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LICENSING TOPICAL REPORT

AIRBORNE RELEASES FROM BWR'S FOR ENVIRONMENTAL IMPACT EVALUATIONS

T. R. MARRERO

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ABSTRACT

The airborne radiological releases from building heating, ventilating, and air conditioning (HVAC) and condenser mechanical vacuum pump (MVP) exhausts of BWR's were determined on the basis of data obtained by utility personnel and special in-plant studies by independent organizations and the General Electric Company. These data include releases of iodine-131 (I-131), mixed noble radiogases, and particulates from domestic operating BWR plants. The average annual release of I-131 is <0.1 curie/plant in inorganic forms and <0.4 curie/plant as CH_3I. Inorganic forms of I-131 include elemental, particulates, and hypoiodous acid. The continuous utilization of the MVP during refueling/maintenance outages is the major source-point of CH_3I release. Approximately 6500 curies/plant per year of noble radiogases are released; two-thirds of this total is released from the turbine building. Twenty particulates with half-lives >8 days have been identified; the principal species is Co-60 with an average annual release of less than 0.05 curie/plant. The total particulate release rate per plant is approximately 0.1 curie/year.

1. INTRODUCTION

The studies associated with the development of Appendix I to 10CFR50 have established the need for greater attention to the sources and emissions of noble radiogases, radioiodines and particulates to the atmosphere in order to enable realistic estimates of off-site doses from nuclear power plant airborne effluents. The two principal emission sources from operating BWR's not equipped with such augmented effluent treatment systems have been the steam-jet-air-ejector and turbine gland-seal-steam exhausts. The releases from these sources have been minimized on current generation plants by charcoal treatment of the steam-jet-air-ejector exhaust, and the use of separate "clean" steam for the gland seal steam system.

Emissions to the atmosphere in the future from BWR's will arise principally from process leakage to plant building exhaust ventilation, and emission from operation of the condenser mechanical vacuum pump (MVP) during plant shutdowns. Difficulties in attempts to establish calculational models (see References at end of chapter, GESSAR Section 12.2.3) for these currently minor releases have led to the conclusion that future plant predictions should be based on applicable data derived from currently operating plants. It should be pointed out that this operating data should give conservative results when applied to new plants because the design (and to varying extents the operation) of plants in current operation predates the ALARA guidance of 10CFR50 Appendix I.

Appendix I indicates that the most significant potential dose pathway is due to I-131 emission and its uptake and transfer to man via nearby food sources, with the principal food of interest being milk. Thus, the important first step in radiological impact evaluations for future plants is the establishment of appropriate I-131 emission source terms. Studies associated with Appendix I also indicate the importance of iodine chemical form with regard to the various dose pathways to man.

The Nuclear Regulatory Commission (NRC) staff, in performing evaluations for Environmental Impact Statements, has used various I-131 source terms which have been based on a very small portion of the available operating plant data, and has given no consideration to the chemical form of the iodine. These factors, combined with conservative assumptions of transport and food use, have led to the conclusion by the NRC that augmented treatment of ventilation exhausts would be required to meet Appendix I dose objectives in current licensing on some projects. The disagreement of the General Electric Company with this conclusion is a matter of record.

The objective of this report is to summarize and evaluate all available airborne release data from operating BWR plants and to provide a basis for the establishment of reasonably conservative source terms for the evaluation of future plants with regard to building ventilation and MVP releases.

The results in this report are based primarily on two sources of data. First is the BWR building ventilation release data as reported in the public record, that is, semi-annual operating reports by utilities which must be submitted to the NRC. From this source, data are available from six BWR's starting in 1972. In this report, semi-annual report data include measurements up to June 30, 1975. This date was set as a convenient cut-off point. The measurements include more than 16 plant-years of BWR commercial operation. Second is the ventilation and MVP measurements by the Electric Power Research Institute (EPRI). These measurements were performed by Nuclear Environmental Services (NES) which also performed a limited study for the Yankee Atomic Electric Company. The EPRI-sponsored program includes relatively long-term studies at three BWR's; Oyster Creek, Monticello, and Vermont Yankee. The total sampling period for these measurements is approximately 2 plant-years of BWR commercial operation.

Additional building ventilation measurements have been made by the Atomic Energy Commission (now the NRC) and by the General Electric Company. In these studies, the sample periods have been shorter in duration than the measurements mentioned above. These short-term special in-station measurements have been used to establish release rates in those situations when long-term data were not available.

References to all the data are listed in the Bibliography. The experimental methods used to obtain effluent data are briefly described in Appendix A.

In the General Electric Company product line there are several BWR types and containment designs. A selected survey of BWR stations is presented in Appendix B. The BWR/2 was the first large direct-cycle plant, first offered in 1963. The Oyster Creek station is a BWR/2. The BWR/3's were first offered in 1965 and featured improved Emergency Core Cooling System (ECCS) and reactor water recirculation systems, for example Dresden 2 and Pilgrim 1. The BWR/4 which had higher power densities was introduced in 1966. Stations in this class are Vermont Yankee and Browns Ferry. Both BWR/5's and BWR/6's are presently under construction; the BWR/6 is the current product line. There are three basic containment types for BWR's. All the operating stations have Mark I designs except for the first few plants, like Dresden 1, see Appendix C. There are not many BWR's with Mark II containment designs and none are in commercial operation yet. The Mark II suppression system is an "over-under" type as illustrated in Appendix C. The current containment design is a Mark III which places the components of a Mark I reactor building into three separate buildings; the containment, fuel, and auxiliary buildings. The Mark I has an enclosed pool for pressure suppression, the Mark III has an open suppression pool. For the purposes of this report the reactor building ventilation releases include fuel, auxiliary and containment structures of Mark III plants and the affected releases are assumed to be equivalent to the measured reactor building releases from operating BWR's.

The building ventilation release results do not include data from overseas BWR plants, or licensees of the General Electric Company. There are several domestic BWR's that do not have separate building ventilation exhausts. These plants release airborne activity through a tall stack. There are also a number of domestic BWR's that have recently been put into commercial service, namely BWR/4's. In general the origins of airborne releases from within the BWR buildings are not discussed in this report. Information available about *stack* and building ventilation annual airborne releases of I-131 and noble radiogases from all operating BWR's plants are summarized in Appendices D and E, respectively.

The results in this report are grouped similarly to results in NRC Draft Regulatory Guide, 1.CC, for comparison purposes and to answer the question, "What are the airborne effluent rates from a BWR station to the atmosphere?" The airborne releases of I-131, noble radiogases, and particulates from ventilation exhausts are grouped according to the following sources:

reactor building,
radwaste building,
turbine building,
gland seal steam, and
mechanical vacuum pump exhausts.

The sum of these sources constitutes a total plant release for currently designed BWR's (BWR/6, Mark III). The proportions of inorganic and organic forms of I-131 are specified for each source. Chemical form data are presented for both shutdown and normal power generation periods. The final results represent average annual release values to be expected from currently designed BWR's.

The average annual release values were determined from statistical evaluations of the data. The data base involves thousands of individual measurements from several BWR's. A relationship between I-131 building ventilation releases and reactor water concentrations is apparent from the available data. Results from various plants have been adjusted to correspond to releases from BWR's with I-131 concentrations expected in new plants.

The results of this report are to be used for BWR environmental impact evaluations starting January 1, 1976. The retrieval and evaluation of effluent data is a continuing program at General Electric. The recommended airborne releases will be periodically updated as additional data becomes available.

A comparison of the NRC [Regulatory Guide 1.CC (Draft), 9/9/75] and GE (this report) average annual releases was made; see Table 12-1. The results of this comparison show that for I-131 in elemental form, the NRC value is more than 6.5 times greater than the results reported here. The GE results are conservative because the elemental I-131 release includes particulate and hypoiodous acid forms of iodine. For I-131 as CH_3I the NRC value is zero, in contrast to this report, 0.37 curies/year of CH_3I.

The I-131 ventilation releases have been shown to be proportional to the reactor water I-131 concentration. The available data indicates significant improvements in fuel performance, or less leakage of I-131 from the fuel rods to the water, or reactor water I-131 concentrations less than 1 x 10^{-3} μCi/ml. Thus, the specified release rates of I-131 are considered conservative.

For mixed noble radiogases, the totals in this report and by the NRC are equal, 6500 $\pm$ 18 curies/year. Particulate (half-lives greater than 8 days) releases according to the NRC total 0.27 curies/year (14 nuclides). This report indicates a total of 0.13 curies/year for the same isotopes or a factor of 2.1 less than the NRC. By both evaluations Co-60 is the principal species, about 40% of the NRC and 32% of the GE totals. In addition this report identifies five particulates not included by the NRC; however, these releases are almost negligible.

References about as-low-as-practicable AEC hearings, Appendix I, previous estimates of ventilation releases by the General Electric Company, and the proposed NRC values are listed below.

REFERENCES

Nuclear Regulatory Commission, April 30, 1975, "Appendix I — Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion "As Low as Practicable" for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents," 10CFR50, as Reported in Federal Register, Vol. 40, No. 87-Monday, May 5, 1975, pp. 19442-43.

Nuclear Regulatory Commission, September 2, 1975, "Application of Cost-Benefit Analysis Requirements of Appendix I to Certain Nuclear Power Plants," 10CFR50, as Reported in Federal Register Vol. 40, No. 172-Thursday, September 4, 1975, pp. 40816-18.

Nuclear Regulatory Commission, September 9, 1975, "Calculation of Releases of Radioactive Materials in Liquid and Gaseous Effluents from Boiling Water Reactors (BWR's)," Regulatory Guide 1.CC (Draft).

Related Reports Are As Follows:

Nuclear Regulatory Commission, April 30, 1975, "Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents," Docket RM-50-2, Federal Register 40, No. 87, May 5, 1975, pp. 19439-42.

U.S. Atomic Energy Commission, February 20, 1974, "Concluding Statement of Position of Regulatory Staff, Public Rulemaking Hearing On: Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion 'As Low as Practicable' for Radioactive Material in Light-Water-Cooled Nuclear Power Reactors," Docket RM-50-2.

General Electric Company, January 21, 1974, "Closing Statement of the General Electric Company, Rule Making Hearing, Effluents From Light-Water-Cooled Nuclear Power Reactors," Docket No. RM-50-2.

General Electric Company, 1974, BWR/6, Standard Safety Analysis Report (GESSAR):

a. Engineered Safety Features, Vol. 6, Standby Gas Treatment System (SGTS) (§6.5); Design Evaluation in Regard to ALAP Guidelines (§6.5.3.2), Revised January 31, 1975.

b. Auxiliary Systems, Vol. 9, Air Conditioning, Heating, Cooling, and Ventilating (Environmental) Systems (§9.4); Containment, Chronic Leakages and Emissions (§9.4.5.4.2), Revised May 9, 1974.

c. Radioactive Waste Management, Vol. 11; Gaseous Effluent Treatment Systems (§11.3), Other Radioactive Gas Sources (§11.3.2.2), Revised November 6, 1974.

d. Radiation Protection, Vol. 12; Ventilation (§12.2); Source Terms (§12.2.3), Revised May 9, 1974.

Nuclear Environmental Services, 1974, "Measurement of Sources of Iodine-131 Releases to the Atmosphere from Nuclear Power Plants," C. A. Pelletier, J. E. Cline, and J. H. Keller, IEEE Trans. Nucl. Sci., **21,** pp. 478-83.

2. SUMMARY OF RESULTS

On the basis of BWR operating plant performance, the estimated annual airborne release of I-131 in inorganic form (elemental, particulate, and hypoiodous acid) is <0.1 curie per plant per year (see Tables 2-1 and 2-2).

In Table 2-1 the chemical forms of I-131 are simply divided into two types, inorganic and organic. The inorganic form includes I-131 observed as particulate matter, elemental (I_2), and hypoiodous acid (HOI). Organic iodine is methyl iodide (CH_3I) for all practical purposes. A few tests have been made that indicate only a fraction of a percent of the organic iodine is other than CH_3I. These two forms of I-131 have been delineated because the calculated ingestion dose for methyl iodide is significantly less than from that for other inorganic iodine species. All species other than methyl iodide have been grouped together as "inorganic" iodine which is conservative.

The annual release of inorganic I-131 is 0.093 curie per year per plant. This amounts to less than 20% of the total plant release. A majority of the inorganic I-131 will be released from the reactor building (or the containment, fuel, and auxiliary buildings of BWR's with Mark III containment designs), and the least amount from the radwaste building. The I-131 release as CH_3I is 0.37 curie per year per plant. Most of the CH_3I release is due to the use of the mechanical vacuum pump during refueling/maintenance outages to reduce in-plant airborne activity in the turbine building. Iodine-131 releases according to chemical form, operating period, and source are summarized in Table 2-2. From Table 2-2 the I-131 release during refueling/maintenance outage is approximately 80% of the total annual release.

The amount of I-131 found in milk at farms near operating BWR's has been about background levels, which indicates that BWR releases will have a negligible effect on I-131 concentrations in milk.

The annual release of noble radiogases is expected to be 6500 curies per plant (see Tables 2-3 and 2-4). Approximately 2/3 of the plant release is from the turbine building. Noble radiogas release will contribute a negligible off-site dose in comparison to normal background levels.

Recent special in-plant measurements have provided needed data on particulate releases. Approximately 20 isotopes have been identified with half-lives greater than 8 days (see Table 2-5). The principal particulate release is Co-60 which has an expected annual total plant release of 0.04 curie. The particulate release rates are greatest from the reactor building and least from the radwaste building.

Table 2-1
ESTIMATED ANNUAL AIRBORNE RELEASES OF IODINE-131 FOR ENVIRONMENTAL IMPACT EVALUATIONS OF BWR's

Source Building/Exhaust	Release[a] Curies per Year per Plant	Chemical Form[b] Inorganic Percent
Reactor	0.091	65
Radwaste	0.034	15
Turbine	0.022	71
Gland Seal Steam and Mechanical Vacuum Pump	0.32	4

[a]Includes all detected forms of I-131.

[b]Inorganic is defined as the sum of particulate, elemental (I_2), and hypoiodous acid (HOI) release. The remainder of the I-131 is in the form of methyl iodide, CH_3I.

Table 2-2
ESTIMATED ANNUAL AIRBORNE RELEASES OF IODINE-131 FROM BWR's DURING POWER GENERATION AND REFUELING/MAINTENANCE OUTAGE CURIES PER PLANT

	Chemical Form of Iodine-131										
	Inorganic (Particulate+Elemental+Hypoiodous Acid)					Organic (CH_3I)					
	Operating Period					Operating Period					
Plant Source	Power Generation	+	Refueling Outage		Total Release (Inorganic)	Power Generation	+	Refueling Outage		Total Release (Organic)	
Reactor Building	0.0160	+	0.0434	=	0.0594	0.0083	+	0.0233	=	0.0316	
Radwaste Building	0.0039	+	0.0011	=	0.0050	0.0146	+	0.0144	=	0.0290	
Turbine Building	0.0112	+	0.0044	=	0.0156	0.0015	+	0.0048	=	0.0065	
Gland Seal	0.0041		–	=	0.0041	0.0332		–	=	0.0332	
Mechanical Vacuum Pump	–		0.0085	=	0.0085	–		0.2741	=	0.2741	
	Total[a] (Inorganic)			=	0.093	Total[a] (Organic)			=	0.37	
	rate			≈	0.0029 μCi/s	rate			≈	0.012 μCi/s	

[a]Total rounded to 2 significant figures.

NOTES:

(1) The gland seal steam release rate should be negligible, or zero, for plants with separate steam on the gland seals.

(2) The gland seal steam release does not occur during the refueling/maintenance outage.

Table 2-3
ESTIMATED ANNUAL MIXED NOBLE RADIOGAS HVAC AND MVP RELEASES FOR ENVIRONMENTAL IMPACT EVALUATIONS OF BWR's

Source[a]	Release Ci/Year	Release μCi/s
Reactor Building	500	≈ 16
Turbine Building	4000	≈130
Radwaste Building	1500	≈ 50
Total HVAC	6000	≈190
Mechanical Vacuum Pump[b]	500	≈ 16

[a]Sources exclude gland seal steam exhaust which is assumed to have clean steam, otherwise add 4200 curies (≈130 μCi/s).

[b]Xe-133 and Xe-135.

Table 2-4
MIXED NOBLE RADIOGAS NUCLIDES, CURIES/YEAR

Nuclide	Half-Life	Reactor	Turbine	Radwaste	Gland Seal Steam	MVP	Total[b]
Kr-89	3.2m	1	503	34[c]	ND	ND	538
Xe-137	3.9m	78	386	113[c]	ND	ND	577
Xe-138	14.2m	12	1179	2	1483	ND	1193
Xe-135m	15.7m	111	464	667	1212	ND	1242
Kr-87	76m	6	95	a	312	ND	101
Kr-88	2.79h	9	102	a	218	ND	111
Kr-85m	4.4h	6	2	a	132	ND	8
Xe-135	9.16h	173	672	328	645	200	1373
Xe-133m	2.3d	ND	ND	60	ND	ND	60
Xe-133	5.27d	103	581	294	195	300	1278
Total Annual Release		500	4000	1500	4200	500	6481

a = Less than 1 curie/year.
b = Excludes gland seal steam, the total release including gland seal steam releases is 10,700 curies per year.
c = These results are overestimates because such short-lived radioisotopes are not normally expected in the radwaste building; however, data have been reported for these species at one plant, see Table 8-8.
ND = Not Detected

Table 2-5
ESTIMATED AIRBORNE PARTICULATE (HALF-LIVES >8 DAYS) RELEASES FROM HVAC SYSTEMS FOR ENVIRONMENTAL IMPACT EVALUATIONS OF BWR's

		Annual Release, curies, from Building			
Nuclide	**Half-Life**	**Reactor**	**Turbine**	**Radwaste**	**Total**
Cr-51	27.8 d	3 E-3	1 E-3	9 E-4	5E-3
Mn-54	313.0 d	3 E-3	2 E-3	5 E-3	1E-2
Co-58	71.4 d	2 E-3	9 E-5	4 E-4	2E-3
Fe-59	45.0 d	1 E-4	4 E-4	8 E-4	1E-3
Co-60	5.26 y	3 E-2	3 E-3	6 E-3	4E-2
Zn-65	243.7 d	3 E-3	4 E-4	2 E-4	7E-3
Sr-89	50.8 d	1 E-2	— —	— —	1E-2
Sr-90	28.9 y	2 E-3	— —	— —	2E-3
Nb-95	35.1 d	3 E-4	9 E-6	2 E-4	5E-4
Zr-95	65.5 d	1 E-4	8 E-6	1 E-4	2E-4
Ru-103	39.8 d	3 E-5	2 E-4	1 E-4	3E-4
Ag-110m	253.0 d	7 E-6	— —	— —	7E-6
Sb-124	60.2 d	3 E-5	6 E-5	3 E-4	4E-4
Cs-134	2.06 y	5 E-3	5 E-4	3 E-4	6E-3
Cs-136	13.0 d	2 E-3	1 E-4	5 E-5	2E-3
Cs-137	30.2 y	7 E-3	2 E-3	4 E-4	9E-3
Ba-140	12.8 d	4 E-3	2 E-2	5 E-4	3E-2
Ce-141	32.5 d	4 E-4	2 E-3	2 E-4	3E-3
Ce-144	284.4 d	5 E-6	— —	— —	5E-6
	Totals	0.1	0.03	0.02	0.1

NOTES:

(1) Sr-89 and Sr-90 not measured in turbine and radwaste buildings.

(2) Gland seal steam and MVP releases are listed on Tables 10-19 and 10-20.

(3) For particulates with half-lives less than 8 days the annual releases are as follows:

(4) This tabulation excludes I-131 which is included with inorganic I-131 release results, see Tables 2-1 and 2-2.

	Half-Life	**Reactor**	**Turbine**	**Radwaste**	**Total**
Tc-99m	6.0 h	2 E-4	ND	ND	2 E-4
La-140	40.2 h	3 E-3	ND	ND	3 E-3
Np-239	2.35	2 E-1	4 E-2	1 E-3	2 E-1
Mo-99	2.78 d	3 E-2	4 E-3	5 E-4	4 E-2

(5) Example of exponential notation; 3E-3 = 3×10^{-3}.

Table 2-5
ESTIMATED AIRBORNE PARTICULATE (HALF-LIVES >8 DAYS) RELEASES FROM HVAC SYSTEMS FOR ENVIRONMENTAL IMPACT EVALUATIONS OF BWR's (Continued)

Nuclide	Half-Life	Environs Inventory (see Note 2), curies, from Building: Reactor	Turbine	Radwaste	Total
Cr-51	27.8 d	3 E-4	1 E-4	1 E-4	5 E-4
Mn-54	313.0 d	4 E-3	2 E-3	6 E-5	6 E-3
Co-58	71.4 d	4 E-4	3 E-5	1 E-4	4 E-4
Fe-59	45.0 d	2 E-5	7 E-5	1 E-4	2 E-4
Co-60	5.26 y	2 E-1	2 E-2	5 E-2	3 E-1
Zn-65	243.7 d	6 E-3	4 E-4	2 E-4	7 E-3
Sr-89	50.8 d	3 E-3	– –	– –	3 E-3
Sr-90	28.9 y	8 E-2	– –	– –	8 E-2
Nb-95	35.1 d	5 E-5	1 E-6	3 E-5	8 E-5
Zr-95	65.5 d	4 E-5	2 E-6	3 E-5	7 E-5
Ru-103	39.8 d	– –	3 E-5	2 E-5	5 E-5
Ag-110m	253.0 d	5 E-6	– –	– –	5 E-6
Sb-124	60.2 d	7 E-6	1 E-5	6 E-5	8 E-5
Cs-134	2.06 y	2 E-2	2 E-3	8 E-4	2 E-2
Cs-136	13.0 d	1 E-4	7 E-6	3 E-6	1 E-4
Cs-137	30.2 y	3 E-1	7 E-2	2 E-2	4 E-1
Ba-140	12.8 d	2 E-4	1 E-3	3 E-5	1 E-3
Ce-141	32.5 d	5 E-5	2 E-4	2 E-5	3 E-4
Ce-144	284.4 d	5 E-6	– –	– –	5 E-6
	Totals	0.6	0.09	0.07	0.8

NOTES:

(1) For particulates with half-lives less than 8 days the inventories are as follows:

	Reactor	Turbine	Radwaste
Tc-99m	2 E-7	ND	ND
La-140	2 E-5	ND	ND
Np-239	2 E-3	1 E-4	1 E-5
Mo-99	4 E-4	4 E-5	5 E-6

(2) The inventory is that total amount of radioactive material in the environs, assuming a constant average emission rate, and thus properly accounts for radioactive decay. The conventional use of curies emitted per year gives a distorted impression of actual quantity present for short-half-life radioisotopes.

Table 2-5
ESTIMATED AIRBORNE PARTICULATE (HALF-LIVES >8 DAYS) RELEASES FROM HVAC SYSTEMS FOR ENVIRONMENTAL IMPACT EVALUATIONS OF BWR's (Continued)

		Release Rates, μCi/s, from Building			
Nuclide	Half-Life	Reactor	Turbine	Radwaste	Total
Cr-51	27.8 d	8 E-5	3 E-5	3 E-5	1 E-4
Mn-54	313.0 d	1 E-4	5 E-5	2 E-4	4 E-4
Co-58	71.4 d	5 E-5	3 E-6	1 E-5	6 E-5
Fe-59	45.0 d	4 E-6	1 E-5	3 E-5	4 E-5
Co-60	5.26 y	8 E-4	8 E-5	2 E-4	1 E-3
Zn-65	243.7 d	2 E-4	1 E-5	5 E-6	2 E-4
Sr-89	50.8 d	4 E-4	NM	NM	4 E-4
Sr-90	28.9 y	6 E-5	NM	NM	6 E-5
Nb-95	35.1 d	1 E-5	3 E-7	7 E-6	2 E-5
Zr-95	65.5 d	5 E-6	3 E-7	4 E-6	9 E-6
Ru-103	39.8 d	1 E-6	5 E-6	4 E-6	1 E-5
Ag-110m	253.0 d	2 E-7	ND	ND	2 E-7
Sb-124	60.2 d	9 E-7	2 E-6	8 E-6	1 E-5
Cs-134	2.06 y	2 E-4	2 E-5	8 E-6	2 E-4
Cs-136	13.0 d	7 E-5	4 E-6	2 E-6	8 E-5
Cs-137	30.2 y	2 E-4	5 E-5	1 E-5	3 E-4
Ba-140	12.8 d	1 E-4	6 E-4	2 E-5	7 E-4
Ce-141	32.5 d	1 E-5	5 E-5	5 E-6	7 E-5
Ce-144	284.4 d	2 E-7	ND	ND	2 E-7
	Totals	0.002	0.0009	0.0005	0.004

NOTE:

For particulates with half-lives less than 8 days the release rates are as follows:

	Reactor	Turbine	Radwaste
Tc-99m	6 E-6	ND	ND
La-140	1 E-4	ND	ND
Np-239	6 E-3	1 E-3	4 E-5
Mo-99	1 E-3	1 E-4	1 E-5

ND = not detected
NW = not measured

PART A

IODINE-131 RELEASES

3. AIRBORNE IODINE-131 RELEASE DATA

This section presents data according to organization that performed the measurements. When data are reported in terms of average release rates over a period of time, the total release (curies) for that period is calculated by taking the product of release rate and sampling time. These calculated releases are reported here. In addition, this summary of data presents calendar quarter releases which are pertinent to 10CFR50, Appendix I.

3.1 MEASUREMENTS BY UTILITIES

The following data were reported in semi-annual operating reports by several utilities. These data are obtained by routine procedures of health physics/chemistry personnel. These data provide long-term histories of BWR airborne I-131 releases.

3.1.1 Boston Edison Company (Pilgrim 1)

Pilgrim 1 was the last of the BWR/3's to go on-line; commercial service began December 1972.

The ventilation air releases are measured at the reactor building exhaust plenum, which includes effluents from three buildings: reactor, turbine, and radwaste. The reported reactor building vent data actually correspond to HVAC releases for a total nuclear plant, except for the mechanical vacuum pump discharge and gland seal steam exhausts. Table 3-1 lists monthly I-131 releases from January 1973 to June 1975, inclusive. References are listed in the Bibliography. This tabulation also lists particulate releases, species with half-lives ≥8 days. The average particulate release is less than 8% of the I-131 release. This percentage is based on the ratio of the calendar quarter geometric means (see Table 3-2). The cumulative probability distribution of the calendar quarterly data are presented in Figures 3-1 and 3-2. The annual releases for both I-131 and particulates are summarized in Table 3-3. The chronological history of Pilgrim 1 HVAC airborne releases for I-131 and particulates are shown in Figures 3-3 and 3-4, respectively. These graphs show the monthly values for almost the entire operating history of this BWR; the data are reported for a 2-1/2 year period. Additional data about particulate releases is presented in Part C of this report.

3.1.2 Commonwealth Edison Company

The Commonwealth Edison Company has five operating BWR's, Dresden 1, 2 and 3 and Quad Cities 1 and 2.

The releases from Dresden 1 are excluded from this study because it is too different in comparison to modern plants. Dresden 1 which went into commercial service in 1960, has the building ventilation air releases combined with the process gas and discharge to the atmosphere via a tall stack rather than having separate ventilation discharge. The Dresden 1 containment design is also markedly different from the current designs. It has a dry containment; i.e., no pressure suppression pool. For these reasons, Dresden 1 data *are not* used to establish estimates of HVAC airborne releases for current BWR's.

The Dresden 2 and 3 stations are comparable in size and design to the Quad Cities stations (see Appendix B).

The Quad Cities stations have a reactor water cleanup system different from the Dresden 2/3 stations. At Quad Cities, Powdex (or equivalent) resin is used whereas the Dresden plants use deep-bed resin. In Powdex plants, the pumps that circulate water through the cleanup system are located upstream of the resin. Deep-bed plants have the pumps downstream of the resin. Thus, in deep-bed plants, the pumps see decontaminated and cooled reactor water, whereas the opposite is true for the Powdex plants. Thus, in the event of reactor water leakage from the pump seals, the Powdex plants would have higher airborne releases than deep-bed plants. The results for the Dresden and Quad Cities stations are a source of such a comparison, all other factors being equal.

The currently designed BWR's have Powdex resins and reactor water cleanup pumps located on the upstream side of the resin.

Measurements of HVAC releases are routinely made on a daily basis. In some instances the daily data logs were used to determine total I-131 releases for a month. The utility measurements give a total iodine, that is, both inorganic and organic forms of iodine. This procedure was necessary in order to determine the releases on an individual plant basis, information which was not available in the semi-annual reports.

3.1.2.1 Dresden 2

Table 3-4 lists the monthly I-131 releases from Dresden 2 over the period of January 1972 to June 1975, inclusive. These values correspond to essentially only one building of the nuclear power plant, namely the reactor building. The calendar quarterly and annual releases that were calculated from the monthly data are listed in Tables 3-5 and 3-6. Figure 3-5 presents the probability distribution of the calendar quarterly data. The distribution is log-normal. Figure 3-6 shows the monthly I-131 reactor building releases over a 3-1/2 year period, up to June 1975.

3.1.2.2 Dresden 3

The Dresden 3 reactor building I-131 monthly releases are listed in Table 3-7. Available data begins with January 1972. Calendar quarterly and annual totals are listed in Tables 3-8 and 3-9, respectively. Figure 3-7 shows the calendar quarterly probability distribution. The monthly releases from January 1972 to June 1975 are shown in Figure 3-8.

3.1.2.3 Quad Cities 1

The I-131 HVAC airborne releases are tabulated by month, calendar quarter, and year in Tables 3-10, 3-11, and 3-12, respectively. Figure 3-9 presents the calendar quarter release probability distribution, and Figure 3-10 shows the chronology of monthly releases between June 1972 and June 1975.

3.1.2.4 Quad Cities 2

The I-131 HVAC airborne releases are tabulated by month, calendar quarter, and year in Tables 3-13, 3-14, and 3-15, respectively. Figure 3-11 presents the calendar quarter release probability distribution. Figure 3-12 shows monthly I-131 releases as a function of time for the period June 1972 to June 1975. The sharp decreases, or valleys, in release occur during the latter part of refueling/maintenance outages.

3.1.3 Northern States Power Company (Monticello)

The I-131 data for Monticello includes 1974 and the first-half of 1975 only; previous data for releases during 1972 and 1973 have been unavailable. This BWR station began commercial service in July 1971. This station routinely reports a monthly total release that includes the off-gas and ventilation releases. However, measurements of the HVAC releases are routinely compiled on a weekly basis, not monthly, as in all the other tabulations of data by utilities. These results are listed in Tables 3-16, 3-17, and 3-18 for a weekly, quarterly, and annual basis, respectively.

Probability distributions are shown for I-131 and particulates (half-lives >8 days) in Figures 3-13 and 3-14, respectively. Note that particulate releases are approximately one decade less than I-131 releases. For 1974 and the first six months of 1975 the weekly release values are plotted for I-131 and particulates in Figures 3-15 and 3-16, respectively. The release rate of I-131 and particulates appear to have the same trend and are roughly proportional to each other. Additional data about particulate releases is presented in Part C of this report.

3.2 MEASUREMENTS BY ELECTRIC POWER RESEARCH INSTITUTE

The Electric Power Research Institute (EPRI) contracted Nuclear Environmental Services (NES) to perform in-plant measurements of airborne releases. These measurements have been sponsored by EPRI in order to evaluate radioiodine sources and other radionuclide effluents at nuclear power plants. Thus far, EPRI measurements have been made at three

BWR's — Oyster Creek, Monticello, and Vermont Yankee. At these stations, the sampling periods have been rather long. The sampling periods have been approximately 180, 230, and 400 days at Oyster Creek, Monticello, and Vermont Yankee, respectively.

3.2.1 Oyster Creek

The Oyster Creek plant began commercial service in December 1969. Table 3-19 lists the effluent releases for the reactor, turbine, and radwaste buildings, plus releases via the gland-seal-steam/mechanical vacuum pump exhaust. Oyster Creek building ventilation releases are discharged to the atmosphere from one point, a 114 meter tall stack. Normally, separate monitoring of the building releases is not made. The HVAC releases are combined with the process off-gas prior to release. The total stack release is monitored and reported. However, the EPRI measurements provide detailed information about building releases. The data in Table 3-19 are the product of the sampling time (in seconds) and the average release rate (μCi/s), as reported in the EPRI data compilations (see Bibliography). The I-131 concentrations in the reactor water during a refueling/maintenance outage are generally much less, by a factor of roughly 100, and comprise a separate set. The average stack releases are listed in Table 3-20 and in Figure 3-17. These data are useful toward the determination of the MVP releases during the refueling/maintenance outage. During this period the MVP exhaust was not sampled. However, the difference of the stack releases and the vent releases should be approximately equal to the MVP I-131 releases. Table 3-21 summarizes the total releases for Oyster Creek during 1975.

The turbine building releases at Oyster Creek have been affected by leakage via the moisture separators and reheaters. The design of the reheater includes an air purge for shutdown maintenance. This feature is at only one other BWR, Nine Mile Point 1. The air protection system has been changed to a steam blanket in other operating BWR's, as in the current plant designs.

3.2.2 Monticello

EPRI in-plant measurement data are shown in Tables 3-22 and 3-23. Table 3-22 summarizes the I-131 release data, excluding chemical form. Table 3-23 summarizes the total releases from each BWR building.

During shutdown the MVP is in operation and there is no process off-gas. The MVP exhausts to the off-gas stack. Therefore, the off-gas stack release data may be used to approximate the MVP discharge during a refueling/maintenance outage. Table 3-24 lists weekly average stack release rates for the January 1975 refueling outage. The MVP release of I-131 is estimated at 0.35 curie for the entire refueling/maintenance outage. About 80% of the MVP release occurred during the first 2 weeks of the outage.

Figure 3-18 shows the stack release during refueling outage of January 1975. This graph shows that I-131 release rate decays with a half-life about equal to the 8.07-day half-life of I-131. The stack release is due primarily to use of the MVP since the steam-jet-air-ejectors are off. About 80% of the MVP release occurs during the first 2 weeks of the refueling/maintenance outage.

This author made a comparison of the total I-131 release measurements by EPRI and the plant personnel in order to assess the reliability of data. For the period of about 125 days the difference in total release was 9%. The station total was 0.37 curie (11/18/74 to 3/30/75) and the EPRI total was 0.33 curie of I-131 (11/15/74 to 3/25/75). This good agreement is also consistent with Dr. C. A. Pelletier's (Manager, Nuclear Environmental Services) remarks regarding the good reliability of plant reported airborne release data (Personal Communication, 1975).

3.2.3 Vermont Yankee

Table 3-25 summarizes the EPRI I-131 data for the Vermont Yankee plant. The total sample period is approximately 400 days, more than an entire year including a refueling/maintenance outage. The three principal BWR buildings plus the gland seal steam and mechanical vacuum pump exhausts were continuously monitored. Values for particulate releases are not included here because their magnitudes are a few decades less than I-131 released in gaseous form. Table 3-26 lists calendar quarter releases. This listing indicates a dramatic decrease in I-131 releases following the refueling outage during the fourth quarter of 1974. The core was changed almost completely to 8-by-8 fuel bundles which are an improved type of fuel. Table 3-27 summarizes the EPRI measurements at Vermont Yankee and indicates the I-131 releases during normal power generation and refueling/maintenance outages.

3.3 MEASUREMENTS BY NUCLEAR REGULATORY COMMISSION

During 1972 and 1973, the Atomic Energy Commission, Directorate of Regulatory Operations, contracted for measurements at six BWR's in order to develop "source terms" for the release of radioactive materials. These measurements were independent of utility data for release rates. The measurements were conducted in two separate programs. The first measurements were in-plant radioactivity and releases from BWR's, including the determination of iodine species. In the second program, radioiodine behavior in the environs of BWR's was observed. Releases were determined at seven BWR's and environs measurements were made at three of these plants. Most measurements were made at the Oyster Creek plant; releases and species were determined over a 3-month period, during the next year environs studies were also performed over a 3-month period. At the other BWR stations, the tests were for shorter periods. Table 3-28 summarizes the I-131 release data obtained by the AEC (now the NRC).

On the basis of the NRC data obtained at Oyster Creek, annual release rates were estimated by the NRC as follows:

Building	I-131 Release (Ci/year)
Reactor	0.144
Turbine	1.020
Radwaste	0.036
Total	1.2

The turbine building contributes 85% of the total release, and the reactor and radwaste building exhausts have significantly smaller contributions, 12% and 3%, respectively. In terms of various station operations, the estimates for Oyster Creek were as follows:

Mode of Operation	Annual Release (curies)
Normal	0.75
Purge	0.039
Refueling	0.35

For all three modes, the turbine building is the dominant source of release at Oyster Creek.

3.4 MEASUREMENTS BY GENERAL ELECTRIC COMPANY

The General Electric Company has conducted ventilation studies at five BWR stations. These studies, like the NRC measurements, are short-term observations of I-131 releases. The special studies were made over a 3-year period, 1971 to 1974. The purposes of the GE studies were to provide an independent set of observations of BWR gaseous activity releases using advanced equipment and techniques, and to evaluate the adequacy of station instrumentation to provide reliable gaseous effluent data.

The GE release measurements were to be complemented by knowledge of operating variables in order to generate a correlation between release rates and in-station iodine transport. The NRC studies had a similar intent. However, such a correlation is beyond the scope of this report, and neither of the above organizations have developed such a correlation, to date.

Table 3-29 summarizes the I-131 release data obtained by the General Electric Company. In this summary, I-131 reactor water concentrations are included.

Table 3-1
HVAC AIRBORNE RELEASES, CURIES PER MONTH
PLANT – PILGRIM 1
BUILDINGS – REACTOR, TURBINE, AND RADWASTE

Year	Month	Iodine-131 (Gaseous)	Particulates Gross Beta-Gamma Radioactivity (Half-Lives > 8 Days)
1973	January	1.23 E-3	0.119 E-3
	February	0.972	0.101
	March	2.09	0.268
	April	12.4	0.657
	May	41.8	0.172
	June	5.32	0.163
	July	2.96	0.126
	August	5.37	0.235
	September	7.73	0.559
	October	3.74	0.377
	November	3.45	0.776
	December	3.05	1.60
1974	January	2.39	1.89
	February	0.429	0.449
	March	0.010	0.373
	April	ND	0.266
	May	ND	0.185
	June	ND	0.699
	July	0.00151 E-3	0.259
	August	0.626	0.776
	September	7.68	0.958
	October	7.81	0.500
	November	53.8	2.70
	December	83.3	3.55
1975	January	109	1.10
	February	55.4	1.72
	March	66.2	2.62
	April	126	3.37
	May	163	3.81
	June	113	5.21

ND = No detectable activity

Table 3-2
HVAC AIRBORNE RELEASES, CURIES PER CALENDAR QUARTER
PLANT – PILGRIM 1
BUILDINGS – REACTOR, TURBINE, AND RADWASTE

Year	Quarter	Iodine-131 (Gaseous)	Particulates (Half-Lives > 8 Days)
1973	1st	0.429 E-2	0.0488 E-2
	2nd	5.952	0.0992
	3rd	1.606	0.0920
	4th	1.024	0.2753
1974	1st	0.2829	0.2712
	2nd	ND	0.1150
	3rd	0.831	0.199
	4th	14.49	0.675
1975	1st	23.06	0.544
	2nd	40.20	1.239
Geometric Mean (9)		2.871 E-2	(10) 0.2259 E-2
Standard Deviation		6.146	2.755
Arithmetic Mean (10)		8.787 E-2	0.3558 E-2
Standard Deviation		13.44	0.3716

ND = No detectable activity

NOTE: Determination of geometric mean for I-131 (gaseous) excludes 2nd quarter 1974 because of exceedingly long shutdown, ~6 months, for refueling/maintenance outage.

