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CANCER NEAR THE THREE MILE ISLAND NUCLEAR PLANT:
Radiation Emissions

Maureen C. Hatch, Jan Beyea, Jeri Nieves
and Mervyn Susser

Columbia University School of Public Health
and National Audubon Society
New York, New York

Summary based on a paper by the same title in the September 1990 issue of the American Journal of Epidemiology (vol 132, No. 3, pp 397-412).

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Introduction

In the study summarized here, we tested the hypothesis that the risk of certain cancers might have been raised by exposure to airborne radiation from the Three Mile Island nuclear power plant, which had a widely publicized reactor accident early on the morning of March 28, 1979. Monitoring equipment was limited but, based on available measurements, dosimetry experts stated that the average exposure to individuals living near Three Mile Island was in the range of 0.1 - 0.25 mSv (that is, 0.01 - 0.025 rem). According to these estimates, exposure from accident releases was a fraction of the average yearly exposure from natural background radiation (about 0.8 - 1 mSv, or 0.08 - 0.1 rem). Official reports predicted that among those within 50 miles of the Three Mile Island facility, at most one cancer death would occur as a result of the accident. Nonetheless, when a survey by area residents found a cluster of cancer deaths, there was concern in the community that accident releases had not been correctly estimated.

At the request of the Three Mile Island Public Health Fund, we agreed to investigate the situation further, by specifically testing whether the geographic patterns of cancer occurrence and airborne radiation emissions from the plant could be related. In addition to accident releases, we considered routine emissions from TMI during normal operations, since the plant operated for some years prior to the accident. Outdoor background gamma radiation was considered as well, using data available from a national program that monitors background levels around nuclear facilities.

DESIGN OF THE STUDY

We proposed, as a first step, a study based on cancer data in medical records and death certificates. The study's objective would be to detect any geographic patterns suggesting an association between cancer and radiation exposure. If such an association were indicated, this could be followed up by an in-depth study involving interviews with area residents. We focused this first-stage study on two types of cancer - leukemia (all ages) and childhood cancers. These cancers are sensitive to low-level radiation and, unlike other types of cancer, they begin to appear in a fairly short period of time after exposure occurs (about 2-5 years). For the sake of completeness, other cancer types were considered as well. However, we assumed that if there were a cancer risk from radiation emissions at Three Mile Island, then this should be evident in children in particular, since children are at least twice as sensitive as adults to radiation-induced leukemias and other cancers. Also, if radioactivity from the plant was increasing cancer risk, similar increases should be seen in relation to background radiation.

The study methods were designed to increase the possibility of recognizing small risks if they were present. Three features are worth noting. First, cancer incidence - the frequency of new cases - was the focus of the study rather than cancer deaths. This is because changes in cancer incidence occur earlier than changes in mortality, and only a short time had elapsed since the reactor accident in 1979. Also, cancer mortality does not necessarily reflect cancer incidence when survival is reasonably good, as it is for childhood leukemia. In order to identify medically verified incident cancers, we reviewed the records of 25 hospitals. This included all hospitals located within 30 miles of TMI. We also searched the records of six regional referral hospitals in Philadelphia, Pittsburgh and Baltimore because some cases might have been sent directly to a specialized facility, bypassing the local hospital. This approach, which involved review of many thousands of medical charts, was extremely tedious and time-consuming but we believed it was important.

A second feature of the study was that cancer rates were calculated for small geographic subunits. This is because analysis of larger areas, like counties or census tracts which have been used in some studies, would tend to dilute any minor elevations in risk confined to the portion of the population actually exposed. We began with a circle approximately 10 miles in radius around the Three Mile Island plant, with a population of about 160,000 [Fig. 1]. We divided the study area into 69 units that were roughly equal in size, projecting out at angles from the plant [Fig. 2]. These units, called study tracts, were built up from census blocks and have an average population size of 2300.

A third feature of the study was that rather than use distance from the plant to indicate radiation exposure (e.g., a 5-mile radius), we attempted to describe the geographic distribution of radioactivity more precisely. For accident releases and radioactive emissions during routine operation of the plant, we used mathematical models to predict exposure in each of the 69 small units within the study area, taking account of factors such as height of the releases, wind speed and direction, and the modifying effect of terrain. The models were intended to identify those portions of the study area that actually received exposures to plant emissions. We were concerned that a conventional approach based on simple distance zones might define people as exposed who in fact were not exposed and, as a result, dilute out any association.

There had been uncertainty about the magnitude of accident releases because monitors at the reactor went off scale and dosimeters outside the plant were believed to be too few to capture all of the emissions. Therefore, our models were based on the relative distribution of emissions, not on absolute values, and our analysis tested whether areas with higher exposures, according to the model, also had higher cancer rates. Because of this approach, the study's findings did not depend on knowing the true radiation dose but only on predicting where in the environment it would have concentrated.

Eventually, it became possible to compare the model's predictions about the pattern of exposure with the pattern derived from the readings of the radiation monitors in place outside the plant at the time of the accident. These proved to be in excellent agreement [see Fig. 3]. This is important because it indicates that the monitors probably did provide adequate coverage and, therefore, that the official estimates of accident releases were reasonably accurate. However, our results concerning the pattern of radiation exposure and cancer occurence are based on relative dosimetry, as described above, and do not depend on the official dosimetry.

Exposure Models

In the analysis of cancer trends by predicted radiation exposure, the 69 geographic sub-units were considered individually but, to convey the exposure patterns visually, we have grouped the units into four levels of exposure (quartiles). For each source of radiation, therefore, the darker areas shown in subsequent figures will indicate higher exposures and the lighter areas, the lower exposures. The pattern projected by the accident model [Fig. 4] indicates that exposures were concentrated in an area north-northwest of the plant. For 20 study tracts located elsewhere in the area, exposures were estimated to be zero.

