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ENVIRONMENTAL MEASUREMENTS DURING THE TMI-2 ACCIDENT

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Environmental Measurements During the TMI-2 Accident*

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Introduction

Even though the prior arrangements for it had not been clearly defined, a large integrated state and federal environmental monitoring response was made to the TMI-2 accident. The following presentation considers its emergency phase, which commenced at about 0700 on March 29, 1979 and which extended through the next three weeks. Particular emphasis is placed on the role of the Department of Energy (DOE), which committed major resources to support this effort.

Soon after the declaration of a General Emergency at 0724, the initial off-site response was made by teams from the plant operator at that time, Metropolitan Edison. Coordination with the Pennsylvania Department of Environmental Resources (DER) was provided by its staff nuclear engineer who was on site with an an open phone link to the DER Office in downtown Harrisburg, some 12 miles (7 km) away from the TMI site. This initial effort was supplemented in late morning by personnel from the Region 1 Office of the NRC, who made a few off-site measurements during the first day of the emergency.

A team of six health physicists from DOE's Radiological Assistance Program (RAP) at Brookhaven National Laboratory arrived in a U.S. Coast Guard

*This investigation was supported by Contract DE-AC02-76CH00016 to the Safety and Environmental Protection Division by the Department of Energy.

helicopter at the Capital City Airport near Harrisburg in mid-afternoon. This coincided with the arrival of an aerial survey helicopter from the Eastern Office of DOE's Aerial Measurements Service (AMS), which is located at Andrews Air Force Base at Suitland, MD. The RAP Team operated out of the DER office to supplement its sampling and dose assessment efforts, while the AMS helicopter performed plume tracking.

Meanwhile DOE's Atmospheric Advisory Capability (ARAC) at Lawrence Livermore Laboratory (LLL) in Livermore, CA, commenced projections of plume trajectories which were initially relayed by phone to the NRC. The principal AMS resources at Las Vegas were alerted, as were those at several DOE national laboratories. The DOE effort gradually expanded during the following days. By April 2, about 100 DOE radiation protection professionals and support personnel were engaged in plume tracking, field environmental monitoring and sampling, sample analysis, and dose assessment (1). They were based at a Command Post which had been established at the Capital City Airport, which is located about 10 miles (16 km) northwest of the TMI site. A team of 21 EPA professionals who arrived on March 30 were also colocated at the Command Post.

Much of the largely ad hoc command structure, organizational arrangements and lines of communication involving the state and several federal agencies in this joint effort became the conceptual basis for the current Federal Radiological Monitoring and Assessment Plan (FRMAP), in which DOE is initially the lead agency for the technical component within FEMA's Federal Radiological Emergency Response Plan (2).

In-Plant Monitoring

At about the time that the General Emergency was declared, a downwind dose-rate projection of 40 R/hr (0.01 C/kg) at Goldsboro (1.5 mi or 2.4 km west of the TMI site) was made by a plant engineer on the basis of a containment monitor reading of 400 R/hr (0.103 C/kg) (3). The NRC's subsequent investigation disclosed that, at that time, the true reading was only 400 mR/hr (1×10^{-3} C/kg). However, it subsequently increased to 6,000 R/hr (1.55 C/kg) by 0900. The initial projection was based on an assumed containment leakage rate at an overpressure of 55 psi (3.8×10^{5} Pa), whereas the actual level at the time it was made was about 1.5 psi (1.0×10^{4} Pa).

Starting at about 0655, there were many indications of a sudden increase in in-plant radiation levels. The unit vent gas monitor went off-scale ($\sim 2 \times 10^{-2}$ μCi/cm^3 or 740 Bq/cm^3) shortly thereafter. The iodine and particulate monitors also went off-scale within an hour or two, apparently due to the high gas concentrations and increased radiation backgrounds in the vicinity at these monitors.

For the next few days after this effective disabling of the effluent monitors, there was no data available from the plant on gaseous emissions except for a few grab samples, the first of which was not obtained until March 31. Also, due to high radiation levels in their vicinity the iodine effluent samples were changed only infrequently during the first week after the accident. A retrospective reconstruction of the trend of these grab samples,

along with meteorology and TLD data, suggests an initial release rate on March 28 of about 55 Ci/sec (2.0 GBq/sec) in a concentration of about 5 $\mu Ci/cm^3$ (185 Bq/cm^3). It declined almost exponentially over the next two weeks, with a half-time of about 1.5 d (4). The ^{131}I release data showed considerable variability. The largest release rate was 22.2 μCi/sec (821 kBq/sec) for a total of 4.2 Ci (155 GBq) in an average concentration of about 4×10^{-7} Ci/cm^3 (15 mBq/cm^3) between 1900, March 29, and 2200, March 30. A total of about 7 Ci (259 GBq) was released during the first week after the accident and 3 Ci (111 GBq) during each of the following two weeks. A reconstruction of the release concentrations of ^{133}Xe and ^{131}I is shown in Figure 1, from which it is evident that the release of the latter declined much more slowly from its initial level (5).

Beyond a general knowledge of plant conditions, at the time of the accident and for the next few days the agencies involved in the response to the accident were largely dependent on environmental measurements as a basis for the estimation of plant releases and for the formulation of protective actions.

Early Field Monitoring, Day 1 and Day 2

During the first two days after the accident Metropolitan Edison's off-site teams made about 50 measurements. The first at Goldsboro in mid-morning showed an external exposure rate of 1-2 mR/hr ($2.6\text{-}5.2 \times 10^{-4}$ C/kg). A field measurement, using a single-channel analyzer and NaI detector, indicated a ^{131}I concentration of 1×10^{-8} $\mu Ci/cm^3$ (3.7×10^{-4} Bq/cm^3), which caused some temporary concern since it suggested a significant airborne release rate was

occurring. However, a subsequent laboratory analysis of the sample by the DER indicated a concentration of $< 1.5 \times 10^{-11}$ $\mu Ci/cm^3$ (5.5×10^{-7} Bq/cm^3) and that the field measurement was apparently a response to absorbed radiogases on the charcoal sampling medium.