Table 3-3
HVAC AIRBORNE RELEASES, CURIES PER YEAR
PLANT – PILGRIM 1
BUILDINGS – REACTOR, TURBINE, AND RADWASTE

Year	Iodine-131 (Gaseous)	Particulates (Half-Lives > 8 Days)
1973	0.090	0.005
1974	0.156	0.013
1975[a]	0.633	0.018

[a]January through June, inclusive

Geometric Mean	0.19	0.011
Standard Deviation	2.986	2.229

Table 3-4
HVAC AIRBORNE RELEASES, CURIES PER MONTH
PLANT – DRESDEN 2
BUILDING – REACTOR

Year	Month	Iodine-131 (Gaseous)	
1972	January	2.	E-3
	February	8.	
	March	5.	
	April	1.	
	May	3.	
	June	1.	
	July	2.	
	August	1.	
	September	1.	
	October	1.	
	November	1.	
	December	1.	
1973	January	1.	
	February	1.	
	March	8.	
	April	3.	
	May	2.	
	June	2.	
	July	1.04	
	August	2.99	
	September	1.99	
	October	4.18	
	November	3.56	
	December	2.94	
1974	January	3.54	
	February	6.22	
	March	3.89	
	April	3.11	
	May	4.06	
	June	3.80	
	July	3.20	
	August	7.43	
	September	7.60	
	October	3.20	
	November	9.2	
	December	18.4	
1975	January	3.0	
	February	4.0	
	March	3.0	
	April	3.8	
	May	2.7	
	June	3.8	

Table 3-5
HVAC IODINE-131 AIRBORNE RELEASES, CURIES PER CALENDAR QUARTER
PLANT – DRESDEN 2
BUILDING – REACTOR

Year	Quarter	Iodine-131 (Gaseous)
1972	1st	1.5 E-2
	2nd	<0.5
	3rd	0.4
	4th	<0.1
1973	1st	<1.0
	2nd	0.7
	3rd	0.6
	4th	1.07
1974	1st	<1.37
	2nd	<1.10
	3rd	<1.82
	4th	3.08
1975	1st	1.00
	2nd	1.03

Table 3-6
HVAC IODINE-131 AIRBORNE RELEASES, CURIES PER YEAR
PLANT – DRESDEN 2
BUILDING – REACTOR

Year	Iodine-131 (Gaseous)
1972	0.0250
1973	0.0337
1974	0.0737
1975[a]	0.0203

[a]January through June, inclusive

Table 3-7
HVAC AIRBORNE RELEASES, CURIES PER MONTH
PLANT – DRESDEN 3
BUILDING – REACTOR

Year	Month	Iodine-131 (Gaseous)
1972	January	1.0 E-3
	February	2.0
	March	1.
	April	2.
	May	3.
	June	1.
	July	4.
	August	1.
	September	4.
	October	1.
	November	2.
	December	2.
1973	January	1.
	February	1.
	March	11.
	April	1.
	May	1.
	June	1.
	July	2.13
	August	2.52
	September	1.71
	October	4.34
	November	10.23
	December	6.77
1974	January	4.06
	February	2.76
	March	5.36
	April	2.59
	May	2.68
	June	2.59
	July	5.27
	August	2.68
	September	5.53
	October	3.20
	November	23.1
	December	9.3
1975	January	3.0
	February	4.0
	March	3.0
	April	3.8
	May	2.9
	June	2.6

Table 3-8
HVAC IODINE-131 AIRBORNE RELEASES, CURIES PER CALENDAR QUARTER
PLANT – DRESDEN 3
BUILDING – REACTOR

Year	Quarter	Iodine-131 (Gaseous)
1972	1st	0.40 E-2
	2nd	0.60
	3rd	0.90
	4th	0.50
1973	1st	1.30
	2nd	0.30
	3rd	0.64
	4th	2.13
1974	1st	1.22
	2nd	0.79
	3rd	1.35
	4th	3.56
1975	1st	1.00
	2nd	0.93

Table 3-9
HVAC IODINE-131 AIRBORNE RELEASES, CURIES PER YEAR
PLANT – DRESDEN 3
BUILDING – REACTOR

Year	Iodine-131 (Gaseous)
1972	0.0240
1973	0.0437
1974	0.0692
1975[a]	0.0193

[a]January through June, inclusive

Table 3-10
HVAC AIRBORNE RELEASES, CURIES PER MONTH
PLANT – QUAD CITIES 1
BUILDING – REACTOR

Year	Month	Iodine-131 (Gaseous)
1972	June	0.30 E-3
	July	1.09
	August	1.21
	September	3.08
	October	1.06
	November	1.51
	December	0.39
1973	January	ND
	February	0.57
	March	0.92
	April	1.65
	May	8.11
	June	1.33
	July	9.75
	August	5.92
	September	6.48
	October	12.5
	November	6.68
	December	2.72
1974	January	3.65
	February	1.71
	March	7.42
	April	7.78
	May	1.71
	June	4.72
	July	3.53
	August	2.68
	September	10.8
	October	10.2
	November	7.92
	December	7.06
1975	January	18.5
	February	3.59
	March	1.69
	April	2.93
	May	12.3
	June	5.3

Table 3-11
HVAC AIRBORNE RELEASES, CURIES PER CALENDAR QUARTER
PLANT – QUAD CITIES 1
BUILDING – REACTOR

Year	Quarter	Iodine-131 (Gaseous)
1972	3rd	0.54 E-2
	4th	0.30
1973	1st	0.15
	2nd	1.11
	3rd	2.22
	4th	2.19
1974	1st	1.29
	2nd	1.42
	3rd	1.70
	4th	2.52
1975	1st	2.38
	2nd	2.05

Arithmetic Mean	1.489 E-2
Standard Deviation	0.828
Geometric Mean	1.144 E-2
Standard Deviation	2.479

Table 3-12
HVAC AIRBORNE RELEASES, CURIES PER YEAR
PLANT – QUAD CITIES 1
BUILDING – REACTOR

Year	Iodine-131 (Gaseous)
1972[a]	0.86 E-2
1973	5.65
1974	6.92
1975[b]	4.43

[a] June through December, inclusive

[b] January through June, inclusive

Arithmetic Mean	5.953 E-2
Standard Deviation	1.192
Geometric Mean	5.344 E-2
Standard Deviation	1.786

Table 3-13
HVAC AIRBORNE RELEASES, CURIES PER MONTH
PLANT – QUAD CITIES 2
BUILDING – REACTOR

Year	Month	Iodine-131 (Gaseous)
1972	June	0.01 E-3
	July	0.78
	August	0.01
	September	0.03
	October	0.01
	November	0.04
	December	0.02
1973	January	ND
	February	0.01
	March	0.01
	April	0.56
	May	0.51
	June	1.31
	July	0.48
	August	0.97
	September	1.71
	October	3.44
	November	8.76
	December	3.09
1974	January	6.81
	February	1.92
	March	4.17
	April	5.65
	May	3.99
	June	15.0
	July	10.6
	August	9.33
	September	12.9
	October	11.1
	November	10.4
	December	11.9
1975	January	7.99
	February	0.65
	March	0.27
	April	0.22
	May	5.0
	June	11.8

ND = No data

Table 3-14
HVAC AIRBORNE RELEASES, CURIES PER CALENDAR QUARTER
PLANT – QUAD CITIES 2
BUILDING – REACTOR

Year	Quarter	Iodine-131 (Gaseous)
1972	3rd	0.08 E-2
	4th	0.01
1973	1st	0.01
	2nd	0.24
	3rd	0.32
	4th	1.53
1974	1st	1.29
	2nd	2.46
	3rd	3.28
	4th	3.34
1975	1st	0.89
	2nd	1.70

Arithmetic Mean 1.263 E-2
Standard Deviation 1.232

Geometric Mean 4.377 E-3
Standard Deviation 8.103

Table 3-15
HVAC AIRBORNE RELEASES, CURIES PER YEAR
PLANT – QUAD CITIES 2
BUILDING – REACTOR

Year	Iodine-131 (Gaseous)
1972[a]	0.09 E-2
1973	2.09
1974	10.37
1975[b]	2.59

[a] June through December, inclusive

[b] January through June, inclusive

Arithmetic Mean 5.047 E-2
Standard Deviation 4.424

Geometric Mean 2.756 E-2
Standard Deviation 4.559

Table 3-16
HVAC AIRBORNE RELEASES, CURIES PER FISCAL WEEK
PLANT – MONTICELLO
BUILDINGS – REACTOR, TURBINE, AND RADWASTE

Year	Week	Iodine-131 (Gaseous)	Particulates (Half-Lives >8 Days)
1974	1	26.6 E-3	1.85 E-3
	2	11.7	0.968
	3	29.7	2.26
	4	27.4	1.60
	5	19.4	2.01
	6	18.6	2.11
	7	18.9	2.06
	8	28.9	2.26
	9	22.9	3.74
	10	21.8	3.47
	11	94.3	3.21
	12	115.5	0.060
	13	30.1	0.216
	14	10.3	0.373
	15	5.76	0.221
	16	2.00	0.119
	17	1.69	0.265
	18	0.968	0.040
	19	0.319	0.090
	20	0.200	0.448
	21	1.08	1.167
	22	9.13	5.425
	23	11.61	5.219
	24	30.66	2.359
	25	34.59	
	26	44.76	
	27	28.42	0.84
	28	36.28	2.54
	29	35.68	3.32
	30	37.49	6.04
	31	41.73	5.86
	32	47.17	5.98
	33	33.26	7.25
	34	36.89	0.66
	35	34.47	7.25
	36	44.75	7.86
	37	30.24	9.07
	38	30.84	18.14
	39	26.61	20.56
	40	27.82	22.98
	41	24.19	24.19
	42	23.58	15.72
	43	24.19	26.00
	44	21.77	27.82
	45	19.95	21.77
	46	30.24	9.67

Table 3-16
HVAC AIRBORNE RELEASES, CURIES PER FISCAL WEEK
PLANT – MONTICELLO
BUILDINGS – REACTOR, TURBINE, AND RADWASTE (Continued)

Year	Week	Iodine-131 (Gaseous	Particulates (Half-Lives >8 Days)
1974	47	20.56 E-3	4.95 E-3
↓	48	20.56	13.30
	49	33.86	1.99
	50	27.82	33.86
	51	16.4	11.49
	52	16.93	7.25
1975	1	15.12	7.25
↓	2	15.72	18.14
	3	40.52	0.24
	4	15.72	0.19
	5	4.41	0.19
	6	2.35	0.78
	7	4.53	5.62
	8	8.46	7.86
	9	13.91	6.04
	10	4.89	7.25
	11	29.03	4.71
	12	23.58	5.14
	13	26.61	11.49
	14	30.24	12.70
	15	31.44	8.46
	16	37.49	12.09
	17	50.19	30.84
	18	47.17	45.36
	19	102.81	40.52
	20	90.72	12.09
	21	54.43	6.65
	22	56.24	12.70
	23	42.94	38.70
	24	41.73	5.01
	25	59.27	5.50
	26	60.48 ↓	5.62 ↓

Table 3-17
HVAC AIRBORNE RELEASES, CURIES PER CALENDAR QUARTER
PLANT – MONTICELLO
BUILDINGS – REACTOR, TURBINE, AND RADWASTE

Year	Quarter	Iodine-131 (Gaseous)	Particulates (Half-Lives >8 Days)
1974	1st	46.58 E-2	2.58 E-2
↓	2nd	15.31	1.57
	3rd	46.38	1.21
	4th	29.31	2.18
1975	1st	20.49	7.49
↓	2nd	70.52 ↓	23.6 ↓
Arithmetic Mean (6)		38.10 E-2	0.0654
Standard Deviation		20.49	0.0866
Geometric Mean		0.3345	0.0367
Standard Deviation		1.773 ↓	3.023

Table 3-18
HVAC AIRBORNE RELEASES, CURIES PER YEAR
PLANT – MONTICELLO
BUILDINGS – REACTOR, TURBINE, AND RADWASTE

Year	Iodine-131 (Gaseous)	Particulates (Half-Lives >8 Days)
1974	138. E-2	8.17 E-2
1975[a]	91.0 ↓	31.14 ↓

[a]January through June, inclusive

Arithmetic Mean I-131	1.22	0.158

Table 3-19
AIRBORNE I-131 RELEASES FROM OYSTER CREEK STATION, FOR THE PERIOD OF FEBRUARY 22 TO AUGUST 21, 1975
(EPRI MEASUREMENTS)

Sample Period (Month/Day)	Release Rate, μCi/s (Reported)					Sample Period (Days)	Release, Curies (Calculated)[b]				
	Reactor	Turbine	Radwaste	Gland Seal/MVP	Total Vent[a]		Reactor	Turbine	Radwaste	Gland Seal/MVP	Total Vent[a]
2/22–2/26	7.5 E-4	2.5 E-2	4.6 E-4	c	2.6 E-2	4	2.592 E-4	8.640 E-3	1.590 E-4	c	8.986 E-3
2/26–3/12	5.3 E-4	2.8	6.8	c	2.9	14	6.410 E-4	3.387 E-2	8.225 E-4	c	3.508 E-2
3/12–3/28	2.2 E-3	2.8	4.9	c	3.1	16	3.041 E-3	3.871 E-2	6.774 E-4	c	4.285 E-2
3/29–4/15	5.3	8.0	1.05 E-2	c	9.1	17	7.785 E-3	1.175 E-1	1.542 E-2	c	1.407 E-1
4/15–5/1	1.3	5.3	3.4 E-3	c	5.8	16	1.797 E-3	7.327 E-2	4.700 E-3	c	8.018 E-2
5/1–5/15	0.50	4.6 E-3	d	c	5.1 E-3	14	6.048 E-4	5.564 E-3	d	c	6.169 E-3
5/15–5/29	0.20	0.42	0.48 E-4	c	0.67	14	2.419 E-4	0.508	5.806 E-5	c	8.104 E-4
5/29–6/16	0.75	2.9	1.6	c	3.9	18	1.166 E-3	4.510	2.488 E-4	c	6.065 E-3
6/16–6/30	1.1	4.6	1.5	1.4 E-3	5.9	14	1.331 E-3	5.564	1.814 E-4	1.693 E-3	7.137 E-3
6/30–7/17	1.1	2.7	4.6	1.22	4.3	17	1.616 E-3	3.966	6.756 E-4	1.792 E-3	6.316 E-3
7/17–8/5	0.42	5.6	1.01 E-3	6.6	7.1	19	6.895 E-4	9.193	1.658 E-3	1.083 E-2	1.166 E-2
8/5–8/21	0.33	7.5	7.2 E-4	2.2	8.6	16	4.562 E-4	1.037 E-2	9.953 E-4	3.041 E-3	1.189 E-2

[a]Excludes gland seal and MVP exhaust

[b]Calculated results to 4 digits, final results shall be rounded to 2 significant figures.

[c]Not sampled

[d]Sampler failed

Table 3-20
AVERAGE STACK RELEASES OF I-131 AND AVERAGE POWER LEVELS AT OYSTER CREEK PLANT DURING 1975

Period	Average Power (MWt)	Average Stack Release (μCi/s)	Period	Average Power (MWt)	Average Stack Release (μCi/s)
1/1–1/7	650	0.07	5/21–5/27	24	0.002
1/8–1/14	640	0.11	5/28–6/3	450	0.84
1/15–1/21	670	0.12	6/4–6/10	520	0.71
1/22–1/28	620	0.07	6/11–6/17	290	1.06
1/29–2/4	660	0.18	6/18–6/24	530	0.28
2/5–2/11	90	0.15	6/25–7/1	540	0.17
2/12–2/18	540	0.09	7/2–7/8	540	0.16
2/19–2/25	590	0.13	7/9–7/15	540	0.21
2/26–3/4	610	0.14	7/16–7/22	520	0.11
3/5–3/11	660	0.17	7/23–7/29	450	0.36
3/12–3/18	630	0.16	7/30–8/5	540	0.14
3/19–3/25	640	0.18	8/6–8/12	560	0.12
3/26–4/1	280	0.17	8/13–8/19	550	0.11
4/2–4/8	0	0.57			
4/9–4/15	0	0.11			
4/16–4/22	0	0.06			
4/23–4/29	0	0.02			
4/30–5/6	0	0.015			
5/7–5/13	0	0.006			
5/14–5/20	0	0.002			

Table 3-21
SUMMARY OF AIRBORNE I-131 RELEASES FROM OYSTER CREEK PLANT FOR THE PERIOD OF FEBRUARY 22 TO AUGUST 21, 1975

	Sample Period (Days)	I-131, Curies Building Exhausts: Reactor	Turbine	Radwaste	Gland Seal and MVP	Operating Mode
	118	9.2 E-3	1.148 E-1	5.418 E-3	1.736 E-2[a]	Normal
	61	1.043 E-2	1.968 E-1	2.198 E-2[b]	2.65 E-1[c]	Refuel/ Maintenance
Total	179	1.963 E-2	3.116 E-1	2.740 E-2	2.82 E-1	––

[a]66 Days only

[b]Adjustment made to account for 14 day sample failure; increased measured release by 0.0013 curies on assumption that radwaste building releases were proportional to reactor building releases.

[c]Estimated from stack release less total vent release (reactor + turbine + radwaste buildings).

Table 3-22
AIRBORNE I-131 RELEASES FROM MONTICELLO PLANT FOR THE PERIOD OF NOVEMBER 15, 1974, TO JULY 8, 1975
(EPRI MEASUREMENTS)

Sample Period (Month/Day)	Release Rate, μCi/s (Reported)				Sample Period (Days)	Release, Curies (Calculated) Building			
	Reactor	Turbine	Radwaste	Total Vent		Reactor	Turbine	Radwaste	Total Vent
11/15–11/17/74	0.021	0.0037	0.0053	0.030	2	3.629 E-3	6.394 E-4	9.158 E-4	5.184 E-3
11/20–12/5	0.022	0.019	0.0026	0.044	15	2.851 E-2	2.462 E-2	3.370 E-3	5.702 E-2
12/5–12/18	0.016	0.0094	0.0014	0.027	13	1.797 E-2	1.056 E-2	1.572 E-3	3.033 E-2
12/18–1/6/75	0.0091	0.0070	0.0018	0.018	19	1.494 E-2	1.149 E-2	2.955 E-3	2.955 E-2
1/8–1/9	0.0061	0.0041	0.0012	0.011	1	5.270 E-4	3.542 E-4	1.036 E-4	9.504 E-4
1/13–1/15	0.027	0.034	0.0014	0.065	2	4.666 E-3	5.875 E-3	2.419 E-4	1.123 E-2
1/9–1/13 & 1/15–1/22	0.018	0.039	0.00064	0.058	11	1.711 E-2	3.707 E-2	6.083 E-4	5.512 E-2
1/22–2/7	0.0068	0.0068	0.00028	0.014	16	1.300 E-2	1.300 E-2	5.351 E-4	2.675 E-2
2/7–2/22	0.0031	0.028	0.00045	0.031	15	4.018 E-3	3.629 E-2	5.832 E-4	4.018 E-2
2/22–3/10	0.0081	0.018	0.00026	0.026	16	1.120 E-2	2.488 E-2	3.594 E-4	3.594 E-3
3/10–3/25	0.022	0.020	**	0.042	15	2.851 E-2	2.592 E-2	–	5.443 E-2
3/25–4/7	0.014	0.044	0.0011	0.059	13	1.572 E-2	4.942 E-2	1.236 E-3	6.627 E-2
4/7–4/21	0.021	0.037	0.00084	0.059	14	2.540 E-2	4.476 E-2	1.016 E-3	7.137 E-2
4/21–5/5	**	0.051	0.0010	––	14	––	6.169 E-2	1.210 E-3	––
5/5–5/17	0.077	0.052	0.0014	0.13	12	7.983 E-2	5.391 E-2	1.452 E-3	1.348 E-1
5/19–6/5	0.036	0.041	0.0035	0.081	17	5.288 E-2	6.022 E-2	5.141 E-2	1.190 E-1
6/5–6/23	0.058	0.029	0.0053	0.093	18	9.020 E-2	4.510 E-2	8.243 E-3	1.446 E-1
6/23–7/8	0.077	0.034	0.0075	0.12	15	9.979 E-2	4.406 E-2	9.720 E-3	1.555 E-1

**Not sampled

NOTES:

1 Gland seal steam and MVP exhaust not sampled.

2 Refueling maintenance outage 1/9/75 to 2/7/75; delays to full-power due to loss of recombiner trains until about 2/26.

Table 3-23
SUMMARY OF AIRBORNE I-131 RELEASES FROM MONTICELLO PLANT FOR PERIOD OF NOVEMBER 15, 1974, TO AUGUST 8, 1975

	Sample Period (Days)	I-131, Curies Building Exhausts[a] Reactor	Turbine	Radwaste	Total Vent	Operating Mode
	184	4.691 E-1[a]	4.576 E-1	8.356 E-2	9.05 E-1[a]	Normal
	44	3.879 E-2	9.224 E-2	1.969 E-3	1.33 E-1	Refueling/ Maintenance[b]
Totals	228	0.5079[a]	0.5499	0.0855	1.04[a]	

[a]Only 170 days

[b]Includes start-up period up to 2/26.

Table 3-24
RELEASE RATE OF I-131 FROM TALL-STACK AT MONTICELLO PLANT DURING REFUELING/MAINTENANCE OUTAGE, JANUARY—FEBRUARY 1975

Week Ending	Rate (μCi/s)
1/6	0.012
1/13	0.45
1/20	0.063
1/27	0.020
2/3	0.025
2/10	0.017
2/17	0.0024

Table 3-25
AIRBORNE I-131 RELEASES FROM VERMONT YANKEE PLANT FOR THE PERIOD OF JUNE 20, 1974, TO JULY 29, 1975 (YANKEE ATOMIC AND EPRI MEASUREMENTS)

Sample Period (Month/Day)	Reported Release Rates (μCi/s) Reactor (E-3)	Turbine (E-3)	Radwaste (E-3)	Gland Seal and MVP (E-3)	Sample Period (Days)	Curies Released Reactor (E-3)	Turbine (E-3)	Radwaste (E-3)	Gland Seal and MVP (E-3)
6/20–7/2	3.5	1.16	1.48	0.5	12	3.629	1.203	1.534	0.518
7/2–7/9	21.	2.0	4.0	50.	7	12.701	1.210	2.419	30.24
7/9–7/23	4.2	0.88	2.4	0.36	14	5.080	1.064	2.903	0.435
7/23–7/30	2.6	1.22	1.7	0.48	7	1.572	0.738	1.028	0.290
7/30–8/13	1.89	1.39	1.08	0.43	14	2.286	1.681	1.306	0.520
8/13–8/27	1.76	1.39	1.36	0.40	14	2.129	1.681	1.645	0.484
8/27–9/12	3.9	2.28	1.54	0.32	16	5.391	3.152	2.129	0.442
9/14–9/27	3.5	1.05	3.0	a	13	3.931	1.179	3.370	1.40
9/27–10/10	1.14	0.49	1.37	0.36	13	1.280	} 0.635	} 1.78	0.404
10/11–10/12	17.2	↓	↓	42.	1	1.486			3.629
10/12–10/14	22.			108.	1	1.901			9.331
10/14–10/31	45.3	4.7	8.2	—	17	66.537	6.903	12.044	(152.5)[c]
10/31–11/1	16.4	5.6	1.6	13.5	1	1.417	0.484	0.138	1.166
11/1–11/18	16.7	0.73	0.65	0.62	17	24.529	1.072	0.955	0.911
11/18–12/2	8.7	0.03	0.38	0.17	14	10.524	0.036	0.460	0.206
12/2–12/6	1.17	0.04	0.27	0.18	4	0.404	0.014	0.093	0.062
12/6–12/27	0.064	0.023	—	—	21	0.116	0.042	(0.03)[b]	(100)[c]
12/27–1/28/75	0.016	0.025	0.016	0.030	32	0.044	0.069	0.044	0.083
1/28–2/14	0.009	0.016	0.012	0.020	17	0.013	0.024	0.018	0.029
2/14–3/5	0.064	0.018	0.014	0.037	19	0.105	0.030	0.023	0.061
3/5–3/8	<0.005	0.008	0.030	0.021	3	0.001	0.002	0.008	0.005
3/8–3/26	0.34	0.032	0.035	0.087	18	0.470	0.044	0.048	0.120
3/26–4/10	0.034	0.047	0.012	0.025	15	0.044	0.061	0.016	0.032
4/10–4/26	0.035	0.027	0.0088	0.019	16	0.047	0.0373	0.0122	0.0263
4/26–5/8	0.029	0.060	0.017	0.0131	12	0.0301	0.0622	0.0176	0.0136
5/8–5/29	0.020	0.075	0.016	0.0696	21	0.0363	0.1361	0.0290	0.1263
5/29–6/13	0.042	0.0142	0.0086	0.0736	15	0.0544	0.0184	0.0111	0.0954
6/13–6/26	0.0223	0.037	0.021	0.0155	13	0.0250	0.0416	0.0236	0.0174
6/26–7/10	0.048	0.057	0.028	0.0306	14	0.0581	0.0689	0.0339	0.0370
7/10–7/29	0.026	0.031	0.042	0.0258	19	0.0427	0.0509	0.0689	0.0424

[a] Sampler failed

[b] From previous period release rates

[c] Estimated from total stack release

Table 3-26
IODINE-131 CALENDAR QUARTER AIRBORNE RELEASES AT VERMONT YANKEE PLANT

	Quarter	Dates (Sample Periods)	Reactor	Turbine	Radwaste	Gland Seal
			(Millicuries)			
	3rd–74	6/20–9/27	36.719	11.908	16.334	34.329
Refuel	4th–74	9/27–12/27	108.194	9.186	15.50	268.209
	1st–75	12/27–3/26	0.633	0.169	0.1410	0.298
	2nd–75	3/26–6/26	0.237	0.357	0.1095	0.311
		Totals	146.0	21.6	32.1	303.

Table 3-27
SUMMARY OF AIRBORNE I-131 RELEASES FROM VERMONT YANKEE PLANT FOR THE PERIOD OF JUNE 20, 1974, TO JULY 29, 1975

	Sample Period (Days)	I-131, Curies Building Releases: Reactor	Turbine	Radwaste	Gland Seal and MVP	Station Operating Mode
	324	0.0390	0.0131	0.0182	0.035	Normal
	76	0.107	0.0086	0.0140	0.268	Refueling
Total	400	0.1459	0.0217	0.0322	0.303	

Table 3-28
SUMMARY OF NRC MEASUREMENTS OF I-131 RELEASES AT SIX BWR's

Plant	Operating Mode	Release Rates, μCi/s Reactor	Turbine	Radwaste	Sample Time (Days)
Oyster Creek	Normal	0.0016	0.018	0.00067	14
	Normal	0.0014	0.043	0.00053	14
	Normal	0.0025	NM	NM	14
	Normal	0.0081	0.007	0.0019	14
	Containment Purge	0.14	0.087	0.0011	2
	Refueling	0.011	0.080	0.0025[a]	45
Monticello	Normal[b]	0.0070	0.0050	0.0064	29 hours
	Normal[c]		0.0017		42[d]
Dresden 2	Normal[b]	0.0019	NM	NM	~24 hours
	Normal	NM	0.00028	NM	15
	Normal	NM	0.00027	NM	14
Dresden 3	Normal[b]	0.0061	NM	NM	~24 hours
	Normal	NM	0.00065	NM	13
	Normal	NM	0.0008	NM	14
Dresden 2 & 3	Normal	NM	0.0006	NM	42[d]
Quad Cities 1	Normal	0.0038	NM	NM	1
	Normal	NM	0.00047	––	14
Quad Cities 2	Normal	<0.00023	NM	NM	1

NM = No measurement

[a]First 31 days only

[b]In conjunction with iodine species measurement, assume normal operations

[c]Includes all buildings

[d]Approximate value – see Figure 3-20.

NOTE: Measurements made during 1972, except for Quad Cities 1/2 plants which were investigated in 1973.

Table 3-29
SUMMARY OF AIRBORNE I-131 RELEASES; MEASUREMENTS BY GENERAL ELECTRIC COMPANY

		Release Rates, μCi/s						
Plant	**Mode of Operation**	**Reactor**	**Turbine**	**Radwaste**	**Gland Seal Exhaust**	**Sample Period (hrs)**	**Sample Time month/year**	**I-131 Coolant Concentration (μCi/cc)**
Dresden 2	Normal	0.005	–	–	NM	2	Jan/1971	0.0023
	Normal	NM	0.006		NM	15	Feb/1971	0.0023
Nine-Mile Point 1	Normal	NM	0.0016	NM	NM	NA	Dec/1971	0.0017
	Normal	5.57 E-4 (29.7)	5.57 E-3 (42.4)	1.00 E-3[b] (50.9)		a	March-April/74	0.002
	Normal	6.64 E-4 (44.9)	7.3 E-3 (6.7)	4.04 E-4 (44.1)		a	↓	
	Normal	4.6 E-4 (66.2)	4.54 E-3 (64.2)	4.2 E-5 (48.5)		a	↓	
	Normal	7.97 E-4 (5.3)	7.02 E-3 (65.3)	1.0 E-5 (43.2)		a	↓	
	Normal	7.1 E-4 (15.8)	–	–		a	↓	
	Shutdown	4.48 E-3 (126.3)	1.38 E-3 (47.7)	5.2 E-5 (75.1)		a		
	Shutdown	1.79 E-3 (16.2)	7.81 E-3 (71.8)	1.6 E-4 (43.2)				
Oyster Creek	Normal	<0.00144	<0.0009	<0.00030	<0.006	~1	April/1972	0.0075
			0.0029			~1		
Millstone	Normal	0.00165	NM	0.00105	0.000192	~1	July/1972	0.0034
	Normal	0.00146	NM	–	–	~1	↓	
	Normal	–	0.0026	–	–	9	↓	
	Normal	0.00323		NM	–	~1	↓	
	Normal	0.0058		NM	–	~1	↓	

[a]Sample period (hrs) in parenthesis.

[b]Concentrator steam leak at about this time.

NM = Not Measured

NA = Not Available

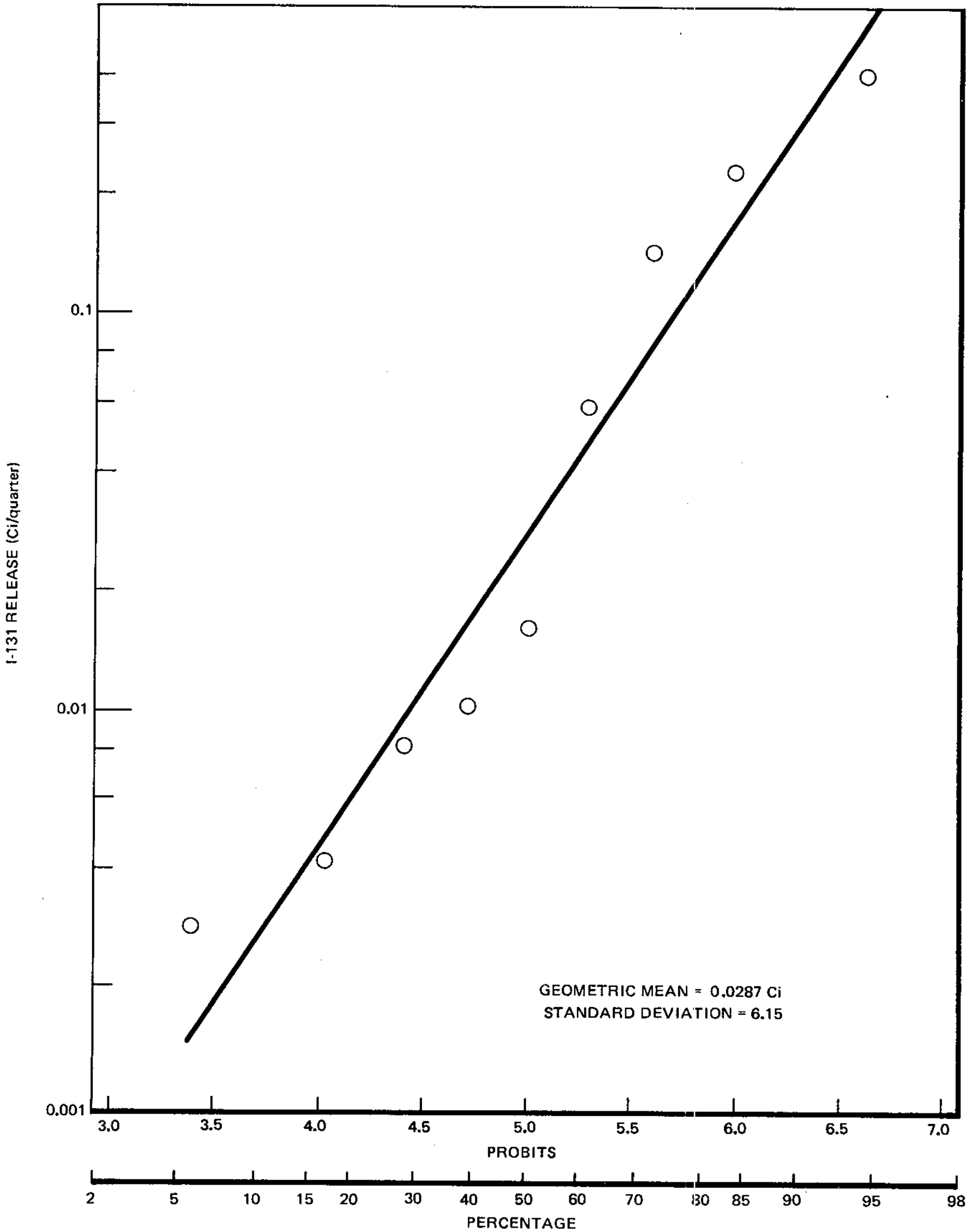

Figure 3-1. Accumulative Probability Distribution of Calendar Quarterly I-131 HVAC Airborne Releases, Pilgrim 1 Station

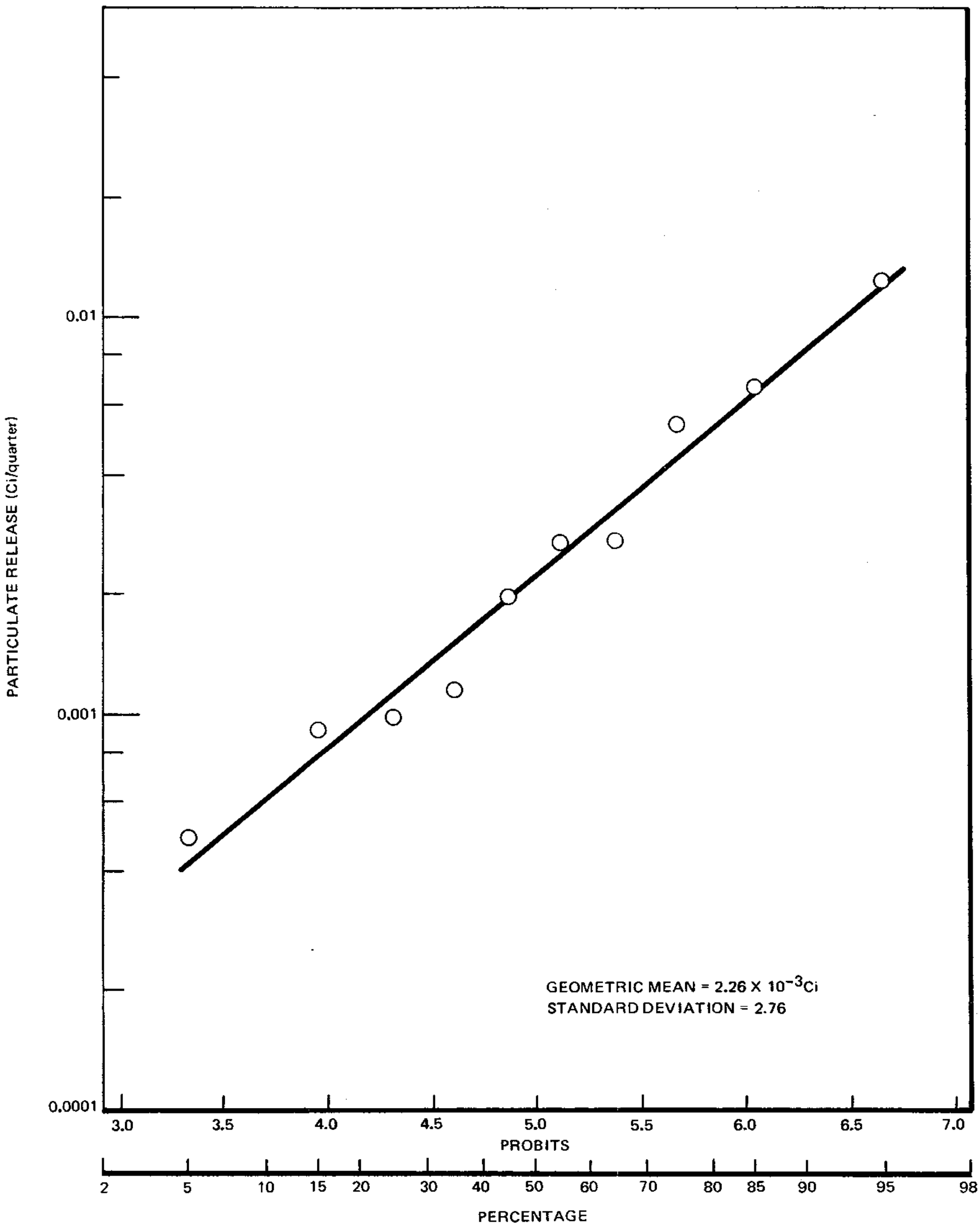

Figure 3-2. Accumulative Probability Distribution of Calendar Quarterly Particulate (Half-Lives > 8 Days) HVAC Airborne Releases, Pilgrim 1 Station

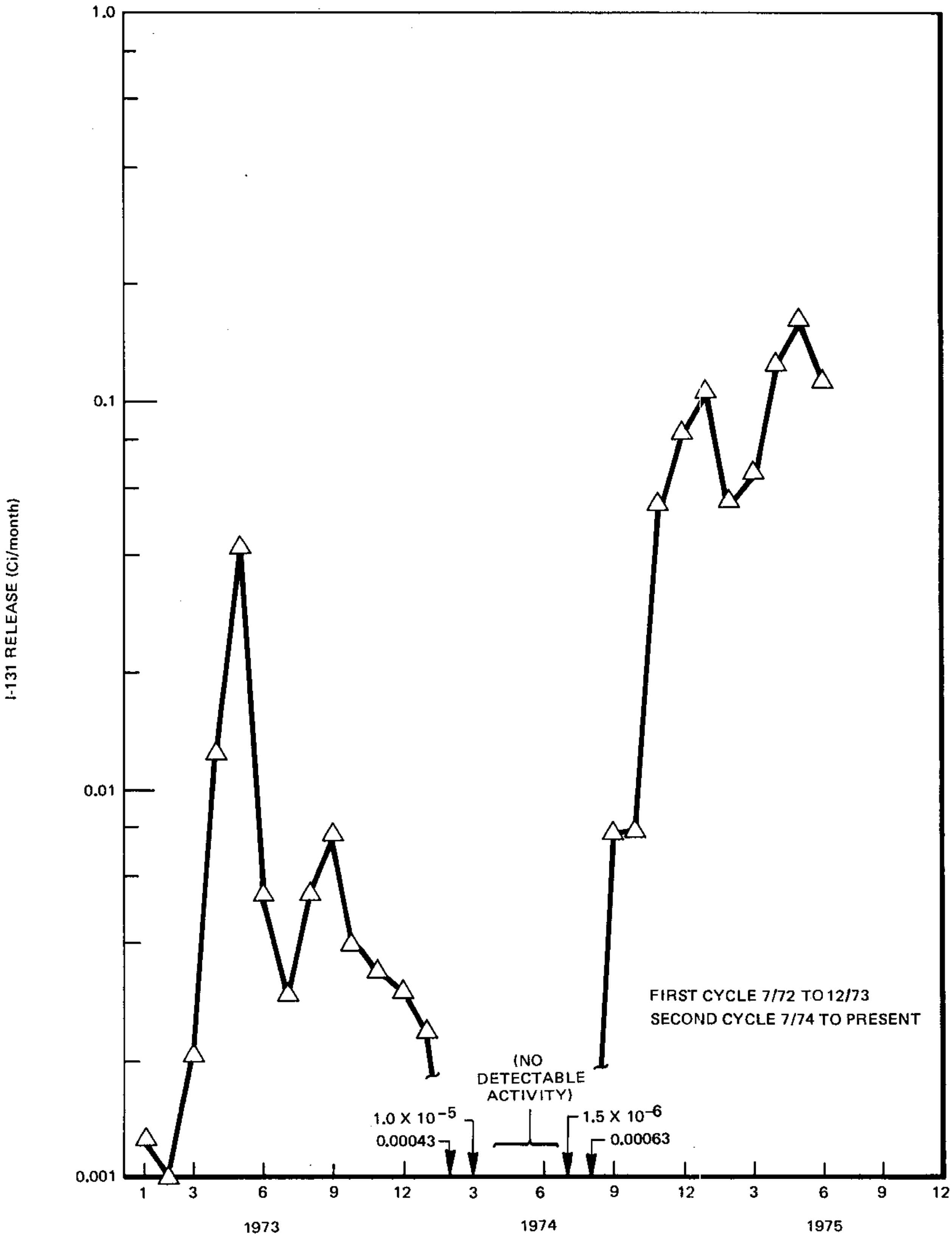

Figure 3-3. Monthly HVAC Airborne I-131 Releases versus Time, Pilgrim 1 Station

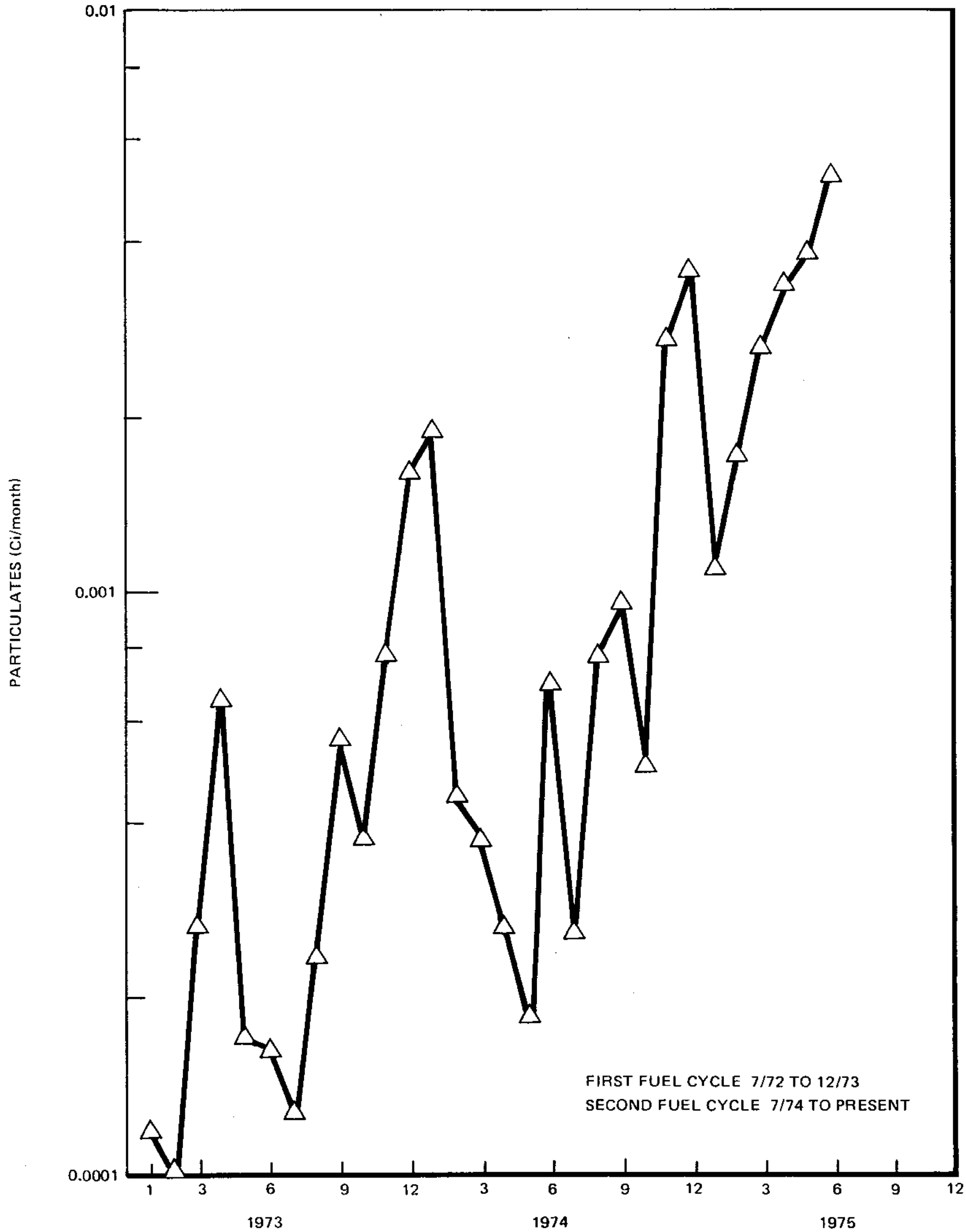

Figure 3-4. Monthly Particulate HVAC Airborne Releases versus Time, Pilgrim 1 Station