To model emissions from routine operation of the plant, we assumed a constant average release. This seemed reasonable since venting of radioactivity follows engineering demands rather than a fixed schedule and should be random with respect to season and weather. Exposures were estimated relative to an arbitrary scaling point and their distribution - close to the plant, particularly in the east-west direction - reflects yearly wind patterns and terrain contours [see Fig 5].

For natural background radiation, dose rates come from a survey by the U.S. Energy, Research and Development Administration and are based on measurements recorded by aircraft fitted with scintillation detectors. The dose rates given are for outdoor gamma radiation (radon was not directly assessed) and they range by a factor of about two, with higher exposures to the south and southeast in the more rural portions of the study area [see Fig. 6]. The dose rates produce annual exposures of 0.5 to 1 mSv, about average for natural background in the U.S.

Statistical Methods

We examined the relationships between radiation exposure and cancer risk. The effects of variation among study tracts in urban/rural status and social class as well as age and sex - factors known to influence cancer risk - were adjusted for statistically. As noted, in the light of uncertain exposure levels, the small size of the population exposed, and a short period of follow-up, we focused on childhood malignancies and on leukemia (all ages) as the cancer types most likely to show increases if any were present.

The results are given in Tables 1 and 2, in terms of Odds Ratios (OR) and their 95% Confidence Intervals (CI). The odds ratio is a measure of the disease risk among those who were exposed compared to the risk among those with no (or lower) exposure. When there is no difference in risk of disease between those with and without exposure, the odds ratio is 1.00. If the exposed are at increased risk, the odds ratio is greater than 1.00. For example, an odds ratio = 1.50 would indicate that, on average, exposure increases a person's risk of the disease under study by 50%. If the exposed are at lower risk compared with the unexposed, the odds ratio is less than 1.00. The 95% confidence interval is a measure of how precise the odds ratio is as an estimate of risk. The 95% confidence interval gives the range of values within which the odds ratio would fall 95% of the time if one were able to repeat the same study 100 times. If the confidence interval includes 1.00 - the value indicating no association between exposure and disease, known as the "null value" - then the result is said not to be statistically significant; that is, the estimate of the odds ratio may have arisen "by chance," because of the natural variability in the occurrence being measured (in this case, cancer rates). If the confidence interval does not overlap 1.00, then chance variation is less likely to explain the result, and the odds ratio is said to be "statistically significant."

RESULTS

The estimates presented in the Tables are for odds ratios that contrast cancer risk in the highest quartile of exposure to that in the lowest. An odds ratio of 1.50 would imply that, on average, individuals in the highest exposure area have a 50% higher cancer rate than individuals in the lowest exposure area. Table 1 shows the data for cancer in relation to accident emissions; Table 2 shows the data for cancer in relation to routine emissions.

ACCIDENT EMISSIONS (Table 1)

For leukemia in adults, there is a positive geographic trend with exposure to accident emissions after 2 years (odds ratio = 1.4); five years after the accident, the association is close to 1.00, the null value (odds ratio = 1.1). For children, there was virtually no trend in cancer as a whole in relation to accident emissions; allowing a two year lag after the accident, the odds ratio is 1.1 with 95% confidence interval from 0.4 to 2.8. For childhood leukemia specifically, the odds ratio was raised (odds ratio = 2.3) but there were only four cases and the confidence interval is very wide and overlaps 1.00 (0.4, 12.8). Even with narrower confidence bounds, an odds ratio based on so small a number of cases would have to be treated with caution as an unstable result.

Thus, we observe no definite associations of accident emissions with the cancer types thought to be most susceptible to radiation carcinogenesis, and most likely to demonstrate increases in a short period of follow-up. In addition, analyses of highly radiosensitive sites with longer latent periods (10-30 years), such as breast cancer and thyroid cancer, indicate either no association or negative trends with exposure (data not shown in table).

We did find an association of accident exposure with nonHodgkin's lymphoma (odds ratio = 2.0; 95% confidence interval 1.2, 3.5) but the cumulative evidence on the atomic bomb survivors indicates that nonHodgkin's lymphoma is not a radiogenic cancer, even at very high doses. There was also an association in the postaccident period between lung cancer and predicted exposure to accident emissions; however, a similar geographic gradient in risk existed prior to the accident (largely contributed by men aged 75 and older). After adjusting for this preaccident gradient, the odds ratio for lung cancer was reduced from 1.8 (95% confidence interval 1.5, 2.1) to 1.3 (95% confidence interval 0.9, 1.8). The trend is stronger in males but also present in females. The adjustment for baseline risk, prior to the accident, should account to some extent for such cancer risk factors as smoking, radon and occupational exposures, but it cannot do so entirely.

ROUTINE EMISSIONS (Table 2)

For exposure to routine emissions, we looked for trends beginning in 1975, a year after the plant began operations. In adults, the leukemia trend with predicted exposure to routine emissions is in the negative direction (odds ratio = 0.8). Among children, the odds ratios for exposure to routine emissions, were elevated both for all cancers and for the subgroup of childhood leukemias but, again, the confidence intervals are large and they include 1.0. For all cancers the odds ratio is 1.5 with 95% confidence interval 0.7 to 3.5; for leukemia the odds ratio is 2.3 with confidence interval from 0.6 to 9.7.

