ENCLOSURE

IODINE SPIKING IN BWR AND PWR COOLANT SYSTEMS *

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INTRODUCTION

"Iodine spiking" is a term of convenience used to describe the temporary increase in the primary coolant iodine concentration frequently observed following significant power changes in BWR and PWR plants. The reported data shows this temporary increase in iodine concentrations to occur following shutdowns, start-ups, rapid power changes, and coolant depressurization. Iodine spikes are characterized by a rapid increase in coolant concentration by as much as three orders of magnitude, followed by a return to pre-spike concentrations. The latter characteristic distinguishes the spiking phenomenon from a step-wise permanent increase in coolant activity level caused by the sudden failure of one or more fuel rods.

The occurrence of temporary increases in reactor water iodine concentrations particularly following shutdowns, has been a well established fact for many years. However, very little data has been reported and, to date, no single, entirely satisfactory explanation of the phenomenon has been demonstrated. Notley and MacEwan[1] observed a stepwise release of fission gases from UO_2 fuel during power transients, and attribute this observation to the release of fission gases trapped in bubbles within the UO_2 matrix. They observe that "(fission) gas appears to be released as the thermal power is decreased to zero during reactor shutdown." Carrol and Sissman[2] measured fission gas releases from cooling UO_2 and attribute the release to thermal stress arising from rapid cooling of the ceramic fuel. The release of trapped fission gas results from the opening of microcracks, and strain along grain boundaries produced by the thermal stress. Eigenwillig and Hock[3] suggest that shutdown spikes may be explained by water leaching of the inner surfaces of defective fuel rods. Following shutdown in BWR's and during power reductions in PWR's water is assumed to penetrate the defective rods and leach out plated-out iodine from the interior of the rod.

No attempt is made in this review to derive a model to describe the mechanism of the release of iodine from the fuel during a spike. Instead the available information concerning iodine spiking behavior is reviewed for empirical correlation with normally observed plant operating parameters.

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SAFETY SIGNIFICANCE OF IODINE SPIKING

The current interest in the iodine spiking phenomenon arises from the recognition that it may have a significant effect on offsite thyroid doses resulting from postulated accidents involving the release of reactor coolant, such as a steam line or instrument line failure in the BWR, or a steam generator tube failure in the PWR. If these accidents do not result in additional fuel failure, the radioactivity carried by the released reactor coolant becomes the primary source term in the assessment of the radiological consequences of the postulated accident. Any increase in the iodine concentration of the reactor coolant, therefore, will increase the resulting thyroid doses. Because these accidents produce the conditions most conducive to iodine spiking, i.e. rapid power reduction followed by system depressurization, a conservative accident analysis must include an account of the resulting iodine spike.

A second consideration is the possibility of an accidental release of primary coolant during a period of high coolant activity resulting from a spike produced by a previous power change. It must be recognized, however, that the probability of this coincidence of a previously initiated iodine spike with an accident occurring at or near the time of peak coolant concentration is significantly smaller than the probability of the accident alone, particularly for plants exhibiting infrequent spiking behavior.

Estimates of the increase in the thyroid doses resulting from these two iodine spiking effects on coolant concentrations during certain postulated accidents have been derived previously.[4] The results of these investigations showed that iodine spiking has a pronounced effect on offsite thyroid doses for the BWR steam line failure, BWR instrument line break, and PWR tube rupture. The BWR steam line failure is not affected by iodine spiking initiated by the scram and depressurization caused by the accident itself, since the coolant activity release is terminated within seconds upon closure of the steam line isolation valves. However, the coincidence of a previously initiated iodine spike with a steam line failure results in thyroid dose increases directly proportioned to the increase in coolant iodine concentration caused by the spike. The analysis of the instrument line failure and the steam generator tube failure indicate significant increases in the offsite doses from the iodine spike caused by the scram and depressurization as well as from the previously initiated spike.

It should be noted that the spiking release rate which was assumed in these calculations was a nominal value (i.e. an increase by a factor of 100 for a period of two hours). The data accumulated since that time shows that this rate has been exceeded repeatedly in operating plants, by as much as one order of magnitude. Similar effects are demonstrated for the use of a PWR steam line failure with large steam generator tube leaks by Fontecilla and Grimes in a paper presented at this conference.

In addition to these considerations, the effects of iodine spiking must be factored into the safety analyses of continuously (or very frequently) purged contain ments. Such containment concepts rely on fast-acting isolation dampers in the containment ventilation system to prevent a significant release in case of a loss-of-coolant accident. Although this isolation may be achieved prior to any significant release of fission products from the damaged fuel, a release of primary coolant containing iodine at spike concentration prior to this isolation frequently represents a significant increase of the thyroid doses calculated for this accident.

