel comfortable with the level of information available until after I had met with my staff on Friday night. At that time my staff had gone through the plant and was able to give me first-hand information on the status of the core, the containment, the effluent treatment system and radiation levels. From Friday night on, I was able to obtain the benefit of expert advice about the possible course and consequences of actions needed to bring the TMI facility to a safe shutdown condition and about the consequences of further problems that might arise from such actions.

QUESTION 17: Looking back now with hindsight, who do you feel was in the best position to advise the Governor on evacuation during Wednesday and Thursday of the incident? during the following days?

ANSWER:

The situation during Wednesday and Thursday indicates the need to improve this area. No one in retrospect appeared to be in a very good position to advise the Governor. Perhaps each licensee needs an incident center near the site which could be manned by technical staff of the licensee, representatives of the NRC, and representatives from State and local governments. After I arrived at the site and had support of a large number of NRC experts, I thought I was in the best position to advise the Governor.

QUESTION 20: On April 23, 1979, Governor Thornburgh testified before this Committee that there are proven hazards in evacuating people - particularly those under medical care. Was NRC aware of these hazards and, if so, were they taken into consideration in the recommendations for precautionary evacuations?

ANSWER:

In my recommendation regarding evacuation on Friday morning, I was considering only avoidance of radiation exposure and the injury to significant numbers of people that might have resulted if no action were taken. I did not attempt to balance the benefits to many against the risks to a few that could result from any evacuation. In subsequent meetings with the Governor and his staff I now appreciate the complexities involved in planning and accomplishing evacuation especially for those who are ill, elderly and difficulty with farm animals. Such factors are clearly important where evacuation may yield only marginal reductions in exposure to the balance of the affected populace.

QUESTION 24: Mr. Denton, on Friday morning, March 30, in Bethesda you recommended a precautionary evacuation. Friday afternoon at the Three Mile Island site you felt there was no immediate need for it. What were the main factors influencing this decision?

ANSWER:

I had changed my views on Friday night as a result of the understanding the staff had obtained of the source of the radioactive material being released and the means for reducing and controlling the releases and resulting offsite doses. From that point on, I believed that any decision on evacuation could and should await the development of circumstances where a release was imminent. Through the actions of the utility and the staff that circumstance did not arise.

QUESTION 25: On Saturday, March 31, you were concerned about the hydrogen bubble and what means to use to attempt to start the reactor towards cold shutdown. Did the Commission have in mind at that point any kind of threshhold level which would trigger evacuation?

ANSWER:

By Saturday, a number of methods had been devised to remove the bubble from the primary system. On Saturday I had in mind a view that certain types of contingency measures, such as attempts to remove the bubble through depressurization and RHR cooling should be attempted only after careful planning for potential evacuation. I considered that if such measures were necessary, a change in the basic cooling mode of the reactor should be made only in the daytime at an announced time and with an ability to evacuate if events proved necessary were fully established.

QUESTION 28: Both Friday and Saturday, March 30 and 31, there were conflicting press reports as to whether the NRC had ordered an evacuation and what kind they were recommending. What factors contributed to this conflicting information?

ANSWER:

Probably the principal factor was that the press was receiving information from a variety of sources during a time when the knowledge of the accident and its consequences were changing rapidly.

QUESTION 31: Do you feel the people of Pennsylvania had enough information to make their own informed decision on whether or not to leave the Three Mile Island area?

ANSWER:

I do not feel that the people of Pennsylvania had sufficient information to make their own informed decisions regarding evacuation during the first few days since the condition of the core and the amount of radioactivity that had been released to the containment and auxiliary building had not been well characterized for the public at that time. I believe one way such situations might be improved would be to devise some way of widely available objective analyses and data about the accident. The early actions such as general assurances of no danger or general warnings of imminent catastrophe do not provide an adequate substitute for such factual information about the accident and the implications of planned actions at the plant. The daily Preliminary Notices issued by the NRC regarding the accident provided a useful vehicle for conveying this type of information.

POPULATION DOSE and HEALTH IMPACT OF THE ACCIDENT AT THE THREE MILE ISLAND NUCLEAR STATION

(a preliminary assessment for the period
March 28 through April 7, 1979)

Ad Hoc Population Dose Assessment Group

Lewis Battist	Nuclear Regulatory Commission
John Buchanan	Nuclear Regulatory Commission
Frank Congel	Nuclear Regulatory Commission
Christopher Nelson	Environmental Protection Agency
Mark Nelson	Department of Health, Education and Welfare
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May 10, 1979

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PREFACE

This report was prepared by technical staff members of the Nuclear Regulatory Commission (NRC), the Department of Health, Education and Welfare (HEW) and the Environmental Protection Agency (EPA), who constitute an Ad Hoc Population Dose Assessment Group. It is an assessment of the health impact on the approximately 2 million offsite residents within 50 miles of the Three Mile Island Nuclear Station from the dose received by the entire population (collective dose). The Ad Hoc Group has examined in detail the available data for the period up to and including April 7, 1979. Based on a preliminary review of data from periods beyond April 7, it appears that the collective dose will not be significantly increased by extending the period past April 7.

The dose and health effects estimates are based primarily on thermoluminescent dosimeters placed at specific onsite and offsite locations. The dosimeters measure the cumulative radiation exposure that occurred at these locations. They permit the most direct evaluation of dose to the offsite population from radionuclides (radioactive materials) released to the environment.

The report also addresses several areas of concern about the types of radionuclides released, about the contribution to population exposure due to beta radiation (which does not penetrate the clothing and skin) emitted from the released radionuclides, about the degree of coverage afforded by available radiation measurements, and about the range of health effects that may result from the estimated collective dose.

DUPE

Based on the current assessment, the Ad Hoc Group concludes that the offsite collective dose associated with radioactive material released during the period of March 28 to April 7, 1979 represents minimal risks (that is, a very small number) of additional health effects to the offsite population. The numerical statement of this conclusion is developed in the report. The Ad Hoc Group is not aware of any radiation measurements made during this period that would alter this basic conclusion, although refinement of the numerical estimates can be expected as the data are updated and verified. The members of the Ad Hoc Group concur that the manner in which the collective dose estimates were computed was conservative (overestimated the actual dose). The uncertainties in the collective dose estimates and health effects are not large enough to alter the Group's basic conclusion, that is, the risk is minimal.

ACKNOWLEDGMENTS

The Ad Hoc Group acknowledges the assistance of Ted Schoenberg of the Department of Energy and Andy Hull of Brookhaven National Laboratory in providing the data and analysis presented in Appendices A and B. We also acknowledge the contributions of the following individuals:

Nuclear Regulatory Commission - Jeannette Kiminas
Walter Pasciak
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James Fairobent
James Martin
William Snell

Food and Drug Administration - Charles Coyle
Dean Elbert
Richard Kisielewski

Environmental Protection Agency - Philip Cuny
ne Latta

POPULATION DOSE AND HEALTH IMPACT OF THE ACCIDENT AT THE THREE MILE ISLAND NUCLEAR STATION

(a preliminary assessment for the period
March 28 through April 7, 1979)

Summary and Discussion of Findings

An interagency team from the Nuclear Regulatory Commission (NRC), the Department of Health, Education and Welfare (HEW) and the Environmental Protection Agency (EPA) has estimated 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 of March 28, 1979. The estimates are for the period from March 28 through April 7, 1979, during which releases occurred that resulted in exposure to the offsite population. The principal dose estimate is based upon ground-level radiation measurements from thermoluminescent dosimeters located within 15 miles of the site. These estimates assume 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 before the accident (as part of their normal environmental surveillance program), from dosimeters placed by Metropolitan Edison after the accident and covering the period to April 6, and from dosimeters placed by NRC from noon of March 31 through the afternoon of April 7, 1979. These measurement programs are continuing. The results for the period beyond April 7, 1979 have not been fully examined. An additional dose estimate developed by the Department of Energy using aerial monitoring that commenced about 4 p.m. on March 28, 1979 is also included. A variety of other data helpful in assessing relatively minor components of collective dose was also reviewed.

The collective dose to the total population within a 50-mile radius of the plant has been estimated to be 3300 person-rem. This is an average of four separate estimates that are 1600, 2800, 3300, and 5300 person-rem. The range of the collective dose values is due to different methods of extrapolating from the limited number of dosimeter measurements. An estimate provided by the Department of Energy (2000 person-rem) also falls within this range. The average dose to an individual in this population is 1.5 mrem (using the 3300 person-rem average value).

The projected number of excess fatal cancers due to the accident that could occur over the remaining lifetime of the population within 50 miles is approximately one. Had the accident not occurred, the number of fatal cancers that would be normally expected in a population of this size over its remaining lifetime is estimated to be 325,000. The projected total number of excess health effects, including all cases of cancer (fatal and non-fatal) and genetic ill health to all future generations, is approximately two.

These health effects estimates were derived from central risk estimates within the ranges presented in the 1972 report of the Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR) of the National Academy of Sciences. Preliminary information on the recently updated version of this report indicates that these estimates will not be significantly changed.

It should be noted that there exist a few members of the scientific community who believe the risk factors may be as much as two to ten times greater than the estimates of the 1972 BEIR report. There also is a minority of the scientific community who believe that the estimates in the 1972 BEIR report are two to ten times larger than they should be for low doses of gamma and beta radiation.

The maximum dose that an individual located offsite in a populated area might receive is less than 100 mrem. This estimate is based on the cumulative dose (83 mrem) recorded by an offsite dosimeter at 0.5 mile east-northeast of the site and assumes that the individual remained outdoors at that location for the entire period from March 28 through April 7. The estimated dose applies only to individuals in the immediate vicinity of the dosimeter site. The potential risk of fatal cancer to an individual receiving a dose of 100 mrem is about 1 in 50,000. This should be compared to the normal risk to that individual of fatal cancer from all causes of about 1 in 7.

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 10-hour period he was on Hill Island (March 28 and March 29) is 37 mrem.

A number of questions concerning this analysis are posed and briefly answered below. More detailed discussions are included in the body of the report.

What radionuclides were in the environment?

The principal radionuclides released to the environment were the radioactive xenons and some iodine-131. 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 (which is chemically non-reactive) 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, which penetrates the body and exposes the internal organs.

What were the highest radiation exposures measured outside the plant buildings?

Some of the Metropolitan Edison dosimeters 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 1020 mrem. These recorded exposure readings do not apply directly to individuals located offsite. However, the onsite dosimeter readings were included in the procedure for projecting doses to the offsite population. This procedure is described in the report.

What is meant by collective dose (person-rem)?

The collective dose is a measure of the total radiation dose which was received by the entire population within a 50-mile radius of the Three Mile Island site. It is obtained by multiplying the number of people in a given area by the dose estimated for that area and adding all these contributions.

Were the radiation measurements adequate to determine population health effects?

The extensive environmental monitoring and food sampling were adequate to characterize the nature of the radionuclides released and the concentrations of radionuclides in those media. The measurements performed by Department of Energy (aerial survey) and Metropolitan Edison and Nuclear Regulatory Commission (ground level dosimeters) are sufficient to characterize the magnitude of the collective dose and therefore the long-term health effects. However, a single precise value for the collective dose cannot be assigned because of the limited number of fixed ground level dosimeters deployed during the accident.

How conservative were the collective dose estimates?

In projecting the collective dose from the thermoluminescent dosimeter exposures, several simplifying assumptions were made that ignored factors that are known to reduce exposure. In each case, these assumptions introduced significant overestimates of actual doses to the population. This was done to ensure that the estimates erred on the high side. The three main factors that fall into this category are:

(1) No reduction was made to account for shielding by buildings when people remained indoors.

(2) No reduction was made to account for the population known to have relocated from areas close to the nuclear power plant site as recommended by the Governor of Pennsylvania, or who otherwise left the area.

(3) [illegible] reduction was made to account for the fact that the actual dose absorbed by the internal body organs is less than the dose assumed using the net dosimeter exposure.

What is the contribution of beta radiation to the total dose?

Beta radiation contributes to radiation dose by inhalation and 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 additional skin dose could result in a small increase in the total potential health effects (about 0.2 health effect) due to skin cancer. The increase in total fatal cancers over that estimated for external exposure from gamma radiation alone would be about 0.01 fatal skin cancer. This contribution would be considerably decreased by clothing. The dose to the lungs from inhalation of xenon-133 for both beta and gamma radiation increases the dose to the lungs by 6 percent over that received by external exposure.

What radionuclides were found in milk and food and what are their significance?

Iodine-131 was detected in milk samples during the period March 31 through April 4. The maximum concentration measured in milk (41 pCi/liter in goat's milk, 36 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 weapons testing. No reactor-produced radioactivity has been found in any of the 377 food samples collected between March 29 and April 30 by the FDA.

Why have the estimates of radiation dose changed?

The original Ad Hoc Group estimate of collective dose (1800 person-rem) presented on April 4 at the hearings before the Senate Subcommittee on Health and Scientific Research covered the period from March 28 through April 2. The data used for this estimate were obtained from preliminary results for Metropolitan Edision offsite dosimeters for the period March 28 through March 31 and preliminary results for NRC dosimeters for April 1 and 2. On April 10, the estimate of 2500 person-rem presented to the Senate Subcommittee on Nuclear Regulation by NRC Chairman Hendrie included the time period from March 28 through April 7. The data base for this estimate included additional NRC dosimetry results for April 3 through 7. The Ad Hoc Group's preliminary report of April 15 stated a value of 3500 person-rem for the time period from March 28 through April 7. This value resulted from better information on the dosimeter measurements and an improved procedure for analyzing the measurements.

The current report states an average value of 3300 person-rem (with a range of 1600 to 5300 person-rem) for the time period from March 28 through April 7. Additional dosimeter data were available and better methods were used to determine the collective dose. Also, the onsite dosimeter measurements are all included in the analysis.

The original estimate of maximum dose (80 mrem) to an individual presented on April 4 increased to 85 mrem in the April 15 preliminary report as a consequence of adding the contribution from April 2 to April 7. This estimate has now been revised slightly to 83 mrem, which is presented as less than 100 mrem so as not to imply more precision than this estimate warrants. New information on dosimeter readings on or very near the site was received after the initial analysis.

It was also learned that an individual was present on one of the nearby islands (Hill Island) for a total of 10 hours during the period March 28 to March 29. The best estimate of the dose which may have been received by the individual is 37 mrem. The text includes a range of dose estimates for that individual.

Will these estimates of dose change again?

The dose and health effects estimates contained in this report are based on the dosimeter results for the period March 28 to April 7, 1979. There still remain some questions concerning interpretation of the dosimeter results. For example, the best values for subtracting background from the Nuclear Regulatory Commission dosimeters have not been determined. Recently available data from additional dosimeters exposed during the March 28 to April 7 period have been reviewed briefly, but could not be included in the calculations in time for this report. The actual contribution to collective dose from the period after April 7, if any, has not been fully assessed. Therefore, the numerical dose values may be subject to some modification.

The Ad Hoc Group feels that these factors represent only minor corrections to the present estimates. In any case, none of the above refinements should cause an increase in any of the current estimates that would alter the basic conclusion regarding the health impact due to the Three Mile Island accident.

1. INTRODUCTION

The Ad Hoc Population Dose Assessment Group was formed from individuals assigned by their respective agencies to the NRC Incident Response Center on Monday, April 2, 1979. The Ad Hoc Group's objective was to obtain an estimate of the public health consequences of this accident to the offsite population and submit the results to each of the constituent agencies for their use.

Because of the urgency to prepare estimates of the health impact for presentation at the April 4, 1979 hearings before the Senate Subcommittee on Health and Scientific Research, the group had to rely upon very early data that were available at the NRC Incident Response Center or easily obtained through existing communication channels with the Federal coordination center adjacent to the Three Mile Island site. An interim report was prepared on April 15, 1979, which extended the estimate through April 7, 1979. The current report is an update of that analysis. The Ad Hoc Group has also had a chance to review its earlier calculations and analyze the data in a more systematic fashion.

2. NATURE OF THE RADIOACTIVE MATERIALS RELEASED

The principal radioactive materials released to the environment appear to be xenon-133 (half-life 5.3 days) and xenon-135 (half-life 9.2 hours) and traces of radioactive iodine, primarily iodine-131 (half-life 8.0 days). This is substantiated by consideration of the known course of events, knowledge that the effluents were released through high efficiency particulate filters and charcoal absorbers, and from subsequent environmental measurements in the diffusing plume of radioactive material (see Appendix B). Based on the physical and chemical nature of these radionuclides they would not be released from the plant under the conditions of the TMI accident. Radionuclides in particulate form such as strontium-90, uranium isotopes, and plutonium would either have been retained in the fuel or if released from the fuel would remain in the coolant water. To our knowledge, these nuclides have not been detected either in the environment (above pre-existing levels of natural background or world-wide fallout) in the vicinity of Three Mile Island (TMI) or in the reactor containment atmosphere or gas decay tanks. Some of the radioactive krypton isotopes such as krypton-87, (half-life 76 min), krypton-85m (half-life 4.5 hours) and krypton-88 (half-life 2.8 hours) may also have been released. However, these are all relatively short-lived radionuclides and none of the reported gamma-ray spectral analyses detected any measurable quantities of these krypton isotopes.

Appendix B describes the environmental surveillance activities of the Department of Energy which measured the radionuclides in the environment from the release.

3. DOSE ASSESSMENT FROM EXTERNAL EXPOSURE

A. Thermoluminescent Dosimeter Data

The available thermoluminescent dosimeter (TLD) data were used as the basis for this evaluation. They provide the best available dosimetry information for the following reasons:

1. The TLD's placed by the licensee as part of the environmental radiation surveillance program for routine operation were the only devices for measuring radiation exposure that were placed at fixed locations throughout the course of the accident, including the first 3 days.

2. The TLD's are exposure-integrating devices and measure total exposure rather than exposure rate.

3. The TLD's used are said to measure exposures as low as about 1 mR. (See the following description of the TLD's.)

At the time of the accident, Metropolitan Edison had environmental TLD's in place at a total of 20 onsite and offsite locations. These locations are described in Table 3-1. The site locations are given in Figures 3-1 through 3-3. Except for three locations (10B1, 14S1, and 16A1), these TLD's had been exposed since December 27, 1978, to measure the environmental radiation exposure during the first quarter of 1979. The three locations, 10B1, 14S1, and 16A1, on islands in the Susquehanna River, had been exposed since September 27, 1978.

All 20 of the Metropolitan Edison locations had environmental TLD's manufactured and read by Teledyne Isotopes. These Teledyne Isotopes environmental dosimeters are rectangular Teflon wafers impregnated with 25% $CaSO_4$:Dy phosphor contained in black polyethylene pouches in rectangular holders with copper filters to make the energy response more uniform ("flatten" the energy response). After exposure in the environment, measurements of the exposure are made on each of four separate areas of the dosimeter. The average of these four readings is used in the calculations. In the product bulletins, these dosimeters are said to have a "minimum sensitivity" of 0.5 mR and to have a "maximum error (1 standard deviation)" of "±0.2 mR or ±3%, whichever is greater" for measurement of exposure from cobalt-60 gamma radiation.

At 10 of their 20 locations, Metropolitan Edison had duplicate dosimeters which were supplied and read by Radiation Management Corporation (RMC) as quality control checks. These 10 locations are indicated in Table 3-1. The suffix "Q" added to the station code indicates data from RMC TLD's at the Metropolitan Edison locations. Two RMC model UD-200S dosimeters were used at each location. Each dosimeter contains two $CaSO_4$:Tm TLD phosphor elements inside a plastic and metal shield to flatten the energy response. Thus, four readings (two dosimeters; two readings per dosimeter) of the exposure of the RMC dosimeters are obtained for each location. The "sensitivity" of these dosimeters is said to be about 0.5 mR.