Because of the large variability, "chance" could explain the results we observed for cancer in children in relation to routine emissions. Moreover, the rates for childhood leukemia in the Three Mile Island area are low compared with national and regional data, in spite of the fact that we reviewed records at referral centers as well as local hospitals to help insure that all cases would be found. Thus, apart from chance, some problem in case-finding (ascertainment) may explain the childhood leukemia trends. Perhaps some cases were not identified because they moved or were treated very far from the study area. This would change the observed geographic trend only if cases were more likely to be missed from the low exposure or high exposure areas. At present, the reason for the low incidence of childhood leukemia and its implication for the result we found are unknown.

Despite the deficit of leukemias, the incidence of childhood cancers as a whole is similar to national and regional figures because the rates of brain and kidney tumors among children in the Three Mile Island area are comparatively high. Ascertainment bias is therefore less of an issue for the childhood cancer category than for the leukemia subgroup. But the result is not statistically significant and one cannot rule out chance as a strong competing explanation for the modest association we observed between childhood cancers as a whole and routine emissions.

Excess cancer cases have been observed in children near nuclear sites in Britain, most notably downstream from the Sellafield fuel reprocessing facility. Smaller increases in childhood cancer incidence have been noted in areas surrounding Britain's 14 other nuclear installations, but attention has focused mainly on Sellafield and a few other fuel processing and weapons development plants where emissions and discharges are higher than at other types of nuclear facilities. The British have made a concerted and systematic effort to follow-up on any apparent risks in such areas. The most recent report - a detailed study of cases and controls around the Sellafield fuel reprocessing facility - found that the geographic excess of childhood leukemia was best explained by the fathers' exposure to radiation during employment at the plant before the child was conceived and not by direct environmental exposure of the fetus or child to radioactive discharges and emissions. As a next step, this hypothesis is being examined at other nuclear sites in Britain, and the results of those investigations will be very important in interpreting whether cancer patterns in children near nuclear plants are more likely to reflect parental occupational exposure than exposure to environmental radioactivity, and in guiding future research.

Apart from childhood cancer, nonHodgkin's lymphoma and cancer of the lung showed associations with estimated exposure from routine emissions, as in the case of accident emissions. For the period 1975-1985, the odds ratio for nonHodgkin's lymphoma is 1.8 (95% confidence interval 1.2, 2.8); for lung cancer the odds ratio is 1.5 (95% confidence interval 1.2, 1.9). Because cumulative exposures to study area residents from background gamma radiation are presumably higher than the average exposure from accident or routine emissions, it was of interest to know whether the two cancer types related to plant emissions also showed relationships with background gamma radiation. For lung cancer there is a very slight trend in risk with background gamma radiation (odds ratio = 1.11; 95% confidence interval 0.9, 1.4). For nonHodgkin's lymphoma no association is seen.

Lung cancer and nonHodgkin's lymphoma were considered in two recent studies of mortality among residents near all nuclear installations in England and Wales, but neither study found an increased risk. The fact that we observed raised risks for lung cancer and nonHodgkin's lymphoma with both accident and routine plant emissions is not easily reconciled with our findings in relation to background radiation, which represents a higher cumulative exposure. Also, the observed period is short for cancers of this type, which take 10-30 years to develop after an exposure occurs. If radiation emitted by the plant contributed to the trends, it would have to be acting at a late stage in the disease, and it has not yet been established that gamma radiation can act in this way. What geographical factors other than radiation could explain these associations is also unclear. Smoking habits are the obvious candidate; if so, smoking frequencies must have been congruent with the quite different geographic distributions of the three radiation exposures. Radon exposure is another explanation that should be considered.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions drawn from the type of study we conducted - called an ecologic study or geographic study - are necessarily tentative because the data on exposure and disease are for areas, not for individuals, and because the information needed to bring the effects of other factors that influence disease risk under strict control is often lacking. However, such studies are a logical first step and when designed so as to be sensitive, as this one was, they should identify any raised risks that might require further investigation in more focused, detailed studies.

Below we summarize and briefly discuss the main findings:

1. Our study found no statistically significant associations between exposure to accident releases or to routine emissions from the Three Mile Island plant and the incidence of leukemia or childhood cancer, although these are the cancer types thought to be most susceptible to low level radiation and most likely to show increases within a short time period.

In the case of routine emissions, there was a positive trend for both leukemia and other cancers in children. The exposure-response trend was not statistically significant and, for leukemia, the number of cases was small (n=8) and the rate was half the national rate. We did find a statistically significant trend in the TMI area for childhood cancer in relation to outdoor background gamma radiation from cosmic and terrestrial sources (reported in the September issue of the International Journal of Epidemiology). In light of these findings and of evolving evidence from Britain, further investigation of cancer in children in the study area may be warranted. A follow-up study could collect more extensive data about environmental radiation exposure, parental occupational exposures to radiation and chemicals, medical x-ray exposure, exposure to radon and electromagnetic fields, and other potentially relevant factors such as age of the mother.

2. Because no definite effects were found for leukemia and childhood cancers, the most sensitive indicators, and because the interval is short for development of other cancers, it is unlikely that associations observed with nonHodgkin's lymphoma and lung cancer are really due to radioactivity from the plant. Other explanations for the trends in lung cancer and non-Hodgkin's lymphoma may need to be considered. For lung cancer, smoking, radon and occupational exposure are possible explanations.

3. The geographic pattern of exposure predicted by a mathematical model independently developed for the study compared well with the pattern projected from monitors in the area at the time of the accident. Thus, if our model is correct, it does not appear that there were large releases of radioactivity that were not picked up by off-site monitors. The official dose estimates for the accident, which predicted an average exposure of about 0.1 - 0.2 mSv (0.01 - 0.02 rem) and a maximum exposure of 1 mSv (0.1 rem), seem to have been in the right range.

