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PREPRINT

A REVIEW OF SOURCE TERM AND DOSE ESTIMATION FOR THE TMI-2 REACTOR ACCIDENT

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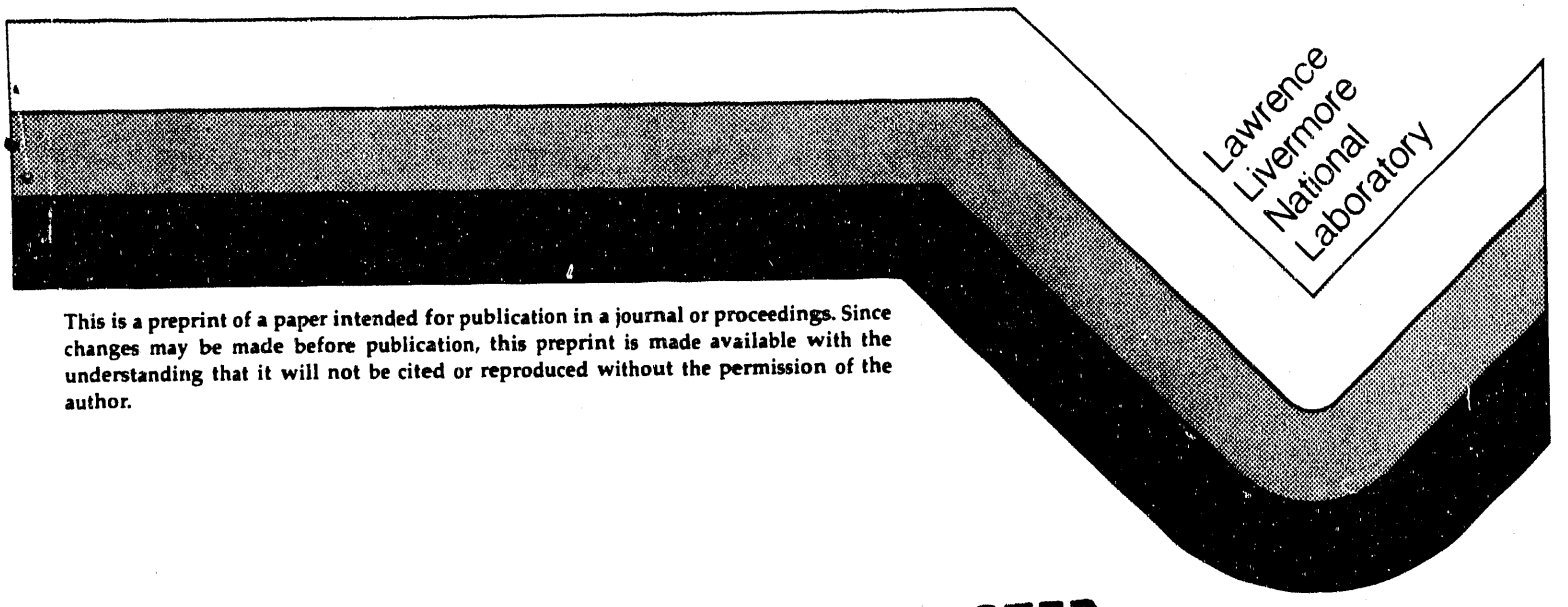

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ABSTRACT

The TMI-2 nuclear reactor accident, which occurred on March 28, 1979 in Harrisburg, Pennsylvania, produced environmental releases of noble gases and small quantities of radioiodine. The releases occurred over a roughly two week period with almost 90% of the noble gases being released during the first three days after the initiation of the accident. Meteorological conditions during the prolonged release period varied from strong synoptic driven flows that rapidly transported the radioactive gases out of the Harrisburg area to calm situations that allowed the radioactivity to accumulate within the low lying river area and to subsequently slowly disperse within the immediate vicinity of the reactor. Meteorological and radiological data, collected throughout the Harrisburg area by numerous organizations, were used in conjunction with atmospheric dispersion modeling to define the time and spatial evolution of the radioactive plume structure for assessing the environmental impact of the release.

