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# PROBABILITY OF THE IODINE SPIKE RELEASE RATE DURING AN SGTR

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*Prepared for the U.S. NUCLEAR REGULATORY COMMISSION*

## ABSTRACT

The Nuclear Regulatory Commission (NRC) requires utilities to determine the response of a pressurized water reactor (PWR) to a steam generator tube rupture (SGTR) as part of the safety analysis for the plant. The SGTR analysis includes assumptions regarding the presence of fission product iodine in the reactor coolant resulting from iodine spikes. Due to uncertainties in the consequences, the NRC has designated this class of accident as a generic safety issue. To get a better understanding of iodine spiking, reactor trip and associated radiochemistry data were collected from 26 PWRs. These data were compared against validation criteria to determine their applicability to an investigation of the magnitude of an iodine spike following a reactor trip. The applicable data and the results of a statistical analysis are presented. Conclusions are made concerning the magnitude of an iodine spike during an SGTR and these are compared with the NRC analysis criteria. The conclusion is made that the iodine release rate specified for analysis of an SGTR is overly conservative and could be reduced significantly while still maintaining adequate protection to the public. The formalism required by the Standard Review Plan in determining the release rate is judged to be inappropriate and an absolute release rate, based on plant electric power, is recommended as a replacement. A value of 0.710 Ci/h*MW(e) is recommended for consideration as a replacement for the current iodine release rate specification for an SGTR with coincident iodine spike.

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## SUMMARY

The concern regarding the consequences of a steam generator tube rupture (SGTR) is dominated by the assumed presence of fission product iodine in the reactor coolant. These consequences vary considerably depending on several factors: the concentration of fission product iodine in the reactor coolant (iodine spike), transport of this iodine to the secondary side, mixing with secondary coolant to dilute the iodine concentration, partitioning of the iodine between liquid and vapor in the steam generator secondary, transport of the iodine out of the steam generator to the environment, dispersion of the iodine off-site, and exposure of the public to the iodine (dose). This study concentrated on the first aspect, concentration of iodine in the RCS coolant due to iodine spiking in conjunction with an SGTR.

The Standard Review Plan (SRP) used by utilities in producing a Final Safety Analysis Report, lists two categories of SGTRs: 1. an SGTR which occurs sometime after initiation of an iodine spike; and 2. an SGTR which occurs coincident with an iodine spike. The SRP guidelines for analysis of the first category specify that the RCS iodine concentration be assumed to vary with the reactor power, a concentration of 60 $\mu$Ci/g corresponding to 100% power. The guidelines for analysis of the second category specify that the initial RCS concentration be assumed to be 1 $\mu$Ci/g and that the iodine release rate (from the fuel to the coolant) be assumed to increase by a factor of 500 upon initiation of the transient. It is the second analysis that is addressed by this report.

Data from 26 PWRs were collected including information on reactor trips and associated radioiodine concentrations. A data base on the release rate of iodine from the fuel to the RCS was developed from these data and this data base is presented in this report. The data were statistically analyzed to determine the probability that a reactor trip would result in an iodine spike of a given magnitude. An SGTR event from

power invariably results in a reactor trip. Therefore, it is judged that the probability that an SGTR event results in an iodine spike of a given magnitude is the same as that for a reactor trip.

Based on the results from the statistical analysis of the data base, it is concluded that the current specifications for the assumed iodine release rate in an analysis of an SGTR with coincident iodine spike are overly conservative. The magnitude of the assumed release rate could be reduced significantly while maintaining adequate protection to the public. In addition, the specification of the release rate could be changed to reflect an absolute release rate rather than a ratio of transient to steady state release rates as is now the case. A value of 0.710 Ci/h*MW(e) is recommended for consideration as a replacement for the current iodine release rate specification for an SGTR with coincident iodine spike.

## ACKNOWLEDGMENTS

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## INTRODUCTION

In pressurized water reactors (PWRs), water in the primary coolant system is pressurized to prevent it from boiling. This high-pressure water is circulated through heat exchanger tubes in the steam generators where its heat is transferred to lower pressure secondary coolant, producing steam which is used to generate electrical power. The tubes represent a large fraction of the reactor coolant system (RCS) boundary and rupture of these tubes can result in a direct path to the environment for primary coolant (containment bypass) through either the atmospheric dump valves or secondary relief valves. Since the primary coolant can carry radioactive materials, a steam generator tube rupture (SGTR) accident has been designated as a design basis accident for PWRs and is analyzed as part of a plant's Final Safety Analysis Report (FSAR). The Nuclear Regulatory Commission (NRC) regulations regarding the FSAR for PWRs are listed in Title 10 of the Code of Federal Regulations Part 50[1]. Guidelines are provided for interpretation of these regulations in the Standard Review Plan (SRP)[2]. A previously issued report[3] documents the results from a task to evaluate the risk involved in an SGTR event and includes data from commercial PWR operations on the magnitude of iodine spikes which could occur during an SGTR. These data were documented in Licensee Event Reports (LERs) by the involved utilities. This report contains the results of a study that was conducted to address the probability that an iodine spike of a given magnitude will occur during and as a result from an SGTR.

## REQUIREMENTS FOR ANALYSIS OF IODINE SPIKING DURING AN SGTR

The current requirements for analysis of the design basis SGTR event specify that an iodine spike must be assumed to occur during the event. An iodine spike is a temporary increase in the concentration of fission product iodine which sometimes occurs as a result of a large reactor power or RCS pressure change. The iodine, a fission product which is released to the coolant, comes either as a product of the fissioning of tramp uranium on the fuel element cladding surface or from the fuel itself, being released through tiny holes in the cladding of otherwise undamaged fuel rods. This iodine (specifically $^{131}I$) represents the principal source of radiation which is potentially leaked to the environment during an SGTR. The presence of this iodine causes the principal concern during this design basis accident.

There are two specific assumptions listed in Reference 2 for the determination of iodine concentration in the RCS during an SGTR, each requiring a separate SGTR analysis. The first analysis includes an assumption that an iodine spike occurs prior to initiation of the SGTR which raises the concentration to a constant (during the accident) value specified by the applicable standard technical specification[4,5,6]. This value ranges from 60 to 275 $\mu$Ci/g, depending on the reactor power, and is the same for each of the vendor standard technical specifications. Figure 1 illustrates the iodine concentration to be assumed in this analysis.

The second analysis to be performed assumes that the iodine concentration results from an accident-initiated iodine spike which increases the iodine release rate (the rate at which the iodine is released from the fuel element) to a value 500 times greater than the steady-state release rate. Reference 2 further directs that the steady-state release rate should correspond to the iodine concentration at the equilibrium value listed in the vendor standard technical specification. This equilibrium iodine concentration is 1 $\mu$Ci/g and, as is the case for the pre-accident iodine spike, is the same for each of the vendor standard technical specifications. This report addresses the second SRP analysis category. The first SRP assumption is addressed in detail in Reference 3. The data base in this report is insufficient to address the first assumption because this data base includes only iodine spikes caused

