EPRI

REVIEW OF IODINE SPIKE DATA FROM PWR POWER PLANTS IN RELATION TO SGTR WITH MSLB

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A. K. Postma

Benton City Technology
Dallas, Oregon 97338

Prepared for
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303

EPRI Project Manager
D. A. Steininger

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Organization that prepared this report:

Benton City Technology

ABSTRACT

A review of iodine spiking in PWRs was carried out in order to compare a current spiking data base with methodology formalized in the Standard Review Plan (SRP) published by the Nuclear Regulatory Commission (NRC) in 1981. Two spike cases in the SRP (a pre-existing spike and an accident-initiated spike) are important because they prescribe iodine source terms for MSLB/SGTR accident sequences. Available spike data (several hundred spikes) were analyzed to quantity mean values and distribution parameters for measured peak concentrations (μCi/g) and release rates (Ci/hr) calculated from concentration-time data pairs. The highest peak concentration reported during the past decade was 9 μCi/g. This value is appreciably smaller than the SRP value of 60 μCi/g for the pre-existing spike case. The accident-initiated spike case was analyzed by integrating calculated release rates over an initial two hour period. Based on this analysis, it was concluded that two hour average concentrations calculated for the accident-initiated spike case were bounded by the measured peak concentrations. The highest release rates computed from available data were lower by more than an order of magnitude than those prescribed in the SRP.

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SUMMARY AND CONCLUSIONS

Summary

This report presents results from a review of available data on iodine spiking phenomena in pressurized water reactors (PWRs). The phenomenon of interest herein is the increase in iodine release rate from fuel into primary coolant as a result of a reactor transient (power transient, pressure transient, etc). The magnitude of the temporary increase in iodine release rate (the so-called spike) is important because the iodine in primary coolant represents a source term in postulated accidents involving steam generator tube ruptures (SGTR) with a concurrent main steam line break (MSLB).

Two types of iodine spiking events are identified in standard review plan (SRP) methodology (NRC-1981). The first is a transient-induced spike that is assumed to occur prior to the SGTR/MSLB event. The SGTR/MSLB event is assumed to occur at the time when iodine concentration in primary coolant is maximum. The second event involves a spike induced by the SGTR/MSLB event itself. For this event the primary coolant iodine concentration is predicted on the basis of a prescribed release rate from fuel.

During the past decade the data base on iodine spiking phenomena has been appreciably expanded as compared to that which existed when SRP methodology was formulated. The objective of the present study was to evaluate and compare currently available data on iodine spiking with SRP methodology. Specifically, it is the iodine concentration in primary coolant (μCi/g) over the initial two hour time period that is of interest in this report.

The sample of available spike events has been analyzed to quantify peak iodine concentrations (μCi/g) and release rates (Ci/hr). An assumption of the present study is that the available sample of spike events is representative of the population of spikes that could occur in postulated SGTR/MSLB accident sequences.

Conclusions

The following conclusions and summary statements characterize the finding of this review.

1. Iodine release rates computed from spike data are significantly smaller than rates prescribed in the SRP. For example a realistic analysis of 95 spikes indicated that 98% had release rates of 795 Ci/hr or less. The largest release rate was 1000 Ci/hr. These rates are small compared to a release rate of ~15,000 Ci/hr calculated using SRP methodology.

2. Peak I-131 concentrations in spikes have trended lower with time, possibly as a result of improved fuel manufacturing processes. For times after 1980, measured peak spike concentrations have fallen below 9 μCi/g. This value is lower than the 60 μCi/g stipulated in SRP methodology by a factor of 6.7.

3. Available spike concentration-time data were analyzed by treating each spike as a pre-existing spike and as an accident-initiated spike. For the accident-initiated spike case, concentrations over the initial two hour time period were predicted for zero iodine removal by the reactor coolant cleanup system. Comparison of two hour average concentrations for the two cases indicates that the pre-existing spike case dominates.

4. Equilibrium I-131 concentrations (prior to 219 spike events) have a log-mean of 0.027 μCi/g. For 95% of these analyzed events, the equilibrium concentration was 0.3 μCi/g or less.

5. Equilibrium I-131 release rates, computed from equilibrium concentrations, have a log-mean of 0.47 Ci/h. For 95% of these analyzed events, the calculated equilibrium release rate is 5.6 Ci/h or less.

6. Peak I-131 concentrations for 189 spike events that occurred from 1970 through 1988 have a log-mean of 0.30 μCi/g. 95% of these events had peak concentrations of 8.2 μCi/g or less.

7. Best-estimate release rates of I-131 for 95 spike events have a log-mean of 74.5 Ci/h. For 95% of these analyzed events, the release rates were 562 Ci/h or less.

8. Conservatively calculated I-131 release rates published by Adams (1989b) are ~3.3 times larger than realistic estimates. For these conservatively calculated spike rates (168 events), 95% of the calculated rates are 1280 Ci/hr or less.

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OBJECTIVE AND SCOPE

Objective

The objective of this study is to obtain estimates of iodine concentrations in primary coolant in PWRs under postulated SGTR/MSLB accident conditions. Focus is on iodine concentration during the initial two-hour period of the postulated accident. The goal is to compare estimates based on the current extensive data base with those specified under SRP methodology which in turn was based on a relatively sparse data base.

Scope

The following statements characterize the scope of this study.

- The sample of available characterized spikes included spikes caused by the thermal (reactor power) and pressure transients and it is assumed that the analyzed spikes are representative of those which could occur in the postulated SGTR/MSLB accident sequence. Iodine spiking caused by reactor transients is treated phenomenologically. No attempt is made to develop a mechanistic understanding of this observed phenomenon.

- Available, non-proprietary, data in published reports is used as the data base.

- Two spike cases, as described in the SRP, are considered: (1) a pre-accident spike caused by a reactor transient and (2) a spike induced by the assumed accident.

- Data are analyzed by simple calculational methods which put the data into perspective. Detailed statistical testing of the data sets is not done.

3

BACKGROUND

In this report section, iodine spiking phenomenology is briefly discussed. The purpose of the discussion is to provide a baseline for interpreting the data to be presented in following report sections.

Iodine Spiking Phenomena

The word "spike" is used herein to characterize a temporary increase in iodine concentration in reactor coolant water as a result of a reactor transient. Under steady state operation, iodine escapes at a low rate from fuel rods and enters the coolant water. The escape rate is balanced by the cleanup rate of the primary water purification system. The result is a low equilibrium concentration of iodine in primary coolant water, of the order of 0.04 μCi per gram of coolant, I-131 equivalent.

Experience has shown that changes in operating conditions (power or pressure change) can cause an increase in release rate of iodine which is reflected in a temporary increase in the iodine concentration in coolant water. With time the operation of the cleanup system lowers the iodine concentration to a low steady state value as noted above.

Typically, the peak in iodine concentration occurs from two to ten hours after the transient itself has occurred (Lutz-1975).

Current Data Base on Iodine Spiking

Early studies of iodine spiking were carried out by several reactor vendors. General Electric published a study applicable to boiling water reactors (BWRs) in 1972 (Brutschy-1972). Westinghouse published an analysis of iodine spiking in PWRs in 1975 (Lutz-1975) and Combustion Engineering followed with a report on both PWRs and BWRs in 1976 (Caruthers and Green-1976). Data in the latter report is considered proprietary by Combustion Engineering, and hence data presented by Caruthers and Green-1976 will not be considered herein.

Pasedag (1977) describes a spiking model applicable to both BWRs and PWRs, and also presents specific data on thermal hydraulic parameters and iodine concentrations for spiking events in a number of commercial power plants.

Recent studies of iodine spiking in commercial PWRs have been carried out under sponsorship by the Nuclear Regulatory Commission (NRC) and have been published by Adams-1989a, 1989b. As will be shown in the next report section, the major fraction of the current data base on iodine spiking in PWRs is embodied in the reports of Adams (1989a, 1989b).

Iodine Source Terms in Analyzed Accidents

Based on the Standard Review Plan (SRP), acceptance criteria for the siting of PWRs require that calculated iodine doses for SGTR/MSLB accidents do not exceed 10% of those stipulated in 10 CFR Part 100 (NRC-1981). The doses are calculated for a two-hour exposure period and hence iodine transport over the initial two-hour segment of an accident sequence is of prime interest.

Two cases of iodine spikes are analyzed under SRP methodology. In the first, it is assumed that a pre-accident transient has caused the I-131 equivalent concentration to increase to 60 µCi/g (NRC-1993). This concentration is then assumed to remain constant for the two hour calculational period. It is assumed that the primary coolant cleanup system is not operable for the two hour period of analysis.

The second case involves a coincident spike which is quantified in terms of a release rate from fuel, under the assumption that the cleanup system is inoperable. The rate is calculated as 500 times the release rate which gives a reactor coolant activity of 1.0 µCi/g.

It is these two spike cases that will be the focus of the review of data in Section 4.0.

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REVIEW OF IODINE CONCENTRATIONS AND CALCULATED RELEASE RATES IN CHARACTERIZED SPIKE EVENTS

Equilibrium Concentrations and Rates

Equilibrium Iodine Concentrations

Equilibrium iodine concentrations are defined herein as steady-state values that are reached after a reactor has operated under reasonably constant conditions for many hours.

In each reported spike event, the equilibrium concentration was used as a baseline against which the spike could be compared. A total of 219 events were selected for evaluation as follows.

Lutz (1975) analyzed spikes associated with 12 power transients and a number of depressurization transients. Only those data applicable to power transients were included here because for depressurization transients the pre-spike iodine concentration was affected by the earlier power transient typically associated with depressurization events.

Pasedag (1977) analyzed 33 spike events but only three were used here. The other 30 events were either already included in the 12 data of Lutz (see above paragraph) or resulted from depressurization events.

Adams (1989a) presents initial concentrations for 58 events analyzed for spike release rate. Three of the 58 events were taken from Lutz (1975); hence 55 unique events were available and included in this data base. It should be noted that Adams (1989a) selected the 58 events from a sample of 144 events that had been chosen from a larger population. In order to be included in the 144 event sample, the peak spike iodine concentration had to equal or exceed 1μCi/g. Events with peaks below 1μCi/g were excluded by Adams(1989a). Thus the 55 events taken from Adams (1989a) may have initial concentrations that are biased toward the high side.

Adams (1989b) presents initial iodine concentrations for 168 events analyzed for rate of release. Of these, 19 events were listed for which the measured peak spike concentration was equal to or lower than the initial concentration and it was not obvious that a spike had occurred. These 19 events were excluded from rate analyses presented later in this report, and hence were excluded from the data set on equilibrium concentration. A net number of 149 data points were selected from the 168 data point set presented by Adams (1989b).

The mean and standard deviation of the 219 (12 + 3 + 55 + 149) point data set was calculated for both the concentrations and their logarithms. The sample mean and standard deviation were:

sample mean = 0.082 μCi/g

std. deviation = 0.13 μCi/g

The logarithmic distribution parameters were calculated by simply working with the logarithm of each concentration rather than the concentration itself. The log-mean and geometric standard deviation were then expressed by taking the antilog of the corresponding parameter. Results are:

log-mean = 0.027 μCi/g

geometric std. deviation = 6.3.

The reader is reminded that the geometric std. deviation stated above is a unitless number that represents the ratio of concentration at 1 std. deviation to the mean concentration.

The distribution of equilibrium iodine concentrations for the 219 point data set is illustrated by a graph with log-normal coordinates in Figure 4-1. A log-normal distribution can be represented by a straight line on these coordinates.

The data set was arbitrarily divided into 10 bins of equal width (based on logarithms) and the accumulated percent of events having concentrations equal to or smaller than the upper limit of the respective bins was plotted as open circles on Figure 4-1.

Also shown on Figure 4-1 is a straight line that represents a log-normal distribution having the log-mean and geometric standard deviation of the 219 point data set. For these data, the log-normal line goes through the point set but does not accurately represent the actual data. The benefit of the plot is that the bulk of the data is presented on a simple graph, allowing the reader to see how the concentrations are distributed, and how well the data fit a log-normal distribution.

The entire data set is also exhibited in tabular form in Table 4-1 where the nominal cumulative probability is calculated for each point. Also, the reference for each data point is listed. As indicated, 50% of the observations have concentrations higher and lower than 0.045 μCi/g, the median. At the higher concentration end, 90% of the events have concentrations of 0.2 μCi/g or lower. At the 95 percentile of the empirical distribution, the corresponding concentration is 0.33 μCi/g. Finally, 98% of the events have concentrations of 0.56 μCi/g or less. The maximum reported initial concentration was 0.94 μCi/g.