On March 31, NRC placed TLD's at 37 locations and on April 5, an additional 10 dosimeters were placed at various schools. The locations of these dosimeters are described in Table 3-2. The site locations are shown in Figures 3-4 and 3-5. These dosimeters were also supplied and read by Radiation Management Corporation (RMC) but are different from the TLD's supplied by RMC to Metropolitan Edison. The RMC dosimeters used by NRC are either the RMC model UD801 dosimeter or the model UD804 environmental dosimeter. Each of the UD801 dosimeters contains two $Li_2B_4O_7$:Cu,Ag phosphor elements and two $CaSO_4$:Tm phosphor elements. One $Li_2B_4O_7$ element has an open window (to minimize attenuation of beta radiation) and the other a 280 mg/cm^2 filter; one of the $CaSO_4$ elements also has a 280 mg/cm^2 filter, while the second has a 700 mg/cm^2 filter of lead to flatten the energy response. The UD801 dosimeters are said to have a "sensitivity, whole body" of "1 mR - 2000 R." Each of the UD804 environmental dosimeters contains three $CaSO_4$:Tm phosphor elements, with a lead filter to flatten the energy response; thus, three readings are obtained from each of these dosimeters. These UD804 environmental dosimeters are said by RMC to have a "sensitivity" of "1 mR-200 R (30 keV-10 MeV)." Starting on April 1, 1979, at each NRC site, two dosimeters were changed daily; thus, either 6 or 8 dosimeter readings (depending on the dosimeter type) were obtained for each location each day, depending on which type of dosimeter was used. In addition, beginning on April 1, 1979, two dosimeters were left at each location for longer exposures than the period considered in this report.

Exposures measured at Metropolitan Edison TLD stations (including both Teledyne Isotopes and RMC data) are listed in Table 3-3. These Metropolitan Edison data include exposures from the time of the accident on March 28, 1979, to April 6, 1979. Exposures measured at NRC stations are listed in Table 3-4 for the time periods from March 31, 1979 (when the NRC dosimeters were first placed at these locations), until April 7, 1979. Each entry in Tables 3-3 and 3-4 is an average of multiple readings of the exposure at that location for that time period together with the standard deviation of the multiple readings.

Exposures measured at Metropolitan Edison locations during 1978 are listed in Table 3-5 (Teledyne Isotopes data) and Table 3-6 (RMC data). These data provide an estimate of the background exposures.

All exposure (mR) measurements are based on calibrations with cesium-137 sources. Samples of each type of TLD placed by the various organizations around the TMI site have been collected and exposed to known sources of xenon-133 at the National Bureau of Standards. Preliminary results indicate that the energy response of the Metropolitan Edison and NRC TLD's to the gamma radiation from a xenon-133 source varies from about 25% less than the calibration value to about 30% greater than the calibration value. These experiments were not designed to be, nor should they be interpreted as being, a precise calibration of the TLD's under actual field conditions or for the exact spectrum of radiation that was emitted during the course of the accident.

Since the spectrum incident upon the dosimeters is not known, and since the calibration of the dosimeters to xenon-133 radiation is still tentative, these correction factors were not applied to the dosimeter measurements. However, the external exposure calibration does confirm that the dosimeters are sufficiently sensitive to the xenon-133 radiation that their response at low energies would not introduce a significant uncertainty in the dose or health impact estimates.

Table 3-1. METROPOLITAN EDISON TLD STATION LOCATIONS

STATION CODE	LOCATION DESCRIPTION*
1S2**	0.4 miles N of site at N Weather Station
1C1	2.6 miles N of site at Middletown Substation
2S2	0.7 miles NNE of site on light pole in middle of North Bridge
4S2**	0.3 miles ENE of site on top of dike, East Fence
4A1	0.5 miles ENE of site on Laurel Rd., Met. Ed. pole #668-OL
4G1**	10 miles ENE of site at Lawn - Met. Ed. Pole #J1813
5S2**	0.2 miles E of site on top of dike, East Fence
5A1**	0.4 miles E of site on north side of Observation Center Building
7F1**	9 miles SE of site at Drager Farm off Engle's Tollgate Road
7G1	15 miles SE of site at Columbia Water Treatment Plant
8C1**	2.3 miles SSE of site
9S2	0.4 miles S of site at South Beach of Three Mile Island
9G1	13 miles S of site in Met. Ed. York Load Dispatch Station
10B1	1.1 miles SSW of site on south beach of Shelley Island
11S1**	0.1 miles SW of site on dike west of Mechanical Draft Towers
12B1	1.6 miles WSW of site adjacent to Fishing Creek
14S1	0.4 miles WNW of site at Shelley Island picnic area
15G1**	15 miles NW of site at West Fairview Substation
16S1**	0.2 miles NNW of site at gate in fence on west side of Three Mile Island
16A1	0.4 miles NNW of site on Kohr Island

*All distances measured from a point midway between the Reactor Buildings of Units One and Two. All 20 stations had Teledyne-Isotopes Environmental TLD's.

**Stations with RMC TLD's. Data obtained with RMC TLD's at these locations are designated by adding the letter "Q" as a suffix to the station code.

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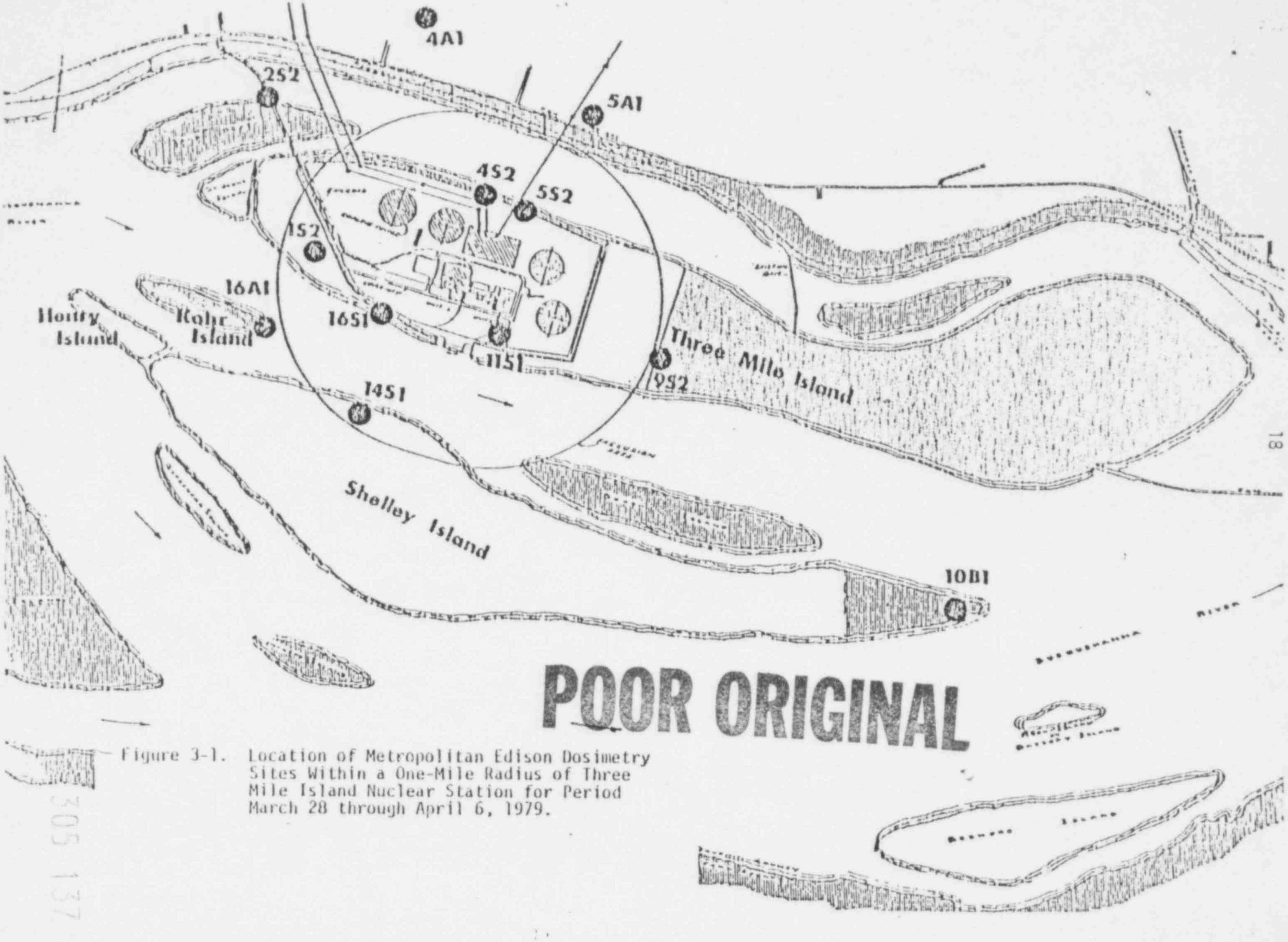

Figure 3-1. Location of Metropolitan Edison Dosimetry Sites Within a One-Mile Radius of Three Mile Island Nuclear Station for Period March 28 through April 6, 1979.

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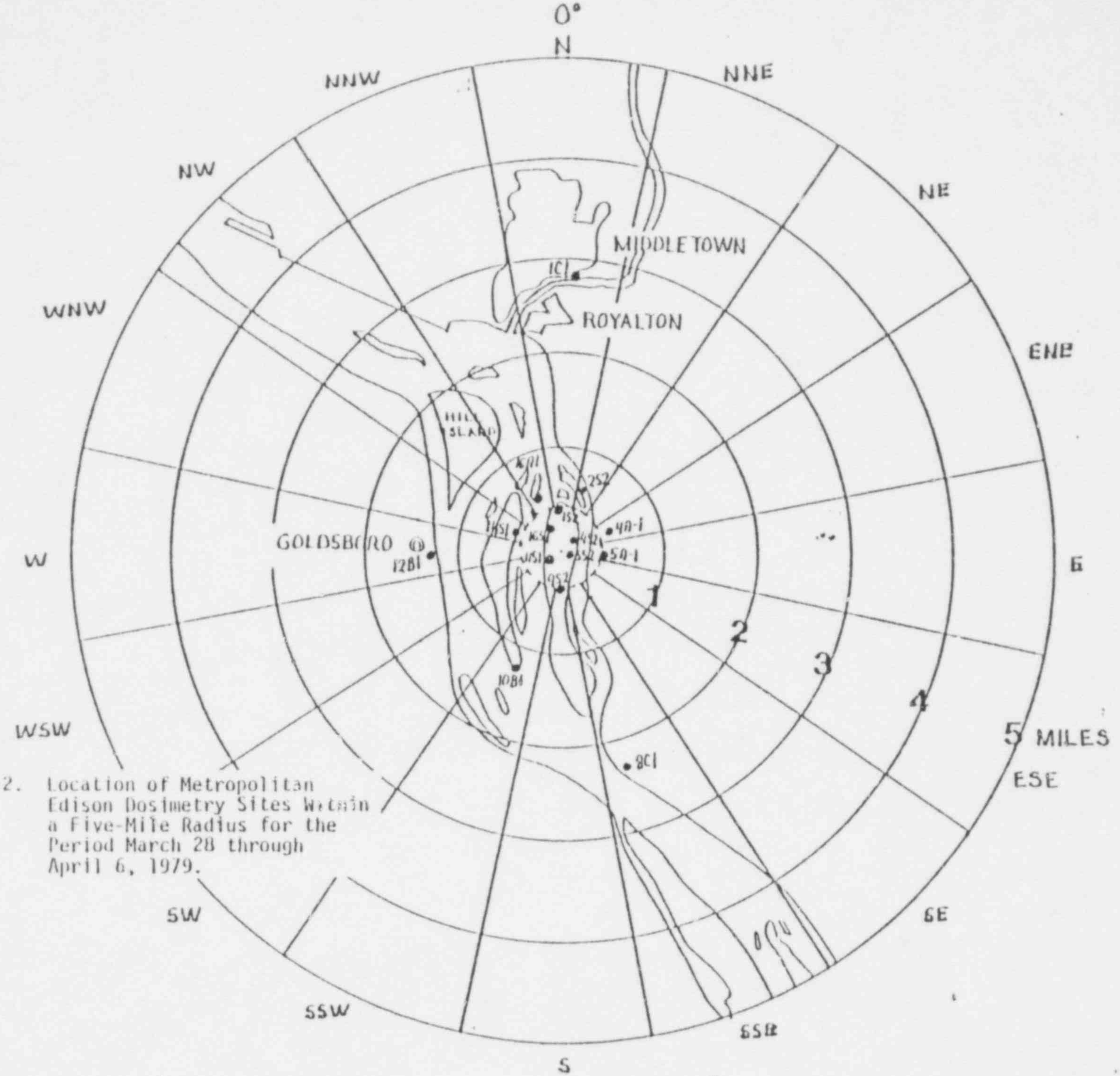

Figure 3-2. Location of Metropolitan Edison Dosimetry Sites Within a Five-Mile Radius for the Period March 28 through April 6, 1979.

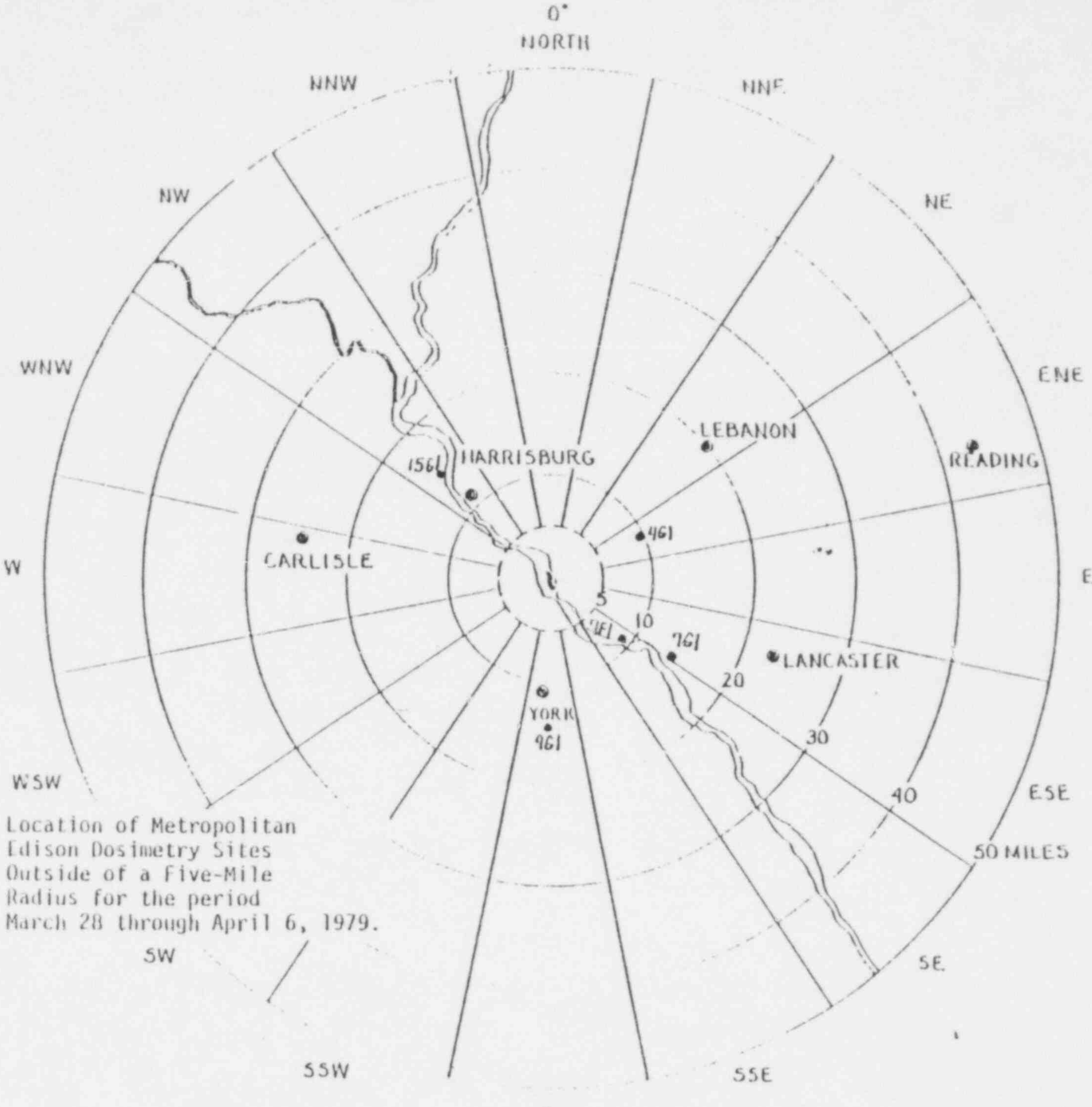

Figure 3-3. Location of Metropolitan Edison Dosimetry Sites Outside of a Five-Mile Radius for the period March 28 through April 6, 1979.

Table 3-2. NRC TLD LOCATIONS

STATION	DISTANCE	DIRECTION	SECTOR	DESCRIPTION
N-1a	2.4 mi	356°	N	School (added 4/5/79)
N-1	2.6 mi	358°	N	Middletown
N-1c	3.0 mi	0°	N	School (added 4/5/79)
N-1e	3.5 mi	349°	N	" "
N-1f	4.0 mi	351°	N	" "
N-2	5.1 mi	0°	N	Clifton
N-3	7.4 mi	6°	N	Hummelstown
N-4	9.3 mi	0°	N	Union Deposit
N-5	12.6 mi	3°	N	-
NE-1	.8 mi	25°	NNE	North Gate
NE-2	1.8 mi	19°	NNE	Geyers Ch
NE-3	3.1 mi	17°	NNE	Township School
NE-3a	3.6 mi	44°	NE	School (added 4/5/79)
NE-4	6.7 mi	47°	NE	-
E-1	.5 mi	61°	ENE	1200' N of E-1a
E-5 (E-1a)	0.4 mi	90°	E	Residence
E-3	3.9 mi	94°	E	Newville
E-4	7.0 mi	94°	E	Elizabethtown
E-2	2.7 mi	110°	ESE	Unpopulated area
SE-4	4.6 mi	137°	SE	Highway 441
SE-4a	5.0 mi	146°	SE	School (added 4/5/79)
SE-5	7.0 mi	135°	SE	Bainbridge
SE-1	1.0 mi	151°	SSE	Unnamed community on Highway 441
SE-2	1.9 mi	162°	SSE	Falmouth
SE-3	2.3 mi	160°	SSE	Falmouth
S-1	3.2 mi	169°	S	York Haven
S-1a	3.35 mi	173°	S	School (added 4/5/79)
S-2	5.3 mi	178°	S	Conewago Hts
S-3	9.0 mi	181°	S	Emigsville
S-4	12.0 mi	184°	S	Woodland View
SW-1	2.2 mi	200°	SSW	Bashore Island
SW-2	2.6 mi	203°	SSW	Pleasant Grove
SW-3	8.3 mi	225°	SW	Zions View
SW-4	10.4 mi	225°	SW	Eastmont
W-2	1.3 mi	252°	WSW	Goldsboro
W-3a	4.4 mi	247°	WSW	School (added 4/5/79)
W-1	1.3 mi	263°	W	Goldsboro
W-3	2.9 mi	270°	W	Unnamed community
W-4	5.9 mi	272°	W	Lewisberry
W-5	7.4 mi	262°	W	Lewisberry
NW-1	2.6 mi	303°	WNW	Harrisburg Airport
NW-3	7.4 mi	297°	WNW	New Cumberland
NW-2	5.9 mi	310°	NW	Highspire
NW-4	9.6 mi	306°	NW	Harrisburg
NW-5	13.8 mi	312°	NW	Harrisburg
N-1b	2.75 mi	346°	NNW	School (added 4/5/79)
N-1d	3.5 mi	333°	NNW	" "