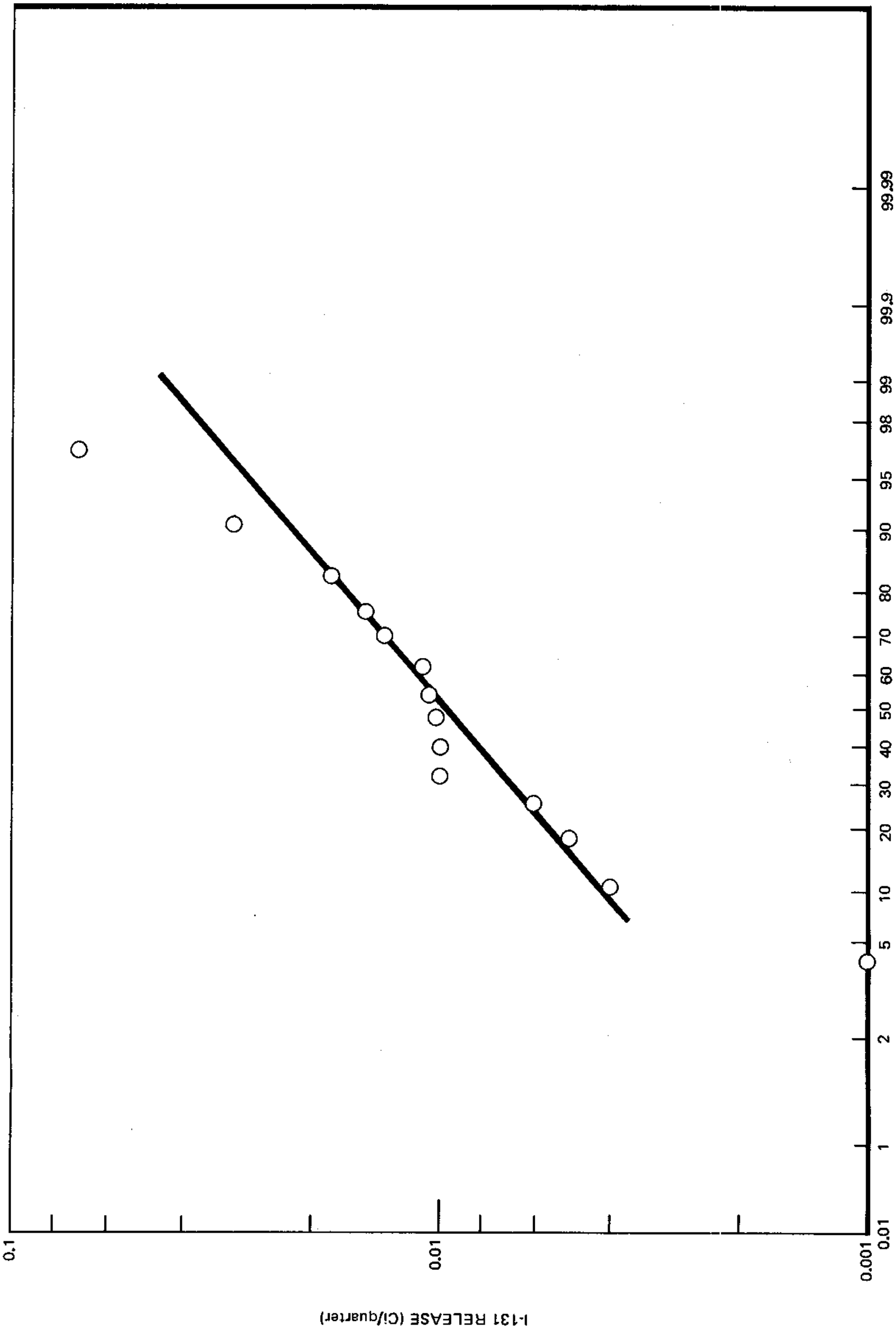

Figure 3-5. Accumulative Probability Distribution of Calendar Quarterly I-131 HVAC Releases, Dresden 2 (Reactor Building)

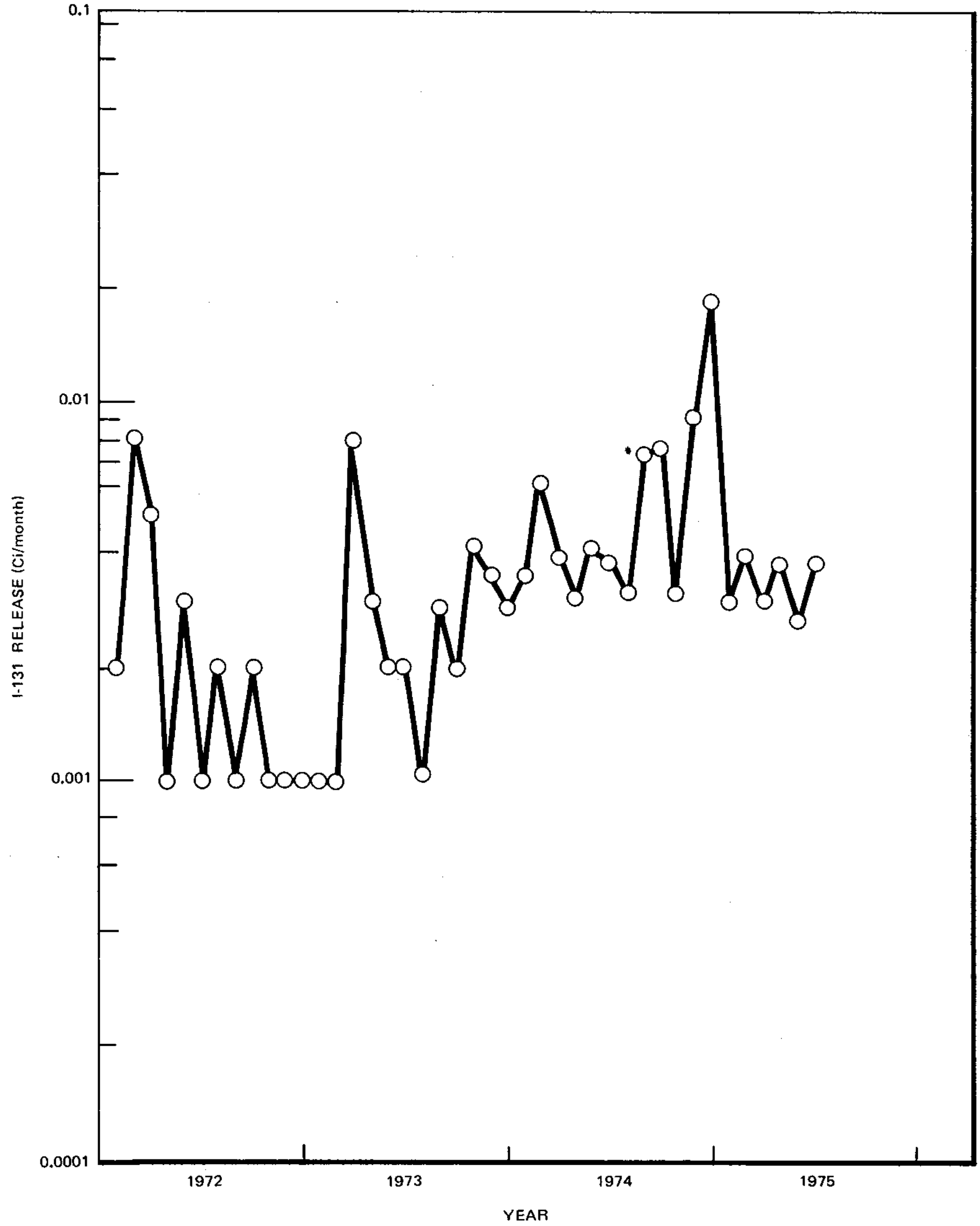

Figure 3-6. Monthly I-131 HVAC Releases versus Time, Dresden 2 (Reactor Building)

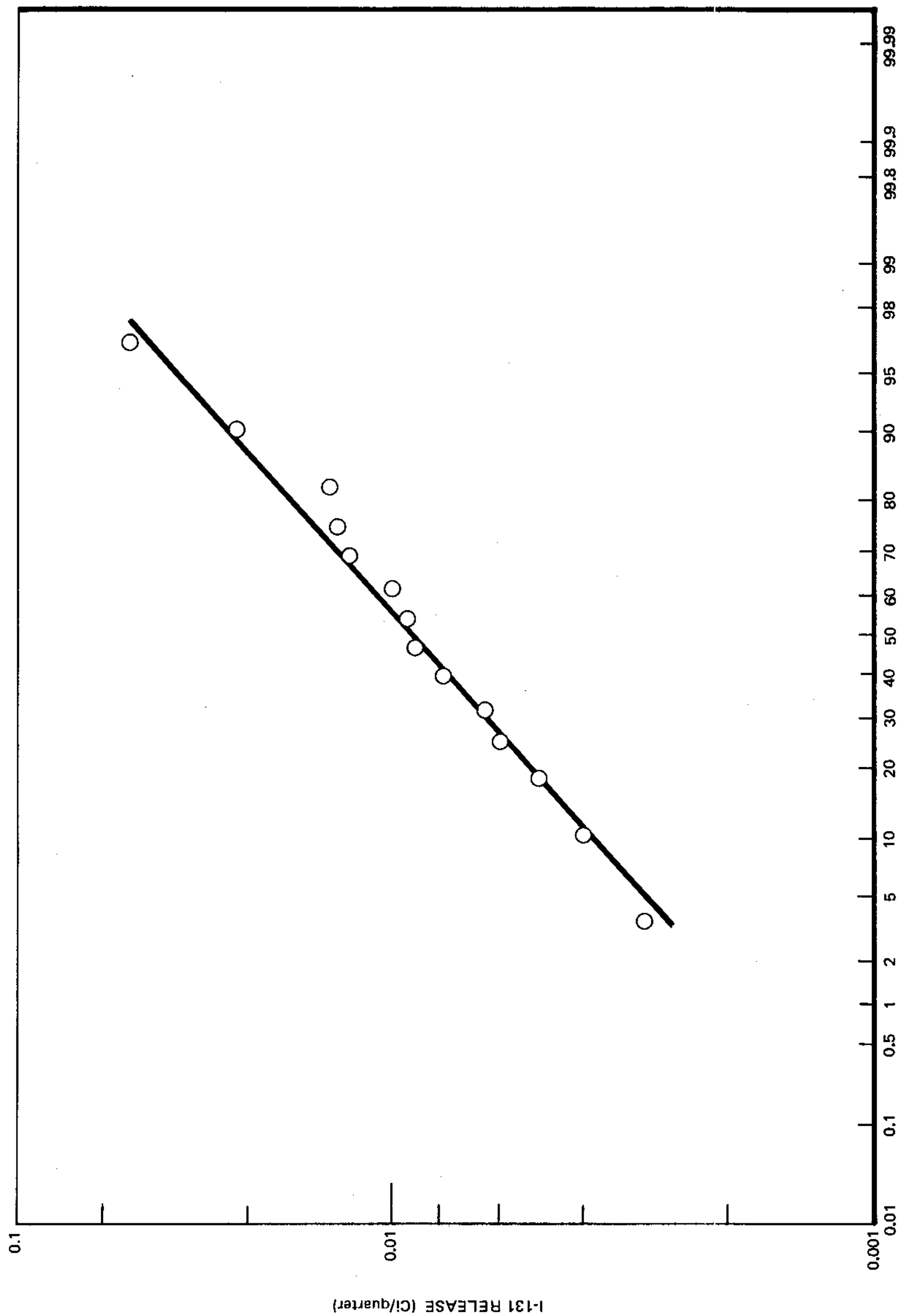

Figure 3-7. Accumulative Probability Distribution of Calendar Quarterly I-131 HVAC Releases, Dresden 3 (Reactor Building)

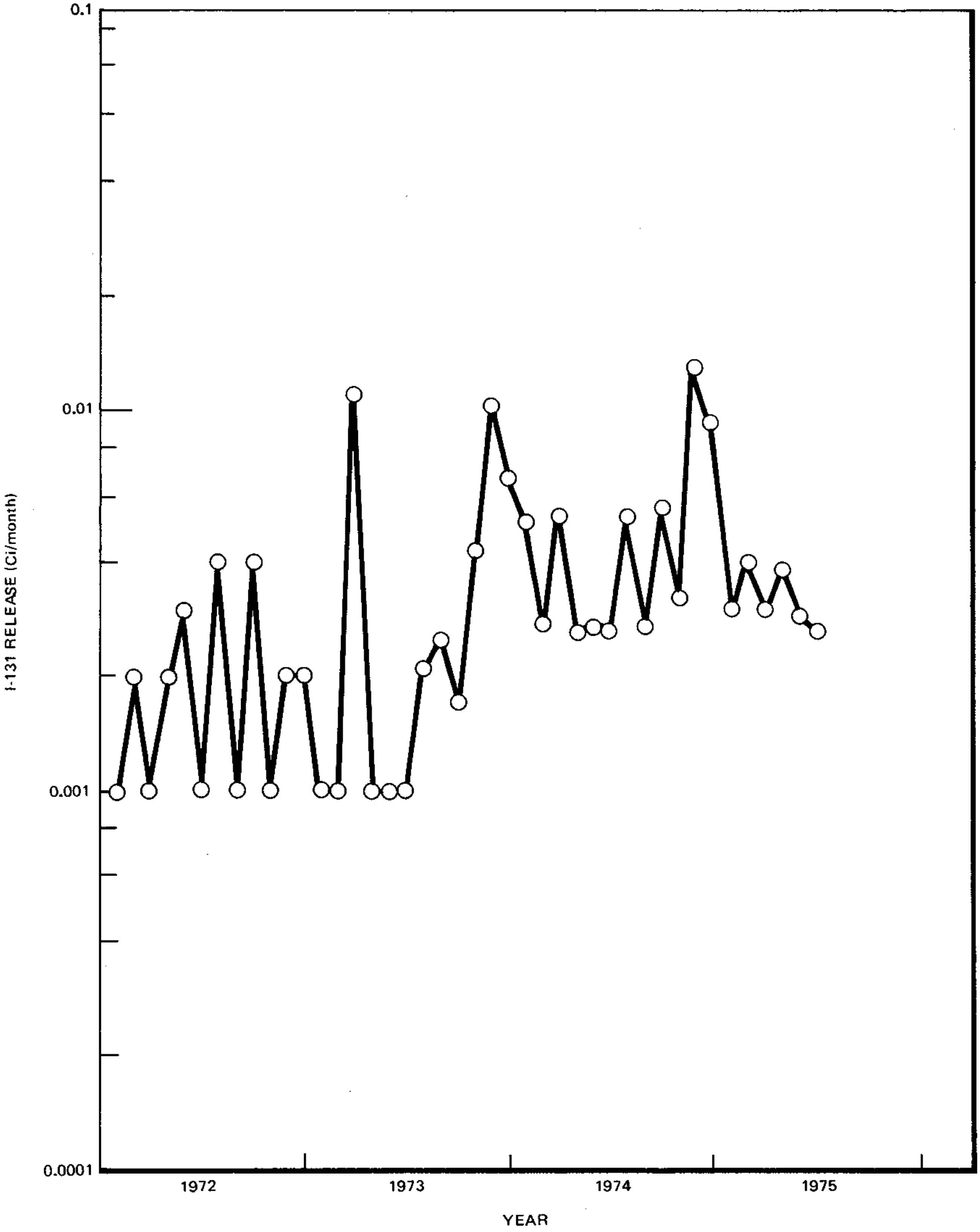

Figure 3-8. Monthly I-131 HVAC Releases Versus Time, Dresden 3 (Reactor Building)

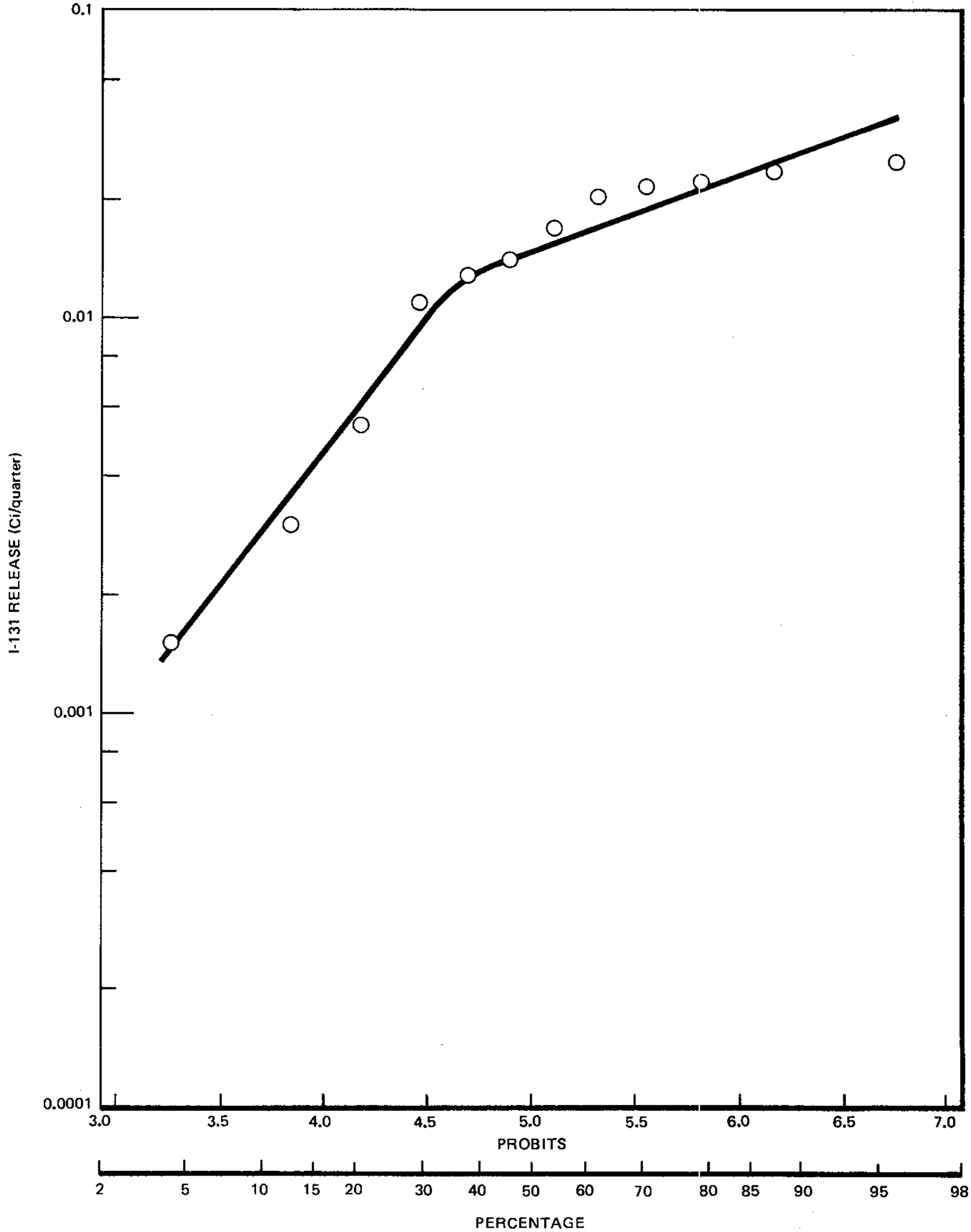

Figure 3-9. Accumulative Probability Distribution of Calendar Quarterly I-131 HVAC Releases, Quad Cities 1 (Reactor Building)

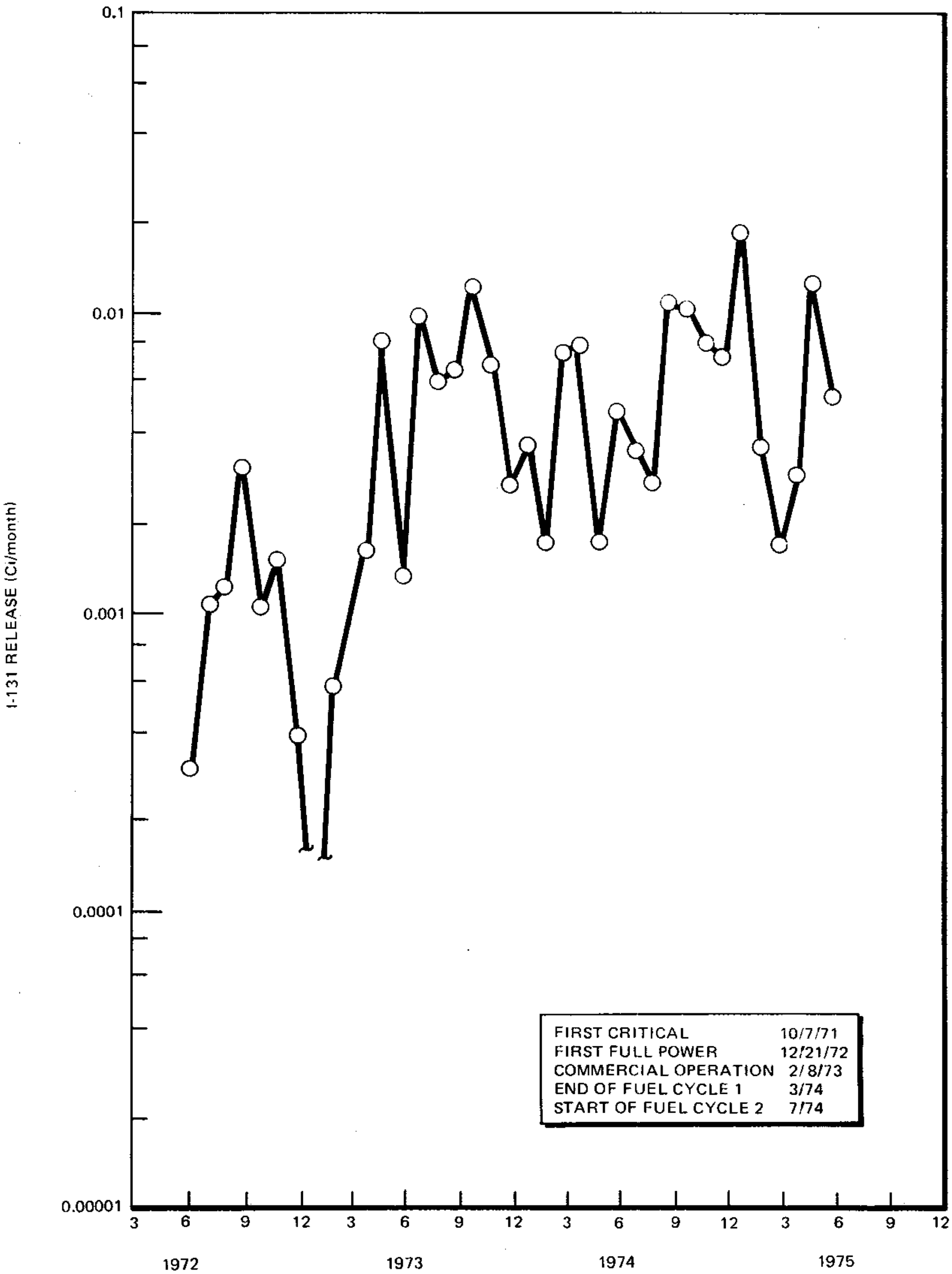

Figure 3-10. Monthly I-131 HVAC Releases Versus Time, Quad Cities 1 (Reactor Building)

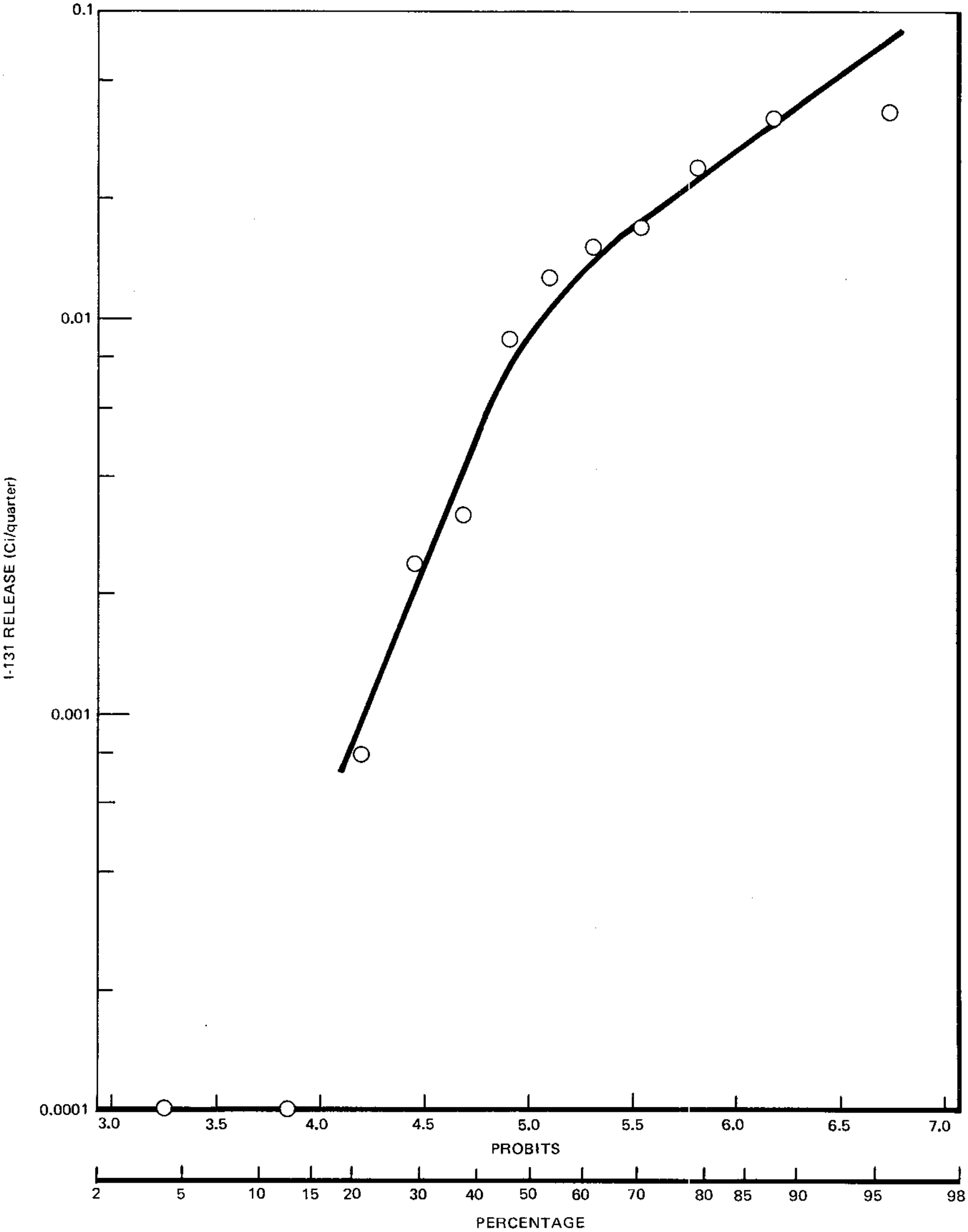

Figure 3-11. Accumulative Probability Distribution of Calendar Quarterly I-131 HVAC Releases, Quad Cities 2 (Reactor Building)

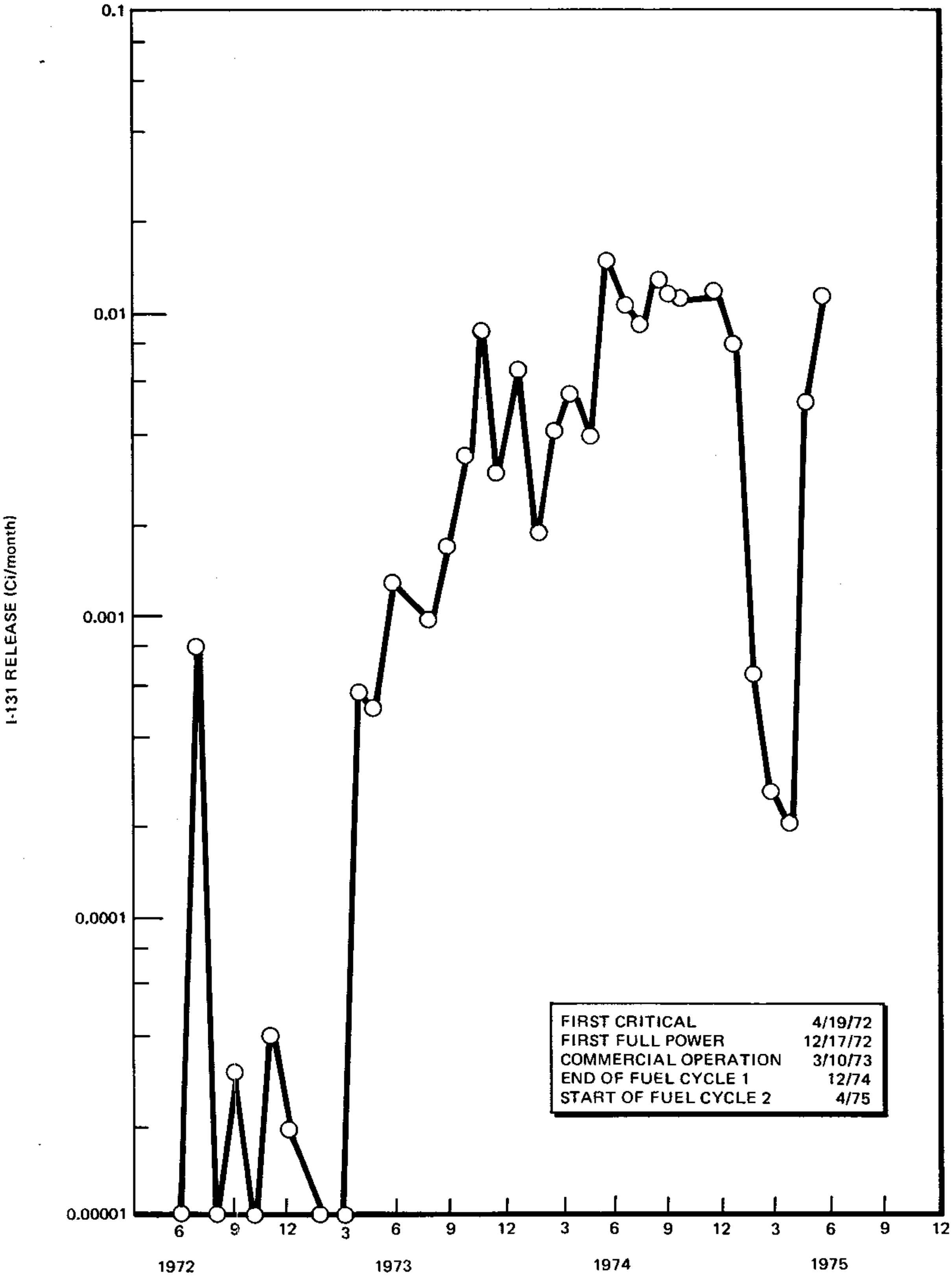

Figure 3-12. Monthly I-131 HVAC Releases Versus Time, Quad Cities 2 (Reactor Building)

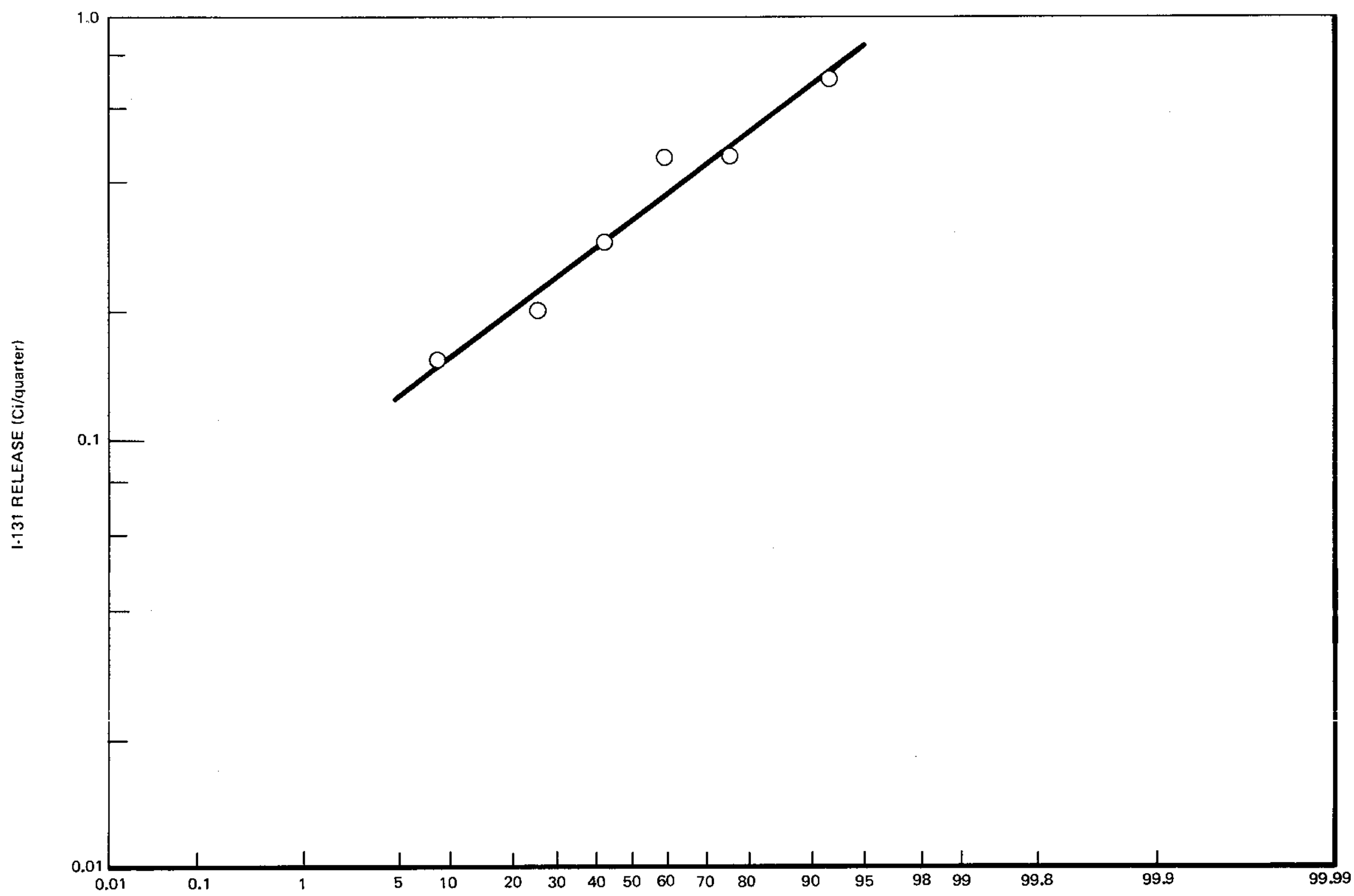

Figure 3-13. Accumulative Probability Distribution of Monticello HVAC Airborne I-131 Releases, January 1974 to June 1975 (Curies Per Calendar Quarter)

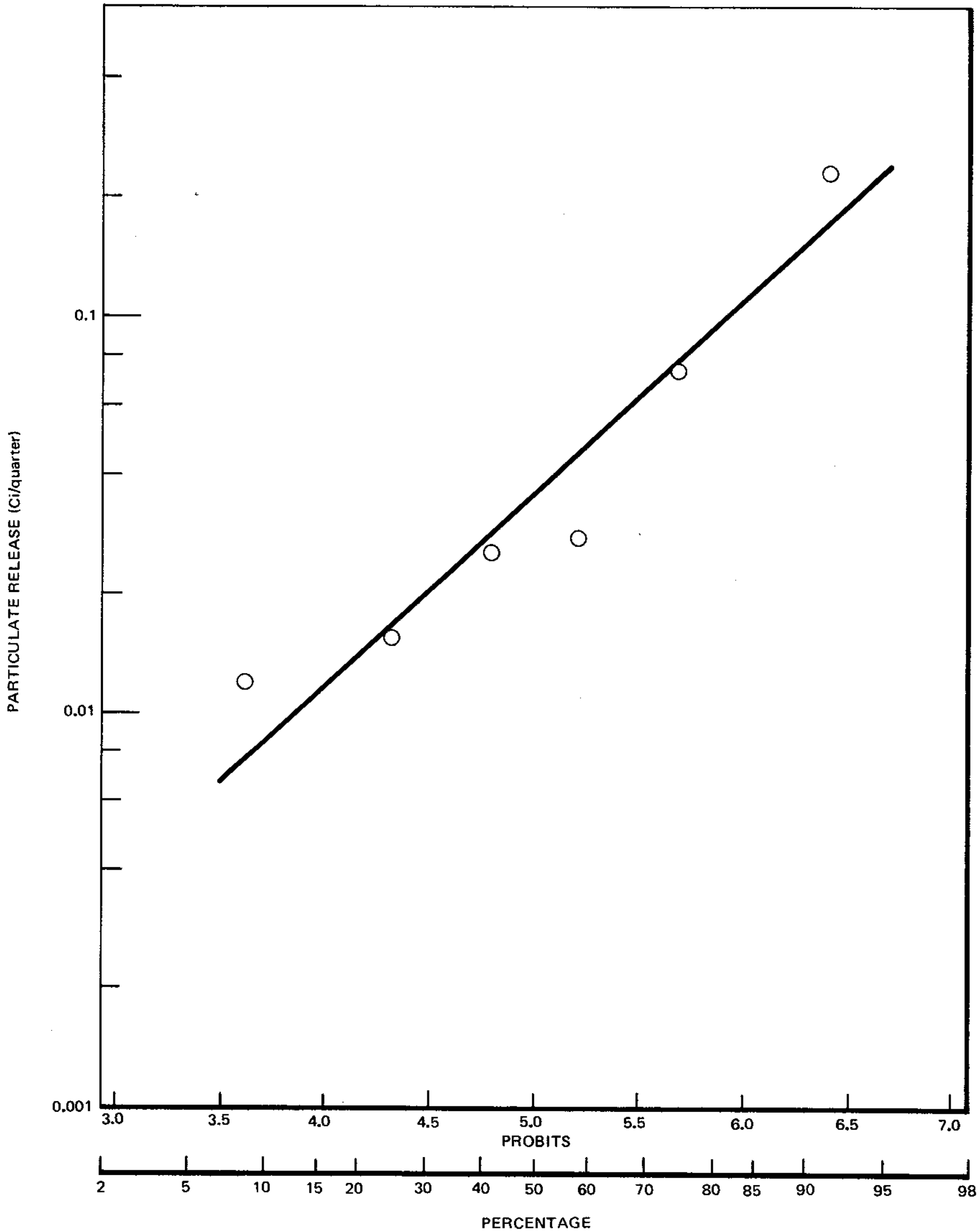

Figure 3-14. Accumulative Probability Distribution of Monticello HVAC Particulate Releases, January 1974 to June 1975 (Curies Per Calendar Quarter)

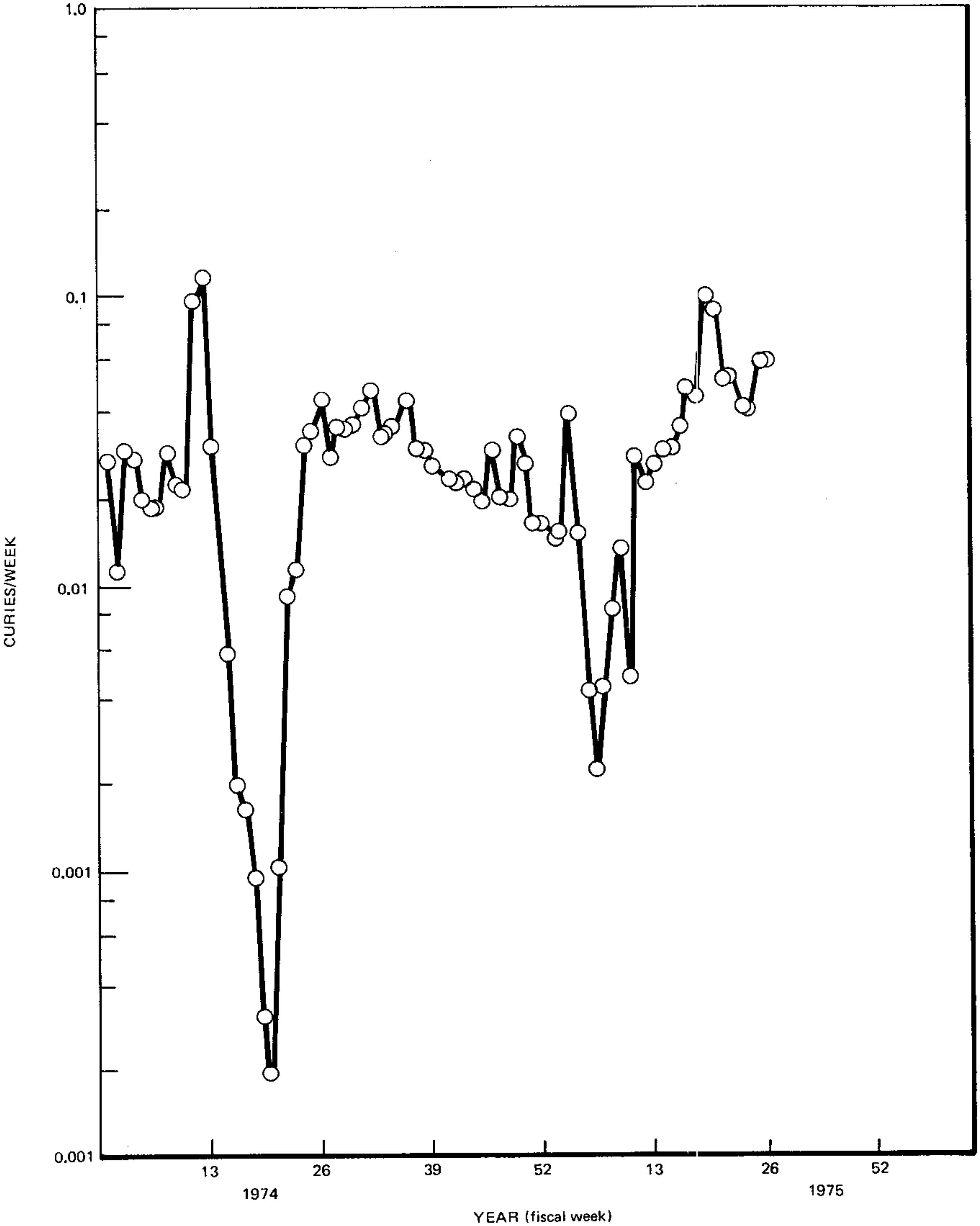

Figure 3-15. Monticello HVAC Airborne I-131 Releases January 1974 through June 1975, Curies Per Week

