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ESTIMATES OF DOSE TO THE POPULATION WITHIN FIFTY MILES DUE TO NOBLE GAS RELEASES FROM THE THREE MILE ISLAND INCIDENT

MASTER

Charles W. Miller
Sherri J. Cotter
Robert E. Moore
Craig A. Little

Health and Safety Research Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

ABSTRACT

Estimates have been made of the dose to the population within 80 km (50 miles) due to noble gas releases from the Three Mile Island Unit 2 incident for the period March 28 to April 15, 1979. Source term, meteorological, and monitoring data used in these estimates were supplied by the Task Group on Health Physics and Dosimetry of the President's Commission on the Accident at Three Mile Island. The 22.5° sector-averaged form of the Gaussian plume atmospheric dispersion model was used to calculate doses due to immersion in air and inhalation. Our best estimate of the population dose to the total body is 15 person-sieverts (1500 person-rem).

INTRODUCTION

Beginning on March 28, 1979, a sequence of events occurred at the Three Mile Island (TMI) Unit 2 nuclear power reactor near Harrisburg, Pennsylvania, which resulted in the release of an amount of radioactive gases to the atmosphere in excess of that emitted during routine reactor operations. A comprehensive study of this incident has been prepared by the President's Commission on the Accident at Three Mile Island [1]. As part of this study the Task Group on Health Physics and Dosimetry requested the authors to estimate the dose to the population within 80 km (50 miles) of the reactor for the period March 28 thru April 15, 1979. Subsequent to these calculations, dosimetric monitoring data from around the plant were examined and adjustments were made in the population dose calculations. The purpose of this paper is to present our best estimate of the population dose from the TMI incident and to discuss the methodology used in making the calculation.

METHODS

AIRDOS-EPA

The AIRDOS-EPA computer code [2] was used to estimate the dose to the population within 80 km of the TMI plant. This code calculates downwind air concentrations using a constant mean wind velocity Gaussian plume atmospheric dispersion model [3]. The 22.5° sector-averaged form of this model as used in this study is given by

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$$\chi = \frac{Q}{0.15871\ \pi\ x\ \sigma_z\ \bar{u}} \exp\left[-1/2 \left(\frac{H}{\sigma_z}\right)^2\right] \quad (1)$$

where

χ = ground-level air concentration (Bq/m^3) at downwind distance x (m),
Q = uniform radionuclide release rate (Bq/sec),
$\bar{u}$ = mean wind speed (m/sec),
σ_z = vertical dispersion coefficient (m), and
H = effective stack height (m).

The air concentrations calculated using Eq. (1) were used to estimate doses. The dose due to immersion in air is given by

$$D_{imm} = \chi\ C_{imm}\ (1 \times 10^{-6}) \quad (2)$$

where

χ = ground-level air concentration (Bq/m^3),
D_{imm} = air immersion dose (Sv),
C_{imm} = dose conversion factor for immersion in air (Sv/y per Bq/cm^3), and
1×10^{-6} = units conversion factor.

Doses due to inhalation were also calculated, but they were found to be insignificant when compared to the air immersion doses in this study. Doses were estimated for total body, red bone marrow, lungs, endosteal cells, stomach wall, lower large intestine wall, thyroid, liver, kidneys, testes, and ovaries.

The AIRDOS-EPA computer code also has the capability of estimating wet and dry deposition effects and the resulting doses from surface exposure and ingestion. Such calculations were not made for this study, however, since the only radionuclides considered were nonreactive noble gases.

Meteorological Data

Meteorological data taken at the TMI tower were obtained and adjusted for use as input in the AIRDOS-EPA calculations. Hourly values of wind direction, wind speed, and the vertical temperature gradient for the time period being considered were used. The temperature data were used to derive hourly values of the Pasquill atmospheric stability classes [4]. A joint frequency distribution of the average wind speed for each of 16 wind direction sectors and 7 stability classes was constructed.

Mixing height values for the period of the TMI release were not supplied by the Task Group staff. Instead, mean values of the mixing height for January and June were obtained [5] and averaged. The resulting value of 900 m was used in the AIRDOS-EPA calculations.