At about noontime the NRC measured 20 mR/hr (5.2×10^{-3} C/kg) in the plume during a brief steam dump. However, this was later ascribed to radiogases being emitted concurrently from the unit vent. At 1500 a plant team measured 50 mR/hr (1.3×10^{-2} C/kg) at about 0.5 mi (.8 km) northeast of Unit 2 on the east bank of the Susquehanna River. At 2238 13 mR/hr (3.4×10^{-3} C/kg) was measured at 5.6 miles (9.0 km) north-northwest of the plant. On March 29 at 0600, 30 mR/hr (7.7×10^{-3} C/kg) was measured at Goldsboro and at 2235 3 mR/hr (7.7×10^{-4} C/kg) at Royalton, which is 2.5 mi or 4.0 km north of TMI. At 0906 on March 30, 15 mR/hr (3.9×10^{-3} C/kg) was measured at location S-11, which is 1 mile or 1.6 km south of TMI. All other Metropolitan Edison team measurements were apparently < 1 mR/hr (2.6×10^{-4} C/kg). Some 57 air samples of radioiodines were obtained. A few field measurements indicated the presence of radioiodines. However, subsequent laboratory analyses indicated that all were $< 2\text{-}6 \times 10^{-11}$ Ci/cm^3 (7×10^{-7}-2×10^{-6} Bq/cm^3).

The utility also obtained over 300 helicopter measurements of radiation levels, but these were mostly in the vicinity of the plant. While this information was utilized by plant personnel, it was not made available at the time for environmental assessment.

Commencing on the late afternoon at March 28, two BNL RAP teams made downwind measurements using survey meters and a portable analyzer. They conducted air sampling using a silica-gel medium for the collection of

radioiodines which has a low affinity for radiogases (6). Levels of 1-2 mR/hr ($2.5\text{-}5 \times 10^{-4}$ C/kg) were found at 5-10 mi (8-16 km) north to north-northwest of TMI. The portable analyzer indicated a prominent line at 0.23 keV, which was associated with ^{m133}Xe (T 1/2 = 2.19 d). The 0.36 keV ^{131}I photopeak was not discernible. Field measurements of air samples for ^{131}I indicated a concentration of $< 1 \times 10^{-10}$ $\mu Ci/cm^3$ (3.7×10^{-6} Bq/cm^3). A subsequent DER lab analysis indicated $< 6 \times 10^{-11}$ (2.2×10^{-6} Bq/cm^3). On the basis of information that the situation at the plant appeared stable, at midnight of April 28-29 the RAP team field surveys were suspended until the next morning.

The AMS helicopter was also deployed in late afternoon of March 28. It initially located the plume center line to the north of the plant. It had a width of about 30^{o}. Radiation levels in it were 0.2 mR/hr (5.2×10^{-5} C/kg) at a distance of 7 miles (11.3 km) and 0.1 mR/hr (2.6×10^{-5} C/kg) at a distance of 16 miles (26 km) (7). Its on-board measurement system for the establishment of ground level dose rates was swamped out by high count rates (> 80,000 cps). Spectra obtained on March 28-29 using a portable -analyzer, which are shown in Figures 2-3, confirmed the presence of fission product noble gases and the relative absence of ^{131}I.

On March 29, the AMS helicopter was provided with portable scintillation and GM survey meters. Four plume tracking flights were made. At 1630 a level of 0.2 mR/hr (5.2×10^{-5} C/kg) was found at 10 mi (16 km) northwest and at 2200 0.5 mR/hr (1.3×10^{-4} C/kg) at 0.5 miles (0.8 km) northwest of TMI.

Supplemented by a back-up team of six from Brookhaven which arrived by 0200 on March 29, the DOE RAP teams recommenced ground surveys on the morning of March 29. Levels up to 0.2 mR/hr (5×10^{-5} C/kg) were measured at

Goldsboro at about 0800. All ^{131}I samples were < 1 x 10^{-11} $\mu Ci/cm^3$ (3.7 x 10^{-7} Bq/cm^3).

In the late afternoon of March 29, the BNL RAP team was relieved by a contingent of seventeen from the Bettis Atomic Power Laboratory (BAPL) at Pittsburgh. In addition to survey instruments and air samplers, their equipment included a Ge-Li detector for field analysis of samples.

Field Activity Subsequent to Day 2

It is apparent from Figure 1 that the largest releases of radiogases occurred during the first two days after the accident. It is also doubtful that there ever was a sufficient quantity of airborne radioiodines within the containment, fuel handling or auxiliary buildings to have constituted a significant environmental problem (8-9). However, this was not apparent at the time.

By Friday March 30, the reactor was not yet on natural circulation cooling. However, the situation at the plant appeared to be under control. Attempts to depressurize it resulted in periodic venting of gas storage tanks. A "false alarm" recommendation for a limited evacuation was occasioned at mid-morning due to a misunderstanding at the NRC headquarters at Bethesda, MD, of the location of a 1,200 mR/hr (0.31 C/kg) reading which was obtained by a utility helicopter during one such expected gas venting. Subsequently, with the propounding by the NRC of a "hydrogen gas bubble" in the vessel and the further hypothesis that it might lead to an explosion, an evacuation recommendation was made and the federal off-site response escalated dramatically.

In addition to the recall of an augmented BNL RAP team of 15, a contingent of 16 was called out from DOE's Knolls Atomic Power Laboratory (KAPL). Both BNL and KAPL brought NaI and Ge-Li detectors, which were set up at the Capital City Airport Command Post. Using them and the BAPL system, an around the clock counting effort was mounted to make gamma analyses of the growing backlog of environmental samples. On March 30, thirty-eight samples were analyzed and by April 4 over 800 samples had been analyzed in this improvised field counting laboratory.

Back-up support for the initial AMS group was provided by some 17 persons from Andrews Air Force Base. Logistic support including portable power, communications, and photographic equipment in airborne pods and some 37 DOE support personnel were flown in from the AMS-West base at Las Vegas. A field Ge-Li and High Pressure Ionization Chamber measurement capability was subsequently provided on April 2 by a team of four from DOE's Environmental Measurements Laboratory (EML) in New York City.

The Command Post also included a number of DOE management personnel from BNL, RAPL, BAPL, the Chicago and Las Vegas DOE offices and DOE Headquarters. Additional DOE personnel who were assigned to assist the NRC and the DER were recruited from Oak Ridge National Laboratory, Argonne National Laboratory and Mound Laboratory. By agreement with the DER and other involved federal agencies, DOE established a central data base at the Command Center for all of the available environmental measurements and assumed the responsibility for their distribution to interested parties. A data evaluation and dose assessment capability was also established and daily briefings were conducted at the Command Post.