These examples demonstrate the need for a method to predict, or at a minimum, to derive bounding values for the iodine spiking phenomenon.

In the following paragraphs, an attempt is made to examine all available data for such a bounding value.

IODINE SPIKING DATA

In 1972, in response to AEC concerns, GE submitted a topical report[5] documenting over twenty cases of iodine spiking at eight operating BWR plants. Significant increase in reactor water iodine concentrations were observed following power changes, depressurization, and start-ups. Considerable variation in spiking behavior was observed, not only among different plants, but also for individual plants. The authors noted, however, that there was a definite reproducibility of spikes in the same plant when the fuel status was the same.

All of the GE data came from plants operating at relatively low fuel defect levels. An interesting and frequently made observation is that the ratio of peak spiking concentration to pre-spike reactor water concentration appears to be larger at lower fuel defect levels. If one extrapolates this postulated trend, iodine spiking effects would become smaller as the normal reactor coolant concentrations increase, and would eventually become insignificant at large failed fuel levels. An enlargement of the data base to include all data reported to date, including several data points at higher fuel levels, however, does not bear out this conclusion.

Eickelpasch and Hock[6] report measurements of concentrations during yearly shutdowns of the Gundremmingen BWR between 1970 and 1973. In all cases they observed spikes in the rate of activity release, after shutdown, with ^{131}I exhibiting the most pronounced spiking behavior. Considerable differences in the time of occurrence and the number of spikes were observed. In all cases, however, the release rate coefficient for ^{131}I, at its peak, was found to be about a factor of 100 larger than during power operation.

Iodine spiking in PWR systems is reported in Westinghouse and Combustion Engineering reports. R. Lutz[7] discusses 13 spiking sequences in five PWR's, and concludes that shutdown sequences can be separated into three distinct spikes, resulting from the power change (e.g. scram), the initial phase of pressure reduction, and final depressurization.

Combustion Engineering[8] reports fifteen data sets at several PWR's but considers the majority of this data proprietary information, thereby preventing its examination in this public forum.

In addition to these topical reports, individual data points are documented in several plant-specific reports.[10,11,12]

DISCUSSION OF DATA

All of the above-referenced data, as well as several unpublished data points, are reproduced in a uniform format in Tables I and II, wherever the appropriate data was available. The entries in these tables are best explained by use of several examples.

First, consider the spiking behavior exhibited in Figure 1, which is reproduced from reference 5. This figure shows a three peak spiking sequence which is typical of several spikes observed during planned shutdowns. For the purposes of this discussion, this sequence is considered to consist of a sequence of three individual spikes initiated by the reactor condition associated with a single shutdown.

The initiating events for each individual spike are concluded to have been a power reduction of approximately 40 percent, a further 60 percent power reduction to shutdown, and depressurization of the coolant system. (The power changes indicated in Table I are expressed in percent of full power wherever possible. Because full power level is not provided in Figure 1, these entries reflect the assumption of full power prior to the first power reduction.)

The "equilibrium" conditions listed in Table I represent the iodine concentrations during normal, full power operation, without any spiking contributions and represent the lowest concentrations at (or near) full power operation. The "equilibrium" cleanup rate refers to the average cleanup rate prevailing at the time of (and leading up to) the equilibrium coolant concentration. For the spiking sequence shown in Figure 1, this equilibrium concentration was assumed to be the first data point on the graph, i.e. approximately 0.0035 uCi/ml.*

Table II lists the initial and peak coolant concentrations for each individual spike. The "spiking time" associated with these peaks is 6.25, 3.5, and 3 hours, respectively, which corresponds to the time from the onset of a rapid concentration increase to the time of the peak. The downward slope following the peaks, in most cases, corresponds approximately to the reduction achieved by the cleanup system and, therefore, has been neglected in this analysis.

The term "total release," as used in Tables I and II, therefore, reflects the integral of the iodine 131 appearance rate from the onset of the spike to the time of the peak. For the three spikes shown in figure 1, a total release of 7, 142, and 546 curies was calculated. For the entire spiking sequence, therefore, a total of 695 curies were released. It should be noted that spikes even for similar shutdown procedures at the same plant do not always follow the ascent from a very small to a large spike demonstrated in this example. Similarly, a spiking sequence may consist of a larger or smaller number of individual spikes.