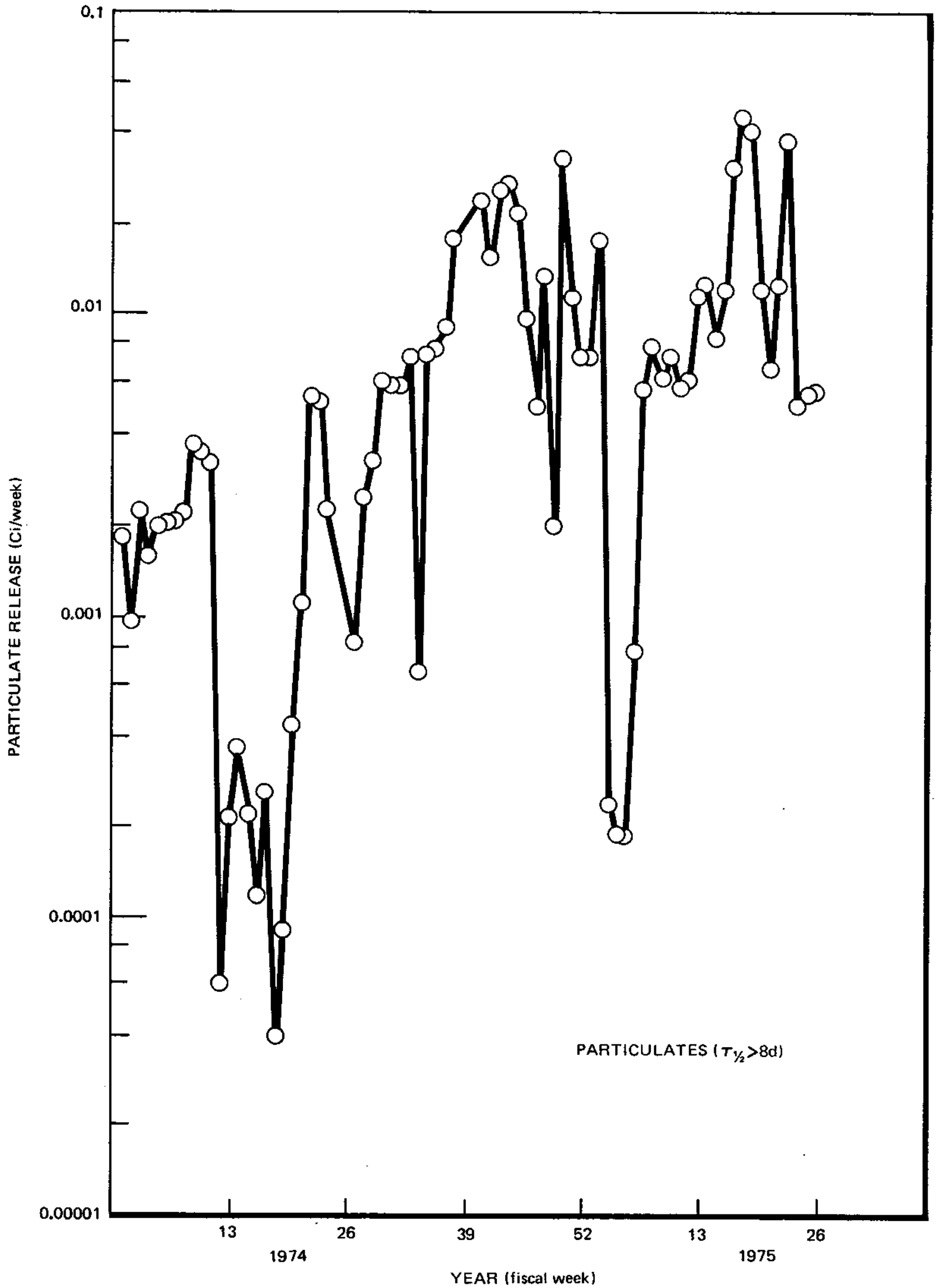

Figure 3-16. Monticello HVAC Airborne Particulate (Half-Lives > 8 Days) Releases, January 1974 through June 1975, Curies Per Week

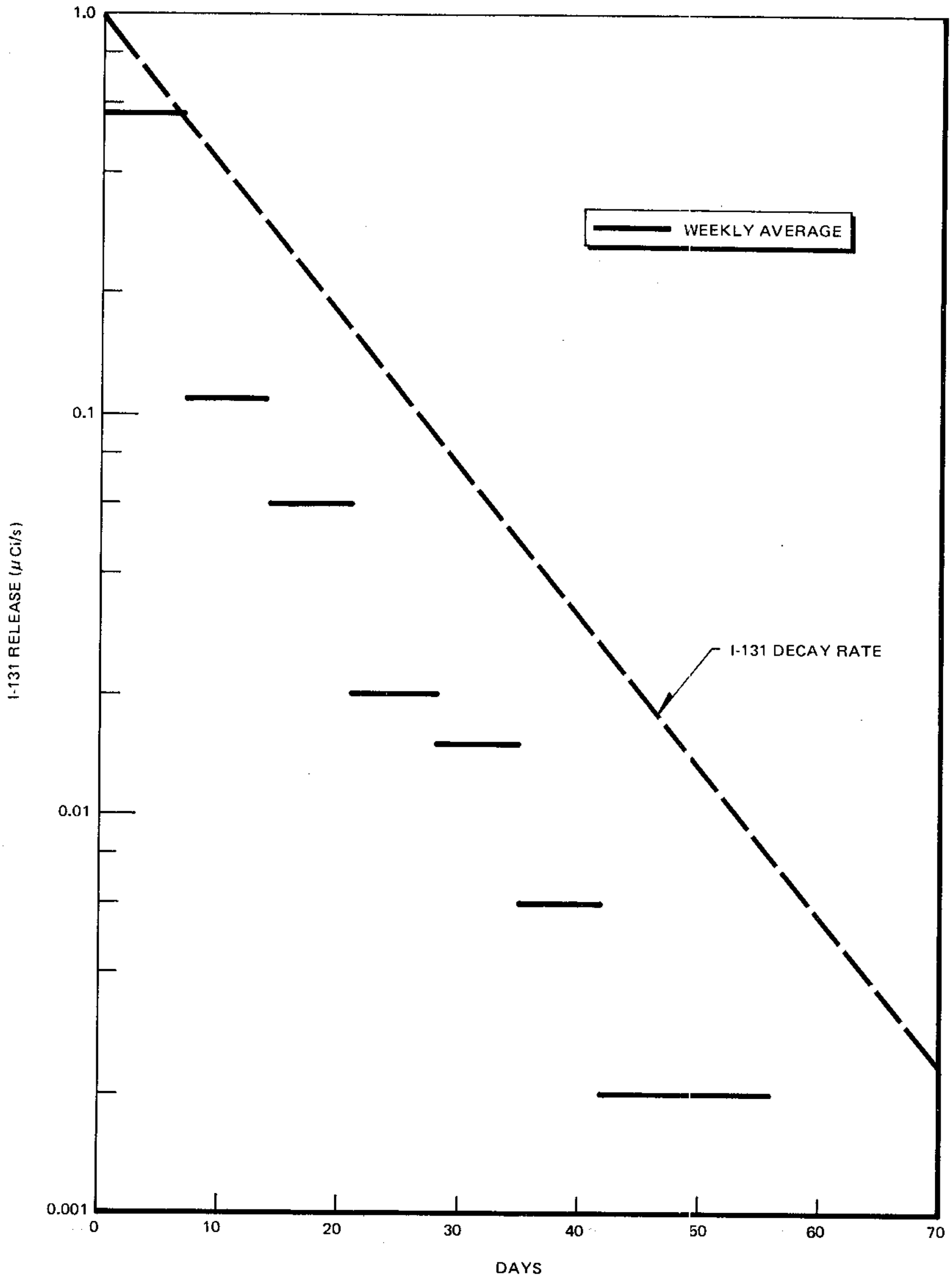

Figure 3-17. Stack Releases of I-131 at Oyster Creek Station During Refueling/Maintenance Outage, April 1975

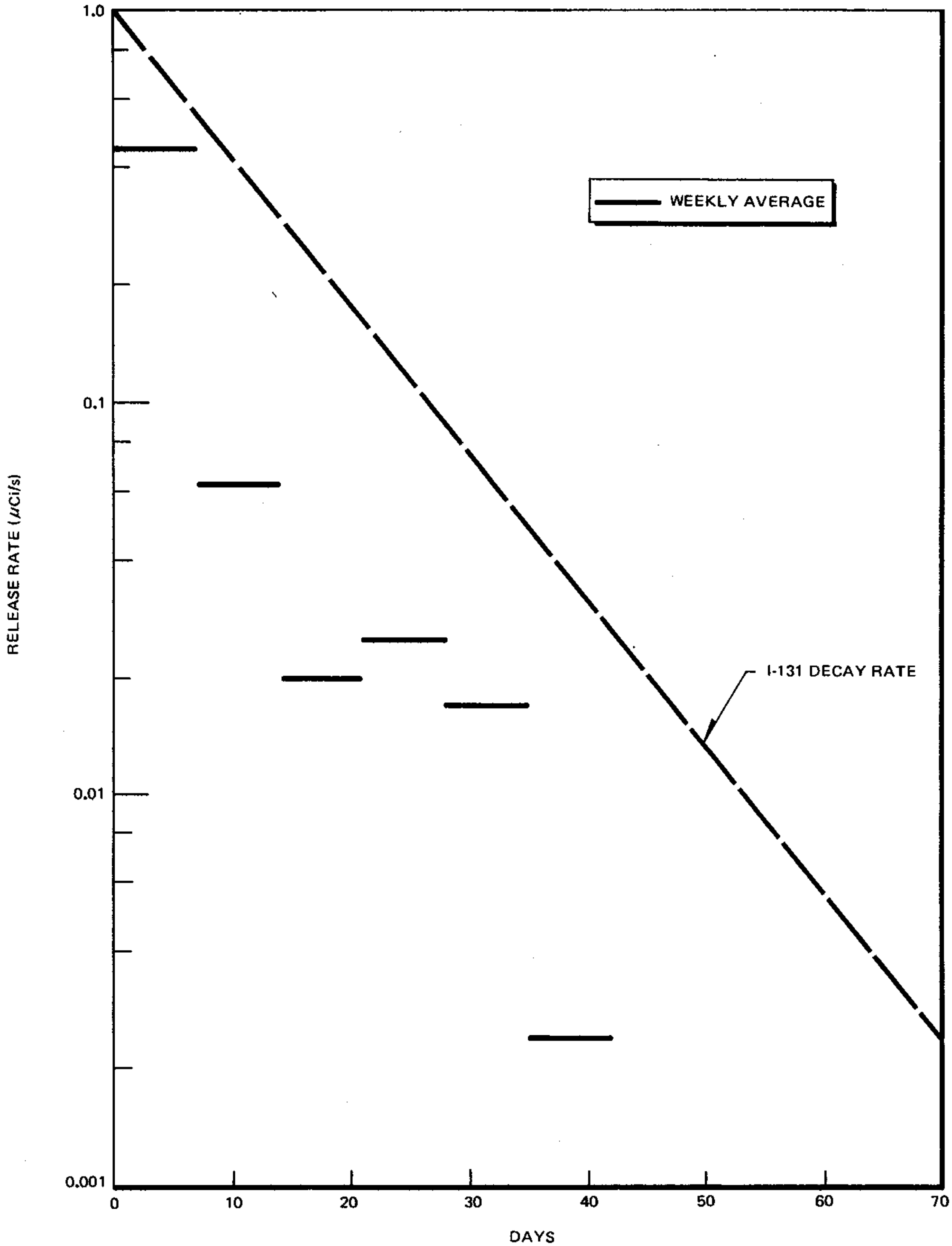

Figure 3-18. Stack Releases of I-131 at Monticello Station During Refueling/Maintenance Outage of January 1975

4. CHEMICAL FORM OF IODINE-131 RELEASES

The chemical form of radioiodine releases is an important factor in a realistic and proper environs dose evaluation. The specification of I-131 chemical form is in accord with Appendix I of 10CFR50 which requires realistic dose evaluations. From BWR operating plant experience, I-131 exists in several forms, both inorganic and organic. Organic iodine (methyl iodide) is not a significant contribution to the milk pathway dose. However, CH_3I would contribute to an inhalation dose. Methyl iodide is known to have a much smaller deposition velocity than elemental iodine, thus it does not readily deposit on vegetation which could be eaten by cows and converted to milk. The CH_3I remains in the atmosphere and could be breathed by people in the BWR environs. Inorganic iodine forms of interest are particulate, elemental (I_2), and hypoiodous acid (HOI). For ingestion dose evaluations, the amount of inorganic I-131 releases is needed. For the purposes of this report, inorganic iodine is considered the sum of the particulate, I_2, and HOI forms of I-131.

The importance of iodine chemical form in BWR releases has been recognized by the NRC. In 1972, the NRC (then AEC) contracted for measurements of BWR releases which included measurements of radio-iodine species. Similar species measurements with improved techniques were conducted in 1973. In addition to the NRC measurements, GE has independently conducted species measurements at a few BWR plants. The most extensive measurements of radio-iodine species have been recently completed by EPRI.

The chemical form, of I-131 varies significantly between BWR operating modes. The relative amounts of inorganic and organic iodine change from normal power generation periods to refueling maintenance outages. Furthermore, the I-131 species concentrations are different for each of the principal building ventilation sources and the gland seal/mechanical vacuum pump exhausts. The available measurements on I-131 species are listed in Tables 4-1, 4-2, 4-3 and 4-4 are for the reactor, turbine, radwaste, and gland seal/MVP exhausts, respectively.

Table 4-5 summarizes the chemical form data. These results were calculated from the arithmetic mean of the available data for each source, all plants were weighted equally. The data for normal power generation operations were treated separate from refueling/maintenance outages.

Table 4-1
SUMMARY OF MEASUREMENTS OF IODINE-131 CHEMICAL SPECIES IN BWR REACTOR BUILDINGS

Plant	Sample Date month/day/year	Operating Mode	Percent of Total Species: Particulate[a]	I_2	HOI	CH_3I	Measurements By
Vermont Yankee	1974	Normal	3.7	23.5	14.5	59.4	EPRI
	6/23/74	Normal	4	24	15	57	EPRI
	3/8/75	Normal	<1	50	50	<1	EPRI
	7/5/74	Shutdown	— 77.7 —		12.5	9.8	EPRI
	9/12/74	Normal	7	25	18	50	EPRI
	10/10/74	Normal	7	6	7	80	EPRI
	10/31/74	Refuel	2	16	59	23	EPRI
Dresden 2	1973	Normal	8	45	15	32	AEC
Dresden 3	1973	Normal	0	71	18	11	AEC
Monticello	1973	Normal	26	53	7	14	AEC
	11/18/74	Shutdown	24.8	47.6	11.8	15.8	EPRI
	11/74 & 1/75	Normal	— 79.5 —		11.7	8.8	EPRI
	1/8/75	Normal	22.6	56.4	12	9	EPRI
	1/75	Refuel	— 60.1 —		32.2	7.7	EPRI
	1/13/75	Refuel	0	68	14	18	EPRI
Oyster Creek	3/8/72	Normal	— 20 —		–	(80)[b]	AEC
	4/–/72	Refuel	— 7 —		–	(93)[b]	AEC
	2/22/75	Normal	49	17	<2	34	EPRI
Nine Mile Point 1	3/24/74	Normal	11	44	3	42	GE
	3/29/74	Normal	25	41	0	34	GE

[a] Contains both particulate and elemental iodine, I_2.

[b] By difference, assuming HOI is negligible.

Table 4-2
SUMMARY OF MEASUREMENTS OF IODINE-131 CHEMICAL SPECIES IN BWR TURBINE BUILDINGS

Plant	Sample Date month/day/year	Operating Mode	Percent of Total Release — Species: Particulate	I_2	HOI	CH_3I	Measurements By
Vermont Yankee	6/23/74	Normal	25	64	<1	11	EPRI
	7/5/74	Normal	— 89.5 —		0	10.5	EPRI
	9/12/74	Normal	17	61	18	14	EPRI
	10/10/74	Normal	34	57	9	<1	EPRI
	10/31/74	Refuel	2	10	57	31	EPRI
	3/8/75	Normal	50	50	<1	<1	EPRI
Monticello	11/74 & 1/75	Normal	— 80.4 —		11.6	8.0	EPRI
	11/18/74	Normal	15.6	55.4	12.8	16.2	EPRI
	1/8/75	Normal	10	72.4	10.2	7.4	EPRI
	1/75	Refuel	— 56.5 —		17.8	25.7	EPRI
	1/13/75	Refuel	0	60.4	17.2	22.4	EPRI
Oyster Creek	3/1972	Normal	— 40 —			(60)[a]	AEC
	4/1972	Refuel	— 2 —			(98)[a]	AEC
	2/22/75	Normal	27	47	19	7	EPRI
Nine Mile Point 1	3/24/75	Normal	13	49	2	9	GE

[a]Value by difference, assumes HOI is negligible.

Table 4-3
SUMMARY OF MEASUREMENTS OF IODINE-131 CHEMICAL SPECIES IN BWR RADWASTE BUILDINGS

Plant	Sample Date month/day/year	Operating Mode	Percent of Total Release Species				Measurements By
			Particulate	I_2	HOI	CH_3I	
Vermont Yankee	1974	Normal	— 14.4 —		10.6	75	EPRI
	6/23/74	Normal	2	15	11	74	EPRI
	7/5/74	Shutdown	— 13.9 —		11.1	75	EPRI
	9/12/74	Normal	2	12	9	79	EPRI
	9/26/74	Normal	0.5	8	9	82	EPRI
	10/10/74	Normal	0.9	16	5	78	EPRI
	10/31/74	Refuel	1	5	7	87	EPRI
	3/8/75	Normal	<1	<1	<1	<99	EPRI
Monticello	11/18/74	Shutdown	0.1	1.6	1.4	96.9	EPRI
	1/8/75	Normal	<1	<1	<1	100	EPRI
	1/13/75	Refuel	0.3	3.9	3.9	91.9	EPRI
Oyster Creek	3/1972	Normal	— 3 —		–	(97)[a]	AEC
	4/1972	Refuel	— 1 —		–	(99)[a]	AEC
	2/22/75	Normal	<2	20	30	50	EPRI
Nine Mile Point 1	3/24/74	Normal	9	56	1	34	GE

[a]By difference assumes HOI is negligible.

Table 4-4
SUMMARY OF MEASUREMENTS OF I-131 CHEMICAL SPECIES IN BWR GLAND SEAL STEAM/MECHANICAL VACUUM PUMP EXHAUSTS[a]

Plant	Sample Date month/day/year	Operating Mode	Particulate	I_2	HOI	CH_3I
			Species			
				Percent of Total Release		
Vermont Yankee	1974	Normal	6.4	0.4	0.8	89.4
	1974	Normal	3.6	1.0	3.9	91.5
	6/23/74	Normal	4	1	4	91
	7/5/74	Shutdown	—— 5.7 ——		2.4	91.8
	9/12/74	Normal	11	1	2	86
	10/10/74	Normal	2	3	3	92
	10/11/74	Refuel	0.3	0.1	0.1	99.5
	10/12/74	Refuel	0.2	0.2	0.2	99.4
	10/31/74	Refuel	<1	<1	<1	>99
	3/8/75	Normal	12	6	4	78
Monticello[b]	11/10/75	Refuel	0.4	0.9	1.8	96.6
	1/11/75	Refuel	0.8	2.8	6.9	89.5
	1/14/75[c]	Refuel	1.0	10.3	45.1	43.6

[a]All measurements by EPRI.

[b]May include SGTS or SJAE room, tank vents, and MVP.

[c]Heat-traced sampler, pump flow reduced to zero due to ice at 22 hours; value rejected here.

[d]The gland seal steam release occurs during normal operation and the mecahnical vacuum pump release occurs during shutdown and refueling/maintenance outages.

Table 4-5
SUMMARY OF I-131 CHEMICAL SPECIES DATA FOR BWR VENTILATION SOURCES

	Plant Operating Mode			
	Refueling		Normal	
	Percent of Total			
Source	CH_3I	Inorganic	CH_3I	Inorganic[a]
Gland Seal and MVP	97	3	89	11
Reactor Building	35	65	34	66
Turbine Building	52	48	12	88
Radwaste Building	93	7	79	21

[a]By difference, includes particulate I_2, and HOI.

5. IODINE-131 IN MILK

The purpose of this section is to present I-131 milk data as obtained from farms in the environs of BWR's. The I-131 concentration in milk will depend on the total plant release, stacks and vents, chemical form, and meteorological and topographical conditions. Other critical factors are the proximity of the farms to the BWR and the presence of cows on the farm.

The airborne I-131 releases from BWR plants can deposit on the vegetation of dairy farms located near the plants. The cow's milk will then contain some I-131. Subsequent consumption of the milk leads to a thyroid dose. Depending upon proximity of the cow relative to the plant, this dose pathway may be a critical item for the environmental impact evaluation of BWR's.

Iodine-131 milk data presently available are particularly important because the observations correspond to BWR's operating without the augmented off-gas treatment systems which are now incorporated into BWR plant designs. For this reason the I-131 milk levels should be much less for future plants than those data reported below for operating BWR's. The data relate release rate to milk concentration without assumptions about plant meteorology, deposition rates, transfer of iodine from grass to cow, etc.

The I-131 milk analyses are routinely obtained by utilities in accordance with regulatory requirements. The sensitivity of the milk analyses varies. By current techniques, the analyses are reliable to ±1/2 piocurie/liter. Tables 5-1, 5-2, and 5-3 list I-131 concentrations in milk near the Monticello plant and a few other BWR's. The data include results from one special NRC and Environmental Protection Agency study.

The available milk data are primarily from one plant, Monticello. The total plant annual release was over 1 curie, including the inorganic and CH_3I forms of I-131. Average I-131 concentrations in milk have been observed to be <1 picocurie/liter, at farms about 2.5 miles from the plant. Background levels of I-131 in milk are approximately 1/3 picocurie/liter.

Monticello has a modified off-gas system with recombiner units. This system was tested in 1974 and in semi-continuous operation since the first quarter of 1975. The ratio of stack and vent releases presented in Table 5-1 show a significant change between the second-half of 1974 and the first-half of 1975. In 1975 about 2/3 of the plant release was from the vent, indicating that the I-131 release via the stack was greatly reduced by the operation of the modified off-gas system.

An estimate of the dose due to the ingestion of milk containing I-131 is as follows. If an infant drank milk all year with an I-131 concentration of 2.4 picocuries/liter then the thyroid dose would be 15 mRem. The NRC dose objective is 15 mRem. The I-131 milk concentrations listed in Tables 5-1 and 5-2 correspond to doses very much less than this criterion.

Table 5-1
IODINE-131 CONCENTRATIONS IN MILK, IN ENVIRONS, OF MONTICELLO AND MILLSTONE PLANTS

			Farm											
			Dwinger (13.0 mi @ 335°)	Kirchenbauer (11.5 mi @ 323°)	Kotilinek (5.6 mi @ 230°)	Vandergon (8.3 mi @ 247°)	Holland (8.1 mi @ 199°)	Hopkins (7.6 mi @ 193°)	Becker (10 mi @ 130°)	Vetsch (9.4 mi @ 128°)	Nelson (2.4 mi @ 269°)	Olson (2.4 mi @ 24°)	Peterson (2.3 mi @ 111°)	Shovelain (3.0 mi @ 250°)
Plant	**Date**	**I-131 Release (Curies)**	**I-131 Concentrations in Milk, pico curie/liter**											
Monticello	July-Dec '74	Stack – 3.0 Vent – 0.76	0.35 ± 0.07	0.47 ± 0.12	0.53 ± 0.07	0.34 ± 0.08	0.40 ± 0.10	0.16 ± 0.11	0.13 ± 0.09	0.18 ± 0.09	Not Measured			
	Jan-June '75	Stack – 0.62 Vent – 0.91	<0.24	<0.27	<0.28	<0.31	<0.20	<0.21	<0.22	<0.18	0.35 ± 0.06	0.28 ± 0.05	0.42 ± 0.07	0.42 ± 0.05
			See additional details in Table 5-2											
Millstone	Jan-June '74	Stack–0.291	<0.5, no detectable activity from cow's milk at 4 locations											
			<0.5, no detectable activity from goat's milk at 2 locations											
	July-Dec '74	Stack – 2.89	<0.5, no detectable activity from cow's milk at 4 locations											
			<0.5, no detectable activity from goat's milk at 2 locations											

Table 5-2a
IODINE-131 CONCENTRATIONS IN MILK AT FARMS ABOUT 2.5 MILES FROM MONTICELLO PLANT

Date month/day/year	Farm Peterson (2.3 mi @ 111°)	Nelson (2.4 mi @ 267°)	Shovelain (3.0 mi @ 250°)	Olson (2.5 mi @ 24°)	Total Plant Release (curies/month)[a]
	I-131 Concentration (pico Ci/liter)				
2/11/75	<0.18	<0.17	<0.21	<0.23	0.427/Jan 0.047/Feb
3/11/75	<0.19	<0.13	<0.18	<0.16	0.115/Mar
4/9/75	<0.20	<0.24	<0.23	<0.20	0.188/Apr
5/13/75	<0.18	<0.58	1.6 ± 0.2	<0.23 ± 0.17	0.462/May
6/3/75	1.2 ± 0.3	0.80 ± 0.23	0.31 ± 0.18	0.37 ± 0.25	
6/10/75	1.1 ± 0.4	<0.27	<0.30	<0.29	
6/17/75	0.17 ± 0.11	0.20 ± 0.19	<0.20	0.75 ± 0.11	
6/25/75	0.57 ± 0.10	1.1 ± 0.2	0.93 ± 0.21	0.42 ± 0.10	0.291/Jun

[a]See Table 5-2b for additional details on station releases from tall-stack and vent.

[b]Grazing season extends from 5/30 to 10/15.

Table 5-2b
IODINE-131 RELEASES FROM MONTICELLO DURING FIRST HALF OF 1975

	I-131 Rate (μCi/s)	
Week Ending	**Vent**	**Tall Stack**
1/6	0.025	0.012
1/13	0.026	0.45
1/20	0.067	0.063
1/27	0.026	0.020
2/3	0.0073	0.025
2/10	0.0039	0.017
2/17	0.0075	0.0024
2/24	0.014	0.0033
3/3	0.023	0.0069
3/10	0.0081	0.0015
3/17	0.048	0.015
3/24	0.039	0.0094
3/31	0.044	0.0084
4/7	0.050	0.0097
4/14	0.052	0.0089
4/21	0.062	0.0086
4/28	0.083	0.011
5/5	0.078	0.0051
5/12	0.17	0.011
5/19	0.15	0.16
5/26	0.090	0.012
6/2	0.093	0.059
6/9	0.071	0.025
6/16	0.069	0.018
6/23	0.098	0.029
6/30	0.10	0.025

Table 5-3
IODINE-131 CONCENTRATIONS IN MILK, SPECIAL STUDY BY NRC/EPA (NUREG 75/021, MARCH 1975)

Dresden Pasture (1.3 km (0.8 miles) West of Stacks)

Date 1973	pCi/liter
May 1 to 28	<0.1
29	0.17
30	0.13
31	0.26
June 1	<0.1
2	0.17
3 to 29	<0.1
30	0.27 ± 0.08
July 1	<0.2
2 to 5	<0.1

Note: Release rates for Dresden station are shown in Figure 3-20.

(Monticello Pasture (2.7 km (1.7 miles) NW of Stack)

June 12 to 18	<0.1
19	0.21 ± 0.05
20	<0.1
21	0.17
22 to 25	<0.1
26	0.24
27 & 28	0.26
29	<0.2
30	0.31 ± 0.05
July 1	<0.2
2	0.32 ± 0.05
3	0.23 ± 0.05
4	<0.2
5	<0.1

Note: Release rates for Monticello station are shown in Figure 3-19.

6. CORRELATION OF IODINE-131 RELEASES WITH ITS CONCENTRATION IN REACTOR WATER

A relationship between the turbine building I-131 vent rate and coolant concentration was observed earlier (R. S. Gilbert, July 1973, "Release Rate of Halogen Activity To Ventilation Exhaust. A Review of Data From Operating Plants," General Electric Company, NEDM-12286, Rev. A, p. 3). This observation was based on limited data from the KRB (Germany), Nine Mile Point 1, and Dresden 2 plants. The reported ratios of turbine building vent rate to coolant concentrations (μCi/s divided by μCi/cc = cc/s) were as follows: Nine Mile Point 1, 0.94; Dresden 2, 1.3; and KRB 0.04 to 1.1, 0.24 average. The ratio for KRB was noted to increase with time during each fuel cycle. This early study concluded that the release rate to concentration ratio is about 0.5 cc/s.

Release rate to coolant concentration ratios for I-131 are summarized in Table 6-1. The results are based on data reported by EPRI, which is presented later, and include observations only during BWR normal operating periods. During refueling/maintenance outages the ratios appear to have different characteristics. The vent rate to concentration ratios listed in Table 6-1 are consistent with other information about the plants. At Oyster Creek the turbine building is the principal source of I-131 release via the stacks. At Monticello, the reactor building release has been high due to excessive leakage from the reactor water cleanup pump seals. For both these buildings, the calculated ratios are $\geq$1, whereas all the other buildings have smaller ratios. The high ratio for the Oyster Creek turbine building is in agreement with observations at Nine Mile Point 1 by GE personnel. The ratios at Nine Mile Point 1 were 0.9 and 3 during tests conducted during 1971 and 1974, respectively.

The Nine Mile Point 1 and Oyster Creek stations are the only BWR's in operation that have moisture separator/reheaters with air driers during shutdowns. This feature has been identified as a major leakage source at Nine Mile Point 1. The radwaste building has the smallest average ratio of all buildings. Vermont Yankee, a BWR/4 station has leakage ratios less than for the other stations.

The I-131 releases and coolant concentrations were correlated in the following manner. The available data for each building of a plant were plotted on log-log paper. The graphs indicate that an increase in coolant concentration results in an increase in vent rate. Mathematically, the relationship is of the form $\log y \cong s \log x$, where y is the vent rate (μCi/s), x is the coolant concentration (μCi/cc), and s is the slope of the line. By means of a correlation the I-131 vent release data from the various BWR's could be normalized to one concentration.

The available data on I-131 coolant concentration are submittals to GE under fuel warranty provisions, and results reported by EPRI, NRC and GE measurements. In this report the concentration data obtained under fuel warranty provisions designate the BWR's by letter, only. The GE measurements were listed in Table 3-29. The NRC data are listed in Table 6-2.

The data are from BWR/2, 3, and 4 plants. Iodine-131 coolant concentrations are divided into two categories according to type of fuel in the BWR, improved and unimproved (see Reference at end of chapter), as follows:

BWR Plant	No. of Samples	I-131 Coolant Concentrations (μCi/ml) Median	Range low/high	Burnup (GWd/t)
Improved Fuel				
A	32	$1.0x10^{-5}$	$4.3x10^{-6}/7.8x10^{-5}$	2 to 6.6
B	23	$3.0x10^{-5}$	$2.9x10^{-6}/1.8x10^{-4}$	0.8 to 3.2
C	41	$1.8x10^{-6}$	$3.4x10^{-7}/5.4x10^{-6}$	0.7 to 5.7
D	25	$1.7x10^{-6}$	$1.1x10^{-6}/4.7x10^{-6}$	1.5 to 4.4
E	37	$8x10^{-4}$	$4x10^{-4}/1.1x10^{-3}$	0.3 to 5.0

Unimproved Fuel

	Operating Period	Mean	Range (low/high)	Fuel Cycle
F	6/75 to 10/75	2.4 E-3	1.6 E-3/3.4 E-3	4th
G	7/73 to 4/75	3.3 E-3	2/3 E-4/7.0 E-3	2nd & 3rd
H	8/72 to 12/73	2.2E-3[a]	See Figure 6-1	1st
H	7/74 to 6/75	0.7E-3[a]	See Figure 6-2	2nd
I	11/72 to 12/73	0.6E-3[a]	See Figure 6-3	1st
J	1/75 to 4/75	7.2E-3	See Figure 6-4	4th & 5th
J	5/75 to 8/75	1.9E-3		
K	11/74 to 1/75	1.0E-1	See Figure 6-5	3rd & 4th
K	2/75 to 7/75	9.9E-2		
L	8/74 to 6/75	1.0E-2	See Figure 6-6	2nd

Note: From Figures 6-4 to 6-6, the I-131 has a log-normal distribution. The median is different from arithmetic means, quoted above. These differences are not significant for the purposes of this report.

[a]Median values from log-normal distributions, see Figures 6-1 through 6-3.

Additional I-131 coolant concentrations as reported in the EPRI data compilations are presented in Tables 6-3, 6-4, and 6-5 for the Oyster Creek, Monticello, and Vermont Yankee stations. Figures 6-7, and 6-8 are the probability distributions for data from the Oyster Creek and Monticello plants. Insufficient data was available from Vermont Yankee to generate a probability distribution.

The I-131 coolant concentrations summarized here indicate that there is a significant difference between plants with unimproved fuel bundles and those with improved fuel. The older types of fuel have more fission product leakage that results in plants with higher coolant concentrations of I-131. These plants have average concentrations of 0.002 to 0.1 μCi/ml, whereas the plants with improved 7x7 bundles have average concentrations of the order of 2×10^{-6} to 3×10^{-5} μCi/ml during the first fuel cycle with burnups less than 7 GWd/t. It is expected that at the end-of-cycle (EOC) the amount of fission product leakage will increase from old 7x7 fuel bundles to the coolant. Current experience with improved fuels indicates *no* increase in I-131 coolant concentrations with average core burnups up to 8 GWd/t.

Current design for BWR's changes the flow distribution through the balance-of-plant components outside the reactor vessel. Operating stations have a once-through distribution. The new plants will have a "pumped forward" flow pattern. This feature will return more I-131 to the reactor vessel and less will enter the condenser. Most of the I-131 will be carried back to the reactor vessel via condensation processes in the moisture separator (between the high-pressure and low-pressure shells of the turbine). The new effect on I-131 coolant concentrations is an increase by a factor of less than 2.

Thus, on these bases it appears reasonable to conclude that the typical I-131 reactor water concentrations will be about 1×10^{-3} μCi/ml for current plants with unimproved fuel, and the plants with new fuel should have lower concentrations. This result is less than the value of 5×10^{-3} μCi/ml assigned by the American Nuclear Society Standard, N237, "Radioactive Materials in Principal Fluid Streams of Light-Water-Cooled Nuclear Power Plants," July 1975 (Draft).

Figures 6-9 through 6-14 present building ventilation releases as a function of I-131 coolant concentration for Oyster Creek and Monticello. A strong relationship is apparent for the reactor and radwaste buildings, but not so evident for the turbine building.

Figure 6-15 shows the total plant release (reactor + turbine + radwaste buildings) for the Monticello and Pilgrim 1 stations. The I-131 reactor water concentration range was from 3.0 E-4 to 2 E-1, almost three decades. Data were plotted on a log-log basis and a least square correlation generated. The correlation is $y = 0.93x - 0.22$, where y is $\log_{10}$ (vent rate μCi/s) and x is the $\log_{10}$ (concentration μCi/ml). The data for the two plants were consistent with each other. At I-131 reactor water concentrations of 0.0001, 0.01 and 0.1 μCi/cc the total vent releases were approximately 0.001, 0.008, and 0.07 μCi/s, respectively.

REFERENCE

General Electric Company, January 1975, "General Description of a Boiling Water Reactor," Chapters 1 and 3, Nuclear Energy Division, San Jose, California.

Table 6-1
SUMMARY OF I-131 VENT RELEASE RATE TO CONCENTRATION RATIOS FOR THREE BWR's (EPRI REPORTED DATA)

Plant	Building		
	Reactor	Turbine	Radwaste
		Ratio,[a] cc/s	
Oyster Creek	0.3	4	0.1
Monticello	1	0.5	0.03
Vermont Yankee	0.1	0.04	0.04

[a]Ratio equals I-131 vent rate, μCi/s, divided by I-131 coolant concentration, μCi/cc, at about same date or period.

Table 6-2
REACTOR WATER I-131 CONCENTRATIONS AT SEVEN BWR's (AEC MEASUREMENTS)

Plant	Concentration (μCi/ml)	Date
Oyster Creek	3.90 E-3	1972
Millstone Point	5.77 E-3	1972
Monticello	3.45 E-2	1972
Dresden 2	6.20 E-4	1972
Dresden 3	4.14 E-3	1972
Quad Cities 1	2.1 E-3	3/12/73
Quad Cities 2	7.1 E-5	3/13/73

Table 6-3
REACTOR WATER I-131 CONCENTRATIONS AT OYSTER CREEK PLANT, AS REPORTED IN EPRI DATA COMPILATIONS DURING 1975

Period Month/Day	Concentration (μCi/liter)	Period Month/Day	Concentration (μCi/liter)
1/1–1/7	2.3	5/21–5/27	0.64
1/8–1/14	5.0	5/28–6/3	1.4
1/15–1/21	4.3	6/4–6/10	1.7
1/22–1/28	4.1	6/11–6/17	1.8
1/29–2/4	3.8	6/18–6/24	4.1
2/5–2/11	4.2	6/25–7/1	2.0
2/12–2/18	4.7	7/2–7/8	1.7
2/19–2/25	4.8	7/9–7/15	1.7
2/26–3/4	6.7	7/16–7/22	1.7
3/5–3/11	6.2	7/23–7/29	1.8
3/12–3/18	7.2	7/30–8/5	1.8
3/19–3/25	6.2	8/6–8/12	1.5
3/26–4/1	37.	8/13–8/19	1.7
4/2–4/8	3.9		
4/9–4/15	0.7		
4/16–4/22	0.44		
4/23–4/29	0.053		
4/30–5/6	0.016		
5/7–5/13	0.020		
5/14–5/20	0.022		

Table 6-4
REACTOR WATER CONCENTRATIONS OF I-131[a] AT MONTICELLO STATION, NOVEMBER, 1974 TO AUGUST, 1975

Date	Concentration (μCi/gm)	Date	Concentration (μCi/gm)
1974		3/3	0.029
11/4	0.058	3/13	0.046
11/7	0.048	3/17	0.025
11/9	0.53	3/20	0.027
11/10	0.56	3/24	0.046
11/11	0.25	3/25	0.026
11/12	0.17	3/27	0.051
11/14	0.12	3/31	0.029
11/22	0.056	4/3	0.049
11/25	0.057	4/7	0.039
11/28	0.095	4/10	0.047
12/2	0.076	4/14	0.039
12/5	0.077	4/17	0.066
12/12	0.084	4/21	0.069
12/16	0.089	4/24	0.052
12/19	0.064	4/28	0.057
12/23	0.069	5/1	0.057
12/26	0.061	5/5	0.10
12/30	0.075	5/8	0.062
		5/12	0.057
1975		5/15	0.068
		5/18	0.21
1/2	0.070	5/19	0.11
1/6	0.056	5/20	0.062
1/9	0.054	5/26	0.053
1/13	0.042	5/29	0.49
1/15	0.0051	5/30	0.17
1/16	0.0042	6/2	0.12
1/17	0.0033	6/5	0.14
2/5	0.00057	6/9	0.11
2/6	0.0012	6/12	0.15
2/7	0.0040	6/16	0.10
2/10	0.010	6/19	0.18
2/11	0.0091	6/23	0.18
2/12	0.015	6/24	0.12
2/13	0.013	6/26	0.14
2/17	0.0096	7/3	0.12
2/20	0.0061	7/7	0.18
2/24	0.016	7/10	0.14
2/27	0.073	7/14	0.24

[a]Data supplied by plant personnel, as reported in EPRI compilation.