Source Term

Radionuclides from the TMI incident were emitted via a vent stack located atop the auxiliary building adjacent to the unit 2 containment building (Fig. 1). The stack is 55 m above ground level but only 6 m above the auxiliary building roof and 3 m above the closest obstruction. The stack is 1.2 m in diameter, and the effluent had an exit velocity of 36 m/sec. The temperature of the effluent was assumed to be near ambient [6].

A direct measurement of stack effluents during the TMI incident was not performed and thus the amount and identity of the aerosols released are unknown. It was assumed for dose calculational purposes that the release consisted of ^{88}Kr, ^{133}Xe, and ^{135}Xe. Other gases in the core inventory at the time of shutdown decayed rapidly during the first few hours, and made insignificant contributions to dose. The composition of the gas mixture as a function of time during the 19 day release was calculated using estimated quantities of the radionuclides in the core at shutdown and their half-lives [6]. It was found that of the total release 1% was ^{88}Kr, 95% was ^{133}Xe, and 4% was ^{135}Xe.

The total release of radionuclides used in these calculations was inferred from the response of a stationary gamma radiation monitor located external to the base of the stack. Release rate estimates (Bq/min) for various time periods during the incident were supplied to the authors by the Task Group staff. From this information, hourly release rates (Bq/hr) were generated assuming a linear change in the release rate between the data points supplied. The total release from this analysis was found to be 8.9×10^{16} Bq (2.4×10^{6} Ci). This total was distributed among the 16 wind direction sectors by assigning each estimated hourly release to the wind direction sector reported for that hour. The resulting release into each sector was apportioned among the three radionuclides considered as noted above and then dispersed out to a distance of 80 km using Eq. (1).

Population

The projected 1980 population within 80 km of TMI, adjusted for the actual 1979 population out to 3.2 km, was also supplied by the Task Group staff [6]. This area was divided into the 16 wind direction sectors and 10 annular distances: 0-1.6 km, 1.6-3.2 km, 3.2-4.8 km, 4.8-6.4 km, 6.4-8.0 km, 8-16 km, 16-32 km, 32-48 km, 48-64 km, and 64-80 km. In AIRDOS-EPA, the air concentration and subsequent individual dose is calculated at down-wind distances at the center of each annular ring in each wind direction sector. This dose is then assumed to be received by each individual at that distance and direction. The resulting population dose for each sector and annular ring is the product of the individual dose and total population for that area.

RESULTS

Initial Calculations

Population dose estimates were prepared for the Task Group staff by assuming that the plume remained elevated during release. Plume rise due to the momentum of the emissions was taken into account. The total-body external dose conversion factors (Sv/y per Bq/cm^3) used in these estimates are 3.2 (^{88}Kr), 5.1 x 10^{-2} (^{133}Xe) and 3.8 x 10^{-1} (^{135}Xe)[7]. The resulting total body population dose by sector is shown in Table 1. While ^{88}Kr composed only 1% of the total release, its comparatively large dose conversion factor resulted in ^{88}Kr contributing up to 26% of the population dose in a given sector. The total population dose of approximately 4 person-sieverts (395 person-rem) is about a factor of 7 less than the 28 person-sieverts estimated from extrapolation of limited thermoluminescent dosimeter (TLD) measurements taken at the time of the incident [6].

Comparison of Observed and Predicted Doses

It is clear from Fig. 1 that the release point for the noble gases considered in this study is surrounded by buildings and other structures. As a result, downdrafts could at times have brought all or part of the TMI plume to ground level. Methods are available for estimating the effects of such downdrafts and building wakes on downwind air concentrations [8,9]. However, no such methods are available in AIRDOS-EPA.

Subsequent to the preparation of the population dose estimates for the Task Group staff, measured net dose values were obtained from twenty TLD's placed around the TMI site prior to the incident. These TLD's were located in various directions from the plant at distances ranging from 0.16 to 24 km. Comparisons were made between these measured values and values predicted using Eq. (1) assuming both an elevated release, as used above, and a ground-level (1 m) release. The latter release height was chosen to approximate the potential downdraft effects due to the presence of the buildings.