The average release rate factors of Table II represent the ratio of the iodine 131 appearance rate, averaged for the spiking time, as defined above, to the equilibrium release rate prior to the spike. Maximum release rate factors were determined for spikes for which sufficiently frequent measurements were reported to determine release rates for periods shorter than the total spiking time. In all cases, however, these shorter intervals consisted of periods of one hour or greater. For the spiking sequence shown in Figure 1, the average release rate factors are 7, 148, and 815. The second spike in this sequence has an obvious maximum release rate factor of 314 between 2 00 and 0100 hours. The third spike has a maximum release rate of 1030 times the equilibrium value between 0700 and 0800 hours. From this great variation of the release rate factor from 7 to 1030 for this spiking sequence alone, it is apparent that it will be difficult to characterize iodine spikes by their release rates. It also demonstrates that this parameter is particularly sensitive to the sampling frequency. It must be expected that significant maxima in this parameter are not identified for sampling intervals greater than two hours. Unfortunately, the majority of the reported data falls into this category.

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*Concentration data given per units volume were assumed to be measured at room temperature, so that 1 ml$\sim$1gm.

The "release rate" listed in Table I refers to the release of ^{131}I from the fuel during non-spiking equilibrium operation and, based on the assumption of equilibrium, is obtained by the product of the clean-up rate and the "equilibrium" concentration.

DATA CORRELATION

The parameter describing iodine spiking which is most useful in safety and accident analyses is the release rate factor. An examination of the data, however, indicates that this parameter is not suitable for use in empirical model because of its fluctuations not only for different spikes but within a given spiking sequence itself, and the susceptibility of this parameter to the inaccuracies resulting from insufficient sampling frequency. An integrated variable involving many measurements may be expected to be less susceptible to inaccuracies in measurement. Based on this reasoning the most reliable parameter to be extracted from this data appears to be the integral of the concentrations during each spiking sequence, i.e., the total curies released during the sequence.

A plot of this parameter versus the equilibrium release rate is shown in Figure 2. Although there is no single-valued correspondence between these variables, it is possible to draw a bounding line subtended by all spiking sequences. This boundary line indicates direct proportionality of the maximum observed release for any spiking sequence with the equilibrium release rate. Only one data point falls above this line, i.e., the plant A spiking sequence of 9/24/71. However, the deviation from direct proportionality is only 10 percent, which is well within the error band associated with this data.

The proportionality constant for this line is 10 Ci/(μCi/sec), or

$$Q = 10^7 R,$$

where: Q is the maximum release of ^{131}I during a spiking sequence (μCi),
R is the equilibrium release rate observed prior to the spiking sequence (μCi/sec).

Realizing that the equilibrium release rate is an indicator (albeit a very cursory one) of the power generated in defective fuel rods, the direct proportionality of the envelope of all spiking sequences to this parameter suggest that there is a certain limited fraction of a defective rods inventory which is available for spiking. Therefore, as the number of failed rods increases, the inventory available for spiking increases in proportion to the equivalent failed fuel level.

In order to determine the fraction of the failed rod's inventory available for release in a spike, an accurate measure of the fuel failure level is required. At present, not enough of the available iodine spiking data sets include the $^{131}I/^{133}I$ ratio, or other indicators, to permit an accurate assessment of core conditions prior to the spike. If the equilibrium appearance rate is assumed to originate only from power-averaged failed rods without any contribution from recoil fission products, the maximum release line shown on Figure 4 represents about 12% of the saturation ^{131}I inventory of these failed rods.

A plot of the curies released during each individual spike vs. the equilibrium ^{131}I release rate is shown in Figure 3. Although the release from each individual spike may be expected to be significantly less than the summation of the total release for a spiking sequence, Figure 3 shows that the largest single spikes observed are comparable to the sequence sums. The proportionality constant, therefore, is approximately 10^7 (sec^{-1}) for individual spikes as well.

This observation, i.e. that the maximum release during a single spike is nearly the same as that for the multiple-spike sequence suggests that the "spiking inventory" described above is independent of the method of release. This conclusion, however, does not address the question of which spiking sequence, or what order of the initiating events elicits the maximum release. The answer to this question requires further study of the spiking mechanisms.

CONCLUSION

The available iodine spiking data from both PWR and BWR plants was reviewed for possible correlation with operating plant parameters. It is concluded that the number, duration, and magnitude of spikes cannot be predicted without further study. However, a maximum ^{131}I release of 10 curies per µCi/sec of the equilibrium pre-spike iodine release rate from the fuel can be demonstrated for both BWR and PWR plants. This correlation suggests direct proportionality between a maximum inventory available for spiking and the failed fuel level of the core.