During the next few days after March 30, AMS helicopter flights were scheduled on a three hour basis, weather permitting. By April 10 they made some 60 flights. At NRC's request, special flights were made during the anticipated gas releases. The highest measured level during any one release was 20-30 mR/hr (5.1-7.7 C/kg) at 1/4 mi (0.4 km) from Unit 2 on March 30. Some 200 routine helicopter based measurements were made, principally at 1 mi (1.6 km), 3 mi (4.8 km), and at 10 mi (16 km). At 1 mi (1.6 km) the highest measured level was 9 mR/hr (2.3×10^{-3} C/kg) on March 30. Subsequently most were < 1 mR/hr (2.6×10^{-4} C/kg), with the following daily maxima: April 1—3mR/hr (7.7×10^{-4} C/kg), April 2--1 mR/hr (2.6×10^{-4} C/kg), April 3--4 mR/hr (1.0×10^{-3} C/kg), April 4--7 mR/hr (1.8×10^{-3} C/kg), April 5--6 mR/hr (1.5×10^{-3} C/kg), April 6--3 mR/hr (7.7 C/kg), April 7--5 mR/hr (1.3×10^{-3} C/kg), April 8--3 mR/hr (7.7×10^{-4} C/kg), April 9--2 mR/hr (5.2×10^{-4} C/kg), and April 10 2 mR/hr (5.2×10^{-4} C/kg). The exposure rates at 1 mi (1.6 km) from the TMI site, as measured by the AMS helicopter crews between March 30 and April 14, are shown in Figure 4. As shown in Figure 5, their daily averages declined exponentially, with a half-time of about two days.

On March 30, ARAC established a field capability at the Command Post (10). It included the regular facsimile reception of LLL's projections of plume directions and extent. These were used to guide both the helicopter flights and ground surveys and sampling.

During the period March 28-April 3 the DOE field teams made some 500 ground-level radiation measurements out to a distance of 10 mi (16 km) from

TMI. Most were below 1 mR/hr (2.6×10^{-4} C/kg) and the highest was < 10 mR/hr (2.6×10^{-3}). From these, a total β/γ absorbed dose of 6,090 person-rems (60.9 person-Sv) was calculated for the population within 50 miles (80 km) (11). On the basis of a ratio of open to closed window measurements of 5, a total gammma dose about 1,220 persons-rems (12 person-Sv) was estimated by this method.

From March 29 to mid-April, the rate of decline in the daily average concentration of ^{133}Xe in the release, as indicated in Figure 1, corresponds closely to that of its estimated concentrations in the plume center line as shown in Figure 5.

However, when the calculated center line concentrations of ^{133}Xe as derived from helicopter-based radiation level measurements are compared with those indicated in Figure 1, the inferred average dispersion factors (X/Q) appear to be almost an order of magnitude in excess of those which seem reasonable (higher concentrations than reasonable). This may be at least in part an artifact of the 3-5 x over-response of the survey meters used in making the helicopter based measurements to the 81 keV photopeak of ^{133}Xe, as established by NBS calibrations on May, 1979 (12). It was also noted during light winds on several occasions the gaseous emissions had a tendency to "puddle" rather than to disperse as a classical Gaussian plume.

Contours of isodose lines for the total external exposure between March 28 and April 3 out to 2 mi (3.2 km) and out to 10 mi (16 km) are shown on Figures 6 and 7. The numbers in the boxes are TLD readings for the same period. They were not utilized in plotting the contours, but were added subsequent to their development. Their agreement with the adjacent contours

Table I

Collective Dose to Population 0.50 miles from Three Mile Island Nuclear Station March 29, through April 3, 1979
(DOE Aerial Radiation Survey)

Radius (Mile)	Collective Dose Person-Rem**	Total Population*	Average Individual Exposure (mrem)
0-1	51.2	685	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	0.092 (0.9)

*Estimated population for 1980 by 22.50 sectors and distance obtained from FSAR for TMI-2.

**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.

Note: 1 person-rem = 0.01 person-Sv
1 mrem = 0.01 Sv

From Reference 14

Table II

Summary of Results of Analyses of Field Samples Obtained by DOE Teams in the Vicinity, March 28-April 10, 1979

	Sample type	No. of samples collected	No. of samples less than MDA*	No. of samples greater than MDA*	Range of positive values
Period from	Stagnant surface water	122	122	-	-
3/28	Rain water	0	0	0	-
4/6	Vegetation	236	234	2	0.1 - 0.3 nCi/m^2
	Soil	225	224	1	0.3 nCi/m^2
	Air	19	11	3	7×10^{-12} to 3×10^{-11} $\mu Ci/cm^3$
		602			
Period from	Stagnant surface water	60	60	0	-
4/7	Rain water	17	17	0	-
4/10	Vegetation	78	69	9	0.5 to 0.7 nCi/m^2
	Soil	27	27	0	
	Air	23	11	12	6×10^{-12} to 9×10^{-11} $\mu Ci/cm^3$
		205			

*The minimum detectable activity or concentration levels varied but were about 0.1 nCi/m^2 or 5×10^{-4} $\mu Ci/cm^3$ (1 nCi = 37 Bq, 1 $\mu Ci/cm^3$ = 37 kBq/cm^3).

From Reference 16

Table III

Concentrations of ^{131} in Milk Samples in TMI Vicinity

March 30-April 5

Date	No. Positive	Average Concentration (pCi/l)	(Bq/l)
3/30	1	21	0.78
3/31	14	20	0.74
4/1	11	19	0.70
4/2	13	14	0.52
4/3	3	16	0.59
4/4	2	19	0.70
4/5	4	10	0.37

*Data from reference 16.

Table IV

Levels of Deposited ^{131}I as Measured by EML in the Vicinity of TMI

April 3-19, 1979

Direction	Distance (km)	Date	Amount of deposited ^{131}I nCi/m^2	(Bq/m^2)
ESE	0.8 k	4/9	1.9	70.3
ESE	1.9	4/19	0.8	29.6
SE	3.0	4/10	0.4 ± 0.3	14.8 ± 11.1
SSE	2.9	4/4	0.6 ± 0.6	22.2 ± 22.2
S	4.0	4/11	0.3 ± 0.3	11.1 ± 11.1
NW	3.0	4/5	0.2 ± 0.2	7.4 ± 7.4
NW	10.2	4/7	0.4 ± 0.4	14.8 ± 14.8
N	1.9	4/3	0.4 ± 0.3	14.8 ± 11.1

From Reference 17.