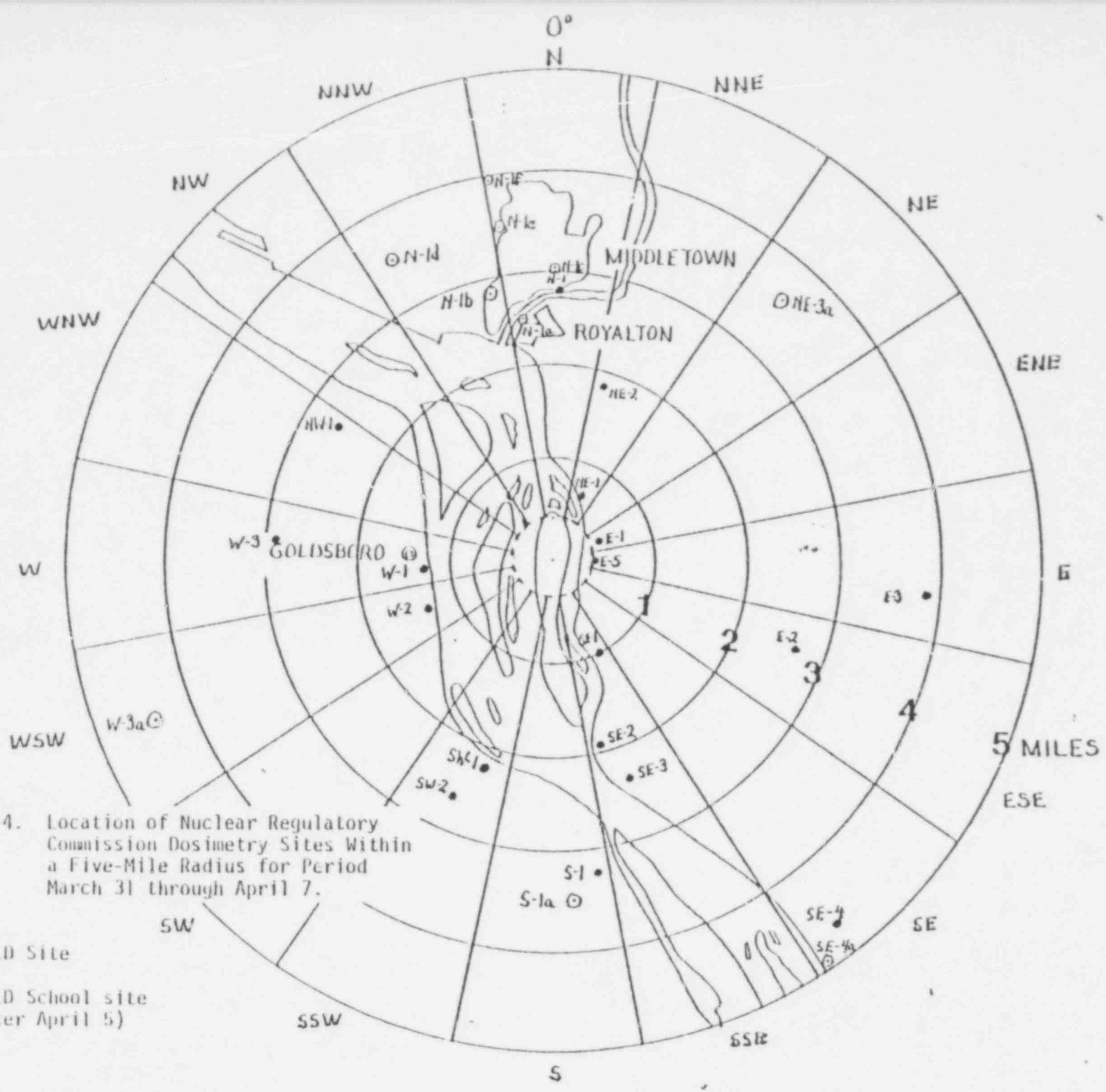

Figure 3-4. Location of Nuclear Regulatory Commission Dosimetry Sites Within a Five-Mile Radius for Period March 31 through April 7.

• NRC TLD Site

⊙ NRC TLD School site
(After April 5)

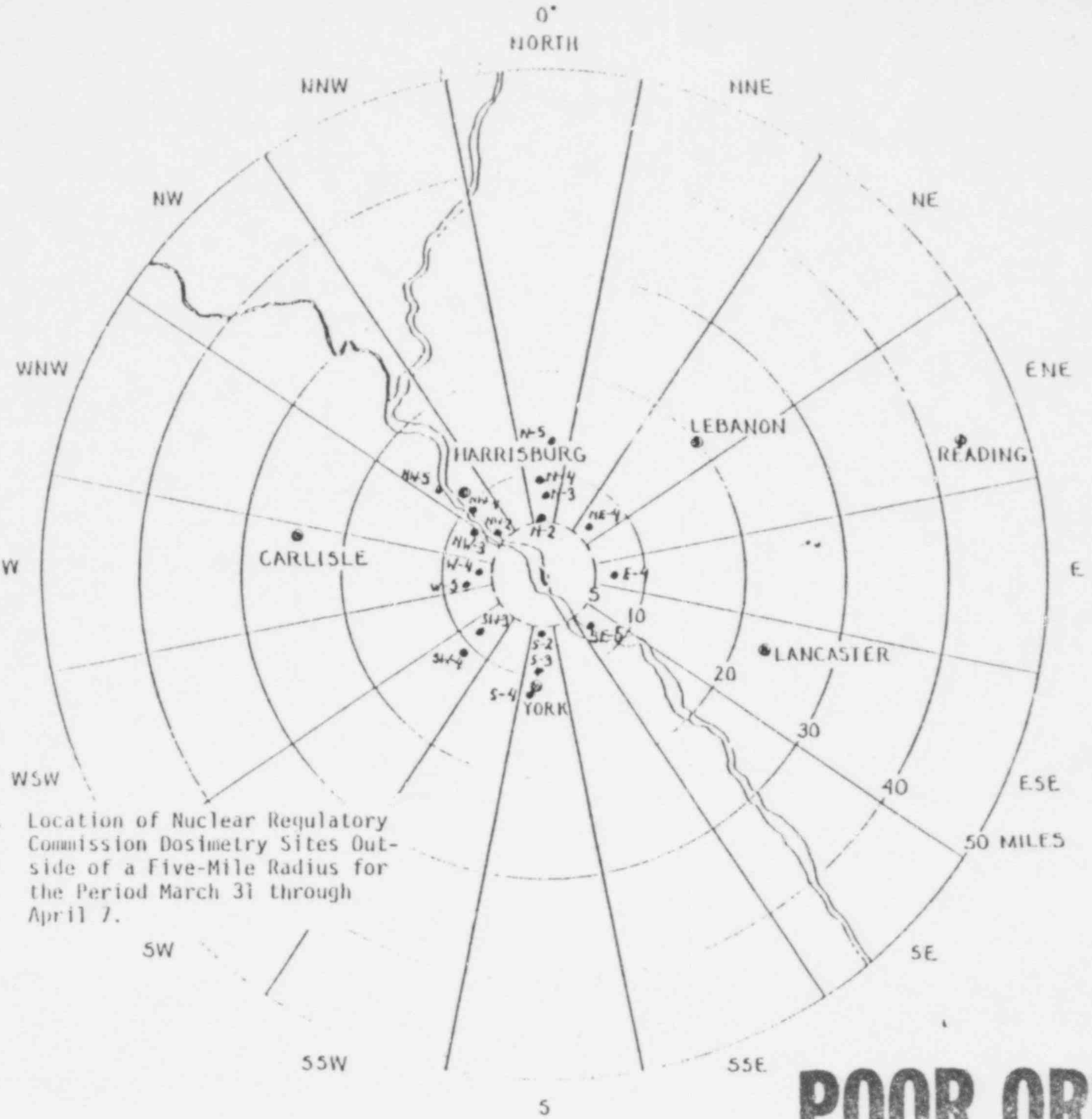

Figure 3-5. Location of Nuclear Regulatory Commission Dosimetry Sites Outside of a Five-Mile Radius for the Period March 31 through April 7.

Table 3-3. METROPOLITAN EDISON TLD DATA - RADIATION EXPOSURES
FOR PERIODS ENDING 04/06/79

Station(1)	Exposure Period			
	12/27/78 -03/29/79	03/29/79 -03/31/79	03/31/79 -04/03/79	04/03/79 -04/06/79
	mR ± std. deviation per exposure period (includes background)			
1C1	20.1±1.3	3.2±0.7	1.4±0.4	0.5±0.1
7F1	24.1±1.8	1.1±0.1	0.5±0.5	0.9±0.1
7F1Q	23.3±0.5	0.8±0.2	1.5±0.2	0.9±0.0
15G1	18.4±2.0	1.9±0.3	-0.7±0.1	0.5±0.0
15G1Q	17.6±0.6	1.1±0.1	0.8±0.1	0.7±0.2
12B1	16.3±0.9	9.4±1.6	0.2±0.3	1.2±0.2
9G1	21.3±1.4	1.4±0.1	0.1±0.2	0.6±0.1
5A1	18.6±1.0	8.3±2.8(3)	7.7±2.5	3.0±1.2
5A1Q	16.1±1.3	5.4±1.0	5.2±0.9	2.0±0.6
4A1	20.2±1.3	34.3±8.6	41.4±8.5	2.2±0.4
2S2	43.7±4.4	32.5±5.6	3.4±0.6	0.9±0.2
1S2	97.9±1.9	20.0±3.4	-0.1±0.1	0.6±0.1
1S2Q	95.7±5.0	15.3±3.2	1.3±0.1	0.8±0.1
16S1	1044.2±128.2	83.7±17.5	7.0±0.7	1.5±0.3
16S1Q	929.4±90.5	61.6±12.2	5.6±1.0	1.3±0.5
11S1	216.0±24.1	107.1±12.7	45.0±15.2	21.8±7.3
11S1Q	168.5±15.6	75.7±12.7	35.2±3.3	14.2±1.1
9S2	25.0±3.0	25.3±2.6	4.6±1.0	1.8±0.3
4S2	35.5±4.3	124.3±32.7	28.0±9.1	7.9±2.3
4S2Q	31.4±1.6	71.4±13.0	21.3±6.6	4.7±0.4
5S2	30.5±1.3	49.3±11.2	26.7±5.3	15.5±5.0
5S2Q	27.7±4.0	36.6±0.8	21.2±3.1	11.5±2.4
4G1	17.2±2.1	1.2±0.2	0.6±0.2	0.6±0.1
4G1Q	17.7±0.1	0.6±0.1	1.4±0.1	0.7±0.1
8C1	13.0±0.3	10.7±1.6	1.7±1.1	1.3±0.4
8C1Q	12.6±0.6	8.4±1.0	2.6±0.2	1.1±0.1
7G1	25.8±0.6	1.0±0.1	-0.5±0.0	0.8±0.0
16A1	907.7±49.4(2) 453.4±12.2(2)	45.1±2.1	1.7±1.1	0.9±0.1
14S1	131.2±20.6(2) 148.3±9.7(2)	48.8±8.6	9.5±4.3	1.5±0.4
10B1	40.6±3.5(2) 36.6±1.3(2)	14.9±0.9	0.4±0.3	1.1±0.2

(1) Suffix "Q" indicates RMC data; otherwise data are from Teledyne Isotopes.
(2) Results for 6-month exposure period 09/27/78-03/29/79.
(3) Additional values for 5A1: 7.8±1.5, 7.4±1.2.

Table 3-4. NRC TLD DATA-RADIATION EXPOSURES FOR PERIODS
FROM 03/31/79 to 04/07/79 (includes background)

Station	3/31-4/1 mR	4/1-4/2 mR	4/2-4/3 mR	4/3-4/4 mR	4/4-4/5 mR	4/5-4/6 mR	4/6-4/7 mR
N-1	1.0 ± .1	.3	.37 ± .08	.32 ± .08	.28 ± .08	.32 ± .04	.43 ± .05
N-2	(wet)	.3	.45 ± .05	.40 ± .06	.33 ± .08	.48 ± .15	.40 ± .05
N-3	1.2 ± .3	.3	.43 ± .05	.32 ± .08	.34 ± .09	.47 ± .05	.50 ± .11
N-4	1.0 ± .1	.3	.48 ± .08	.33 ± .05	.37 ± .05	.42 ± .02	.48 ± .10
N-5	(wet)	.3	.58 ± .08	.37 ± .05	.35 ± .05	.48 ± .10	.52 ± .08
NE-1	7.0 ± 2.1	.2	.45 ± .08	.32 ± .04	.45 ± .05	.38 ± .04	.45 ± .08
NE-2	(wet)	.3	.48 ± .09	.37 ± .10	.33 ± .08	.47 ± .10	.47 ± .12
NE-3	1.6 ± .5	.3	.42 ± .09	.38 ± .08	.37 ± .08	.46 ± .05	.45 ± .10
NE-4	2.1 ± .5	.3	.37 ± .05	.38 ± .04	.33 ± .05	.40 ± .09	.43 ± .05
E-1	25.0 ± 8.1	.4	.53 ± .1	.32 ± .04	2.6 ± .60	.50 ± .09	.48 ± .08
E-5(E-1a)	8.4 ± 4.6	.3	.73 ± .2	.38 ± .08	1.7 ± .45	1.2 ± .27	.32 ± .04
E-2	4.3 ± .5	.3	.55 ± .7	.55 ± .10	.38 ± .08	.45 ± .10	.35 ± .08
E-3	2.1 ± .4	.4	.42 ± .1	.40 ± .06	.50 ± .06	.48 ± .08	.32 ± .08
E-4	2.5 ± .4	.3	.4 ± .1	.35 ± .14	.43 ± .19	.42 ± .04	.22 ± .04
SE-1	10.1 ± 2.0	.3	9.1 ± 1.6	.43 ± .10	.92 ± .19	.40 ± .00	.55 ± .06
SE-2	3.5 ± .5	.3	4.4 ± .7	.87 ± .16	.38 ± .08	.35 ± .05	.25 ± .05

Table 3-4. (Continued)

Station	3/31-4/1 mR	4/1-4/2 mR	4/2-4/3 mR	4/3-4/4 mR	4/4-4/5 mR	4/5-4/6 mR	4/6-4/7 mR
SE-3	2.3 ± .6	.3	2.8 ± .7	.57 ± .10	.45 ± .05	.40 ± .06	.25 ± .05
SE-4	3.0 ± .4	.3	2.1 ± .4	.30 ± .06	.53 ± .08	.47 ± .08	.25 ± .05
SE-5	2.5 ± .7	.3	.13 ± .1	.42 ± .04	.37 ± .08	.62 ± .31	.38 ± .13
S-1	1.6 ± .1	.4	2.2 ± .4	1.1 ± .05	.37 ± .05	.35 ± .05	.40 ± .00
S-2	1.0 ± .2	.4	1.5 ± .2	.52 ± .08	.32 ± .10	.35 ± .05	.43 ± .08
S-3	1.2 ± .3	.4	1.5 ± .3	.47 ± .05	.40 ± .08	.40 ± .06	.55 ± .10
S-4	1.2 ± .2	.3	1.4 ± .2	.33 ± .05	.45 ± .10	.55 ± .18	.42 ± .08
SW-1	.9 ± .1	.8	1.2 ± .3	1.1 ± .18	.37 ± .08	.37 ± .10	.45 ± .05
SW-2	.9 ± .2	.5	1.3 ± .3	.37 ± .12	.30 ± .09	.43 ± .08	.38 ± .08
SW-3	1.1 ± .3	.4	.78 ± .1	.65 ± .10	.45 ± .10	.38 ± .08	.42 ± .02
SW-4	.9 ± .1	.5	.75 ± .1	.62 ± .10	.45 ± .14	.50 ± .14	.50 ± .09
W-1	3.0 ± 1.9	1.2	1.4 ± .24	1.7 ± .35	1.3 ± .29	.57 ± .10	.48 ± .08
W-2	.9 ± .1	.5	1. ± .1	.62 ± .04	.72 ± .04	.37 ± .08	.38 ± .08
W-3	1.1 ± .1	.5	.78 ± .2	1.1 ± .15	.42 ± .08	.38 ± .08	.47 ± .08
W-4	1.0 ± .2	.4	.67 ± .1	.42 ± .10	.45 ± .14	.45 ± .05	.57 ± .08
W-5	1.2 ± .2	.6	.4 ± .15	.65 ± .12	.60 ± .13	.40 ± .06	.57 ± .14

Table 3-4. (Continued)

Station	3/31-4/1 mR	4/1-4/2 mR	4/2-4/3 mR	4/3-4/4 mR	4/4-4/5 mR	4/5-4/6 mR	4/ 4/7 mR
NW-1	.9 ± .2	1.7	1.3 ± .25	.30 ± .06	.38 ± .08	.52 ± 12	.53 ± .04
NW-2	1.2 ± .5	.4	.62 ± .08	.40 ± .15	.33 ± .05	.35 ± .05	.38 ± .08
NW-3	1.4 ± .7	.8	.63 ± .12	.40 ± .25	.38 ± .04	.40 ± .09	.42 ± .05
NW-4	5.5 ± 1.8	.3	.4 ± .06	.30 ± .06	.37 ± .08	.32 ± .04	.45 ± .10
NW-5	4.6 ± 2.	.4	.42 ± .04	.42 ± .21	.32 ± .04	.48 ± .08	.45 ± .05
S-1a	Not in Service until 4/5/79					.35 ± .05	.43 ±
SE-4a	" " " " "					.33 ± .05	.25 ± .05
W-3a	" " " " "					.65 ± .39	.45 ± .10
NE-3a	" " " " "					.38 ± .08	.57 ± .08
N-1a	" " " " "					.50 ± .19	.47 ± .04
N-1b	" " " " "					.40 ± .06	.50 ± .06
N-1c	" " " " "					.40 ± .09	.45 ± .08
N-1d	" " " " "					.35 ± .05	.50 ± .06
N-1e	" " " " "					.40 ± .06	.44 ± .08
N-1f	" " " " "					.47 ± .15	.37 ± .08

Table 3-5. METROPOLITAN EDISON COMPANY: TELEDYNE ISOTOPES DOSIMETERS
TLD RADIATION EXPOSURE RATES - 1978

Results in Units of mR/Standard month(1)

STATION NO.	12-30-77 to 03-29-78	03-29-78 to 06-28-78	06-28-78 to 09-30-78	09-30-78 to 12-27-78	AVERAGE ±2σ
Control Locations					
TM-ID-7F1	6.57±0.17	11.9±0.3	7.30±0.43	7.50±0.20	8.32±4.84
TM-ID-4G1	5.30±0.30	8.53±0.40	5.77±0.13	5.90±0.[illegible]3	6.38±2.92
TM-ID-9G1	5.60±0.13	9.47±0.50	6.00±0.20	5.97±0.[illegible]	6.76±3.64
TM-ID-15G1	5.13±0.10	8.73±0.43	5.57±0.23	5.63±0.50	6.27±3.32
TM-ID-7G1	15.8±0.7	10.4±0.5	7.13±0.63	7.20±0.10	10.1±8.2
Indicator Locations					
TM-ID-1S2	4.67±0.13	7.37±0.47	5.03±0.13	5.37±0.20	5.61±2.42
TM-ID-2S2	4.07±0.13	6.03±0.17	4.73±0.33	4.20±0.20	4.76±1.80
TM-ID-4S2	4.80±0.20	8.07±0.27	5.17±0.13	4.33±0.27	5.59±3.38
TM-ID-5S2	4.30±0.13	8.00±0.27	5.03±0.40	4.23±0.10	5.39±3.56
TM-ID-8C1	3.50±0.23	5.57±0.30	4.10±0.17	3.50±0.13	4.17±1.96
TM-ID-9S2	4.67±0.10	8.53±0.33	5.57±0.20	5.67±0.37	6.11±3.34
TM-ID-11S1**	5.07±0.20	17.0±0.4	6.50±0.27	5.60±0.10	8.54±10.3
TM-ID-14S1**	2.17±0.13	12.2±0.4	5.77±0.73	*	6.71±10.2
TM-ID-16S1	6.40±0.27	19.4±0.7	6.93±0.40	5.60±0.27	9.58±12.2
TM-ID-4A1	4.60±0.20	7.57±0.13	5.03±0.20	5.13±0.30	5.58±2.68
TM-ID-5A1	4.60±0.17	7.47±0.17	4.57±0.27	4.63±0.23	5.32±2.88
TM-ID-16A1	2.03±0.07	7.83±0.37	5.13±0.23	*	5.00±5.80
TM-ID-10B1	1.97±0.20	9.43±0.37	6.57±0.10	*	5.99±7.52
TM-ID-12B1	3.57±0.07	6.40±0.30	4.03±0.27	4.10±0.10	4.53±2.54
TM-ID-1C1	4.10±0.20	6.43±0.23	4.13±0.30	4.33±0.27	4.75±2.26
Average ±2σ	4.95±5.70	9.32±7.04	5.50±2.00	5.23±2.18	

(1) Standard month = 30.4 days; values originally reported as 1 mrem/standard month assuming 1 mrem = 1 mR.