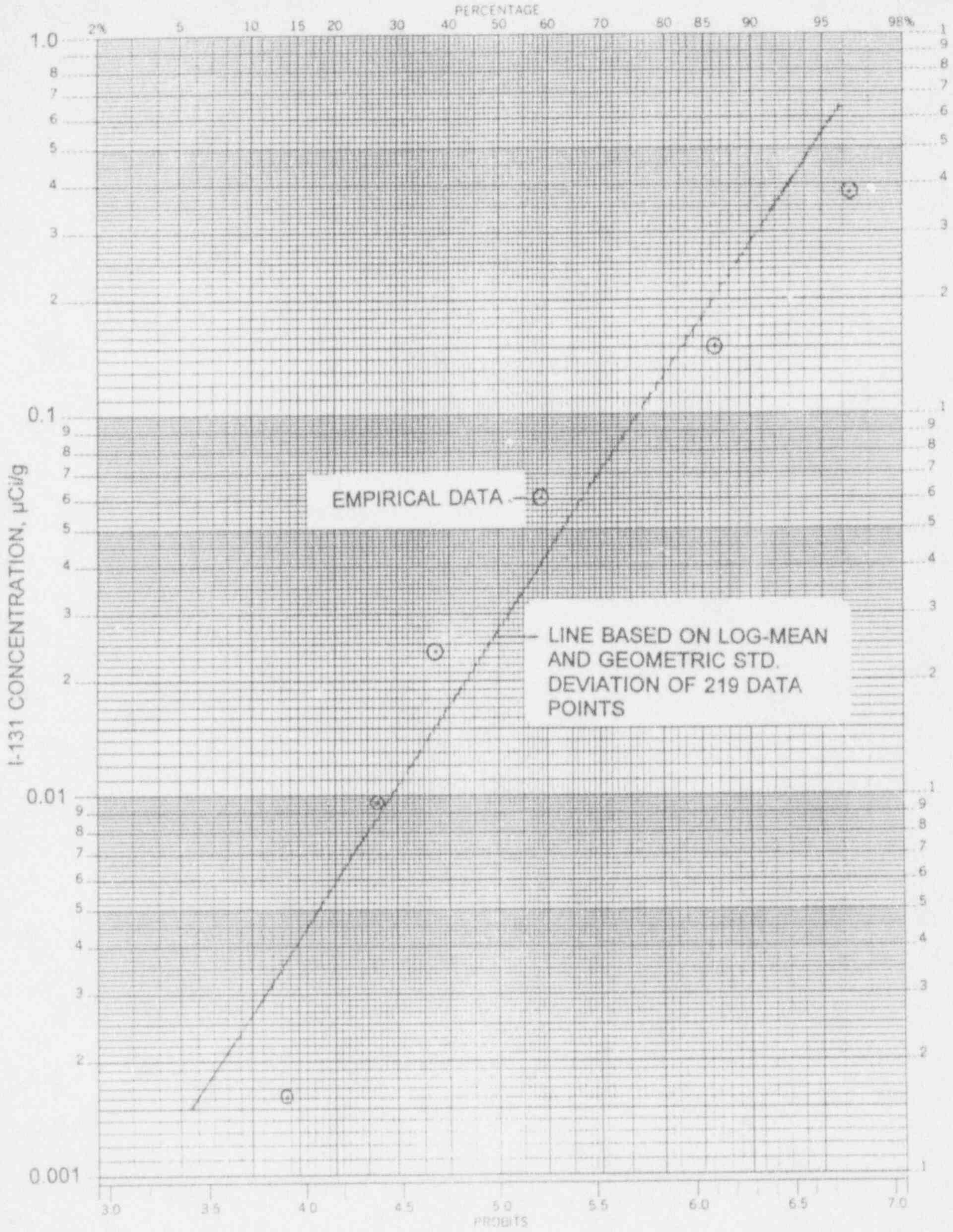


Figure 4-1
Probability Distribution for Equilibrium I-131 Concentration

Table 4-1
Equilibrium Iodine Concentrations Measured Prior to 219 Spike Events

TABLE 4-1

Event Rank No.	Equil. Conc. µCi/g	Cumul. Prob.	Data Reference	Event Rank No.	Equil. Conc. µCi/g	Cumul. Prob.	Data Reference
1	0.0001	0.005	Adams-1989b	24	0.003	0.109	Adams-1989b
2	0.0001	0.009	Adams-1989b	25	0.003	0.113	Adams-1989b
3	0.0001	0.014	Adams-1989b	26	0.003	0.118	Adams-1989b
4	0.0002	0.018	Adams-1989b	27	0.003	0.123	Adams-1989b
5	0.0002	0.023	Adams-1989b	28	0.0032	0.127	Adams-1989b
6	0.0002	0.027	Adams-1989b	29	0.0036	0.132	Adams-1989b
7	0.0003	0.038	Adams-1989b	30	0.0037	0.136	Adams-1989b
8	0.0004	0.036	Adams-1989b	31	0.004	0.141	Adams-1989b
9	0.0005	0.041	Adams-1989b	32	0.004	0.145	Adams-1989b
10	0.0006	0.045	Adams-1989b	33	0.004	0.150	Adams-1989b
11	0.0006	0.050	Adams-1989b	34	0.004	0.155	Adams-1989b
12	0.0007	0.055	Adams-1989b	35	0.004	0.159	Adams-1989a
13	0.0007	0.059	Adams-1989b	36	0.0041	0.164	Adams-1989b
14	0.0008	0.064	Adams-1989b	37	0.0043	0.168	Adams-1989b
15	0.0011	0.068	Adams-1989b	38	0.0047	0.173	Adams-1989b
16	0.0012	0.073	Adams-1989b	39	0.005	0.177	Adams-1989b
17	0.0014	0.077	Adams-1989b	40	0.0051	0.182	Adams-1989b
18	0.0016	0.082	Adams-1989b	41	0.0053	0.186	Adams-1989b
19	0.002	0.086	Adams-1989b	42	0.0055	0.191	Adams-1989b
20	0.002	0.091	Adams-1989b	43	0.0055	0.195	Adams-1989b
21	0.0021	0.095	Adams-1989b	44	0.0055	0.200	Adams-1989b
22	0.0022	0.100	Adams-1989b	45	0.0056	0.205	Adams-1989b
23	0.0024	0.105	Adams-1989b	46	0.0059	0.209	Adams-1989b

TABLE 4-1

Event Rank No.	Equil. Conc. µCi/g	Cumul. Prob.	Data Reference	Event Rank No.	Equil. Conc. µCi/g	Cumul. Prob.	Data Reference
47	0.0065	0.214	Adams-1989b	75	0.016	0.341	Adams-1989b
48	0.0066	0.218	Adams-1989a	76	0.016	0.345	Adams-1989b
49	0.0068	0.223	Adams-1989b	77	0.0172	0.350	Adams-1989b
50	0.0069	0.227	Adams-1989b	78	0.02	0.355	Adams-1989a
51	0.0069	0.232	Adams-1989b	79	0.02	0.359	Adams-1989a
52	0.007	0.236	Adams-1989b	80	0.0215	0.364	Adams-1989b
53	0.007	0.241	Adams-1989b	81	0.022	0.368	Adams-1989b
54	0.0079	0.245	Adams-1989b	82	0.024	0.372	Adams-1989b
55	0.008	0.250	Adams-1989b	83	0.024	0.377	Adams-1989b
56	0.0083	0.255	Adams-1989b	84	0.0252	0.382	Adams-1989b
57	0.0084	0.259	Adams-1989b	85	0.026	0.386	Adams-1989b
58	0.0086	0.264	Adams-1989b	86	0.0286	0.391	Adams-1989b
59	0.009	0.268	Adams-1989b	87	0.0298	0.395	Adams-1989b
60	0.01	0.273	Adams-1989a	88	0.03	0.400	Lutz-1975
61	0.0108	0.277	Adams-1989b	89	0.03	0.405	Adams-1989a
62	0.011	0.282	Adams-1989b	90	0.0308	0.409	Adams-1989b
63	0.011	0.286	Adams-1989b	91	0.033	0.414	Adams-1989a
64	0.0117	0.291	Adams-1989b	92	0.033	0.418	Adams-1989b
65	0.013	0.295	Adams-1989a	93	0.036	0.423	Adams-1989b
66	0.013	0.300	Adams-1989b	94	0.0365	0.427	Adams-1989a
67	0.013	0.305	Adams-1989b	95	0.037	0.432	Adams-1989a
68	0.0132	0.309	Adams-1989b	96	0.037	0.436	Lutz-1975
69	0.0138	0.314	Adams-1989b	97	0.04	0.441	Adams-1989b
70	0.014	0.318	Adams-1989b	98	0.0401	0.445	Adams-1989b
71	0.014	0.323	Adams-1989a	99	0.0406	0.450	Adams-1989b
72	0.015	0.327	Adams-1989b	100	0.041	0.455	Adams-1989b
73	0.015	0.332	Adams-1989b	101	0.041	0.459	Lutz-1975
74	0.015	0.336	Pasedag-1977	102	0.0417	0.464	Adams-1989b

TABLE 4-1

Event Rank No.	Equil. Conc. µCi/g	Cumul. Prob.	Data Reference	Event Rank No.	Equil. Conc. µCi/g	Cumul. Prob.	Data Reference
103	0.042	0.468	Adams-1989a	131	0.061	0.595	Lutz-1975
104	0.042	0.473	Adams-1989a	132	0.0619	0.600	Adams-1989b
105	0.0423	0.477	Adams-1989b	133	0.062	0.605	Adams-1989b
106	0.044	0.482	Adams-1989b	134	0.0647	0.609	Adams-1989b
107	0.0443	0.486	Adams-1989b	135	0.0647	0.614	Adams-1989b
108	0.0449	0.491	Adams-1989b	136	0.065	0.618	Adams-1989b
109	0.045	0.495	Adams-1989b	137	0.0686	0.623	Adams-1989b
110	0.045	0.500	Adams-1989a	138	0.0687	0.627	Adams-1989a
111	0.045	0.505	Adams-1989a	139	0.0702	0.632	Adams-1989b
112	0.0455	0.509	Adams-1989b	140	0.071	0.636	Adams-1989b
113	0.047	0.514	Adams-1989b	141	0.0725	0.641	Adams-1989a
114	0.048	0.518	Adams-1989b	142	0.074	0.645	Adams-1989b
115	0.05	0.523	Lutz-1975	143	0.0743	0.650	Adams-1989b
116	0.05	0.527	Adams-1989b	144	0.0744	0.655	Adams-1989b
117	0.05	0.532	Adams-1989b	145	0.075	0.659	Adams-1989a
118	0.05	0.536	Adams-1989b	146	0.075	0.664	Adams-1989a
119	0.0504	0.541	Adams-1989b	147	0.076	0.668	Adams-1989b
120	0.0505	0.545	Adams-1989b	148	0.076	0.673	Adams-1989b
121	0.051	0.550	Lutz-1975	149	0.0761	0.677	Adams-1989b
122	0.053	0.555	Adams-1989a	150	0.0761	0.682	Adams-1989a
123	0.0551	0.559	Adams-1989b	151	0.0769	0.686	Adams-1989a
124	0.056	0.564	Adams-1989b	152	0.077	0.691	Adams-1989a
125	0.057	0.568	Adams-1989b	153	0.0782	0.695	Adams-1989b
126	0.0575	0.573	Adams-1989b	154	0.0789	0.700	Adams-1989b
127	0.059	0.577	Adams-1989b	155	0.083	0.705	Adams-1989b
128	0.06	0.582	Adams-1989a	156	0.084	0.709	Adams-1989b
129	0.061	0.586	Adams-1989a	157	0.085	0.714	Adams-1989a
130	0.061	0.591	Adams-1989a	158	0.087	0.718	Adams-1989b

TABLE 4-1

Event Rank No.	Equil. Conc. µCi/g	Cumul. Prob.	Data Reference	Event Rank No.	Equil. Conc. µCi/g	Cumul. Prob.	Data Reference
159	0.09	0.723	Adams-1989a	185	0.13	0.841	Adams-1989b
160	0.09	0.727	Adams-1989a	186	0.13	0.845	Adams-1989a
161	0.0905	0.732	Adams-1989a	187	0.13	0.850	Lutz-1975
162	0.0925	0.736	Adams-1989b	188	0.14	0.855	Pasedag-1977
163	0.093	0.741	Adams-1989b	189	0.143	0.859	Adams-1989a
164	0.095	0.745	Adams-1989b	190	0.146	0.864	Adams-1989a
165	0.0958	0.750	Adams-1989b	191	0.158	0.868	Adams-1989a
166	0.0989	0.755	Adams-1989b	192	0.16	0.873	Adams-1989b
167	0.1	0.755	Adams-1989a	193	0.179	0.877	Adams-1989b
168	0.1	0.764	Adams-1989a	194	0.182	0.882	Adams-1989b
169	0.1	0.768	Adams-1989a	195	0.188	0.886	Adams-1989a
170	0.1	0.773	Adams-1989a	196	0.191	0.891	Adams-1989a
171	0.101	0.777	Adams-1989b	197	0.195	0.895	Lutz-1975
172	0.106	0.782	Lutz-1975	198	0.2	0.900	Adams-1989a
173	0.11	0.786	Adams-1989a	199	0.2	0.905	Adams-1989a
174	0.115	0.791	Adams-1989b	200	0.2	0.909	Adams-1989a
175	0.116	0.795	Adams-1989b	201	0.201	0.914	Adams-1989b
176	0.118	0.800	Adams-1989a	202	0.218	0.918	Adams-1989a
177	0.119	0.805	Lutz-1975	203	0.22	0.923	Adams-1989a
178	0.12	0.809	Adams-1989a	204	0.238	0.927	Adams-1989a
179	0.121	0.814	Adams-1989a	205	0.246	0.932	Adams-1989b
180	0.123	0.818	Adams-1989b	206	0.261	0.936	Adams-1989b
181	0.125	0.823	Adams-1989a	207	0.268	0.941	Adams-1989a
182	0.127	0.827	Adams-1989b	208	0.3	0.945	Pasedag-1977
183	0.128	0.832	Adams-1989b	209	0.329	0.950	Adams-1989a
184	0.129	0.836	Adams-1989b	210	0.35	0.955	Adams-1989a

TABLE 4-1

Event Rank No.	Equil. Conc. μCi/g	Cumul. Prob.[a]	Data Reference	Event Rank No.	Equil. Conc. μCi/g	Cumul. Prob.[a]	Data Reference
211	0.362	0.959	Adams-1989b	216	0.564	0.982	Adams-1989b
212	0.39	0.964	Adams-1989a	217	0.7	0.986	Lutz-1975
213	0.403	0.968	Adams-1989b	218	0.91	0.991	Lutz-1975
214	0.427	0.973	Adams-1989b	219	0.943	0.995	Adams-1989a
215	0.505	0.977	Adams-1989b				

a - nominal cumulative probability = Event Rank No./(Total Events + 1)

Equilibrium Iodine Release Rates

Equilibrium concentrations can be translated into release rates by means of a mathematical model. The model is based on a material balance of iodine in primary coolant, and may be expressed as:

$$C = C_{I_0} e^{-\lambda t} + \frac{R}{M\lambda}(1 - e^{-\lambda t}) \qquad \textbf{(eq.1)}$$

where C = iodine concentration at time t, Ci/g,

C_{I_0} = iodine concentration at time = 0, Ci/g,

R = a constant release rate, Ci/hr,

M = mass of water in primary system, g,

λ = loss rate constant for iodine, hr^{-1},

t = time, hr.

The loss rate constant λ, can be expressed as the sum of its several terms:

$$\lambda = \frac{FE}{M} + \frac{L}{M} + \lambda_d \qquad \textbf{(eq.2)}$$

where λ = iodine loss rate constant, hr^{-1},

F = cleanup system flow rate, g/hr,

E = fractional efficiency of cleanup system for iodine,

M = mass of water in primary system, g,

L = leak rate from primary system, g/hr,

λ_d = decay constant for I-131 equivalent, hr^{-1}.

At equilibrium (long times), the exponential terms in eq. 1 go to zero, so the equilibrium release rate is expressible as:

$$R_0 = C_0 M \lambda \quad \text{(eq.3)}$$

where R_0 = equilibrium release rate, Ci/hr,

C_0 = equilibrium iodine conc., Ci/g.

It is evident that three parameters, C_0, M, and λ must be known in order to calculate the numerical value of R_0.

Four separate data sets were combined to yield a total of 219 events. As discussed in ***Equilibrium Iodine Concentrations***, 12 data points were selected from Lutz (1975), three from Pasedag (1977) and 55 from Adams (1989a). The 149 data point set of Adams(1989b) does not explicitly list values of R_0 or of λ or M. Values of initial concentration, peak concentration, and a release rate based on a two-hour time period and a conservative estimate of peak concentration (3 times the measured peak concentration) are listed by Adams (1989b) for each event. An estimate of R_0 was computed from a combination of eq. 1 and eq. 3:

$$R_0 = \frac{C_0 R\ (1-e^{-\lambda t})}{(C_p - C_0 e^{-\lambda t})} \quad \text{(eq.4)}$$

where R_0 = equilibrium release rate, Ci/hr,

C_0 = equilibrium concentration, Ci/g,

R = release rate in spike, Ci/hr,

C_p = peak concentration in spike, Ci/g,

t = time of peak, assumed 2 hr by Adams (1989b),

λ = iodine removal rate, hr^{-1}.

The value of λ was not reported by Adams (1989b) so an average value as used. The average, 0.075 hr^{-1} is the logarithmic average of high and low values cited by Pasedag (1977). For λ values at the two extremes (0.22 hr^{-1} and 0.088 hr^{-1}), the values of R_0 calculated using the average would be in error by a factor of 1.58. In as much as R_0 values vary over a range of 4 orders of magnitude, this potential error is not considered to be highly significant.

The sample mean and standard deviation of the 219 values of R_0 was calculated to be:

mean = 1.53 Ci/hr,

std. deviation = 2.59 Ci/hr.

Based on logarithms of R_0, the mean and geometric standard deviation are calculated to be:

log mean = 0.46 Ci/hr,

geometric std. deviation = 6.82.

The R_0 data set is shown graphically in Figure 4-2. The open circle points, as noted in ***Equilibrium Iodine Concentrations***, represent the accumulated percent of events for which R_0 is equal to or smaller than the stated value.

Also shown on Figure 4-2 is a line that defines a log-normal distribution having a log mean of 0.46 and a geometric std. deviation of 6.82. The fit of the line to the data is similar to that exhibited in Figure 4-1 which applied to equilibrium concentrations. The similarity in distributions is expected because the two data sets are closely related (R_0 is calculated from eq. 3, in which C_0 is the most important variable).

Values for the empirical probability distribution for the 219 points are listed in Table 4-2. As can be seen from Table 4-2, the median R_0 is 0.74 Ci/hr. R_0 values corresponding to nominal probabilities of 90%, 95%, and 98% are 3.98, 5.64, and 8.82 Ci/hr respectively.