Figure 7 presents evidence from other investigations of cancer risk following exposure to low levels of radiation. The observed risk ratios are plotted by radiation dose, to help in interpreting the findings from this study. Although our analysis did not depend on knowing the true radiation dose, the comparison between our models and the off-site monitors suggests the average exposures sustained in the Three Mile Island area fall in the lowest dose category, of less than 1 mSv. Based on the latest and most pertinent evidence, cancer risks do not appear to increase appreciably above 1.00, even in children, until exposure reaches 10 mSv (1 rem) or more.

4. At present, based on all of the medical evidence available concerning low-level radiation, as well as the overall pattern of results in this study, we do not feel that our findings point to airborne radiation emissions from the TMI facility as a cause. There is, however, currently great interest in this area of research, in England and elsewhere, and the next several years should see a number of new studies reported that will bear on the results presented here and their interpretation. These results should be monitored closely. In addition, we are completing analyses of radiation emissions and reproductive patterns. In the meantime, follow-up of childhood cancer in the Three Mile Island area, and perhaps lung cancer as well, could provide more detailed data on possible explanations for the geographic trends.

TABLE 1

Accident Emissions and Cancer Incidence: Odds Ratios (OR)⁺ and 95% Confidence Intervals (CI) for specific cancer types at different times before and after the accident at the Three Mile Island nuclear plant

Cancer Grouping	Number of Cases	OR (95% C.I.)
Childhood Cancers		
0-14		
1975-79	19	0.67 (0.18, 2.47)
1981-85	18	1.06 (0.40, 2.82)
1984-85	6	0.39 (0.01, 12.02)
0-24		
1975-79	34	1.21 (0.64, 2.29)
1981-85	47	0.995 (0.57, 1.75)
1984-85	15	0.82 (0.26, 2.38)
Leukemia *		
0-14		
1975-79	1	—
1981-85	4	2.28 (0.40, 12.82)
1984-85	1	—
0-24		
1975-79	1	—
1981-85	5	2.81 (0.49, 16.19)
1984-85	1	—
25+		
1975-79	28	0.59 (0.15, 2.38)
1981-85	48	1.43 (0.77, 2.63)
1984-85	23	1.12 (0.41, 3.08)
Lymphoma		
Non-Hodgkin's		
1975-79	67	0.95 (0.53, 1.72)
1981-85	91	1.48 (0.99, 2.20)
1984-85	34	2.01 (1.15, 3.49)
Hodgkin's		
1975-79	22	1.02 (0.56, 2.78)
1981-85	24	0.85 (0.33, 2,14)
1984-85	14	1.04 (0.37, 2.92)
All Cancer		
all minus lung		
1975-79	1529	0.99 (0.88, 1.12)
1981-85	2391	1.00 (0.91, 1.10)
1984-85	986	1.02 (0.89, 1.18)
lung		
1975-79	194	1.28 (0.96, 1.72)
1981-85	440	1.76 (1.47, 2.08)
1984-85	188	1.72 (1.33, 2.22)

⁺ Odds ratios comparing median exposure in highest quartile with median exposure in lowest quartile, derived from logistic analysis adjusted for age, sex, density, median income and education. The following time periods are considered: 1975-1979, prior to the accident; 1981-85, postaccident allowing a 2 year lag; 1984-85, postaccident allowing a 5-year lag. * Excludes chronic lymphocytic leukemia.

TABLE 2

Routine Emissions and Cancer Incidence: Odds Ratios (OR)+ and 95% Confidence Intervals (CI) for specific cancer types at different times before and after routine operation of the Three Mile Island nuclear plant

Cancer Grouping	Number of Cases	OR (95% C.I.)
Childhood Cancers		
0-14		
1975-79	19	2.04 (0.62, 6.73)
1979-85	30	1.20 (0.37, 3.90)
1975-85	49	1.52 (0.66, 3.53)
0-24		
1975-79	34	2.05 (0.81, 5.23)
1979-85	70	1.07 (0.45, 2.54)
1975-85	104	1.38 (0.73, 2.61)
Leukemia *		
0-14		
1975-79	1	----
1979-85	7	2.50 (0.61, 10.34)
1975-85	8	2.32 (0.56, 9.68)
0-24		
1975-79	1	----
1979-85	9	2.33 (0.59, 9.23)
1975-85	10	2.16 (0.54, 8.58)
25+		
1975-79	27	0.42 (0.11, 3.38)
1979-85	65	0.89 (0.31, 2.52)
1975-85	92	0.79 (0.31, 1.98)
Lymphoma		
Non-Hodgkin's		
1975-79	67	1.06 (0.40, 2.84)
1979-85	113	2.13 (1.29, 3.51)
1975-85	180	1.81 (1.16, 2.82)
Hodgkin's		
1975-79	22	1.44 (0.37, 5.59)
1979-85	38	1.12 (0.36, 3.46)
1975-85	60	1.24 (0.52, 2.96)
All Cancer		
all minus lung		
1975-79	1527	1.14 (0.93, 1.39)
1979-85	3207	1.10 (0.95, 1.26)
1975-85	4734	1.12 (0.996, 1.26)
lung		
1975-79	194	1.31 (0.78, 2.18)
1979-85	563	1.55 (1.18, 2.03)
1975-85	757	1.50 (1.18, 1.91)

+Odds ratios comparing median exposure in highest quartile with median exposure in lowest quartile derive from logistic analysis adjusted for age, sex, density, median income and education. The following time periods are considered: 1975-79, prior to the accident; 1979-85, following the accident (plant shut down); 1975-85, the entire 11-year study period. * Excludes chronic lymphocytic leukemia.