*TLDs were left in field.

**Originally reported, erroneously, as Stations 11S2 and 14S2.

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Table 3-6. METROPOLITAN EDISON COMPANY: RADIATION MANAGEMENT CORPORATION DOSIMETERS
TLD RADIATION EXPOSURE RATES - 1978
Results in Units of mR/standard month(3)

STATION NUMBER	12-30-77 to 3-29-78	3-29-78 to 6-28-78	6-28-78 to 9-28-78	9-27-78 to 12-27-78	AVERAGE ± 2σ
Control Locations					
TM-IDM-7F1Q	6.15±0.73	7.60±0.67	7.79±0.29	8.04±0.45	7.40±1.70
TM-IDM-4G1Q	4.94±0.52	5.95±0.38	5.68±0.46	6.37±0.77	5.74±1.20
TM-IDM-15G1Q	4.70±0.40	5.61±0.38	5.65±0.45	6.47±0.50	5.61±1.45
Indicator Locations					
TM-IDM-1S2Q	5.71±0.34	5.32±0.31	5.31±0.42	5.82±0.27	5.54±0.53
TM-IDM-4S2Q	4.91±0.44	5.69±0.24	5.55±0.51	5.05±0.43	5.30±0.76
TM-IDM-5S2Q	4.32±0.21	5.15±0.56	5.47±0.32	5.44±0.44	5.10±1.07
TM-IDM-11S1Q	5.35±0.45	9.72±0.88	6.75±0.52(4)	6.09±0.23	6.98±1.92
TM-IDM-16S1Q	3.93±0.27	12.09±1.31	6.68±0.75	6.02±0.61	7.18±6.95
TM-IDM-5A1Q	4.57±0.16	5.18±0.38	4.88±0.28	5.60±0.17	5.06±0.88
TM-IDM-8C1Q	(1)	4.07±0.16	(2)	4.35±0.31	4.21±0.40
TM-IDM-4A1Q	4.56±0.60	(2)	(2)	(2)	4.56
TM-IDM-8S1Q	(2)	(2)	4.04±0.21	(2)	4.04
Average ± 2σ	4.91±1.33	6.64±4.96	5.78±2.11	5.93±1.96	

(1) "TLDs stolen."
(2) "No sample received."
(3) Standard month = 30.4 days; originally reported as "mrem/standard month" assuming 1 mrem = 1 mR.
(4) Originally reported, erroneously, as value for Station "11S2".

B. OFFSITE POPULATION COLLECTIVE DOSE ESTIMATE

1. Introduction

The collective dose for the population within 50 miles of the plant was calculated for the time period of March 28 to April 7, using two independent procedures. The first procedure utilized the empirical distribution of TLD dose data within each direction sector. Doses at distances between those locations with measured values were estimated by interpolation. A power law method was used to extrapolate when necessary. The second procedure utilized onsite meteorological data in conjunction with the TLD readings to estimate the distribution of dose within a 50-mile radius of the facility. The distribution of dose and population were then used to obtain the collective dose.

The population data used for the dose estimates were the 1980 projected offsite population distribution as presented in the Final Safety Analysis Report (FSAR).(1) These population distributions are contained in Tables 3-7 and 3-8 covering radii of 0-10 miles and 10-50 miles respectively.

2. Dosimeter Background Correction

The TLD exposure data reported in Tables 3-3 and 3-4 include a background due to terrestrial radiation, cosmic radiation and other sources unrelated to plant releases. In order to estimate the net exposure due to plant emission, this background must be subtracted from the total TLD exposure. The background

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(1) Final Safety Analysis Report, Three Mile Island Nuclear Station, Unit 2, Vol-1, Chapter 2, Figures 2.1-5 and 2.1-10.

Table 3-7. PROJECTED 1980 POPULATION DISTRIBUTION, 0-10 MILES
THREE MILE ISLAND NUCLEAR STATION, UNIT 2
(FROM FIG. 2.1-5 of FSAR)

	Distance (Miles)						
Sector	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 10	0 - 10
N	19	212	3,970	3,772	415	11,840	20,228
NNE	55	75	169	480	373	11,223	12,375
NE	42	134	271	428	186	2,246	3,307
ENE	58	55	186	461	262	1,567	2,589
E	42	60	39	137	552	10,431	11,261
ESE	6	36	149	214	236	2,809	3,450
SE	6	94	67	203	395	2,095	2,860
SSE	88	197	117	78	43	3,840	4,363
S	0	0	136	817	1,317	12,190	14,460
SSW	84	98	584	217	732	6,883	8,618
SW	84	104	181	562	219	4,297	5,447
WSW	29	273	117	796	237	2,961	4,413
W	36	369	36	331	571	7,155	8,498
WNW	22	106	253	197	235	11,823	12,636
NW	39	106	64	41	1,177	29,482	30,909
NNW	48	98	1,240	942	1,921	16,632	20,881
	658	2,017	7,579	9,676	8,891	137,474	166,295

Table 3-8. PROJECTED 1980 POPULATION DISTRIBUTION, 10-50 MILES
THREE MILE ISLAND NUCLEAR STATION, UNIT 2
(FROM FIG. 2.1-10 of FSAR)

	Distance (Miles)				Total
Sector	10-20	20-30	30-40	40-50	10-50
N	12,663	9,005	8,941	47,588	78,197
NNE	18,240	6,826	14,478	45,115	84,659
NE	39,726	38,979	9,546	62,345	150,596
ENE	10,205	14,757	45,445	177,672	248,079
E	18,853	62,028	42,445	38,754	162,080
ESE	34,339	124,988	27,822	42,737	229,886
SE	20,152	10,000	10,600	26,958	67,710
SSE	44,204	10,774	15,097	66,763	136,838
S	111,002	14,648	13,477	75,781	214,908
SSW	31,917	44,031	18,596	37,729	132,273
SW	11,801	19,931	25,536	18,979	76,247
WSW	5,882	7,996	8,948	23,010	45,836
W	21,769	35,025	10,370	20,602	87,766
WNW	70,460	14,188	5,333	3,681	93,662
NW	99,593	9,308	9,970	12,630	131,501
NNW	26,482	10,517	7,256	12,866	57,121
Total	577,288	433,001	273,860	713,210	1,997,359

0-10 mile population 166,295

0-50 mile population 2,163,654

varies from station to station and also depends on the type of TLD being used. Each set of TLD data requires its own appropriate background estimate.

The background value for each Metropolitan Edison Station with Teledyne Isotopes dosimeters in Table 3-3 was estimated on the basis of data collected with similar dosimeters for the period December 30, 1977 - March 29, 1978, as shown in Table 3-5. Inherent in the use of these data is the assumption that there were no significant plant releases during that time period. Since the first quarter of 1978 is used as the background for the first quarter of 1979, any seasonal effect on background should be minimized. An exception was made for station 7G1, which is inside a brick building at the Columbia water treatment plant. Since the first quarter exposure for 1978 (15.8 mR/std. mo.) was substantially greater than that for the subsequent quarters, the exposure for the most recent quarter (7.20 mR/std. mo. for the last quarter of 1978) was used in order not to overestimate the background.

As mentioned previously, Metropolitan Edison utilized RMC dosimeters at several sites as a quality control check on the Teledyne Isotope dosimeters. The RMC results for 1978 (Table 3-6) are in reasonable agreement with those of Teledyne Isotopes for 1978 (Table 3-5) with the possible exception of the second quarter of 1978 which is a period during which fallout from a Chinese nuclear test made a substantial contribution to the measured exposures.

Also, as mentioned previously, the NRC dosimeters which were also analyzed by RMC are not identical to either the Teledyne Isotopes (TI) or the RMC TLD's used for Metropolitan Edison. Since these TLD's were not deployed prior to the incident there are no previous data to provide background estimates for these particular dosimeters at the NRC locations. The assumption was made that the backgrounds for those locations which are located near the Metropolitan Edison stations are the same as for the TI TLD's at those locations. Pairs of Metropolitan Edison and NRC dosimeters with similar locations are: N-1 and 1C1, SE-5 and 7F1, NW-5 and 15G1, W-2 and 12B1, S-4 and 9G1, E-1a (E-5) and 5A1, E-1 and 4A1, NE-1 and 2S2, and SE-3 and 8C1. The background for the remaining NRC stations was estimated as the mean of the Metropolitan Edison/TI stations for the first quarter of 1978 (except that the value for the last quarter of 1978 was used for station 7G1). These values probably underestimate the background for the NRC dosimeters and therefore result in an overestimate of the plant's contribution to reported dose readings.

3. Conversion from TLD Exposure to Dose*

The net exposure at each TLD location was estimated by subtracting an appropriate background for that station and time period from the TLD exposure. This net exposure (mR) was converted to dose equivalent (mrem) assuming a conversion factor of 1 mrem/mR. In some cases duplicate dosimeters were placed at particular locations. In such instances, the dose for that location and period was estimated as the mean of the doses based on each dosimeter exposure.

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*The term "dose" is used for brevity rather than the more precise term "dose equivalent."

4. Standard Grid and Population Data

The region surrounding the plant is represented on a circular grid centered at a point midway between the reactor buildings. This standard grid contains 16 sectors (N clockwise through NNW) centered on the appropriate direction. Each sector is divided into segments at standard distances of 2000 ft (.379 mi), 1, 2, 3, 4, 5, 10, 20, 30, 40, and 50 miles. The 2000-ft distance corresponds to the radius of the exclusion area for the plant. Tables 3-7 and 3-8 show the estimated 1980 population for each sector segment for distances 0-10 miles and 10-50 miles respectively.

5. Dose Estimation for Locations Within the Standard Grid

The first step in estimating doses based on the TLD measurements for each period is to estimate the doses at each location on the standard grid. This was accomplished by an interpolation which was equivalent to plotting the measured doses for each sector on logarithmic coordinate graph paper and joining the measured values by straight line segments. The intersection of each line segment with a standard distance for the grid was taken as the dose at that distance. In instances where the net dose calculated for a location was not greater than zero, this method could not be used. In such cases, linear interpolation was used to estimate the doses at standard distances.

Doses at distances beyond the outermost dosimeter or within the innermost dosimeter were estimated by extrapolation using the assumption that the dispersion in a sector is proportional to distance to the (-1.5) power.(2)* A DOE analysis concludes that their airborne measurements and the TLD data suggest a more rapid decrease of exposure with distance, more consistent with an exponential function or a power function with an exponent of (-2) (Appendix A). The (-1.5) power assumption is therefore conservative, yielding a higher collective dose.

Doses for the standard distances in sectors in which no measurements were made were estimated by interpolating linearly between the dose values of the adjacent sectors for which measured data were available.

The mean dose within each sector segment was estimated by weighting the dose, H(r), by the area within the sector

$$\bar{H} = \frac{\int_{r_1}^{r_2} H(r)rdr}{\int_{r_1}^{r_2} rdr}$$

where $\bar{H}$ is the mean dose, H(r) is the dose as a function of distance, r, and r_1 and r_2 are the inner and outer radii of the sector segment, respectively.

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(2) M. Smith (Ed.) "Recommended Guide for the Prediction of the Dispersion of Airborne Effluents," American Society of Mechanical Engineers, New York (1968), p. 44-46. This reference shows that the airborne concentration varies as r^{-p} where p can vary from 1.4 (stable conditions) to 1.8 (very unstable conditions). The value p = 1.5 approximates a daily average value.

*An empirical test was performed to check the sensitivity of this parameter. Changing the power to (-1.3) and (-1.7) changed the collective dose calculated (+17%) and (-9%) respectively.

The collective dose for each sector segment is the product of the corresponding mean dose and the population as given in Tables 3-7 and 3-8. The sum of the collective doses for all sector segments and periods is the total collective dose for the entire assessment area for the total period under consideration.

6. Collective dose calculations*

Four approaches were used in estimating the total collective dose for the period March 28-April 7. Each utilizes data from the Metropolitan Edison TLD stations for the period March 28 through March 31, since there were no NRC TLD's in place before March 31.

For the first calculational approach, all Metropolitan Edison data for the period March 28-March 31 were used for estimating the collective dose for the periods March 28-29 and March 29-31 (3200 person-rem). The NRC data, which are all from offsite locations, provided the data for the periods from April 1 through April 7. The increase in total collective dose with time using this approach is shown in Figure 3-6. Note that there is a significant contribution to the collective dose (1100 person-rem) from the first NRC period (3/31-4/1) and that there is a continuing steady contribution each day for the remaining periods. A strength of this method is that it utilizes the

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* A copy of the computer program for generating the collective doses is available from Christopher Nelson, Environmental Protection Agency, Office of Radiation Programs (ANR-461) Washington, D.C. 20460.

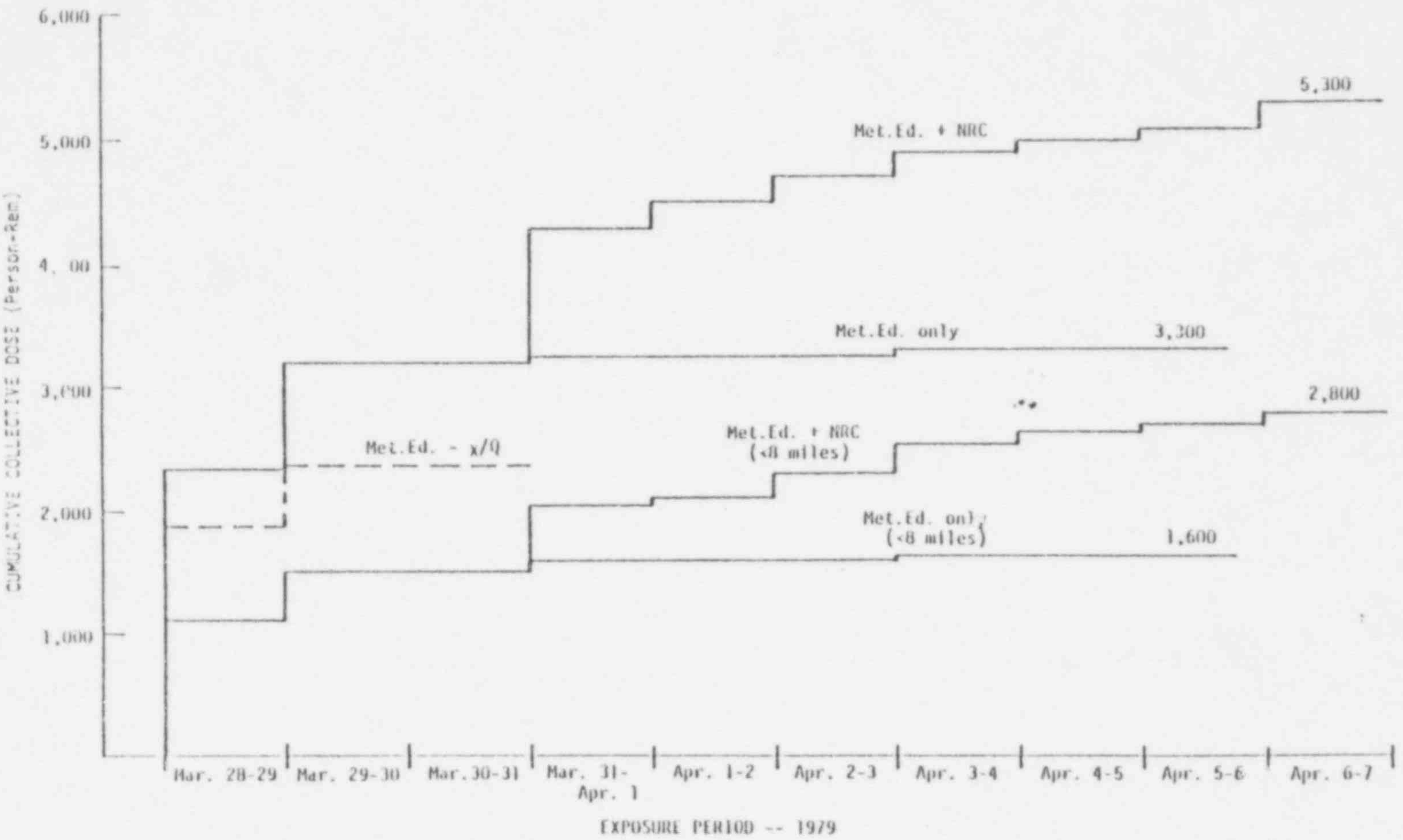

Figure 3-6. Increase in Collective Dose as a Function of Time for Various Calculation Strategies

maximum possible number of individual observations and therefore would be expected to be least dependent on any one of them. Since the NRC locations are nearly all offsite, they provide better general coverage of the populated areas surrounding the plant. However, there are limitations to using this method. For example, a positive net measurement may easily represent nothing more than a low estimate of the background for that location. If the location is distant from the facility, and is the only measurement in the sector, it can contribute to a significant overestimate in the collective dose. Another limitation of this method lies in the uncertainty of the background values for the NRC locations. As indicated previously, these background values are believed to be low. The continuing rise in the collective dose in later periods, when there is no reason to expect any significant contribution from the facility, confirms this expectation. The collective dose through April 7 using this methodology is 5300 person-rem and is believed to be a high estimate for the reasons given.

The second approach is based on the Metropolitan Edison TLD data only. This approach has the advantage of using a consistent set of data with the same dosimeter type and locations throughout the period. The background values are reasonably well known by experience for these stations. A disadvantage to this approach is that there are only 20 dosimeters, so that three sectors (NE, ESE, W) have no measurements at all and seven (NNE, SSE, SSW, SW, WSW, WNW, NW) have only one. There was concern that the onsite TLD's might be influenced by radiation levels associated with radionuclides contained within the facility and would therefore not be appropriate for estimating offsite doses. This, however, does not appear to be the case. These dosimeters around the periphery of Three Mile Island show a variation from time period to time period, which would not be expected if they were appreciably affected by contained onsite radiation sources. Onsite radiation monitoring with hand-held radiation monitors also confirms the absence of a significant "direct radiation" component except very close to the containment or auxiliary buildings. The total collective dose through April 6 using this approach is 3300 person-rem. April 6 becomes the cutoff point in this method because of the 3-day dosimeter cycle under which the Metropolitan Edison TLD's were deployed and read out.

A third approach is based on a subset of the dosimeters used in the first method. Those locations outside 8 miles were dropped from the analysis, eliminating 5 Metropolitan Edison and 7 NRC stations. This has the advantage of minimizing the effect of exposure uncertainties at those locations which are least likely to have been exposed to radioactive material from the facility. The disadvantage is that a significant dose at a distance greater than 8 miles in a direction where there are no other dosimeters nearer to the facility will be missed completely. Note that this substantially reduces both the March 29-31 Metropolitan Edison dosimeter contribution to the collective dose and the contribution from the first day of NRC observations. The total collective dose through April 7 using this approach is 2800 person-rem.