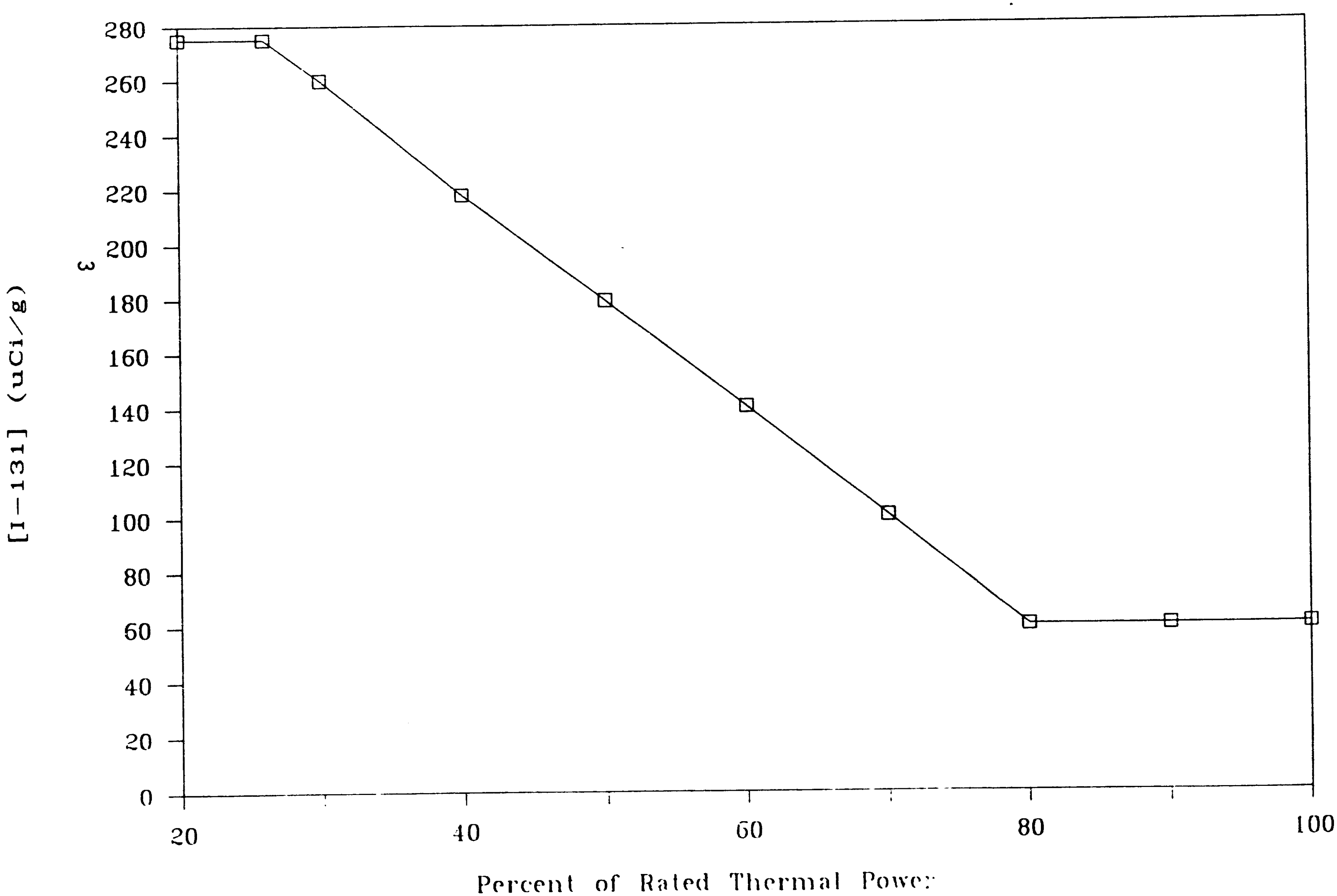


Figure 1: SRP specified iodine concentration for Category 1 SGTRs

by reactor trips and does not include any other possible initiators such as power increases or pressure transients.

The values for iodine concentration in the RCS during an SGTR analysis were specified in the early 1970's, prior to the existence of a significant data base. At the same time, utilities were requested to start generating data on the concentration of iodine in the RCS during power excursions. Though the requirements were not uniform from utility to utility or even from plant to plant within a utility, a potentially large base of data has become available with which to assess the behavior of radioactive iodine within the RCS and evaluate the SRP specifications for assumed iodine behavior during an SGTR.

## ANALYSIS

The objective of this task was to determine the probability that an SGTR would result in an iodine spike of a given magnitude. In the analysis below, this probability is considered to be equal to the probability of a reactor trip resulting in an iodine spike of the same magnitude. The methodology used in this task was to first develop a data base of reactor trips and associated radioiodine concentrations from commercial PWR operations; second to bound the magnitude of the maximum iodine concentration following the trip; third to determine the release rate from the fuel to the RCS during each event; and finally to estimate the desired probabilities.

### Iodine Spiking Data Base

Fewer than ten SGTR events have occurred in US PWRs. Thus, the iodine spiking data from these events alone are insufficient for predicting the behavior of future iodine spiking events. However, an SGTR occurring during power operations would result in a reactor trip, which is a large power excursion. Since it is this power excursion which causes the iodine spike, it may be assumed that the probability than an SGTR event results in an iodine spike of a given magnitude is equivalent to the same probability resulting from a reactor trip. This assumption, that it is the reactor trip which causes the iodine spike rather than anything else associated with the SGTR itself, allows a much larger data base to be developed. There are other phenomena which can affect the iodine spike, specifically a power increase or a pressure transient. The power increase (for example, if the reactor is quickly brought back to power following a spurious trip) may be ignored since it is highly unlikely that such a transient would occur if the initial reactor trip was caused by an SGTR. There is a pressure transient inherent with a reactor trip since the principal heat source is immediately lost when the control rods are inserted while the heat sink is maintained until the main steam stop valves can be closed. Additional pressure transients may occur as the operators attempt to bring the plant to a safe shutdown condition. However, it is expected that operators would require some time to diagnose the transient and initiate depressurization (~ 1/2 h). Buildup of the iodine is exponential and thus a large fraction of the concentration increase would occur prior to the pressure transient. Therefore, it is considered that any perturbing effects of a depressurization transient will be relatively small and are adequately covered by the conservatism built into the analysis.

Iodine spiking data resulting from reactor trips were collected from 26 plants. These plants were selected from all regions of the country and from all three PWR vendors. The PWRs are listed in Table 1 which includes the plant, operating utility, vendor, time frame from which the data were collected, and the number of events which ultimately satisfied the validation criteria. Of the plants used in this study, 13 (50%) were Westinghouse design, 5 (20%) were B&W design, and 8 (30%) were CE design. As the data were collected, specific criteria were used to ensure that these data could be compared and that the resulting data base would be valid. These criteria were as follows:

Table 1.
Summary of Plants Used in this Study

| Plant | Utility | NSSS Vendor | Time Frame | No. Events |
|---|---|---|---|---|
| Arkansas Nuclear One-1 | Arkansas Power & Light | B&W | 1976 - 89 | 3 |
| Arkansas Nuclear One-2 | Arkansas Power & Light | CE | 1980 - 89 | 18 |
| Calvert Cliffs-1 | Baltimore Gas & Electric | CE | 1979 - 89 | 5 |
| Calvert Cliffs-2 | Baltimore Gas & Electric | CE | 1979 - 89 | 1 |
| Catawba-1 | Duke Power | W | 1986 - 88 | 3 |
| Catawba-2 | Duke Power | W | 1986 - 88 | 5 |
| Cook-1 | Indiana & Michigan Electric | W | 1983 - 89 | 4 |
| Cook-2 | Indiana & Michigan Electric | W | 1984 - 89 | 2 |
| Crystal River-3 | Florida Power Corp. | B&W | 1977 - 89 | 0 |
| Haddam Neck | Connecticut Yankee | W | 1984 - 89 | 6 |
| McGuire-1 | Duke Power | W | 1986 - 88 | 6 |
| McGuire-2 | Duke Power | W | 1986 - 88 | 6 |
| Millstone-2 | Northeast Utilities | CE | 1984 - 89 | 6 |
| Millstone-3 | Northeast Utilities | W | 1987 - 89 | 2 |
| North Anna-1 | Virginia Power | W | 1978 - 89 | 14 |
| North Anna-2 | Virginia Power | W | 1980 - 89 | 7 |
| Oconee-1 | Duke Power | B&W | 1986 - 88 | 0 |
| Oconee-2 | Duke Power | B&W | 1986 - 88 | 1 |
| Oconee-3 | Duke Power | B&W | 1986 - 88 | 0 |
| Palisades | Consumers Power | CE | 1980 - 89 | 12 |
| Prairie Island-1 | Northern States Power | W | 1974 - 89 | 7 |
| Prairie Island-2 | Northern States Power | W | 1975 - 89 | 7 |
| San Onofre-2 | Southern Cal. Ed. | CE | 1984 - 89 | 11 |
| San Onofre-3 | Southern Cal. Ed. | CE | 1984 - 89 | 8 |
| Surry-1 | Virginia Power | W | 1972 - 89 | 24 |
| Surry-2 | Virginia Power | W | 1973 - 89 | 10 |

1. There must have been a period of at least 5 days of steady state power operations prior to the trip. This criterion was set so that sufficient fission product inventory had built up to measure the iodine released from the fuel. Five days of operation results in a minimum of 35% of the equilibrium concentration of fission product $^{131}I$ in the fuel. In nearly all cases, the steady state power operations lasted several weeks rather than the minimum 5 days.

2. The steady state iodine concentration prior to reactor trip must be known. In general, 1 - 3 days of concentration values were averaged and used in the analysis. The scatter in the data was very small, typically less than 20% of the average value.

3. There must be a post-trip RCS sample taken between 2 and 6 hours after trip. If the sample is taken prior to 2 hours after trip, the buildup of iodine in the RCS may not have peaked. If the sample is taken later than 6 hours after trip, the concentration may have decreased too far. The concentration of this sample is used to bound the maximum iodine concentration during the iodine spike, as discussed in the next section.

4. The post-trip RCS sample must be taken prior to starting the reactor up after trip. The power excursion associated with reactor startup can also cause an iodine spike which can mask the spike associated with the trip if startup occurs prior to the sample.