REFERENCES

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TABLE I

IODINE SPIKING DATA - INITIAL CONDITIONS

PLANT NAME	DATE	REF.	PRIMARY COOLANT MASS (kg)	EQUIL. CLEANUP COEF(sec^{-1})	EQUIL. I-131 CONC. (uCi/gm)	RELEASE RATE (uCi/sec)	PROBABLE INITIATING EVENT	DATA SET NO.
BWR PLANTS								
Plant A	6/27/70	5	1.48E+5	2.4E-4	1.3E-3	45	-25 % in 0.5 hr	A-11
"	"	"	"	"	"	"	Depress.	A-12
Plant A	10/1/70	5	1.48E+5	2.4E-4	1.9E-3	47	-25 % in 0.5 hr	A-21
"	"	"	"	"	"	"	Depress.	A-22
Plant A	5/2/71	5	1.48E+5	2.4E-4	3.5E-3	93	-40 % in 0.5 hr	A-31
"	"	"	"	"	"	"	-60 % in 2 hr	A-32
"	"	"	"	"	"	"	Depress.	A-33
Plant A	9/24/71-9/25	5	1.48E+5	2.4E-4	5.0E-4	17	-20 % in 1.75hr	A-41
"	"	"	"	"	"	"	Depress.	A-42
Plant B	5/1/71	5	1.6E+5	2.5E-4	6.5E-3	260	-90 % in 1 hr	B-11
"	"	"	"	"	"	"	Depress	B-12
Plant B	6/6/7	5	1.6E+5	2.5E-4	6.5E-3	260	-75 % in 2 hr	B-21
"	"	"	"	"	"	"	Depress.	B-22
Dresdn.2	9/29/71-9/30	5	2.43E+5	1.25E-4	2.3E-3	70	-40 % in 6 hr	D-11
"	"	"	"	"	"	"	Depress.	D-12
"	"	"	"	"	"	"	Shutdown	D-13
Dresdn.3	10/5/71	5	2.43E+5	1.25E-4	1.5E-4	5	-100 %	D-21
"	-10/6	"	"	"	"	"	Depress.	D-22
"	-10/7	"	"	"	"	"	Repress.	D-23
"	"	"	"	"	"	"	Restart	D-24
"	-10/9	"	"	"	"	"	Scram(?)	D-25
"	"	"	"	"	"	"	Power Increase	D-26
Oyst.Cr.	9/17/71-9/18	5	1.94E+5	1.0E-4	4.3E-3	85	Unknown	O-11
"	"	"	"	"	"	"	-45 % in 2 hr	O-12
"	"	"	"	"	"	"	Depress.	O-13

TABLE I

IODINE SPIKING DATA - INITIAL CONDITIONS

PLANT NAME	DATE	REF.	PRIMARY COOLANT MASS (kg)	EQUIL. CLEANUP COEF(sec^{-1})	EQUIL. I-131 CONC. (uCi/gm)	RELEASE RATE (uCi/sec)	PROBABLE INITIATING EVENT	DATA SET NO.
9 Mile Pt.	9/17/71	5	1.95E+5	1.25E-4	2.6E-3	65	-50 % in 0.5 hr	N-11
"	"	"	"	"	"	"	Depress.	N-12
Millst.1	8/6/71	5	1.74E+5	6.8E-5	1.6E-3	19	-60 % in 3 hr	M-11
"	"	"	"	"	"	"	Depress.	M-12
Millst.1	9/22/71-9/24	5	1.74E+5	1.1E-4	1.9E-3	36	-100 % in 2 hr	M-21
"	"	"	"	"	"	"	Depress.	M-22
"	"	"	"	"	"	"	Unknown	M-23
Millst.1	9/28/71-9/29	5	1.76E+5	1.3E-4	1.9E-3	43	+30 % in 1 hr	M-31
"	"	"	"	"	"	"	Scram	M-32
Millst.1	10/2/71	5	1.74E+5	1.36E-4	?	?	+30 % in 2 hr	M-41
PWR PLANTS								
Ginna	2/26/71	7	1.2E+5	2.75E-5	1.0E-1	3640	Scram	G-11
"	-2/27	"	"	"	"	"	Depress.	G-12
"	-3/1	"	"	"	"	"	Depress.	G-13
Ginna	4/14/72	7	1.2E+5	2.75E-5	5.0E-1	2100	Scram-restrt-scram	G-21
"	4/15-16	"	"	"	"	"	Depress.	G-22
"	4/17-18	"	"	"	"	"	Part.-repress.	G-23
"	-4/18	"	"	"	"	"	Part.-repress.	G-24
Haddam	4/15/71-4/18	7	2.42E5	2.86E-5	<3.5E-2	<242	Scram	H-11
"	"	"	"	"	"	"	Depress.	H-12
Haddam	6/9/72	7	2.42E+5	3.4E-5	5.0E-1	4100	-100 % in 1 hr	H-21
"	-6/10	"	"	"	"	"	Depress.	H-22
"	-6/11	"	"	"	"	"	Part.repress.	H-23
Mihama	1/8/75	7	1.63E+5	1.86E-5	5.0E-2	151	-100 % in 4 hr	I-11
"	-1/9	"	"	"	"	"	Depress.	I-12