The fourth approach is based on using those Metropolitan Edison TLD data from locations that are not more than 8 miles from the facility. Again the method has the advantage of a consistent base of data for the entire period and the disadvantage of making a small data base even smaller. The effect of eliminating the distant stations is to reduce the collective dose calculated for the period. Using approach four, the collective dose through April 6 is 1600 person-rem.

Time did not permit the inclusion in the dose calculations of the Metropolitan Edison - RMC TLD data (which provide independent measurements of the exposure at 10 of the Metropolitan Edison TLD locations). Inspection of these RMC results, in Tables 3-3 and 3-6, indicates that including them in the calculations would lower the calculated collective dose values.

Given the limited number of observations (especially for the period March 28-31, when it would appear that most of the collective dose was delivered) it is evident that any approach to assessing the collective dose depends strongly on a relatively small number of measurements. No amount of sophisticated analysis can change this fundamental limitation. On the other hand, it is also clear that the data do allow reasonable estimates of the collective dose to be made.

7. Calculations Employing Meteorological Dispersion Factors

Computed values of the meteorological dispersion factor (χ/Q) for the time period of March 28, 4:00 a.m. through March 29, 8:00 a.m. and March 29, 8:00 a.m. through March 31, 4:00 a.m. were used to estimate collective dose. This method was intended to serve as an independent check on the methods described earlier. These values of χ/Q calculated hourly were time-averaged over these periods for each distance and direction segment.*

The dose H (mrem) for time interval, Δt, is calculated from the following equation:

$$H = (\frac{\chi}{Q})\ Q\ (DF)\ \Delta t$$

where

H	dose received over the time interval, Δt (mrem)
Q	source (Ci/sec)
(χ/Q)	meteorological dispersion factor (sec/m^3)
DF	dose factor (mrem m^3/Ci sec)
Δt	length of time interval (sec).

Assuming that the release rate, Q, is constant over time interval, Δt, the quotient, $H/(\chi/Q)$, is constant for each sector section since the product, $Q(DF)\Delta t$, is also constant. Doses based on exposures appearing in Table 3-3 for the first two time periods were divided by the corresponding χ/Q values determined by interpolation of the meteorological data. These quotients were then averaged for each time period. Multiplication of these two average $H/(\chi/Q)$

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*These data and calculations are available if requested. Contact Dr. F. Congel, U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation (P-712), Washington, D.C. 20555.

values by the appropriate χ/Q value at different sector segments for the two time intervals yielded an estimate of the dose at those locations for each time interval. The total collective dose was estimated by multiplying the sector segment population by dose at the inner boundary. Since the inner boundary dose is always larger than the outer boundary dose for each sector segment, a conservative estimate of collective dose is obtained.

The total 0-50 mile collective dose for the first and second period was 1900 person-rem and 680 person-rem, respectively, for a total value of about 2600 person-rem. This value lies in the middle of the range of values estimated in the preceding section (see Figure 3-6).

C. OFFSITE MAXIMUM DOSE TO AN INDIVIDUAL

The estimated maximum dose to an individual depends upon the local meteorological conditions, namely, wind direction, wind speed, and plume dispersion characteristics. The known meteorological conditions throughout the accident period indicate that there were three predominant directions in which radioactive material released from the plant would be expected to be found. These directions were characteristic of the near-field 0-5 mile dispersion values (χ/Q), as well as the far-field 5-50 mile, dispersion values. In addition to the meteorological considerations, TLD's placed at locations within and beyond the site boundaries, airborne measurements of plume exposure by helicopter flights made by the Department of Energy (DOE) after the onset of the accident and throughout the period, and both onsite and offsite survey meter readings support the conclusion that the effluents were dispersed in three predominant directions. Figure A-1 (see Appendix A) depicts estimated exposure isopleths. This figure was prepared using DOE data for the period from March 28 through April 3.

The lobes of the isopleths of Figure A-1 indicate the predominant exposures to offsite individuals to be in the NNW, ENE, and SSE sectors. The maximum exposed individual would be expected to reside in one of these sectors, and also at a location close to the plant within one of these sectors since the airborne concentration of radionuclides in the plume decreases as distance from the source increases.

Figure 3-7 shows the locations of the TLD's used in estimating maximum individual doses and the locations of the nearest populated areas. The populated area closest to the plant is in the ENE sector. The TLD in the ENE sector at a distance of 0.5 mile registered a net cumulative dose of 83 mrem. This dose value represents an upper limit for the period March 28 through April 7 since no individual member of the general public could be closer to the plant. The next nearest populated land mass outside the plant boundary is in the SSE sector and is located approximately 0.8 mile from the plant. The nearest TLD located in the south sector is approximately 0.4 mile from the plant. The net cumulative dose at this location is 41 mrem. It is expected that the maximum dose to an individual in this area (SSE

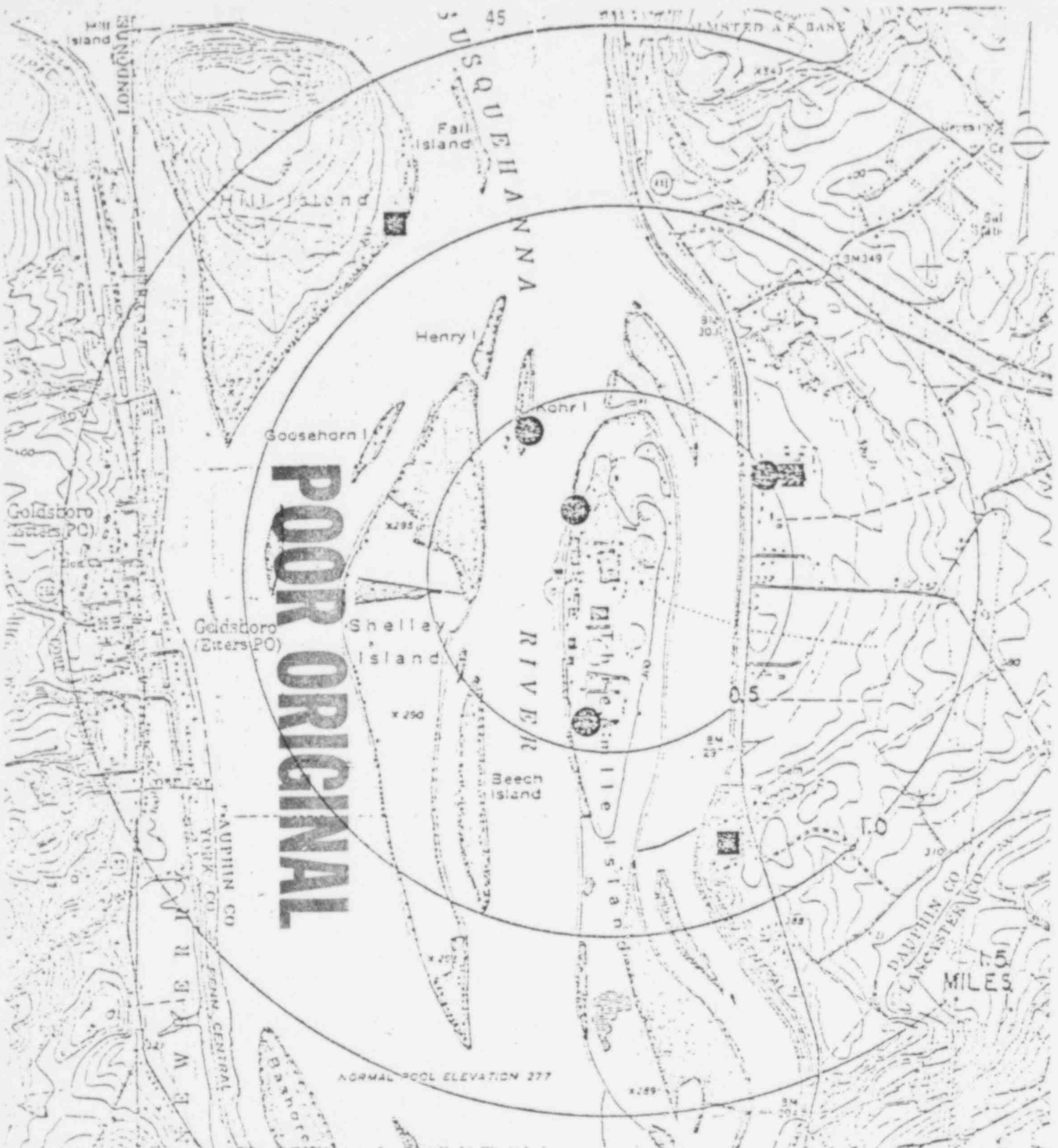

Figure 3-7. Sites of Potential Maximum Exposed Individuals

sector) would be less than the 41 mrem because the populated area is twice as far from the plant as is the detector location.

The nearest offsite area in the NNW sector is Kohr Island. However, Kohr Island was uninhabited during the period following the accident.[*] On April 19, 1979, inspectors from the NRC Office of Inspection and Enforcement received reports that as many as three people may have been on Hill Island (about 1 mile NNW of the TMI Island plant) on March 28 or 29. Through subsequent inquiries, NRC was only able to confirm that one individual was on the Island. He was interviewed and stated that he was the only individual present on the island following the accident and was working on a summer cottage. He was present nine and one-half hours (from 11:00 am to 4:30 pm on March 28 and from 11:00 am to 3:00 pm on March 29).

The potential dose to an individual at that particular location on Hill Island was estimated from TLD's that were close to the TMI facility and in the same direction sector (NNW) as the island. The following data were used to estimate the exposure at Hill Island (1.1 miles NNW).

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[*] This is based upon surveys conducted by the Metropolitan Edison Company staff and NRC Office of Inspection and Enforcement personnel.

	Dose (mrem)	Distance (miles)	Metropolitan Edison Station Code (see Table 3-1)
4:00 a.m. 3/28 -	1020*	0.20	16S1
12:10 p.m. 3/29	440 900	0.42 0.42	16A1 16A1
12:10 p.m. 3/29 -	83	0.20	16S1
10:45 a.m. 3/31	45	0.42	16A1

The discrepancy (900 versus 440 mrem) between the two TLD dosimeter values for the initial time period was investigated, but could not be explained. However, based on an examination of the meteorological dispersion during that time period and the dosimeters at site 16S1*, it appears that the 440 mrem value is more plausible. Using the 440 mrem value, the extrapolated dose at the cottage location on Hill Island would be about 150 mrem for the first time period. The dose at Hill Island for the second time period would be about 18 mrem.

Since the person was not present on the island during the entire period (from the time of the accident until 10:45 on March 31), the exposure has to be reduced accordingly. This "occupancy factor" is determined by assuming that the exposure rate was constant for each time period and as follows: The individual was present for about 5.5 hours on March 28 and slightly more than 1

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*A second quality assurance dosimeter placed by Radiation Management Corporation (RMC) at this location (16S1) for the same period gave a net result of 917 mrem. This supports the magnitude of the dose at this site.

hour on March 29 until the first TLD's were replaced at 12:10 p.m. The total individual exposure time was 7 hours for the first time period. It was assumed that the releases started at about 7:00 a.m. March 28, and continued at a uniform rate until the TLD's were replaced at 12:10 p.m. on March 29 for a total TLD exposure time of 29 hours for the first time period. The second time period began at 12:10 p.m. March 29, and ended 10:45 a.m. on March 31, for a total TLD exposure time of 47 hours. The individual on Hill Island was exposed during the second time period for 3 hours. Using the actual occupancy time on the island, the estimated individual exposure becomes approximately 37 mrem.

If the higher initial period TLD reading (900 mrem) was used, the individual's dose would be estimated at about 180 mrem. If the two TLD's with the large discrepancy are averaged (670 mrem), the individual's dose would be estimated at about 93 mrem. However, it appears that the most probable estimate of dose to the individual is 37 mrem.

4. POTENTIAL HEALTH IMPACT OF EXTERNAL EXPOSURE

A. Health Effects from Low-Level Radiation

The health risks from low-level radiation are derived by assuming that the effects observed at high doses from high dose rates can be directly and linearly extrapolated to low doses delivered at very much lower dose rates. It is also assumed that there is no absolutely safe dose (or threshold) below which there is no health risk. These assumptions result in a linear, non-threshold, dose-rate-independent dose-effect relationship. This relationship is generally* believed to overestimate the health risk from low-level beta and gamma radiation doses (1-3).

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*The 1972 BEIR Committee (3) noted that (p. 88): "...Expectations based on linear extrapolation from the known effects in man of larger doses delivered at high dose rates in the range of rising dose-incidence relationship may well overestimate the risks of low-LET radiation at low dose rates and may, therefore, be regarded as upper limits of risk for low-level low-LET irradiation. The lower limit, depending on the shape of the dose-incidence curve for low-LET radiation and the efficiency of repair processes in counteracting carcinogenic effects, could be appreciably smaller (the possibility of zero is not excluded by the data). On the other hand, because there is greater killing of susceptible cells at high doses and high dose rates, extrapolation based on effects observed under these exposure conditions may be postulated to underestimate the risks of irradiation at low doses and low dose rates."

There are a few recent studies that suggest that the risks of low-level ionizing radiation might be greater than predicted from linear extrapolation from high doses. However, the results of these studies have not been generally accepted by the scientific community. It is important to consider both studies that present higher risk estimates and studies that present lower risk estimates together with the complete body of scientific literature on the effects of ionizing radiation rather than relying on the results of a single, or even a few, studies.

(1) International Commission on Radiological Protection, "Recommendations of the International Commission on Radiological Protection Adopted January 13, 1977" ICRP Publication 26, Pergamon Press, Oxford (1977) Section E pp 6-7.

(2) National Council on Radiation Protection and Measurements, "Review of the Current State of Radiation Protection Philosophy." NCRP Report No. 43, NCRP, Washington, D.C. (January 15, 1975) p.4.

(3) Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR) "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," National Academy of Sciences - National Research Council, Washington, D.C. November 1972, Chapter VII, Section IV pp 87-88.

Somatic Effects

Somatic radiation effects are those effects that may appear in the irradiated individual. The primary somatic effect observed following high doses of radiation is an increase in cancer deaths (cancer mortality). The risk of cancer per unit dose of radiation can be expressed in an absolute sense or in relative (comparative) sense. The absolute risk is the difference in risk between an exposed (irradiated) population and an unirradiated population of similar characteristics. Under the linear dose-effect relationship, the absolute risk may be expressed as the increased number of radiation-related cases of cancer per year in an exposed population per unit of dose; for example, 10 deaths per year per million people exposed per rem (10 deaths/year per 10^6 person-rem).

The relative risk is the ratio between the risk of the irradiated population and the unirradiated population. It is usually stated as a fraction or multiple of the natural risk for that particular effect; for example, 0.5% per year. In order to convert the relative risk into units comparable to the absolute risk, it is necessary to multiply the relative risk by the natural cancer mortality rate for each type of cancer (cancer deaths per year/10^5 people); for example, for total cancer mortality the death rate is approximately 2000 deaths per year per 1,000,000 people; therefore:

$$\frac{0.005(0.5\%)}{\text{rem}} \times \frac{2000\ \text{cancer deaths}}{10^6\ \text{person-year}} = \frac{10\ \text{cancer deaths/year}}{10^6\ \text{person-rem}} .$$

The risk of cancer may [illegible] immediately after irradiation. It can require several years before the risk becomes increased (typically 2-20 years, depending upon the cancer type and age of the person irradiated*). This

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*For in utero (in the womb) irradiation there may be no latent period [(3) p. 171].

time interval between irradiation and the appearance of cancer is called the latent period. Following this latent period, there is a period where there is an increased risk of cancer in an irradiated population. In order to estimate the total risk of cancer from a single dose of radiation, it is necessary to multiply either the absolute risk or the relative risk by the duration (length) of this period. The exact length of the period of increased risk is not known for most radiation-induced cancers. Therefore, two assumptions have been made concerning this: Assumption A is that the risk remains elevated for 30 years following the latent period and then drops to zero, assumption B is that the risk remains elevated for the remainder of the individual's lifetime. The risks of fatal cancer from radiation exposure, estimated from the data in the 1972 BEIR Report(3) for both relative risks and absolute risks and for Assumptions A and B, are shown in Table 4-1.

Genetic Effects

It is firmly established that ionizing radiation can cause genetic mutations and other anomalies in animals. These effects can be manifested as congenital anomalies (birth defects) or hereditary abnormalities in descendents of an irradiated parent or parents. However, the exact numerical value for the risk of genetic injury from low doses in man is uncertain. The genetic effects estimated in the 1972 Report of the Advisory Committee on the Biological Effects of Ionizing Radiation(3) are based upon estimates that the radiation dose which would double the natural incidence of genetic anomalies (doubling dose) is between 20 and 200 rem (20,000 and 200,000 mrem). The lower the doubling dose, the

Table 4-1. RADIATION-INDUCED CANCER MORTALITY ESTIMATED IN THE 1972 BEIR REPORT (3)

	1972 BEIR Report Estimates		Derived Risk	
	Annual number of deaths resulting from exposure of the U.S. population to a radiation dose rate of 0.1 rem [100 millirem] per year[(a)]		Number of Cancer Deaths per 10^6 person-rem[(b)]	
	Absolute Risk Model	Relative Risk Model	Absolute Risk Model	Relative Risk Model
Leukemia	516	738	26	37
Other Fatal Cancers				
Assumption A:[(c)]	1210	2436	61	123
Assumption B:[(d)]	1485	8340	75	421
Total (Range)[(e)]	1726-2001	3174-9078	87-101	160-458
Nominal Range[(f)]	1700-2000	3200-9100	90-100	160-460

Geometric mean $(95 \times 310)^{1/2}$ = 200 (172)

(a) 1967 U.S. population = 197,863,000. Collective Dose Rate = (198×10^6 people) x (0.1 rem/yr) = 19.8×10^6 person-rem/year. From Table 3-3 (Relative Risk and Table 3-4 (Absolute Risk) of the 1972 BEIR Report (3) pp. 172-173.

(b) 1972 BEIR Values (Cancer deaths/year) divided by the collective dose rate of 19.8 [10^6 person-rem]/year.

(c) Assumption A: 30-year period of elevated risk following irradiation.

(d) Assumption B: Lifetime period of elevated risk following irradiation.

(e) Low estimate = Leukemia Risk + Assumption A for other fatal cancers.
High estimate = Leukemia Risk + Assumption B for other fatal cancers.

(f) Preceeding values rounded to two significant figures.

greater the risk from a given radiation dose. Table 4-2 summarizes the calculation of the genetic risk per unit radiation dose from the data given in the 1972 BEIR report. This calculation was based upon the 1967 birth rate of approximately 18.2 births per year per 1,000 people. The use of the 1976 birth rate of 14.2 births per year per 1,000 people would give lower risks per person-rem by a factor of 14.2/18.2 or about 0.8.

B. Comparison of Doses to Individuals from the TMI Accident with Natural Background Radiation and its Variability

Man is continually exposed to ionizing radiation which occurs naturally. There are three primary sources of this natural radiation "background": (1) solar and galactic cosmic radiation, (2) long-lived radionuclides in the earth's crust (primordial radionuclides) and (3) radionuclides formed in the upper atmosphere from the interactions of the cosmic radiation with gases in the atmosphere (cosmogenic radionuclides). The magnitude and variation in the radiation dose from these natural radiation sources provides one baseline for comparing the doses and the potential health impact from the Three Mile Island accident.

Estimates of the dose from background radiation at several locations in the United States are shown in Table 4-3. None of these values are measured values but they are generally consistent with reported measurements.(4-5)

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(4)D.T. Oakley, "Natural Radiation Exposure in the United States," EPA Report ORP/SID 72-1, U.S. Environmental Protection Agency, Washington, D.C. (1972).

(5)National Council on Radiation Protection and Measurements, "Natural Background Radiation in the United States" NCRP Report No. 45, NCRP, Washington, D.C., November 15, 1975.