Table 6-5
REACTOR WATER I-131 CONCENTRATIONS AT VERMONT YANKEE PLANT
(AS REPORTED IN EPRI DATA COMPILATIONS)

Date month/day/year	Concentration (μCi/ml)
6/18/74	0.025
9/11/74	0.0378
10/11/74	0.0336
3/7/75	0.00081
5/29/75	0.00074

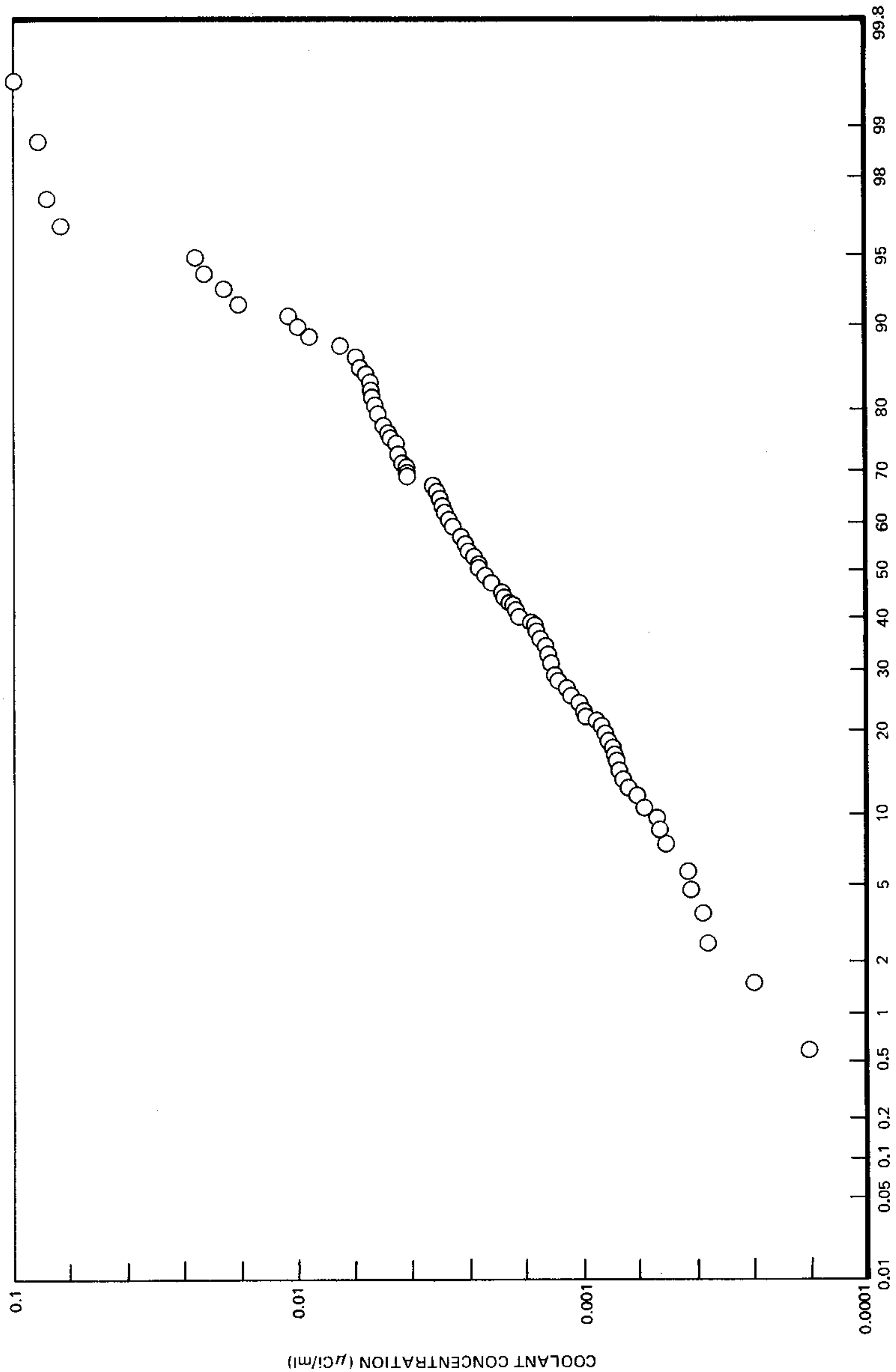

Figure 6-1. Probability Distribution of I-131 Reactor Water Concentration, Plant H, First Fuel Cycle

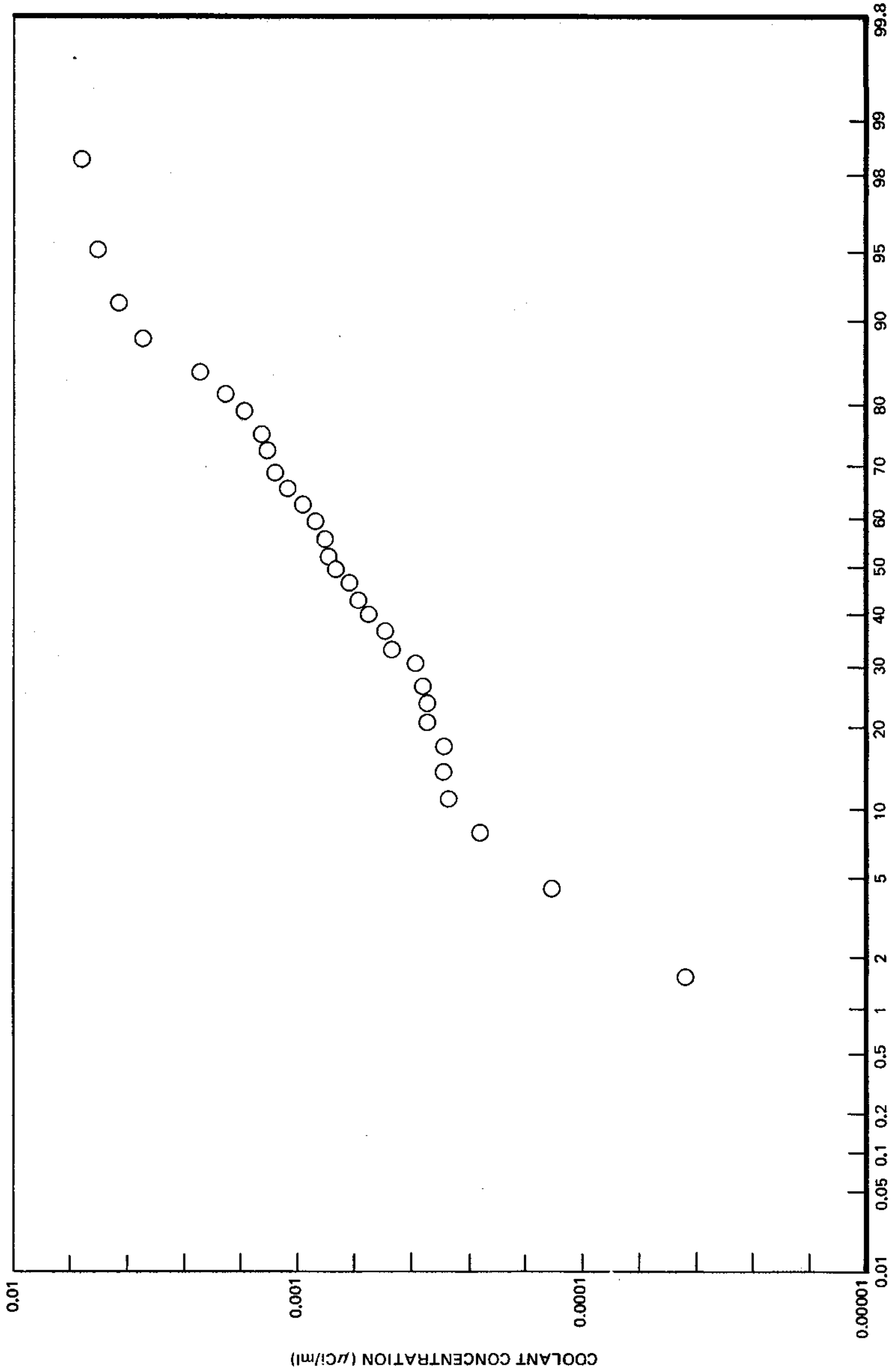

Figure 6-2. Probability Distribution of I-131 Reactor Water Concentration, Plant H, Second Fuel Cycle

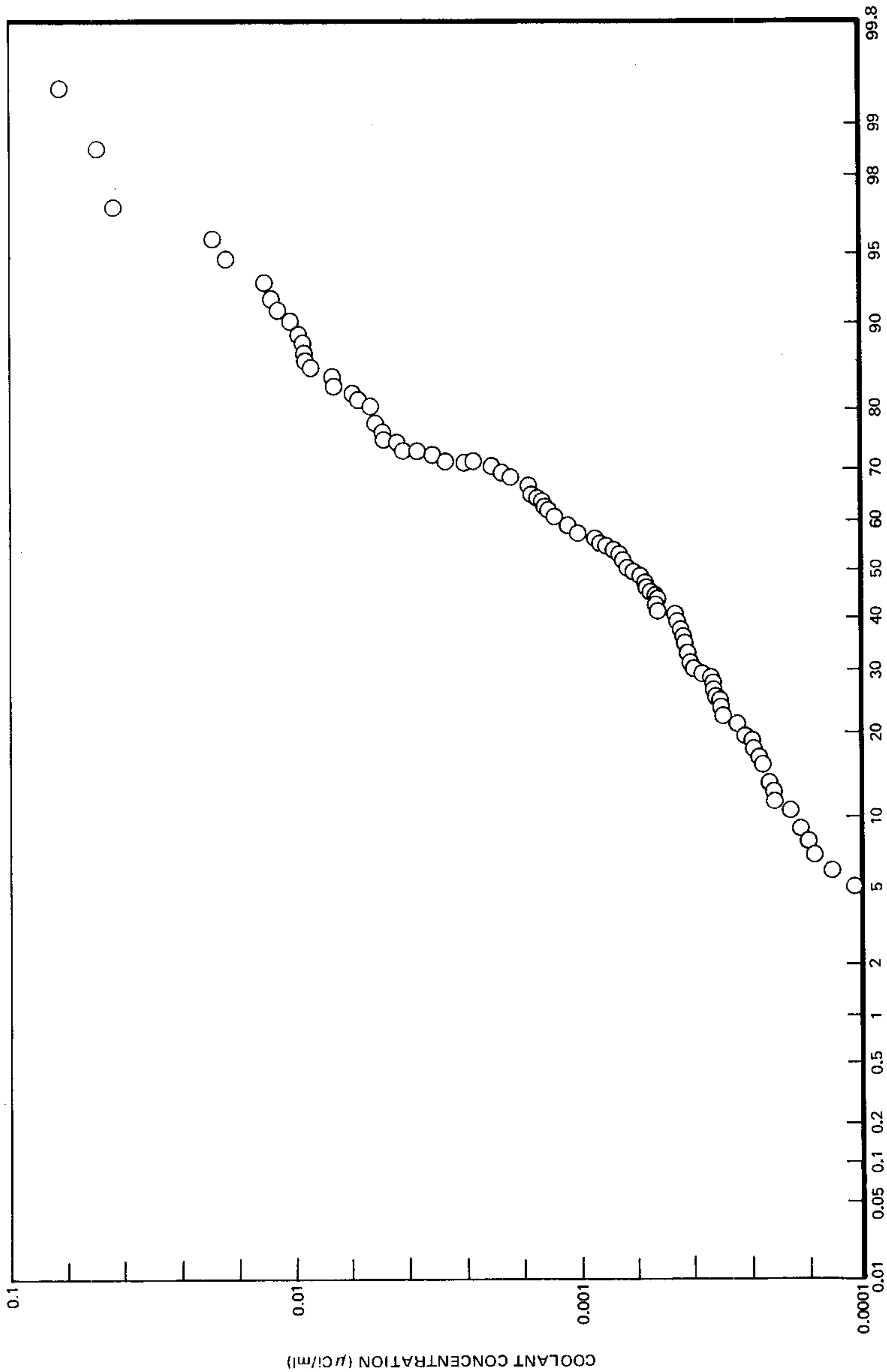

Figure 6-3. Probability Distribution of I-131 Reactor Water Concentration, Plant I, First and Second Fuel Cycles

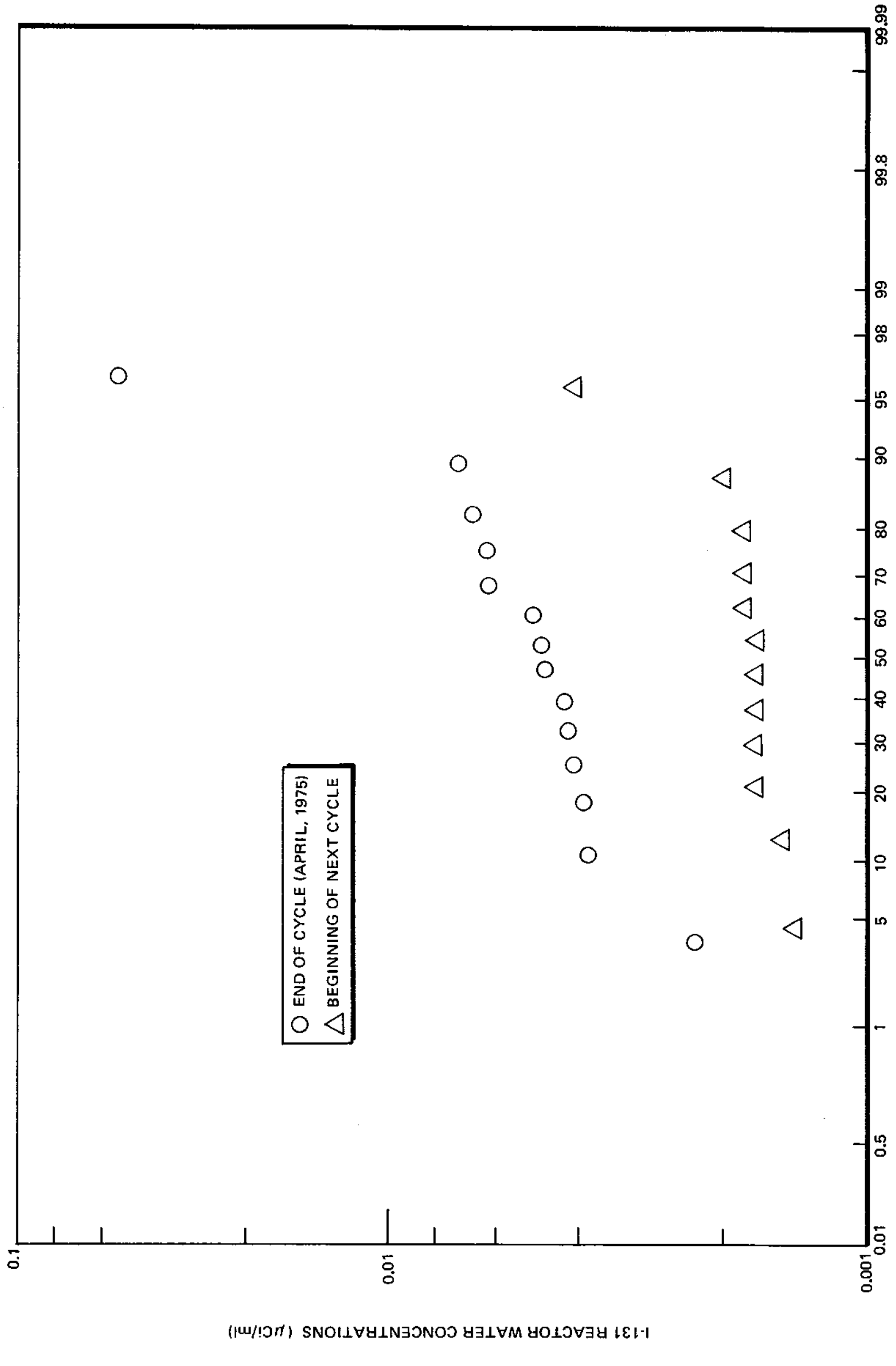

Figure 6-4. Probability Distribution of I-131 Reactor Water Concentration, Plant J, Fourth and Fifth Fuel Cycles

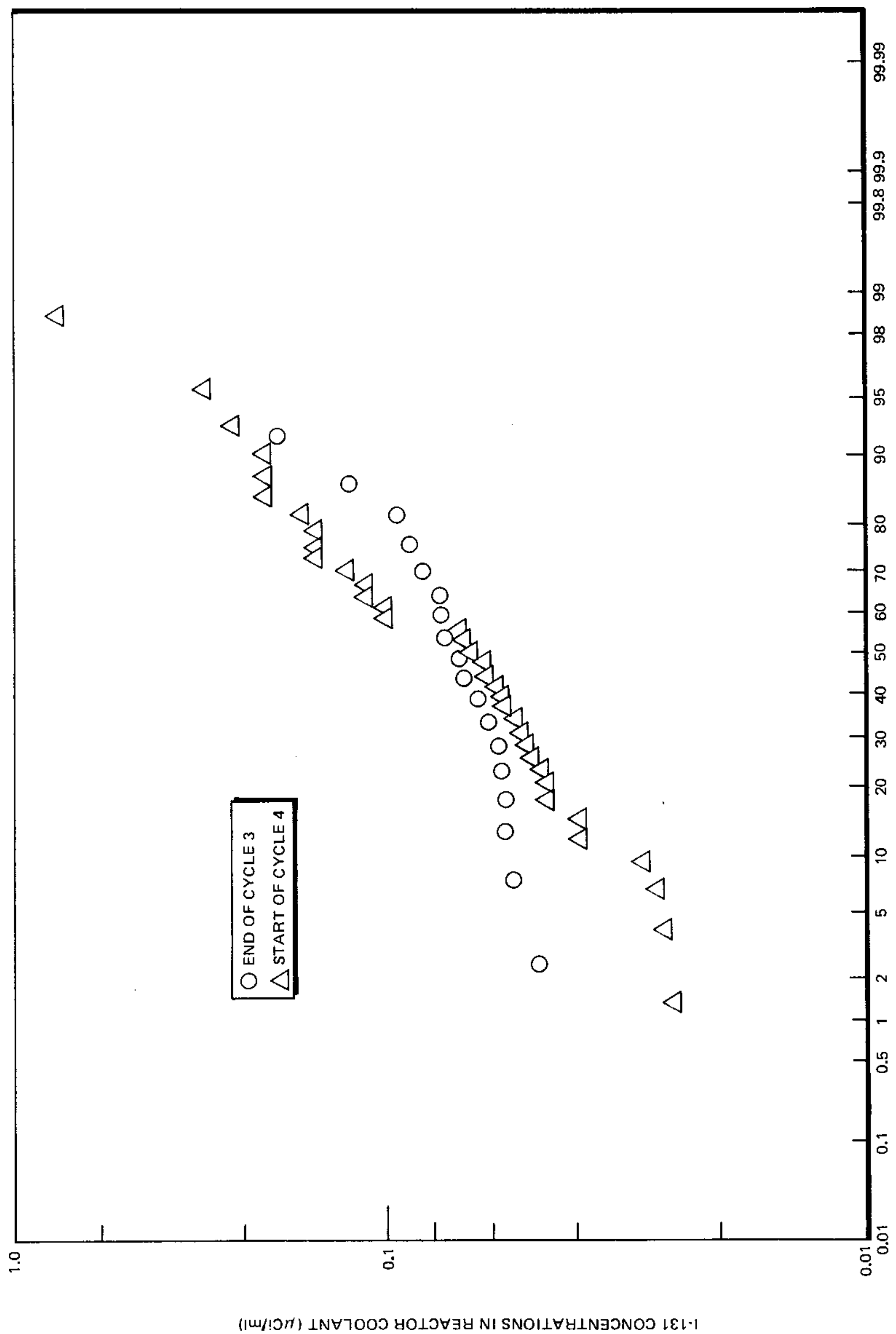

Figure 6-5. Probability Distribution of I-131 Reactor Water Concentration, Plant K, Third and Fourth Fuel Cycle

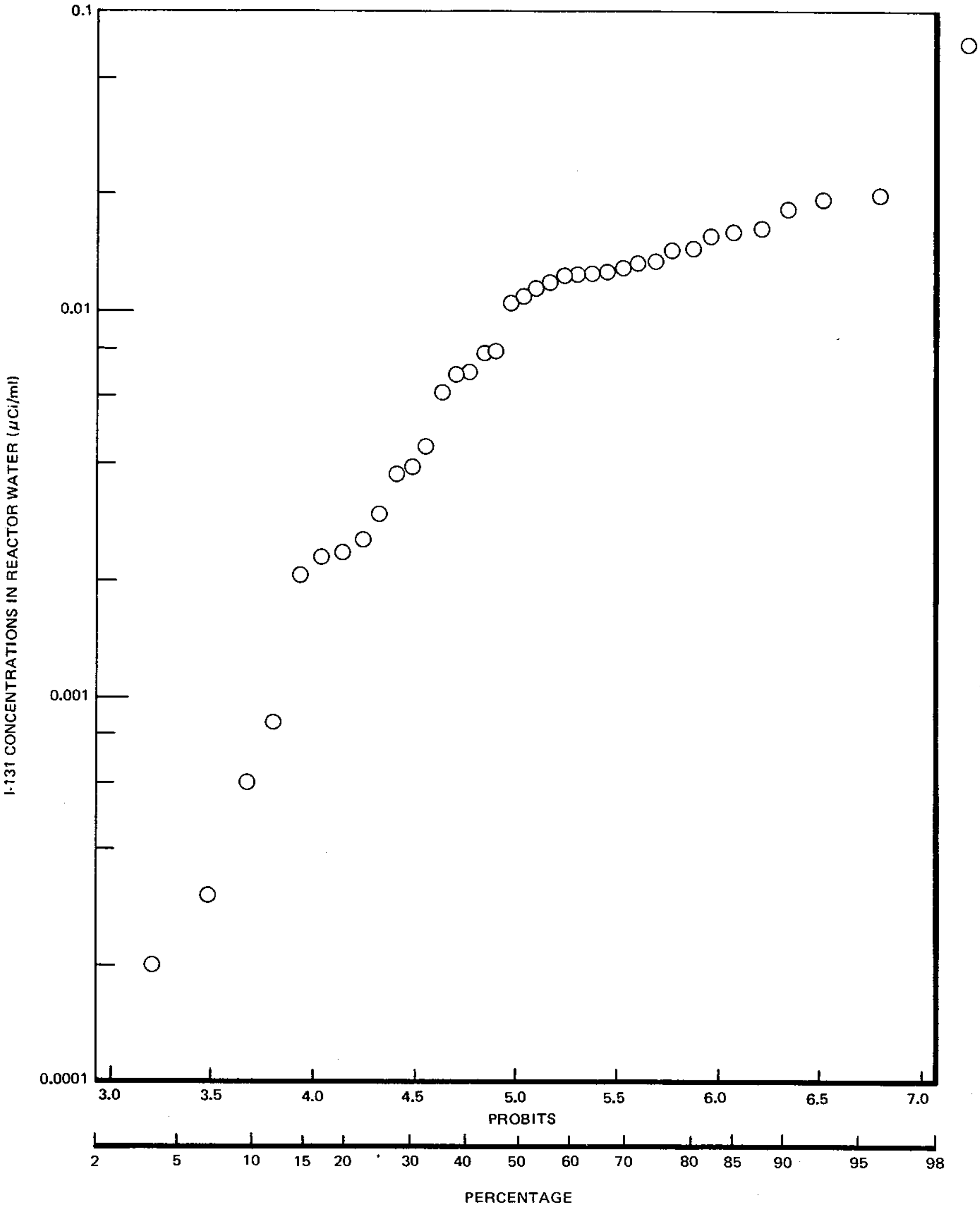

Figure 6-6. Probability Distribution of I-131 Reactor Water Concentration, Plant L, Second Fuel Cycle

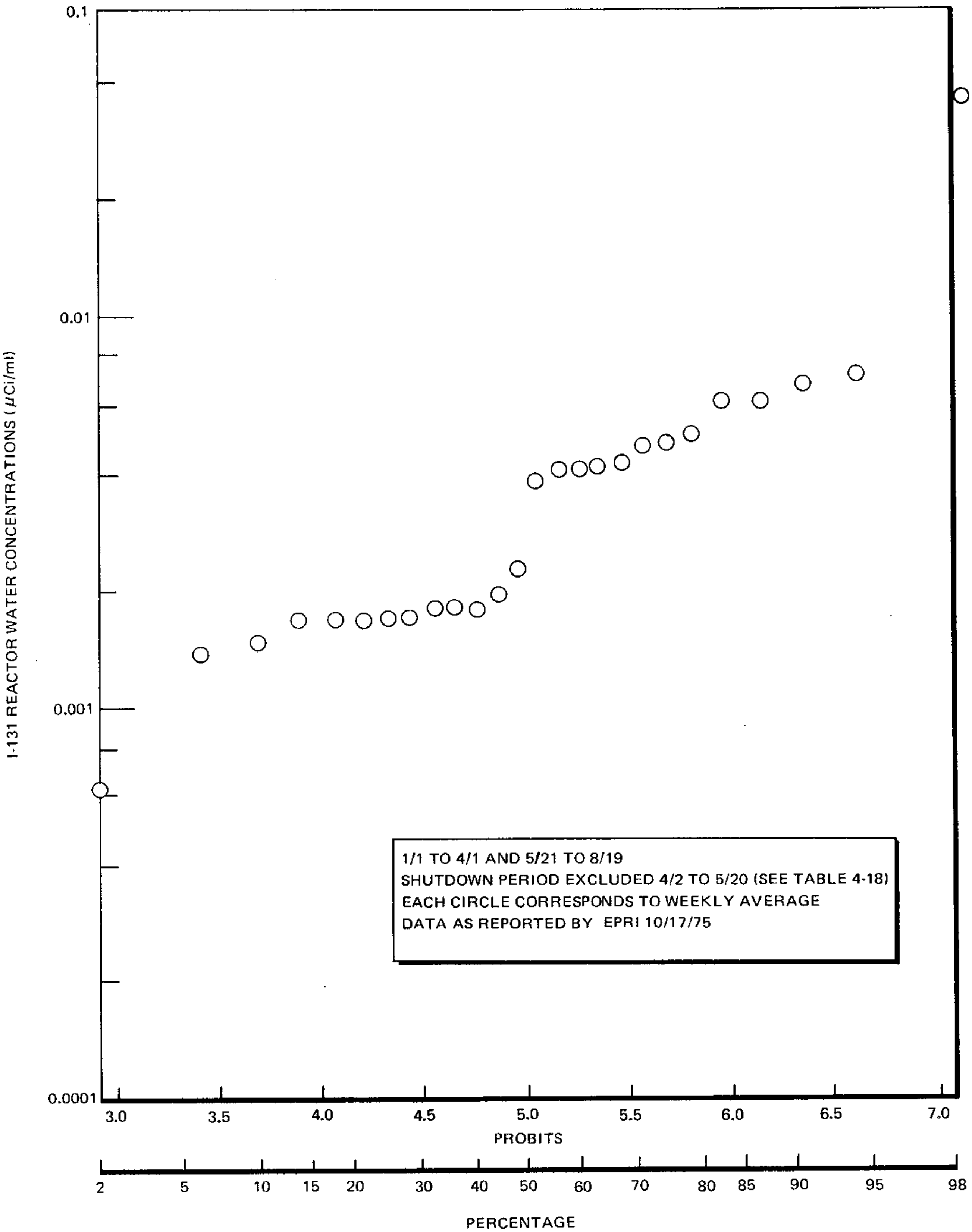

Figure 6-7. Probability Distribution of I-131 Concentrations in Reactor Water at Oyster Creek during 1975 (Data Reported in EPRI Compilations)

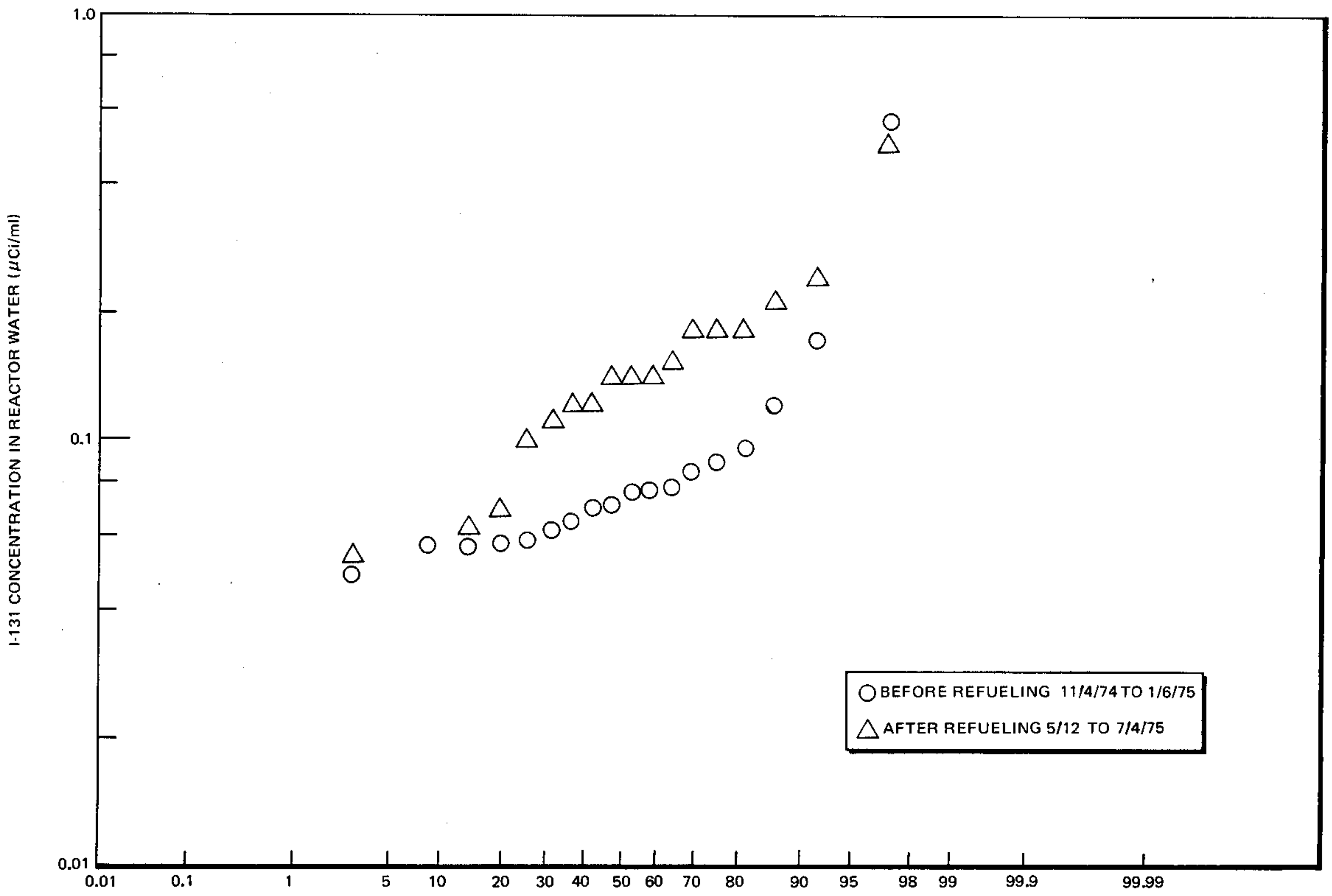

Figure 6-8. Probability Distribution of I-131 Concentrations in Reactor Water at Monticello from November 14, 1974 to January 6, 1975 and May 12 to July 4, 1975 (Data Reported in EPRI Compilations)

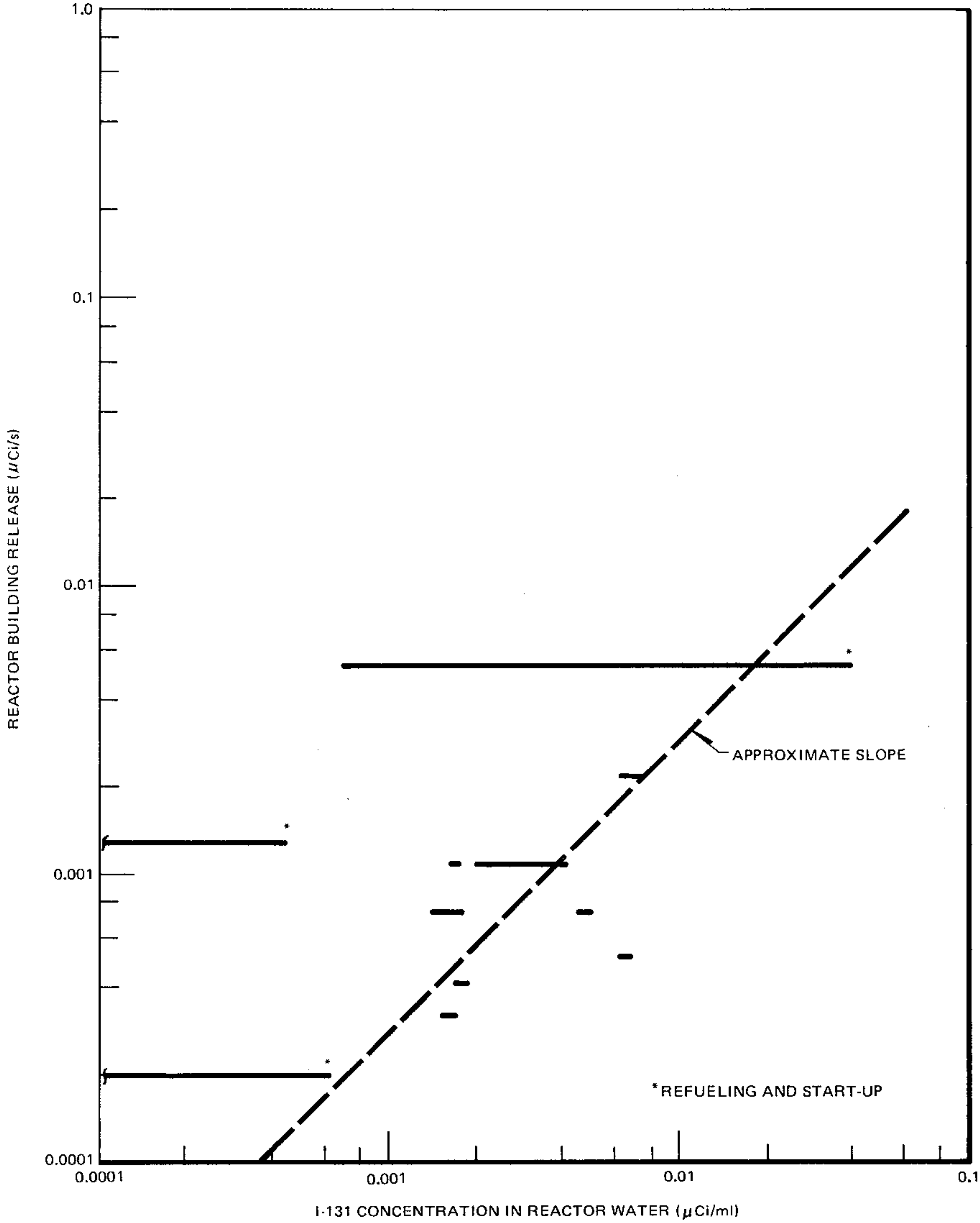

Figure 6-9. Reactor Building I-131 Vent Release Versus I-131 Reactor Water Concentration, Oyster Creek

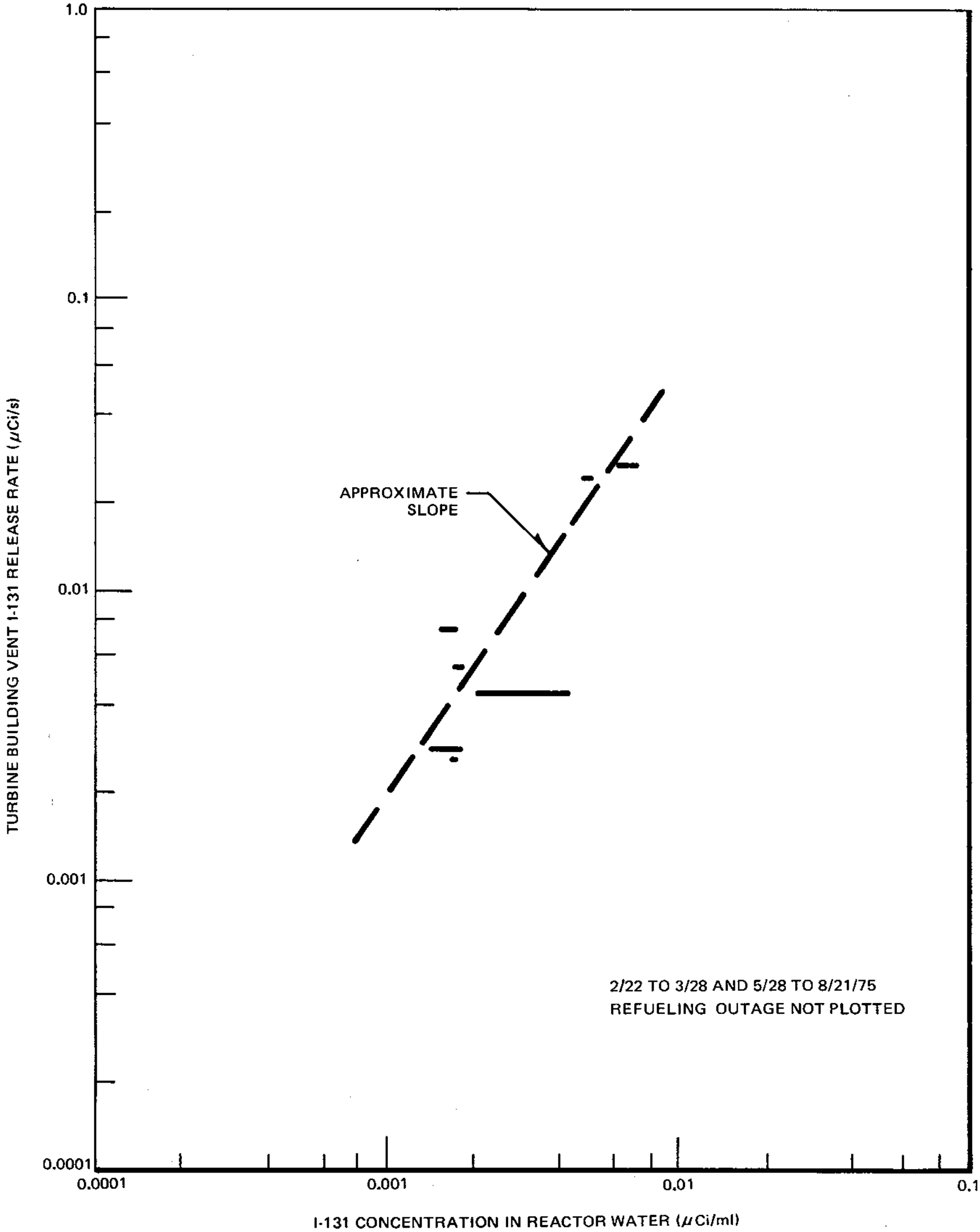

Figure 6-10. Turbine Building I-131 Vent Release Versus I-131 Reactor Water Concentration, Oyster Creek

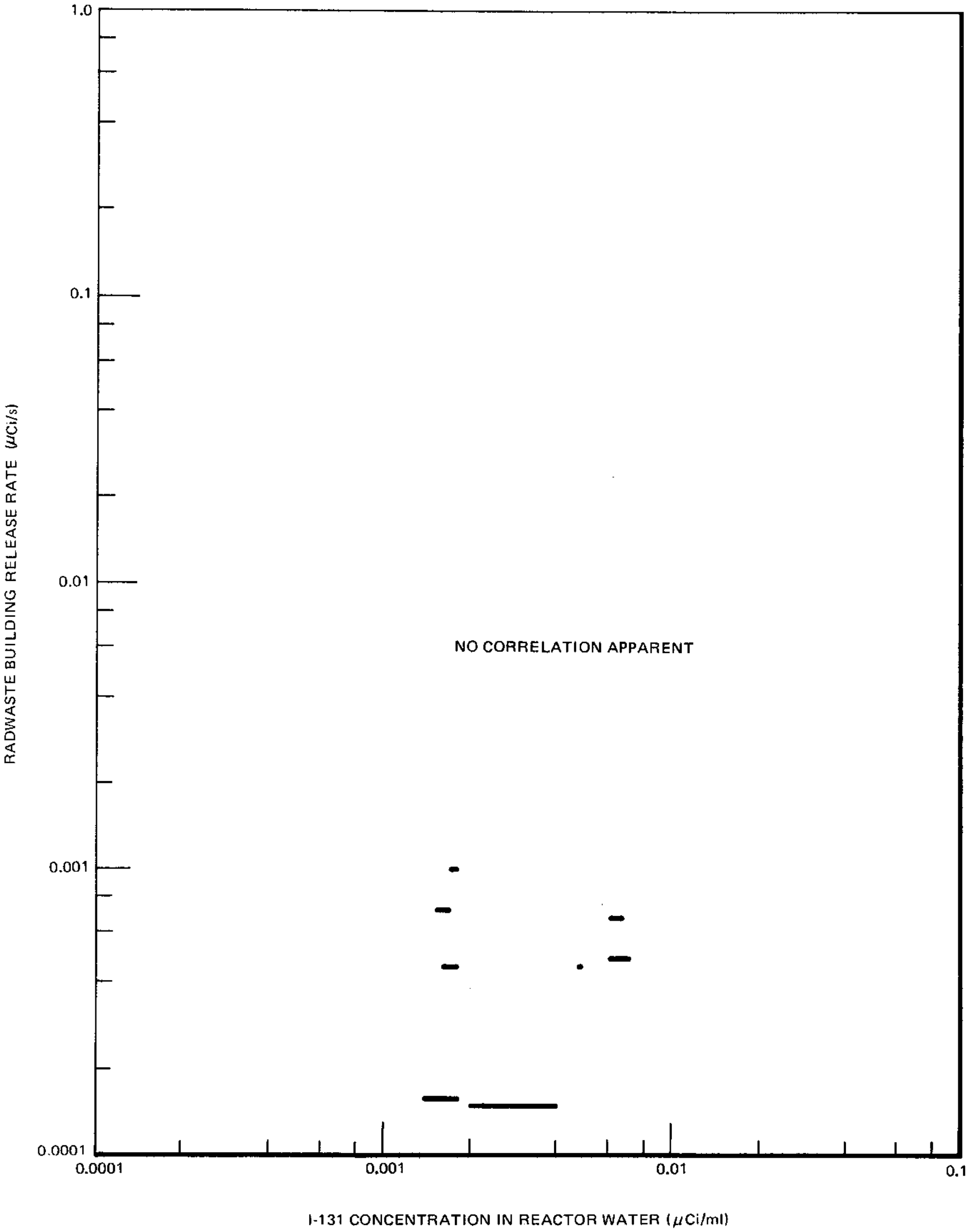

Figure 6-11. Radwaste Building I-131 Vent Release Versus I-131 Reactor Water Concentration, Oyster Creek

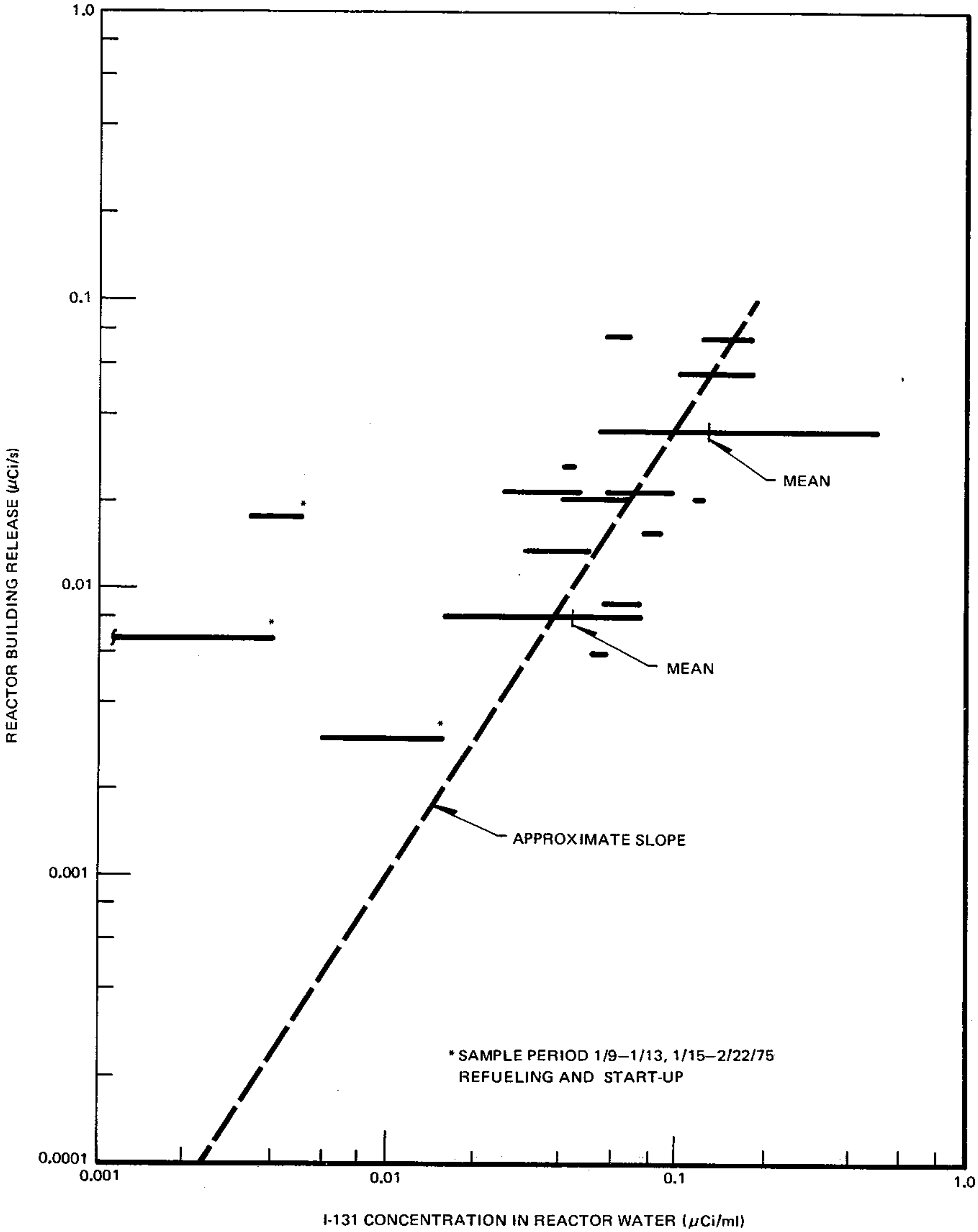

Figure 6-12. Reactor Building I-131 Vent Release Versus I-131 Reactor Water Concentration, Monticello