The results reported by various analysts, revealed that approximately 2.4–10 million curies of noble gases (mainly Xe-133), and about 14 curies of I-131 were released. During the first two days, when most of the noble gas release occurred, the plume was transported in a northerly direction causing the most exposed area to lie within a northwesterly to northeasterly direction from TMI. Changing surface winds caused the plume to be subsequently transported in a southerly direction, followed by an easterly direction. Thus, the total dose pattern was governed by the complexities inherent in the temporal evolution of the source term, the changing meteorology and the terrain.

The calculated maximum whole body dose due to plume passage exceeded 100 mrem over an area extending several kilometers north of the plant, although the highest measured dose was 75 mrem. The collective dose equivalent (within a radius of 80 km) due to the noble gas exposure ranged over several orders of magnitude with a central estimate of 3300 person-rem. The small I-131 release produced barely detectable levels of activity in air and milk samples. This may have produced thyroid doses of a few milirem to a small segment of the population.

INTRODUCTION

On March 28, 1979 the Three-Mile-Island Unit 2 nuclear power reactor experienced a severe fuel damage accident that resulted in the release of fission products from the core into the containment atmosphere. Some of the fission products escaped from the primary containment by means of the Makeup and Purification System that transported primary coolant into the auxiliary building. Outgassing of the primary cooling water into the auxiliary building atmosphere permitted volatile fission products to enter the building ventilation system leading to environmental releases of noble gases and small amounts of radioiodine.

The amounts of specific radionuclides released into the atmosphere and the associated environmental consequences were extensively investigated by numerous organizations. The primary studies of interest here were conducted by the plant operator, General Public Utilities (GPU); the Department of Energy (DOE), the AD HOC Interagency Study Group that included participation by the Nuclear Regulatory Commission (NRC), the Department of Health, Education and Welfare (HEW) and the Environmental Protection Agency (EPA); and, the task forces supporting the President's Commission on the Accident at Three Mile Island.

These studies were based on extensive data gathered during the accident and our knowledge of the physical processes governing the behavior of radionuclides in the environment whenever data were lacking. The data were acquired by radiation measurements within the plant, thermoluminescent detectors (TLD) placed in the environs surrounding the facility, environmental radiation measurements made by both surface and airborne detection systems, radionuclide analysis of numerous environmental samples, and meteorological data from the site and the surrounding area. These data were used either independently or in conjunction with atmospheric dispersion modeling to estimate the time evolution of the source term from the auxiliary building vent, and the spatial and temporal evolution of the integrated dose pattern over the Harrisburg region.

This review, which summarizes the major findings of these studies, reveals that the environmental and health impact to the surrounding population was minimal. However, the details of the source term, the population and individual dose estimates may differ by factors of three or four from one study to another. This paper presents the authors views of the most likely consequences of the accident and a credible range of uncertainty associated with these estimates.

NOBLE GAS SOURCE TERM ESTIMATION

Several independent attempts were made to estimate the magnitude of the noble gas releases from the auxiliary building vent where essentially all of the atmospheric releases occurred. Unfortunately, the normal vent monitor, which was designed to measure routine operational releases, exceeded its saturation limit early in the accident with attendant loss of valuable source term information. Thus, it was necessary to utilize various indirect approaches to estimate the release magnitudes. The GPU derived noble gas source term estimate was based on a combination of numerical modeling techniques and in-plant and environmental radiation measurements.[1] This involved a multistep approach that