Table 4-2. ESTIMATES OF GENETIC EFFECTS OF LOW-LEVEL IONIZING RADIATION

Disease Classification	Natural Incidence (per 10^6 live births)	Effects per 10^6 live births[a] of 5 rem per generation[b]		Estimated Risk per 10^6 person-rem[c]	
		First Generation	Equilibrium	First Generation	Equilibrium
Dominant diseases	10,000	50 to 500	250 to 2500	6 to 60	30 to 300
Chromosomal and recessive diseases	10,000	relatively slight	very slow increase	relatively slight	very slow increase
Congenital anomalies	15,000				
Anomalies expressed later	10,000	5 to 500	50 to 5,000	0.6 to 60	6 to 600
Constitutional and degenerative diseases	15,000				
TOTAL	60,000	60 to 1000	300 to 7500	7 to 120	36 to 900
Risk per 10^6 people	1,200[d]/year				
			Geometric Mean	$(36 \times 900)^{1/2} = 200$ (180)	

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[a] From the 1972 BEIR Report (3), Table 4 p. 57 which is believed to be erroneously titled. This table, like the preceding tables 2-3 pp. 54-55, is believed to be for a population of one million "live births" not for a population of one million. The range of values corresponds to assumed doubling doses between 20 rem (high values) and 200 rem (lower values).

[b] A generation is assumed to be 30 years.

[c] Risk per 10^6 person-rem = (cases/10^6 live births) × (30 years/5 rem) × (4×10^6 live births/year per 2×10^8 people) = 0.12 × cases/10^6 live births.

[d] Cases/10^6 live births × (4×10^6 live births per year/ 2×10^8 people).

Table 4-3

Estimates of Natural "Background" Radiation Levels in the United States

Location	Annual Dose Rate (mrem/year) Cosmic Radiation(a)	Terrestrial Radiation(a)	Internal Radiation(b)	Total
Atlanta, Georgia	44.7	57.2	28	130
Denver, Colorado	74.9	89.7	28	193
HARRISBURG, PA.	42.0	45.6	28	116*
Las Vegas, Nev.	49.6	19.9	28	98
New York, NY	41.0	45.6	28	115
PENNSYLVANIA	42.6(c)	36.2(c)	28	107
Washington, DC	41.3	35.4	28	105
UNITED STATES(d)	40-160	0-120	28	70-310

(a) From [(4) Table A-1]

(b) Based upon total for soft tissue (gonads) doses from [(5) Tables 42 and 43, p. 104].

(c) From [(4) Table A-2]

(d) From [(4), Table 15, p. 34]

* The value used elsewhere in this report is 125 mrem/year which is based upon the Final Environmental Statement for the Three Mile Island Facility (AEC, 1972, Section VD 7, p. V-28). As neither value represents direct measurements and ambient radiation dose rates are expected to vary by at least 25% between locations within a 50-mile radius, these estimates are essentially identical.

Table 4-4 compares the estimated individual doses from the Three Mile Island accident to some of the variations in annual radiation doses from background radiation. It should be noted, however, that the "background" doses are delivered continuously, whereas the accident doses were delivered over a period of a few days. The possible significance of this higher dose rate is discussed in a following section on dose-rate effects. It should also be noted that the "average" doses to individuals within 10 and within 50 miles of the site are numerical averages obtained by dividing the collective population doses by the size of enclosed population. Clearly, some individuals received more than this dose and others less, depending upon wind direction and distance from the TMI site.

C. Existing Cancer Rates and Risks

Cancer is the second leading cause of death (next to heart disease) in the United States [(6) p. 14)]. The Vital Statistics of the United States, 1976 shows that there were 377,312 deaths in the U.S. from cancer, which corresponds to a rate of about 180 cancer deaths per 100,000 people per year [(6) p. 14]. Cancer deaths accounted for approximately one-fifth (0.198) of all deaths in the U.S. in 1976. The existing cancer rate provides an indication of the possibility of detecting any potential increase in cancer incidence due to the Three Mile Island accident.

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(6)From American Cancer Society, "Cancer Facts and Figures - 1979," Reproduced by permission of the American Cancer Society who retains copyright. Subsequent quotations should acknowledge the American Cancer Society as the source of these values.

Table 4-4

Comparison of Individual Doses from the Three Mile Island Accident With Variations in Natural Background Radiation Doses

THREE MILE ISLAND ACCIDENT	CUMULATIVE TOTAL BODY DOSES DELIVERED THRU 4/7/79
Individual remaining out-of-doors at location of highest estimated offsite dose	less than 100 mrem
Average dose to a typical individual within:	
50 miles of site	1.5 mrem
10 miles of the site	8 mrem
(These values correspond to the 3,300 person-rem collective dose estimate)	

NATURAL BACKGROUND VARIATION	ESTIMATED DIFFERENCE IN ANNUAL DOSES
Living in Denver, Colorado compared to Harrisburg, PA (from Table 4-4)	+ 80 mrem/yr
Living in a brick house instead of a wood frame house [Yeates data in (4) Table 16, p. 35]	+ 14 mrem/yr
Added dose from potassium-40 due to being male instead of female (There is 25% less potassium in women than men [(5), p. 106])	+ 4.8 mrem/yr

The cancer death rate for the State of Pennsylvania estimated by The American Cancer Society [(6) p. 12] is 208 deaths per year per 100,000 people (2.08×10^{-3}). Portions of the State of Maryland are also located within 50 miles of the TMI site. Maryland has a lower estimated rate (179 per 100,000)- which is closer to the estimated U.S. rate of 180 per 100,000 [(6) p. 12]. Applying the U.S. or Pennsylvania values to the 2,164,000 people estimated to reside within 50 miles of the Three Mile Island site gives an approximate estimate of 3,900 (U.S.) to 4,500 (Pa) deaths per year for the existing cancer death rate for that population. Table 4-5 shows the estimated incidence (number of new cases) and death rate for the U.S. population for selected types of cancers.

The American Cancer Society [(6) p. 14] estimates that, out of 100,000 people, 25,000 will eventually develop cancer and, of these 25,000, about 15,000 will eventually die of cancer. This gives an estimate of the risk of cancer death of 0.15.* Applying this approximate statistic to the population within 50 miles of the Three Mile Island site indicates that approximately 325,000 people in that area would normally die of cancer.

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[*] This has a range between 0.15 and 0.17 depending upon the source of the data and the year to which it applies.

Table 4-5

Estimated New Cancer Cases and Deaths in the United States for 1979 (Existing Rates)

Specific Cancers	Estimated* New Cases	Estimated* Deaths	Deaths/Cases(a)
Digestive Organs	182,900	105,150	0.57
Lung	112,000	97,500	0.87
Bone	1,900	1,750	0.92
Skin	13,600(b)	4,300(b)	0.32
Breast	106,900	34,500	0.32
Genital Organs	143,500	44,800	0.31
Leukemia	21,500	15,400	0.72
Thyroid	9,000	1,000	0.11
All Sites* (including cancers not listed above)	765,000	395,000	0.52

(a) If cancer rates and the population (and its age composition) were constant this ratio would be a measure of the probability of dying from having specified types of cancer. As neither existing cancer rates nor the U.S. population and its age breakdown are constant, this is only an approximate measure of severity of cancers at a particular site.

(b) This only for melanoma, a rare skin cancer with a high mortality rate (for skin cancers).

* From American Cancer Society, "Cancer Facts and Figures-1979" p. 10. Reproduced by permission of the copyright holder, the American Cancer Society. All subsequent quotations of these values should acknowledge the American Cancer Society as the source of these estimates.

D. Summary of the Health Impact to the Exposed Population

Table 4-6 shows the estimated potential health effects from the Three Mile Island Nuclear Accident.* The central estimate is associated with the mean value of the collective dose (3300 person-rem) delivered to the population within 50 miles of the reactor. These estimates consider fatal cancers, non-fatal cancers and genetic ill-health to all future generations. The projected total number of fatal cancers is less than 1 (0.7). The additional number of non-fatal cancers is also less than 1 (0.7). The additional number of genetic effects for all generations is also less than 1 (0.7). The total number of health effects is approximately 2. The ranges given in Table 4-6 represent the extreme values considering both the range of the collective dose estimates and the range of risk estimates given in the 1972 BEIR report. All of these values are small compared to either the existing annual incidence of similar effects or the potential effects estimated to result from the natural background radiation. The total collective dose from natural background to the population within 50 miles of the Three Mile Island site is estimated to be about 270,000 person-rem per year (0.125 rem per year x 2,164,000 persons). The potential health consequences of the natural radiation exposure are shown in Table 4-7. Comparing the total potential health impact of the accident with the estimated lifetime natural risk indicates that these effects, if they were to occur, would not be discernible. The uncertainties in the risk from low-level ionizing radiation would not alter this conclusion.

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* An independent EPA assessment of the potential health effects corresponding to an earlier collective dose estimate of 2000 [1800] person-rem is presented in Appendix E.

Table 4-6. PROJECTED POTENTIAL HEALTH IMPACT OF THE THREE MILE ISLAND ACCIDENT TO THE OFFSITE POPULATION WITHIN 50 MILES

Effect	Estimated Number who would normally develop effect	Potential Impact of Natural Background Radiation	Potential Lifetime Impact of Population Dose from the TMI Accident from March 28, 1979 through April 7, 1979	
			Range(a)	Central Estimate(b)
Fatal Cancers	325,000(c)	1,700 - 9,000(d)	0.15 - 2.4(e)	0.7
Non-Fatal Cancers	216,000(f)	1,700 - 9,000(d,g)	0.15 - 2.4(c,f)	0.7
Genetic Effects				
first generation	78,000(h)	60 - 970(i)	(0.01 - 0.64)(j)	-
all future generations	-		0.05 - 4.8(k)	0.7
All Health Effects			0.4 - 10(l)	2.0(l)

Footnotes next page

Footnotes for Table 4-6

(a) This represents the extreme range of health effects estimates considering both the range of the collective dose estimates and the range of the estimates of the risks of low-level ionizing radiation as estimated in the 1972 BEIR Report (3).

(b) The central estimate is based upon taking the geometric mean (square root of the product) of the upper and lower bounds of the dose-to-health-risk conversion factors from Table 4-1 and multiplying this by the mean estimate of the population dose (3,300).

(c) Based upon the American Cancer Society projection that the risk of cancer death is 0.15 (0.15 x 2,164,000 = 324,600).

(d) Based upon multiplying the annual rates in Table 4-7 by 70 years, the mean life span.

(e) Based upon multiplying the lower range estimate of the population dose (1,600 person-rem) by the lower range of the absolute radiation-induced cancer risk (90×10^{-6}) and the upper range estimate of the population dose (5,300) by upper range of the relative radiation-induced cancer risk (460×10^{-6}).

(f) Based upon the difference between the American Cancer Society projection of the risk of getting cancer (0.25) and the risk of dying of cancer (0.15). The value given is the product of this difference (0.25 - 0.15 = 0.10) and the size of the population (2,164,000).

(g) Based upon the assumption that there are twice as many cancers as there are cancer fatalities.

(h) Based upon the natural annual incidence of genetic effects (1,200 per year per 10^6 population) from table 4-2 times an assumed reproductive period of 30 years.

(i) Based upon multiplying the risk to the first generation from table 4-2 by an assumed reproductive period of 30 years and by the natural background dose rate of 270,500 person-rem per year.

(j) Based upon multiplying the lower bound of first generation risk (7×10^{-6}) from Table 4-2 by the lower bound of the collective dose estimate (1,600 person-rem) and multiplying the upper bound of the first generation risk (120×10^{-6}) from Table 4-2 by the upper bound of the collective dose estimate (5,300 person-rem). The first generation risk is included in the risk to all generations and therefore, should not be separately added into the total.

(k) Based upon the procedure described in (j) but using the equilibrium risk bounds rather than the first generation risk.

(l) This is done for the convenience of providing an estimate of the total potential health impact. Technically, the effects are not equivalent and cannot be added.

Table 4-7. PROJECTED ANNUAL IMPACT OF NATURAL BACKGROUND RADIATION EXPOSURE ON THE POPULATION RESIDING WITHIN 50 MILES OF THE THREE MILE ISLAND SITE

Effect	Estimated Existing Rate (per year)	Estimated Impact of Natural Background Radiation[(a)] (per year)	Estimated Percentage of Existing Rate Which Might be Caused by Natural Background Radiation
Fatal Cancers	3,900	Absolute risk 24-27	0.6-0.7%
		Relative risk 43-124	1.1-3.2%
		Central Estimate 54[(b)]	1.4%
Spontaneous Mutations (Genetic Effects)	2,600[(c)]	10-245	0.4-9.4%
		Central Estimate 54[(b)]	2.1%

[(a)] Assumed to be 125 millirem (0.125 rem) per year to the 2,163,654 people projected (1980) to live within 50 miles. This gives a collective dose rate of 270,500 person-rem per year.

[(b)] The central estimate is obtained from the geometric mean of the risk estimates.

[(c)] 1,200 per year per 10^6 people (from Table 4-2) × 2.163 million people.

E. Potential Added Risk to Maximum Individual

The added lifetime risk of fatal cancer to the hypothetical maximum exposed individual from the accident is 2.0×10^{-5} (0.00002). This is based upon a presumed 100 mrem dose rather than the estimated values. This added risk (0.00002) is extremely small compared to the normal risk (0.15) to an individual of dying from cancer. It is also small (1.1 percent) compared to the potential lifetime fatal cancer risk that would be associated with natural background radiation using the same dose-to-health effect relationships as used for the accident impact.

F. Dose Rate Effects

The estimated maximum dose to a hypothetical individual (less than 100 mrem) is numerically approximately the same as the annual dose from natural background radiation to residents in the Harrisburg area (115-125 mrem/yr). There has been some concern that, because this dose was delivered in 1 week instead of 1 year, the biological effects of this accident would be greater than from natural background radiation. This presumes that radiation delivered at a higher rate is more dangerous than radiation delivered at lower rates (that there is a "dose-rate effect").

If there were such a "dose-rate effect," then the linear extrapolation of the number of effects observed at high doses and dose rates would overestimate the risk per unit dose at low doses and low dose rates.* This is because the estimates of the health effects of low-level radiation are derived from observations made at much higher doses and dose-rates than experienced during the Three Mile Island Accident. The estimates of the health impact of the Three Mile Island accident have not included any additional factors to account for reductions due to a dose-rate effect. However, a factor of 3 was used by the 1972 BEIR Committee for genetic effects in their report [(3) p. 53, p. 61 (Note 4)].

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* One estimate indicates that somatic effects (cancer) might be overestimated at low doses by a factor of 2 to 4. United Nations Scientific Committee on The Effects of Atomic Radiation, "Sources and Effects of Ionizing Radiation - 1977 Report", UNSCEAR, United Nations, N.Y., N.Y. (1977), Annex G, p. 366, paragraph 36.

5. OTHER SOURCES OF EXPOSURE

A. Skin Doses and Health Risks from Beta and Gamma Radiation

The contribution of beta radiation from xenon-133 is not included in the doses calculated in Section 3 or the health effects computed in Section 4. Those sections dealt only with external exposure to gamma radiation. Considerations that must be taken into account in assessing the beta radiation contribution include:

(1) The range of beta particles (electrons) in air is short. The maximum energy (0.35 MeV; average energy 0.12 MeV) of the beta particle from xenon-133, for example, has a maximum range in air of only 30 inches; therefore, an individual must be standing in or very near the xenon-133 plume to be exposed to beta radiation. The time that any individual would be so exposed is not known.

(2) The beta radiation would be stopped by clothing.

(3) At the present time, the sensitivity or response of the thermoluminescent dosimeters to beta irradiation is not known (it is assumed to be zero).*

(4) The composition of the radioactive gases in the plume is not well known for most of the locations of interest.

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*If there were a significant beta dose contribution to the dose recorded by the thermoluminescent dosimeters (TLDs), then the total body dose estimated from the TLD readings would have to be reduced to allow for this non-penetrating beta dose contribution. The beta skin dose is estimated in this section from a theoretical ratio of the beta dose to the gamma dose. If the "gamma" dose recorded by the TLDs is too high because it includes a beta dose contribution, then the beta skin dose estimated from the beta/gamma ratio would also be overestimated.

(5) The principal health consequences of skin irradiation is skin cancer, which is not a predominant form of radiation-induced fatal cancer.

Although the beta radiation dose cannot be assessed by direct measurement during the accident, it can be estimated from the technical literature. The depth dose from xenon-133 electrons and beta particles decreases by a factor of 0.39 at a skin depth of 0.005 cm or 50 μm (an areal density in tissue of 0.005 g/cm^2). This depth is approximately the thickness of the non-living protective layer of skin.(1-2) The depth dose to internal organs from these beta particles is essentially zero. The beta particle skin dose rate at the 50 μm depth per unit of xenon-133 concentration in air, estimated from the depth-dose calculations of Berger(3) is 4.7×10^8 mrem/yr per μCi xenon-133/cm^3 compared to estimates of the gamma-ray total body dose of 1.90×10^8 mrem/yr per μCi xenon-133/cm^3,(4) or approximately a factor of 2.5 higher. The gamma-ray skin dose rate is 2.55×10^8 mrem/yr per μCi xenon-133/cm^3.(4) Therefore, the combined beta and gamma "skin" dose rate is 7.25×10^8 mrem/yr per μCi xenon-133/cm^3, or a factor of 3.8 times the total body gamma-ray dose rate. Table 5-1

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(1)"Recommendations of the International Commission on Radiological Protection Adopted January 27, 1977," ICRP Publication 26. Pergamon Press, Oxford, England, paragraphs (63) and (64), p. 13.

(2)National Council on Radiation Protection and Measurements, "Krypton-85 in the Atmosphere - Accumulation, Biological Significance, and Control Technology," NCRP Report No. 44, National Council on Radiation Protection and Measurements, Washington, D.C., July 1, 1979. Table 13, p. 30.

(3)M.J. Berger, "Beta-ray dose in tissue-equivalent material immersed in a radioactive cloud," Health Physics, vol. 26 (1): 1-12 (January 1974).

(4)D.C. Kocher, "Dose-Rate Conversion Factors for External Exposure to Photon and Electron Radiation from Radionuclides Occurring in Routine Releases from Nuclear Fuel Cycle Facilities," U.S. Nuclear Regulatory Commission Contract Report NUREG/CR-0494 (Oak Ridge National Laboratory Report ORNL/NUREG/TM-283), April 1979.

provides the ratio of the beta plus gamma skin dose to the total body gamma dose for the principal radionuclides measured at offsite locations. For a total body gamma dose of approximately 100 mrem, the beta plus gamma dose from xenon-133 would be about 380 mrem (for a 50 mm skin depth), if the individual were exposed in the plume out-of-doors without benefit of shelter or clothing for the entire period.

The 1972 report of the National Academy of Sciences' Advisory Committee on the Biological Effects of Ionizing Radiation(5) does not provide numerical estimates of the risk at low doses for skin cancers. Skin cancers from radiation exposure reported in this report are associated with doses above 230,000 mrem in rats and above 450,000 mrem in humans. This latter dose is sufficient to cause visible effects on the skin and is more than a factor of 1,000 greater than the estimated total (beta and gamma) skin dose (380 mrem) to any exposed individual, even neglecting shielding by clothing or by being indoors.

The International Commission on Radiological Protection (ICRP) considers skin to be less likely to develop fatal cancers after irradiation than other tissues(1). They recommend a lifetime occupational dose limit for skin of 2,000,000 mrem(1) or 5,000 mrem per year for members of the general public [(1) p. 25]. It is also significant that the ICRP has considered the organ at the highest risk (critical organ) for exposure to radioactive noble gases, such as xenon-133, to be the total body and not the skin or lung(6).

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(5) Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR), "The Effects on Populations of Exposure to Low-Levels of Ionizing Radiation", National Academy of Sciences - National Research Council (1972) pp 132-135.