TABLE I

IODINE SPIKING DATA - INITIAL CONDITIONS

PLANT NAME	DATE	REF.	PRIMARY COOLANT MASS (kg)	EQUIL. CLEANUP COEF(sec^{-1})	EQUIL. I-131 CONC. (uCi/gm)	RELEASE RATE (uCi/sec)	PROBABLE INITIATING EVENT	DATA SET NO.
Pt.Beach1	4/5/74-4/6	7	1.72E+5	1.28E-5	1.3E-1	287	Scram	P-11
"	-4/7	"	"	"	"	"	Depress.	P-12
"	-4/8	"	"	"	"	"	Depress.	P-13
Pt.Beach2	2/26/76	7	1.72E+5	2.77E-5	6.1E-3	30	-90 % in 2 hr	P-21
San Onof.	10/2/70-10/3	7	1.97E+5	3.2E-5	7.4E-2(?)	467(?)	-100% in 24 hr	S-11
"	-10/4	"	"	"	"	"	Depress.	S-12
"	-10/6	"	"	"	"	"	Depress.	S-13
"	-10/7	"	"	"	"	"	Depress.	S-14
San Onof.	12/26/71	7	1.97E+5	2.88E-5	2.3E-2(?)	139(?)	Depress.	S-21
"	"	"	"	"	"	"	Depress.	S-22
Maine Y.	4/5/74	8	2.38E+5	1.8E-5	3.0E-1	1285	Scram	Y-11
Oconee	12/12/73-12/13	10	3.2E+5	2.7E-5	1.4E-1	680	Scram	E-11
3 Mile Is.	2/21/76	11	2.3E+5	1.67E-5	?	94	-75 % in <1 hr	T-11
"	"	"	"	"	"	"	Depress.	T-12
Cook	11/20/76-11/22	13	2.62E+5	1.8E-5	2.0E-2	95	Scram at 70%	C-11
Cook	12/23/76-12/24	14	2.62E+5	2.9E-5	1.5E-2	115	-90 %in 25 hr	C-21
"	"	"	"	"	"	"	Depress.(?)	C-22
"	"	"	"	"	"	"	Depress.(?)	C-23
"	"	"	"	"	"	"	Depress.(?)	C-24

NOTES:

1. Indicated references do not always provide all data listed, and in several cases the entries in these tables reflect the author's interpretation.
2. Percentages in "Probable Initiating Event" column refer to escalation (+), or reduction (-) of power in percent of full power.

TABLE II

IODINE SPIKING DATA - SPIKING BEHAVIOR

DATA SET NO.	INITIAL CONC. (uCi/gm)	PEAK CONC. (uCi/gm)	AVG. CLEANUP DURING SPKE. (sec^{-1})	SPIKING TIME (hrs)	RELEASE RATE FACTR AVG./MAX.	RELEASE PER SPIKE (Ci)	RELEASE FOR SEQ. (Ci)
BWR PLANTS							
A-11	6.0E-1	1.2E-2	2.4E-4	6.0	6 / -	5.7	
A-12	5.6E-3	7.5E-2	1.14E-4	3.5	35 / -	19.6	25
A-21	1.4E-3	1.4E-1	2.4E-4	6.25	35 / -	38.	
A-22	4.7E-2	5.6E-1	1.2E-4	3.5	260 / 385	155.	193
A-31	3.5E-3	1.4E-2	1.9E-4	3.0	7 / -	6.6	
A-32	4.1E-3	8.0E-1	1.9E-4	4.0	148 / 314	142.	
A-33	2.8E-1	3.9E 0	2.8E-5	2.0	815 /1030	546.	695
A-41	9.0E-4	3.0E-1	1.9E-4	5.0	363 / -	79.	
A-42	4.5E-2	1.8E-1	1.2E-4	0.7	1800 /1800	55.	134
B-11	6.6E-3	6.0E-2	2.5E-4	0.4	34 / -	34.	
B-12	3.4E-2	1.5E-1	1.2E-4	2.0	20 / -	37.	50
B-21	5.5E-3	5.0E-2	2.5E-4	0.4	24 / -	9.	
B-22	2.8E-2	1.3E-1	1.2E-4	2.0	15 / -	27.	36
D-11	2.3E-3	2.7E-2	1.5E-4	1.0	31 / -	7.8	
D-12	7.2E-3	2.6E-1	1.5E-4	1.0	415 / -	104.	
D-13	1.5E-2	1.3E-1	1.15E-4	7.5	52 / 150	98.	210
D-21	1.5E-4	4.0E-4	1.2E-4	1	11 / -	0.2	
D-22	1.9E-4	2.4E-2	1.6E-4	3.5	255 / -	16.	
D-23	1.0E-3	1.2E-2	1.4E-4	3.0	86 / -	4.6	21
D-31	4.5E-4	2.2E-3	1.2E-4(?)	2.5	15 / -	0.7	
D-32	6.8E-4	2.2E-3	1.2E-4(?)	9.0	10 / -	1.7	
D-33	6.1E-4	2.8E-3	1.3E-4	2.2	24 / -	1.0	3
O-11	4.3E-3	6.3E-2	1.0E-4	3.1	14 / -	13.6	
O-12	5.8E-2	7.2F-1	1.0E-4	5.0	203 / 380	305.	
O-13	2.1E-1	6.0E-1	1.1E-4	1.5	340 / -	155.	474