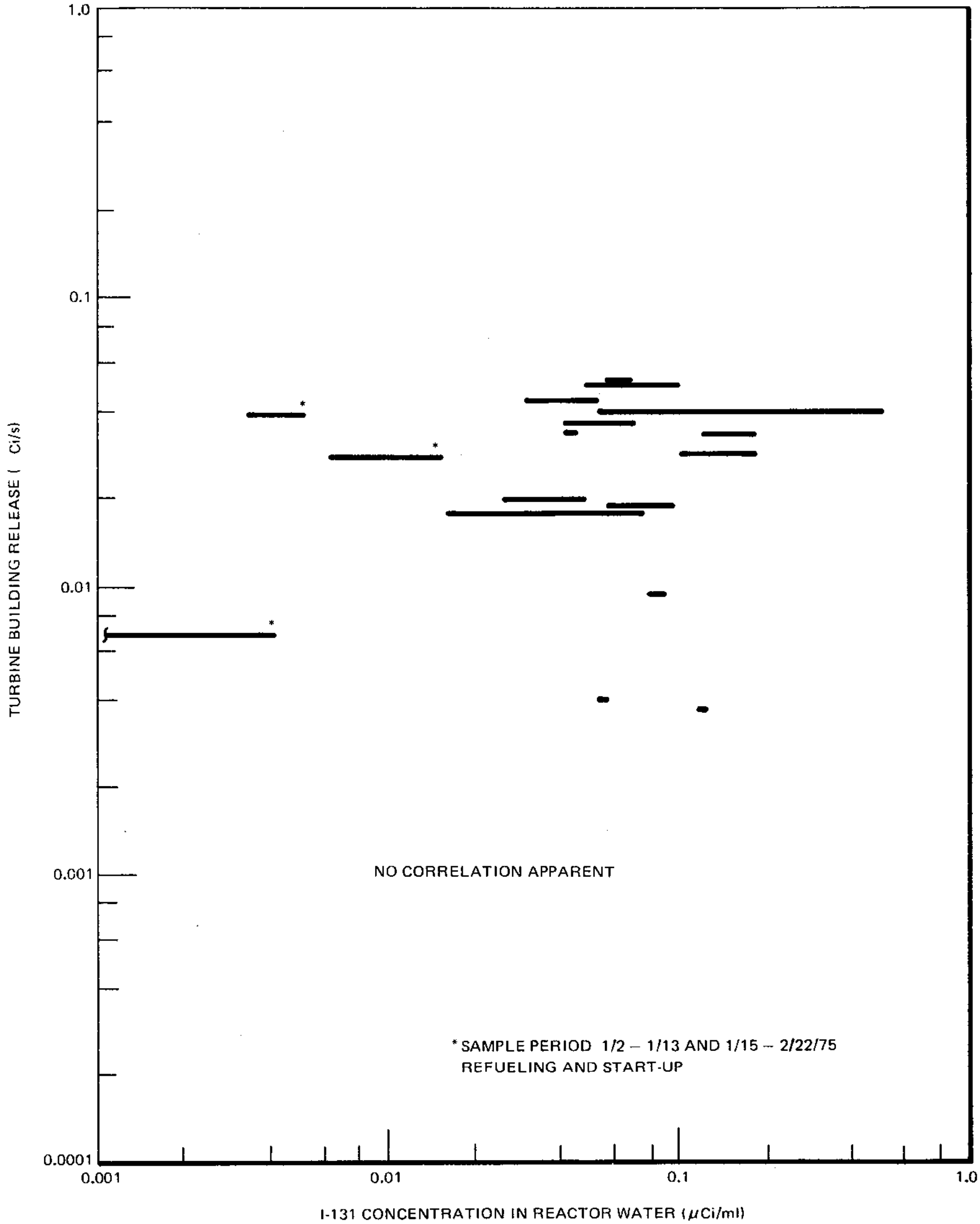

Figure 6-13. Turbine Building I-131 Vent Release Versus I-131 Reactor Water Concentration, Monticello

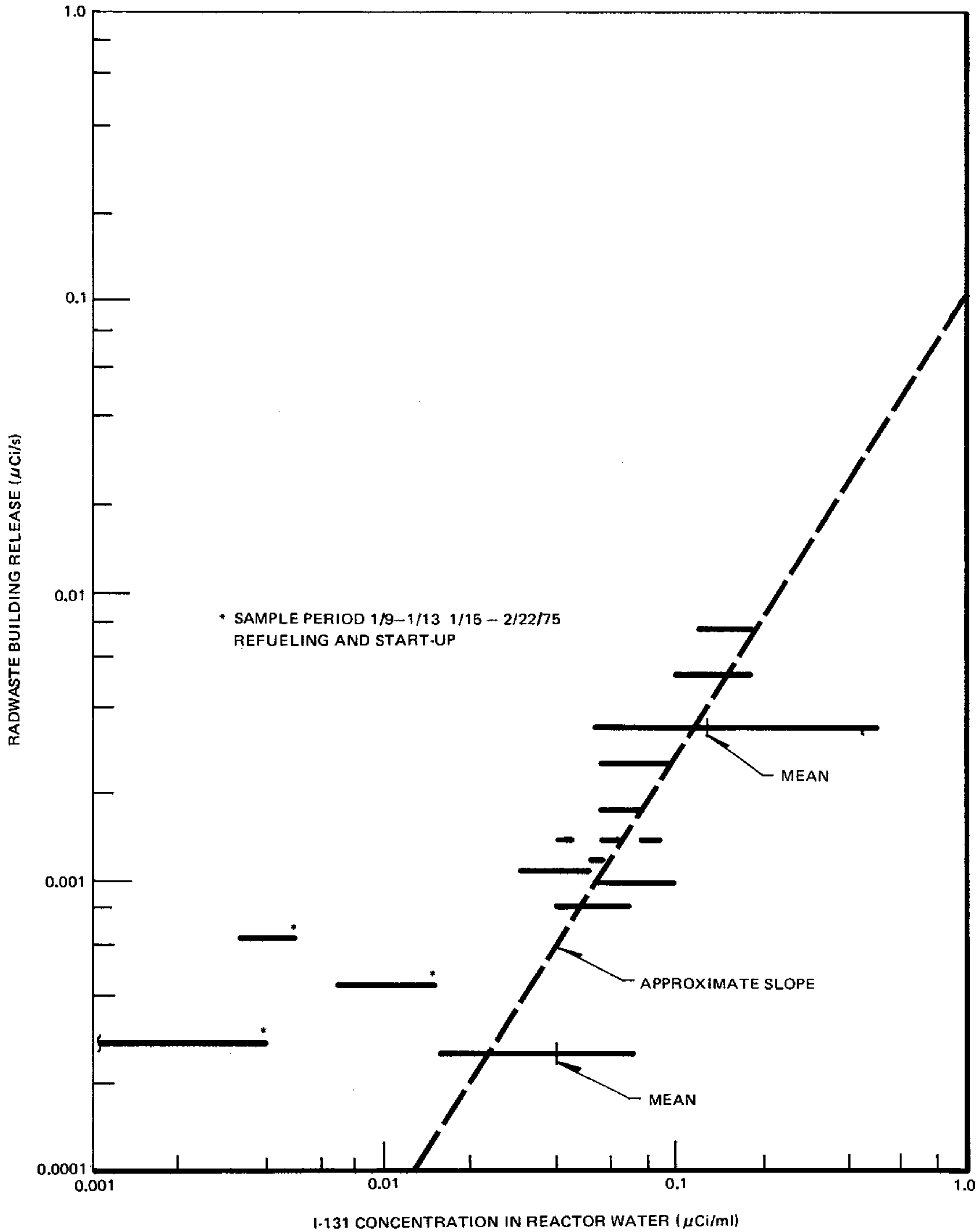

Figure 6-14. Radwaste Building I-131 Vent Release Versus I-131 Reactor Water Concentration, Monticello

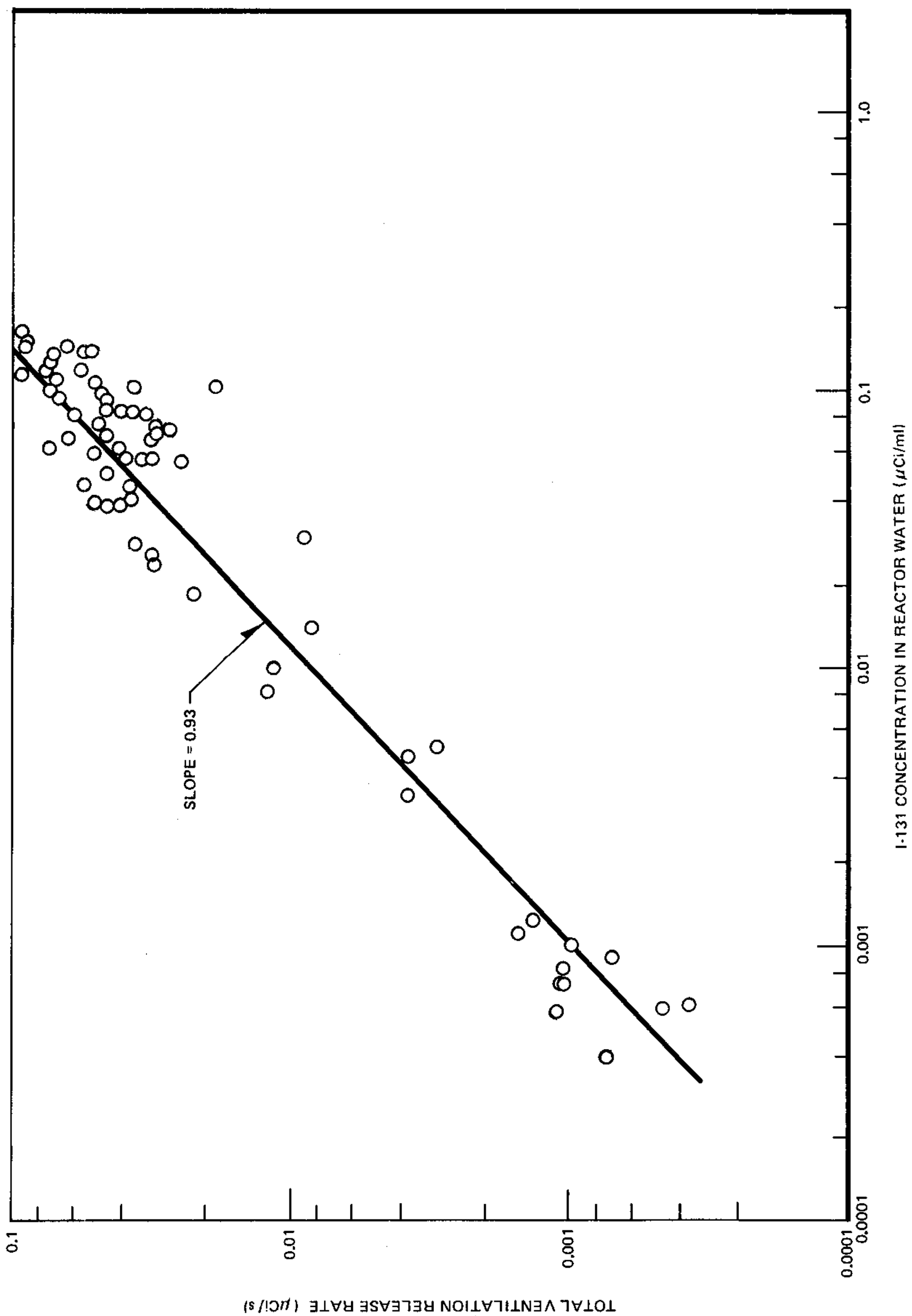

Figure 6-15. Total (Reactor + Turbine + Radwaste Buildings) I-131 Vent Release Versus I-131 Reactor Water Concentration, Monticello and Pilgrim 1 Stations

7. RESULTS FOR IODINE I-131 RELEASES

The available data shows conclusively that I-131 releases are in the form of methyl iodide and inorganic forms, I_2 particulate, and HOI. The composition of the effluent release varies between BWR buildings and the plant operating mode. Quantitative information about chemical form has already been presented in Section 4.

The reactor building I-131 releases for plants with RWCU pumps upstream or downstream from the filter demineralizers are of interest. Such data would indicate whether or not there is a significant effect on release due to the pump location, assuming all other leakage is the same. The average annual release for Dresden 2/3 plants is less than one standard deviation below the average release for Quad Cities 1/2 plants. The Dresden 2/3 plants have RWCU pumps downstream from the filter-demineralizers, and the Quad Cities 1/2 plants have the pumps upstream. There is no significant difference between the reactor building releases of these plants. Thus, these data are inconclusive as to the better location for the RWCU pump on the basis of average annual airborne releases. However, in the event that serious RWCU pump seal leakage occurs with the RWCU pump in an upstream location, its leakage predominates in the reactor building, as at the Monticello plant.

The annual release for the three plants studied by EPRI was estimated as follows. The EPRI measurements for each plant included a refueling/maintenance outage. The normal operation releases were estimated by linearly extrapolating the data obtained during said period to a time interval equal to 365 days less the time of the outage. For Oyster Creek and Monticello, these were ratios of 304/118 and 321/170, respectively. For Vermont Yankee the study extended to 400 days, and a 367-day sampling period was selected to approximate an annual release. The first measurements at Vermont Yankee were directly sponsored by the utility. The time period after the refueling was truncated in order to have a more conservative annual release value. The annual releases estimated on the basis of the EPRI measurements are listed in Table 7-1.

The calculation of annual I-131 releases considered all the data sources, routine measurements by utility personnel at six BWR's, the EPRI extensive studies at three stations, the 3-month study at Oyster Creek, and special short-term measurements at five other BWR's by the NRC, and finally the short-term analyses obtained by GE personnel. The longest GE study was for about 2 weeks; most sample periods were for about 1 day. These data were weighted on a time basis. The weighting process gave the GE and NRC measurements a much smaller contribution than the data by EPRI or the utilities. Further consideration was given to the I-131 reactor water concentration at the time of vent measurements which eliminated the Monticello and Pilgrim 1 results from the final average. With regard to the turbine building, all values for Oyster Creek and Nine Mile Point 1 were discounted because of their unique maintenance feature (air-dry) on the reheaters. This design allows for a direct leak of steam carrying I-131 into the turbine building HVAC system upon leakage of one valve (which has occurred). Finally, consideration was given to whether the BWR had Powdex or deep-bed RWCU systems. Current BWR's are Powdex units. On this basis the Dresden 2/3 results were not included in the final averaging; this is conservative. These results with weighting factors are listed in Table 7-2. The weighting factors are zero or the total number of plant years of sampling.

The weighted mean annual I-131 releases are listed in Table 7-3. By themselves these results are incomplete regarding dose evaluation because of the absence of percentages of organic and inorganic iodine. The chemical species in the releases have been presented in Table 4-5. The results indicate that of the total station vent releases, 80% is CH_3I. Most of the CH_3I is released during refueling/maintenance outages. Presumably, continuous operation of the MVP during an outage exhausts I-131 from the inside surfaces of components in the turbine building. Components which contain large wetted areas, such as the condenser, are likely sources of CH_3I release. In future BWR's the steam distribution has been changed to a "pumped forward flow" design. Operating BWR's may have a smaller release from the MVP because the condenser will "see" steam with a lower I-131 concentration. The reduction in MVP release due to pumped forward flow is speculative at the time.

Annual releases for the gland seal steam have been taken to be those of operating BWR's, which is a conservative basis. The results reported here are also conservative because no consideration was given to the use of "clean" steam for the turbine gland seal. Operating plants have not incorporated this effluent control feature. For plants with separate steam on the gland seals the release rate should be negligible, or zero.

Table 7-1
PLANT ANNUAL I-131 RELEASES ON THE BASIS OF EPRI MEASUREMENTS

	Plant		
Source	**Oyster Creek**	**Monticello**	**Vermont Yankee**
	I-131 Annual Release, (Curies)		
Normal Operations			
Reactor	0.0237	0.886	0.039
Turbine	0.296	0.798	0.013
Radwaste	0.014	0.146	0.018
Gland Seal/MVP	0.080	NM	0.035
Refuel/Maintenance Outage			
	(61 days)	(44 days)	(76 days)
Reactor	0.010	0.039	0.107
Turbine	0.197	0.092	0.009
Radwaste	0.022	0.002	0.014
Gland Seal/MVP	0.265	NM	0.268
TOTAL			
Reactor	0.034	0.925	0.146
Turbine	0.49	0.891	0.021
Radwaste	0.036	0.148	0.032
Gland Seal/MVP	0.35	NM	0.303

NM= not measured

Table 7-2

SUMMARY OF ANNUAL AIRBORNE I-131 DATA AND WEIGHTING FACTORS

BWR Type	Plant	I-131 Curies/Year Reactor	Radwaste	Turbine	Gland Seal	Total Plant Release	Weighting Factor
IV	Vermont Yankee (EPRI)	0.146	0.033	0.022	0.303	–	1.09
III	Dresden 2 1973/1975	0.0511	–	–	–	–	0[a]
III	Dresden 3 1973/1975	0.0529	–	–	–	–	0[a]
III	Quad Cities 1 1973/1975	0.0789	–	–	–	–	2.00
III	Quad Cities 2 1973/1975	0.0741	–	–	–	–	2.00
III	Monticello (EPRI)	0.74	0.125	0.686	–	1.49	0[a]
III	Pilgrim 1 (1974–1975)	–	–	–	–	0.315	0[a]
II	Oyster Creek (EPRI)	0.034	0.036	0.49	0.35	–	0.49 (Turbine = 0)

Total number of plant years of sampling = 12.7

[a]See discussion, page 7-1.

Table 7-3

WEIGHTED AVERAGE ANNUAL I-131 RELEASES FROM BWR'S[a]

Source	I-131 Release (Curies/Year)
Reactor Building	0.091
Turbine Building	0.034
Radwaste Building	0.022
Gland Seal/Mechanical Vacuum Pump	0.32
TOTAL	0.47

[a]Not to be used for environmental impact evaluations without specification of chemical species

PART B

MIXED NOBLE RADIOGAS RELEASES

8. AIRBORNE NOBLE RADIOGAS DATA

The mixed noble radiogas release rates from the HVAC systems of BWR's are estimated in this part of the report on airborne emissions. The purpose is to determine an annual release rate on the basis of BWR operating plant performance. These releases are necessary input data toward the prediction of gamma and beta radiation doses to the population present in the environs of BWR's. Noble radiogas release rate data are available from measurements routinely performed by utilities and by special measurements. The General Electric Company has sponsored a number of measurements at various BWR's since 1972. Recently EPRI has conducted a few release rate determinations. These data are not as extensive as data available for I-131 because the dose from population immersion of noble radiogas releases is significantly less critical than the iodine-grass-milk-thyroid pathway.

In this section the utility data are presented first, followed by special measurements.

8.1 MEASUREMENTS BY UTILITIES

Measurements by various utilities were compiled and evaluated. There are two major types of HVAC noble radiogas measurements. Two utilities routinely monitor the total release from the reactor, turbine, and radwaste building exhausts. The relative amounts for each source are not determined. The BWR plants and utilities are as follows.

Plant	Utility	Measurements Available for Period
Monticello	Northern States Power	July 1974 to June 1975
Pilgrim 1	Boston Edison	January 1973 to June 1975

For these plants, there is a total of 3.5 plant-years of data. The results from Monticello are presented in Tables 8-1 and 8-2. Figure 8-1 shows the probability distribution of the weekly average release rates for a given calendar quarter. Tables 8-3 and 8-4 list the Pilgrim 1 data, and Figure 8-2 shows the distribution of calendar quarter releases. This figure indicates a log-normal distribution with data from two populations. A significant change in the release rate started during the 4th quarter of 1974. This period corresponds to the second fuel cycle.

The second type of ventilation data is for the routine monitoring of only the reactor building. Table 8-5 lists reported values for Quad Cities 1/2 plants. For many months, there was no detectable activity in the vent. The Quad Cities 1/2 semiannual reports were searched from January 1973 to June 1975. A similar search was made of the Dresden 2/3 semiannual reports and for each month no detectable activity was reported for the reactor building HVAC releases.

8.2 SPECIAL IN-PLANT MEASUREMENTS

Special measurements by the General Electric Company and Electric Power Research Institute are given in the tables listed below according to building. Apparently, the NRC has not measured noble radiogas emissions from HVAC systems. The data which are available are relatively meager.

The tabulations are as follows.

Table	Source	No. of Plants	Number of Independent Measurements	Year Data Taken
8-6	Reactor Building	3	3	1972, 1975
8-7	Turbine Building	4	5	1973, 1974, 1975
8-8	Radwaste Building	3	3	1972, 1975
8-9	Gland Seal Steam	2	2	1972
8-10	Mechanical Vacuum Pump	3	4	1969, 1972

The releases for the MVP include data from Dresden 1 because of lack of data from other BWR's.

Table 8-1

MIXED NOBLE RADIOGAS RELEASE RATES FROM COMBINED REACTOR, TURBINE, AND RADWASTE BUILDING EXHAUSTS, MONTICELLO, JULY 1, 1974, TO JUNE 30, 1975[a]

Total Annual Release = 7700 Curies

Weekly Average Rate μCi/s[b]	Weekly Average Rate μCi/s[b]
100	250
100	270
100	272
100	280
106	310
146	325
155	333
157	340
158	340
162	352
164	355
165	358
170	375
170	388
173	390
178	407
179	407
185	420
188	440
193	480
205	500
208	540
220	582
225	630
226	637
236	920

[a] Data provided by plant personnel
[b] Ascending order

Table 8-2

MIXED NOBLE RADIOGAS HVAC CALENDAR QUARTERLY RELEASES, REACTOR + TURBINE + RADWASTE BUILDINGS, MONTICELLO, JULY 1974 TO JUNE 1975

	Quarter 1974		1975	
	3	4	1	2
	Rate Release (μCi/s)			
	170	193	375	280
	164	178	637	310
	185	226	100	340
	158	208	100	390
	157	146	100	440
	165	162	100	500
	155	236	270	388
	170	920	630	582
	106	340	352	355
	205	407	272	325
	188	407	220	333
	173	358	225	540
	179	420	250	480
Median	170	236	250	388
Curies/Calendar Quarter	1337	1856	1966	3051

Total for Year = 8210 Curies

Table 8-3

MIXED NOBLE RADIOGAS RELEASE OF REACTOR + TURBINE + RADWASTE BUILDINGS, PILGRIM 1

	Year		
	1973	1974	1975
Month		Release (Curies)	
January	149	86.4	2,060
February	137	124	1,150
March	147	122	3,270
April	73	122	3.970
May	539	84.4	4,370
June	308	63.7	5,300
July	417	48	–
August	565	511	–
September	449	572	–
October	155	1,040	–
November	179	2,500	–
December	322	3,890	–
Total	3,440	9,163.5	20,100

Table 8-4

MIXED NOBLE RADIOGAS HVAC CALENDAR QUARTERLY RELEASE RATES, REACTOR + TURBINE + RADWASTE BUILDINGS

Pilgrim 1, January 1973 to June 1975

Year	Calendar Quarter	Total Release (Curies)	
1973	1	433	3,440
	2	920	
	3	1,431	
	4	656	
1974	1	332.4	9,104
	2	210.1	
	3	1,131.1	
	4	7,430	
1975	1	6,480	20,120
	2	13,640	

Table 8-5

MIXED NOBLE RADIOGAS HVAC RELEASE FROM REACTOR BUILDING QUAD CITIES 1/2, JANUARY 1973 TO JUNE 1975[a]

Month	Release (Curies)	
1973		
April	460	584
May	124	
1974		
March	34	461
April	117	
May	166	
June	129	
July	15	

[a]For months not listed, release was not detected

Table 8-6
MIXED NOBLE RADIOGAS RELEASE RATES DURING NORMAL OPERATION, BY SPECIAL MEASUREMENTS

Half-Life	Species	Reactor Building Release Rate (μCi/s)				
3.2m	Kr-89	0.38	–	–	–	–
3.9m	Xe-137	<30	–	–	–	–
14.2m	Xe-138	<0.4	–	<0.3	0.87	–
15.7m	Xe-135m	3.5	2.5	–	3.04	4.13
76m	Kr-87	<0.1	–	–	0.287	0.19
2.79hr	Kr-88	<0.2	–	<0.022	0.56	0.196
4.4hr	Kr-85m	<0.2	–	–	0.44	0.071
9.16hr	Xe-135	1.8	14.0	2.1	3.12	2.9
2.3d	Xe-133m	–	–	–	–	–
5.27d	Xe-133	<2	–	14.8	0.67	0.356
	Date	8/4/75	7/18/75	4/18/72	7/21/72	7/24/72
	Plant	Monticello	Oyster Creek		Millstone	
	Observer	EPRI	EPRI	GE	GE	

Table 8-7

MIXED NOBLE RADIOGAS HVAC RELEASE RATES DURING NORMAL OPERATION

Species	**Turbine Building Release Rate (μCi/s)**								
Kr-85m	4.6	–	0.1	2.68	–	–	0.13	0.16	–
Kr-87	11.9	0.53	0.15	5.30	–	–	0.52	0.72	0.36
Kr-88	8.1	0.39	0.065	8.2	10.4	–	0.63	–	–
Kr-89	140	–	42	–	–	–	1.93	11.6	–
Xe-133m	–	–	–	–	–	–	–	–	–
Xe-133	–	–	5.0	7.35	13.2	12.4	0.48	0.77	9.28
Xe-135m	50	1.33	8.2	<29	≤23	–	1.24	4.95	1.24
Xe-135	13.7	1.02	6.8	25.3	35	14	3.33	2.32	1.24
Xe-137	230	–	86	–	–	–	–	–	–
Xe-138	190	4.2	11	63.3	51.7	–	2.94 (7.50)	7.50 (7.43)	2.40 (2.55)
Sample Date	3/19/75	7/18/75	8/4/75	7/25/72	4/18/72	4/27/72	3/26/74	3/26/74	3/27/74
Station	Oyster Creek		Monticello	Millstone	Oyster Creek		Nine Mile Point 1		
Observer	EPRI	EPRI	EPRI	GE	GE	GE	GE	GE	GE

( ) = Estimates from Cs-138

Table 8-8
MIXED NOBLE RADIOGAS HVAC RELEASE RATES DURING NORMAL OPERATION

Radwaste Building

Species	Release Rate (μCi/s)		
Kr-85m	<0.05	–	–
Kr-87	<0.03	–	–
Kr-88	<0.05	–	–
Kr-89	<3.0[b]	–	–
Xe-133m	5.3	–	–
Xe-133	26	0.26	0.56
Xe-135m	59	–	4[a]
Xe-135	29	1.98	1.5
Xe-137	<10[b]	–	–
Xe-138	<0.2	–	–
Sample Date	8/4/75	7/24/72	4/18/72
Station	Monticello	Millstone	Oyster Creek
Observer	EPRI	GE	GE

[a]I-133 interference possible.
[b]Decay time between sample collection and counting was too long for meaningful analysis.

Table 8-9
MIXED NOBLE RADIOGAS RELEASE RATES DURING NORMAL OPERATION

Gland Seal Steam Exhaust

Species	**Release Rate (μCi/s)**	
Kr-85m	5.6	–
Kr-87	13.2	–
Kr-88	12.3	4.4
Kr-89	–	–
Xe-133m	–	–
Xe-133	9.98	4.7
Xe-135m	57	32.5
Xe-135	34.4	14.4
Xe-137	–	–
Xe-138	45	57.5
Sample Date	7/27/72	4/20/72
Station	Millstone	Oyster Creek
Observer	GE	GE

Table 8-10
NOBLE RADIOGAS RELEASE VIA MECHANICAL VACUUM PUMP DISCHARGE

Station	Release			
	Xe-135[a]	hrs	Date	Off-gas[b] (mCi/s)
Dresden 1	76	7	1/23/69	30
	79	9	2/15/69	26
	230	9	8/2/69	66
	79	10	8/4/69	53
	150	9	8/14/69	49
	Total 614 curies	—		
Millstone	1.5 curies Xe-133/100 min. at 48 hours after shutdown			
	0.068 curies Xe-135/100 min. at 48 hours after shutdown			
Dresden 2	100 curies Xe-133/entire shutdown			
	200 curies Xe-133/anticipated post shutdown gas peaking			
	300 curies			
	(The approximate Xe-133 release rate at SJAE prior to shutdown is 5 mCi/s)			

[a]Assumed Xe-135.
[b]Rate prior to shutdown.

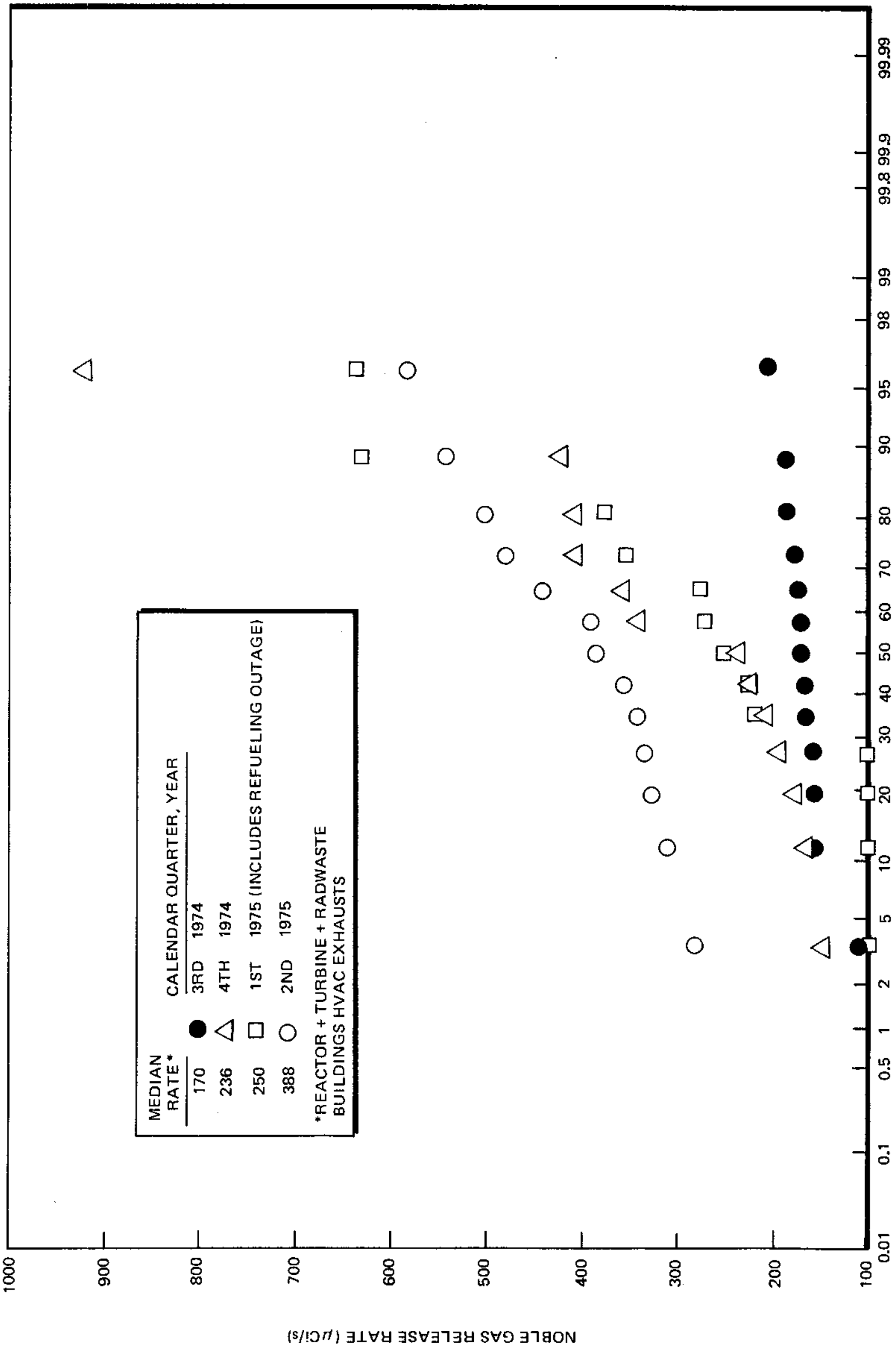

Figure 8-1. Probability Distribution of Mixed Noble Radiogas HVAC Releases (Reactor + Turbine + Radwaste Buildings) for Monticello.

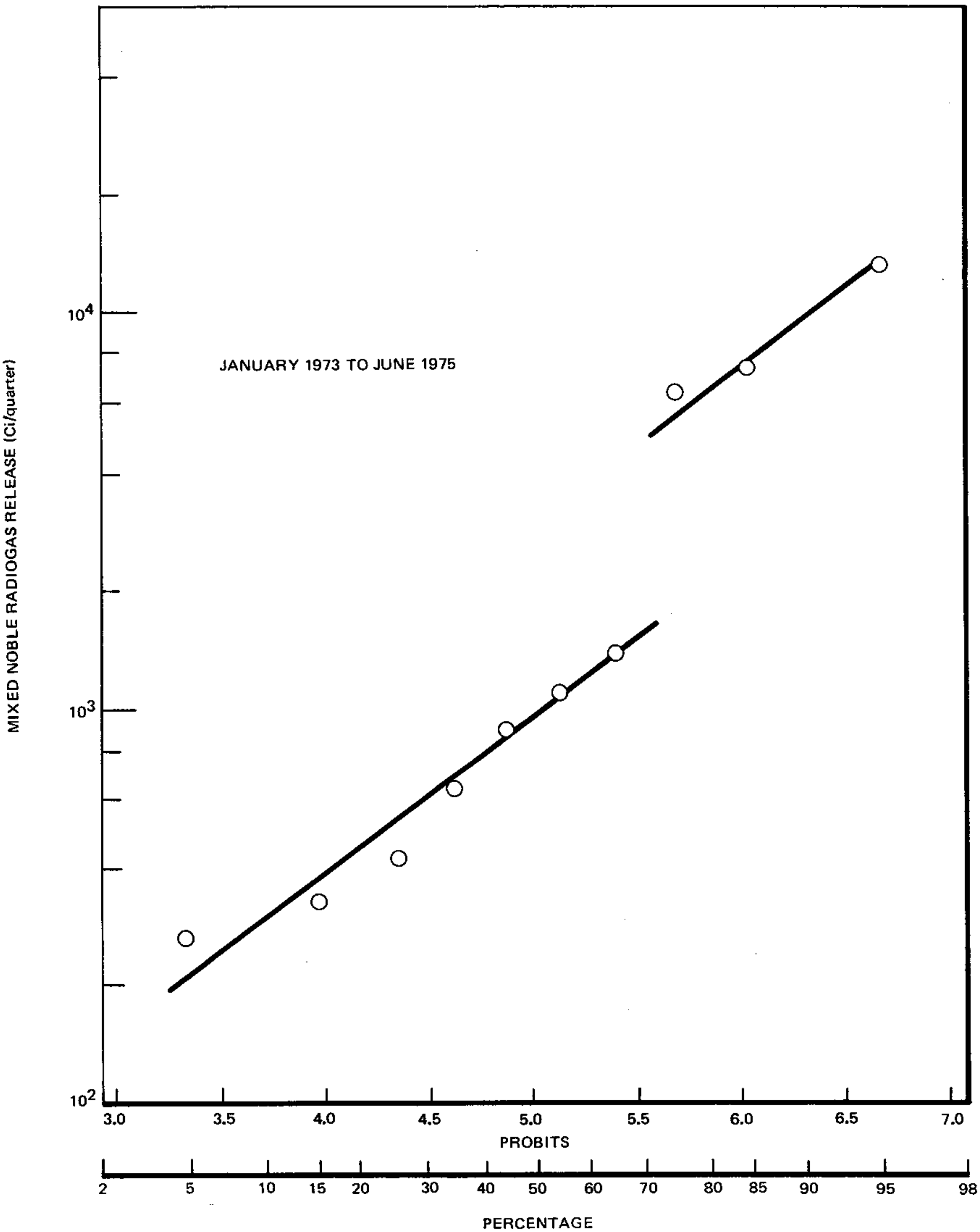

Figure 8-2. Probability Distribution of Mixed Noble Radiogas HVAC Releases (Reactor + Turbine + Radwaste Buildings) for Pilgrim 1

9. RESULTS FOR NOBLE RADIOGAS RELEASES

The evaluation of the above measurements of BWR noble radiogas releases led to estimates of annual releases per plant. These results have been summarized in Tables 2-3 and 2-4.

The data reported by utilities were the basis for the average annual releases. For Monticello, this is the total release over a 52-week period based on weekly average release rates. For Pilgrim 1 data are available for 2.5 years. The results for Quad Cities reactor buildings (Units 1 and 2) were averaged on a 30-month period, detectable releases were reported for 7 months in this period. The average release was divided by 2 to obtain a release rate per plant, or reactor building. The Dresden 2 and 3 releases were so low that detectable amounts of noble gases were not reported. However, these measurements, or the absence of data, were not factored into the final average BWR releases for conservatism.

The special measurements were treated as follows. For each measurement a total release rate was obtained by the sum of release rates reported for each nuclide. The fraction of the total release for each nuclide was calculated. These fractions were averaged over the number of reported measurements, 5, 9, and 3 for the reactor, turbine, and radwaste buildings, respectively.

A total release rate was determined considering the results from special measurements (EPRI and GE) and utility data. For the reactor building, the utility data average is 210 curies/year, and the average by special measurements is 544. The final release was conservatively set at 500 curies/year. This value puts more weight on the special measurements (higher) value. The release rate for the total of turbine building plus radwaste building was estimated from the special measurements. The total plant releases reported for Monticello and Pilgrim 1 stations were used as upper limits for release rates. Since these two plants have operated with unimproved fuel, their releases of I-131 have been relatively high, and the total plant releases for the future BWR's are estimated to be a fraction of the Monticello and Pilgrim 1 experience. The total releases for the turbine and radwaste buildings were taken to be 4000 and 1500 curies/year, respectively. These totals are based on the average of the special measurements. These results indicate a total plant release about 2/3 the average for Monticello and Pilgrim 1, that is, 6000 curies/year compared to 8700 curies/year. Release rates for the gland seal exhaust and mechanical vacuum pump were determined by averages of the available data.

The annual release rates per building, or source, were multiplied by the average fractions of nuclide to obtain the annual release rate for the nuclides, listed in Table 2-4. The average fraction for each radioisotope is the arithmetic mean of its release rate to the total release reported by special measurements at the various BWR's for each building, gland seal steam exhaust, or MVP. As stated above, the nuclide distribution was determined only from special measurement data. The results reported here are in qualitative agreement with data available for the nuclide distribution at Quad Cities. These data indicate that Xe-138 has the largest release of all the nuclides, followed by Xe-133.

PART C

PARTICULATE RELEASES

10. AIRBORNE PARTICULATE RELEASE DATA

Until 1975 particulate releases were considered an insignificant source of dose to the population in the environs of BWR's. The available data indicated negligible amounts of particulate releases from BWR's and the major interest in dose evaluations was directed toward I-131 and noble radiogases. The data summary presented in the report probably is the first extensive survey of particulate releases from BWR's. Measurements of particulate releases are routinely performed by utilities and reported in their semi-annual operating reports. In addition, NES under the sponsorship of the Electric Power Research Institute, and GE have obtained data on particulate releases from special in-plant measurements. The particulate release data are divided according to information source. The release rates are averaged according to release point (building) and nuclide. The results indicate that Co-60, Sr-89, and Cs-137 are the three principal particulate releases from BWR's.

The amount of I-131 in particulate form has been discussed in earlier sections of this report.

10.1 MEASUREMENTS BY UTILITIES

Data obtained by utilities provide information on particulate releases only from the BWR reactor building. The available results have been obtained by personnel of the Commonwealth Edison Company at Dresden and Quad Cities. The survey includes monthly releases from Quad Cities 1 and 2 from December 1973 through June 1975, and Dresden for the first 6 months of 1975. These data are tabulated in Tables 10-1, 10-2, and 10-3. From these data, the average release rate values and inventories were calculated (see Table 10-4).

10.2 SPECIAL IN-PLANT MEASUREMENTS

The Electric Power Research Institute has recently obtained information about particulate releases from Oyster Creek, Monticello, and Vermont Yankee plants. These measurements provide data for the reactor, turbine, and radwaste building releases for several months at each plant. The longest sampling, about 8 months, was done at Vermont Yankee. In addition, particulate releases were measured from the gland seal steam exhaust and MVP at the Oyster Creek and Vermont Yankee plants.

The EPRI data are here compiled according to source: reactor, turbine, radwaste buildings, and gland seal steam exhaust. From these measurements, a weighted mean average release was calculated. Results reported as "less than" were considered "equal to" which is a conservative assumption. Measurements at three different BWR's were weighted approximately according to the total sample period. To simplify computations for a specific BWR the sampling periods were assumed equal, approximately 2 weeks each. However a few sample periods were of 1, 2, or 4 days and these were not included in the average. Another sample period of 32 days was given double weight. The reported data are listed in Tables 10-5 through 10-15; average release rates are summarized in Tables 10-16 through 10-19, and the estimated annual releases plus nuclide inventories are listed in Table 10-20. The final results for the reactor building are taken as the arithmetic mean of the results by utilities and EPRI.

The available particulate measurements by GE personnel consist of measurements at the Nine Mile Point 1 plant radwaste building prior to a refueling/maintenance outage in 1974. The average release rates were determined by 2-day samples over approximately 2 weeks. The mean radwaste building release rates during normal operations are as follows.

Nuclide	Rate[a] (μCi/s)
Mn-54	1.5 E-4
Co-58	4.0 E-5
Co-60	1.2 E-3
Zn-65	8.0 E-5
Cs-134	5.2 E-4
Cs-137	1.1 E-3

[a] Data (sample of 3/22) shortly after leak in waste concentrator excluded from average; results significantly different from other samples.

Except for Cs-134 and Cs-137 nuclides, these GE results are in reasonable agreement with EPRI results. The cesium nuclide releases at NMP 1 are about a a factor of 20 greater than the Oyster Creek (also a BWR/2 plant) results by EPRI. Since the available measurements by GE personnel were for such a limited time span, these results do not affect the final average release rates for particulates.

Subsequent to the analysis of all the above data, two additional data sources became available. These data are not tabulated here, but were evaluated and found to be reasonably consistent with the results of this report. These data pertain to utility measurements at the Dresden 2/3 plants and 1972 AEC measurements; brief descriptions of these evaluations follow.

At the Dresden 2 and 3 plants particulate releases were determined only for the turbine building over a 30-day period. An interesting test at the Dresden 2 and 3 plants was to compare results by the AEC to the utility measurements at the stack. The comparison is considered good and indicated that the turbine building exhaust was the main source of particulate radioactivity and the stack sampler was collecting a representative sample.

During 1972 the AEC made special measurements of particulates at Oyster Creek, Dresden 2, and Dresden 3. The measurements at Oyster Creek were over a 3-1/2-month period, including a refueling outage. Data were obtained for the reactor, turbine, and radwaste buildings. The estimated annual release for Co-60 by the AEC measurements is 0.04 curie/year which is in agreement with the final results (Table 2-5) of this survey. The estimated annual releases for Ba-140, Sr-89, Fe-59, and Mn-54 are about 1.6 times the final results, here. The Cr-51 annual release was estimated to be 0.024 curie in comparison to 0.005 curie in this report, a factor of five difference. About 98% of the Cr-51 at Oyster Creek was released from the turbine building. All the other isotopes identified at Oyster Creek (1972 AEC measurements) have estimated annual release values less than or equal to the final results reported in Table 2-5; the isotopes are Cs-137, Co-58, Ce-141, Zn-65, Sb-124, Sr-90, and Ru-103 in order of decreasing activity.