5. In addition, all of the requisite information (purification flow, trip date and time, post-trip sample date and time, etc.) must be available.

These five criteria were applied to each reactor trip event and those events which did not meet the criteria were not included in the data base. For example, Criterion 3 eliminated approximately 40 % of the events (including all of the events measured in Oconee-1 and Oconee-3) which had passed the other four criteria. Criterion 5 eliminated all of the data from Crystal River 3 because the purification flow was typically changed after trip but the exact timing of the change could not be determined from the available data. While statistics were not kept on the other three criteria, it is estimated that only approximately 10 - 20% of all the reactor trips which were studied resulted in valid events for this data base.

Application of the validation criteria resulted in the following mix of events by vendor: 103 (61%) of the events from Westinghouse design, 4 (2%) of the events from B&W design, and 61 (37%) of the events from CE design plants. The low representation from B&W design plants resulted from a combination of few plants which had operated for a significant period of time, coupled with failure against one or more of the validation criteria as discussed above. It is judged that the use of these criteria did not result in any bias to the data either toward higher or lower iodine spike concentrations, except as discussed below.

Utility personnel provided data for all reactor trips within a time period. This time period varied from plant to plant due to ease of retrieval of the data. In many cases, data from the early operations of a given plant were insufficient to provide events which met all the validation criteria. This was because either sampling during early operations was less frequent (typically once daily) or because the data could not be retrieved with reasonable effort and time. Thus, the resultant data base is biased toward later operational periods. For example, of the valid events, 94% occurred since 1979 and 50%, since 1984. This may bias the resultant data base toward smaller iodine spikes because fuel manufacturing techniques have improved and current fuel may be expected to have fewer defects. The conclusions based on this data base are still judged to be valid since they concern future iodine spikes.

The resultant data base is listed in Table 2. Included in the table are the plant, NSSS vendor, the trip date, percent reactor power prior to trip, the pre-trip iodine concentration, post-trip (between two and six hours after trip) maximum measured concentration, and the calculated iodine release rate for each of the transient events. The release rate in this table is based on the bounded maximum iodine concentration (three times the measured post-trip concentration as discussed in the next section) and an assumed time after trip of 2 h (as discussed below).

## Bounding Analysis for Maximum Iodine Concentration

An analysis was performed to bound the actual maximum iodine concentration based on the data. This analysis was necessary because the iodine concentration was not monitored continuously.

The data in Table 2 could not be used for this analysis because in most cases the iodine concentration did not exceed the technical specification limit of 1$\mu$Ci/g and therefore too few samples were obtained. Instead, data used in this bounding analysis were obtained as follows. Iodine spiking events were extracted from Licensee Event Reports (LERs) Of the 144 such events listed in Reference 3, those events were used for which the shape of the iodine spike trace could be approximated. Events were not used if there were only two values for the iodine concentration in the first 14 hours, or if there were no measured values before six hours. They were not used because there was no basis for determining the maximum concentration. There were 23 usable events from the LERs plus one from the data provided by a utility. These 24 events are listed in Table 3, which includes the estimated concentrations at two and six hours after trip, the minimum measured concentration between two and six hours, and the estimated bound on the maximum concentration. The full data used in this bounding analysis, forming the basis for Table 3, are included in Appendix A to this report.

Table 2: Iodine Release Rate Following a Reactor Trip (a)

| No. | Plant | NSSS Vendor | Trip date | Power % | Pre-I (uCi/g) | Post-I (uCi/g) | R3(2) (Ci/h) |
|---|---|---|---|---|---|---|---|
| 1 | ANO-1 | B&W | 800822 | 100 | 5.64E-01 | 1.44E+01 | 5.53E+03 |
| 2 | ANO-1 | B&W | 801208 | 75 | 2.46E-01 | 7.43E+00 | 2.86E+03 |
| 3 | ANO-1 | B&W | 850531 | 100 | 7.02E-02 | 3.32E+00 | 1.28E+03 |
| 4 | ANO-2 | CE | 800129 | 100 | 2.61E-01 | 1.11E+00 | 3.36E+02 |
| 5 | ANO-2 | CE | 800624 | 100 | 1.28E-01 | 3.00E-01 | 8.48E+01 |
| 6 | ANO-2 | CE | 800724 | 100 | 1.27E-01 | 4.39E-01 | 1.30E+02 |
| 7 | ANO-2 | CE | 810217 | 100 | 1.23E-01 | 1.11E+00 | 3.47E+02 |
| 8 | ANO-2 | CE | 810820 | 100 | 3.62E-01 | 4.81E-01 | 1.20E+02 |
| 9 | ANO-2 | CE | 811123 | 100 | 5.05E-02 | 1.79E-01 | 5.30E+01 |
| 10 | ANO-2 | CE | 811221 | 95 | 6.47E-02 | 2.46E-01 | 7.36E+01 |
| 11 | ANO-2 | CE | 840617 | 100 | 4.06E-02 | 1.94E-01 | 5.89E+01 |
| 12 | ANO-2 | CE | 840720 | 100 | 3.08E-02 | 1.53E-01 | 4.66E+01 |
| 13 | ANO-2 | CE | 840828 | 100 | 2.98E-02 | 1.71E-01 | 5.25E+01 |
| 14 | ANO-2 | CE | 841026 | 100 | 4.43E-02 | 2.36E-01 | 7.22E+01 |
| 15 | ANO-2 | CE | 850204 | 100 | 5.51E-02 | 3.88E-01 | 1.20E+02 |
| 16 | ANO-2 | CE | 850813 | 100 | 9.25E-02 | 6.83E-01 | 2.12E+02 |
| 17 | ANO-2 | CE | 860211 | 100 | 5.75E-02 | 9.00E-01 | 2.86E+02 |
| 18 | ANO-2 | CE | 860421 | 100 | 4.80E-02 | 8.74E-01 | 2.79E+02 |
| 19 | ANO-2 | CE | 870909 | 100 | 5.06E-03 | 6.07E-03 | 1.47E+00 |
| 20 | ANO-2 | CE | 881201 | 100 | 7.82E-02 | 5.45E-01 | 1.69E+02 |
| 21 | ANO-2 | CE | 890418 | 100 | 4.17E-02 | 5.31E-01 | 1.68E+02 |
| 22 | CalClf-1 | CE | 810116 | 92 | 3.24E-03 | 1.70E-03 | 3.01E-01 |
| 23 | CalClf-1 | CE | 820711 | 84 | 3.59E-03 | 2.64E-02 | 9.56E+00 |
| 24 | CalClf-1 | CE | 830126 | 100 | 2.86E-02 | 4.48E-01 | 1.66E+02 |
| 25 | CalClf-1 | CE | 830919 | 96 | 2.15E-02 | 2.75E-01 | 1.01E+02 |
| 26 | CalClf-1 | CE | 870911 | 100 | 4.23E-02 | 3.95E-01 | 1.44E+02 |
| 27 | CalClf-2 | CE | 870301 | 95 | 7.44E-02 | 8.58E-01 | 3.15E+02 |
| 28 | Catawba-1 | W | 860419 | 100 | 4.70E-03 | 3.88E-03 | 1.00E+00 |
| 29 | Catawba-1 | W | 860514 | 100 | 5.50E-03 | 3.15E-02 | 1.18E+01 |
| 30 | Catawba-1 | W | 870409 | 100 | 3.90E-03 | 3.54E-03 | 9.59E-01 |
| 31 | Catawba-2 | W | 870128 | 100 | 8.10E-04 | 1.89E-03 | 6.56E-01 |
| 32 | Catawba-2 | W | 870506 | 100 | 6.10E-04 | 9.34E-04 | 3.02E-01 |
| 33 | Catawba-2 | W | 870727 | 90 | 3.80E-04 | 2.91E-04 | 7.23E-02 |
| 34 | Catawba-2 | W | 880626 | 100 | 6.10E-04 | 6.80E-04 | 2.00E-01 |
| 35 | Catawba-2 | W | 880929 | 95 | 4.60E-04 | 7.88E-04 | 2.60E-01 |
| 36 | Cook-1 | W | 860722 | 90 | 2.40E-03 | 5.67E-02 | 2.34E+01 |
| 37 | Cook-1 | W | 861122 | 90 | 2.10E-03 | 4.84E-01 | 2.10E+02 |
| 38 | Cook-1 | W | 870604 | 90 | 2.20E-03 | 2.99E-01 | 1.30E+02 |
| 39 | Cook-1 | W | 881123 | 90 | 1.00E-04 | 8.00E-04 | 3.36E-01 |
| 40 | Cook-2 | W | 841119 | 96 | 1.20E-03 | 8.00E-04 | 1.89E-01 |