TABLE II

IODINE SPIKING DATA - SPIKING BEHAVIOR

DATA SET NO.	INITIAL CONC. (uCi/gm)	PEAK CONC. (uCi/gm)	AVG.CLEANUP DURING SPKE. (sec^{-1})	SPIKING TIME (hrs)	RELEASE RATE FACTR AVG./MAX.	RELEASE PER SPIKE (Ci)	RELEASE FOR SEQ. (Ci)
N-11	4.9E-3	1.5E-1	1.5E-4	3.9	53/ -	49	
N-12	6.0E-2	4.0E-1	1.7E-4	12	-	253	300
M-11	1.6E-3	3.0E-3	6.8E-5	3	5.	1	
M-12	3.0E-3	4.0E-1	6.8E-5	10	230/420	156	160
M-21	1.15E-3	3.9E-1	2.7E-4	2	600/ -	155	
M-22	2.2E-2	2.8E-1	7.0E-5	4	87/120	70	
M-23	3.2E-3	2.5E-1	7.0E-5	3	115/250	70	300
M-31	5.4E-3	1.9E-1	1.4E-4	5	117/290	90	
M-32	3.3E-3	1.6E-1	1.9E-4	2	96/140	42	130
M-41	5.7E-4	5.8E-2	8 E-5	6	?	14	14

PWR PLANTS

DATA SET NO.	INITIAL CONC. (uCi/gm)	PEAK CONC. (uCi/gm)	AVG.CLEANUP DURING SPKE. (sec^{-1})	SPIKING TIME (hrs)	RELEASE RATE FACTR AVG./MAX.	RELEASE PER SPIKE (Ci)	RELEASE FOR SEQ. (Ci)
G-11	9.0E-1	6.9E 0*	2.0E-5	24	8/ -	2440	
G-12	5.9E 0	1.8E+1	1.8E-5	14	22/ -	4100	
G-13	8.7E-1	5.2E 0*	1.4E-5	8	6/ -	600	7100
G-21	6.9E-1	1.8E+1	2.2E-5	6	83/130	3800	
G-22	6.8E 0	1.1E+1	1.25E-5	12	-	1570	
G-23	1.3E 0	5.5E 0*	1.2E-5	14.4	-	1100	
G-24	1.7E 0	7.5E 0*	1.25E-5	5	-	1240	7700
H-11	4.1E-2	3.0E 0*	1.2E-5	10	102/ -	890	
H-12	2.2E 0	3.0E 0*	2.35E-5	5	117/ -	408	1300
H-21	3.0E-2	6.5E-1*	3.4E-5	7.5	2/ -	236	
H-22	4.4E-1	6.0E 0*	3.1E-5	11	15/ -	2480	
H-23	3.5E 0	1.2E+1*	3.2E-5	5.75	40/ -	3380	6100