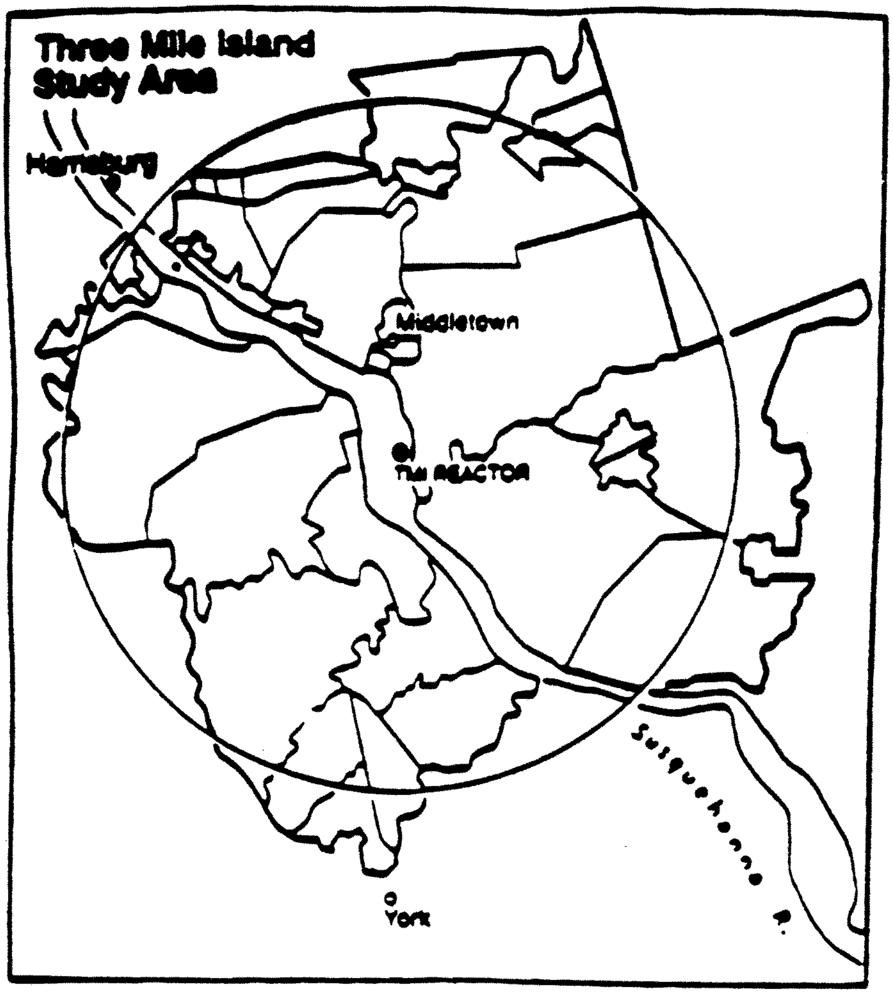

Figure 1. Map of Three Mile Island study area, showing main towns, the Three Mile Island plant and the surrounding 10 mile radius.

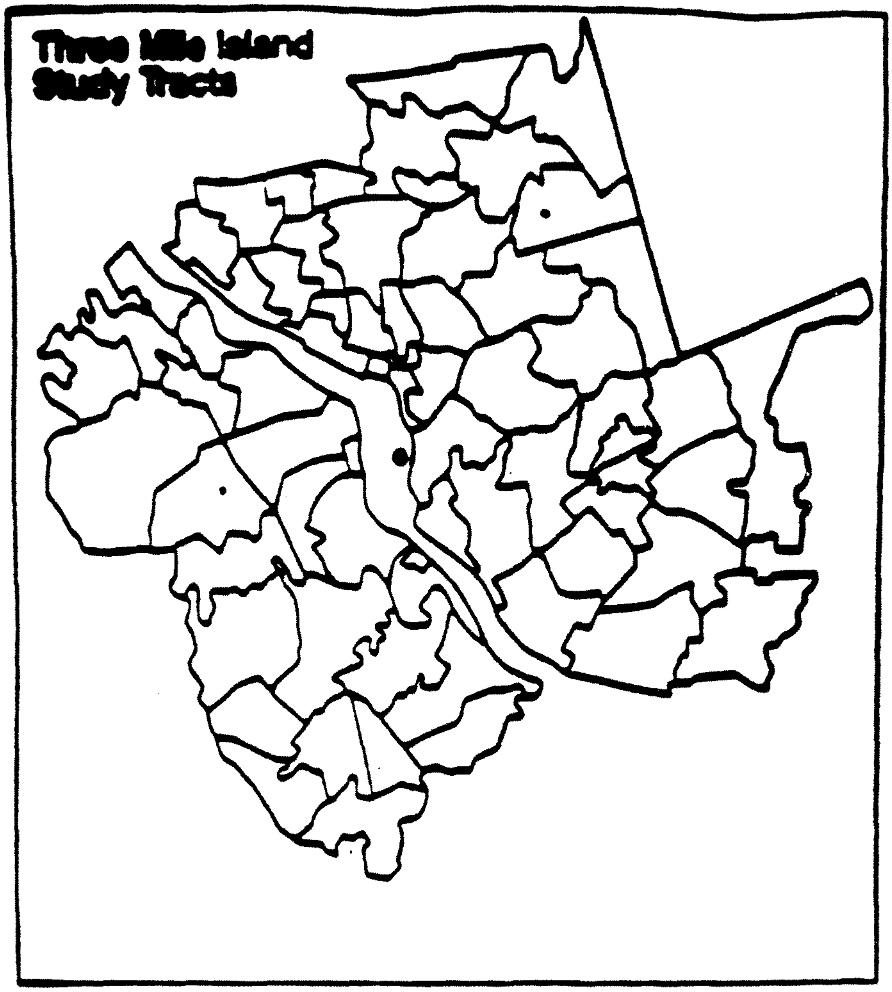

Figure 2. Map of Three Mile Island study area subdivided into 69 study tracts (average population 2,300) for purposes of analysis.