(6) "Recommendations of the International Commission on Radiological Protection. Report of Committee II on Permissible Dose for Internal Radiation," ICRP Publication 2, Pergamon Press, Oxford, England, 1959.

Table 5-1. RATIO OF SKIN DOSE TO TOTAL BODY GAMMA DOSE

	Skin Dose (beta + gamma) / Total Body Gamma Dose
xenon-133	3.44
xenon-133m	6.45
xenon-135	2.85
iodine-131	1.70

Note: The skin dose is calculated to a depth of 70 μm, which corresponds to the average skin depth recommended by the International Commission on Radiological Protection. The values for xenon-133 in the text are calculated to the minimum depth of 50 μm. This difference is responsible for the difference between the factor of 3.8 for xenon-133 in the text and the factor of 3.44 given above.

The technical methodology used for this calculation is presented in Appendix C.

The ICRP$^{(7)}$ has recommended a fatal skin cancer risk value of 10^{-6} per rem (1 per 10^6 person-rem). This is in good agreement with risk values of 0.5×10^{-6}/rem for fatal skin cancer obtained from data in the UNSCEAR Report$^{(8)}$, as shown in Appendix D. Because the skin dose from xenon-133 is a factor of 3.44 higher than the total body dose, the ratio of the total fatal skin cancer risk from beta and gamma irradiation to the total risk of fatal cancers due to total body gamma irradiation would be:

$$\frac{3.44 \text{ skin dose}}{\text{total body dose}} \times 1.0 \times 10^{-6} \frac{\text{skin cancer deaths}}{\text{person-rem}} \times 3.3 \times 10^{3} \text{ person-rem}$$

$$= 0.01 \text{ fatal skin cancer.}$$

The ratio of fatal skin cancers to all skin cancers is approximately 0.06$^{(8)}$ Assuming that this ratio (morbidity to mortality) is also true for radiation-induced skin cancers, the total number of skin cancers might be 0.01/0.06 = 0.2 (0.17).

B. Inhalation Dose to the Lung

Radioactive noble gases irradiate the lung in two ways: (1) from penetrating gamma radiation from external sources and (2) by beta and gamma radiation emitted by radioactive gases inhaled into the lung. As is the case with

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(7) International Commission on Radiological Protection, "Statement from the 1978 Stockholm Meeting of the International Commission on Radiological Protection," Annuals of the ICRP, Volume 2, Number 1 (1978).

(8) United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), "Sources and Effects of Ionizing Radiation," 1977 Report, United Nations, N.Y. (1977), Annex G, Radiation Carcinogensis in man. Section H. pp. 411-412.

skin irradiation by beta radiation, inhalation of radioactive gases can only occur when the individual is actually located within the radioactive plume. Irradiation of the lung by gamma radiation from radioactive gases outside of the body can occur even though the individual is not actually within the radioactive plume. This external dose contribution to the radiation dose to the lung is included in the previous evaluation of the total body dose. The potential health effects from lung irradiation due to external gamma irradiation are also included in the evaluation of the cancer risk from total body irradiation. In that evaluation, it was assumed that the lung dose from external gamma radiation was equal to the total body dose. More refined calculations show that, for xenon-133, the lung dose is about 25% less than the total body dose(4).

The dose to the lung from inhaled radioactive xenons is only a small fraction (2.8 to 7.3 percent) of the dose to the total body from external gamma radiation as shown in Table 5-2. It is not possible to determine whether or not and how long anyone was actually breathing the radioactive xenon gas. The above fraction is the maximum contribution that would occur if all the total body dose resulted from immersion in the xenon gas.

The risk of a fatal lung cancer per unit dose is about one-fifth (0.22) of the total fatal cancer risk (see Appendix D). the total number of estimated fatal cancers would only be increased slightly. The magnitude of this increase (for xenon-133 inhalation) would be about a 1 percent increase

Table 5-2. RELATIVE CONTRIBUTIONS OF OTHER NOBLE-GAS DOSES COMPARED TO THE GAMMA TOTAL BODY DOSE FROM RADIOACTIVE XENON GASES

	Fraction of Gamma Whole Body Dose							
	Beta Skin Dose (surface)	Beta Skin Dose to 1000 µm (1 mm)	Lung Dose From Inhalation			Internal Whole Body Dose from Gases Dissolved in Body Fluids in Equilibrium		
Radionuclide			Beta	Gamma	Total	Beta	Gamma	Total
Xenon-133	2.71	0.00016	0.039	0.017	0.057	0.0045	0.002	0.0065
Xenon-133m	-	-		0.073	0.073	-	0.009	0.009
Xenon-135	1.83	0.165	0.027	0.0022	0.029	0.003	0.001	0.004

Derived from J.L. Russell and F.L. Galpin, "Comparison of Techniques for Calculating Doses to the Whole Body and to the Lungs from Radioactive Noble Gases," in Radiation Protection Standards: Quo Vadis (W.P. Howell and J.P. Corley, compilers), Proceedings of the Sixth Annual Health Physics Society Topical Symposium, Richland, Washington, November 1971.

in the total number of fatal cancers (0.0566 x 0.22 = 0.012). This contribution is small compared to the other uncertainties in the health impact analysis, especially considering the assumption that all individuals were totally immersed in the cloud. Small quantities of noble gases may also be dissolved in body fluid (blood) and irradiate the body internally. However, the dose contribution from this dose contribution is less than 1 percent of the total body dose as shown in Table 5-2.

C. Airborne Radioiodine Concentrations and Associated Inhalation Doses

Metropolitan Edison has, as part of its routine radiological environmental monitoring program, air particulate and radioiodine samplers in the TMI plant vicinity. The NRC Office of Inspection and Enforcement also monitored the air in the vicinity of TMI for radionuclides including radioiodine. To obtain an estimate of thyroid dose, it was conservatively assumed that a child was present at the Observation Center ("Trailer City") from the time the accident began until April 5, 1979. The dose to a child's thyroid was calculated using the methods and parameters given in reference(9).

At two points during this time period, Metropolitan Edison measured a higher concentration of radioiodine at an offsite location other than the Observation Center. It was conservatively assumed that these concentrations existed at

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(9) U.S. Nuclear Regulatory Commission, Regulatory Guide 1.109, "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I," Rev. 1, October 1977.

the Observation Center for dose calculational purposes. Only iodine-131 was used to calculate the dose since iodine-133 data were not available at the time of the calculation. The data and doses are summarized below.

Location (0.5 mi SSE)	Time Period	Iodine-131 Concentration (pCi/m^3)	Child Thyroid Dose (mrem)
Observation Center (Met. Ed.)	3/21-28/79	<0.30	0.094
	3/29-31/79	20.	1.8
	3/31-4/3/79	1.4	0.19
Trailer City (NRC)	4/1 - 4/79	<0.90	0.12
	4/5/79	1.6	0.071
	TOTAL		2.3

D. Thyroid Dose from Ingestion of Iodine-131 in Milk

A large number of milk samples were collected during the period March 28 through April 4, 1979 from farms and dairies throughout the area surrounding the accident site by the Pennsylvania Department of Environmental Resources, the Food and Drug Administration and Metropolitan Edison. Aliquots of several of these were also analyzed by the Environmental Protection Agency. A summary of the reported results is given below:

Milk Samples (March 24 to April 4)	Pennsylvania	FDA	EPA	Metropolitan Edison
Number of analyses performed	133	106	4	21
Number of positive results	7	41	2	18
Average value of positive results (pCi/liter)	15	20	17	7
Range of positive results (pCi/liter)	11-20	13-36	10-24	1-41
Average minimum detectable concentration (pCi/liter)	<20	<10	<10	<1

Additional milk samples collected between April 4 and April 17 were below detectable levels. Eight out of 80 samples were positive between April 18-20 with a range of 15 to 36 pCi/liter. A summary of all Food and Drug Administration samples collected from March 30 to April 29 is given in Table 5-3.

The highest concentration of iodine-131 observed in any sample of milk was 41 pCi/liter (in goat's milk). This was reported by the Metropolitan Edison Company. The total dose to the thyroid of an infant who drank 1 liter of milk per day having a peak radioiodine concentration of 41 pCi/liter would be 5 mrem. This is derived from the protective action guide that relates peak concentration of radioiodine in milk of 12,000 pCi/liter to a 1.5 rem dose to the thyroid(10). Under these conditions, an adult drinking the same milk would receive a lifetime thyroid dose of 0.5 mrem, based on a thyroid weight 10 times greater than the infant (20 g versus 2 g).

Cesium-137 was also detected in some of the milk samples at levels generally less than 25 pCi/liter. The maximum reported level was 37 pCi/liter. The presence of this radionuclide is probably due to fallout produced from previous atmospheric testing. Review of results from pasteurized milk samples analyzed for the previous year from Pittsburgh and Philadelphia by EPA shows the presence of cesium-137 for several samples during that period. The levels were less than 12 pCi/liter.

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(10) Food and Drug Administration, U.S. Department of Health, Education, and Welfare, "Accidental Radioactive Contamination of Human and Animal Feeds and Potassium Iodide as a Thyroid-Blocking Agent in a Radiation Emergency," FEDERAL REGISTER, December 15, 1978 (43 FR 58790).

The Pittsburgh and Philadelphia samples represent milk samples composited from more than one source; the samples collected during the Three Mile Island incident represent specific farms and dairies which exhibit greater variability than composite samples.

Table 5-3. IODINE-131 LEVELS IN MILK (pCi/liter)
(FOOD AND DRUG ADMINISTRATION MEASUREMENTS)

Date (1979)	Number of Samples	Number of Positive Samples*	Min.	Max.	Range	Positive Sample Average
03-31	10	4	18	30	12	25
04-01	18	14	13	36	23	20
04-02	24	12	14	30	16	18
04-03	24	5	16	25	9	20
04-04	24	6	13	22	9	18
04-05	26					
04-06	26					
04-07	28					
04-08	19					
04-09	26					
04-10	20					
04-11	23					
04-12	23					
04-13	25					
04-14	21					
04-15	18					
04-16	30					
04-17	26					
04-18	26	4	15	24	9	19
04-19	31	3	19	29	10	22
04-20	23	1	36	36	0	36
04-21	17					
04-22	18					
04-23	23					
04-24	27					
04-25	28					
04-26	34					
04-27	30					
04-28	28					
04-29	26					

*Minimum detectable concentration is 10 pCi/liter.

APPENDIX A

Department of Energy (DOE) Estimate of External Whole Body Radiation Exposure to the Population Around the Three Mile Island (TMI) Nuclear Power Station.

A collective dose estimate in the vicinity of the Three Mile Island Nuclear Power Station for the period March 28 through April 10, 1979 has been prepared. It is based principally upon the average of measurements of the radiation exposure rates in the plume made during helicopter flights, supplemented by plant meteorological information, including projections of the plume location.

Subsequent to an earlier estimate of the collective dose of 1700 person-rem, TLD data obtained by Metropolitan Edison (as supplied by NRC) made it apparent that a substantial portion of the exposure must have occurred during the first day after the incident, prior to the time that regular helicopter measurements were initiated. A projection of the probable exposure rate in the plume during this interval has been made from the many measurements obtained during the period March 30 through April 9. The principal radionuclide in the plume during this period was xenon-133. The concentration of xenon-133 was estimated from the measured exposure rate and then extrapolated back for the period March 28 through March 29. An exposure rate for this early period was then projected by considering the exposure attributable to the shorter-lived radionuclides which could have been present (assuming that there was an equilibrium mixture of fission product gases present at the time of the incident) in the plume at that time.

Ground level exposure rates were assigned to each sector for hourly intervals during the first 48 hours; average exposure rates were assigned to each sector for each daily interval thereafter. An exponentially decreasing relationship for plume exposure rate with distance was observed using the data obtained with the helicopter. This was compared to curves with $1/R$, $1/R^{1.5}$ and $1/R^2$ behavior. The exponential relationship leads to a smaller collective dose estimate than do these other curves. The available TLD data for stations which were at varying distances in a given sector also suggest a rapid decrease of exposure with distance, consistent with $1/R^2$ or the observed decreasing exponential relationship.

The DOE assessment of the external whole body collective dose to the population around the Three Mile Island (TMI) nuclear power station was based on over 200 aerial radiation measurements taken in the center of the plume of airborne discharges. These measurements were taken from helicopters, using Geiger-Mueller survey instruments with probes having open, low density windows, to enable measurements of the gamma radiation exposure, plus any contribution from high energy beta radiation. The radiation survey probe was held external to the helicopter(s) to minimize attenuation of any radiation. The measurements were made at various distances out to 20 miles from the TMI plant. At various distances, the helicopter was maneuvered to find the maximum radiation exposure rate, and this maximum value was used in the calculation of collective dose within that particular sector.

The geographical region within a 50-mile radius of the plant was subdivided into sectors, and the collective dose within each was calculated based on the measured radiation exposure rates, records of the helicopter location for each measurement, the path of the plume, the duration of its passage, predictions of its course and speed from current meteorological data, and population figures for each segment projected for the 1980 census. A factor of 2 reduction of the measured exposure rate was selected by DOE to account for the aircraft being within the plume, whereas an exposed person would be located on the ground surface. This estimate would apply only if all members of the population were out-of-doors during the entire duration of passage of the plume. The exposure rates at distances beyond 10 miles from the plant were extrapolated from a curve drawn through the exposure measurements as a function of distance within 10 miles of the plant, since exposure rates beyond 10 miles were generally too low to measure. Figures A-1 and A-2 show accumulated exposure profiles for the 0-2 mile and the 0-10 mile radii, respectively, for the average exposure to individuals on the ground remaining outdoors during the entire period of March 28 to April 3.

The collective dose to external radiation within the 50-mile radius using the above data and assumptions was approximately 2000 person-rem (+ 500 or - 1,000 person-rem) through April 3, 1979. DOE estimates that the increase in collective dose for the period April 3 through April 10, 1979 would be a total of approximately 50 person-rem. Table A-1 provides the contributions to the collective dose for distances out to 50 miles. The maximum estimated exposure would be 200 ± 50 (mR) to an individual located about one mile north-northwest of the station continuously for the entire week following the TMI occurrence (see Figure A-1). This location corresponds to Hill Island. There is also a populated region within the 100 mR isoexposure curve that extends up to 3.5 miles north of Three Mile Island and slightly inland on the eastern bank of the Susquehanna River. Individuals in this region located outdoors for the entire week could also have received about 100 mrem.

This assessment overestimates the actual exposure because of the following:

(a) No reduction of the radiation exposure was made for shielding of individuals during periods they were inside.

(b) The maximum doses measured in the plume were applied to the entire sector affected.

(c) An expected significant over-response of the Geiger-Mueller survey instrument. DOE has supplied the Ad Hoc Group with preliminary calibration curves for the Geiger-Mueller survey instrument used in the helicopter which show a significant over-response for the xenon-133 gamma-ray energy (81 keV) of at least a factor of 3 as compared to the energy at which the instrument was calibrated (660 keV, Cs-137). The exposures and collective dose presented in Appendix A have not been adjusted for this calibration.

While the data presented in Appendix A are useful estimates of the relative exposure patterns during the period March 28 to April 3, the Ad Hoc Group cannot draw quantitative conclusions on the exposure levels from the present data, until a complete calibration of the Geiger-Mueller survey instrument is performed.

Table A-1. Collective Dose to Population 0-50 miles from Three Mile Island Nuclear Station March 28 through April 3, 1979 (Department of Energy Aerial Radiation Survey)

Radius (Mile)	Collective Dose Person-Rem**	Total Population*	Average Individual Exposure (mR)
0-1	51.2	658	77.8
1-2	66.7	2,017	33.1
2-3	482.2	7,579	63.3
3-4	352.2	9,676	36.4
4-5	76.4	8,891	8.6
5-10	810.0	137,474	5.9
10-20	137.4	577,288	0.24
20-30	27.3	433,001	0.063
30-40	1.9	273,857	0.0069
40-50	0.3	713,210	0.00048
TOTAL	2,005.7 (2,000)	2,165,651	0.92 (0.9)

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[*] Estimated population for 1980, by 22.50 sectors and distance obtained from FSAR for Three Mile Island II.

[**] Based on projected ground level exposure rates under the plume of radioactive gas, which were assumed to have been one-half of those found during the helicopter flights within it.

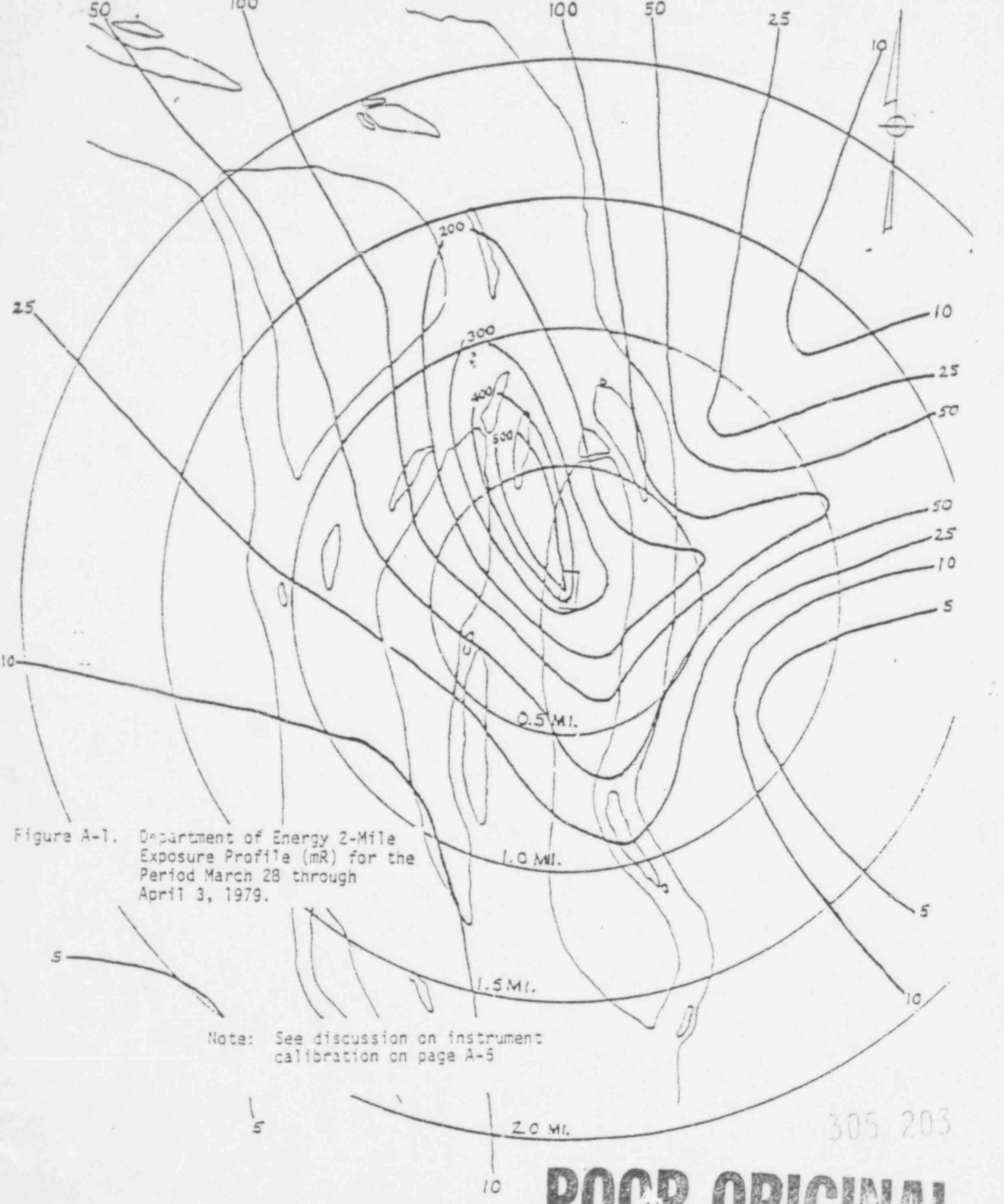

Figure A-1. Department of Energy 2-Mile Exposure Profile (mR) for the Period March 28 through April 3, 1979.