TABLE II

IODINE SPIKING DATA - SPIKING BEHAVIOR

DATA SET NO.	INITIAL CONC. (uCi/gm)	PEAK CONC. (uCi/gm)	AVG. CLEANUP DURING SPKE. (sec^{-1})	SPIKING TIME (hrs)	RELEASE RATE FACTR AVG./MAX.	RELEASE PER SPIKE (Ci)	RELEASE FOR SEQ. (Ci)
I-11	5.0E-2	4.4E-1*	2.6E-5	5.17	30/50	84	
I-12	3.1E-1	6.0E-1	1.9E-5	5.67	25/ -	77	160
P-11	1.3E-1	4.6E-1*	1.3E-5	8	9/ -	76	
P-12	4.6E-2	2.0E 0	1.3E-5	2.5	138/ -	357	
P-13	6.7E-1	1.2E 0*	1.3E-5	1.4	73/ -	106	540
P-21	6.1E-3	5.3E-2	2.8E-5	1.0	89/ -	10	10
S-11	7.4E-2	8.5E-1*	3.2E-5	7	21/ -	244	
S-12	2.9E-1	1.05E 0*	2.4E-5	7.75	20/ -	246	
S-13	2.8E-2	8.0E-1*	2.4E-5	5.2	22/ -	191	
S-14	5.7E-1	1.02E 0	0	6.3	8/ -	87	778
S-21	2.3E-2	2.5E-1*	2.9E-5	3.2	36/ -	54	
S-22	1.2E-1	2.35E 0*	2.1E-5	3.0	340/ -	478	532
Y-11	4.4E-1	1.55E+1	3.2E-5	6.5	100/ -	4400	4400
E-11	1.5E-1	5.2E-1	1.4E-5(?)	4.25	14/ -	150	
E-12	1.5E-1	4.3E-1	1.6E-5	2.0	20/26	100	250
T-11	2.4E-2	1.5E-1	1.7E-5	3.55	26/50	34	
T-12	1.3E-1	1.8E-1	1.7E-5	4.0	16/20	21	55
C-11	2.0E-2	2.8E 0	1.6E-5	24	110/450	870	870
C-21	1.2E-2	2.5E 0	2.9E-5	1.0	1660/1660	687	
C-22	8.3E-1	1.6E 0	2.9E-5	1.0	560/560	235	
C-23	1.5E 0	1.8E 0	2.9E-5	5.0	150/ -	306	
C-24	1.4E 0	1.8E 0	2.9E-5	2.0	50/ -	42	1270

NOTE:

Peak concentrations marked by (*) indicate values estimated by Westinghouse. (Ref. 7)

FIG. 1
IODINE SPIKING SEQUENCE AT PLANT A (BWR)
(From Reference 5)