included (1) reactor core radionuclide inventory modeling and analysis of air samples collected from the building vent system to define the isotopic mix of the noble gases, (2) analysis of temporal variations of the output from area monitors situated within the auxiliary building to indicate the relative release rate as a function of time since the vent monitoring system became saturated during the high release period, (3) atmospheric dispersion modeling based on a relative source rate and on-site meteorological measurements to calculate the gamma dose to ground level receptors, and (4) optimizing the agreement between the calculated dose rates with the environmental TLD measurements by source term scaling. This process produced the estimated total noble gas release rates shown in Fig. 1. Combining these release rates with the time dependent isotopic composition, and integrating with time produced the estimated noble gas radionuclide specific total activity releases shown in Table 1. The results indicate that about 10 million curies of noble gases were released during the period from March 28 through April 30. Approximately 80% of the noble gas activity released was due to Xe-133. A review of the temporal variation of the release revealed that about 66% of the total activity was released during the first day and a half of the accident, while another 22% of the total activity was released during the following two days; from 1700 on March 29 to 1600 on March 31. Essentially all of the release had occurred by April 6.

A different approach for source term estimation was taken by the Task Group of Health Physics and Dosimetry of the President's Commission on the Three Mile Island Accident.[2] Their approach focused on a careful analysis of the response of a building area radiation monitor, situated near the ventilation ducts that led to the stack vent where the radiation levels were sufficiently low to avoid detector saturation. Intercomparison of this detector's response with that of the vent monitor at various radiation levels below the vent monitor's saturation limit, permitted extrapolation of vent radiation levels above the vent monitor's saturation level. This analysis led to a total noble gas release of 2.4 million curies.

The uncertainty associated with the noble gas release estimates are within a factor of 4. The 10 million curie estimate, which represents about 8–10% of the noble gas core inventory at the time of the accident, seems to be in reasonable agreement with more recent information on the post accident inventory and distribution of radionuclides within the TMI-2 reactor system. This study revealed that 91% of the Kr-85 could be accounted for within the containment atmosphere, the previously melted fuel, and the in-tact fuel-rods; thus, inferring a 9% loss to the atmosphere.[3]

EXTERNAL DOSE ESTIMATION

Several approaches were taken to estimate the radiation dose received by the affected population due to the release of noble gases. This included several independent studies based on atmospheric dispersion modeling in conjunction with the environmental radiation measurements as well as spatial interpolation of the TLD measurements at a limited number of locations surrounding the site. The various dispersion modeling efforts used a variety of models that ranged from Gaussian to complex three-dimensional models.

Meteorological data were available from the on-site tower as well as from several local sources. The meteorological conditions during the first five days of the accident, when the highest release rates occurred, consisted mainly of up and down-river flows. From the

morning on March 28, when the release was initiated, until mid-afternoon on March 29, the winds were primarily from the southeast- southwest direction at approximately 3 m/s. Subsequently the winds rotated to a northeast-northwest direction with an average speed of 1–2 m/s. Calm and highly variable conditions were observed during the night of March 29-30. These calm and variable conditions continued until the evening of March 30 when strong and steady southerly winds of about 3 m/s returned. On April 1 the winds rotated into the westerly to northwesterly directions with speeds generally ranging between 1–3 m/s.

Atmospheric dispersion modeling, based on these meteological conditions, permitted elucidation of the temporal evolution of the time-integrated dose pattern. This is illustrated in Fig. 2 which shows the evolving integrated dose pattern.[4] These results were generated by means of a three-dimensional mass-consistent wind field model coupled with a particle-in-cell transport and diffusion model using a normalized one million curie release that varied in time according to that shown in Fig. 1. The figure shows how the dose pattern was quickly and predominantly established by the generally south-to-north flow during the initial release period. Thereafter, the low levels of release resulted in only relatively minor but discernible changes in the initial dose pattern. Note particularly the southward extension of the pattern from March 29 to March 30, the east and southeast spread from March 30 to March 31, and finally the "diffusion-like" effect of nine days of synoptic and diurnal meteorological variations with a small source term.