Table 2: Iodine Release Rate Following a Reactor Trip (continued)

| No. | Plant | NSSS Vendor | Trip date | Power % | Pre-I (uCi/g) | Post-I (uCi/g) | R3(2) (Ci/h) |
|---|---|---|---|---|---|---|---|
| 41 | Cook-2 | W | 860201 | 80 | 1.40E-03 | 3.06E-02 | 1.26E+01 |
| 42 | HadmNk | W | 851110 | 100 | 1.30E-02 | 2.37E-01 | 7.41E+01 |
| 43 | HadmNk | W | 851121 | 100 | 6.80E-03 | 8.96E-02 | 2.79E+01 |
| 44 | HadmNk | W | 860604 | 97 | 8.60E-03 | 8.93E-03 | 2.16E+00 |
| 45 | HadmNk | W | 860617 | 98 | 4.30E-03 | 1.01E-02 | 2.87E+00 |
| 46 | HadmNk | W | 860830 | 100 | 5.50E-03 | 1.08E-02 | 2.99E+00 |
| 47 | HadmNk | W | 870416 | 100 | 8.40E-03 | 1.00E-01 | 3.10E+01 |
| 48 | McGui-1 | W | 860105 | 100 | 7.87E-03 | 3.00E-01 | 1.22E+02 |
| 49 | McGui-1 | W | 860924 | 100 | 5.30E-03 | 3.30E-02 | 1.30E+01 |
| 50 | McGui-1 | W | 870415 | 100 | 5.60E-03 | 1.10E-01 | 4.27E+01 |
| 51 | McGui-1 | W | 880323 | 100 | 5.50E-03 | 1.70E-01 | 6.86E+01 |
| 52 | McGui-1 | W | 880416 | 100 | 6.90E-03 | 1.40E-01 | 5.64E+01 |
| 53 | McGui-1 | W | 880620 | 100 | 1.10E-02 | 6.20E-01 | 2.52E+02 |
| 54 | McGui-2 | W | 860115 | 100 | 6.50E-03 | 4.10E-02 | 1.55E+01 |
| 55 | McGui-2 | W | 860722 | 93 | 1.60E-03 | 3.60E-02 | 1.41E+01 |
| 56 | McGui-2 | W | 860827 | 100 | 3.70E-03 | 7.30E-02 | 2.86E+01 |
| 57 | McGui-2 | W | 870120 | 100 | 5.90E-03 | 9.10E-02 | 3.48E+01 |
| 58 | McGui-2 | W | 870916 | 100 | 9.50E-02 | 5.80E-01 | 2.21E+02 |
| 59 | McGui-2 | W | 880112 | 89 | 1.50E-02 | 2.80E-01 | 1.10E+02 |
| 60 | Mill-2 | CE | 841115 | 100 | 5.04E-02 | 1.05E+00 | 3.68E+02 |
| 61 | Mill-2 | CE | 841128 | 100 | 6.19E-02 | 7.04E-01 | 2.44E+02 |
| 62 | Mill-2 | CE | 860812 | 100 | 4.09E-03 | 5.25E-03 | 1.42E+00 |
| 63 | Mill-2 | CE | 870723 | 100 | 8.30E-03 | 8.77E-02 | 3.03E+01 |
| 64 | Mill-2 | CE | 871116 | 100 | 1.60E-02 | 1.35E-01 | 4.45E+01 |
| 65 | Mill-2 | CE | 881025 | 100 | 1.08E-02 | 1.55E-01 | 5.41E+01 |
| 66 | Mill-3 | W | 881005 | 100 | 1.17E-03 | 6.79E-01 | 2.79E+02 |
| 67 | Mill-3 | W | 881022 | 100 | 3.22E-03 | 3.14E-01 | 1.28E+02 |
| 68 | NoAnna-1 | W | 781024 | 100 | 4.50E-02 | 9.73E-03 | 9.53E-01 |
| 69 | NoAnna-1 | W | 781214 | 98 | 4.10E-02 | 3.93E-02 | 9.63E+00 |
| 70 | NoAnna-1 | W | 800618 | 100 | 3.00E-03 | 3.55E-02 | 1.18E+01 |
| 71 | NoAnna-1 | W | 810624 | 100 | 6.50E-02 | 2.59E-01 | 8.25E+01 |
| 72 | NoAnna-1 | W | 810710 | 100 | 7.60E-02 | 8.45E-01 | 2.82E+02 |
| 73 | NoAnna-1 | W | 810803 | 100 | 8.30E-02 | 8.24E-01 | 2.74E+02 |
| 74 | NoAnna-1 | W | 830606 | 100 | 4.40E-02 | 9.37E-01 | 3.16E+02 |
| 75 | NoAnna-1 | W | 841114 | 100 | 3.00E-03 | 3.00E-03 | 7.47E-01 |
| 76 | NoAnna-1 | W | 841231 | 100 | 4.00E-03 | 2.40E-03 | 4.49E-01 |
| 77 | NoAnna-1 | W | 851024 | 100 | 8.00E-03 | 5.74E-02 | 1.89E+01 |
| 78 | NoAnna-1 | W | 860223 | 100 | 4.00E-03 | 1.11E-01 | 3.76E+01 |
| 79 | NoAnna-1 | W | 860326 | 100 | 4.00E-03 | 1.33E-01 | 4.51E+01 |
| 80 | NoAnna-1 | W | 860520 | 100 | 4.00E-03 | 1.98E-01 | 6.73E+01 |

Table 2: Iodine Release Rate Following a Reactor Trip (continued)

| No. | Plant | NSSS Vendor | Trip date | Power % | Pre-I (uCi/g) | Post-I (uCi/g) | R3(2) (Ci/h) |
|---|---|---|---|---|---|---|---|
| 81 | NoAnna-1 | W | 860531 | 100 | 4.00E-03 | 1.16E-01 | 3.93E+01 |
| 82 | NoAnna-2 | W | 810122 | 100 | 5.00E-03 | 3.02E-01 | 1.03E+02 |
| 83 | NoAnna-2 | W | 810306 | 100 | 1.00E-02 | 4.03E-01 | 1.37E+02 |
| 84 | NoAnna-2 | W | 810606 | 100 | 1.50E-02 | 2.60E-01 | 8.74E+01 |
| 85 | NoAnna-2 | W | 811209 | 100 | 1.40E-02 | 2.22E-01 | 7.45E+01 |
| 86 | NoAnna-2 | W | 830227 | 100 | 1.30E-02 | 1.59E-01 | 5.31E+01 |
| 87 | NoAnna-2 | W | 860529 | 100 | 1.00E-03 | 1.00E-03 | 2.49E-01 |
| 88 | NoAnna-2 | W | 860629 | 100 | 1.00E-03 | 1.00E-03 | 2.49E-01 |
| 89 | Ocon-2 | B&W | 870420 | 87 | 2.40E-02 | 1.60E-01 | 5.86E+01 |
| 90 | Palis | CE | 800826 | 88 | 7.10E-02 | 7.28E-01 | 2.82E+02 |
| 91 | Palis | CE | 800928 | 81 | 4.50E-02 | 2.58E-01 | 9.76E+01 |
| 92 | Palis | CE | 801009 | 96 | 2.01E-01 | 9.18E-01 | 3.44E+02 |
| 93 | Palis | CE | 801223 | 99 | 5.00E-02 | 3.04E-01 | 1.15E+02 |
| 94 | Palis | CE | 810115 | 98 | 1.16E-01 | 7.64E-01 | 2.91E+02 |
| 95 | Palis | CE | 821016 | 100 | 5.00E-02 | 5.60E-01 | 2.17E+02 |
| 96 | Palis | CE | 821028 | 90 | 8.40E-02 | 1.36E-01 | 4.38E+01 |
| 97 | Palis | CE | 830126 | 97 | 4.00E-02 | 1.70E-01 | 6.30E+01 |
| 98 | Palis | CE | 830519 | 99 | 5.00E-02 | 1.35E-01 | 4.94E+01 |
| 99 | Palis | CE | 850811 | 98 | 1.10E-02 | 8.80E-03 | 2.33E+00 |
| 100 | Palis | CE | 870620 | 100 | 8.70E-02 | 4.70E-01 | 1.83E+02 |
| 101 | Palis | CE | 870710 | 94 | 5.70E-02 | 1.90E-01 | 7.16E+01 |
| 102 | PrIsl-1 | W | 770107 | 100 | 1.10E-03 | 6.40E-02 | 1.35E+01 |
| 103 | PrIsl-1 | W | 780831 | 100 | 2.52E-02 | 1.15E+00 | 2.43E+02 |
| 104 | PrIsl-1 | W | 790608 | 100 | 6.88E-03 | 1.79E-01 | 3.77E+01 |
| 105 | PrIsl-1 | W | 791115 | 64 | 7.24E-04 | 6.66E-02 | 1.42E+01 |
| 106 | PrIsl-1 | W | 801111 | 100 | 1.47E-04 | 1.09E-04 | 1.42E-02 |
| 107 | PrIsl-1 | W | 810831 | 100 | 2.87E-04 | 2.58E-04 | 3.76E-02 |
| 108 | PrIsl-1 | W | 850915 | 100 | 1.00E-04 | 3.42E-02 | 7.35E+00 |
| 109 | PrIsl-2 | W | 750121 | 45 | 5.28E-05 | 3.90E-05 | 5.04E-03 |
| 110 | PrIsl-2 | W | 791101 | 100 | 7.35E-04 | 7.40E-04 | 1.14E-01 |
| 111 | PrIsl-2 | W | 801020 | 100 | 4.36E-04 | 4.95E-04 | 7.88E-02 |
| 112 | PrIsl-2 | W | 810516 | 100 | 1.37E-04 | 2.15E-04 | 3.77E-02 |
| 113 | PrIsl-2 | W | 811205 | 100 | 2.63E-04 | 2.30E-04 | 3.33E-02 |
| 114 | PrIsl-2 | W | 820325 | 100 | 3.40E-04 | 2.85E-04 | 4.01E-02 |
| 115 | PrIsl-2 | W | 860728 | 100 | 2.00E-04 | 3.20E-02 | 6.86E+00 |
| 116 | SanOno-2 | CE | 840104 | 100 | 7.89E-02 | 2.36E-01 | 8.07E+01 |
| 117 | SanOno-2 | CE | 850518 | 100 | 1.38E-02 | 5.72E-02 | 2.10E+01 |
| 118 | SanOno-2 | CE | 850801 | 100 | 1.32E-02 | 7.47E-02 | 2.69E+01 |
| 119 | SanOno-2 | CE | 850820 | 100 | 1.72E-02 | 5.14E-02 | 1.76E+01 |
| 120 | SanOno-2 | CE | 850912 | 100 | 1.60E-02 | 6.98E-02 | 2.47E+01 |