A summary of the results of these comparisons is shown in Table 2 [10]. It can be seen that the use of a ground-level release in the model results in a more favorable comparison than when the original elevated release condition is assumed in the model.

Revised Population Dose Estimates

Revised population dose estimates have now been made assuming a ground-level (1 m) release. The total-body dose estimates resulting from this calculation are also shown in Table 1. Revised estimates for other organs have been tabulated elsewhere [11]. The total dose to the population within 80 km is 15 person-sieverts, which is within a factor of two of that extrapolated from the TLD measurements (28 person-sieverts).

DISCUSSION

There is no universally accepted method for estimating health effects from radiation doses. The highest population dose estimated from the TMI incident (28 person-sieverts) is, however, only about one percent of the annual collective dose resulting from natural background (2400 person-sieverts). It has been estimated that the dose from TMI is too small to cause any detectable increase in cases of cancer, developmental abnormalities, or genetic ill-health [1].

There are a number of potential sources of error in these calculations that should be noted. The results of any Gaussian plume model calculation are directly proportional to the source term used as input if all other parameters are assumed constant. As a result, any error in the composition or magnitude of the assumed TMI source term will result in a like error in the dose.

The Gaussian plume dispersion parameters used in AIRDOS-EPA are based primarily on data measured over relatively flat terrain. As shown in Fig. 1, the TMI site is located in a river valley surrounded by rolling terrain. The Gaussian model may not perform as well under these conditions as it does for flat terrain [12].

More information is needed on the behavior of plumes around building complexes such as the TMI site. It is unlikely that the TMI plume was brought to ground 100% of the time during the release, but no information seems to be available on the behavior of the plume around the structures. Such information could help increase the accuracy of the dose calculations.

AIRDOS-EPA is designed primarily for estimating long term average doses from continuous releases of radionuclides, not relatively short-term releases like those considered here. The uncertainty associated with such short-term calculations is undoubtedly larger than the uncertainty associated with long term averages [12].

CONCLUSIONS

The AIRDOS-EPA computer code has been used to estimate the total-body dose to the population within 80 km due to noble gas releases from the TMI incident. These calculations are based on a 22.5° sector-averaged Gaussian plume atmospheric dispersion model assuming a ground-level release. The latter assumption was used because it resulted in better agreement between observed and predicted TLD doses than did use of an elevated release in the model. Our value of 15 person-sieverts is within a factor of two of the 28 person-sieverts estimated from extrapolation of TLD measurements without considering shielding effects due to dwellings. It has been estimated that the population dose received from the TMI incident is too small to cause any detectable physical health effects [1].

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Table 1. Summary of estimated population doses to total body by sector resulting from the incident at Three Mile Island (March 28-April 15, 1979)

Compass direction[a]	Sector	Number of persons	Population dose (person-Sv) Elevated release	Population dose (person-Sv) Ground-level release
N	1	98,425	0.35	2.45
NNW	2	77,858	1.12	1.94
NW	3	162,267	0.63	2.83
WNW	4	106,277	0.53	1.54
W	5	96,229	0.22	0.64
WSW	6	50,221	0.03	0.16
SW	7	81,611	0.05	0.14
SSW	8	140,808	0.07	0.47
S	9	229,370	0.10	0.34
SSE	10	141,201	0.12	0.36
SE	11	70,570	0.04	0.10
ESE	12	233,336	0.06	0.16
E	13	173,341	0.06	0.28
ENE	14	250,668	0.10	0.46
NE	15	153,903	0.08	0.76
NNE	16	97,034	0.39	2.45
Total		2,163,119	3.95	15.08

[a]Wind "toward."

Table 2. Summary of a comparison between predicted and observed doses resulting from the incident at Three Mile Island (March 28-April 15, 1979)

Height of release	Ratio $\left(\frac{\text{predicted dose}}{\text{observed dose}}\right)^a$ Range	Ratio $\left(\frac{\text{predicted dose}}{\text{observed dose}}\right)^a$ Median	Correlation coefficient, log (observed dose) vs log (predicted dose)[b]
1 m	5×10^{-2} - 6.2×10^{0}	0.84	0.91
55 m	2×10^{-5} - 2×10^{-1}	0.01	0.1

[a]A value of 1 signifies perfect agreement between predicted dose and observed dose.