Integration of atmospheric dispersion patterns with the environmental radiation measurements permitted the estimation of the total integrated dose to the exposed populations. Using the DOE aerial radiation measurements made within the plume on a regular basis over a two week period, resulted in the DOE integrated dose pattern shown in Fig. 3.[5] Note that the highest doses occurred in the areas immediately north of the plant with secondary nodes extending in the southeast and easterly directions. A similar pattern was generated by GPU after integrating the TLD measurements with their finite plume dispersion modeling.[1] These studies indicate that a total dose of 100 mrem was exceeded over an area extending several kilometers in a northeast to northwest direction from the plant, although the highest measured off-site dose by the TLD network was 75 mrem.

Integration of the dose pattern with the population distribution throughout the affected region led to an assessment of the collective dose equivalents. The most credible estimates are given in Table 2. The estimates resulting from analysis of the DOE aerial measurements was 2000 person-rem[5] in contrast to 3300-3400 person-rem obtained by the AD HOC Interagency Study Group on the basis of spatial interpolation of the TLD measurements by either atmospheric dispersion modeling or by inverse distance scaling.[6,7] The GPU obtained 3300 person-rem by combining dispersion modeling with the 10 million curie source term and the TLD measurements.[1] The lowest collective dose estimate, 500 person-rem, was derived on the basis of atmospheric dispersion using the 2.4 million curie source term.[2] Thus, the central estimate is about 3300 person-rem with a range of several orders of magnitude.

IODINE RELEASE

The release of small quantities of radioiodine was detected by analysis of air samples collected by filter and charcoal samplers situated in the building ventilation system. These analyses revealed the estimated I-131 release rates from March 28 to April 25, 1979, given in Fig. 4, which led to a total release of 14 curies of I-131. An additional 2.6 curies of I-133 was also released. It is of interest to note that the I-131 release rates do not decrease rapidly like those for the noble gases shown in Fig. 1, but stays reasonably constant throughout the measurement period. This is most likely due the fairly constant evaporation rate of the iodine from the contaminated water that flooded the auxiliary building. The fraction of iodine released is extremely small due to its preferential retention in the water and the subsequent plateout within the building.

On the basis of these release rates and atmospheric dispersion modeling, the highest adult thyroid dose due to inhalation was estimated to be about 7 mrem at a distance of 2400 m from the plant, and the collective thyroid dose for the two million people within an 80 km radius was estimated to be about 180 person-rem. Measurements of iodine air concentrations suggested that these estimates have an uncertainty of about a factor of 4 and are most likely to be higher than indicated by the measurements.

Milk samples were collected at numerous dairies to evaluate the I-131 concentrations. Of approximately 250 samples collected, less than half of the samples showed detectable concentrations. The highest measured concentration in milk was 41 pci/l and the average concentration was less than 20 pCi/l.[5] This potentially could have resulted in a child thyroid dose of about one millirem.

CONCLUSIONS

Extensive environmental monitoring of radioactivity throughout the Harrisburg area during the TMI-2 accident revealed that the environmental and health implications of the noble gas and iodine releases were minimal. Approximately 2.4–10 million curies of noble gases (mainly Xe-133) were released; the higher value being the most likely. The collective dose resulting from the release to the 2 million people living within a radius of 80 km of the plant was about 3300 person-rem. This represents about 1% of the normal annual background radiation dose for that area. The average dose to an individual living within 8 km of the plant was estimated to be about 10% of the annual background dose. The maximum estimated dose received by an off-site individual was about 75 mrem.

The 14 Ci release of I-131 resulted in barely detectable levels of I-131 in air and milk samples collected during the accident. These low levels of activity may have produced thyroid doses of a few millirem to a small segment of the surrounding population. Thus, no detectable health impacts due to radiation exposure were expected to occur as a result of the accident.

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FIGURE CAPTIONS

Fig. 1. Estimated noble gas release rates from the TMI-2 accident.

Fig. 2. Normalized calculated integrated dose patterns in units of millirem due to TMI-2 noble gas release on (a) March 29 (24-h integration), (b) March 30 (48-h integration), (c) March 31 (72-h integration), and (d) April 7, 1979 (240-h integration). The patterns are based on the release of one million curies of Xe-133.