Table 2: Iodine Release Rate Following a Reactor Trip (continued)

| No. | Plant | NSSS Vendor | Trip date | Power % | Pre-I (uCi/g) | Post-I (uCi/g) | R3(2) (Ci/h) |
|---|---|---|---|---|---|---|---|
| 121 | SanOno-2 | CE | 851018 | 100 | 1.17E-02 | 5.90E-02 | 2.12E+01 |
| 122 | SanOno-2 | CE | 860109 | 100 | 4.01E-02 | 3.25E-01 | 1.25E+02 |
| 123 | SanOno-2 | CE | 860812 | 100 | 9.89E-02 | 1.20E+00 | 4.46E+02 |
| 124 | SanOno-2 | CE | 860913 | 60 | 7.43E-02 | 1.70E+00 | 6.69E+02 |
| 125 | SanOno-2 | CE | 861210 | 100 | 6.86E-02 | 1.66E+00 | 6.53E+02 |
| 126 | SanOno-2 | CE | 870205 | 100 | 7.61E-02 | 2.04E+00 | 8.05E+02 |
| 127 | Sanono-3 | CE | 840106 | 100 | 4.27E-01 | 2.16E+00 | 8.05E+02 |
| 128 | Sanono-3 | CE | 840601 | 100 | 4.03E-01 | 1.99E+00 | 7.47E+02 |
| 129 | Sanono-3 | CE | 840611 | 100 | 5.05E-01 | 2.61E+00 | 9.83E+02 |
| 130 | Sanono-3 | CE | 860412 | 100 | 4.55E-02 | 7.51E-02 | 2.48E+01 |
| 131 | Sanono-3 | CE | 860726 | 100 | 6.47E-02 | 2.65E-01 | 9.82E+01 |
| 132 | Sanono-3 | CE | 860904 | 94 | 4.70E-02 | 1.92E-01 | 7.13E+01 |
| 133 | Sanono-3 | CE | 870621 | 100 | 9.58E-02 | 5.26E-01 | 1.99E+02 |
| 134 | Sanono-3 | CE | 880219 | 100 | 4.49E-02 | 5.64E-02 | 1.74E+01 |
| 135 | Surry-1 | W | 770726 | 100 | 2.20E-02 | 6.93E-01 | 2.22E+02 |
| 136 | Surry-1 | W | 800603 | 100 | 7.00E-03 | 2.30E-01 | 7.38E+01 |
| 137 | Surry-1 | W | 810822 | 100 | 7.60E-02 | 1.98E+00 | 6.34E+02 |
| 138 | Surry-1 | W | 811125 | 100 | 1.82E-01 | 5.07E+00 | 1.63E+03 |
| 139 | Surry-1 | W | 811216 | 100 | 5.90E-02 | 8.12E-01 | 2.58E+02 |
| 140 | Surry-1 | W | 820325 | 100 | 1.60E-01 | 5.57E+00 | 1.79E+03 |
| 141 | Surry-1 | W | 820413 | 100 | 1.79E-01 | 5.14E+00 | 1.65E+03 |
| 142 | Surry-1 | W | 820425 | 100 | 1.30E-01 | 3.12E+00 | 9.99E+02 |
| 143 | Surry-1 | W | 820713 | 100 | 1.15E-01 | 8.97E+00 | 2.89E+03 |
| 144 | Surry-1 | W | 820824 | 100 | 9.30E-02 | 8.20E+00 | 2.65E+03 |
| 145 | Surry-1 | W | 821104 | 100 | 6.20E-02 | 2.65E+00 | 8.52E+02 |
| 146 | Surry-1 | W | 821129 | 100 | 1.29E-01 | 5.18E+00 | 1.67E+03 |
| 147 | Surry-1 | W | 830914 | 100 | 1.10E-02 | 5.35E-01 | 1.72E+02 |
| 148 | Surry-1 | W | 840106 | 100 | 5.60E-02 | 9.22E-01 | 2.94E+02 |
| 149 | Surry-1 | W | 840206 | 100 | 7.40E-02 | 1.44E+00 | 4.60E+02 |
| 150 | Surry-1 | W | 840613 | 100 | 3.60E-02 | 1.18E+00 | 3.79E+02 |
| 151 | Surry-1 | W | 840926 | 80 | 3.30E-02 | 6.31E-01 | 2.01E+02 |
| 152 | Surry-1 | W | 850126 | 100 | 1.01E-01 | 1.49E-01 | 3.98E+01 |
| 153 | Surry-1 | W | 850804 | 100 | 2.60E-02 | 1.44E+00 | 4.64E+02 |
| 154 | Surry-1 | W | 860107 | 97 | 2.40E-02 | 1.72E+00 | 5.55E+02 |
| 155 | Surry-1 | W | 870516 | 100 | 6.00E-03 | 3.30E-03 | 5.68E-01 |
| 156 | Surry-1 | W | 870807 | 100 | 4.00E-03 | 3.30E-03 | 7.34E-01 |
| 157 | Surry-1 | W | 870920 | 100 | 7.00E-03 | 2.42E-01 | 7.77E+01 |
| 158 | Surry-1 | W | 880216 | 100 | 9.00E-03 | 9.30E-01 | 3.00E+02 |
| 159 | Surry-2 | W | 771108 | 100 | 2.00E-04 | 3.00E-04 | 8.04E-02 |
| 160 | Surry-2 | W | 780624 | 100 | 5.00E-04 | 3.00E-04 | 5.54E-02 |

Table 2: Iodine Release Rate Following a Reactor Trip (continued)

| No. | Plant | NSSS Vendor | Trip date | Power % | Pre-I (uCi/g) | Post-I (uCi/g) | R3(2) (Ci/h) |
|---|---|---|---|---|---|---|---|
| 161 | Surry-2 | W | 821010 | 100 | 2.00E-03 | 6.70E-02 | 2.15E+01 |
| 162 | Surry-2 | W | 830208 | 100 | 2.00E-03 | 1.82E-01 | 5.87E+01 |
| 163 | Surry-2 | W | 830412 | 100 | 3.00E-03 | 5.35E-01 | 1.73E+02 |
| 164 | Surry-2 | W | 830620 | 100 | 3.00E-03 | 3.31E-01 | 1.07E+02 |
| 165 | Surry-2 | W | 840113 | 100 | 3.00E-04 | 2.00E-03 | 6.22E-01 |
| 166 | Surry-2 | W | 841029 | 100 | 2.00E-04 | 2.00E-04 | 4.81E-02 |
| 167 | Surry-2 | W | 841211 | 100 | 2.00E-04 | 3.00E-04 | 8.04E-02 |
| 168 | Surry-2 | W | 860511 | 100 | 2.00E-04 | 2.00E-04 | 4.81E-02 |

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a. Pre-I is the measured steady state iodine concentration before trip. Post-I is the maximum measured iodine concentration between 2 and 6 hours after trip.
R3(2) is the iodine release rate based on bounded maximum iodine concentration and assumed 2 h time from trip to maximum concentration.