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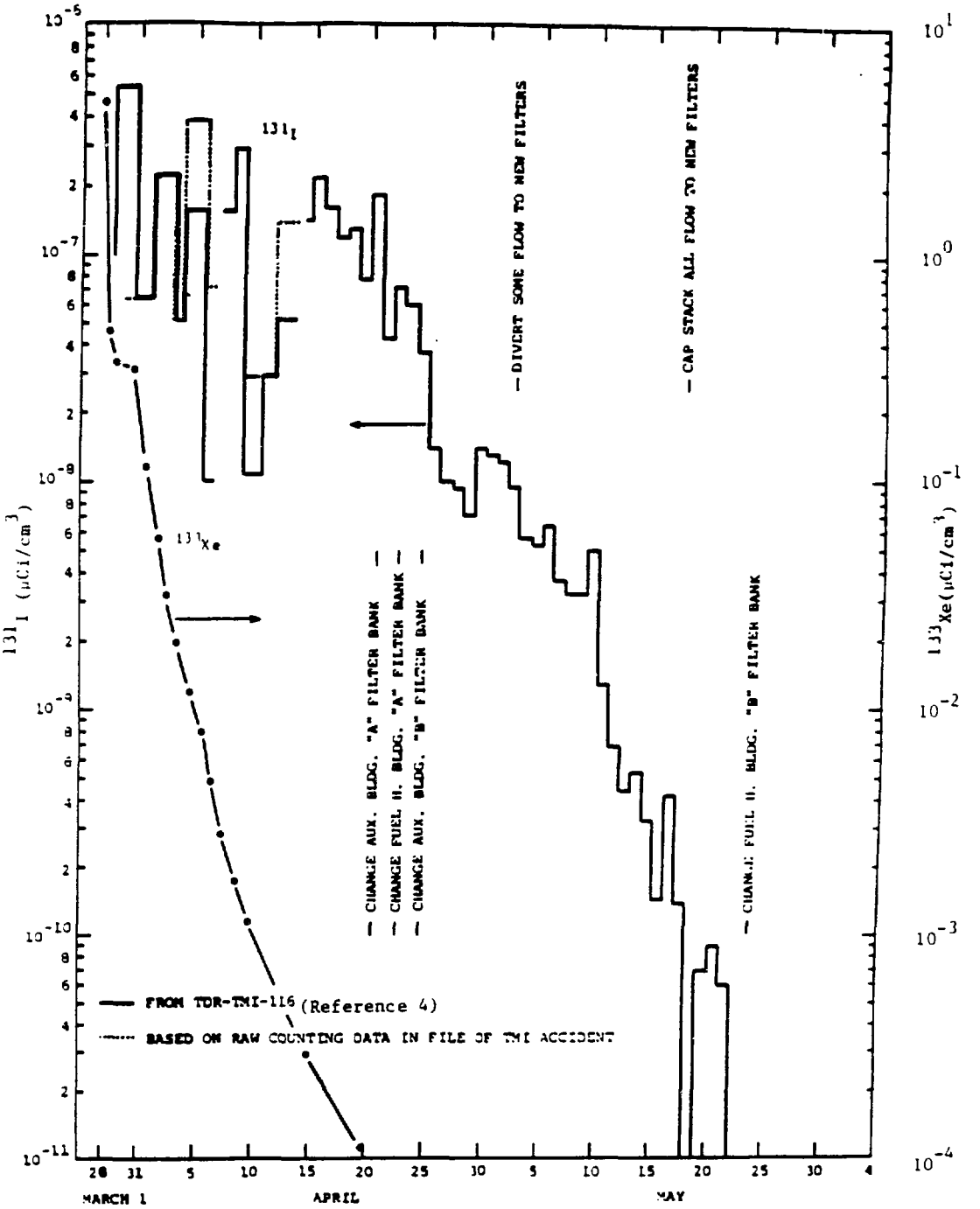
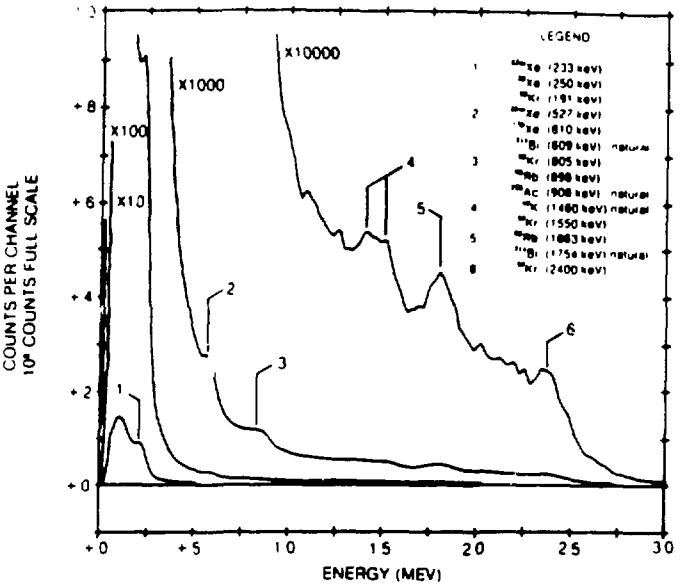