Table 10-1
HVAC AIRBORNE PARTICULATE RELEASES, QUAD CITIES 1, REACTOR BUILDING

Date	Fe-59	Cr-51	Mn-54	Co-58	Co-60	Zn-65	Nb-95	Zr-95	Ag-110m	Sb-124	I-131	Cs-134	Cs-136	Cs-137	Ba-140	La-140	Ce-141	Ce-144
									Nuclide (μCi/Month)									
1973																		
December	11.7	ND	19.1	28.4	57.2	ND	ND	ND	2.2	ND	119	11.7	ND	23.4	ND	4.2	ND	ND
1974						↓	↓	↓		↓					↓		↓	↓
January	ND	73.3	2.6	3.4	10.4	↓	↓	↓	ND	↓	108	5.6	ND	15.1	↓	ND	↓	↓
February	4.3	94.3	18.9	21.9	1.24	↓	↓	↓	ND	↓	767.6	41.3	12.9	106.1	↓	13.3	↓	↓
March	13.1	ND	20.8	29.6	53.0	↓	↓	↓	4.42	↓	225.5	16.9	ND	35.2	↓	ND	↓	↓
April	ND	15.8	22.1	18.8	165.4	↓	6.2	↓	4.25	↓	44	44	ND	115	↓	↓	↓	↓
May	↓	74.4	13.9	15.3	110.3	9.0	7.4	↓	1.44	↓	989	43.7	28.1	90.1	↓	↓	↓	↓
June	↓	192.8	36.7	33.9	204.4	15.9	10.1	12.1	ND	↓	351.4	120.7	15.2	190.2	↓	14.0	↓	↓
July	↓	358.5	67.9	64.8	441.7	ND	ND	ND	↓	↓	208	205.1	ND	367.6	↓	28.7	↓	↓
August	↓	655.0	65.1	64.2	324.5	21.7	↓	↓	↓	↓	460.9	68.6	ND	134.5	43.7	55.1	↓	↓
September	↓	ND	25.4	19.2	104	12.1	↓	↓	↓	↓	195	184	43.9	314	ND	ND	↓	↓
October	↓	211	44.5	38.43	173.23	ND	↓	↓	↓	↓	630	175	ND	283	ND	56	—	—
November	↓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
December	↓	244	27.3	20.5	258	ND	ND	ND	ND	ND	815	156	46.3	269	ND	69.3	ND	ND
1975	↓								↓	↓					↓		↓	↓
January	↓	477	54.8	56.5	647	113	33.5	31.2	↓	↓	3.28	8.12	ND	140	↓	ND	↓	↓
February	↓	35.6	52.99	38.9	505.8	46.8	13.2	11.5	↓	↓	75.7	99	↓	166.2	↓	ND	5.9	17.5
March	↓	554	213	324	5940	748	65.4	28.1	↓	17.4	260	145	↓	230	237	259	ND	ND
April	↓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
May	↓	656	38.7	30.6	321	28.4	5.73	ND	ND	ND	789	296	69.3	514	340	471	3.58	8.83
June	↓	2600	167	114	490	63.0	—	ND	20.0	ND	653	186	ND	308	1090	1480	11.7	ND

ND = Not detected
— = No data available

Table 10-2
HVAC AIRBORNE PARTICULATE RELEASES,
QUAD CITIES 2, REACTOR BUILDING

Nuclide (μCi/Month)

Date	Fe-59	Cr-51	Mn-54	Co-58	Co-60	Zn-65	Nb-95	Zr-95	Ag-110m	Sb-124	I-131	Cs-134	Cs-136	Cs-137	Ba-140	La-140	Ce-141	Ce-144
1973																		
December	ND	230	31.9	36.5	50.6	7.62	ND	ND	ND	21.3	343	15.2	ND	34.9	ND	ND	ND	ND
1974																		
January	↓	329	5.3	20	35.3	5.3	↓	↓	↓	ND	386	39.6	ND	39.6	↓	↓	↓	↓
February	↓	102.8	ND	6.4	22.9	ND	↓	↓	↓	↓	1098.1	24.2	20.8	51.1	↓	↓	↓	↓
March	↓	1800	13.4	11.8	25.9	3.6	2.6	↓	↓	↓	247.4	13.1	ND	27.9	↓	↓	↓	↓
April	↓	127.5	11.4	11.6	43.5	ND	4.0	↓	↓	↓	354	22	ND	40	↓	↓	↓	↓
May	↓	157.6	25.0	24.9	67.4	8.9	4.8	↓	↓	↓	535	32.2	7.9	69.1	↓	15.8	↓	3.81
June	↓	292.3	36.4	35.8	108.9	13.0	5.1	↓	↓	↓	759	147.4	27.0	263.6	↓	ND	↓	ND
July	↓	349.2	23.3	28.6	103.4	15.4	ND	↓	↓	↓	836.6	181.8	25.8	301.3	52.6	68.7	↓	↓
August	↓	402.4	ND	29.0	ND	15.6	↓	↓	↓	↓	1618.7	83.3	20.3	151.5	116.8	161.1	↓	↓
September	↓	ND	6.67	6.21	30.4	4.38	↓	↓	↓	↓	308	77.5	16.3	130	ND	ND	↓	↓
October	↓	258	27	23	137	19	↓	↓	↓	↓	703	146	ND	246	58	67	↓	↓
November	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
December	ND	758	34.4	3.93	388	52.7	14.0	ND	ND	ND	740	142	ND	253	133	191	ND	—
1975																		
January	↓	58.8	9.05	5.59	115	22.8	2.79	↓	↓	↓	45.4	28.2	↓	51.7	ND	ND	↓	↓
February	↓	ND	13.47	10.5	142.6	14.9	5.75	↓	↓	↓	12.2	34.7	↓	56.3	↓	↓	↓	5.7
March	↓	ND	31.9	36.2	767	85.7	8.89	↓	↓	↓	ND	24.8	↓	294	↓	↓	3.11	8.48
April	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
May	ND	535	39.0	35.7	413	68.1	ND	ND	8.72	↓	1180	185	61.5	369	403	535	7.16	ND
June	↓	159	25.8	14.7	289	30.2	ND	↓	ND	↓	806	106	ND	211	137	159	1.72	ND

ND = Not detected
— = Data not available

Table 10-3
AIRBORNE PARTICULATE RELEASES FROM REACTOR BUILDING, DRESDEN 2 AND 3
JANUARY TO JUNE 1975

Nuclide (Ci/Month)

Month	Cr-51	Mn-54	Co-58	Co-60	Sr-89	Sr-90	Nb-95	Mo-99	Tc-99m	I-131	Cs-134	Cs-137	Ba-140	La-140
January	2.2 E-3	5.4 E-3	1.8 E-3	4.6 E-2	3.1 E-3	3.0 E-4	ND	1.3 E-3	1.4 E-3	5.2 E-3	9.0 E-4	1.7 E-3	3.8 E-3	3.0 E-3
February	——	3.3 E-3	1.4 E-3	4.6 E-2	9.0 E-4	3.0 E-4	ND	ND	——	7.9 E-3	1.5 E-3	2.1 E-3	4.9 E-3	5.6 E-3
March	——	1.4 E-3	9.0 E-4	1.0 E-2	4.3 E-3	5.0 E-4	7.0 E-4	ND	——	9.0 E-3	3.1 E-3	4.5 E-3	4.6 E-3	4.9 E-3
April	——	9.0 E-4	7.0 E-4	4.5 E-3	9.9 E-3	5.0 E-4	ND	ND	ND	1.1 E-2	1.2 E-3	8.0 E-4	5.5 E-3	6.3 E-3
May	——	3.6 E-3	2.3 E-3	4.9 E-2	3.1 E-3	4.0 E-4	9.0 E-4	ND	ND	ND	5.8 E-3	7.4 E-3	ND	ND
June	——	2.4 E-3	1.6 E-3	3.3 E-2	2.0 E-3	2.0 E-4	6.0 E-4	ND	ND	ND	4.2 E-3	5.3 E-3	ND	ND
Total	2.2 E-3	1.7 E-2	8.7 E-3	1.6 E-1	2.3 E-2	2.2 E-3	2.2 E-3	1.3 E-3	1.4 E-3	3.3 E-2	1.7 E-2	2.2 E-2	1.9 E-2	2.0 E-2

I-131 excluded here for reference purposes only, and is not considered in this part of the report; see Part A.

ND = Not detected
—— = Data not available

Table 10-4
AVERAGE PARTICULATE RELEASE RATES AND INVENTORIES FROM REACTOR BUILDING ON BASIS OF AVAILABLE DATA BY UTILITY PERSONNEL AT DRESDEN 2 AND 3 AND QUAD CITIES 1 AND 2 BWR's

Nuclide	Release Rate (μCi/s)	Inventory (Curies)
Cr-51	1.3 E-4	4.5 E-4
Mn-54	1.5 E-4	6.0 E-3
Co-58	8.4 E-5	7.5 E-4
Fe-59	2.1 E-7	1.2 E-6
Co-60	1.4 E-3	3.5 E-1
Zn-65	1.2 E-5	3.6 E-4
Sr-89	4.1 E-4	2.6 E-3
Sr-90	6.1 E-5	8.1 E-2
Nb-95	2.0 E-5	8.8 E-5
Zr-95	7.2 E-7	5.9 E-6
Mo-99	1.1 E-5	3.8 E-6
Tc-99m	1.2 E-5	3.7 E-1
Ag-110m	4.1 E-7	1.3 E-5
Sb-124	3.1 E-7	2.3 E-6
Cs-134	1.7 E-4	1.6 E-2
Cs-136	3.4 E-6	5.5 E-6
Cs-137	2.3 E-4	3.2 E-1
Ba-140	1.8 E-4	2.9 E-4
La-140	2.0 E-4	4.1 E-5
Ce-141	3.0 E-7	1.2 E-6
Ce-144	3.0 E-7	1.1 E-5
Totals	3.1 E-3	1.1 E-0

NOTE: The inventory is that total amount of radioactive material in the environs, assuming a constant average emission rate, and thus properly accounts for radioactive decay. The conventional use of curies emitted per year gives a distorted impression of actual quantity present for short-half-life radioisotopes.

Table 10-5
HVAC AIRBORNE PARTICULATE RELEASES, OYSTER CREEK REACTOR BUILDING (EPRI MEASUREMENTS)

Nuclide (μCi/s)

Sample Dates	Cr-51	Mn-54	Co-58	Fe-59	Co-60	Zn-65	Nb-95	Zr-95	Mo-99	Ru-103	Sb-124	Cs-134	Cs-136	Cs-137	Cs-138	Ba-139	Ba-140	Ce-141	Np-239	Sample Time (Days)
1975																				
2/22–2/26	<5 E-4	2.7 E-4	ND	ND	9.3 E-4	ND	ND	ND	<4 E-4	ND	ND	2.0 E-4	<1 E-5	3.6 E-4	2.6 E-1	<1 E-4	4.5 E-4	<5 E-5	<1 E-5	4
2/26–3/12	2.6 E-4	2.3 E-4	ND	ND	4.8 E-4	ND	ND	ND	<4 E-4	ND	ND	1.7 E-5	<1 E-5	2.1 E-4	a	a	3.0 E-4	<1 E-5	<1 E-5	14
3/12–3/28	2.0 E-4	2.9 E-4	ND	ND	7.2 E-4	ND	ND	ND	3.6 E-4	ND	ND	3.9 E-5	<1 E-5	8.1 E-5	a	a	6.0 E-4	1.1 E-5	<1 E-5	16
3/29–4/15	<3 E-6	2.0 E-4	<1.5 E-5	<2 E-5	<2 E-5	a	a	a	<1 E-4	<1 E-5	a	2.1 E-5	ND	5.2 E-5	ND	ND	<1 E-6	<2 E-6	<1 E-4	17
4/15–5/1	3.6 E-5	7.8 E-5	<1.5 E-5	2.4 E-5	1.5 E-4	a	a	a	<1 E-4	<1 E-5	a	2.1 E-5	ND	3.9 E-5	ND	ND	<1 E-6	<2 E-6	<1 E-4	16
5/1–5/15	<3 E-6	2.0 E-4	2.8 E-5	4.4 E-5	3.4 E-4	a	2.3 E-6	2.7 E-6	<1 E-4	<1 E-5	a	2.3 E-5	ND	2.2 E-5	ND	ND	<1 E-6	6.8 E-6	<1 E-4	14
5/15–5/29	1.6 E-4	2.3 E-4	3.6 E-5	6.5 E-5	4.2 E-4	a	<2 E-6	<2 E-6	<1 E-4	<1 E-5	a	3.1 E-5	ND	3.8 E-5	ND	ND	<1 E-6	<2 E-6	<1 E-4	14
5/29–6/16	<1 E-5	1.7 E-4	1.0 E-4	7.0 E-5	6.5 E-4	<1 E-5	<2 E-6	<2 E-6	2.2 E-4	<1 E-5	<1 E-5	3.1 E-5	ND	5.5 E-5	ND	ND	3.6 E-4	<3 E-6	<1 E-4	18
6/16–6/30	8.3 E-5	8.1 E-5	6.8 E-5	2.5 E-5	3.3 E-4	<1 E-5	<2 E-6	<2 E-6	1.4 E-4	<1 E-5	<1 E-5	1.3 E-5	ND	2.0 E-5	ND	ND	2.3 E-5	<3 E-6	2 E-4	14
6/30–7/17[b]	6.0 E-5	4.4 E-5	3.4 E-5	2.4 E-5	1.7 E-4	<1 E-5	<2 E-6	<2 E-6	1.2 E-4	<1 E-5	<1 E-5	8.8 E-6	ND	7.3 E-6	ND	ND	3.6 E-5	<3 E-6	<1 E-4	18
Sum	81.5 E-6	191.9 E-5	29.6 E-5	27.2 E-5	32.8 E-4	3 E-5	10.3 E-6	10.7 E-6	16.4 E-4	8 E-5	3 E-5	20.4 E-5	2 E-5	52.43 E-5			1323 E-6	42.8 E-6	8.2 E-4	145
Average	9.1 E-5	2.1 E-4	3.3 E-5	3.0 E-5	3.6 E-4	6.0 E-6	2.1 E-7	1.5 E-6	1.8 E-4	8.9 E-6	6.0 E-6	2.3 E-5	2.2 E-6	5.8 E-5	0	0	1.5 E-4	4.8 E-6	9.1 E-5	

Weight Factor

$$\frac{(145-4)}{365} = 0.386$$

[a]Measured concentration considered unreliable because sampling period ≫ activity half-life.

[b]Sampler failed during subsequent sample periods, 7/17 – 8/5 and 8/5 – 8/21.

Table 10-6
HVAC AIRBORNE PARTICULATE RELEASES,
MONTICELLO REACTOR BUILDING
(EPRI MEASUREMENTS)

Sample Dates	Mn-54	Co-60	Zn-65	Nb-95	Zr-95	Mo-99	Cs-134	Cs-136	Cs-137	Ba-140	Ce-141	Np-239	Sample Period (Days)
	Nuclide (μCi/s)												
1974													
11/15–11/17	ND	ND	ND	ND	ND	ND	4.4 E-4	1.3 E-6	7.7 E-4	4.2 E-4	<6 E-5	1.3 E-2	2
11/20–12/5[a]	ND	3.0 E-5	6.5 E-5	ND	ND	3.2 E-3	3.6 E-4	8.7 E-5	5.7 E-4	2.1 E-3	<4 E-6	4.6 E-2	15
12/5–12/18[a]	ND	5.1 E-5	2.8 E-4	ND	ND	2.3 E-3	2.1 E-4	1.2 E-4	3.4 E-4	4.2 E-3	<3 E-6	1.1 E-1	13
12/18–1/6[a]	ND	1.2 E-5	3.3 E-5	4.2 E-6	ND	b	7.6 E-5	<3 E-5	1.2 E-4	1.1 E-3	1.2 E-5	b	19
1975													
1/8–1/9	ND	<2 E-3	<2 E-3	ND	ND	<6 E-5	<2 E-4	<4 E-4	<2 E-4	9.1 E-4	<1 E-4	1.6 E-2	1
1/13–1/15	ND	2.6 E-4	2.0 E-4	ND	ND	<5 E-5	8.5 E-5	<5 E-4	1.2 E-4	8.3 E-5	<9 E-4	8.3 E-4	2
1/9–1/13 1/15–1/22	ND	5.5 E-4	3.9 E-4	ND	ND	b	1.1 E-4	2.7 E-5	1.8 E-4	4.0 E-5	1.2 E-4	b	11
1/22–2/7	ND	1.7 E-4	1.4 E-4	ND	ND	<2 E-5	9.4 E-5	1.2 E-5	1.5 E-4	<1 E-5	9.7 E-5	<2 E-3	16
2/7–2/21	ND	1.8 E-4	6.5 E-5	ND	ND	8.7 E-4	1.1 E-4	2.8 E-5	1.7 E-4	4.2 E-4	9.2 E-6	1.2 E-2	14
2/21–3/10	ND	5.2 E-5	1.4 E-4	ND	ND	1.3 E-3	1.7 E-4	5.2 E-5	2.7 E-4	1.9 E-3	2.0 E-5	3.2 E-2	17
3/10–3/25	ND	4.4 E-5	1.1 E-4	ND	ND	2.1 E-3	2.6 E-4	1.5 E-4	4.1 E-4	2.5 E-3	<3 E-6	2.3 E-2	15
3/25–4/7	<5 E-5	2.4 E-5	7.2 E-5	ND	ND	2.1 E-4	2.4 E-4	ND	3.4 E-4	1.9 E-4	<1 E-4	9.8 E-3	13
4/7–4/21	6.2 E-7	1.7 E-5	6.6 E-5	ND	ND	2.8 E-3	1.9 E-4	ND	2.6 E-4	1.6 E-3	<1 E-4	1.1 E-2	14
4/21–5/5						No Sample							
5/5–5/17	8.2 E-5	4.2 E-4	2.1 E-3	ND	ND	<3 E-2	1.6 E-3	ND	2.3 E-3	1.5 E-2	<1 E-4	1.1 E-1	12
5/19–6/5	8.1 E-6	4.8 E-5	9.5 E-3	ND	ND	4.3 E-3	6.2 E-4	ND	1.0 E-3	1.4 E-3	<1 E-4	1.0 E-2	17
6/5–6/23	2.9 E-6	1.4 E-5	8.2 E-5	ND	ND	5.0 E-3	6.0 E-4	ND	7.8 E-4	1.6 E-3	<1 E-4	1.4 E-2	18
6/23–7/8	1.0 E-4	1.5 E-4	2.0 E-4	ND	ND	1.6 E-2	8.9 E-4	ND	1.0 E-3	3.2 E-3	<1 E-4	4.0 E-2	15
Sum	243.62 E-6	176.2 E-5	1324.3 E-5	4.2 E-6	0	686 E-4	55.3 E-4	50.6 E-4	78.9 E-4	35.26 E-3	8.682 E-4	41.98 E-2	214
Average	1.7 E-5	1.3 E-4	9.5 E-4	3.0 E-7	0	5.7 E-3	4.0 E-4	3.6 E-4	5.6 E-4	2.5 E-3	6.2 E-5	3.5 E-2	

Weight Factor

$\frac{(214-5)}{365} = 0.573$

[a]Ventilation exhaust

[b]Sample analyzed after activity decayed.

ND = Not detected

Table 10-7
HVAC AIRBORNE PARTICULATE RELEASES, VERMONT YANKEE REACTOR BUILDING (EPRI MEASUREMENTS)

Sample Dates	Nuclide (μCi/s) Cr-51	Mn-54	Co-58	Co-60	Zn-65	Nb-95	Zr-95	Mo-99	Cs-134	Cs-136	Cs-137	Ba-140	Np-239	Sample Period (Days)
1974														
12/6–12/27	<3 E-5	1.7 E-5	2.1 E-5	1.1 E-4	1.7 E-4	ND	3.2 E-5	ND	1.9 E-5	<8 E-7	4.8 E-5	<5 E-6	ND	21
12/27–1/28	ND	5.5 E-6	ND	3.0 E-5	3.5 E-5	5.5 E-6	ND	ND	<3 E-7	<3 E-7	<3 E-7	<4 E-6	ND	32
1975														
1/28–2/14	ND	5.3 E-6	3.4 E-6	2.7 E-5	3.1 E-5	ND	ND	ND	4.8 E-6	<1 E-6	9.4 E-6	<4 E-6	ND	17
2/14–3/5	4.3 E-5	2.8 E-6	ND	2.0 E-5	2.7 E-5	ND	ND	2.3 E-5	9.6 E-6	<2 E-6	2.6 E-5	7.4 E-6	ND	19
3/10–3/26	2.2 E-4	8.6 E-6	2.0 E-5	1.0 E-4	5.5 E-4	2.7 E-5	1.7 E-5	7.2 E-5	5.4 E-5	ND	1.4 E-4	1.1 E-5	2.0 E-4	16
3/26–4/10	ND	2.4 E-6	<3 E-6	1.5 E-5	1.7 E-5	ND	ND	ND	2.3 E-6	ND	6.4 E-6	<2 E-6	ND	15
4/10–4/26	ND	1.3 E-6	<2 E-6	7.1 E-6	<2 E-5	2.0 E-6	ND	ND	<4 E-6	ND	2.3 E-6	5.7 E-6	ND	16
4/26–5/8	ND	2.9 E-5	1.9 E-5	7.7 E-5	6.7 E-5	ND	ND	ND	<6 E-5	ND	3.9 E-5	<1 E-4	ND	12
5/8–5/29	4.8 E-5	<6 E-7	3.5 E-6	1.4 E-5	1.2 E-5	ND	4.6 E-6	ND	2.0 E-6	ND	5.4 E-6	1.2 E-5	ND	21
5/29–6/13	1.1 E-4	2.5 E-5	3.4 E-5	1.5 E-4	1.1 E-4	ND	ND	ND	1.1 E-5	ND	2.2 E-5	<9 E-6	ND	15
6/13–6/26	ND	<2 E-6	<1 E-6	3.1 E-5	3.0 E-5	ND	ND	ND	<4 E-6	ND	5.2 E-6	<8 E-6	ND	13
6/26–7/10	ND	<2 E-6	<2 E-6	2.4 E-5	2.9 E-5	ND	ND	ND	<5 E-6	ND	<5 E-6	<1 E-5	2.3 E-4	14
7/10–7/29	2.0 E-5	<1 E-6	3.6 E-6	2.5 E-5	3.1 E-5	2.6 E-6	ND	9.5 E-6	2.1 E-6	ND	<3 E-6	<6 E-6	2.4 E-4	19
Sum	47.1 E-5	108 E-6	11.25 E-5	66.01 E-5	116.4 E-5	42.6 E-6	5.36 E-5	10.45 E-6	178 E-6	4.4 E-6	312.3 E-6	188.1 E-6	6.7 E-4	230
Average	3.4 E-5	7.7 E-6	8.0 E-6	4.7 E-5	8.3 E-5	3.0 E-6	3.8 E-6	7.5 E-7	1.3 E-5	3.1 E-7	2.2 E-5	1.3 E-5	4.8 E-5	

ND = Not detected

Weight Factor

$$\frac{230}{365} = 0.630$$

Table 10-8
HVAC AIRBORNE PARTICULATE RELEASES, OYSTER CREEK, TURBINE BUILDING (EPRI MEASUREMENTS)

Sample Date	Nuclide (μCi/s)																	Sample Time (days)
	Cr-51	Mn-54	Co-58	Fe-59	Co-60	Zn-65	Nb-95	Zr-95	Mo-99	Ru-103	Sb-124	Cs-134	Cs-136	Cs-137	Ba-140	Ce-141	Np-239	
1975																		
2/22–2/26	<1 E-3	<1 E-4	ND	ND	<2 E-5	ND	ND	ND	<1 E-3	ND	ND	<1 E-4	<1 E-5	<1 E-4	ND	<1 E-4	<2 E-2	4
2/26–3/12	<3 E-4	3.3 E-5	ND	ND	1.0 E-5	ND	ND	ND	3.8 E-4	ND	ND	2.4 E-5	<1 E-5	2.6 E-4	ND	5.7 E-5	<7 E-3	14
3/12–3/28	2.4 E-4	4.6 E-5	ND	ND	1.1 E-5	ND	ND	ND	9.5 E-4	ND	ND	4.1 E-5	<1 E-5	5.7 E-4	ND	2.2 E-4	8.4 E-3	16
3/29–4/15	1.4 E-4	3.9 E-4	<1 E-5	6.3 E-5	5.3 E-4		a	a	<1 E-4	8.4 E-5	a	6.7 E-5	ND	<2 E-6	1.1 E-4	1.3 E-4	<1 E-4	17
4/15–5/1	1.0 E-4	1.7 E-4	<1 E-5	<2 E-5	4.6 E-4	a	a	a	<1 E-4	2.3 E-5	a	3.9 E-5	ND	1.1 E-4	5.6 E-5	1.4 E-4	<1 E-4	16
5/1 –5/15	2.3 E-4	7.0 E-4	3.5 E-5	2.2 E-4	6.9 E-4	a	a	a	<1 E-4	4.2 E-5	a	5.6 E-5	ND	6.3 E-5	<3 E-6	<3 E-6	<1 E-4	14
5/15–5/29	1.2 E-4	2.2 E-5	2.2 E-5	9.8 E-5	3.7 E-4	a	2 E-6	a	<1 E-4	<1 E-5	a	3.2 E-5	ND	3.9 E-5	<3 E-6	<3 E-6	<1 E-4	14
5/29–6/16	<1 E-5	1.1 E-4	<2 E-6	2.2 E-5	2.1 E-4	<1 E-5	<2 E-6	<2 E-6	<1 E-5	<1 E-5	<1 E-5	1.9 E-5	ND	1.3 E-4	1.1 E-3	<3 E-6	<1 E-4	18
6/16–6/30	<1 E-5	8.4 E-5	<2 E-6	1.7 E-5	1.7 E-5	<1 E-5	<2 E-6	<2 E-6	<1 E-5	<1 E-5	<1 E-5	5.5 E-6	ND	2.9 E-5	7.7 E-4	<3 E-6	<1 E-4	14
4/30–7/17[b]																		
7/17–8/5	<1 E-5	2.1 E-4	<2 E-6	3.6 E-5	2.8 E-4	<1 E-6	<1 E-6	<1 E-6	<1 E-6	9.1 E-6	<1 E-5	1.1 E-5	ND	4.1 E-5	8.4 E-4	1.6 E-5	<1 E-4	19
8/5 –8/21	<1 E-5	5.6 E-5	<2 E-6	<1 E-5	8.4 E-5	<1 E-6	<1 E-6	<1 E-6	2.8 E-5	<1 E-6	<1 E-5	<1 E-6	ND	4.3 E-5	1.2 E-3	4.2 E-5	<1 E-4	16
Sum	117 E-5	182.1 E-5	8.5 E-5	48.6 E-5	266.2 E-5	2.2 E-5	8 E-6	6 E-6	18.59 E-4	18.82 E-5	4.0 E-5	29.55 E-5	2.0 E-5	128.7 E-5	408.2 E-5	61.7 E-5	162 E-4	162
Average	1.2 E-4	1.8 E-4	8.5 E-6	4.9 E-5	2.7 E-4	3.7 E-6	1.1 E-6	1 E-6	1.9 E-4	1.9 E-5	6.7 E-6	3.0 E-5	2.0 E-6	1.3 E-4	4.1 E-4	6.2 E-5	1.6 E-3	

[a]Measured concentration considered unreliable because sampling period >> activity half-life.

[b]Sampler failed during this sample period.

Table 10-9
HVAC AIRBORNE PARTICULATE RELEASES, MONTICELLO TURBINE BUILDING
(EPRI MEASUREMENTS)

	Nuclide (μCi/s)										
Sample Dates	Mn-54	Co-60	Zn-65	Mo-99	Cs-134	Cs-136	Cs-137	Ba-140	Ce-141	Np-239	Sample Period (Days)
1974											
11/15–11/17	ND	ND	ND	ND	<2 E-5	<5 E-5	<3 E-5	<3 E-5	<7 E-5	<2 E-4	2
11/20–12/5[a]	ND	<3 E-6	<2 E-5	<9 E-5	<8 E-6	<3 E-5	8.6 E-6	6.0 E-4	5.0 E-5	<5 E-3	15
12/5–12/18[a]	ND	<3 E-6	<2 E-5	<9 E-5	<6 E-6	<2 E-5	5.5 E-6	6.5 E-4	5.5 E-5	<6 E-3	13
12/18–1/6[b]											19
1975											
1/8–1/9	ND	<1 E-4	<7 E-4	<2 E-5	<3 E-4	<6 E-4	<3 E-4	8.3 E-5	<1 E-4	<3 E-4	1
1/13–1/15	ND	<1 E-3	<2 E-3	<6 E-5	<2 E-4	<6 E-4	<2 E-4	<3 E-5	<1 E-3	<2 E-4	2
1/9–1/13 1/15–1/22	ND	1.2 E-6	2.7 E-7	b	1.2 E-7	<7 E-6	1.1 E-5	2.0 E-4	1.5 E-4	b	11
1/22–2/7	ND	<3 E-6	<3 E-6	<2 E-5	<2 E-6	<8 E-6	5.0 E-6	4.2 E-5	4.4 E-6	<3 E-3	16
2/7–2/21	ND	7.2 E-5	2.5 E-5	7.6 E-5	7.8 E-5	<2 E-5	1.3 E-4	1.4 E-3	1.8 E-4	2.0 E-3	14
2/21–3/10	ND	2.3 E-6	1.8 E-6	<2 E-5	2.6 E-5	<3 E-5	4.7 E-5	9.6 E-4	1.1 E-4	<4 E-4	17
3/10–3/25	ND	2.3 E-5	1.8 E-5	3.4 E-4	5.0 E-5	2.9 E-5	8.5 E-5	9.8 E-4	6.8 E-5	2.9 E-3	15
3/25–4/7	<1 E-5	<2 E-5	<3 E-5	<8 E-5	9.4 E-7	ND	1.4 E-6	2.1 E-3	8.1 E-5	<8 E-4	13
4/7–4/21	<1 E-5	<2 E-5	<3 E-5	<8 E-5	1.6 E-5	ND	1.9 E-5	1.7 E-3	1.6 E-4	<8 E-4	14
4/21–5/5	<1 E-5	<2 E-5	<3 E-5	4.2 E-4	1.4 E-5	ND	4.5 E-5	1.4 E-3	1.6 E-4	<2 E-4	14
5/5–5/17	<1 E-5	<3 E-5	<4 E-5	<1 E-3	1.8 E-6	ND	3.9 E-6	2.9 E-3	2.3 E-4	<1 E-2	12
5/19–6/5	<1 E-5	<2 E-5	<3 E-5	7.3 E-5	2.0 E-5	ND	1.7 E-4	5.5 E-3	9.6 E-5	<1 E-4	17
6/5–6/23	<1 E-5	<2 E-5	<3 E-5	<3 E-5	5.2 E-7	ND	1.8 E-5	8.5 E-4	4.3 E-5	<1 E-4	18
6/23–7/8	<1 E-5	<2 E-5	<3 E-5	<3 E-5	1.0 E-5	ND	1.1 E-5	9.3 E-4	5.5 E-5	<1 E-4	15
Sum	7.0 E-5	25.75 E-5	30.81 E-5	234.9 E-5	233.38 E-6	14.4 E-5	560.4 E-6	202.12 E-4	144.24 E-5	31.40 E-3	228
Average	5.0 E-6	1.8 E-5	2.2 E-5	1.8 E-4	1.7 E-5	1.0 E-5	4.0 E-5	1.4 E-3	1.0 E-4	2.4 E-3	Weight = $\frac{228-5-19}{365}$ = 0.559

[a] Taken as reported condenser area release

[b] Sampler failed during sample period

ND = Not detected

Table 10-10
HVAC AIRBORNE PARTICULATE RELEASES, VERMONT YANKEE TURBINE BUILDING
(EPRI MEASUREMENTS)

Sample Dates	Nuclide (μCi/s) Mn-54	Co-58	Co-60	Zn-65	Cs-134	Cs-136	Cs-137	Ba-140	Sample Period (Days)
1974									
12/6–12/27	ND	ND	<2 E-6	ND	1.8 E-6	<1 E-6	2.4 E-6	9.5 E-6	21
12/27–1/28	ND	ND	<1 E-6	ND	2.0 E-6	<1 E-6	2.9 E-5	2.9 E-5	32
1975									
1/28–2/14	ND	ND	<2 E-6	ND	<2 E-6	<2 E-6	<2 E-6	3.6 E-5	17
2/14–3/5	ND	ND	<3 E-6	ND	5.7 E-8	<6 E-6	1.3 E-5	2.8 E-5	19
3/10–3/26[a]	<3 E-6	<3 E-6	3.4 E-6	<6 E-6	2.4 E-6	ND	1.2 E-6	5.7 E-5	16
3/26–4/10	<3 E-6	<3 E-6	<3 E-6	<6 E-6	<3 E-6	ND	3.4 E-6	4.7 E-5	15
4/10–4/26[b]	<3 E-6	<2 E-6	<6 E-6	<2 E-5	<7 E-6	ND	<7 E-6	3.6 E-6	16
4/26–5/8	<4 E-6	<3 E-6	5.7 E-6	<3 E-5	2.3 E-6	ND	3.8 E-6	4.3 E-5	12
5/8–5/29	<3 E-6	<2 E-6	5.4 E-6	<2 E-5	<7 E-6	ND	<7 E-6	1.0 E-4	21
5/29–6/13	<3 E-6	<3 E-6	<6 E-6	<2 E-5	<7 E-6	ND	<7 E-6	1.9 E-5	15
6/13–6/26	<3 E-6	<2 E-6	<6 E-6	<2 E-5	<8 E-6	ND	<8 E-6	2.4 E-5	13
6/26–7/10[c]	<3 E-6	<2 E-6	<6 E-6	<2 E-5	<8 E-6	ND	4.8 E-6	5.1 E-5	14
7/10–7/29	<2 E-6	<2 E-6	<4 E-6	<2 E-5	<5 E-6	ND	<5 E-6	2.9 E-5	19
Sum	27.0 E-6	22.0 E-6	53.50 E-6	16.2 E-5	55.557 E-6	10 E-6	93.6 E-6	47.61 E-5	230
Average	2.1 E-6	1.7 E-6	4.1 E-6	1.2 E-5	4.3 E-6	7.7 E-7	7.2 E-6	3.7 E-5	

[a] Also Cr-51 <3 E-6; average = 2.3 E-7

[b] Also Ru-103 = 3.3 E-6; average = 2.5 E-7

[c] Also Ce-141 = 7.9 E-6; average = 6.1 E-7

ND = Not detected

Table 10-11
HVAC AIRBORNE PARTICULATE RELEASES, OYSTER CREEK, RADWASTE BUILDING (EPRI MEASUREMENTS)

Sample Dates	Nuclide (μCi/s) Cr-51	Mn-54	Co-58	Fe-59	Co-60	Zn-65	Nb-95	Zr-95	Mo-99	Ru-103	Sb-124	Cs-134	Cs-136	Cs-137	Cs-138	Ba-139	Ba-140	Ce-141	Np-239	Sample Time (days)
1975																				
2/22–2/26	1 E-5	4.8 E-5	ND	ND	5.8 E-4	ND	ND	ND	<1 E-5	ND	ND	3.6 E-5	<1 E-5	1.0 E-4	1.2 E-1	<1 E-5	<1 E-5	<1 E-5	<4 E-5	4
2/26–3/12	<7 E-5	5.8 E-5	ND	ND	1.2 E-4	ND	ND	ND	<1 E-5	ND	ND	7.6 E-6	<1 E-5	1.6 E-5	b	b	<1 E-5	<1 E-5	<2 E-5	14
3/12–3/28	1.8 E-4	3.4 E-5	ND	ND	1.1 E-4	ND	ND	ND	<1 E-5	ND	ND	1.0 E-5	<1 E-5	3.2 E-5	b	b	7.9 E-6	<1 E-5	<2 E-5	16
3/29–4/15[a]																				
4/15–5/1	<8 E-6	1.6 E-5	<7 E-6	5.0 E-6	4.1 E-5	b	b	b	<5 E-6	<1 E-5	b	4.2 E-6	ND	1.2 E-5	ND	ND	<1 E-6	<2 E-6	<1 E-4	16
5/1 –5/15[a]																				
5/15–5/29	<8 E-6	2.7 E-4	8.4 E-6	5.5 E-5	6.3 E-4	b	<2 E-6	<2 E-6	<5 E-6	9.2 E-6	b	2.2 E-5	ND	3.9 E-5	ND	ND	<1 E-6	3.7 E-6	<1 E-4	14
5/29–6/16	<1 E-5	1.8 E-4	9.7 E-5	3.0 E-5	3.4 E-4	<1 E-5	b	b	<5 E-5	<1 E-5	b	1.5 E-5	ND	2.0 E-5	ND	ND	<2 E-6	<3 E-6	<1 E-4	18
6/16–6/30	1.2 E-5	4.0 E-4	9.7 E-5	4.9 E-5	6.9 E-4	<1 E-5	b	b	<5 E-5	<1 E-5	b	2.6 E-5	ND	3.1 E-5	ND	ND	3.6 E-6	<3 E-6	<1 E-4	14
6/30–7/17	2.0 E-4	2.1 E-3	7.8 E-5	3.7 E-4	2.3 E-3	3.1 E-5	8.4 E-5	4.6 E-5	<5 E-5	5.1 E-5	8.4 E-5	1.1 E-5	ND	3.5 E-5	ND	ND	6.7 E-5	5.2 E-5	<1 E-4	18
7/17–8/5	7.3 E-5	2.1 E-3	7.9 E-5	3.3 E-4	2.5 E-3	3.2 E-5	6.7 E-5	3.8 E-5	8.8 E-5	4.7 E-5	5.9 E-5	1.1 E-4	ND	1.3 E-4	ND	ND	1.8 E-4	5.2 E-5	<1 E-4	19
8/5 –8/21	3.9 E-4	4.6 E-4	2.4 E-5	8.8 E-5	4.8 E-4	1.0 E-6	1.3 E-5	1.0 E-5	4.0 E-5	1.2 E-5	1.2 E-5	3.1 E-5	ND	4.7 E-5	ND	ND	1.2 E-4	2.0 E-5	<1 E-4	16
Average	1.1 E-4	6.2 E-4	4.3 E-5	1.0 E-4	8.0 E-4	1.2 E-5	2.8 E-5	1.6 E-5	3.4 E-5	1.7 E-5	3.1 E-5	2.6 E-5	2.2 E-6	4.0 E-5	0	0	4.4 E-5	1.7 E-5	8.2 E-5	149

[a] Samples not taken during this period.

[b] Sample not analyzed for this activity at this time

ND = Not Detected

Table 10-12
HVAC AIRBORNE PARTICULATE RELEASES,
MONTICELLO RADWASTE BUILDING
(EPRI MEASUREMENTS)

Sample Dates	Nuclide (μCi/s) Mn-54	Co-60	Zn-65	Nb-95	Zr-95	Mo-99	Cs-134	Cs-136	Cs-137	Ba-140	Ce-141	Np-239	Sample Period (Days)
1974													
11/15–11/17	ND	ND	ND	ND	ND	ND	<5 E-6	<1 E-5	<6 E-6	<6 E-6	<2 E-5	<4 E-5	2
11/20–12/5	ND	<5 E-7	<5 E-6	ND	ND	<2 E-5	<1 E-6	<4 E-6	<1 E-6	<3 E-6	<8 E-7	<9 E-4	15
12/5–12/18	ND	<6 E-7	<5 E-6	ND	ND	<1 E-5	<1 E-6	<3 E-6	<1 E-6	<3 E-6	<1 E-6	<1 E-3	13
12/18–1/6	ND	3.0 E-7	<6 E-6	ND	ND	a	2.6 E-7	<7 E-6	6.1 E-7	5.3 E-6	<2 E-6	a	19
1975													
1/8–1/9	ND	<3 E-4	<6 E-4	ND	ND	<2 E-5	<6 E-5	<2 E-4	<6 E-5	<3 E-5	<3 E-5	<6 E-5	1
1/13–1/15	ND	<2 E-4	<4 E-4	ND	ND	<1 E-5	<4 E-5	<1 E-4	<4 E-5	<6 E-6	<2 E-4	<4 E-5	2
1/9–1/13 1/15–1/22	ND	6.4 E-7	<5 E-6	ND	ND	a	<2 E-7	<6 E-7	3.3 E-7	<2 E-6	<1 E-6	a	11
1/22–2/7	ND	<2 E-7	<1 E-6	ND	ND	<5 E-6	<2 E-7	<1 E-6	3.6 E-7	<2 E-6	<4 E-7	<6 E-4	16
2/7–2/21	ND	<3 E-6	<4 E-6	ND	ND	<3 E-6	<1 E-6	<3 E-6	<1 E-6	<5 E-6	<5 E-7	<3 E-5	14
2/21–3/10	ND	<5 E-7	<5 E-6	ND	ND	<2 E-5	<1 E-6	<4 E-6	<1 E-6	<3 E-6	<8 E-7	<9 E-4	17
3/10–3/25	ND	<3 E-6	<2 E-6	ND	ND	<5 E-6	2.5 E-5	<2 E-5	3.5 E-5	1.0 E-4	<6 E-7	<1 E-4	15
3/25–4/7	<1 E-6	<1 E-6	<2 E-6	ND	ND	<2 E-5	<3 E-6	ND	<3 E-6	<4 E-6	<1 E-6	<1 E-4	13
4/7–4/21	<1 E-6	<1 E-6	<2 E-6	ND	ND	<2 E-5	<3 E-6	ND	<3 E-6	<4 E-6	<1 E-6	<1 E-4	14
4/21–5/5	<1 E-6	<1 E-6	<2 E-6	ND	ND	<5 E-6	<3 E-6	ND	<3 E-6	<3 E-6	<1 E-6	<3 E-5	14
5/5–5/17	<2 E-6	<2 E-6	<4 E-6	ND	ND	<7 E-5	<5 E-6	ND	<5 E-6	<1 E-5	<2 E-6	<4 E-4	12
5/19–6/5	5.0 E-7	8.0 E-7	<4 E-6	2.2 E-6	1.2 E-6	<3 E-6	2.1 E-6	ND	3.7 E-6	<2 E-6	<1 E-6	<2 E-5	17
6/5–6/23	<1 E-6	<1 E-6	<2 E-6	ND	ND	<5 E-6	<3 E-6	ND	<3 E-6	<3 E-6	<1 E-6	<3 E-5	18
6/23–7/8	<1 E-6	<1 E-6	<2 E-6	ND	ND	<2 E-5	<3 E-6	ND	<3 E-6	<4 E-6	<1 E-6	<1 E-4	15
Sum	7.5 E-6	165.4 E-7	51 E-6	2.2 E-6	1.2 E-6	20.6 E-5	61.76 E-6	42.6 E-6	64.0 E-6	153.3 E-6	15.1 E-6	72.8 E-4	228
Average[b]	0.5 E-6	1.1 E-6	3.4 E-6	1.5 E-7	0.67 E-8	1.6 E-5	4.1 E-6	2.8 E-6	4.3 E-6	1.0 E-5	1.0 E-6	5.6 E-4	
Average[c]	0	<2.5 E-4	<5 E-4	0	0	<1.5 E-5	<5 E-5	<1.5 E-4	<5 E-5	<1.4 E-5	<1.4 E-4	<5 E-5	

[a]Sample analyzed after activity decayed. ND = Not detected
[b]Average of samples 11/20/74 through 7/8/75, except samples of 1/8 and 1/13/75 (3 days).
[c]Average of 3-day sample period.