Table 3: Bounding Analysis Summary

| Event | Imax "a" Extrap | Interp. at 2 h | | Observed Min | | Interp. at 6 h | |
|---|---|---|---|---|---|---|---|
| | | I | Imax/I | I | Imax/I | I | Imax/I |
| 1 | 1.98 | 0.019230 | 1.3 | 1.61 | 1.2 | 1.63 | 1.2 |
| 2 | 1.5 | b | | 1.16 | 1.3 | 1.35 | 1.1 |
| 3 | 3.2 | b | | 1.52 | 2.1 | 1.66 | 1.9 |
| 4 | 4.74 | b | | 3.61 | 1.3 | 4.2 | 1.1 |
| 5 | 4.83 | 4.6 | 1.1 | 4.4 | 1.1 | 4.47 | 1.1 |
| 6 | 5.11 | 2.72 | 1.9 | 3.69 | 1.4 | 3.91 | 1.3 |
| 7 | 3.28 | b | | 2.75 | 1.2 | 2.37 | 1.4 |
| 8 | 2.01 | 1.32 | 1.5 | c | | 1.13 | 1.8 |
| 9 | 1.58 | 1.14 | 1.4 | 1.04 | 1.5 | 0.95 | 1.7 |
| 10 | 3.61 | 2.3 | 1.6 | 2.47 | 1.5 | 2.64 | 1.4 |
| 11 | 1.34 | b | | 1.19 | 1.1 | 1.24 | 1.1 |
| 12 | 1.4 | b | | 1.09 | 1.3 | 1.12 | 1.3 |
| 13 | 8.7 | 4.95 | 1.8 | 5.46 | 1.6 | 5.45 | 1.6 |
| 14 | 5.55 | b | | 4.04 | 1.4 | 4.05 | 1.4 |
| 15 | 6.13 | b | | 5.63 | 1.1 | 5.6 | 1.1 |
| 16 | 7.85 | 5.85 | 1.3 | 7.46 | 1.1 | 6.37 | 1.2 |
| 17 | 1.81 | b | | 1.28 | 1.4 | 1.02 | 1.8 |
| 18 | 2.14 | b | | 1.89 | 1.1 | 1.6 | 1.3 |
| 19 | 2.4 | b | | 2.15 | 1.1 | 1.8 | 1.3 |
| 20 | 1.9 | b | | 1.57 | 1.2 | 1.05 | 1.8 |
| 21 | 1.5 | 0.94 | 1.6 | 1.47 | 1 | 1.4 | 1.1 |
| 22 | 2.5 | b | | 2.26 | 1.1 | 2.03 | 1.2 |
| 23 | 1.45 | 1.03 | 1.4 | 1.04 | 1.4 | 1.01 | 1.4 |
| 24 | 0.97 | 0.38 | 2.6 | 0.56 | 1.7 | 0.56 | 1.7 |

a. This is the extrapolated bound on the maximum RCS concentration
b. There was insufficient data to determine the concentration at 2 h
c. There was no value taken between 2 and 6 hours

The estimated concentrations at two and six hours are based on straight line interpolation (on the log plot) between adjacent data points, where available. The method used to bound the maximum concentration is discussed in the next paragraphs.

Some example data traces are presented in Figures 2 through 4. The concentrations are plotted on a log scale to allow linear extrapolation, based on equations given below which indicate an exponential behavior with time, after the peak concentration is reached. The extrapolations were based on the assumption that the concentration trace as plotted in the figure is concave near the maximum. Event 1, shown in Figure 2, is an example of events wherein data are available at many times after trip including at least one data point prior to the maximum. The dashed lines show the extrapolation used to bound the maximum concentration. An open circle marks the intersection of the extrapolations. Because of the assumption of local concavity, this intersection should be an upper bound on the true maximum. This is the bound shown in Table 3.

Event 7, shown in the same figure, is an example of an event wherein the maximum RCS concentration may have occurred prior to the first data point. Therefore, the concentration at two hours after trip cannot be estimated by interpolation. It also happens that this event has two possible extrapolated concentration maxima, one before the first data point (conservatively bounded by extrapolating the concentration back to the time of trip) and one between the first two data points. The larger is marked by an open circle in the figure and is shown in Table 3.

The estimated maximum concentration often occurs within six hours after reactor trip. However, Figure 3 shows two events with somewhat different behavior. The first is Event 2, an example of an event with two local maxima. In these cases, only the first maximum is used in the analysis, since it is judged that the second maximum is influenced by additional transients and does not accurately reflect the effect of the trip alone. The data trace is assumed to be locally concave near the maximum. The trace is clearly not globally concave, probably due to