Comparison of ^{133}Xe and ^{131}I Concentrations in Airborne Effluents at TMI-2

From Reference 4

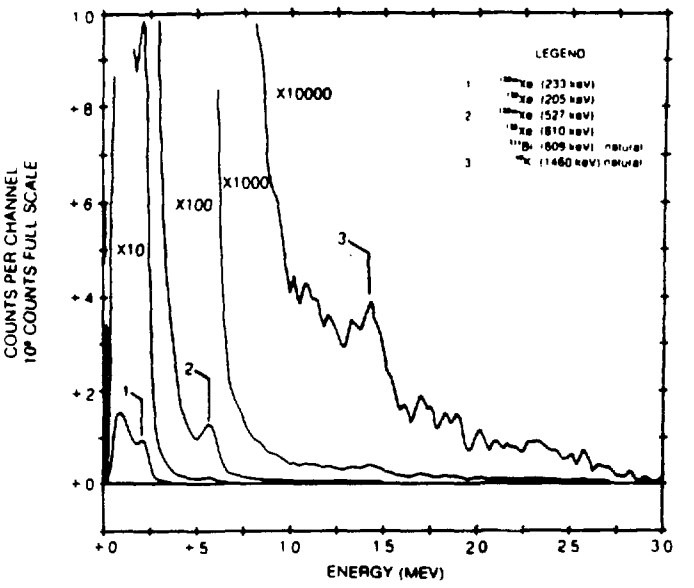
Figure 1



SPECTRUM NO 1
DATE 3/28/79-1
LIVE TIME (MIN) + 428
INTEGRATED CT + 2735122E+07
TYPE REC 311-324
AIRCRAFT H-500

Figure 2

REPRESENTATIVE SPECTRUM TAKEN FROM AIRCRAFT AT TMI ON 28 MARCH 1979



SPECTRUM NO 2
DATE 3/29/79-1
LIVE TIME (MIN) + 747
INTEGRATED CT + 2484370E+07
TYPE REC 188-207
ALTITUDE AIRCRAFT H-500

Figure 3

REPRESENTATIVE SPECTRUM TAKEN FROM AIRCRAFT AT TMI ON 29 MARCH 1979.

From Reference 7

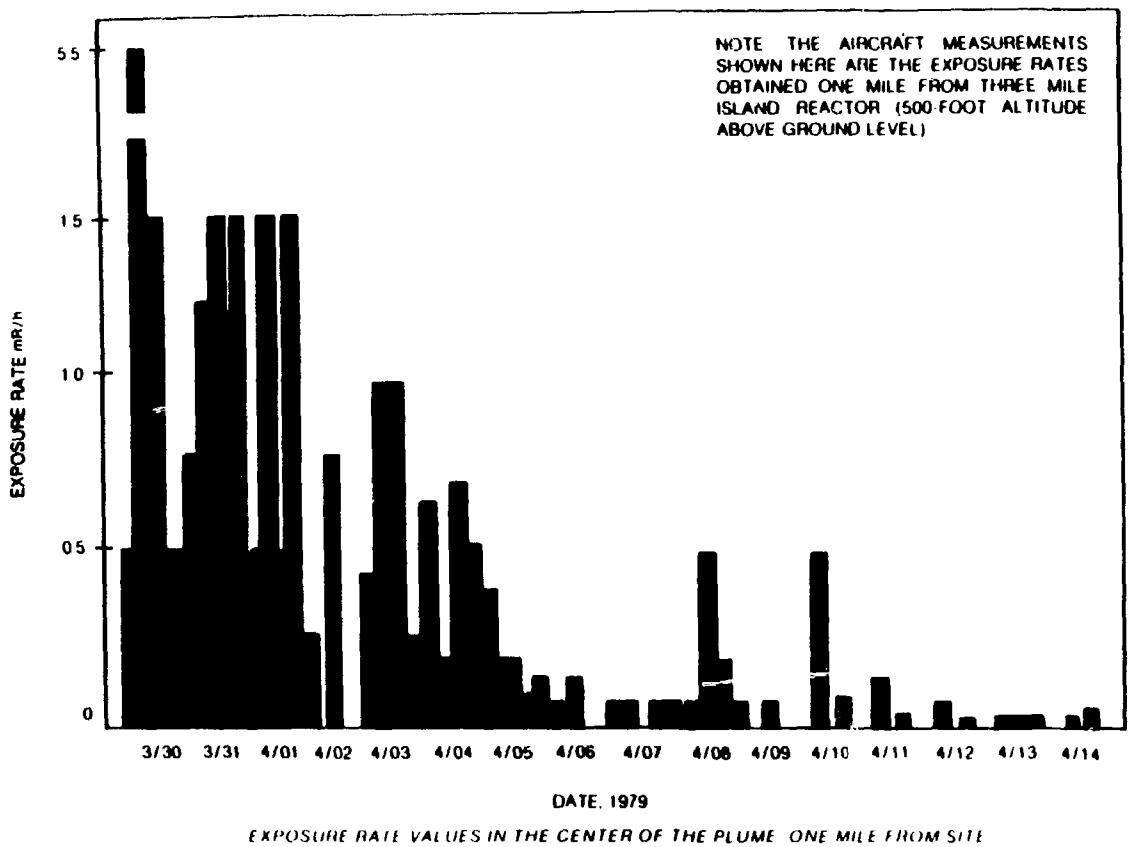


Figure 4

after the start of the incident is shown in Figure 10 An energy spectrum taken the next day is shown in Figure 11 Examination of the latter spectrum indicates the absence of the shorter-lived isotopes (^{88}Kr and ^{88}Rb)

In some instances, increases in exposure rates as a function of distance from the plant were observed This was primarily caused by time-dependent source releases, and variation in meteorological parameters and topography These results are further discussed in Appendix E

For completeness, this report also includes aerial measurements taken during the purging of radioactive krypton gas on 25 and 26 June 1980, 15 months after the accident These results are given and discussed in Appendix F