Fig. 3. Estimated dose pattern derived from the DOE aerial measurements from March 28–April 3, 1979. The units are in millirem.

Fig. 4. Estimated I-131 release rates.

TABLE HEADINGS

Table 1. Estimated noble gas releases (megacuries).

Table 2. Estimates of collective dose equivalents due to noble gas releases from TMI-2 accident.

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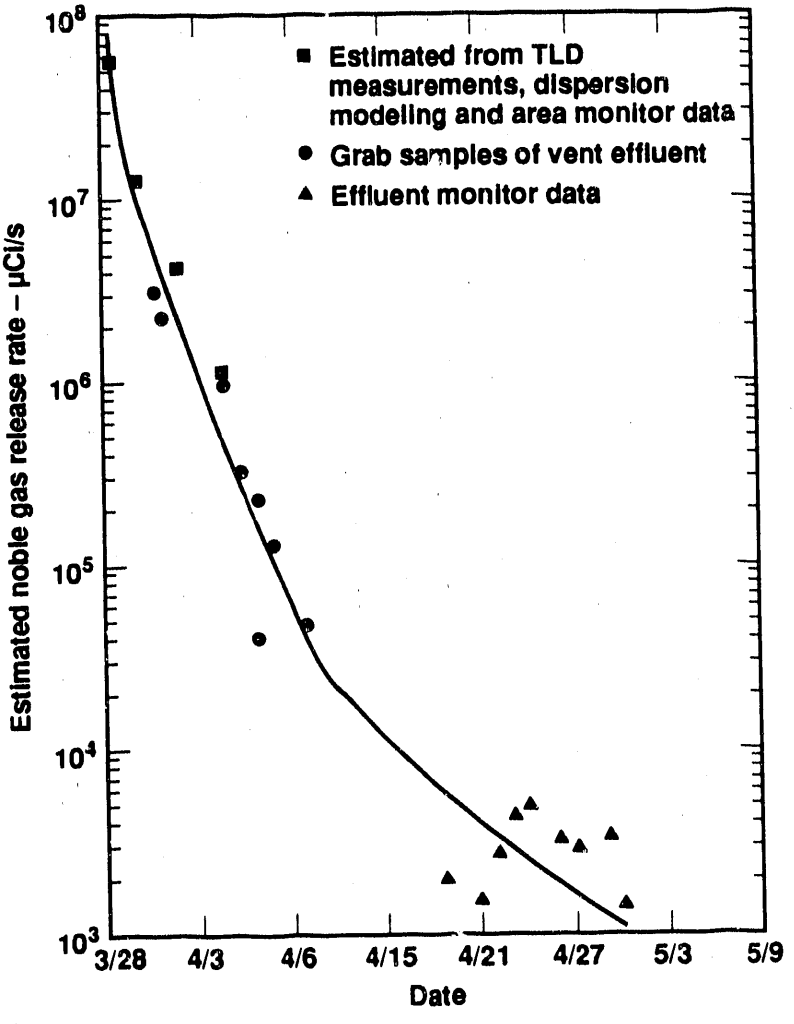