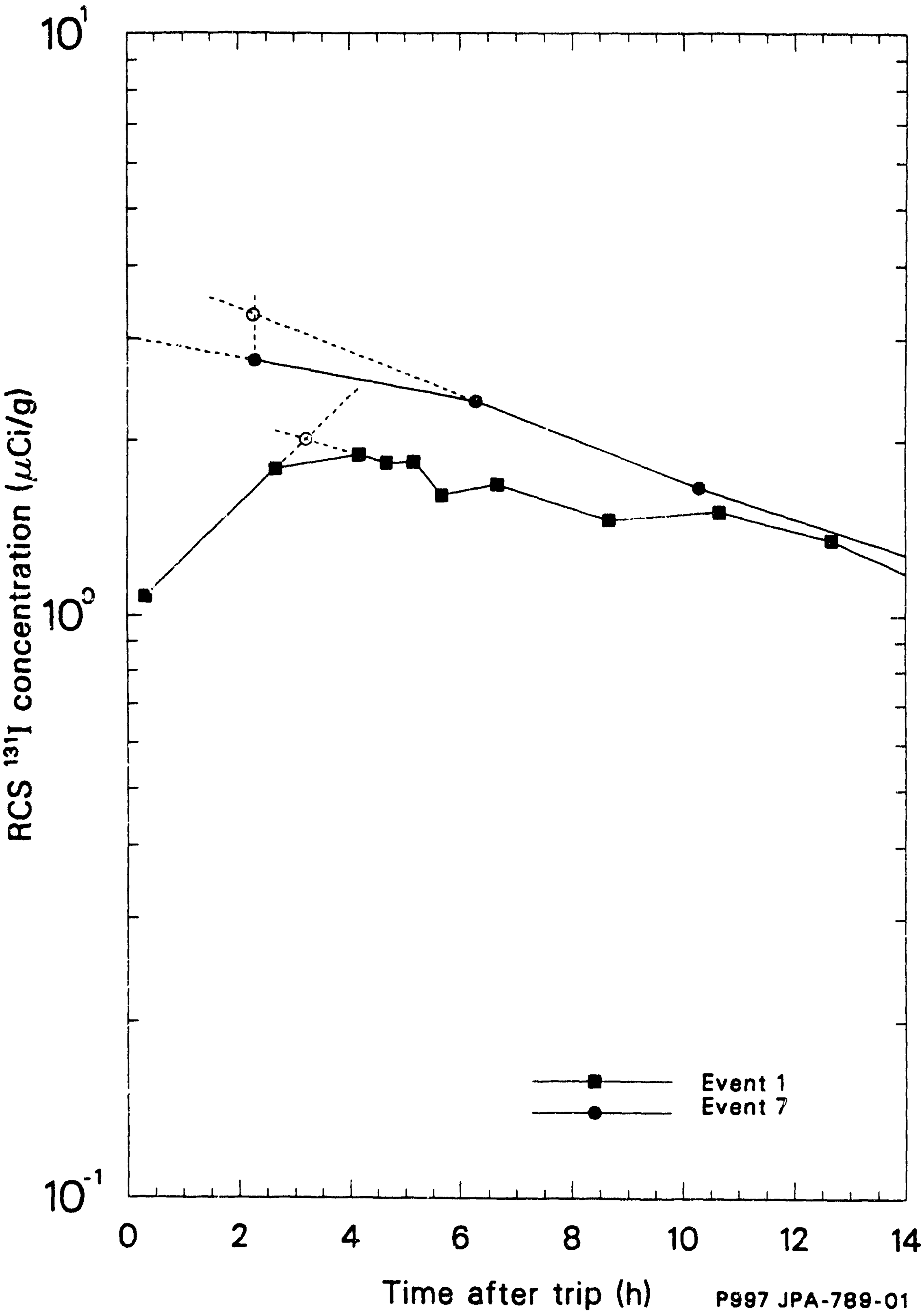


Figure 2: Bounding analysis for Events 1 and 7

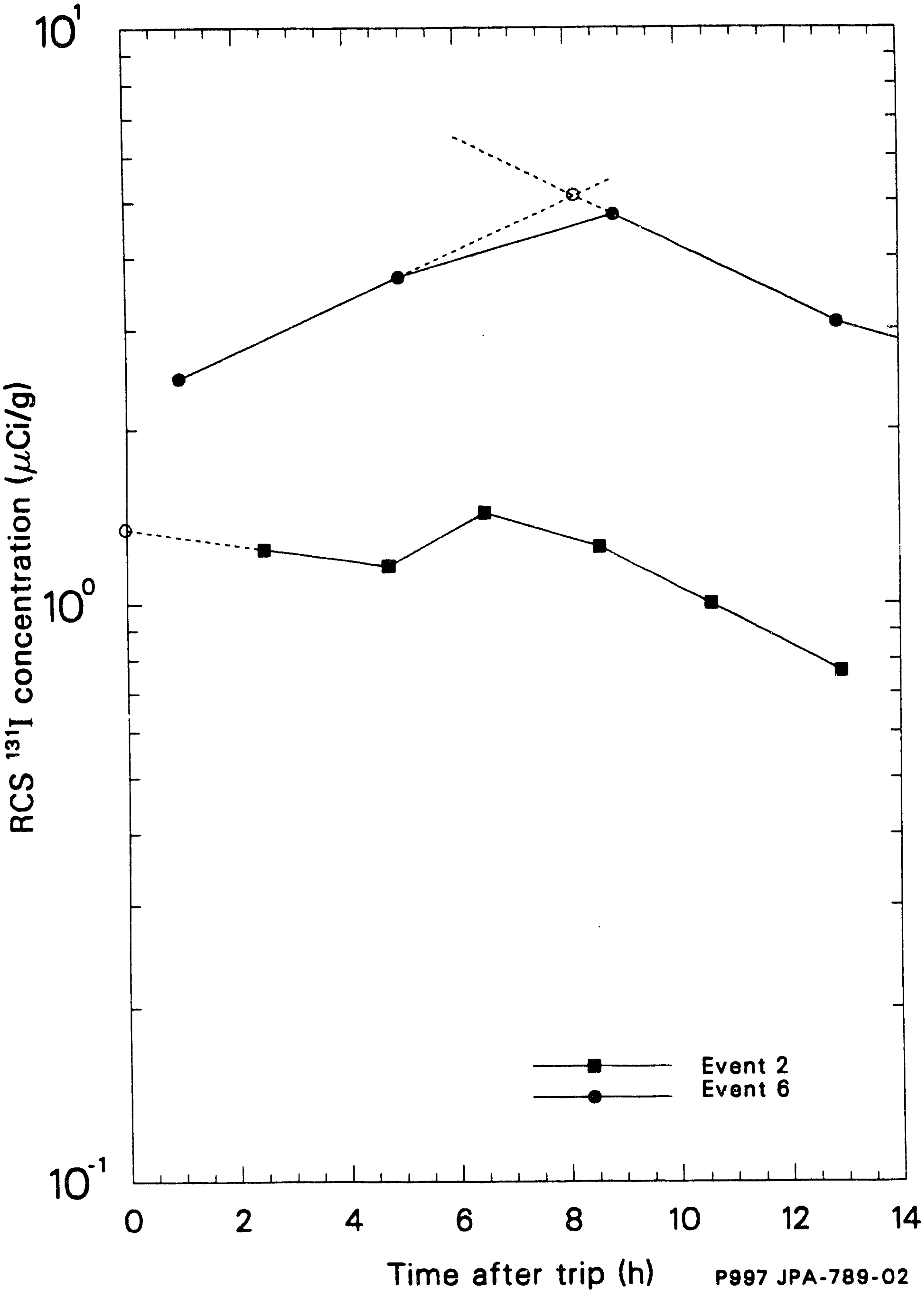


Figure 3: Bounding analysis for Events 2 and 6

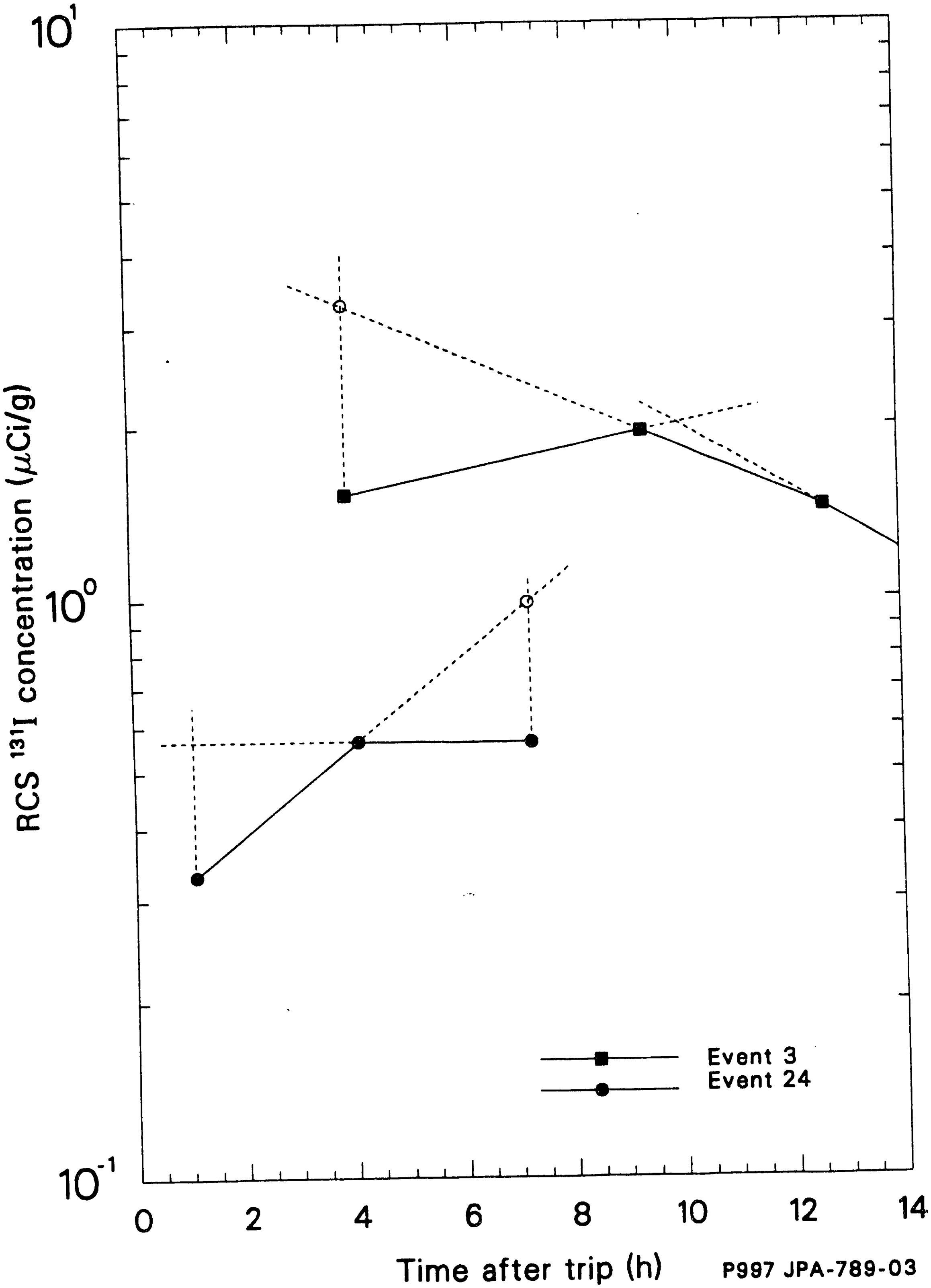


Figure 4: Bounding analysis for Events 3 and 24

transients which occurred after the reactor trip. Unfortunately, there is nothing in the assumptions to rule out the possibility of a steep rise between the first two measurements, which were taken at times 2.5 and 4.75 h after reactor trip. However, the subsequent decrease in concentration is limited by the total iodine removal rate, defined below in Equation (2). This removal rate is typically of magnitude 0.1/h. In the 2.25 h between the two samples, the concentration could not have decreased by more than 20%. Therefore, sharp deviations from the linear interpolation are considered to be very unlikely from the physics of the iodine spiking phenomenon and are not considered here. Event 6 is similar in shape to Event 1 but the maximum occurs later than six hours after reactor trip.