From Reference 7

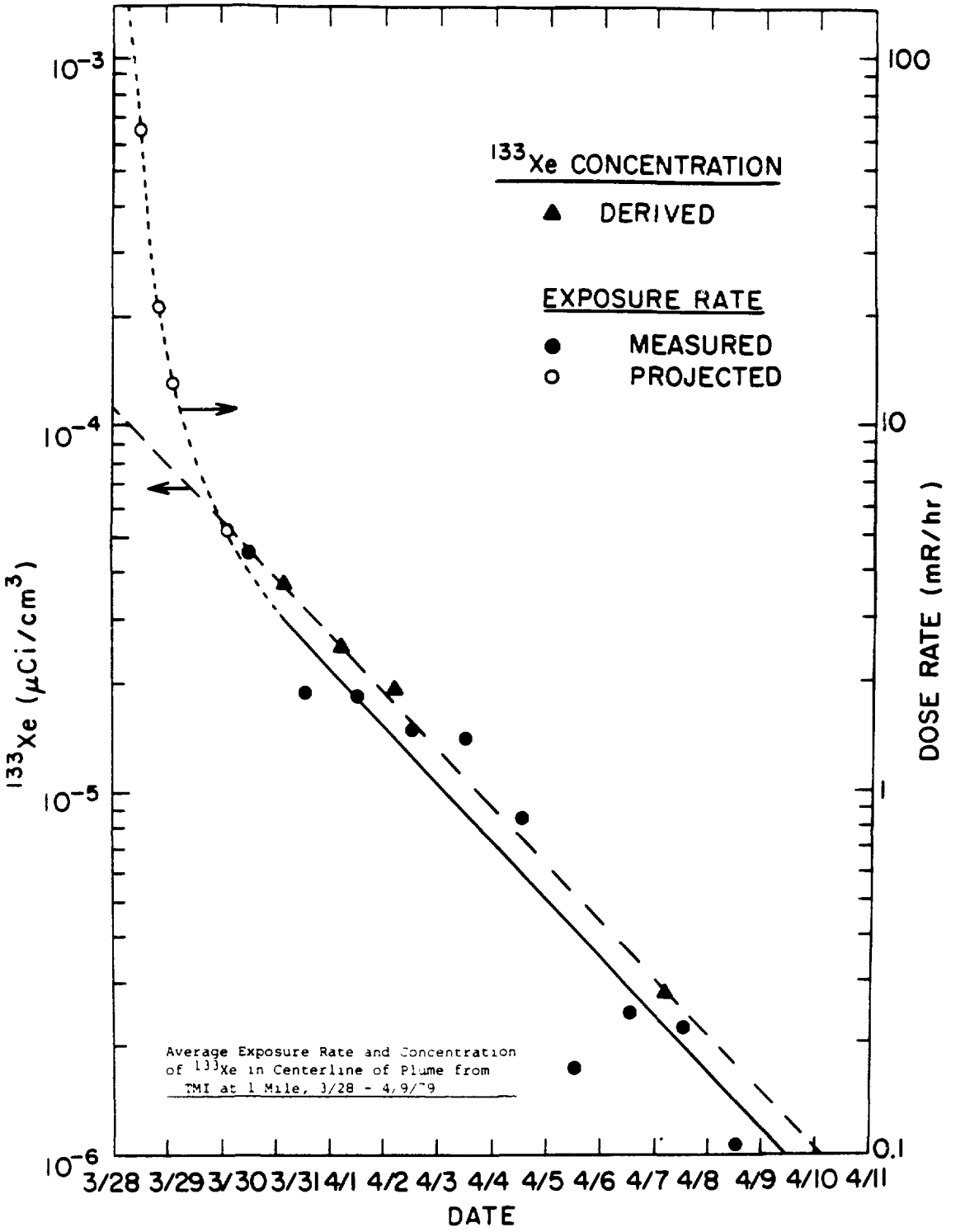

^{133}Xe CONCENTRATION
DERIVED
EXPOSURE RATE
MEASURED
PROJECTED
10^{-3}
10^{-4}
10^{-5}
10^{-6}
^{133}Xe (μCi/cm^3)
100
10
1
0.1
DOSE RATE (mR/hr)
3/28 3/29 3/30 3/31 4/1 4/2 4/3 4/4 4/5 4/6 4/7 4/8 4/9 4/10 4/11
DATE
Average Exposure Rate and Concentration of ^{133}Xe in Centerline of Plume from TMI at 1 Mile, 3/28 - 4/9/79