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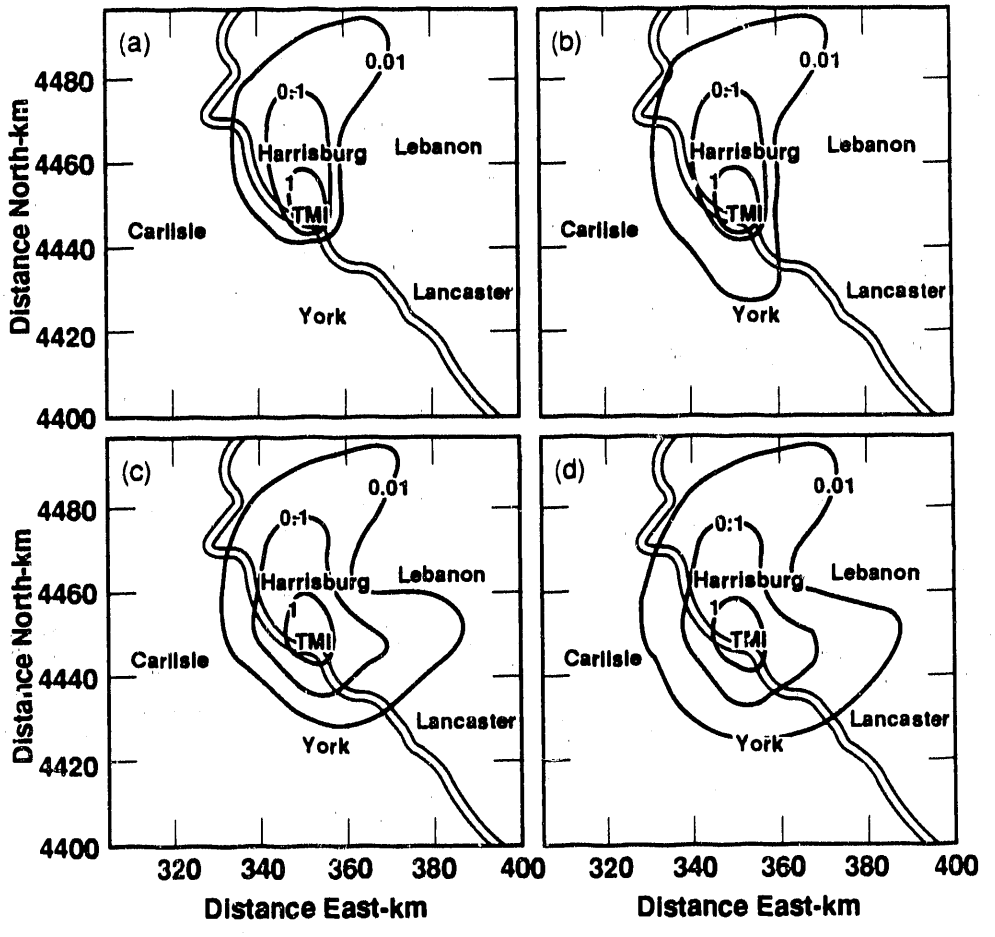

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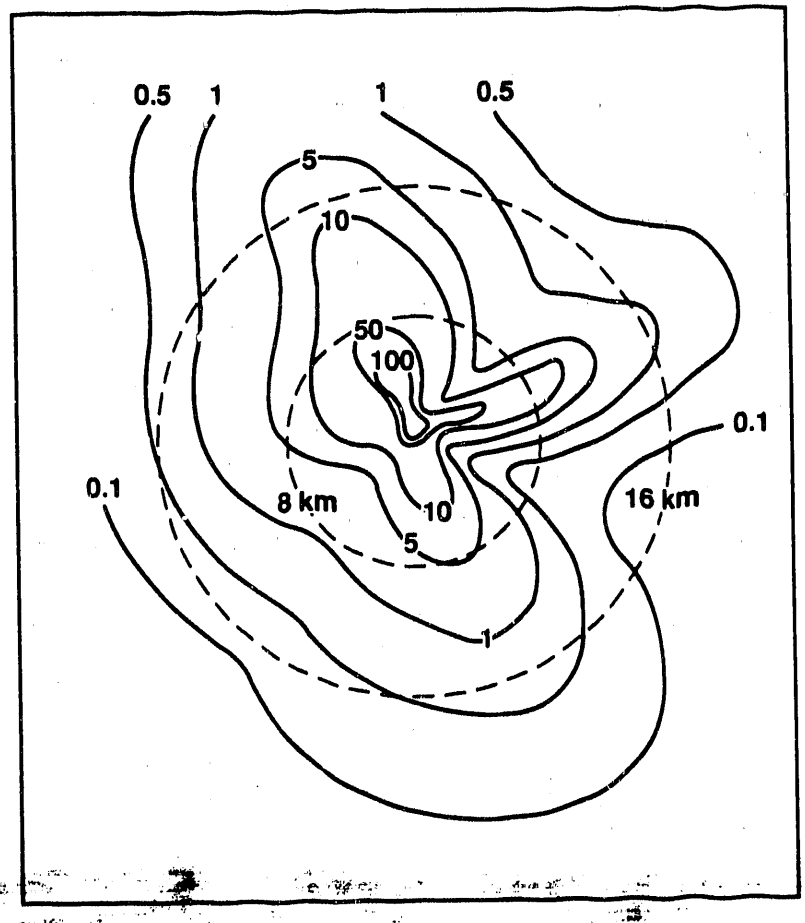