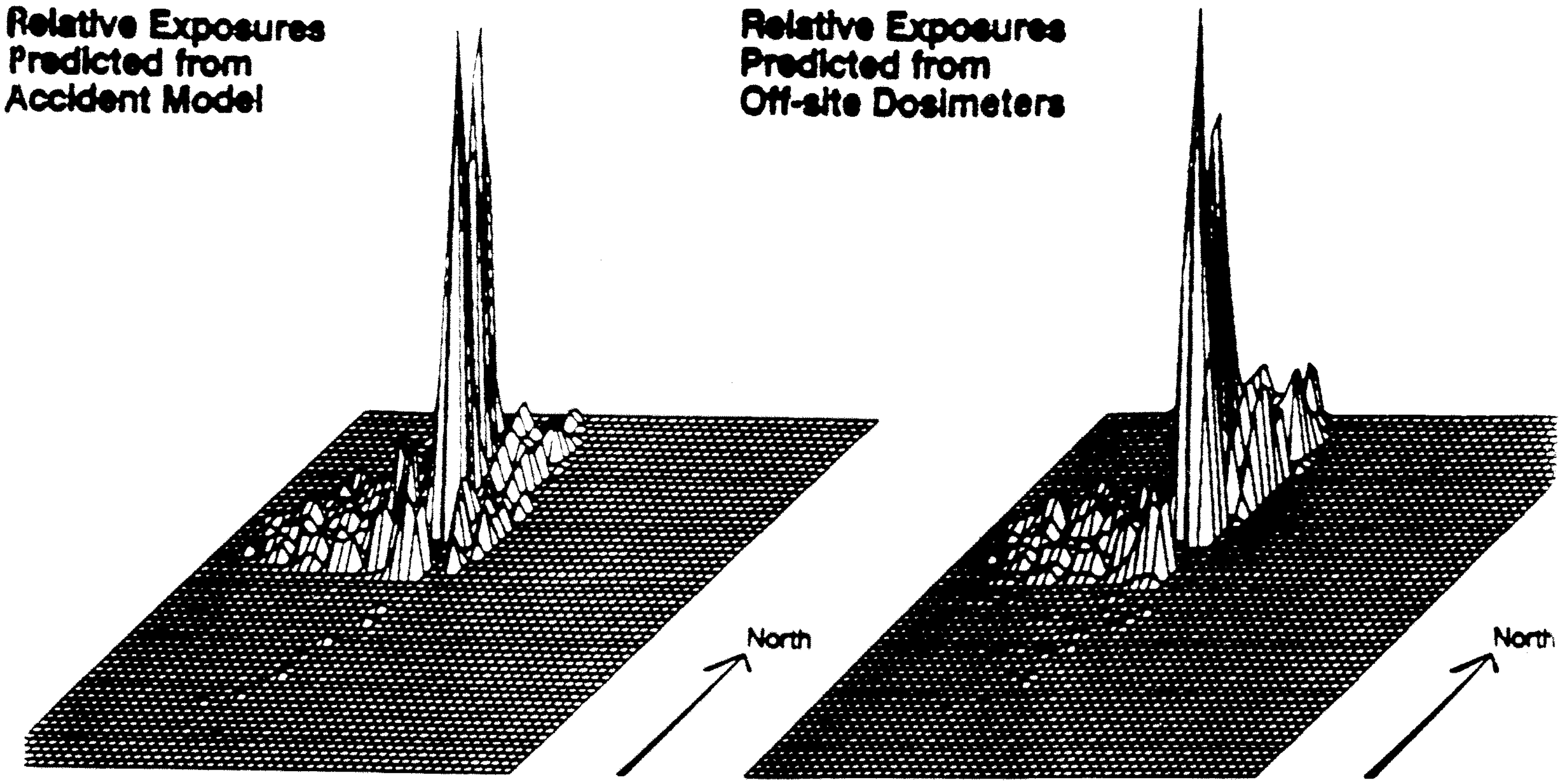

Figure 3. Three-dimensional maps comparing the geographic distribution of exposures predicted from the accident model and from off-site dosimeters.