Figure 5

ESTIMATED DOSE IN VICINITY OF TMI 3/28-4/3/79

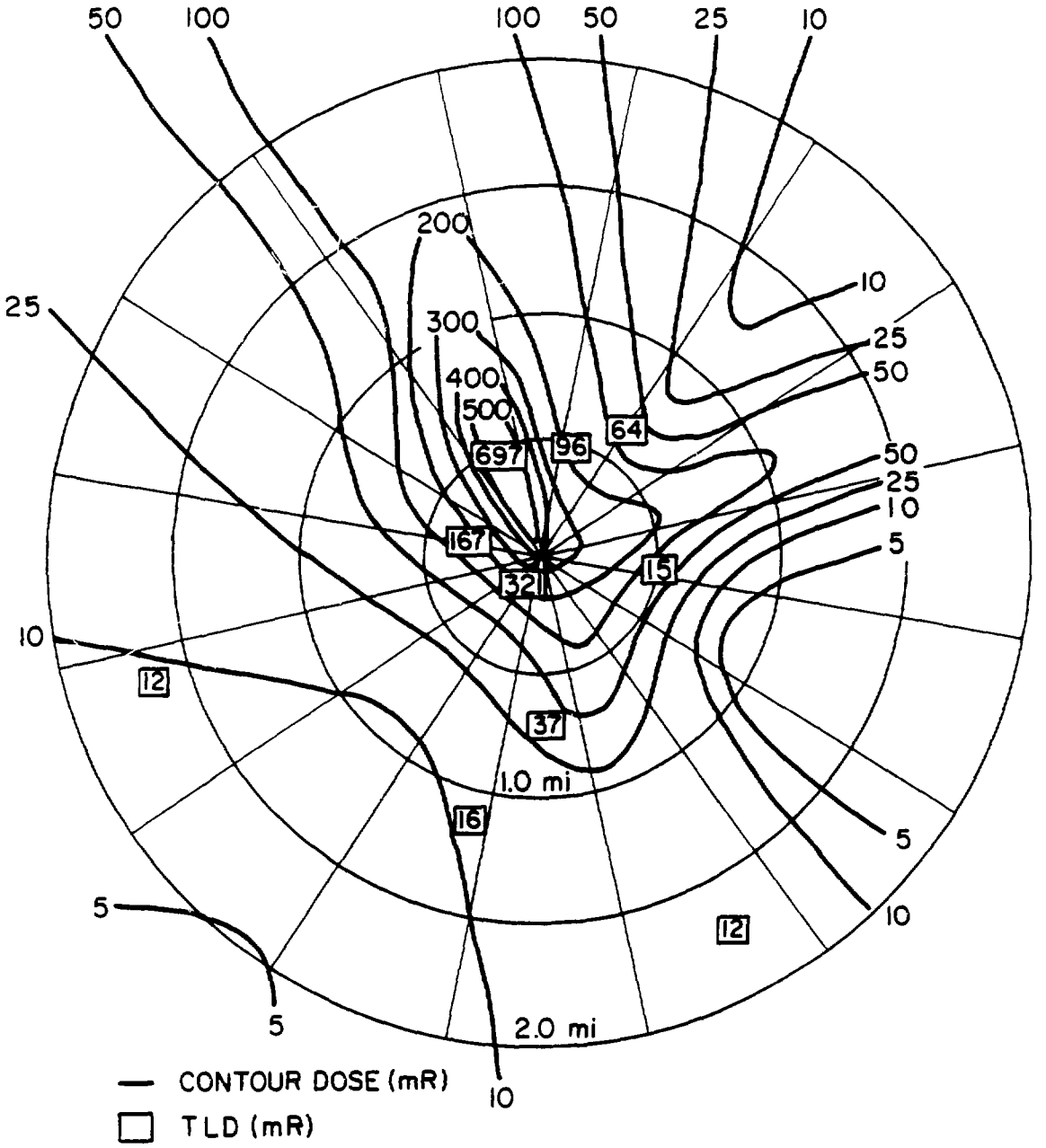


Figure 6

ESTIMATED DOSE IN VICINITY OF TMI 3/28-4/3/79

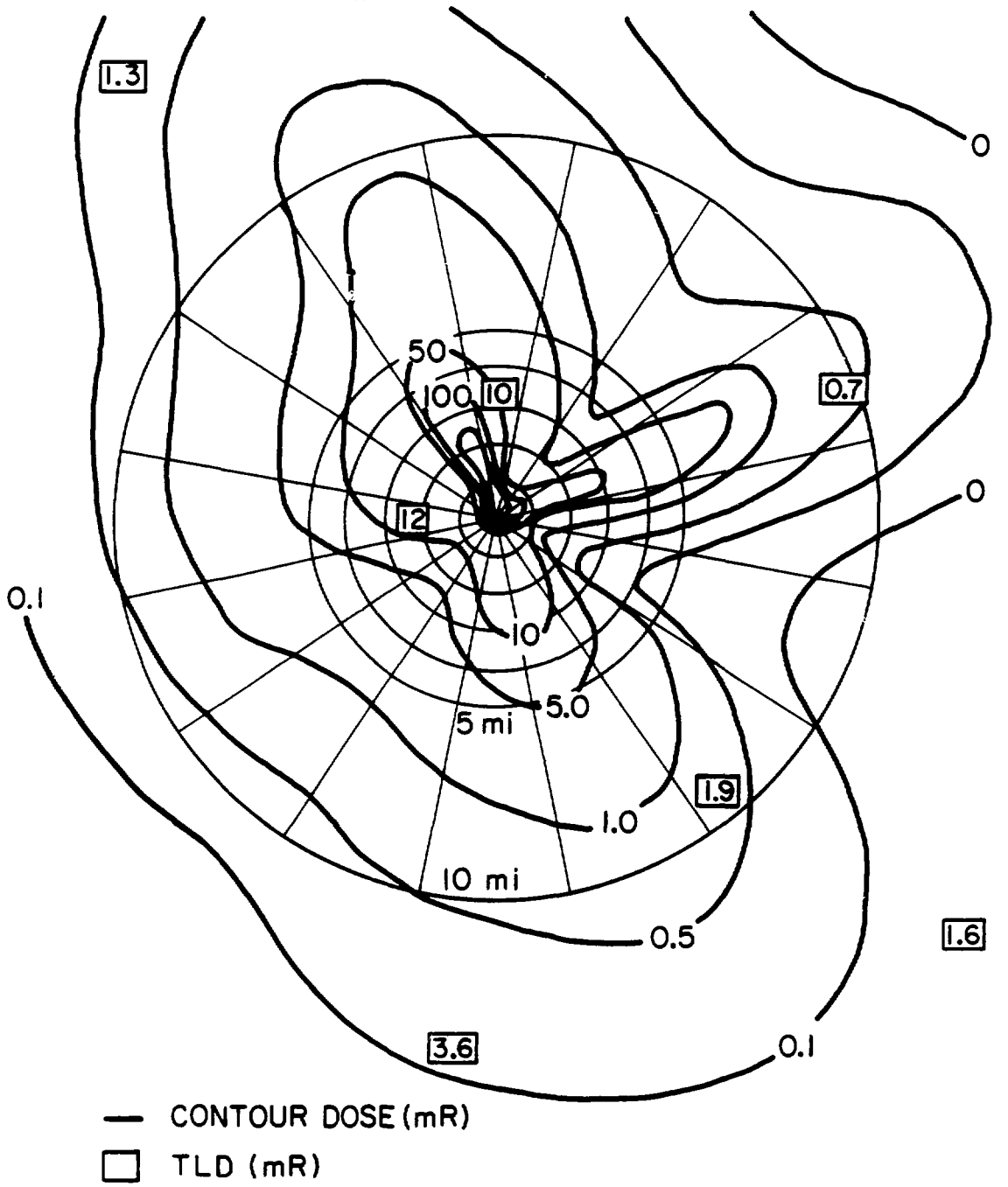


Figure 7

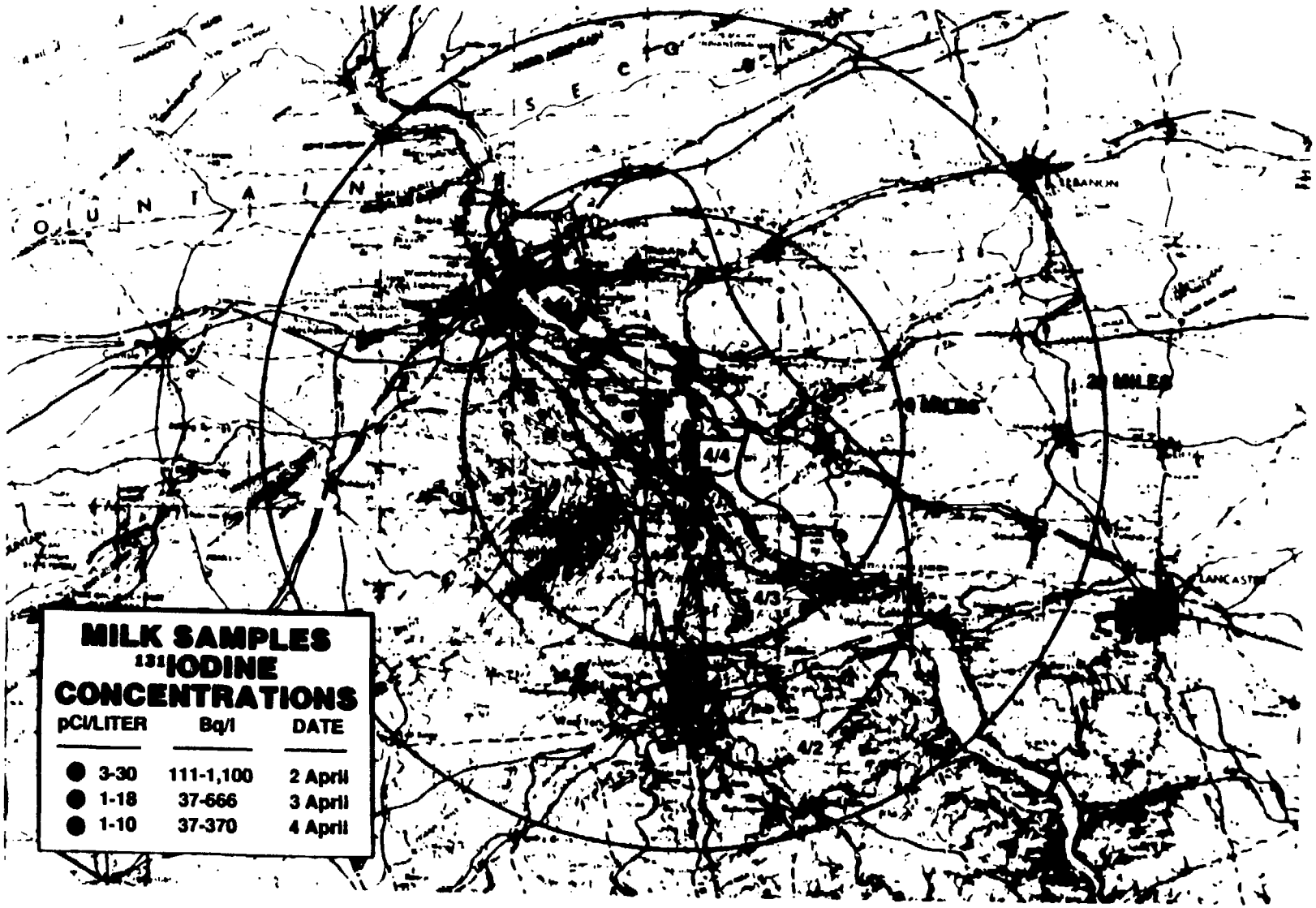
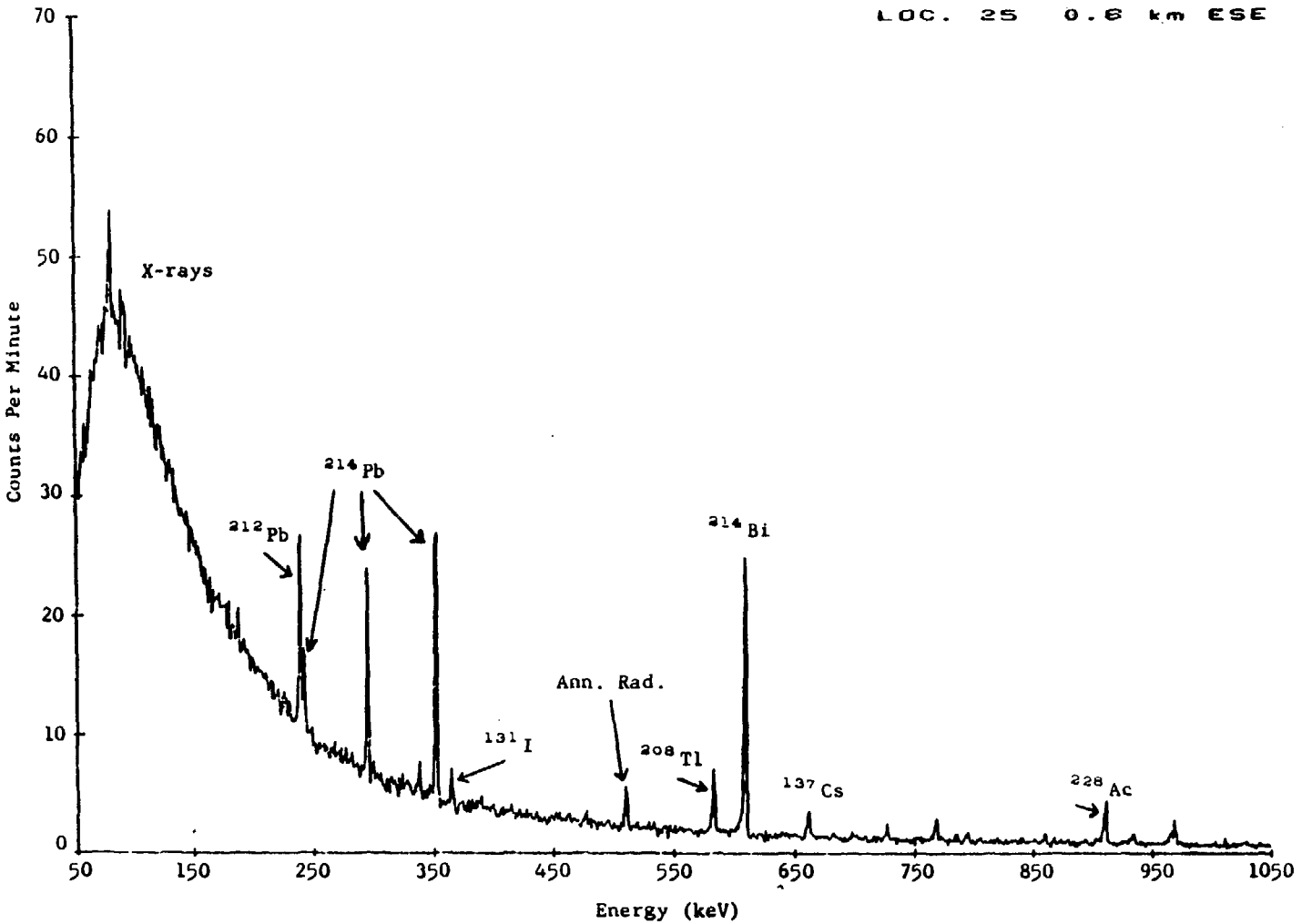

MILK SAMPLES
131IODINE
CONCENTRATIONS
pCi/LITER
Bq/l
DATE
3-30
111-1,100
2 April
1-18
37-666
3 April
1-10
37-370
4 April
4/4
4/3
4/2
LANCASTER

Figure 8



In situ Ge(Li) gamma-ray spectrum showing presence of deposited ^{131}I.

Figure 9

From Reference 17