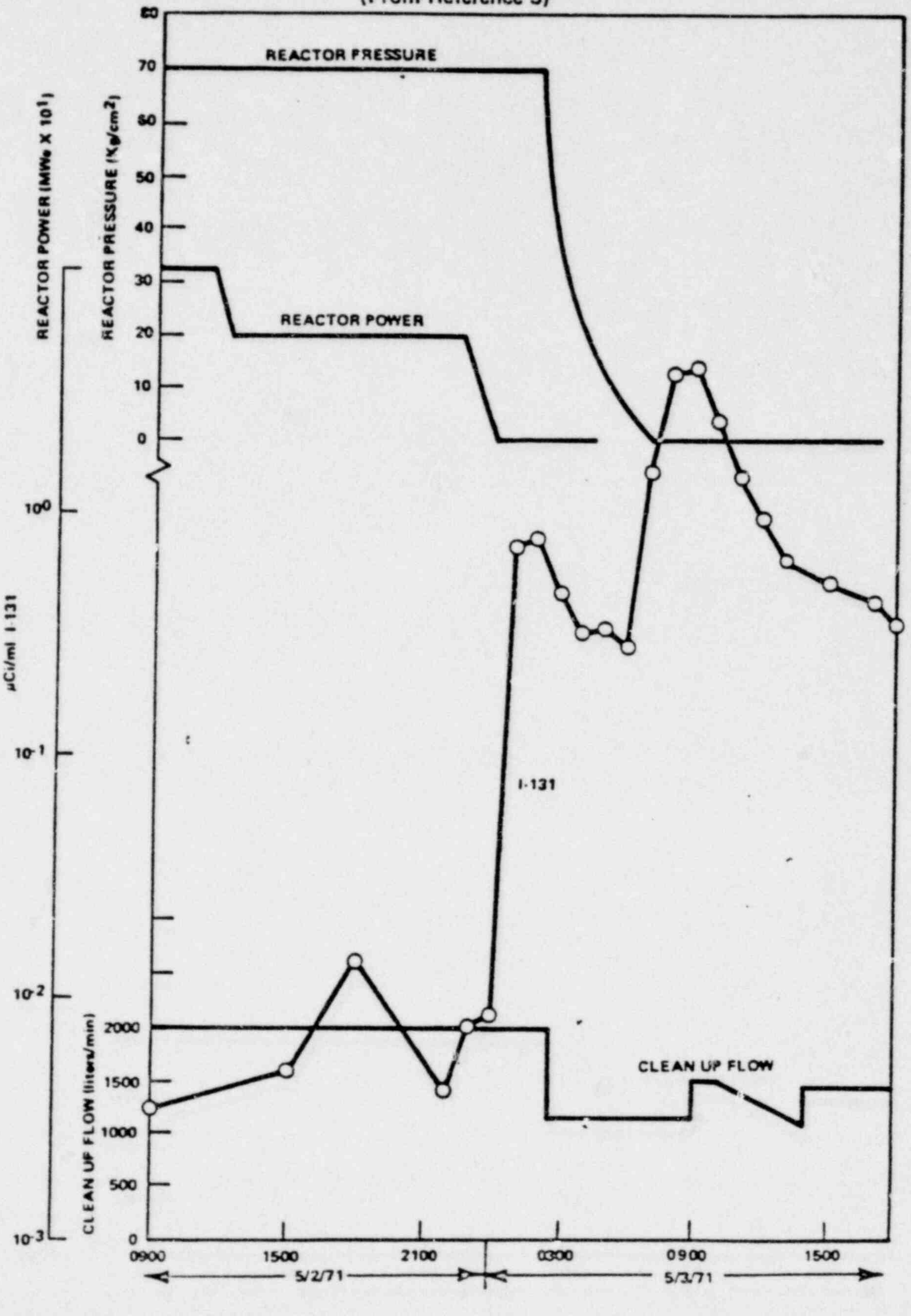

FIG. 2

TOTAL I-131 RELEASE DURING A SPIKING SEQUENCE

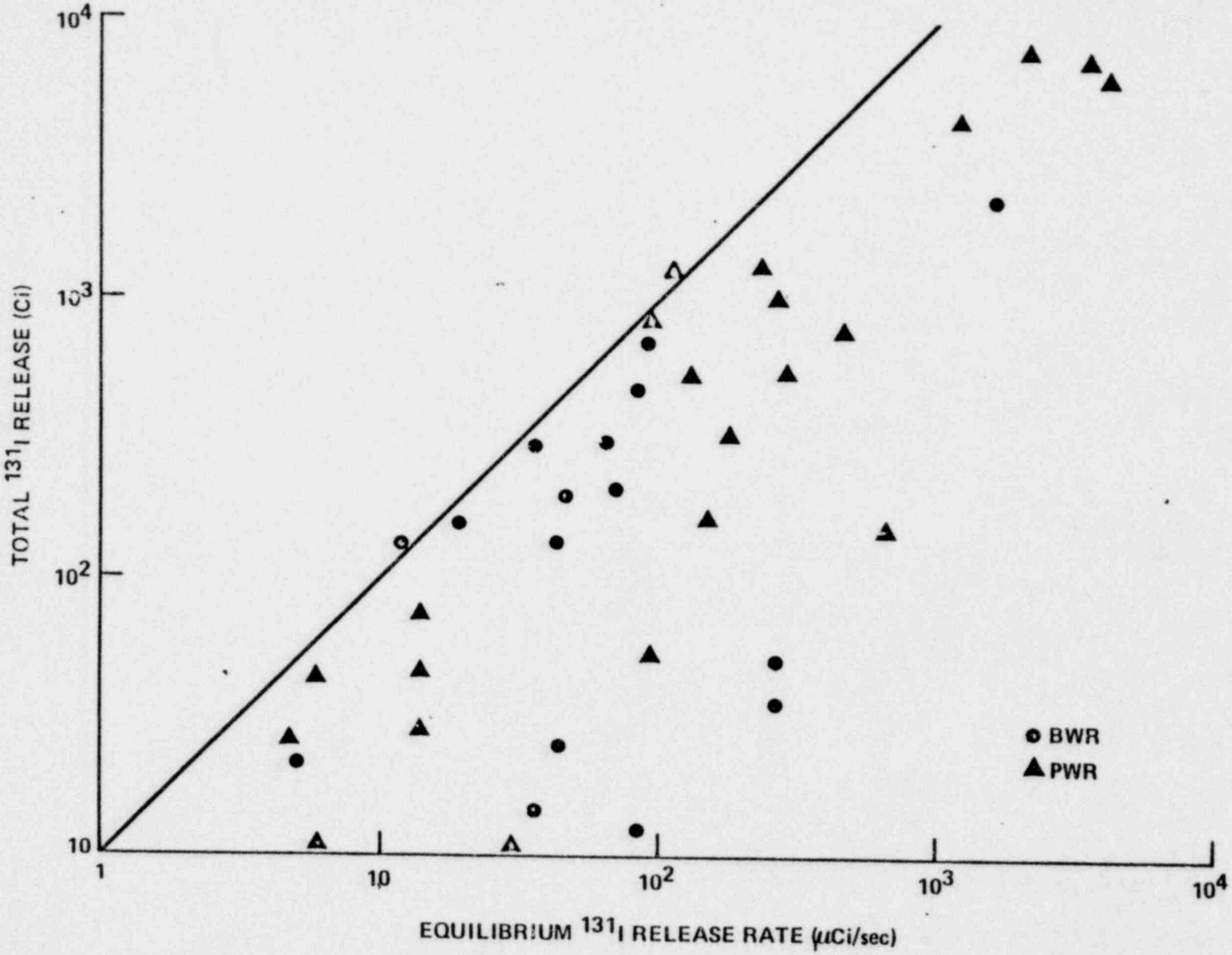

FIG. 3
TOTAL I-131 RELEASE PER INDIVIDUAL SPIKE