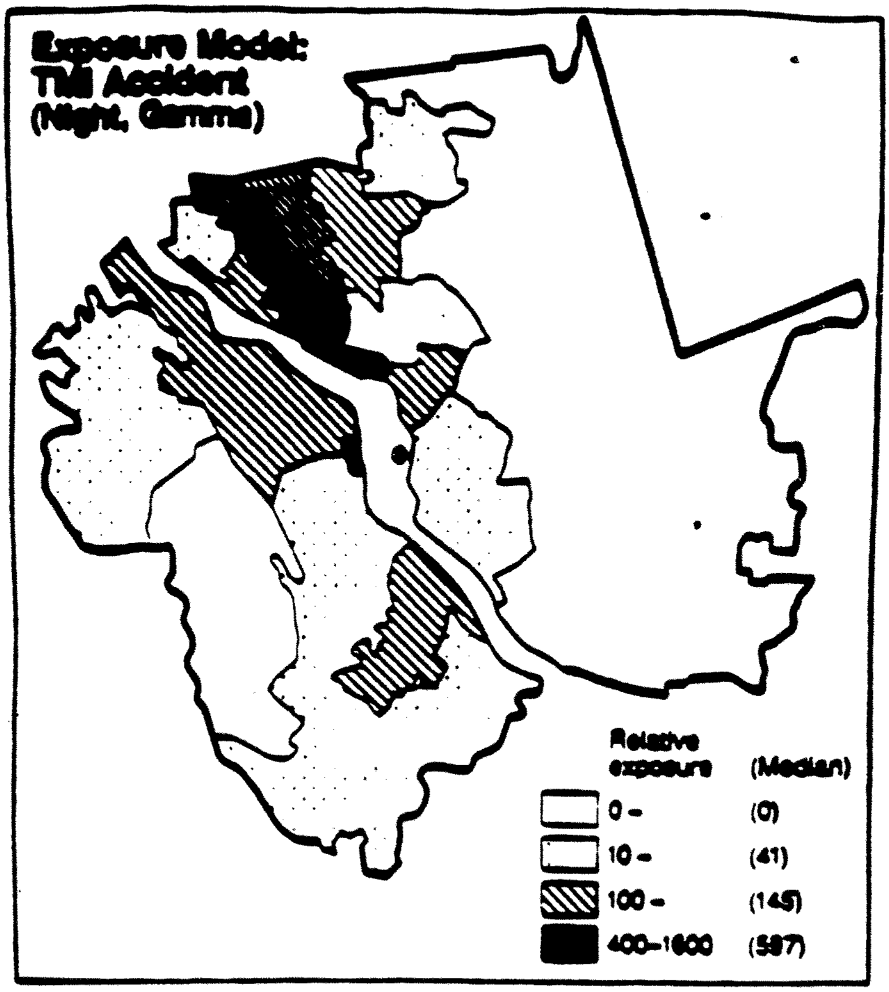

Figure 4. Map showing relative distribution of gamma radiation from the March 1979 accident at the Three Mile Island nuclear plant, as predicted by mathematical dispersion modeling. (Units given are relative to an arbitrary scaling factor; see text for discussion.)

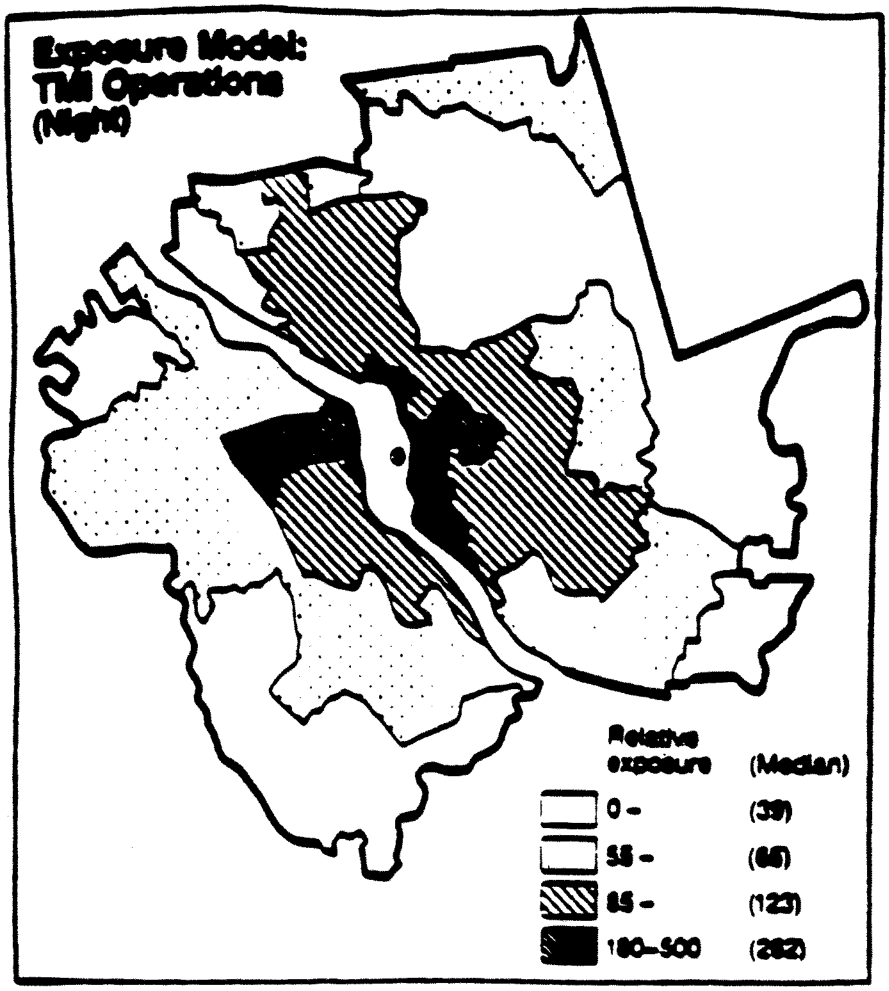

Figure 5. Map showing relative distribution of emissions related to routine operation of the Three Mile Island plant, as predicted by mathematical dispersion modeling. (Units given are relative values, not directly comparable to those for the accident model.)