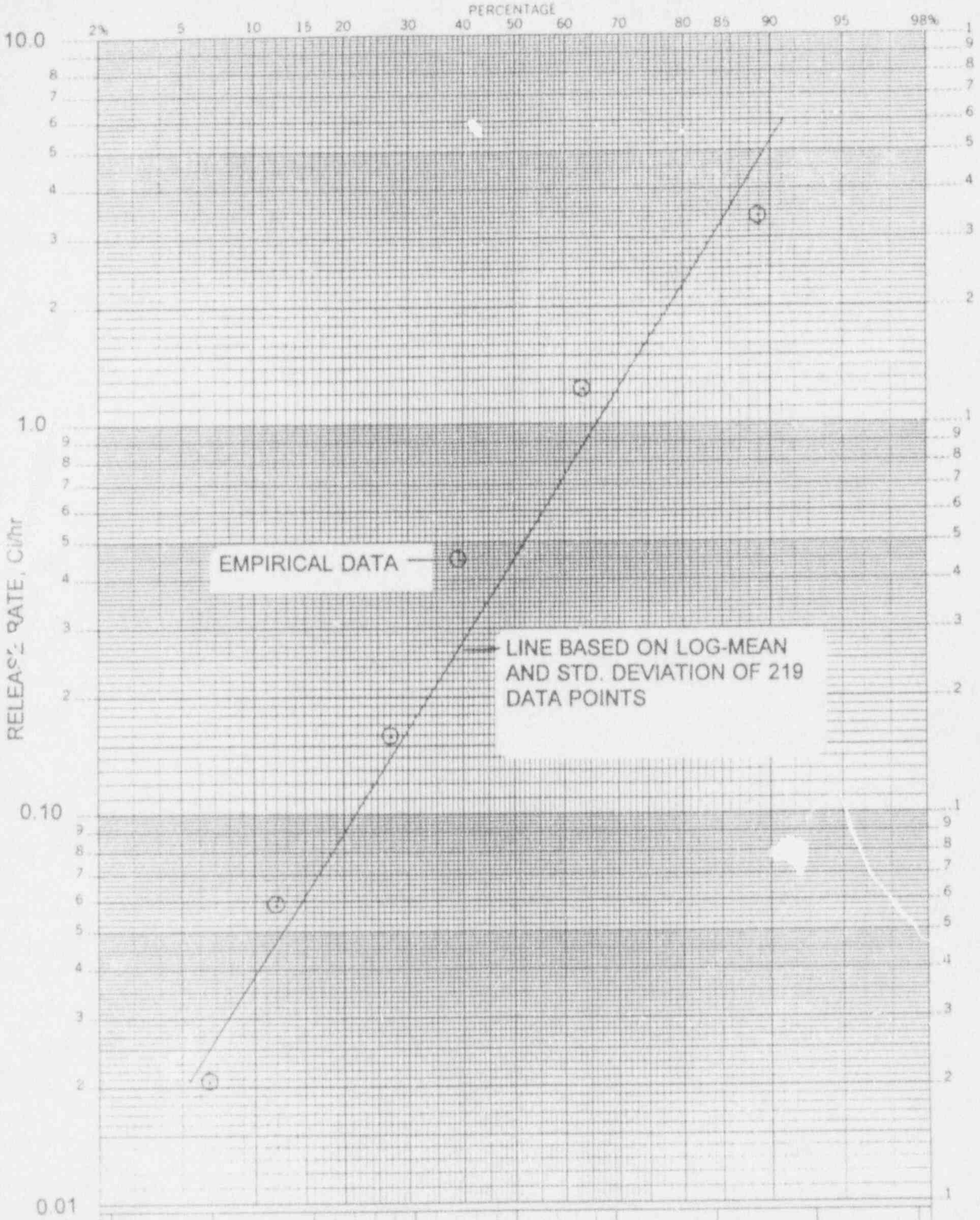


Figure 4-2
Probability Distribution for Equilibrium I-131 Release Rates

Table 4-2
Discrete Probability Distribution for Equilibrium I-131 Release Rates

TABLE 4-2							
Event Rank No.	Release Rate Ci/h	Cumul. Prob.	Data Reference	Event Rank No.	Release Rate Ci/h	Cumul. Prob.	Data Reference
1	0.001	0.005	Adams-1989b	26	0.0475	0.118	Adams-1989b
2	0.0014	0.009	Adams-1989b	27	0.0486	0.123	Adams-1989b
3	0.0020	0.014	Adams-1989b	28	0.06	0.127	Adams-1989a
4	0.0020	0.018	Adams-1989b	29	0.0611	0.132	Adams-1989b
5	0.0031	0.023	Adams-1989b	30	0.0628	0.136	Adams-1989b
6	0.0031	0.027	Adams-1989b	31	0.0635	0.141	Adams-1989b
7	0.0043	0.038	Adams-1989b	32	0.0635	0.145	Adams-1989b
8	0.0045	0.036	Adams-1989b	33	0.0636	0.150	Adams-1989b
9	0.0072	0.041	Adams-1989b	34	0.0636	0.155	Adams-1989b
10	0.0074	0.045	Adams-1989b	35	0.0646	0.159	Adams-1989b
11	0.0085	0.050	Adams-1989b	36	0.0661	0.164	Adams-1989b
12	0.0108	0.055	Adams-1989b	37	0.068	0.168	Adams-1989b
13	0.0112	0.059	Adams-1989b	38	0.0683	0.173	Adams-1989b
14	0.0113	0.064	Adams-1989b	39	0.0748	0.177	Adams-1989b
15	0.0149	0.068	Adams-1989b	40	0.0796	0.182	Adams-1989b
16	0.0223	0.073	Adams-1989b	41	0.0828	0.186	Adams-1989b
17	0.0271	0.077	Adams-1989b	42	0.0862	0.191	Adams-1989b
18	0.0295	0.082	Adams-1989b	43	0.101	0.195	Adams-1989b
19	0.03	0.086	Adams-1989b	44	0.101	0.200	Adams-1989b
20	0.0301	0.091	Adams-1989b	45	0.102	0.205	Adams-1989b
21	0.0424	0.095	Adams-1989b	46	0.102	0.209	Adams-1989b
22	0.0445	0.100	Adams-1989b	47	0.104	0.214	Adams-1989b
23	0.0451	0.105	Adams-1989b	48	0.105	0.218	Adams-1989b
24	0.0451	0.109	Adams-1989b	49	0.105	0.223	Adams-1989b
25	0.0466	0.113	Adams-1989b	50	0.107	0.227	Adams-1989b

TABLE 4-2

Event Rank No.	Release Rate Ci/h	Cumul. Prob.	Data Reference	Event Rank No.	Release Rate Ci/h	Cumul. Prob.	Data Reference
51	0.12	0.232	Adams-1989b	77	0.29	0.350	Adams-1989a
52	0.124	0.236	Adams-1989b	78	0.302	0.355	Adams-1989b
53	0.127	0.241	Adams-1989b	79	0.31	0.359	Lutz-1975
54	0.13	0.245	Adams-1989a	80	0.33	0.364	Adams-1989b
55	0.131	0.250	Adams-1989b	81	0.36	0.368	Adams-1989a
56	0.133	0.255	Adams-1989b	82	0.361	0.372	Adams-1989b
57	0.135	0.259	Adams-1989b	83	0.375	0.377	Adams-1989b
58	0.137	0.264	Adams-1989b	84	0.391	0.382	Adams-1989b
59	0.15	0.268	Adams-1989b	85	0.41	0.386	Pasedag-1977
60	0.159	0.273	Adams-1989b	86	0.426	0.391	Adams-1989b
61	0.165	0.277	Adams-1989b	87	0.447	0.395	Adams-1989b
62	0.179	0.282	Adams-1989b	88	0.45	0.400	Adams-1989a
63	0.19	0.286	Adams-1989a	89	0.462	0.405	Adams-1989b
64	0.192	0.291	Adams-1989b	90	0.47	0.409	Adams-1989a
65	0.206	0.295	Adams-1989b	91	0.48	0.414	Lutz-1975
66	0.207	0.300	Adams-1989b	92	0.496	0.418	Adams-1989b
67	0.209	0.305	Adams-1989b	93	0.501	0.423	Adams-1989b
68	0.222	0.309	Adams-1989b	94	0.52	0.427	Adams-1989a
69	0.232	0.314	Adams-1989b	95	0.542	0.432	Adams-1989b
70	0.238	0.318	Adams-1989b	96	0.548	0.436	Lutz-1975
71	0.24	0.323	Adams-1989a	97	0.56	0.441	Adams-1989a
72	0.249	0.327	Adams-1989b	98	0.59	0.445	Adams-1989a
73	0.253	0.332	Adams-1989b	99	0.609	0.450	Adams-1989b
74	0.253	0.336	Adams-1989b	100	0.627	0.455	Adams-1989b
75	0.278	0.341	Adams-1989b	101	0.665	0.459	Adams-1989b
76	0.281	0.345	Adams-1989b	102	0.666	0.464	Adams-1989b

TABLE 4-2

Event Rank No.	Release Rate Ci/h	Cumul. Prob.	Data Reference	Event Rank No.	Release Rate Ci/h	Cumul. Prob.	Data Reference
103	0.68	0.468	Lutz-1975	129	1.	0.586	Lutz-1975
104	0.698	0.473	Adams-1989b	130	1.02	0.591	Adams-1989b
105	0.7	0.477	Adams-1989a	131	1.03	0.595	Adams-1989a
106	0.72	0.482	Lutz-1975	132	1.04	0.600	Adams-1989b
107	0.723	0.486	Adams-1989b	133	1.05	0.605	Lutz-1975
108	0.738	0.491	Adams-1989b	134	1.09	0.609	Adams-1989b
109	0.739	0.495	Adams-1989b	135	1.1	0.614	Lutz-1975
110	0.742	0.500	Adams-1989b	136	1.11	0.618	Adams-1989b
111	0.75	0.505	Adams-1989a	137	1.14	0.623	Adams-1989b
112	0.755	0.509	Adams-1989b	138	1.17	0.627	Adams-1989b
113	0.825	0.514	Adams-1989b	139	1.2	0.632	Adams-1989b
114	0.832	0.518	Adams-1989b	140	1.21	0.636	Adams-1989b
115	0.832	0.523	Adams-1989b	141	1.26	0.641	Adams-1989b
116	0.834	0.527	Adams-1989b	142	1.27	0.645	Adams-1989b
117	0.84	0.532	Lutz-1975	143	1.27	0.650	Adams-1989a
118	0.844	0.536	Adams-1989b	144	1.3	0.655	Adams-1989b
119	0.844	0.541	Adams-1989b	145	1.31	0.659	Adams-1989b
120	0.864	0.545	Adams-1989b	146	1.32	0.664	Adams-1089b
121	0.872	0.550	Adams-1989b	147	1.34	0.668	Adams-1989a
122	0.889	0.555	Adams-1989b	148	1.37	0.673	Adams-1989b
123	0.89	0.559	Adams-1989a	149	1.38	0.677	Adams-1989a
124	0.922	0.564	Adams-1989b	150	1.39	0.682	Adams-1989b
125	0.923	0.568	Adams-1989b	151	1.39	0.686	Adams-1989b
126	0.932	0.573	Adams-1989b	152	1.4	0.691	Adams-1989b
127	0.951	0.577	Adams-1989b	153	1.41	0.695	Adams-1989b
128	0.972	0.582	Adams-1989b	154	1.43	0.700	Adams-1989a

TABLE 4-2

Event Rank No.	Release Rate Ci/h	Cumul. Prob.	Data Reference	Event Rank No.	Release Rate Ci/h	Cumul. Prob.	Data Reference
155	1.46	0.705	Adams-1989a	181	2.54	0.823	Adams-1989a
156	1.53	0.709	Adams-1989b	182	2.54	0.827	Adams-1989a
157	1.53	0.714	Adams-1989a	183	2.6	0.832	Lutz-1975
158	1.54	0.718	Adams-1989a	184	2.69	0.836	Adams-1989b
159	1.54	0.723	Adams-1989a	185	2.75	0.841	Adams-1989b
160	1.56	0.727	Adams-1989b	186	2.75	0.845	Adams-1989a
161	1.66	0.732	Adams-1989b	187	2.8	0.850	Adams-1989a
162	1.68	0.736	Adams-1989a	188	2.81	0.855	Adams-1989a
163	1.69	0.741	Adams-1989a	189	2.82	0.859	Adams-1989a
164	1.73	0.745	Adams-1989b	190	2.92	0.864	Adams-1989a
165	1.75	0.750	Adams-1989b	191	3.02	0.868	Adams-1989a
166	1.76	0.755	Adams-1989b	192	3.09	0.873	Adams-1989a
167	1.78	0.755	Adams-1989b	193	3.1	0.877	Adams-1989a
168	1.84	0.764	Adams-1989b	194	3.24	0.882	Adams-1989a
169	1.86	0.768	Adams-1989a	195	3.25	0.886	Adams-1989a
170	1.9	0.773	Adams-1989b	196	3.73	0.891	Adams-1989b
171	1.9	0.777	Adams-1989a	197	3.93	0.895	Adams-1989b
172	1.91	0.782	Adams-1989b	198	3.98	0.900	Adams-1989a
173	1.94	0.786	Adams-1989b	199	4.44	0.905	Adams-1989b
174	1.96	0.791	Adams-1989b	200	4.62	0.909	Pasedag-1977
175	2.14	0.795	Adams-1989b	201	4.65	0.914	Adams-1989a
176	2.22	0.800	Adams-1989a	202	4.81	0.918	Adams-1989a
177	2.27	0.805	Adams-1989a	203	4.89	0.923	Adams-1989a
178	2.35	0.809	Adams-1989a	204	5.35	0.927	Adams-1989b
179	2.41	0.814	Adams-1989b	205	5.39	0.932	Adams-1989a
180	2.45	0.818	Pasedag-1977	206	5.44	0.936	Adams-1989a

TABLE 4-2

Event Rank No.	Release Rate Ci/h	Cumul. Prob.[a]	Data Reference	Event Rank No.	Release Rate Ci/h	Cumul. Prob.[a]	Data Reference
207	5.49	0.941	Adams-1989a	214	7.83	0.973	Adams-1989b
208	5.64	0.945	Adams-1989a	215	8.82	0.977	Adams-1989a
209	5.64	0.950	Adams-1989a	216	9.35	0.982	Adams-1989b
210	6.69	0.955	Adams-1989a	217	10.2	0.986	Adams-1989b
211	7.46	0.959	Adams-1989b	218	10.99	0.991	Adams-1989a
212	7.69	0.964	Lutz-1975	219	26.33	0.995	Adams-1989a
213	7.69	0.968	Lutz-1975				

a - nominal cumulative probability = Event Rank No./(Total Events + 1)

Spike Concentrations and Release Rates

Maximum Iodine Concentration in Spiking Events

Following a reactor transient, iodine concentration increases over a matter of hours to a peak. Following the peak, concentrations decrease with time, primarily as a result of operation of the cleanup system.

Under SRP methodology, it is assumed that the SGTR/MSLB accident is initiated at the time of the peak of a pre-existing spike. It is further assumed that the cleanup system becomes inoperable as a result of the SGTR/MSLB sequence, and therefore that iodine concentration remains constant (except for radioactive decay) over the following two-hour calculational period. For this spike case, computed doses are proportional to the peak iodine concentration.

Data on peak iodine concentrations were selected and analyzed as follows. First, Lutz (1975) reports data for 32 spikes which included both power transients and depressurization transients. Second, Pasedag (1977) described 10 spike events that had not been reported earlier by Lutz(1975). These 10 events included both power and pressure transients. All 10 points were included in the data base analyzed herein. The third data source was maximum measured concentrations for 168 scram events reported by Adams (1989b). For 19 of these, the peak concentration was equal to or lower than the pre-spike level. These 19 points were excluded because it was not evident that a measurable spike had actually occurred.

Peak measured concentrations STET may not reflect the peak concentration that actually occurred because samples may not have been taken at the time of the peak. The degree to which samples taken after the peak fall short of the peak can be estimated on the basis of cleanup system operation. As an example, assume that two hours has passed since the peak. If we also assume that the iodine release rate is zero, and that the cleanup system λ is 0.075 hr^{-1}, the concentration at two hours divided by the peak concentration is: $C/C_0 = \exp[-2(0.075)] = 0.86$. Recognizing that spike peak concentration vary over 5 orders of magnitude, the error introduced by not catching the exact peak is not highly significant. Lutz, (1975) used an extrapolation method to estimate the peak concentration..