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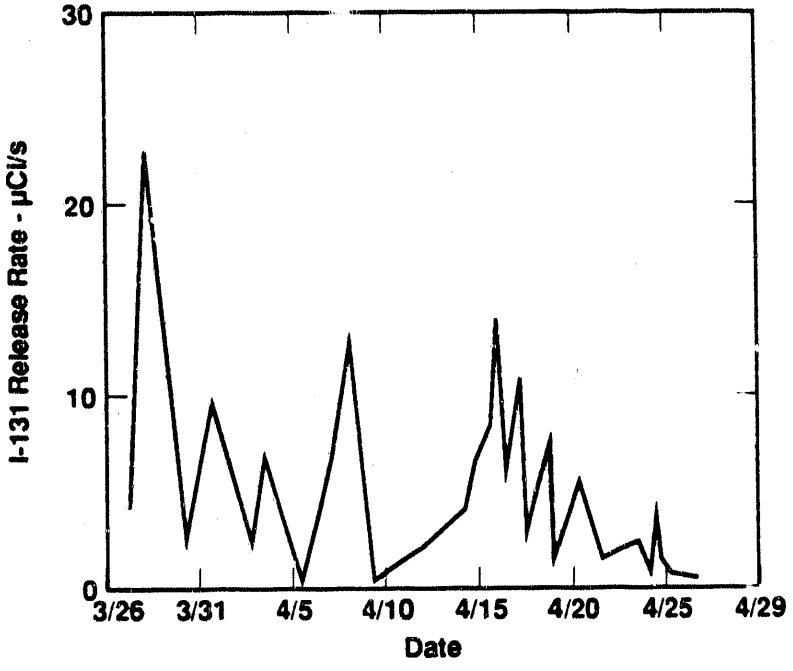

Fig. 4. Estimated I-131 release rates.

Table 1. Estimated Noble Gas Releases* (Megacuries)

	Period					
Isotope	3/28–3/29	3/29–3/31	3/31–4/3	4/3–4/6	4/6–4/30	Total*
Xe-133	4.9	2.1	1.1	0.27	0.015	8.3
Xe-133m	0.12	0.039	0.015	0.0019	—	0.17
Xe-135	1.5	0.077	0.0014	0	0	1.5
Xe-135m	0.14	0.0013	0	0	0	0.14
Kr-88	0.061	0	0	0	0	0.061
Total in Period	6.6	2.2	1.1	0.27	0.015	10.2
% of Total	65	22	10.8	2.6	0.15	100
Cumulative	65	86	97	99.8		

*To 4/30/79

Table 2. Estimates of Collective Dose Equivalent Due To Noble Gas Releases From TMI-2 Accident.

Group	Technique	Person-rem	
		Best Value	Range
DOE	Aerial measurements	2000	
GPU	TLD measurements and dispersion modeling	3300	1650–6600
ADHOC Group	TLD measurements and dispersion modeling	3400	
ADHOC Group	Spatial interpolation of measurements	3300	1600–5300
Pres. Commission	Source term and dispersion modeling	500	50–5000

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