Note: See discussion on instrument calibration on page A-5

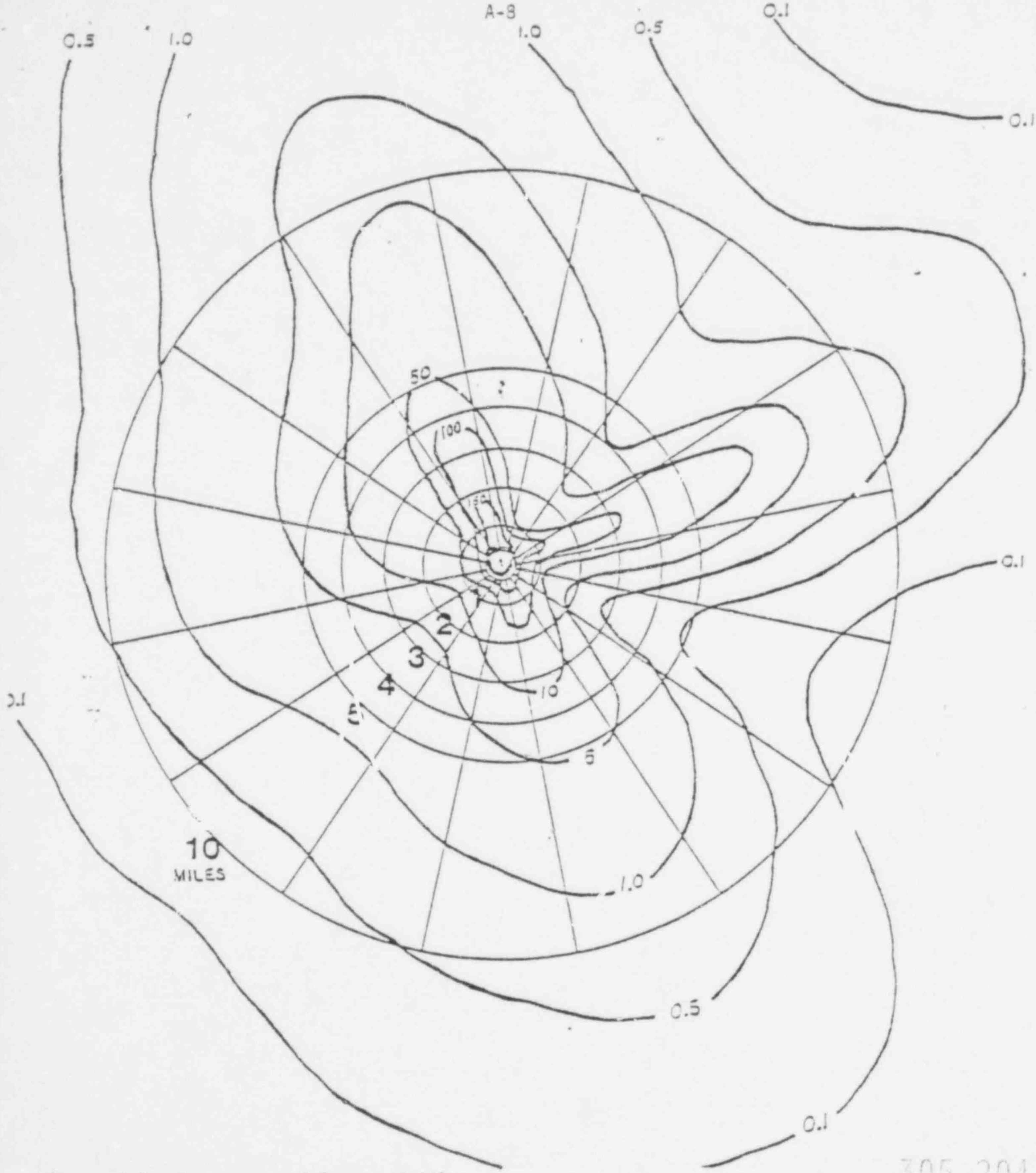

Figure A-2. Department of Energy 10-Mile Exposure Profile (mR) for the Period March 28 through April 3, 1979.

Note: See discussion on instrument calibration on page A-5

APPENDIX B

Department of Energy (DOE) Environmental Deposition Measurements in the Area Surrounding the Three Mile Island Nuclear Power Station.

Following the accident at the Th. Mile Island Nuclear Station, the DOE established the following environmental monitoring activities starting as of 4:00 p.m. on March 28, at the request of the Commonwealth of Pennsylvania, in accordance with the DOE Radiological Emergency Assistance Program:

(a) Helicopter surveys to locate and measure gamma and beta radiation in the airborne discharges.

(b) Ground vehicle radiation surveys in the path of airborne discharges, including some in-situ radionuclide identification by gamma spectrum analysis.

(c) Collection of environmental soil, grass, surface water, and air samples in the path taken by airborne discharges.

(d) Gamma spectrum analyses of these environmental samples to detect, identify and quantify any radionuclides present.

(e) Evaluation and interpretation of survey and analytical data to estimate population exposure.

DOE established three field laboratories for analyzing samples of soil, surface water, grass, and air for gamma-emitting radionuclides. These laboratories were located at the Capitol City Airport. Each utilized a sensitive, high efficiency lithium drifted germanium detector and multi-channel gamma spectrum analyzer. One set of each was brought in and manned by radiochemists from the Brookhaven National Laboratory, Bettis Atomic Power Laboratory, and Knolls Atomic Power Laboratory. Environmental samples were collected by crews from these laboratories, with specific attention to locations near the plant, and to areas over which the plume of discharges from the plant had persisted, and was known to have touched down. Attention was also given to assuring that the sampling method would establish if any radioactivity from the plume had been deposited on the ground. The soil, grass and water specimens were skimmed from the largest surface areas practicable to fill Marinelli geometry containers in order to optimize the sensitivity of the analyses, and thereby increase the likelihood of detection. The air samples were taken by silver-treated silica gel samplers flown into the plume to ensure capture of any non-ionic radioiodine present. Charcoal filters were used in ground sampling larger volumes of air in the plume.

The total number of samples collected and analyzed starting on March 29 has been in excess of 800. The detection sensitivity achieved (minimum detectable activity (MDA)) for iodine-131 was less than one nCi/m^2 for soil and vegetation, 4×10^{-7} μCi/ml for water, and 3×10^{-12} μCi/ml for air. Even lower MDA's were achieved on many samples by longer counting periods, by further idealizing of geometry, and when background radiation was lower. These measures enabled sensitivities as low as 0.5 nCi/m^2 for soil, 0.02 nCi/m^2 for grass and 1×10^{-8} μCi/ml for water. The gamma spectrum measured for each sample was examined in its entirety to detect any photopeaks. The detection sensitivity of this equipment was sufficient to reveal any uranium in the air in the range of allowable occupational concentrations, if any had been present.

The analyses of these environmental samples revealed the presence of iodine-131 in about 3 percent of all samples collected, at barely over the detection limit, when the greater sensitivities were achieved. Table B-1 summarizes these analytical results. In a few soil samples, cesium-137 radioactivity was detected as expected at levels normally found due to world-wide fallout from previous atmospheric testing.

The silver-treated silica gel air samplers which had been flown through the plume, and the charcoal air sample filters used for the high volume ground level samples in the path of the plume. were returned to Brookhaven National Laboratory for further analysis to detect the presence of beta, or alpha emitters by other techniques. However, such species are considered entirely unlikely since the properties of the chemical species in which such radionuclides exist are known to promote retention within the reactor fuel and/or

Table B-1
SUMMARY OF ANALYTICAL RESULTS FOR IODINE-131 IN SAMPLES COLLECTED AND ANALYZED BY DOE

	Sample Type	No. of Samples Collected	No. of Samples less than MDA*	No. of Samples greater than MDA*	Range of Positive Values
Period from 3/28-4/6	Stagnant Surface Water	122	122	0	-
	Rain Water	0	0	0	-
	Vegetation	236	234	2	0.1-0.3 nCi/m^2
	Soil	225	224	1	0.3 nCi/m^2
	Air	19	11	8	7×10^{-12} to 3×10^{-11} µCi/cc
Period from 4/7 - 4/16	Stagnant Surface Water	60	60	0	-
	Rain Water	17	17	0	-
	Vegetation	78	69	9	0.05 to 0.7 nCi/m^2
	Soil	27	27	0	-
	Air	23	11	12	6×10^{-12} to 9×10^{-11} µCi/cc

*Minimum detectable activity (concentration) coolant. Containment air samples analyzed on March 30 did not reveal the presence of any such nuclides.

Direct in-situ measurements of radioactivity on the ground were also made by the DOE Environmental Monitoring Laboratory (EML) using two large volume, pressurized ionization chambers, and a gamma spectrometer using a high efficiency Lithium drifted Germanium detector. These systems enable detection of variations in radiation levels from natural or man-made radioactivity of a fraction of a microroentgen per hour. These vehicle mounted systems were deliberately moved to locations where those few environmental grass samples were taken which, when analyzed in the laboratory indicated iodine-131 at concentrations just above the MDA. These EML measurements confirmed both the concentrations measured in the laboratory, and the identification of the specific radionuclide iodine-131. Other measurements by the EML systems also confirmed the generally negative results found in the laboratory analyses of the environmental soil, water and grass samples.

The date, time and specific location of all of the environmental samples, as well as the results of the laboratory analyses are recorded in the Technical Work Record books of the DOE team.

The results of these analyses of the environmental samples, as well as gamma spectrum analyses of the plume made by the EML mobile system, support the conclusion that the predominant radionuclide in the airborne discharges was the inert gas xenon-133, with a small amount of iodine-131 also present. This conclusion is supported by information received from the NRC licensee (Metropolitan Edison) concerning the measured composition of stack discharges, and the analyses of the airborne radioactive material in the containment.

APPENDIX C

EVALUATION OF SKIN DOSE FACTORS

Dose Factor (mrem/yr per µCi/cc)

Radionuclide	Total	Dose Rate at Body Surface(a,b)		Electron Depth Dose Factor(c)		Effective Skin Dose (70 µm)		
		Photon	Electron	50 µm(d)	70 µm(d)	Electron(e)	Photon(a,f)	Total(g)
Xenon-133	1.90E08	3.86E08	1.22E09	0.392	0.327	3.99E08	2.55E08	6.54E08
Xenon-133m	1.69E08	1.66E08	1.28E09	0.753	0.667	8.54E08	2.38E08	1.09E09
Xenon-135	1.41E09	2.15E09	2.83E09	0.869	0.823	2.33E09	1.69E09	4.02E09
Iodine-131	2.12E09	3.31E09	1.71E09	0.750	0.69[illegible]	1.18E09	2.55E09	3.73E09

Note: 3.86E08 = 3.86 x 10^8. Divide by 24 hrs/day x 365.24 days/yr = 8,766 hrs/yr to get hourly dose rates in mrem/hr per µCi/cc.

(a) Values from D.C. Kocher, "Dose-Rate Conversion Factors for External Exposure to Photon and Electron Radiation from Radionuclides Occurring from Routine Releases from Nuclear Fuel Cycle Facilities" Oak Ridge National Laboratory Report (ORNL/NUREG/TM-283) prepared for the Nuclear Regulatory Commission, NRC Report NUREG/CR-0494 (April 1979)

(b) Kocher, Appendix C, p. 94.

(c) Ratio of depth dose at z = thickness x 1 g/cm^3 x 10^{-4} cm/µm to z = 0.000 g/cm^2 from M.J. Berger, "Beta-Ray Dose in Tissue Equivalent Material Immersed in a Radioactive Cloud," Health Physics, 26(1): pp. 1-12 (January 1974). Tables 6 and 7 using values with leakage correction.

(d) International Commission on Radiological Protection (ICRP Publication No. 26, "Recommendations of the International Commission on Radiological Protection adopted January 17, 1977." Pergamon Press, Oxford (1977) paragraph (64) p. 13. The 50 µm value is recommended as the average thickness of the outer "protective" layer of the skin and 70 µm is recommended as the average depth to be used for evaluating skin dose.

(e) Product of body surface electron dose factor and depth dose factor for 70 µm thickness.

(f) From Kocher Appendix C p. 106.

(g) Sum of two preceeding values.

APPENDIX D

Estimated Risk of Specific Radiation Induced Cancers
Based on the UNSCEAR 1977 (see Reference (8), page 70), Annex G

Cancer Type	Population	Estimated Absolute Risk Cases Per 10^6 Person-rem	Estimated General Population Mortality Risk from 1977 UNSCEAR Report Deaths per 10^6 Person-rem
Breast (pp 385-394)	Adolescent Women	440 (36-1500)	30 (20-35) (a)
	Women (all ages)	180 (140-230)	
Lung (pp 394-399)	Adult Males	50 (20-150)	50 (20-150) (b)
Skin (pp 411-412)	Adults	5 (2-10)	0.5 (0.2-1.0) (c)
Thyroid (pp 377-385)		100 (50-150)	10 (5-15) (d)
Leukemia (pp 370-377)	Adults	25 (15-30)	25 (15-30) (e)
Bone Cancer (pp 399-401)	Adults	3 (2-5)	3 (2-5) (e)
Brain Cancer (p 406)	Fetus	50 (neg-145)	
	child	20 (9-39)	20 (9-39) (e)
Salivary Glands (pp 406-407)	child	10 (5-20)	5 (3-10) (f)
Sinus Mucosa		3 (2-5)	3 (2-5) (e)
Digestive Organs		-	12 (10-15) (e)
Estimated Total Risk (pp. 413-414)		450 (400-500) (f)	230 (200-250) (f)

(a) Assumes 30% mortality and 50% of the general population is female
(b) Assumes 100% mortality and equal risk for women
(c) Assumes 10% mortality (UNSCEAR gives this value as 6%)
(d) Assumes 10% mortality
(e) Assumes 100% mortality
(f) Assumes 50% mortality

APPENDIX E

Letter from William H. Ellett, EPA to Harold T. Peterson, NRC dated April 16, 1979 Regarding EPA Risk Estimates Associated with TMI Accident.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

APR 16 1979

Mr. Harold T. Peterson, Jr.
Health Physicist
Nuclear Regulatory Commission
5650 Nicholson Lane, Room 209
Rockville, MD 20852

Dear Mr. Peterson:

As agreed in our phone discussion April 12, 1979, I am forwarding copies of the risk estimates made by BAB during the Three Mile Island Nuclear Emergency. In using the risk estimates, please remember:

1. Somatic and genetic risk coefficients are derived from the BEIR Report, p. 171.

2. The somatic risk estimates were derived from a modified version of the CAIRD computer code. The modification makes it possible to perform individual analysis of each cohort in an exposed population. Each cohort is followed until its extinction and all deaths from radiation exposure enumerated. A weighted sum of the deaths from each of these analyses is then calculated. The weights are determined by the age distribution of the exposed population at the time of exposure. In this particular analysis, each individual in every cohort was assumed to receive a single one rem dose. The total exposed population was assumed to be 100,000 persons and distributed in age like the 1970 U.S. population. Numbers therefore will resemble BEIR estimates but not be identical.

3. Estimates of thyroid risk were developed outside of BEIR estimates. The estimates are for ^{131}I specifically and are about a factor of 10 lower than would be estimated for x-ray or some other (short half life) radioiodines.

We did not attempt to estimate risk to other specific organs since there were no apparent organ exposures as such. Likewise, we did not attempt to estimate skin cancer risk because the variance of the risk estimate is so great that no realistic estimate can be made at this time. In addition, the uncertainty in incidence as compared to the risk of fatal skin cancer further complicates the picture.

Sincerely yours,

William H. Ellett, Ph.D.
Chief, Bioeffects Analysis Branch
Criteria and Standards Division (ANR-460)
Office of Radiation Programs

2 Enclosures

April 2, 1979

Risk Associated with the PAGs

In terms of the average adult individual, a 1 rem whole body exposure carries with it a lifetime cancer risk of between 10 to 20 fatal cancers per 100,000 adults exposed, and there is an equivalent level of risk of a nonfatal cancer and of an associated serious genetic effect. For children less than ten years of age, the risk of this exposure is highly uncertain ranging from 10 to 200 fatal cancers per 100,000 children exposed. A 1 rem thyroid exposure due to radioiodine has a corresponding potential thyroid cancer risk of about 2 cases per 100,000 for children and about 1 case per 100,000 for adults. Perhaps 10% to 20% of these thyroid cancers would be fatal.
Based on 1970 U.S. population statistics, about 20% of the general population is less than ten years of age.

For internal organs other than thyroid, 1 rem of organ exposure has a potential lifetime cancer risk of about 4 per 100,000. The mortality rate of these cancers varies as a function of the specific organ; for lung and bone marrow the mortality is assumed to be 100 per cent; for different organs it may be less.

These cancer risks for members of the general population represent the chance that a cancer will occur in the individual's lifetime. If the cancer is fatal, the individual lifespan is shortened by an amount ranging from 14 to 30 years depending on the risk model assumed.

Prepared by:
W. H. Ellett and N. S. Nelson
Criteria & Standards Division
Office of Radiation Programs
U.S. Environmental Protection Agency

EPA Risk Estimates for Three Mile Island--April 3, 1979

These risk estimates are based on the linear non-threshold assumption that any dose of ionizing radiation increases the probability of cancer induction. The ages and sex distribution of the population at risk are assumed to be similar to those in the 1970 U.S. population.

As of April 3, 1979, whole body doses to the Pennsylvania population residing in the Three Mile Island area have been estimated as no more than 2,000 person-rem. Using the risk coefficients developed by the 1972 BEIR Committee and published by EPA, the estimated lifetime risk of fatal cancer among exposed adults ranges from 0.16 to 0.32 depending on the specifics of the risk model employed. For children less than ten years of age the risk estimates are more uncertain. Assuming 20 percent of the exposed population is this young, then lifetime risk of fatal cancer ranges from 0.04 to 0.8. In addition to the estimated risk of fatal cancer discussed above, the estimated incidence of non-fatal cancers would also be increased by a like amount.

Estimates of risk due to possible genetic effects vary widely and cannot be estimated with any certainty. Genetic risks, based on the 1972 BEIR Committee Report, average about 20 effects per 10^5 person-rem with a range of 4 to 100 effects per 10^5 person-rem. About 20% of the effects would be expected to occur in the first generation post-exposure.

The 2000 person-rem exposure in the Pennsylvania population might thus lead to 0.4 genetic effects (range 0.08 to 2.0) with 0.08 effects (range 0.025 to 0.4) in the first generation post-exposure.

Prepared by:
W. H. Ellett and N. S. Nelson
Criteria & Standards Division
Office of Radiation Programs
U. S. Environmental Protection Agency

State of Alabama
Department of Public Health
State Office Building
Montgomery, Alabama 36130

IRA L. MYERS, M. D.
STATE HEALTH OFFICER

May 3, 1979

J. Hendrie, Chairman
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Chairman Hendrie:

I have been reading the transcripts of your discussions regarding the evacuation around Three Mile Island. As one who may be required to make a similar decision in the future as I already have made during the Browns Ferry Fire, I would like some information regarding your decision process.

1. As we have found out, early information is not plentiful, although the transcript indicates that on March 30, 1979 some scant data was hinted as being available. What was your staff and your basis for off-site dose projections? For example, for what period of time was a dose projection made, what plant parameters were used, what were the results, and how often updated? etc.
2. If the decision was made primarily on plant conditions, rather than a dose projection as suggested by EPA, then what specific operating conditions suggested the decision?

I would echo Governor Thornburgh's comment that the hardest decision to make is not to evacuate. I certainly found this true during the Browns Ferry Fire.

Thank you for your time and consideration.

Sincerely,

Aubrey V. Godwin, Director
Division of Radiological Health

RECD CHAIRMAN
[illegible]

AVG:rt