The mean and distribution of the 191 peak concentrations described above was calculated using both the concentrations and their logarithms. Results are as follows.

sample mean = 1.45 μCi/g

std. deviation = 2.83 μCi/g

log-mean = 0.31 μCi/g

geometric std. deviation = 8.86

The distribution is shown graphically in Figure 4-3 on log-normal coordinates. The open circles represent cumulative percentages of events for which concentrations are equal to or smaller than the stated value. The straight line represents a log-normal distribution defined by the log-mean (0.31 μCi/g) and geometric standard deviation (8.86) calculated from the 191 data points. The log-normal curve fits the data reasonably well.

The empirical probability distribution is shown in discrete form in Table 4-3 where cumulative nominal probability is listed for each data point. The reference for each data point is also shown in Table 4-3.

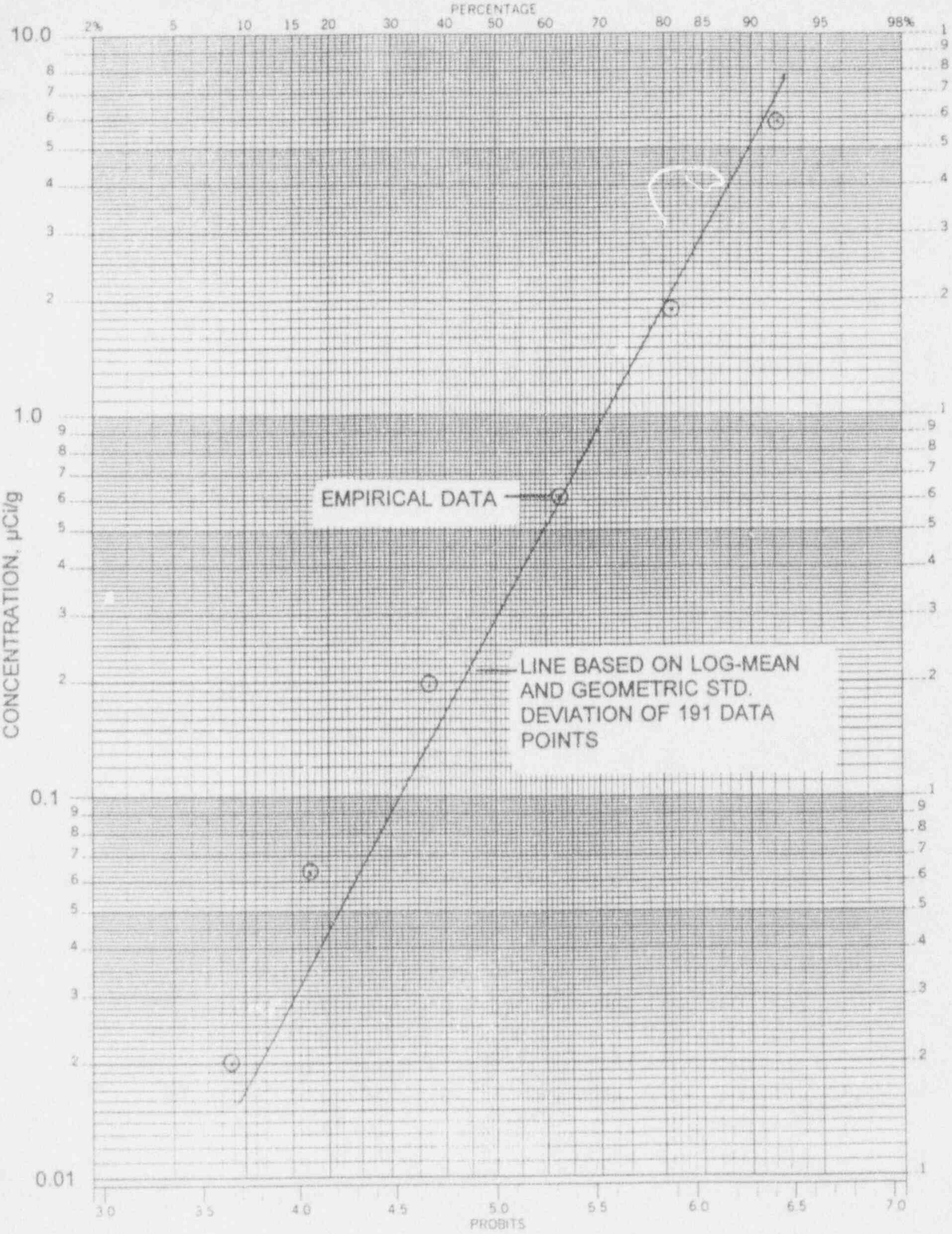


Figure 4-3
Probability Distribution for Peak Concentration of I-131 Resulting from Spikes

Table 4-3 Peak Iodine concentrations Measured for 190 Spike Events

TABLE 4 - 3							
Event Rank No.	Peak Conc. μCi/g	Cumul. Prob.^{a}	Data Reference	Event Rank No.	Peak Conc. μCi/g	Cumul. Prob.^{a}	Data Reference
1	0.000215	0.005	Adams-1989b	26	0.0393	0.135	Adams-1989b
2	0.0003	0.010	Adams-1989b	27	0.041	0.141	Adams-1989b
3	0.000495	0.016	Adams-1989b	28	0.0514	0.146	Adams-1989b
4	0.00068	0.021	Adams-1989b	29	0.0564	0.151	Adams-1989b
5	0.00074	0.026	Adams-1989b	30	0.0567	0.156	Adams-1989b
6	0.000788	0.031	Adams-1989b	31	0.0572	0.161	Adams-1989b
7	0.0008	0.036	Adams-1989b	32	0.0574	0.167	Adams-1989b
8	0.000934	0.042	Adams-1989b	33	0.059	0.172	Adams-1989b
9	0.00189	0.047	Adams-1989b	34	0.064	0.177	Adams-1989b
10	0.002	0.052	Adams-1989b	35	0.0666	0.182	Adams-1989b
11	0.003	0.058	Adams-1989b	36	0.067	0.188	Adams-1989b
12	0.00388	0.063	Adams-1989b	37	0.0698	0.193	Adams-1989b
13	0.00525	0.068	Adams-1989b	38	0.073	0.198	Adams-1989b
14	0.00607	0.073	Adams-1989b	39	0.0747	0.203	Adams-1989b
15	0.00893	0.078	Adams-1989b	40	0.0751	0.208	Adams-1989b
16	0.0101	0.083	Adams-1989b	41	0.0877	0.214	Adams-1989b
17	0.0108	0.089	Adams-1989b	42	0.0896	0.219	Adams-1989b
18	0.0264	0.094	Adams-1989b	43	0.091	0.224	Adams-1989b
19	0.0306	0.099^a	Adams-1989b	44	0.1	0.229^a	Adams-1989b
20	0.0315	0.104	Adams-1989b	45	0.11	0.234	Adams-1989b
21	0.032	0.11	Adams-1989b	46	0.111	0.240	Adams-1989b
22	0.033	0.115	Adams-1989b	47	0.116	0.245	Adams-1989b
23	0.0342	0.12	Adams-1989b	48	0.133	0.25	Adams-1989b
24	0.355	0.125	Adams-1989b	49	0.135	0.255	Adams-1989b
25	0.036	0.130	Adams-1989b	50	0.135	0.260	Adams-1989b

TABLE 4-3

Event Rank No.	Peak Conc. μCi/g	Cumul. Prob.[a]	Data Reference	Event Rank No.	Peak Conc. μCi/g	Cumul. Prob.[a]	Data Reference
51	0.136	0.266	Adams-1989b	77	0.237	0.401	Adams-1989b
52	0.14	0.271	Adams-1989b	78	0.242	0.406	Adams-1989b
53	0.145	0.276	Lutz-1975	79	0.246	0.411	Adams-1989b
54	0.149	0.281	Adams-1989b	80	0.25	0.417	Lutz-1975
55	0.15	0.286	Pasedag-1977	81	0.25	0.422	Lutz-1975
56	0.153	0.292	Adams-1989b	82	0.258	0.427	Adams-1989b
57	0.155	0.297	Adams-1989b	83	0.259	0.432	Adams-1989b
58	0.159	0.302	Adams-1989b	84	0.26	0.438	Adams-1989b
59	0.16	0.307	Adams-1989b	85	0.265	0.443	Adams-1989b
60	0.165	0.313	Lutz-1975	86	0.275	0.448	Adams-1989b
61	0.17	0.318	Adams-1989b	87	0.28	0.453	Adams-1989b
62	0.17	0.323	Adams-1989b	88	0.299	0.458	Adams-1989b
63	0.171	0.328	Adams-1989b	89	0.3	0.464	Adams-1989b
64	0.179	0.333	Adams-1989b	90	0.3	0.469	Adams-1989b
65	0.179	0.339	Adams-1989b	91	0.302	0.474	Adams-1989b
66	0.18	0.344	Pasedag-1977	92	0.304	0.479	Adams-1989b
67	0.182	0.349	Adams-1989b	93	0.314	0.484	Adams-1989b
68	0.19	0.354	Adams-1989b	94	0.325	0.490	Adams-1989b
69	0.192	0.359	Adams-1989b	95	0.331	0.495	Adams-1989b
70	0.194	0.365	Adams-1989b	96	0.35	0.5	Lutz-1975
71	0.198	0.370	Adams-1989b	97	0.388	0.505	Adams-1989b
72	0.222	0.375	Adams-1989b	98	0.395	0.510	Adams-1989b
73	0.23	0.380	Adams-1989b	99	0.4	0.516	Lutz-1975
74	0.23	0.385	Lutz-1975	100	0.403	0.521	Adams-1989b
75	0.236	0.391	Adams-1989b	101	0.41	0.526	Lutz-1975
76	0.236	0.396	Adams-1989b	102	0.425	0.531	Lutz-1975

TABLE 4 - 3

Event Rank No.	Peak Conc. μCi/g	Cumul. Prob.[a]	Data Reference	Event Rank No.	Peak Conc. μCi/g	Cumul. Prob.[a]	Data Reference
103	0.43	0.536	Pasedag-1977	129	0.812	0.672	Adams-1989b
104	0.439	0.542	Adams-1989b	130	0.824	0.677	Adams-1989b
105	0.44		Lutz-1975	131	0.845	0.682	Adams-1989b
106	0.448	0.552	Adams-1989b	132	0.858	0.688	Adams-1989b
107	0.47	0.557	Adams-1989b	133	0.874	0.693	Adams-1989b
108	0.481	0.563	Adams-1989b	134	0.9	0.698	Adams-1989b
109	0.484	0.568	Adams-1989b	135	0.918	0.703	Adams-1989b
110	0.52	0.573	Pasedag-1977	136	0.922	0.708	Adams-1989b
111	0.526	0.578	Adams-1989b	137	0.93	0.714	Adams-1989b
112	0.531	0.583	Adams-1989b	138	0.937	0.719	Adams-1989b
113	0.535	0.589	Adams-1989b	139	1.02	0.724	Lutz-1975
114	0.535	0.594	Adams-1989b	140	1.05	0.729	Lutz-1975
115	0.545	0.599	Adams-1989b	141	1.05	0.734	Adams-1989b
116	0.56	0.604	Adams-1989b	142	1.11	0.740	Adams-1989b
117	0.58	0.609	Adams-1989b	143	1.11	0.745	Adams-1989b
118	0.6	0.615	Lutz-1975	144	1.15	0.75	Adams-1989b
119	0.6	0.620	Lutz-1975	145	1.18	0.755	Adams-1989b
120	0.62	0.625	Adams-1989b	146	1.2	0.760	Adams-1989b
121	0.631	0.630	Adams-1989b	147	1.22	0.766	Lutz-1975
122	0.65	0.635	Lutz-1975	148	1.44	0.771	Adams-1989b
123	0.679	0.641	Adams-1989b	149	1.44	0.776	Adams-1989b
124	0.693	0.646	Adams-1989b	150	1.6	0.781	Pasedag-1977
125	0.704	0.651	Adams-1989b	151	1.66	0.786	Adams-1989b
126	0.728	0.656	Adams-1989b	152	1.7	0.792	Adams-1989b
127	0.764	0.661	Adams-1989b	153	1.72	0.797	Adams-1989b
128	0.8	0.667	Lutz-1975	154	1.8	0.802	Pasedag-1977

TABLE 4 - 3

Event Rank No.	Peak Conc. μCi/g	Cumul. Prob.[a]	Data Reference	Event Rank No.	Peak Conc. μCi/g	Cumul. Prob.[a]	Data Reference
155	1.8	0.807	Pasedag-1977	174	5.2	0.906	Lutz-1975
156	1.98	0.813	Adams-1989b	175	5.5	0.911	Lutz-1975
157	1.99	0.818	Adams-1989b	176	5.57	0.917	Adams-1989b
158	1.99	0.823	Lutz-1975	177	6.	0.922	Adams-1989b
159	2.04	0.828	Adams-1989b	178	6.	0.927	Lutz-1975
160	2.16	0.833	Adams-1989b	179	6.8	0.932	Lutz-1975
161	2.35	0.839	Lutz-1975	180	7.4	0.938	Lutz-1975
162	2.5	0.844	Pasedag-1977	181	7.43	0.943	Adams-1989b
163	2.61	0.849	Adams-1989b	182	8.2	0.948	Adams-1989b
164	2.65	0.854	Adams-1989b	183	8.3	0.953	Adams-1989b
165	2.8	0.859	Pasedag-1977	184	8.97	0.958	Adams-1989b
166	3.	0.865	Lutz-1975	185	10.2	0.964	Lutz-1975
167	3.	0.870	Lutz-1975	186	11.	0.969	Lutz-1975
168	3.	0.875	Lutz-1975	187	12.	0.974	Lutz-1975
169	3.12	0.880	Adams-1989b	188	14.4	0.979	Adams-1989b
170	3.32	0.885	Adams-1989b	189	15.5	0.984	Pasedag-1977
171	5.07	0.891	Adams-1989b	190	18.1	0.990	Lutz-1975
172	5.14	0.896	Adams-1989b	191	18.3	0.995	Lutz-1975
173	5.18	0.901	Adams-1989b				

a - nominal cumulative probability = Event Rank No./(Total Events + 1)

Data of Table 4-3 identify the median peak concentration as 0.35 μCi/g. Concentrations for nominal cumulative probabilities of 90%, 95%, and 98% are 5.14 μCi/g, 8.2 μCi/g, and 14.4 μCi/g respectively.

In addition to the 191 point data base described above, a truncated set of peak concentrations is available from the work of Adams (1989a). This latter set of 144 points was selected (by Adams) from a larger set of data by excluding spikes for which the peak was less than 1.0 μCi/g. Spike events for the truncated data set included both power and pressure transients (Adams-1989a).

The distribution of these 144 spike peaks is illustrated on the log-normal plot shown in Figure 4-4. As indicated, a normalized peak concentration, defined as C_p-0.94, is plotted. This arbitrary off-set caused the distribution to reasonably follow a log-normal curve.

The straight line shown on Figure 4-4 is defined by the log-mean (0.99 μCi/g) and geometric std. deviation of the 144 values of C_p-0.94.

A discrete listing of nominal probabilities for this 144 point data set was presented by Adams(1989a) and will not be repeated here. Peak concentrations for nominal cumulative probabilities of 50%, 90%, 95% and 98%, taken from the analysis done by Adams (1989a) are 1.96 μCi/g, 6.46 μCi/g, 7.46 μCi/g, and 12.0 μCi/g respectively.

The truncated distribution of peak concentration has a higner median than the 189 point distribution (1.96 μCi/g vs. 0.35 μCi/g) as expected. Interestingly, the 95% and 98% concentrations are similar for the two distributions.