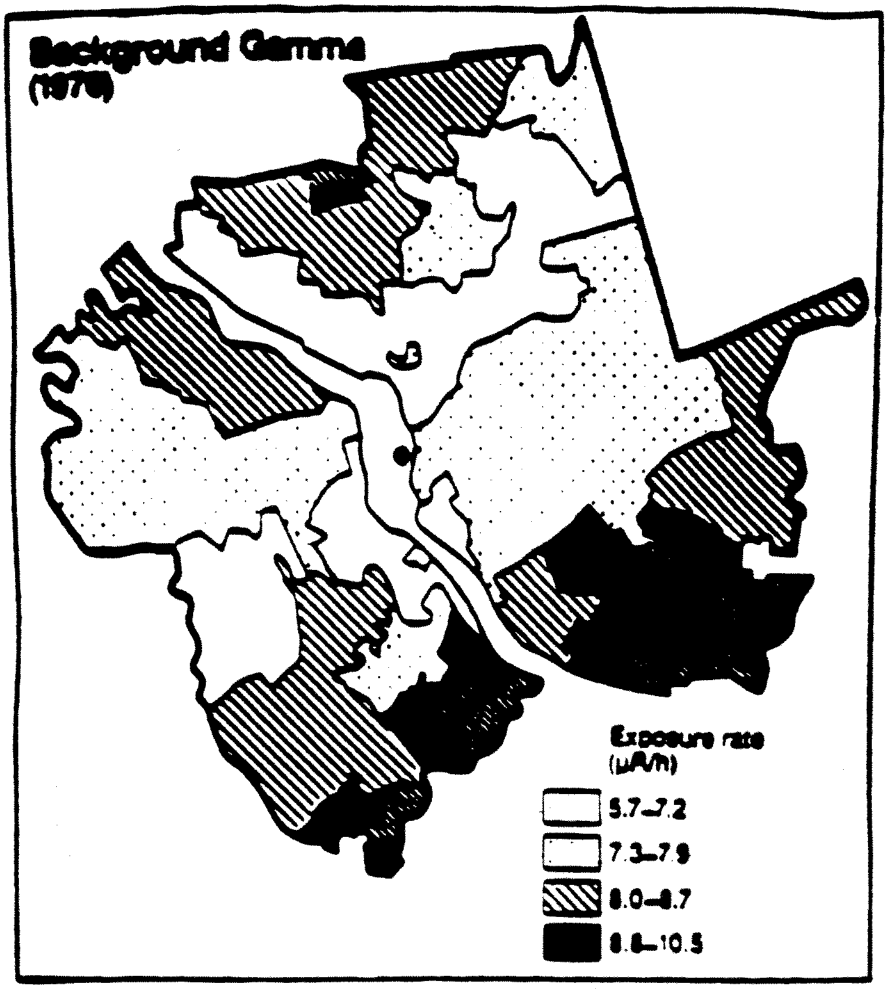

Figure 6. Map showing distribution of exposure to background gamma radiation in the Three Mile Island study area as measured in a 1976 aerial survey.

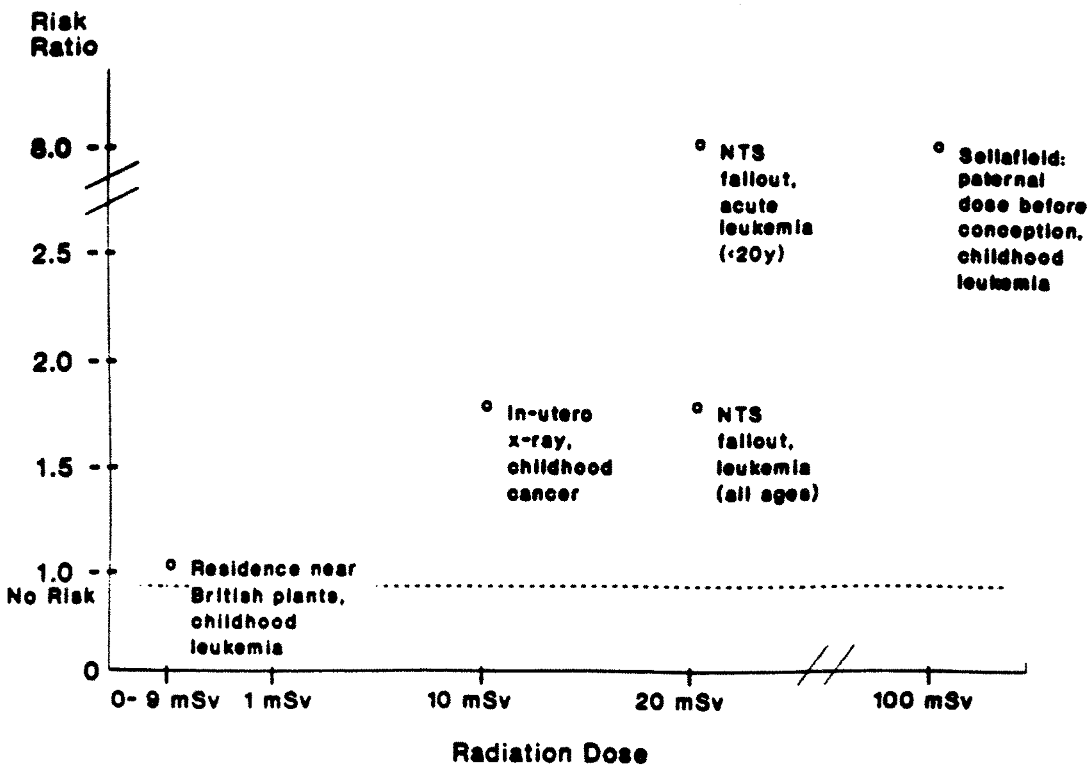

Figure 7. Figure showing the risk ratios observed in some studies of cancer following exposure to low levels of radiation from: residence near (British) nuclear installations; prenatal x-ray; Nevada Test Site fallout; and fathers' occupational exposure to radiation prior to conception.