[b]Maximum value = 1.

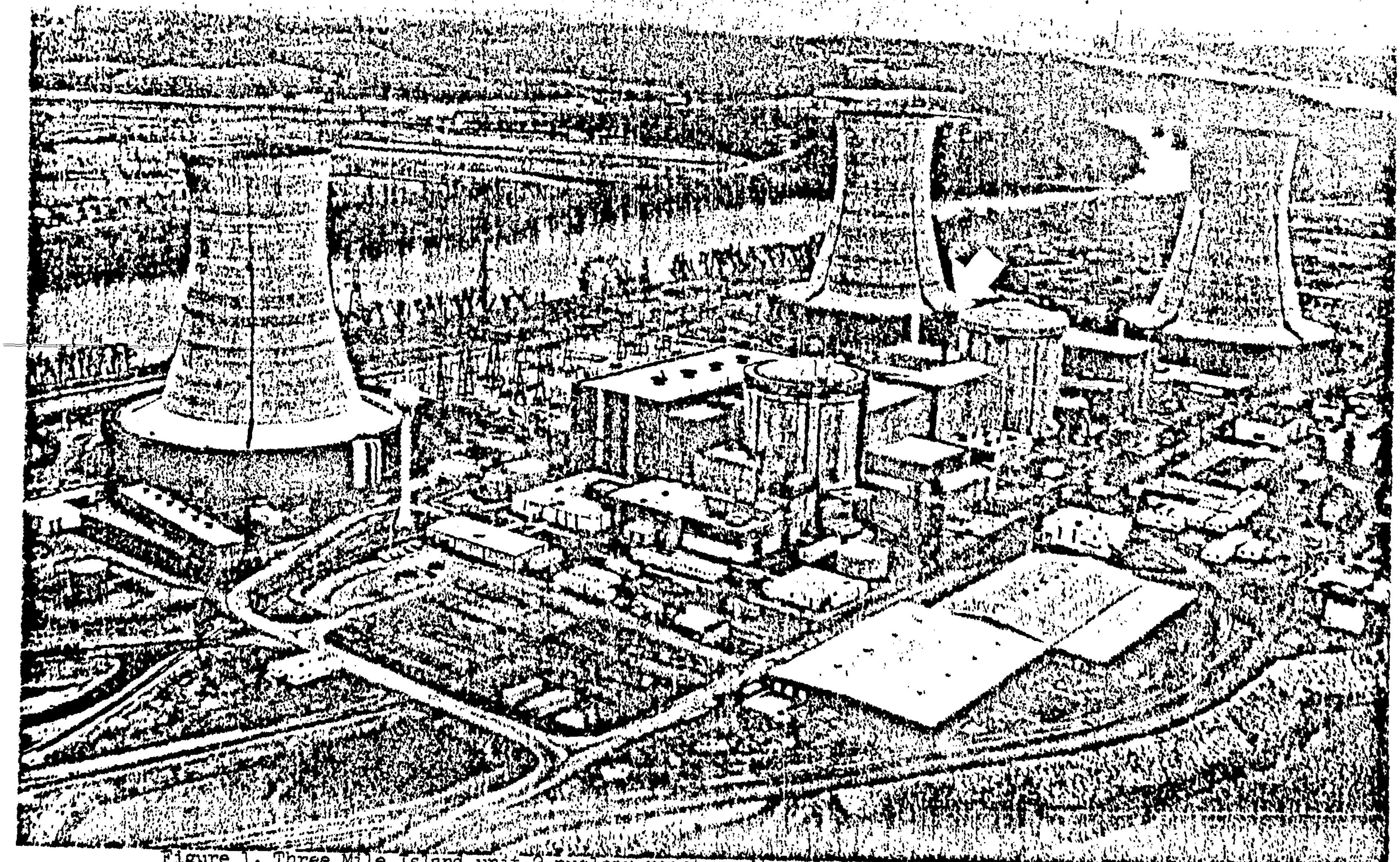

Figure 1. Three Mile Island unit 2 nuclear reactor site showing vent stack (arrow) from which noble gases were released during the period March 28-April 15, 1979.