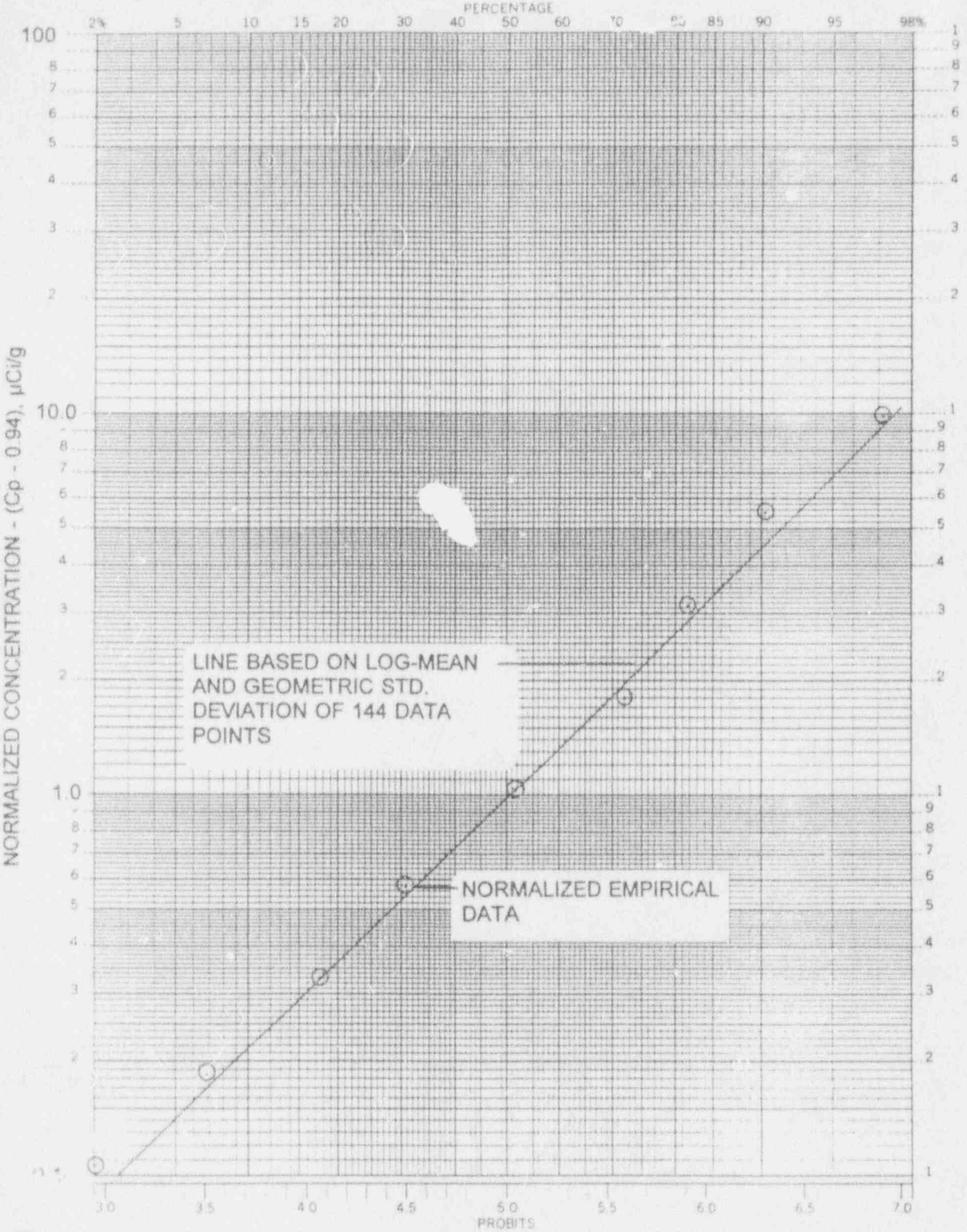


Figure 4-4
Probability Distribution for Peak I-131 Concentration Resulting from Spikes--Truncated Data of Adams (1989a)

Maximum Iodine Release Rates In Spiking Events

Maximum iodine release rates during spiking events are important because accident-initiated spikes are quantified by means of a release rate in SRP methodology (NRC-1981). At the initiation of a SGTR/MSLB sequence it is assumed that a bounding spike event releases iodine at a constant rate for a two hour calculational period. A key question is: "what is the magnitude of the bounding release rate?"

In this section available spike data is analyzed to determine the range of release rates that are consistent with observed iodine concentrations.

As noted earlier, iodine releases rates are not measured directly, but can be inferred from observed increases in iodine concentration in primary water. Solving eq. 1 for the rate of release, R, gives:

$$R = \frac{M\lambda(C_p - C_{t_0}e^{-\lambda t})}{(1 - e^{-\lambda t})} \qquad \text{(eq.1a)}$$

where the symbols are those defined in eq. 1.

Based on observed values of C_p , C_{t_0} , M, and λ, and setting t equal to the time to reach peak, a value of R (an average for the time interval) can be computed from eq. 1a. Generally, sample timing did not coincide exactly with the peak, so the peak concentration was typically obtained by extrapolating post-peak concentration backwards in time using a known value of λ.

Lutz(1975) computed iodine release rates for 32 spiking events which included both power and pressure transients. Lutz(1975) calculates release rates at several times intervals during a spike. Typically these release rates increase to a maximum over several hours, and then fall to small values. For purposes of the present analysis, the maximum release rate listed by Lutz for each event was incorporated into the data set.

Pasedag(1977) presents average release rates for 8 events not analyzed by Lutz(1975) or Adams (1989a). All 8 of these rates were included into the rate data base. These 8 events included power and pressure transients.

Adams(1989a) analyzed 58 spike events (both power and pressure transients) and provides average rates for each event. Three of these were previously reported by Lutz(1975); the 55 unique release rates were included in the present rate data base.

The distribution of release rates for the 95 point data set described above is shown on a log-normal plot in Figure 4-5. The open circles represent cumulative percentages of events having release rates equal to or less than the stated value. Again the sample was put into 10 bins of equal width (on a logarithmic basis) for purposes of this graph.

The straight line shown on Figure 4-5 represents a log-normal distribution having a log-mean (74.9 Ci/hr) and geometric standard deviation (3.14) computed from the 95 data points. The line closely follows the empirical data, indicating that the sample closely follows the log-normal distribution.

The value of the empirical probability for each data point of this set is listed in Table 4-4. As indicated, the median release rate is 73.26 Ci/hr. Release rates corresponding to nominal probabilities of 90%. 95%, and 98% are 327 Ci/hr, 562 Ci/hr, and 795 Ci/hr respectively.

In addition to the "best estimate" values of R in the 95 point data set described in Figure 4-5 and Table 4-4, Adams (1989b) lists 168 values of R that are conservatively calculated. Two conservative factors are involved. First, observed maximum concentrations are multiplied by a factor of 3 to obtain the peak concentration. Second, the time of the peak is conservatively set equal to two hours.

While a detailed analysis of these two conservatisms has not been made, a preliminary judgment is that predicted rates would be high by an average factor of approximately 3 to 4, as compared to best-estimate values. This judgment follows from the explicit factor of 3 and the observation that spike peaks typically occur at times longer than two hours after the causative transient.

The distribution of conservatively estimated spike release rates listed by Adams (1989b) is shown on a log-normal plot in Figure 4-6. The open circles represent cumulative percentages of events having release rate smaller than or equal to the stated rate. The straight line describes a log-normal distribution having a log-mean (29.8 Ci/hr) and a geometric standard deviation (19.1) computed from the 168 data points. The points do not fall very close to the line, indicating that these rate data are not well represented by a log-normal distribution.

Analysis of these 168 rate data in terms of empirical probabilities indicates the median to be 67.3 Ci/hr. Release rates corresponding to percentiles of 90%, 95%, and 98% are 653 Ci/hr, 1280 Ci/hr, and 2650 Ci/hr.

As expected, the conservatively estimated release rates are appreciably larger than those based on best-estimate calculations. The difference can be illustrated by comparing release rates at the 98% probability level, 2650 Ci/hr vs 795 Ci/hr (from Table 4-4). The conservatively calculated release rates at the upper ends of the distribution are approximately 3.3 times larger than best estimate values.

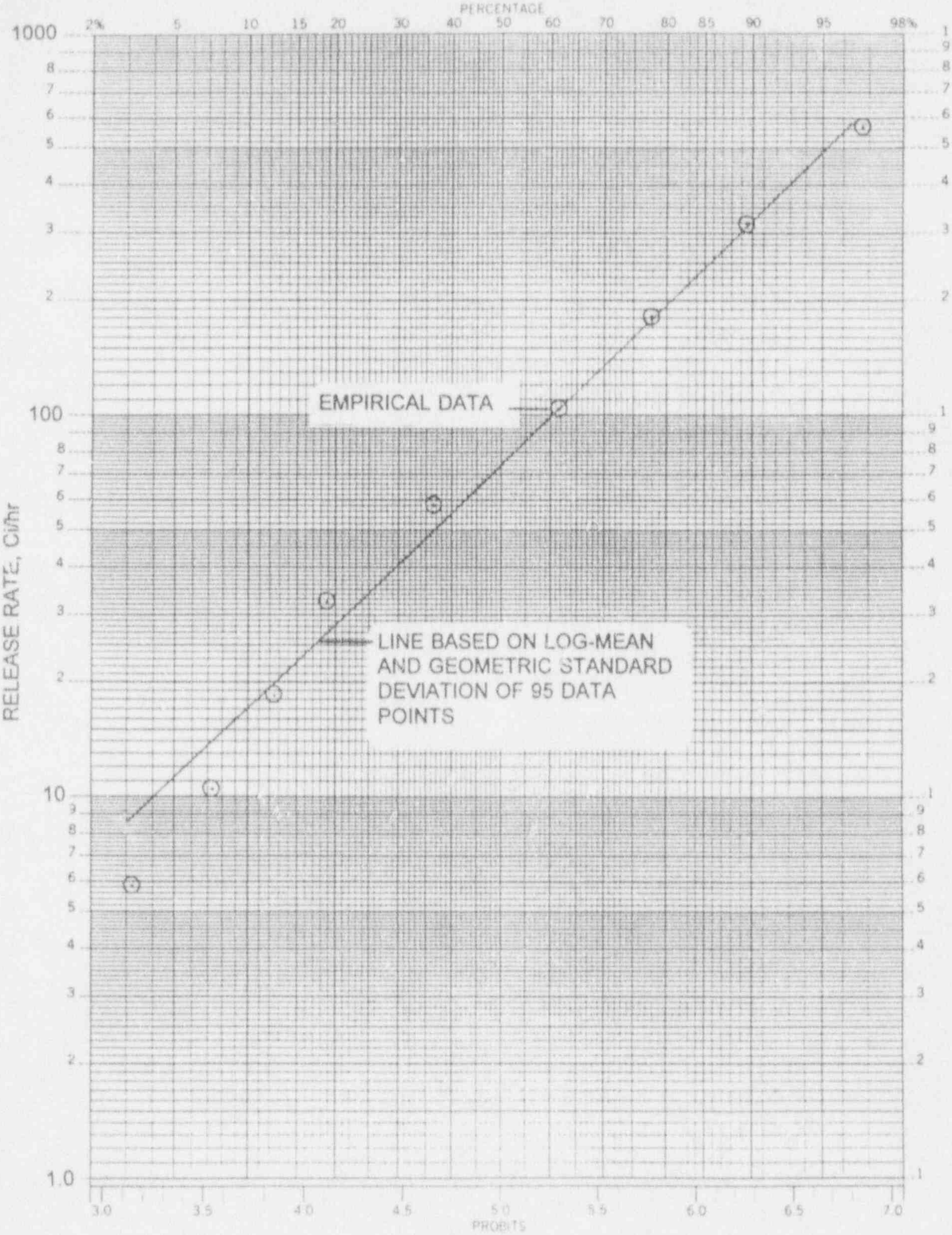


Figure 4-5
Probability Distribution for I-131 Release Rates Computed from Spike Data

Table 4-4 Discrete Probability Distribution for Spike I-131 Release Rates

TABLE 4 - 4

Event Rank No.	Release Rate Ci/h	Cumul. Prob.[a]	Data Reference	Event Rank No.	Release Rate Ci/h	Cumul. Prob.[a]	Data Reference
1	3.35	0.01	Lutz-1975	27	44.8	0.281	Adams-1989a
2	5.2	0.021	Pasedag-1977	28	46.37	0.292	Adams-1989a
3	5.36	0.031	Lutz-1975	29	46.6	0.302	Adams-1989a
4	9.03	0.042	Lutz-1975	30	49.14	0.313	Adams-1989a
5	9.75	0.052	Pasedag-1977	31	53.16	0.323	Adams-1989a
6	9.85	0.063	Lutz-1975	32	53.33	0.334	Adams-1989a
7	10.3	0.073	Lutz-1975	33	54.5	0.344	Lutz-1975
8	12.1	0.083	Lutz-1975	34	55.3	0.354	Lutz-1975
9	13.8	0.094	Lutz-1975	35	55.65	0.365	Adams-1989a
10	14.05	0.104	Adams-1989a	36	58.21	0.375	Adams-1989a
11	16.1	0.005	Lutz-1975	37	58.26	0.385	Adams-1989a
12	17.8	0.125	Lutz-1975	38	61.2	0.396	Pasedag-1977
13	21.87	0.135	Adams-1989a	39	61.43	0.406	Adams-1989a
14	23.83	0.146	Adams-1989a	40	63.56	0.417	Adams-1989a
15	25.2	0.156	Lutz-1975	41	64.71	0.427	Adams-1989a
16	26.5	0.167	Lutz-1975	42	67.29	0.438	Adams-1989a
17	28.6	0.177	Lutz-1975	43	67.7	0.448	Lutz-1975
18	29.2	0.188	Lutz-1975	44	69.94	0.458	Adams-1989a
19	33.4	0.198	Pasedag-1977	45	70.	0.469	Adams-1989a
20	33.77	0.208	Lutz-1975	46	70.73	0.479	Adams-1989a
21	35.5	0.219	Lutz-1975	47	70.9	0.490	Adams-1989a
22	38.65	0.229	Adams-1989a	48	73.26	0.5	Adams-1989a
23	39.22	0.240	Adams-1989a	49	77.87	0.510	Adams-1989a
24	39.9	0.25	Adams-1989a	50	78.42	0.521	Adams-1989a
25	41.9	0.260	Lutz-1975	51	81.47	0.53[illegible]	Adams-1989a
26	44.08	0.271	Adams-1989a	52	84.85	0.54[illegible]	Adams-1989a

TABLE 4 - 4

Event Rank No.	Release Rate Ci/h	Cumul. Prob.[a]	Data Reference	Event Rank No.	Release Rate Ci/h	Cumul. Prob.[a]	Data Reference
53	87.25	0.552	Adams-1989a	75	182.24	0.781	Adams-1989a
54	87.6	0.563	Lutz-1975	76	183.54	0.792	Adams-1989a
55	87.9	0.573	Lutz-1975	77	192.	0.802	Lutz-1975
56	88.59	0.583	Adams-1989a	78	194.94	0.813	Adams-1989a
57	93.6	0.594	Lutz-1975	79	217.24	0.823	Adams-1989a
58	94	0.604	Adams-1989a	80	225.	0.833	Lutz-1975
59	96.4	0.615	Pasedag-1977	81	235.	0.844	Pasedag-1977
60	103.66	0.625	Adams-1989a	82	244.58	0.854	Adams-1989a
61	112.72	0.635	Adams-1989a	83	244.99	0.865	Adams-1989a
62	113.56	0.646	Adams-1989a	84	277.13	0.875	Adams-1989a
63	118.67	0.656	Adams-1989a	85	290.	0.885	Lutz-1975
64	119.	0.667	Lutz-1975	86	327.19	0.896	Adams-1989a
65	119.	0.677	Lutz-1975	87	367.	0.906	Lutz-1975
66	121.49	0.688	Adams-1989a	88	407.73.	0.917	Adams-1989a
67	125.	0.698	Lutz-1975	89	422.03	0.927	Adams-1989a
68	138.69	0.708	Adams-1989a	90	443.13	0.9375	Adams-1989a
69	141.17	0.719	Adams-1989a	91	561.83	0.948	Adams-1989a
70	150.85	0.729	Adams-1989a	92	573	0.958	Lutz-1975
71	155.74	0.740	Adams-1989a	93	687	0.969	Pasedag-1977
72	158.93	0.75	Adams-1989a	94	795	0.979	Pasedag-1977
73	160.99	0.760	Adams-1989a	95	1000.	0.990	Lutz-1975
74	180.	0.771	Lutz-1975				

a - nominal cumulative probability = Event Rank No./(Total Events + 1)