Table 10-13
HVAC AIRBORNE PARTICULATE RELEASES, VERMONT YANKEE RADWASTE BUILDING (EPRI MEASUREMENTS)

Sample Dates	Nuclide (μCi/s) Cr-51	Mn-54	Co-58	Co-60	Zn-65	Cs-134	Cs-136	Cs-137	Ba-140	Sample Period (Days)
1974										
12/27–1/28	ND	ND	ND	4.8 E-7	ND	<3 E-7	<3 E-7	<3 E-7	<4 E-6	32
1975										
1/28–2/14	ND	ND	ND	<4 E-7	ND	<4 E-7	<4 E-7	<4 E-7	<9 E-7	17
2/14–3/5	ND	ND	ND	6.3 E-7	ND	1.1 E-7	<4 E-7	8.0 E-7	<1 E-6	19
3/10–3/26	<4 E-7	<4 E-7	<4 E-7	<4 E-7	<8 E-7	<4 E-7	ND	6.9 E-7	<1 E-6	16
3/26–4/10	<4 E-7	ND	<4 E-7	<4 E-7	<1 E-6	<4 E-7	ND	4.6 E-6	<1 E-6	15
4/10–4/26	ND	1.4 E-7	<3 E-7	<8 E-7	<3 E-6	<1 E-6	ND	2.3 E-7	1.4 E-6	16
4/26–5/8	ND	<5 E-7	<4 E-7	5.0 E-7	<4 E-6	<2 E-6	ND	5.7 E-7	<3 E-6	12
5/8–5/29	ND	<4 E-7	<3 E-7	<8 E-7	<3 E-6	<1 E-6	ND	5.7 E-7	<2 E-6	21
5/29–6/13	ND	<4 E-7	<3 E-7	<9 E-7	<3 E-6	<1 E-6	ND	<1 E-6	<2 E-6	15
6/13–6/36	ND	<5 E-7	<4 E-7	<1 E-6	<4 E-6	<1 E-6	ND	3.6 E-7	<2 E-6	13
6/26–7/10	ND	<5 E-7	<4 E-7	<1 E-6	<4 E-6	<1 E-6	ND	<1 E-6	<2 E-6	14
7/10–7/29	ND	<3 E-7	<3 E-7	5.4 E-7	<3 E-6	<8 E-7	ND	3.2 E-7	<2 E-6	19
Sum	8 E-7	31.4 E-7	32 E-7	78.5 E-7	25.8 E-6	94.1 E-7	11 E-7	67.0 E-7	22.3 E-6	209
Average	0.7 E-7	2.6 E-7	2.67 E-7	6.5 E-7	2.2 E-6	7.8 E-7	0.9 E-7	5.6 E-7	1.9 E-6	––

ND = Not detected

Table 10-14
GLAND SEAL STEAM & MVP EXHAUST
AIRBORNE PARTICULATE RELEASES
OYSTER CREEK (EPRI MEASUREMENTS)

Sample Dates	Nuclide (μCi/s)																Sample Time (days)
	Cr-51	Mn-54	Co-58	Fe-59	Co-60	Zn-65	Nb-95	Zr-95	Mo-99	Ru-103	Sb-124	Cs-134	Cs-137	Ba-140	Ce-141	Np-239	
1975																	
6/16 to 6/30	<2 E-5	<8 E-6	<4 E-6	<4 E-5	9.3 E-7	<2 E-5	<2 E-5	<2 E-5	<8 E-5	<3 E-5	<2 E-5	<3 E-6	1.5 E-5	1.2 E-3	<2 E-6	<2 E-5	14
6/30 to 7/17	<2 E-5	<8 E-6	<4 E-6	<4 E-5	<5 E-7	<2 E-5	<2 E-5	<2 E-5	<8 E-5	<3 E-5	<2 E-5	<3 E-6	1.6 E-5	1.1 E-3	1.5 E-6	<2 E-5	18
7/17 to 8/5	<1 E-5	<1 E-6	<1 E-6	<1 E-6	<1 E-6	<1 E-6	<1 E-6	<1 E-6	<1 E-6	<1 E-6	<1 E-6	<1 E-6	3.0 E-4	6.3 E-4	3.4 E-6	<1 E-6	19
8/5 to 8/21	<1 E-5	<1 E-6	<1 E-6	<1 E-6	<1 E-6	<1 E-6	<1 E-6	<1 E-6	<1 E-6	<1 E-6	<1 E-6	<1 E-6	6.6 E-6	7.8 E-4	<1 E-6	<1 E-6	16
																	67

Notes: 1. No samples from 2/22/75 to 6/16/75
2.. Mechanical vacuum pump (MVP) on during 7/25 to 7/28, at other times release due solely to gland seal steam exhaust.

Table 10-15
GLAND SEAL STEAM AIRBORNE PARTICULATE RELEASES, VERMONT YANKEE (EPRI MEASUREMENTS)

Sample Dates	Nuclide (μCi/s)											Sample Period (days)
1974	**Cr-51**	**Mn-54**	**Co-58**	**Co-60**	**Zn-65**	**Cs-134**	**Cs-136**	**Cs-137**	**Ba-140**	**Ce-141**	**Ce-144**	
12/6 to 12/27[a]												
12/27 to 1/28	ND	ND	ND	<1 E-8	ND	<1 E-8	<1 E-8	4.7 E-7	5.8 E-5	ND	ND	32
1975												
1/28 to 2/14	ND	ND	ND	<2 8	ND	<2 8	<2 8	3.4 7	3.1 5	1.0 E-7	8.2 E-7	17
2/14 to 3/5	ND	ND	ND	2.3 7	ND	1.7 7	<1 8	<1 8	2.5 5	ND	ND	19
3/10 to 3/26	3.3 E-6	<2 E-8	<2 E-8	<2 8	<4 E-8	<2 8	ND	3.8 7	4.9 5	4.1 E-7	1.5 E-6	16
3/26 to 4/10	ND	<2 8	<2 8	<2 7	<4 8	<2 8	ND	2.0 7	3.6 5	ND	ND	15
4/10 to 4/26	2.7 E-6	<2 8	<1 8	<3 8	<1 7	<4 8	ND	1.4 7	2.1 5	2.0 E-7	ND	16
4/26 to 5/8	ND	<1 8	<1 8	<3 8	<9 8	<3 8	ND	6.7 8	9.5 6	6.2 E-8	ND	12
5/8 to 5/29	ND	<4 8	<3 8	<8 8	<3 7	<1 7	ND	1.7 6	1.0 4	8.4 E-7	ND	21
5/29 to 6/13	2.8 E-7	<3 8	<3 8	6.3 7	3.7 7	<8 8	ND	1.5 6	1.7 5	ND	ND	15
6/13 to 6/26	ND	<3 8	<2 8	<5 8	<2 7	<7 8	ND	1.7 7	7.8 6	ND	ND	13
6/26 to 7/10	ND	<7 8	<5 8	<1 7	<5 7	<2 7	ND	3.7 7	3.4 5	4.6 E-7	ND	14
7/10 to 7/29	ND	<5 8	<4 8	3.0 7	<4 7	<1 7	ND	<1 7	2.8 5	2.9 E-7	ND	19

[a]No samples this period

ND = Not Detected

Table 10-16
HVAC AVERAGE AIRBORNE PARTICULATE RELEASE RATES FROM REACTOR BUILDINGS OF THREE BWR's BASED ON EPRI MEASUREMENTS

	Oyster Creek	Monticello	Vermont Yankee	Average Rate (μCi/s)
Weighting Factor	0.386	0.573	0.630	
Nuclide				
Cr – 51	9.1 E-5	–	3.4 E-5	3.6 E-5
Mn – 54	2.1 E-4	1.7 E-5	7.7 E-6	6.0 E-5
Co – 58	3.3 E-5	–	8.0 E-6	1.1 E-5
Fe – 59	3.0 E-5	–	–	7.3 E-6
Co – 60	3.6 E-4	1.3 E-4	4.7 E-5	1.5 E-4
Zn – 65	6.0 E-6	9.5 E-4	8.3 E-5	3.8 E-4
Nb – 95	2.1 E-7	3.0 E-7	3.0 E-6	1.4 E-6
Zr – 95	1.5 E-6	–	3.8 E-6	1.9 E-6
Mo – 99	1.8 E-4	5.7 E-3	7.5 E-7	2.1 E-3
Ru – 103	8.9 E-6	–	–	2.2 E-6
Sb – 124	6.0 E-6	–	–	1.5 E-6
Cs – 134	2.3 E-5	4.0 E-4	1.3 E-5	1.6 E-4
Cs – 136	2.2 E-6	3.6 E-4	3.1 E-7	1.3 E-4
Cs – 137	5.8 E-5	5.6 E-4	2.2 E-5	2.3 E-4
Ba – 140	1.5 E-4	2.5 E-3	1.3 E-5	9.4 E-4
Ce – 141	4.8 E-6	6.2 E-5	–	2.4 E-5
Np – 239	9.1 E-5	3.5 E-2	4.8 E-5	1.3 E-2

Table 10-17
HVAC AVERAGE AIRBORNE PARTICULATE RELEASE RATES FROM TURBINE BUILDINGS OF THREE BWR's BASED ON EPRI MEASUREMENTS

	Oyster Creek	Monticello	Vermont Yankee	Average Rate (μCi/s)
Weighting Factor	0.433	0.559	0.630	
		Release Rate, μCi/s		
Nuclide				
Cr – 51	1.2 E-4	–	2.3 E-7	3.2 E-5
Mn – 54	1.8 E-4	5.0 E-6	2.1 E-6	5.1 E-5
Co – 58	8.5 E-6	–	1.7 E-6	2.9 E-6
Fe – 59	4.9 E-5	–	–	1.3 E-5
Co – 60	2.7 E-4	1.8 E-5	4.1 E-6	8.0 E-5
Zn – 65	3.7 E-6	2.2 E-5	1.2 E-5	1.3 E-5
Nb – 95	1.1 E-6	–	–	2.9 E-7
Zr – 95	1.0 E-6	–	–	2.7 E-7
Mo – 99	1.9 E-4	1.8 E-4	–	1.1 E-4
Ru – 103	1.9 E-5	–	2.5 E-7	5.2 E-6
Sb – 124	6.7 E-6	–	–	1.8 E-6
Cs – 134	3.0 E-5	1.7 E-5	4.3 E-6	1.6 E-5
Cs – 136	2.0 E-6	1.0 E-5	7.7 E-7	4.3 E-6
Cs – 137	1.3 E-4	4.0 E-5	7.2 E-6	5.1 E-5
Ba – 140	4.1 E-4	1.4 E-3	3.7 E-5	6.1 E-4
Ce – 141	6.2 E-5	1.0 E-4	6.1 E-7	5.1 E-5
Np – 239	1.6 E-3	2.4 E-3	–	1.3 E-3

Table 10-18
HVAC AVERAGE AIRBORNE PARTICULATE RELEASE RATES FROM RADWASTE BUILDINGS OF THREE BWR's BASED ON EPRI MEASUREMENTS

	Oyster Creek	Monticello	Vermont Yankee	Average Rate (μCi/s)
		Release Rate, μCi/s		
Weighting Factor	0.397	0.611	0.573	
Nuclide				
Cr – 51	1.1 E-4	–	7.0 E-8	2.8 E-5
Mn – 54	6.2 E-4	5.0 E-7	2.6 E-7	1.6 E-4
Co – 58	4.3 E-5	–	2.7 E-7	1.1 E-5
Fe – 59	1.0 E-4	–	–	2.5 E-5
Co – 60	8.0 E-4	1.1 E-6	6.5 E-7	2.0 E-4
Zn – 65	1.2 E-5	3.4 E-6	2.2 E-6	5.1 E-6
Nb – 95	2.8 E-5	1.5 E-7	–	7.1 E-6
Zr – 95	1.6 E-5	6.7 E-9	–	4.0 E-6
Mo – 99	3.4 E-5	1.6 E-5	–	1.5 E-5
Ru – 103	1.7 E-5	–	–	4.3 E-6
Sb – 124	3.1 E-5	–	–	7.8 E-6
Cs – 134	2.6 E-5	4.1 E-6	7.8 E-7	8.4 E-6
Cs – 136	2.2 E-6	2.8 E-6	1.0 E-8	1.6 E-6
Cs – 137	4.0 E-5	4.3 E-6	5.6 E-7	1.2 E-5
Ba – 140	4.4 E-5	1.0 E-5	1.9 E-6	1.6 E-5
Ce – 141	1.7 E-5	1.0 E-6	–	4.7 E-6
Np – 239	8.2 E-5	5.0 E-5	–	4.0 E-5

Table 10-19
GLAND SEAL STEAM AND MVP AVERAGE AIRBORNE PARTICULATE RELEASE RATES FROM TWO BWR's BASED ON EPRI MEASUREMENTS

	Oyster Creek	Vermont Yankee	Average Rate
	Release Rate (μCi/s)		
Weighting Factor	0.184	0.573	
Nuclide			
Cr – 51	1.5 E-5	4.8 E-7	4.0 E-6
Mn – 54	4.5 E-6	2.2 E-8	1.1 E-6
Co – 58	2.5 E-6	1.8 E-8	6.2 E-7
Fe – 59	2.1 E-5	ND	5.1 E-6
Co – 60	8.6 E-7	1.3 E-7	3.1 E-7
Zn – 65	1.1 E-5	1.6 E-7	2.8 E-6
Nb – 95	1.1 E-5	ND	2.7 E-6
Zr – 95	1.1 E-5	ND	2.7 E-6
Mo – 99	4.1 E-5	ND	1.0 E-5
Ru – 103	1.6 E-5	ND	3.9 E-6
Sb – 124	1.1 E-5	ND	2.7 E-6
Cs – 134	2.0 E-6	6.7 E-8	5.4 E-7
Cs – 136	ND	3.8 E-9	2.9 E-9
Cs – 137	8.4 E-5	4.6 E-7	2.1 E-5
Ba – 140	9.3 E-4	3.6 E-5	2.5 E-4
Ce – 141	1.7 E-6	1.8 E-7	5.5 E-7
Ce – 144	ND	1.8 E-7	1.4 E-7
Np – 239	1.1 E-5	ND	2.7 E-6

Table 10-20
AVERAGE INVENTORIES AND ANNUAL RELEASE RATES OF AIRBORNE PARTICULATES FROM THREE BWR's (EPRI MEASUREMENTS)

Inventory (curies)

Nuclide	Half-Life	Reactor		Turbine		Radwaste		Gland Seal Steam and MVP		Total	
Cr – 51	27.8 d	1.2	E-4	1.1	E-4	9.7	E-5	1.4	E-5	3.4	E-4
Mn – 54	313. d	2.4	3	2.0	3	6.3	5	4.3	5	4.5	3
Co – 58	71.4 d	1.0	4	2.6	5	9.8	5	5.5	6	2.3	4
Fe – 59	45. d	4.1	5	7.3	5	1.4	4	2.9	5	2.8	4
Co – 60	5.26 y	3.7	2	1.9	2	4.8	2	7.4	5	1.0	1
Zn – 65	243.7 d	1.1	2	4.0	4	1.6	4	8.5	5	1.3	2
Nb – 95	35.1 d	5.9	6	1.3	6	3.1	5	1.2	5	5.0	5
Zr – 95	65.5 d	1.6	5	2.3	6	3.3	5	2.2	5	7.3	5
Mo – 99	2.78 d	7.3	4	3.8	5	5.2	6	3.5	6	7.8	4
Ru – 103	39.8 d	1.1	5	2.6	5	2.1	5	1.9	5	7.7	5
Sb – 124	60.2 d	1.1	5	1.4	5	5.9	5	2.0	5	1.0	4
Cs – 134	2.06 y	1.5	2	1.5	3	7.9	4	5.1	5	1.7	2
Cs – 136	13. d	2.1	4	6.7	6	2.6	6	4.7	9	2.2	4
Cs – 137	30.2 y	3.1	1	7.0	2	1.6	2	2.9	2	4.3	1
Ba – 140	12.8 d	1.5	3	9.7	4	2.6	5	4.0	4	2.9	3
Ce – 141	32.5 d	9.5	5	2.1	4	1.9	5	2.2	6	3.3	4
Ce – 144	284.4 d	–	–	–	–	–	–	4.8	6	4.8	6
Np – 239	2.35 d	3.7	3	3.8	4	1.2	5	7.8	7	4.1	3
	Total	3.8	E-1	9.5	E-2	6.6	E-2	3.0	E-2	5.7	E-1

Annual Rate (curies)

Nuclide	Reactor		Turbine		Radwaste		Gland Seal Steam and MVP		Total	
Cr – 51	1.1	E-3	1.0	E-3	8.8	E-4	1.3	E-4	3.1	E-3
Mn – 54	1.9	3	1.6	3	5.1	3	3.5	5	8.6	3
Co – 58	3.5	4	9.3	5	3.5	4	2.0	5	8.1	4
Fe – 59	2.3	4	4.1	4	7.9	4	1.6	4	1.6	3
Co – 60	4.8	3	2.5	3	6.4	3	9.7	6	1.4	2
Zn – 65	1.2	2	4.2	4	1.6	4	8.8	5	1.3	2
Nb – 95	4.3	5	9.3	6	2.2	4	8.4	5	3.6	4
Zr – 95	5.9	5	8.4	6	1.3	4	8.4	5	2.8	4
Mo – 99	6.6	2	3.6	3	4.7	4	3.2	4	7.0	2
Ru – 103	6.8	5	1.6	4	1.3	4	1.2	4	4.8	4
Sb – 124	4.6	5	5.7	5	2.5	4	8.4	5	4.4	4
Cs – 134	4.9	3	4.9	4	2.7	4	1.7	5	5.7	3
Cs – 136	4.1	3	1.4	4	5.2	5	9.1	8	4.3	3
Cs – 137	7.1	3	1.6	3	3.8	4	6.6	4	9.7	4
Ba – 140	3.0	2	1.9	2	4.9	4	8.0	3	5.7	2
Ce – 141	7.4	4	1.6	3	1.5	4	1.7	5	2.5	3
Ce – 144	–	–	–	–	–	–	4.3	6	4.3	6
Np – 239	4.0	1	4.0	2	1.3	3	8.4	5	4.4	1
Total	5.3	E-1	7.3	E-2	1.8	E-2	9.9	E-3	6.2	E-1

11. RESULTS FOR PARTICULATE RELEASES

For the reactor building particulate releases the final results, Table 2-5, are the airthmetic mean of measurements by utilities and EPRI. The principal particulate releases, evident from the tabulations here, are Co-60 and Cs-137. The inventories of these species are about 1/3 of a curie, strontium-90 has an inventory of $\lesssim$0.1 curie. This amount is extremely small relative to the estimates of inventories of these isotopes in the system. Appendix F lists the concentrations of radioisotopes in the BWR coolant.

12. COMPARISON OF RESULTS WITH NRC DRAFT REGULATORY GUIDE 1.CC

The annual I-131 releases as developed in this report are different from the latest NRC source term (Regulatory Guide 1.CC (Draft), "Calculation of Releases of Radioactive Materials in Liquid and Gaseous Effluents from Boiling Water Reactors (BWR's)," September 9, 1975. A comparison of results is given in Table 12-1. A detailed comparison of the I-131 releases by source is as follows:

	NRC[a]	GE[a]
Containment Building	0.17	0.091[b]
Auxiliary Building	0.17	
Turbine Building	0.19	0.022
Radwaste Building	0.046	0.034
Main Condenser Mechanical Vacuum Pump	0.03	0.32 (96% CH_3I)

[a] Chemical form not specified by NRC; for GE results see Section 2 for chemical form results.
[b] Reactor building release rate of Mark I plants, and applies to the total containment, fuel and auxiliary buildings releases of Mark III plants.

The results in this report are based upon a more extensive data base than the NRC results. The NRC rates are based on short-term grab samples and observations at Oyster Creek by the NRC. The NRC vacuum pump release is based on results for Dresden 1 which went into commercial service in 1960 and a number of gross assumptions. The Dresden 1 plant is not designed or constructed like other operating BWR's. In this report the MVP release is based primarily on long-term sampling at the Vermont Yankee station during a refueling/maintenance outage.

A difference between the NRC and the results of this report is the estimate of releases during refueling/maintenance outages. The NRC assumed values based on shutdown releases and normal releases only at the Oyster Creek and Vermont Yankee plants. These ratios were based on grab samples, whereas the results reported here are based on measurements during entire shutdown periods for several BWR's.

The proposed NRC staff source term for BWR ventilation releases does not include different radioiodine species. Yet, the documentation for Regulatory Guide 1.CC (Draft) includes references in which the NRC reported measurements of radioiodine chemical forms and also includes studies by GE and Yankee Atomic Power Corporation of radioiodine species.

The NRC value for the reactor water I-131 concentration is 0.005 μCi/ml which is greater than expected coolant concentrations by this report.

The results of this report for mixed noble radiogases indicate release rates almost equal to those listed in proposed Regulatory Guide 1.CC.

Table 2-3 presents the estimated annual noble radiogas HVAC releases for environmental impact evaluations of BWR's. The corresponding totals by the NRC are 324, 3488, and 55 curies/year for the reactor, turbine, and radwaste building exhausts, respectively. The greatest difference occurs for the radwaste building where some new data indicate higher values. These recent radwaste building measurements indicate the presence of very short-lived species. However, in all cases the data basis for the results reported here is larger than used by the NRC. Table 2-4 presents the noble gas nuclides. In this tabulation results are included for the gland seal steam exhaust for BWR's operated without a separate clean steam supply to the turbine seals. These values may be of interest for cost-benefit analyses.

For particulate releases the proposed Regulatory Guide 1.CC (Draft) is based on two limited studies, the AEC study in 1972 that conducted most of its sampling at Oyster Creek and a limited investigation at Vermont Yankee. In this report the most recent EPRI measurements are included for Oyster Creek, Monticello, and Vermont Yankee. In addition, this study includes data routinely reported by the Commonwealth Edison Company for Quad Cities 1 and 2 and Dresden 2 and 3.

Table 12-1
COMPARISON OF PLANT VENTILATION RELEASE RATES IN PROPOSED NRC R.G. 1.CC AND THIS REPORT[a]

Nuclide	NRC	This Report	Difference (NRC – This Report)	Ratio NRC / This Report
		Release Rate (curies /year)		
Iodine				
I – 131	0.606 (I_2)	0.093 (inorganic)	+0.513	6.5
	0.0 (CH_3I)	0.37 (CH_3I)	–0.37	–
I – 133	2.30	NS	–	–
Noble Radiogases[b,d]				
Kr – 89	c	539[e]	–539	–
Xe – 137	c	577[e]	–577	–
Xe – 138	1454	1193	+261	1.2
Xe – 135m	742	1242	–500	0.60
Kr – 87	196	101	+95	1.9
Kr – 88	236	111	+125	2.1
Kr – 85m	74	8	+66	9.3
Xe – 135	1093	1373	–280	0.80
Xe – 133m	d	60	–60	–
Xe – 133	2722	1278	+1444	2.1
Total	6517	6482	+35	1.0
Particulates				
Cr – 51	0.0226	0.005		4.5
Mn – 54	0.0516	0.01		5.2
Co – 58	0.0063	0.002		3.2
Fe – 59	0.0163	0.001		16
Co – 60	0.112	0.04		2.8
Zn – 65	0.0052	0.007		0.74
Zr – 95	0.00095	0.0002		4.8
Sr – 89	0.00668	0.01		0.67
Sr – 90	0.00033	0.002		0.17
Sb – 124	0.00075	0.0004		1.9
Cs – 134	0.0128	0.006		2.1
Cs – 137	0.0196	0.009		2.2
Ba – 140	0.0119	0.03		0.40
Ce – 141	0.0068	0.003		2.3
Nb – 95	NS	5×10^{-4}		–
Rw – 103	NS	3×10^{-4}		–
Ag – 110m	NS	7×10^{-6}		–
Cs – 136	NS	2×10^{-3}		–
Ce – 144	NS	5×10^{-6}		–
Total	0.27	0.13		
		0.13 (excluding last 5 nuclides)		2.1

NS = Not specified

[a]NRC = Regulatory Guide 1.CC (Draft) 9/9/75, p. C-18-20
[b]Kr – 83m, Kr – 85, Xe – 131m releases not determined or less than 1 curie/year
[c]Less than 1 curie/year
[d]GE values exclude gland seal steam release
[e]These results are overestimates, see Table 8-8.

13. RECOMMENDATIONS

The chemical form of I-131 should be measured on a frequent basis, as a routine measurement of airborne releases by utility personnel. The frequency could be once-a-month, with several determinations during the first 2 weeks following a refueling/maintenance shutdown. The recommended measurements would provide utilities with a more realistic basis for the estimation of dose due to the inhalation and ingestion of I-131.

The available data on noble radiogas releases is meager. It is recommended that additional data be obtained from previous utility measurements, and that special measurements be conducted at operating BWR plants. These measurements would entail frequent sampling and monitoring of the exhaust ducts over at least 1-year's period including a refueling/maintenance outage. The measurements should also include investigations of the sources of noble radiogas releases within the various buildings.

The samples of particulates obtained by EPRI were not analyzed for Sr-89 or Sr-90. These samples are still available. Chemical analysis of these samples for Sr-90 is recommended, particularly of the BWR/4 station (Vermont Yankee) which is more representative of expected BWR performance than samples obtained from Oyster Creek or Monticello.

The design of ventilation ducts should include sampling points for the convenient and accurate measurement of air flow rates.

14. ACKNOWLEDGMENTS

The compilation and evaluation of airborne release data was achieved only by the assistance of many personnel. The author appreciates the cooperation and interest of the following groups: Commonwealth Edison Company — Dresden and Quad Cities Health Physics and Chemistry personnel; Northern States Power — Monticello Environmental Monitoring, Health Physics and Chemistry personnel; Yankee Atomic Power Company, Mr. P. Littlefield; Electric Power Research Institute, Dr. H. Till; Nuclear Environmental Services, Dr. C. A. Pelletier and staff; the General Electric Company personnel of the following uits: Radiological and Special Services, Performance Evaluation and Improvements, Product Service, Fuel Mechanical Design, Reactor Chemistry, Safety and Licensing, and Installation and Service Engineering. The author especially thanks J. M. Smith for his encouragement and kindly assistance.

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APPENDIX A
EXPERIMENTAL METHODS FOR THE DETERMINATION OF AIRBORNE EFFLUENT RELEASES

The purpose of this appendix is to briefly describe the experimental methods used to measure airborne releases. Measurements have been made by two independent investigation groups; namely

a. Dr. R. S. Gilbert (deceased) and H. R. Helmholz, et al., for the General Electric Company, and

b. D. C. A. Pelletier, et al., for the Atomic Energy Commission and now for Nuclear Environmental Services.

In addition, chemists at the various BWR stations perform analyses of airborne releases by procedures accepted by the NRC. Utility data are generally in good agreement with EPRI, within 20%. According to an NRC study, less than 0.4% of the iodine penetrates the CESCO cartridges, used by utilities for iodine sampling, indicating total adsorption of all forms of I-131 (Reference A-1). Table A-1 summarizes the methods employed to determine I-131 releases. The most reliable results are probably from the extensive studies by EPRI, based on samplers evolved from tests started in the late 1960's by Keller, et al. (Reference A-2).

A-1. IODINE-131 MEASUREMENTS

1. AEC Samplers

The samplers used by the AEC were developed by and installed under the direction of Dr. J. H. Keller, Allied Chemical Corporation (References A-2 and A-3).

Total Iodine

CESCO Type B cartridge, which is about 2 inches in diameter and an unimpregnated charcoal bed depth of 5/8 inch.

Iodine Species

In the direction of a flow, the absorbers and species absorbed are as follows:

a. Three glass fiber filters — particulates and some elemental iodine,

b. Cadmium iodide — elemental iodine, I_2;

c. 4-iodophenol — hypoiodous acid, HOI; and

d. Silver zeolite — organic iodide.

2. GE Samplers

Total Iodine

CESCO cartridges, like AEC for earlier tests in 1973, stated to use silver zeolite, 150 grams.

Iodine Species

In the direction of flow the absorbers are as follows:

a. Glass fiber (early tests used Millipore paper 0.8 to 1.2 microns)

b. Cadmium iodide, 100 grams

c. 4-Iodophenol, 150 grams

d. Silver zeolite, 150 grams

The species sampler is approximately 3.5 inches in diameter and each absorbent is in a separate aluminum cartridge. The bed depth of each absorbent is approximately 1 inch (Reference A-4).

3. NES Samplers (EPRI Program)

Particulates

Absolute filter paper type HEPA F700, 5 inches in diameter, supported by a glass frit in glass domes.

Total Iodine

A series of solid absorbents in a 2-in.-diameter cylinder (PVC) with a total absorbent bed depth of approximately 4 inches. The absorbents are preceded by filter paper, type HEPA F700 or Whatman 40. In the direction of air flow the absorbents are as follows:

a. Charcoal type G-618, TEDA impregnated, 8—16 mesh, 22 grams;

b. Silver zeolite, 8—12 mesh, 60 grams (samples after 12/26/74 use 22 grams of G-618 TEDA impregnated 8x8 mesh charcoal in place of silver zeolite); and

c. Charcoal type G-618 TEDA impregnated, 22 grams.

Filter paper is placed after the last bed of charcoal.

Iodine Species

In the direction of flow the absorbents are as follows.

a. Particulate filter (HEPA F700 paper), 1-1/16 in. diameter;

b. Cadmium iodide, (7 grams, 30—60 mesh);

c. 4-iodophenol, (18 grams);

d. Silver zeolite, (17 grams, 20—40 mesh); and

e. Activated charcoal (9 grams, Type BC-151, 20—40 mesh).

The absorbents in the samplers are separated by absolute filter paper. The activity collected on the absorbents is measured by gamma-ray spectrometers using Ge(Li) detectors. For further details of the NES samplers and procedures, the reader is referred to Reference A-5.

A-2. MIXED NOBLE RADIOGAS MEASUREMENTS

Gas samples are collected in small flasks and analyzed by means of Ge(Li) detectors based on the gamma rays emitted by the radioactive nuclides. Various spectrometers have been used by NES and GE personnel. In some studies by GE a cryogenic sampling system has been employed to concentrate the noble radiogas activity.

A-3. PARTICULATES

Samples are collected on particulate filters and analyzed by gamma spectra analysis, except for Sr-89 and Sr-90. These isotopes are chemically separated and their beta activity determined using a low background counter. Details of the methods are available in the reference reports (see Bibliography).

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A-5. Nuclear Environmental Services, January 31, 1975 Plans and Procedures, "Evaluation of Radioiodine Sources and Other Radionuclide Effluents at Nuclear Power Stations," Report to Electric Power Research Institute (Contract RP 274-1).

Table A-1
MEASUREMENT METHODS FOR IODINE-131

Organization	Species	Method	Nominal Flow (cfm)
NES	Particulate	Filter Paper	1
NES	Total Iodine	Solid Adsorbents	1
NES	Particulates, I_2, HOI, CH_3I	Filter/Solid Adsorbents	1
AEC	Total Iodine	CESCO Cartridge (Charcoal) and Silver Zeolite	1–2
AEC	Particulates, I_2, HOI, CH_3I	Filter Paper/Solid Adsorbents	1–2
GE	Total Iodine	CESCO Cartridge (Charcoal)	1
GE	Particulates, I_2, HOI, CH_3I	Filter Paper/Solid Adsorbents	1
Utilities	Particulates	Filter Paper	NA
Utilities	Total Iodine	CESCO Cartridge	NA

NA = Not Available

APPENDIX B
SELECTED SURVEY OF DOMESTIC BWR STATIONS[a]

Plant	BWR Type	Rated Power (MWt)	Commercial Service Year	Reactor Water Clean Up System Type	Architect-Engineer	Utility
Oyster Creek	2	1600	1969	Deep-bed	Burns & Roe	Jersey Central
Nine Mile Point 1	2	1538	1970	Deep-bed	Niagara Mohawk	Niagara Mohawk
Millstone	3	2011	1971	Deep-bed	Ebasco	Northeast Utilities
Monticello	3	1670	1971	Powdex[b]	Bechtel	Northern States Power
Dresden 2	3	2527	1971	Deep-bed	Sargent & Lundy	Commonwealth Edison
Dresden 3	3	2527	1971	Deep-bed	Sargent & Lundy	Commonwealth Edison
Quad Cities 1	3	2511	1972	Powdex	Sargent & Lundy	Commonwealth Edison
Quad Cities 2	3	2511	1972	Powdex	Sargent & Lundy	Commonwealth Edison
Pilgrim 1	3	1912	1972	Powdex	Bechtel	Boston Edison
Vermont Yankee	4	1593	1972	Powdex	Ebasco	Yankee Atomic Power
Peach Bottom 2	4	3293	1974	Powdex	Bechtel	Philadelphia Electric
Peach Bottom 3	4	3293	1975	Powdex	Bechtel	Philadelphia Electric
Cooper 1	4	2381	1974	Powdex	Burns & Roe	Nebraska Public Power
Duane Arnold	4	1593	1974	Powdex	Bechtel	Iowa Electric

[a] All plants have Mark I containments.

[b] Powdex or equivalent resin.

APPENDIX C
BWR PRESSURE SUPPRESSION CONTAINMENT DESIGNS

The three pressure suppression containment designs are shown in Figure C-1.

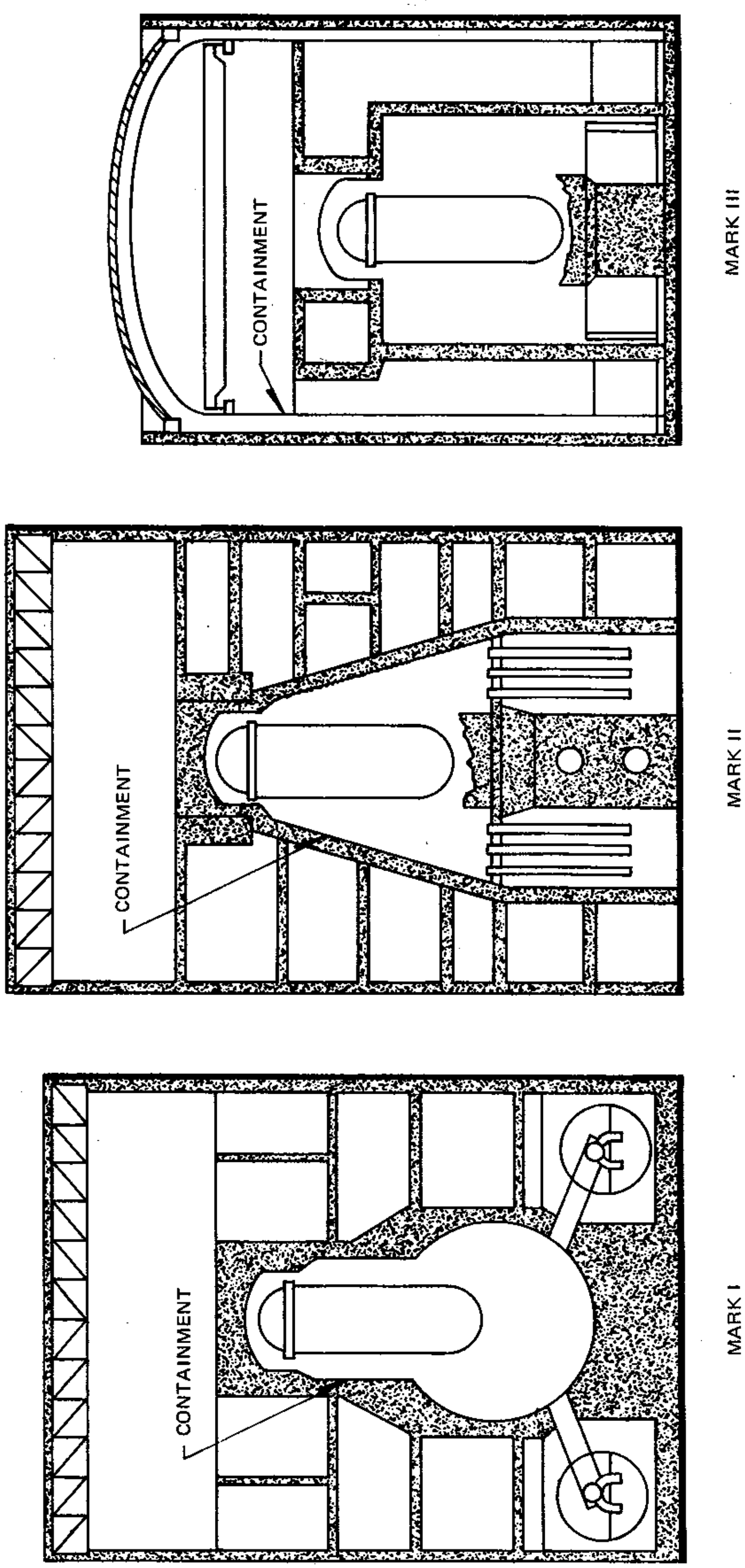

Figure C-1. Pressure Suppression Containments Configurations

APPENDIX D
SUMMARY OF BWR IODINE-131 AIRBORNE RELEASES FROM PROCESS AND HVAC EXHAUSTS, 1970 TO 1975

The airborne releases are given in Table D-1.

REFERENCES FOR EUROPEAN PLANTS

P. Recht, editor, "Radioactive Effluents From Nuclear Power Stations in the Community, Discharge Data Radiological Aspects," Commission of the European communities, directorate — general for social affairs, directorate of health protection, NP-20286 (April 1974).

Table D-1
SUMMARY OF BWR IODINE-131 AIRBORNE RELEASES FROM BWR PROCESS AND HVAC EXHAUSTS, 1970 TO 1975

BWR Type	Plant(s)	Commercial Service (month/year)	Curies Per Year 1970	1971	1972	1973	1974	1975*
1	Dresden 1	8/1960		0.58	2.461	0.47	<0.44	0.48
1	Humboldt Bay	8/1963	0.35	0.30	0.40	0.17		
2	Nine Mile Point 1	12/1969	<0.06	0.78	0.95	1.96	0.72	
2	Oyster Creek	12/1969	0.32	2.14	6.48	6.73	3.31	4.02
3	Dresden 2 and 3 (Process & Vent)	7/1971 and 11/1971		8.11	5.073	5.20	3.91	0.408
	Reactor Buildings, HVAC, Only				<0.05 (1)	0.06 (1)	0.14 (4)	0.058 (14)
3	Millstone	3/1971		3.46	1.23	0.15	3.18	6.91
3	Monticello	7/1971		0.052	0.59	1.20	5.69	1.53
	Reactor, Turbine, and Radwaste Buildings				– –	– –	1.38 (24)	0.91 (59)
3	Pilgrim 1	12/1972			0.03	0.46	1.45	1.173
	Reactor, Turbine, and Radwaste Buildings					0.09 (20)	0.16 (11)	0.633 (54)
3	Quad Cities 1 and 2				0.73	5.49	8.80	0.21
	Reactor Buildings					0.077 (2)	0.17 (2)	0.07 (33)
4	Vermont Yankee	11/1972			0.17	0.07	0.35	–
4	Cooper 1	7/1974					<0.013	0.0025
4	Duane Arnold	2/1975					0.01[a]	–
4	Browns Ferry 1 and 2	8/1974 and 12/1974					0.02	–
4	Peach Bottom 2 and 3	7/1974 and 12/1974					<0.01	0.022[a]
4	Fitzpatrick							<0.0075[a]

[a]Iodine and particulates with half-lives >8 days.

NOTE: Numbers in parentheses are percentages of total plant(s) release.

Table D-1
SUMMARY OF BWR IODINE-131 AIRBORNE RELEASES FROM BWR PROCESS AND HVAC EXHAUSTS, 1970 TO 1975 (Continued)

BWR Type	Plant(s)	Commercial Service (month/year)	1970	1971	1972
	Foreign			**Curies per year**	
1	VAK (Kahl)	6/1961	0.6	0.0029	–
1	KRB (Gundremmingen)	4/1967	0.2	0.35	0.19
1	Garigliano (Caserta)	1/1964	0.06	0.13	0.06
1	Dodewaard (Gelderland)	10/1968	0.0063	0.0063	0.006

APPENDIX E
GE-BWR NOBLE RADIOGAS EMISSION EXPERIENCE

Plant	Emission Limit (mCi/s) Best Estimate	Emission Limit (mCi/s) Tech Spec	Actual Annual Average Emission (mCi/s) '60	'61	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74	First Half '75
Dresden 1	700	560	<1	<1	2	2	17	20	23	8	8	23	30	24	31	25	3	23
Big Rock Point	2600	1000			–	<1	<1	4	23	9	9	6	9	9	8	7		
Humboldt Bay	125	50			–	<1	<1	8	8	29	28	16	17	16	14	11	18	
Garigliano	1000	1000				–	<1	<1	<1	1	3	4	9	20	10			
Gundremmingen	1500	68						–	<1	<1	<1	<1	<1	<1	<1			
Tarapur 1 & 2	580	580									–	3	19	67	38			
Oyster Creek	600	300									–	<1	4	16	28	26	9	10
Nine Mile Point	800	800										<1	<1	8	16	27	19	45
Tsuruga	500	50										–	2	4	<1			
Dresden 2 & 3	1800	900										–	9	18	14	28	20	21
Millstone Point	820	820										–	<1	9	23	3	29	119
Fukushima 1	500	50										–	<1	2	4			
Nuclenor	600	600											–	30	63			
Monticello	480	270											–	3	24	27	50	6
Pilgrim	240	100												–	<1	7	17	3
Vermont Yankee	620	220												–	2	6	2	<0.15
Quad Cities 1 & 2	670	340												–	4	28	30	5
Peach Bottom 2/3															–	<1	<1	0.4
Brown's Ferry 1/2																–	<1	
Cooper																–	<1	<1
Duane Arnold																–	<1	<1
Fitzpatrick																	–	<1

APPENDIX F
CONCENTRATION OF PARTICULATES AND SELECTED ISOTOPES IN PRINCIPAL FLUID STREAMS OF THE REFERENCE BWR (μCi/gm)[a]

Isotope	Reactor Water	Reactor Steam
Na-24	9 E-3	9 E-6
P-32	2 E-4	2 E-7
Cr-51	5 E-3	5 E-6
Mn-54	6 E-5	6 E-8
Mn-56	5 E-2	5 E-5
Fe-55	1 E-3	1 E-6
Fe-59	3 E-5	3 E-8
Co-58	2 E-4	2 E-7
Co-60	4 E-4	4 E-7
Ni-63	1 E-6	1 E-9
Ni-65	3 E-4	3 E-7
Cu-64	3 E-2	3 E-5
Zn-65	2 E-4	2 E-7
Zn-69m	2 E-3	2 E-6
Sr-89	1 E-4	1 E-7
Sr-90	6 E-6	6 E-9
Sr-91	4 E-3	4 E-6
Sr-92	1 E-2	1 E-5
Y-91	4 E-5	4 E-8
Y-92	6 E-3	6 E-6
Y-93	4 E-3	4 E-6
Zr-95	7 E-6	7 E-9
Zr-97	5 E-6	5 E-9
Nb-95	7 E-6	7 E-9
Nb-98	4 E-3	4 E-6
Mo-99	2 E-3	2 E-6
Tc-99m	2 E-2	2 E-5
Tc-101	9 E-2	9 E-5
Tc-104	8 E-2	8 E-5
Ru-103	2 E-5	2 E-8
Ru-105	2 E-3	2 E-6
Ru-106	3 E-6	3 E-9
Ag-110m	1 E-6	1 E-9
Te-129m	4 E-5	4 E-8
Te-131m	1 E-4	1 E-7
Te-132	1 E-5	1 E-8
Ba-139	1 E-2	1 E-5
Ba-140	4 E-4	4 E-7
Ba-141	1 E-2	1 E-5
Ba-142	6 E-3	6 E-6
La-142	5 E-3	5 E-6
Ce-141	3 E-5	3 E-8
Ce-143	3 E-5	3 E-8
Ce-144	3 E-6	3 E-9
Pr-143	4 E-5	4 E-8
Nd-147	3 E-6	3 E-9
W-187	3 E-4	3 E-7
Np-239	7 E-3	7 E-6

[a]ANS 18.1 Working Group, July 7, 1975, "Radioactive Materials in Principal Fluid Streams of Light-Water-Cooled Nuclear Power Plants," Proposed American National Standard, N237. Revision 2.