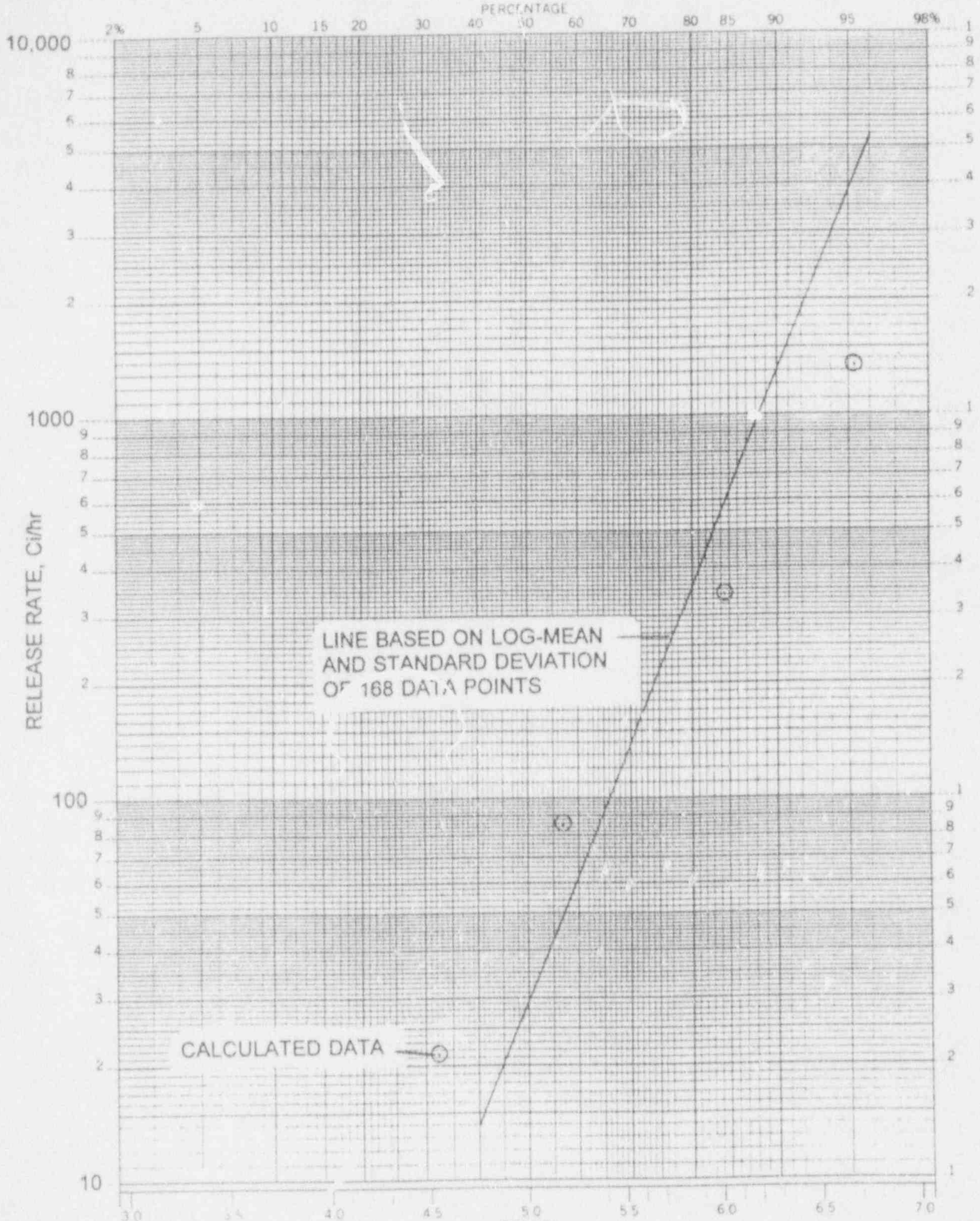


Figure 4-6
Probability Distribution for I-131 Release Rates --
Conservatively Computed from Spike Data by Adams (1989b)

5

DISCUSSION OF IODINE SPIKE DATA IN RELATION TO SRP METHODOLOGY

Maximum Concentration in Pre-existing Spike

As discussed in ***Maximum Iodine Concentration in Spiking Events***, 95% of observed peaks in I-131 concentration were 8.2µCi/g or less. This value is a factor of 6.3 lower than the 60 µCi/g derived from SRP methodology (NRC-1993). Thus available data (a total of 363 analyzed spike events) support the use of a lower spike concentration of I-131 for use in analyzing SGTR/MSLB accidents.

Another aspect of the spike data that supports a lower concentration is the trend with time. Adams (1989a) noted a decrease in spike concentrations with time and suggested that fuel manufacturing has improved over the years.

The reduction in maximum iodine peak concentrations with time is illustrated in Figure 5-1 Shown in Figure 5-1 are the largest spike peaks for each calendar year. The maximum concentrations in analyzed spikes has decreased from approximately 18 µCi/g in the early 1970s to approximately 9 µCi/g after 1980. Taking 9 µCi/g as an upper bound, the SRP value of 60 is an overestimate by a factor of 6.7.

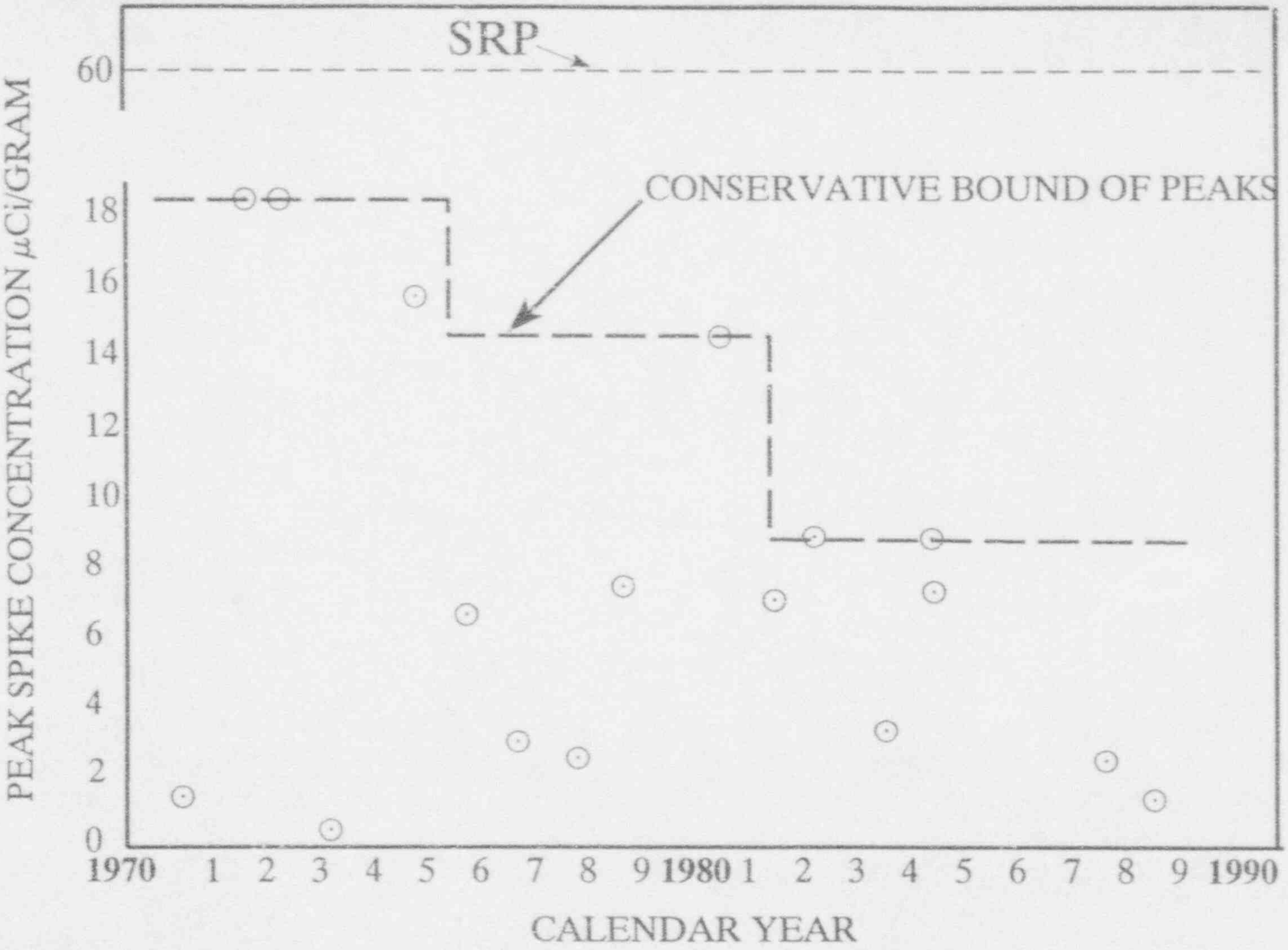


Figure 5-1
Maximum Iodine Spike Concentration Sorted According to Calendar Year

Iodine Release Rate for Accident-Induced Spikes

Average Iodine Concentration Implied by SRP Release Rate Model

For the accident-initiated spike, a release rate of 500 times the equilibrium release rate at a coolant concentration of 1 μCi/g is stipulated by SRP rules. This can be quantified for an individual plant as follows.

First, the equilibrium release rate can be computed from eq. 3:

$$R_0 = C_0 M\lambda \qquad \textbf{(eq. 3)}$$

Taking $C_0 = 1\ \mu\text{Ci/g}$, $M = 3.2\text{ E8 g}$, and $\lambda = 0.0972\text{ hr}^{-1}$, R_0 is:

$$R_0 = 1\text{x}10^{-6}\ \frac{\text{Ci}}{\text{g}}\ \text{x}\ 3.2\text{ E }8\text{ g}\ \text{x}\ \frac{0.0972}{\text{hr}} = 31.1\ \text{Ci/hr}$$

The values of M and λ used above are the values cited by Pasedag (1977) for the Oconee Plant.

Applying the 500 spike factor, the spike rate is:

$$R = 500\ (31.1) = 15{,}600\ \text{Ci/hr.}$$

Applied over a two hour period, the total curies released would be 31,100 Ci. The resultant coolant concentration is thus:

$$C_{2h} = 31{,}100\ \text{Ci}\ \text{x}\ 10^6\ \frac{\mu\text{Ci}}{\text{Ci}}\ \text{x}\ \frac{1}{3.2\text{E8 g}} = 97.2\ \mu\text{Ci/g}$$

This concentration (97.2 μCi/g) is much higher than peak concentrations in characterized spikes (Table 4-3) and on this basis the SRP spike rate model appears to be overly conservative.

The two-hour average concentration would be just half of the two-hour concentration or 48.6 μCi/g. Thus doses computed using a concentration of 48.6 μCi/g would be roughly 5 times higher than for the experimentally measured upper bound for pre-existing spikes (9 μCi/g).

Comparison of SRP Spike Rate with Spike Data

Spike rates analyzed in ***Maximum Iodine Release Rates in Spiking Events*** showed that 98% of spikes subjected to best-estimate analysis were equal to or smaller than 795 Ci/hr (see Table 4-4). The SRP spike rate estimated above (15,600 Ci/h) is 19.6 times larger than the 98 percentile value of 795 Ci/hr.

For conservatively calculated spike rates (Adams-1989b) the 98 percentile rate is 2650 Ci/hr. As noted in ***Maximum Iodine Release Rates in Spiking Events*** the conservatively calculated rates at the upper end of the distribution were roughly 3.9 times larger than best estimate values. The SRP spike model overpredicts even this conservative estimate by a factor of 5.9.

Mathematical Comparison of Pre-Existing and Accident-Initiated Spikes

In this section the two spike cases prescribed in SRP methodology (NRC 1981) are compared. This comparison is based on interpreting available spike data in terms of peak concentration (the pre-existing spike case) or in terms of release rates (the accident-initiated spike case). As will be shown, two-hour average iodine concentrations in reactor coolant are highest when the peak concentration is used to characterize the spike. Thus, for two hour iodine dose calculations, the pre-existing spike case appears to be dominant.

Analysis of Constant Rate Spikes. For this case a spike of arbitrary release rate, R Ci/hr, and duration, t_p hr, is postulated. The temporal variation in iodine concentration in primary coolant is given by eq. 1.

$$C = C_o e^{-\lambda t} + \frac{R}{M\lambda}(1 - e^{-\lambda t}) \qquad \text{(eq.1)}$$

where C = iodine concentration at time t, Ci/g,

C_o = iodine concentration at time = 0, Ci/g,

R = iodine spike rate. Ci/hr,

M = mass of primary water, g,

λ = iodine removal rate, hr^{-1} ,

t = time from beginning of spike, hr.

For spikes on interest, C will increase from C_o to a maximum value C_p . The value of C_p can be determined from eq. 1 by inserting values for C_o, R, M, and λ and setting time equal to spike duration, t_p.

For the pre-existing spike case, one assumes that an accident occurs at time = t_p, when C is a maximum (C_p). The concentration is assumed to remain constant at the peak value because of the assumed unavailability of the cleanup system[1]. The two hour average concentration is simply the peak for this case:

$$C_{2h} = C_p$$

This <u>same</u> arbitrary spike can be analyzed as an accident initiated spike of constant rate. Under SRP methodology the cleanup system is unavailable, so $\lambda = 0$. For this case iodine increases linearly with time:

$$C = C_o + \frac{RT}{M} \qquad \text{(eq.5)}$$

The two-hour average concentration may be obtained by integrating eq. 5 with respect to time and dividing the result by the time span:

---

[1] Radioactive decay, leakage of coolant, iodine plateout and other depletion mechanisms are neglected in this report. The value of λ in eq.1 is assumed to be solely a function of cleanup system operation.

$$C_{avg} = \frac{\int_0^2 (C_o + \frac{RT}{M})\,dt}{(2 - 0)} = C_o + \frac{R}{M} \qquad \text{(eq. 6)}$$

This expression (eq. 6) is valid for times of two-hours or longer. The spike rate, R, for the arbitrary spike may be computed from the peak concentration using eq. 1 :

$$\frac{R}{M} = \frac{(C_p - C_o\, e^{-\lambda t_p})\lambda}{1 - e^{-\lambda t_p}} \qquad \text{(eq. 1b)}$$

The ratio of two-hour average iodine concentrations for the accident-initiated and pre-existing spike case can be solved for by substituting eq. 1b into eq. 6 and then dividing by C_p, the two-hour average for the pre-existing case. The result is:

$$\frac{C_{AI}}{C_{PE}} = \frac{C_o}{C_p} + \frac{(1 - \frac{C_o}{C_p} e^{-\lambda t_p})\lambda}{(1 - e^{-\lambda t_p})} \qquad \text{(eq. 7)}$$

where C_{AI} = two-hour average iodine concentration for accident-initiated spike,

C_{PE} = two-hour average iodine concentration for pre-existing spike,

t_p = time duration of spike, hr.

The ratio expressed in eq. 7 is numerically less than unity for all spike cases of interest ($C_p/C_o >> 1$). Eq. 7 can be simplified for illustration purposes by neglecting C_o/C_p and by approximating $e^{\lambda t_p}$ by $1 - \lambda t_p$. The result is:

$$\frac{C_{AI}}{C_{PE}} = \frac{1}{t_p} \qquad \text{(eq. 8)}$$

For the shortest t_p covered by this analysis, two hours, the ratio C_{AI} / C_{PE} is ½ = 0.5. For longer spikes ($t_p > 2$hr), the ratio predicted by eq. 8 would be smaller than 0.5.

For spikes that persist for less than two hours ($t_p > 2$hr) the integration expressed in eq. 6 is not applicable. For $t_p < 2$ hr a two step integration from $t = 0$ to $t = t_p$ and then from $t = t_p$ to $t = 2$ hr is required. Iodine concentration would increase linearly during the spike ($0 < t < t_p$) and then remain constant at C_p for the remainder of the two hour period ($t_p \leq t \leq 2$hr). The ratio of two hour average concentrations applicable to spikes having durations less than two hours is derived (by performing the two step integration) to be:

$$\frac{C_{AI}}{C_{PE}} = \frac{C_o}{C_p} + \frac{(t_p - t_p^2/4)(1 - \frac{C_o}{C_p}\, e^{-\lambda t_p})\lambda}{(1 - e^{-\lambda t_p})} \qquad \text{(eq.9)}$$

Where t_p = spike duration, hr.

The ratio expressed in eq. 9 has a maximum value of unity for all spike cases of interest ($C_p >> C_o$). Eq. 9 can be simplified for illustration purposes by neglecting C_o / C_p and by approximating exp $(-\lambda t_p)$ by $(1-\lambda t_p)$. Using these approximations, eq. 9 degenerates to:

$$\frac{C_{AI}}{C_{PE}} = 1 - \frac{t_p}{4} \qquad \text{(eq. 10)}$$

It is noted that the denominator of 4 in eq. 10 has the units of hr, so t_p must be expressed in hr.

The ratio expressed in eq. 10 is unity for spikes of zero time duration, and decreases to 0.5 for a duration of two hours.

Based on the analyses in the foregoing paragraphs it is evident that for spikes that are characterized by constant iodine release rates, two hour doses based on peak concentration will equal or exceed two hour doses based on the release rate (with no cleanup). In terms of SRP spike cases, the pre-existing spike case dominates.

Temporal Analysis of Spike Data. In this section available spike data are analyzed using extremely conservative assumptions regarding iodine release rates. The objective is to evaluate the extent to which the constant rate assumption made in the previous section may have been responsible for the conclusion that the pre-existing spike case is dominant compared to the accident-initiated case.

In the analysis that follows iodine spike releases are assumed to occur in **instantaneous bursts** following each measured concentration. While this assumption is not realistic, it provides a means for estimating a hypothetical upper limit to two hour average concentrations for the accident-initiated spike cases called for in SRP methodology. As will be shown, results of this extremely conservative analysis are consistent with the results of the constant rate spike case in that they support the conclusion that the pre-existing spike case dominates.

The method of analysis is depicted schematically in Figure 5-1 where a time-concentration data set for a spike reported by Lutz (1975) is shown. The solid circles represent measured time-concentration pairs. The dashed line drawn to the left of the solid circles represent extrapolations backwards in time, on the basis of a cleanup system λ, hr^{-1} . These extrapolation represent concentration-time histories for the hypothetical case in which it is assumed that iodine is released as instantaneous bursts following the measured concentration. It is then assumed that these bursts occurred for an accident-initiated spike where $\lambda = 0$. The solid lines drawn across the top of the shaded regions represent the concentration that would be predicted for the burst release assumption if no removal occurred.

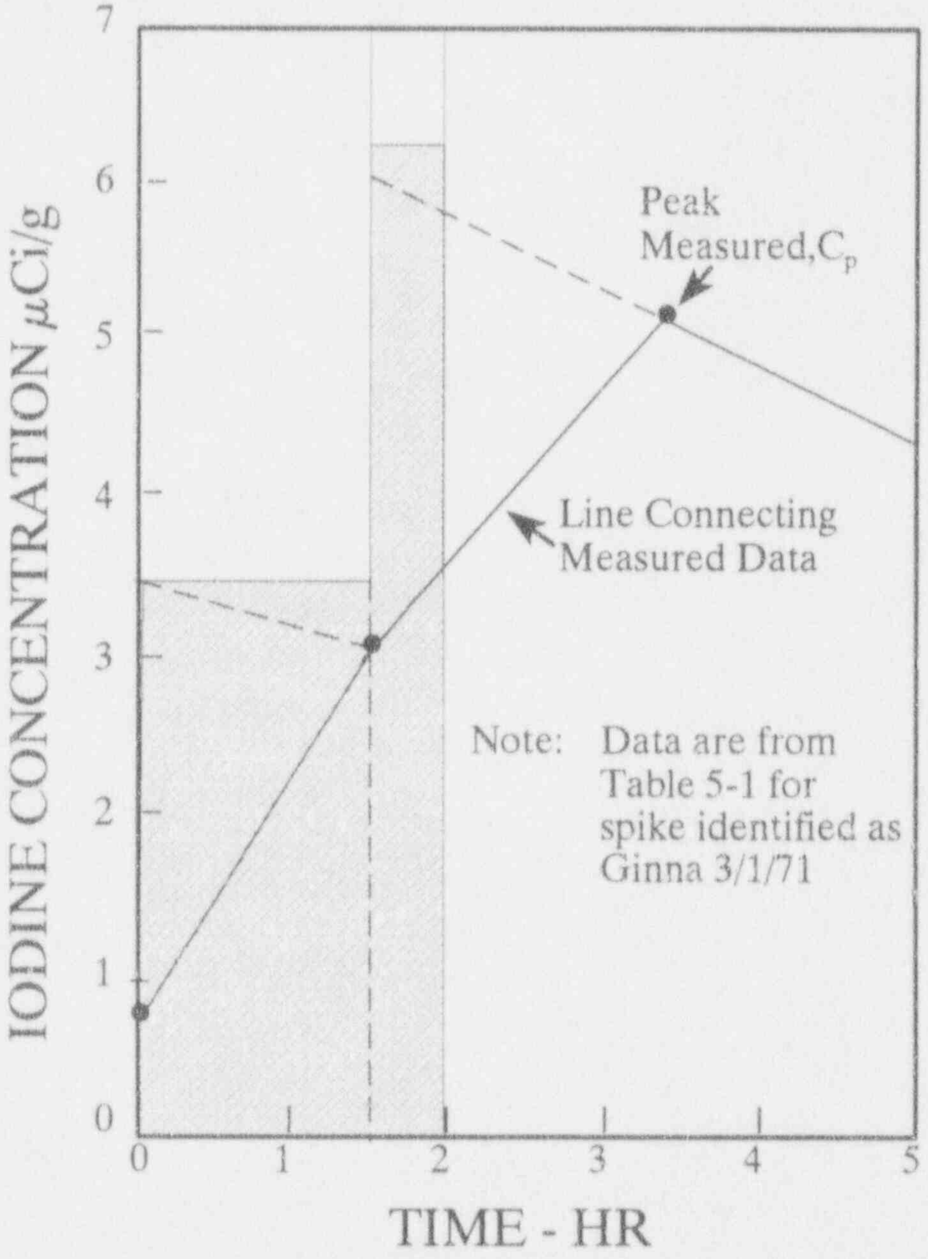


Figure 5-2
Illustration of Temporal Analysis in which Iodine Releases are Treated as Instantaneous Bursts.

A maximum iodine concentration caused by the assumed burst was computed from the measured concentration, effected and predicted depletion of iodine by the cleanup system as follows:

$$C_{max} = C_{meas.} \exp(\lambda \cdot \Delta t) \qquad \text{(eq.11)}$$

Where C_{max} = maximum projected iodine conc., μCi/g,

$C_{meas.}$ = measured iodine concentration, μCi/g,

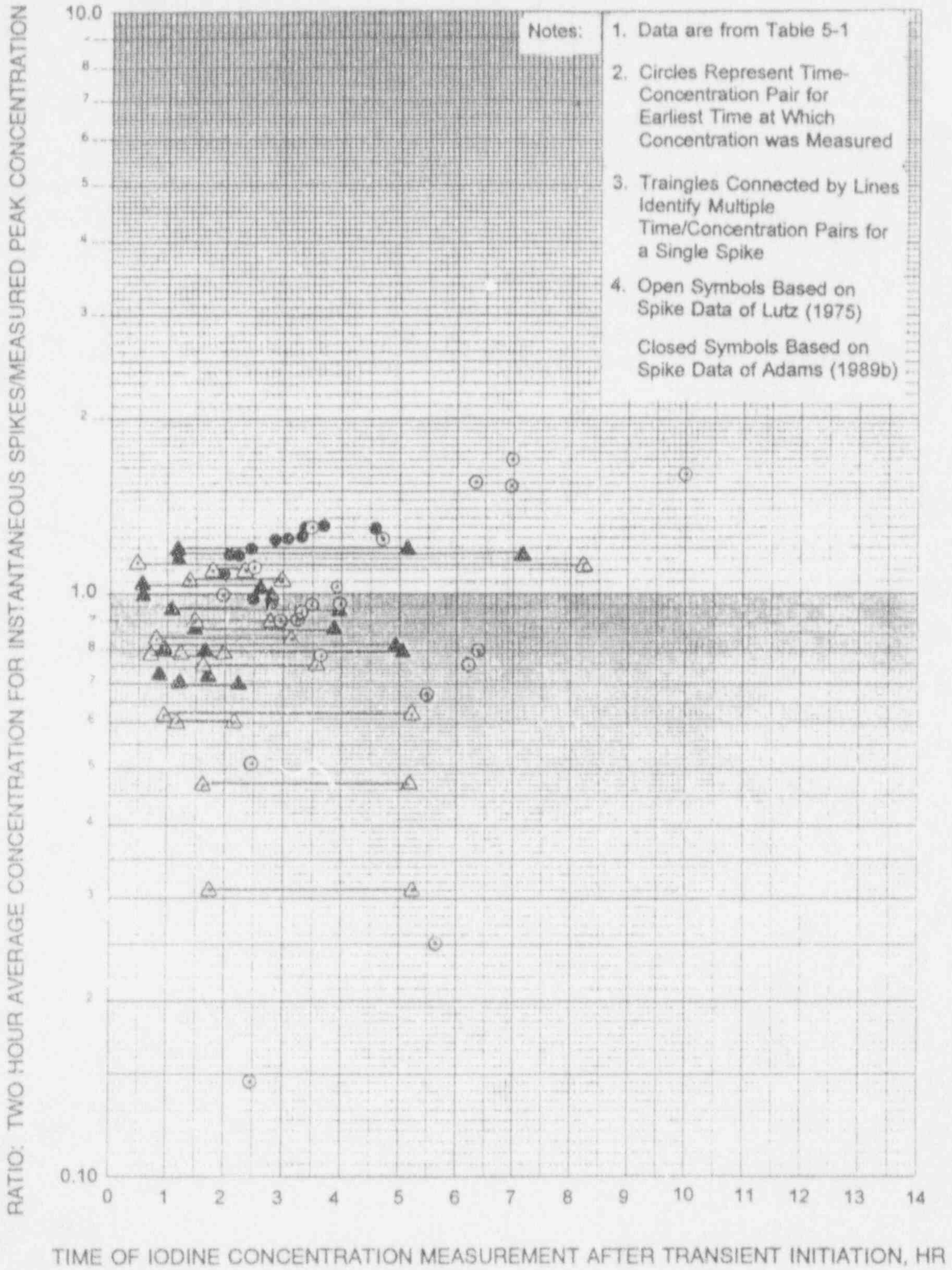
λ = iodine removal rate, hr^{-1},

Δt = time between concentration measurements, hr.

An upper limit projection for the two hour average concentration can be obtained by integrating beneath the horizontal lines which cap the shaded area in Figure 5-1, and then dividing the integral by two hours. The two hour average concentration calculated in this way may be compared to the peak concentration measured for the spike in question. The measured peak concentration is identified as C_p in Figure 5-1. These two concentrations ($C_{max\text{-}2hr}$ and C_p) are linear factors in iodine doses calculated for accident-initiated and pre-existing spike cases respectively. For the specific case depicted in Figure 5-1, the ratio $C_{max\text{-}2h}/C_p$ is 0.76, showing that the pre-existing case dominates (C_p is larger than $C_{max\text{-}2h}$).

The analysis method depicted in Figure 5.1 was applied to the spike data sets published by Lutz (1975) and Adams (1989b). Results of the temporal analysis are depicted graphically in Figure 5-2. Details of the analysis are listed in Table 5-1 and Table 5-2 for each spike analyzed.

Figure 5-2 displays calculated values of the ratio: (2 hr avg. conc. for instantaneous iodine bursts/ measured peak concentration). When this ratio is unity or less, the spike data indicate that the pre-existing spike case dominates as compared to the accident-initiated case in which iodine releases are treated as instantaneous bursts. As shown, most of the spike data have ratios (as defined on the ordinate of Figure 5-2) which are less than unity. Spike data for which the calculated ratio is greater than unity correspond to spikes for which data were not available to define concentrations at early (< 2 hr) times. For example, the highest ratio (1.69) applies to a case for which the earliest data was reported at 7 hours after transient initiation. For all spike cases in which at least one data point in the two hour time frame is available, the value of the ratio is 1.14 or less.



Notes:
1. Data are from Table 5-1
2. Circles Represent Time-Concentration Pair for Earliest Time at Which Concentration was Measured
3. Traingles Connected by Lines Identify Multiple Time/Concentration Pairs for a Single Spike
4. Open Symbols Based on Spike Data of Lutz (1975)

   Closed Symbols Based on Spike Data of Adams (1989b)

Figure 5-3
Temporal Analysis of Spikes Treated As Instantaneous Bursts With No Cleanup.

The results of this temporal analysis of available spike data support the conclusion that the pre-existing case dominates compared to the accident-initiated case when both cases are based on the same spike data base. This conclusion is based on the following observations.

- For spike cases where data are available during the initial two hours of a transient, the pre-existing case dominates even when spikes are analyzed as instantaneous bursts.
- For the relatively few cases where the instantaneous burst release model predicts slightly higher average concentrations than the measured peak concentration, the overprediction is explainable in terms of the time delay between transient initiation and concentration measurement and the conservatism inherent in the instantaneous burst release model.

It is recognized that the scope of the temporal analysis described herein was limited by the availability of time-concentration data for spikes. The conclusions drawn above could be confirmed by analysis of a larger data base, in which data were available at closely spaced time intervals.

Detailed results from the temporal analysis of spike data are presented in Tables 5-1 and 5.2. The numbers presented in Table 5-1 and 5-2 quantify the temporal analysis done under the hypothetical instantaneous burst release assumption.

The cleanup system removal rate constant, λ, was assigned an average value of 0.075 hr^{-1} for all of the spike cases analyzed in Table 5-1. This assumption was made because explicit values of λ were not reported by Lutz (1975) or Adams (1989b). Errors introduced by the use of a mean value of λ are not expected to be important for the initial two hour time period because the cleanup system does not reduce iodine concentrations by more than ~20% during any two-hour period.

Heading in Tables 5-1 and 5-2 are defined as follows.

Plant	The name of the nuclear power station from which spike data were collected.
Date	Month/Day/Year when spike data were determined.
Time	Time in hours measured from the beginning of a transient.
Measured Conc.	Measured I-131 equiv. concentration in reactor coolant at stated time.

Projected C_{MAX}	Iodine concentration obtained by projecting backwards in time using eq. 10.
Projected Spike ΔC	The difference between Projected C_{MAX} and the measured concentration.
2 hr-avg C_{MAX}	The two-hour-integrated average I-131 conc. using the theoretical maximum iodine concentrations (the shaded areas in Figure 5-2).
Measured C_{peak}	The highest measured I-131 conc. for the spike.
Time of Measured Peak	Time in hours after beginning of transient when peak was measured.
Ratio: $C_{MAX-2HR}$ /C_P	C_{MAX-2H} divided by C_p.

Table 5-1
Comparison of Projected Spike two hour average Concentration with Measured Peak Concentrations
(Spike Data from Lutz (1975))

TABLE 5-1

Plant	Date	Time,hr	Measured Conc. µCi/g	Projected C_{max} µCi/g	Projected Spike ΔC µCi/g	2 hr-Avg C_{max} µCi/g	Measured C_{peak} µCi/g	Time of Measured Peak,hr	Ratio: $\frac{C_{max\ 2\,hr}}{C_p}$
Ginna	12/13/72	0.0	0.05						
"	"	5.5	0.074	0.112	0.062	0.112	0.165	13.5	0.67
Ginna	1/12/73	0.0	0.037						
"	"	2.47	0.061	0.073	0.036	0.0734	0.145	11.47	0.51
Ginna	7/22/73	0.0	0.061						
"	"	4.7	0.217	0.309	0.248	0.309	0.25	4.70	1.24
Ginna	10/21/73	0.0	0.082						
"	"	6.42	0.114	0.185	0.103	0.185	0.230	10.16	0.80
Ginna	2/26/71	0.0	0.91						
"	"	0.5	1.16	1.204	0.294				
"	"	8.25	5.53	9.89	8.73	7.75	6.8	10.0	1.14

TABLE 5-1

Plant	Date	Time,hr	Measured Conc. μCi/g	Projected C_{max} μCi/g	Projected Spike ΔC μCi/g	2 hr-Avg C_{max} μCi/g	Measured C_{peak} μCi/g	Time of Measured Peak,hr	Ratio: $\frac{C_{max\ 2hr}}{C_p}$
Ginna	4/14/72	0.0	0.70						
"	"	10.0	13.8	29.2	28.5	29.2	18.3	11.0	1.60
Pt. Beach	4/6/74	0.0	0.13						
"	"	3.33	0.293	0.376	0.246	0.376	0.41	7.5	0.92
San Onofre	10/2/70	0.0	0.195						
"	"	7.0	0.85	1.44	1.24	1.44	0.85	7.0	1.69
Haddam	4/16/71	0.0	0.041						
"	"	6.25	1.40	2.24	2.20	2.24	3.00	10.25	0.75
Haddam	6/9/72	0.0	0.03						
"	"	1.0	0.10	0.108	0.0778				
"	"	5.25	0.50	0.688	0.588	0.402	0.65	7.5	0.62
Mihama 1	5/25/72	0.0	0.106						
"	"	1.67	0.092	0.104	-0.002				
"	"	5.25	0.35	0.458	0.366	0.164	0.35	5.25	0.47
Mihama 2	1/8/75	0.0	0.051						

TABLE 5-1

Plant	Date	Time,hr	Measured Conc. µCi/g	Projected C_{max} µCi/g	Projected Spike ΔC µCi/g	2 hr-Avg C_{max} µCi/g	Measured C_{peak} µCi/g	Time of Measured Peak,hr	Ratio: $\frac{C_{max\ 2hr}}{C_p}$
"	"	2.5	0.051	0.0615	0.001	0.0615	0.44	5.17	0.14
Pt. Beach	4/7/74	0.0	0.046						
"	"	2.5	1.99	2.40	2.35	2.40	1.99	2.5	1.21
San Onofre	10/5/70	0.0	0.195						
"	"	1.75	0.20	0.228	0.033				
"	"	5.25	0.764	0.993	0.793	0.327	1.05	7.75	0.31
San Onofre	12/26/71	0.0	0.023						
"	"	0.84	0.074	0.0788	0.0558				
"	"	3.17	0.25	0.298	0.224	0.209	0.25	3.17	0.84
Ginna	4/15/72	0.0	6.8						
"	"	4.0	7.8	10.5	3.73	10.5	11.0	6.0	0.96
Ginna	2/27/71	0.0	5.82						
"	"	3.0	13.0	16.3	10.5	16.3	18.1	5.5	0.90
Haddam	6/10/70	0.0	0.44						
"	"	5.67	0.98	1.50	1.06	1.50	6.0	11.17	0.25

TABLE 5-1

Plant	Date	Time,hr	Measured Conc. μCi/g	Projected C_{max} μCi/g	Projected Spike ΔC μCi/g	2 hr-Avg C_{max} μCi/g	Measured C_{peak} μCi/g	Time of Measured Peak,hr	Ratio: $\frac{C_{max\ 2hr}}{C_p}$
Mihama 1	5/26/72	0.0	0.177						
"	"	0.75	0.222	0.235	0.0578				
"	"	1.25	0.312	0.324	0.102				
"	"	2.00	0.385	0.407	0.0953	0.334	0.425	2.25	0.79
Mihama 2	1/8/75	0.0	0.312						
"	"	1.17	0.318	0.347	0.0352				
"	"	2.17	0.323	0.348	0.0302	0.360	0.60	5.67	0.60
Pt. Beach	4/8/74	0.0	1.05						
"	"	1.42	1.22	1.36	0.307				
"	"	3.0	1.10	1.24	0.0184	1.37	1.22	1.42	1.12
San Onofre	10/5/70	0.0	0.028						
"	"	3.67	0.471	0.620	0.592	0.62	0.80	5.17	0.78
San Onofre	10/7/93	0.0	0.57						
"	"	6.33	1.02	1.64	1.07	1.64	1.02	6.33	1.60
San Onofre	12/26/71	0.0	0.123						

TABLE 5-1

Plant	Date	Time,hr	Measured Conc. μCi/g	Projected C_{max} μCi/g	Projected Spike ΔC μCi/g	2 hr-Avg C_{max} μCi/g	Measured C_{peak} μCi/g	Time of Measured Peak,hr	Ratio: $\frac{C_{max\ 2hr}}{C_p}$
"	"	1.5	1.66	1.86	1.73				
"	"	3.0	2.35	2.63	0.97	2.10	2.35	3.0	0.90
Ginna	4/16/72	0.0	7.6						
"	"	2.0	8.7	10.1	2.51	10.1	10.2	7.17	0.99
Ginna	4/17/72	0.0	0.2						
"	"	3.5	5.5	7.15	6.95	7.15	5.5	3.5	1.30
Ginna	4/18/72	0.0	1.70						
"	"	7.0	6.7	11.3	9.60	11.3	7.4	9.0	1.53
Ginna	3/1/71	0.0	0.87						
"	"	1.67	3.06	3.47	2.60				
"	"	3.67	5.2	6.04	2.98	3.96	5.2	3.67	0.76
Haddam	4/17/71	0.0	2.15						
"	"	3.25	2.15	2.74	0.593	2.74	3.0	6.75	0.91
Haddam	6/11/72	0.0	3.5						
"	"	3.5	8.84	11.5	7.99	11.5	12.0	5.75	0.96

TABLE 5-1

Plant	Date	Time,hr	Measured Conc. μCi/g	Projected C_{max} μCi/g	Projected Spike ΔC μCi/g	2 hr-Avg C_{max} μCi/g	Measured C_{peak} μCi/g	Time of Measured Peak,hr	Ratio: $\frac{C_{max\ 2hr}}{C_p}$
Mihama 1	5/26/72	0.0	0.235						
"	"	1.83	0.377	0.432	0.197				
"	"	2.50	0.400	0.421	0.044	0.438	0.40	2.5	1.10

Table 5-2
Comparison of Projected Spike two hour average Concentration with Measured Peak Concentrations
(Spike Data From Adams 1989b)

TABLE 5-2

Plant	Date	Time,hr	Measured conc. µCi/g	Projected C_{max} µCi/g	ΔC Projected Spike µCi/g	2 hr Avg C_{max} µCi/g	Measured C_{peak} µCi/g	Time of Measured Peak, hr	Ratio $\frac{C_{max\ 2hr}}{C_p}$
Surry 1	8/04/85	0	0.061						
		0.33	1.08	1.107					
		2.67	1.79	2.133	1.053	1.986	1.89	4.17	1.051
Surry 1	9/11/85	0	0.053						
		2.5	1.24	1.496		1.496	1.43	6.5	1.0
Crystal R.	6/24/77	0	0.206						
		3.95	1.517	2.04		2.04	1.957	9.37	1.04
Crystal R.	1/06/79	0	0.237						
		2.0	4.6	5.34		5.34	4.60	2.0	1.16
M. Yankee	11/05/79	0	0.268						
		2.3	2.75	3.38		3.38	2.75	2.3	1.23

TABLE 5-2

Plant	Date	Time,hr	Measured conc. µCi/g	Projected C_{max} µCi/g	ΔC Projected Spike µCi/g	2 hr Avg C_{max} µCi/g	Measured C_{peak} µCi/g	Time of Measured Peak, hr	Ratio $\frac{C_{max\ 2hr}}{C_p}$
St. Lucie 1	9/08/81	0	0.045						
		4.62	1.193	1.687		1.687	1.287	7.2	1.311
Cryatal R.	1/17/79	0							
		2.75	3.61	4.437		4.437	4.50	9.75	0.086
Crystal R.	1/30/79	0							
		0.97	2.46	2.646					
		4.97	3.69	4.981	2.521	3.944	4.74	8.88	0.832
North Anna	7/10/81	0							
		1.25	1.35	1.483					
		7.20	1.08	1.687	0.337	1.609	1.35	1.35	1.192
North Anna	7/12/81	0							
		1.2	1.17	1.28					
		5.12	1.04	1.481	0.311	1.404	1.17	1.2	1.20
Surry 1	11/29/81	0							
		1.22	1.80	1.972					

TABLE 5-2

Plant	Date	Time,hr	Measured conc. µCi/g	Projected C_{max} µCi/g	ΔC Projected Spike µCi/g	2 hr Avg C_{max} µCi/g	Measured C_{peak} µCi/g	Time of Measured Peak, hr	Ratio $\frac{C_{max\ 2hr}}{C_p}$
		2.22	2.47	2.662	0.862	2.308	3.27	4.22	0.706
St. Lucie 1	12/19/81	0	0.10						
		3.35	1.09	1.401		1.401	1.127	7.35	1.243
Surry 1	4/13/82	0	0.158						
		1.5	4.59	5.137					
		3.8	6.75	8.021	3.431	5.995	6.75	3.8	0.888
Surry 1	4/25/82	0	0.191						
		2.5	4.86	5.862		5.862	4.86	2.50	1.206
Surry 1	1/05/82	0	0.35						
		3.12	5.63	7.114		7.114	5.63	3.12	1.26
Surry 1	3/25/82	0	0.218						
		0.92	3.61	3.868	3.650				
		1.72	5.50	5.84	2.230				
		2.92	7.46	8.163	2.663	5.445	7.46	2.92	0.73
Crystal R.	7/02/87	0	0.065						

TABLE 5-2

Plant	Date	Time,hr	Measured conc. µCi/g	Projected C_{max} µCi/g	ΔC Projected Spike µCi/g	2 hr Avg C_{max} µCi/g	Measured C_{peak} µCi/g	Time of Measured Peak, hr	Ratio $\frac{C_{max\ 2hr}}{C_p}$
		3.7	1.275	1.683		1.683	1.275	3.7	1.32
Surry 1	1/18/84	0	0.121						
		2.85	1.89	2.34		2.34	1.89	2.85	1.238
Surry 1	2/06/84	0	0.125						
		2.47	2.15	2.588		2.588	2.15	2.47	1.204
Surry 1	1/06/84	0	0.113						
		2.1	1.57	1.838		1.838	1.57	2.1	1.171
Pt. Beach	3/08/83	0							
		1.7	0.907	1.030					
		5.07	1.47	1.893	0.986	1.178	1.47	5.07	0.801
Surry 1	1/08/86	0	0.061						
		3.43	2.26	2.923		2.923	2.26	3.43	1.293
Surry 1	1/24/86	0	0.091						
		0.58	1.02	1.065					
		2.83	1.04	1.231	0.211	1.215	1.22	4.33	0.996

TABLE 5-2

Plant	Date	Time,hr	Measured conc. µCi/g	Projected C_{max} µCi/g	ΔC Projected Spike µCi/g	2 hr Avg C_{max} µCi/g	Measured C_{peak} µCi/g	Time of Measured Peak, hr	Ratio $\frac{C_{max\ 2hr}}{C_p}$
San Onofre 3	2/19/93	0							
		1.08	0.331	0.359					
		4.08	0.564	0.706	0.375	0.532	0.564	7.25	0.942

6

IODINE RETENTION IN FAULTED STEAM GENERATOR

In this section, phenomenological aspects of iodine retention in the faulted steam generator are briefly discussed. The purpose is to identify parameters and physico-chemical processes that need to be considered in models for predicting iodine retention. Iodine retention within the faulted steam generator is potentially important in dose evaluations for the SGTR/MSLB sequence. Calculated doses would be reduced in proportion to the decontamination factor achieved within the generator.

Assumed Thermal Hydraulic Conditions

Based on recent thermal hydraulic analyses of SGTR/MSLB sequences (Chappidi et al. 1993, Wagner and Williams, 1993) it appears that the secondary side of the generator will dry-out and become superheated within a relatively brief time span. For this thermal hydraulic scenario, primary water would jet into the shell side of the generator, and be evaporated. Three kinds of liquid/gas interfacial configurations can be identified for evaporation: (1) steam borne drops (2) films attached to solid surfaces, and (3) a pool on the tube sheet.

Iodine Retention Mechanisms

A major fraction of iodine released from fuel during a spike is expected to be non-volatile ionic species. Small fractions of the iodine could be present as elemental iodine (I_2) or other volatile forms (organic iodides, etc.). These species have different retention characteristics, so the fraction of iodine present as each specie would have to be quantified, to allow retention to be predicted.

The relative abundance of iodine species in SGTR sequences was estimated in a study conducted at Pacific Northwest Laboratory (PNL) in 1982 (Postma, 1983). The iodine species considered and the estimated fraction of each is as follows:

- elemental iodine ~ 20%

- organic iodides and HOI ~ 1%
- iodine dissolved irreversibly ~ 80%

The speciation described above was chosen to yield a conservative prediction of iodine transport, i.e., to maximize the release. More recent information would lead one to expect iodine to be released as cesium iodide, and hence that almost all of the iodine would be ionic in form. A more recent study (Beahm, et al., 1989) of iodine speciation in PWR coolant systems indicates that the fraction of I_2 peaks at shutdown and amounts to as much as 20% of total iodine.

Since most iodine would be non-volatile, most iodine would follow the liquid residue after water evaporates. For water which evaporates in a pool or in a surface film, non-volatile iodine would be retained with other dissolved solids (mostly borate or boric acid). For evaporated droplets, the dry kernel would transport as an aerosol particle. A fraction of aerosol particles would be removed by various deposition mechanisms in the steam generator.

Experiments on iodine volatilization were conducted as part of large scale iodine spray removal tests at PNL in 1970 (Postma et al., 1970). In the tests, spray liquid was removed from the spray chamber and evaporated to dryness in the laboratory. Iodine, which had been added to the test vessel as airborne elemental iodine, was mostly retained in the solid residue in the bottom of the flask. The spray water contained 2950 ppm boron, made from boric acid. The pH of this solution was 5.0. The evaporation-to-dryness tests yielded an average iodine desorption fraction of 0.094. The highest observed value was 0.187 and the lowest was 0.038.

In the tests cited above, iodine was added as I_2, and reacted in solution to form non-volatile species. For the spike, most iodine would enter cooling water already in ionic form, and hence should be less volatile than iodine in the evaporation tests. Thus a large fraction (probably >0.9) of iodine present in evaporating water (pools, films, drops) would be expected to be retained with residual solids.

Volatile iodine would be expected to be mainly I_2 , a fraction of which would deposit on exposed surfaces in the steam generator. The fractional deposition could be estimated using applicable flow parameters and an applicable iodine deposition velocity.

Organic iodines are expected to make up too small a part of total iodine to play an important role in iodine retention.

Based on this brief look at iodine retention for the dryout case, retention could be predicted by quantifying the following physico-chemical phenomena;

- abundance of volatile/non-volatile iodine species in primary coolant,
- the fraction of water that evaporates in the physical configuration of pools, surface films, and drops,
- entrainment of drops/particles from boiling pools and films,
- deposition of I_2 onto surfaces in the steam generator
- retention of aerosol particles formed by the evaporation of drops.

The validity of a key assumption in the foregoing discussion, namely that iodine would be mostly non-volatile and would be retained with solid residues after water evaporates, could be verified by relatively simple boil-off tests. In the envisioned tests, reactor coolant water samples, taken from an operating plant during a spike event, would be evaporated to dryness. An adsorber would be used to trap iodine carried off with steam. A comparison of iodine in the adsorber with iodine retained in the boiling flask would permit one to compute the fraction retained with solids in the flask. It is anticipated that only a small fraction of iodine would be found in the sorbent trap.

7

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