This methodology was used to analyze each of the 24 events. The bound on the maximum concentration was compared to three concentrations: those estimated at two and six hours after trip as well as the minimum measured concentration between two and six hours. The ratios were calculated and are included in Table 3 and plotted in Figure 5.

The largest ratios shown in Table 3 and Figure 5 resulted from Events 3 and 24. The data traces for these two events are shown in Figure 4. The lack of data for these two events led to large extrapolated maximum concentrations, resulting in the large ratios.

This analysis of the 24 events was used to bound the maximum RCS concentration for each reactor trip included in the main data base (Table 2). Based on Figure 5, it is judged that the maximum iodine concentration resulting from a reactor trip is no more than a factor of three greater than any value measured between two and six hours after trip. Thus, the maximum measured values (Post-I in Table 2) were conservatively multiplied by a factor of three and these values were used to bound the iodine release rates as discussed in the following section.

It is recognized that this analysis (and the resulting factor of three) is limited by the fact that RCS samples are taken infrequently compared to the rate of change of iodine concentration. A continuous

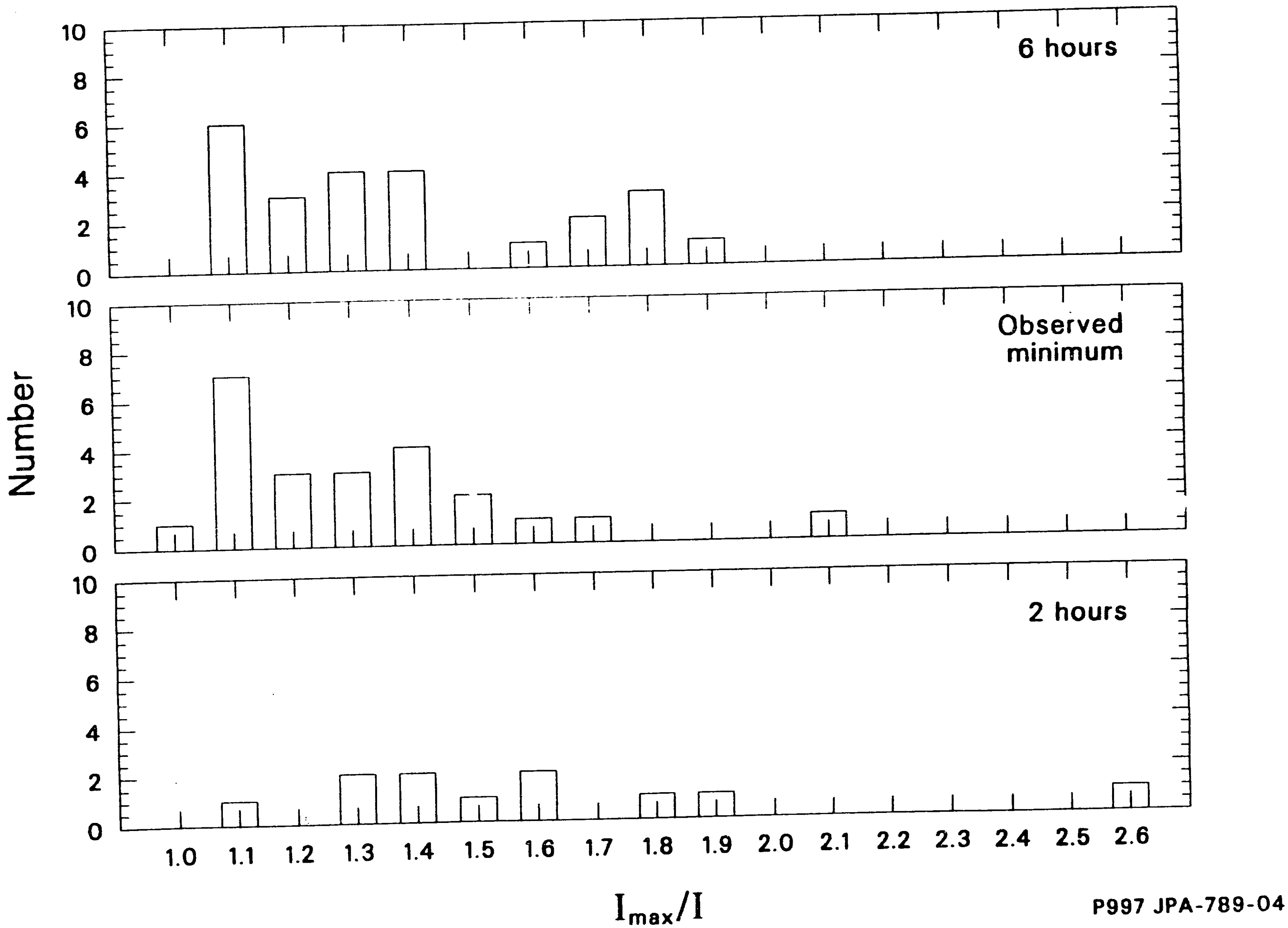


Figure 5: Bounding analysis summary

sample and iodine concentration measurement might reveal a more complicated shape than that assumed in this analysis. However, given the scarcity of data, it is judged that this analysis is as accurate as possible and results in an upper bound to the release rates calculated from the data base.

## Calculation of Iodine Release Rate

The release rate of $^{131}I$ from the fuel to the RCS is shown as R in Table 2. This rate was determined from the data using the following equation:[7]

$$R = \frac{L_t(A - A_0 e^{-L_t t})}{1 - e^{-L_t t}} \qquad (1)$$

where:

R = iodine release rate during the transient (Ci/h)

$R_0$ = steady-state iodine release rate (Ci/h)

$L_t$ = total iodine removal rate ($h^{-1}$)

A = maximum transient RCS iodine inventory (Ci)

$A_0$ = steady-state RCS iodine inventory (Ci)

t = time from iodine spike initiating event to maximum iodine concentration (h)

and:

$$L_t = L_d + L_p \qquad (2)$$

where:

$L_d$ = $^{131}I$ decay constant = 3.59(-3) $h^{-1}$

$L_p$ = purification removal constant

$= \frac{F(1 - 1/DF)}{M}$

and:

F = purification system flow rate (kg/h)

M = RCS mass inventory (kg)

DF = purification system decontamination factor

In all cases included in the table, the purification flow was unchanged from before to after the trip. Additionally, the purification system decontamination factor was assumed to be 99 (i.e. 99% of the radioactive iodine was assumed to be removed from the purification flow stream by the demineralizers). Using the time from reactor trip to maximum measured iodine concentration in the equation results in an average release rate which can be used to estimate the average transient RCS iodine concentration during an SGTR event. The absence of samples taken immediately after reactor trip means that the actual time of the maximum concentration cannot be determined. Because of this, a second release rate was calculated assuming that the maximum concentration occurred at two hours after reactor trip. These release rates are compared in Table 4. Two hours is judged to be adequately conservative but much better data would be required to confirm this. The interested reader who believes that a different minimum time is more appropriate can perform quick comparisons by noting that R is approximately inversely proportional to t for small t.

## PROBABILITY DISTRIBUTIONS FOR THE RELEASE RATE

A statistical analysis was performed on the data base in Table 2 to estimate the probability distribution of the release rate associated with an iodine spike caused by a reactor trip. It was assumed that the events represent a random sampling of the iodine spiking which has occurred and is expected to occur in commercial PWRs. No attempt was made to correlate the data to either specific plants or fuel manufacturers. The results from this statistical analysis are cumulative probability distributions, which are measures of the probability that an SGTR would result in an iodine spike with magnitude less than a given value. Both the nominal probability distribution and the 95% confidence limit probability

Table 4: Comparison of Release Rates

| No. | R/P (a) (Ci/h*MW) | R3/P (b) (Ci/h*MW) | R3(2)/P (c) (Ci/h*MW) | Nominal (d) Prob. | 95% (e) Confid. |
|---|---|---|---|---|---|
| 1 | 5.95E-07 | 9.30E-06 | 9.69E-06 | 0.006 | 0.000 |
| 2 | 9.01E-07 | 1.19E-05 | 2.73E-05 | 0.012 | 0.002 |
| 3 | 1.06E-06 | 3.27E-05 | 6.15E-05 | 0.018 | 0.005 |
| 4 | 1.56E-06 | 3.44E-05 | 6.15E-05 | 0.024 | 0.008 |
| 5 | 1.99E-06 | 3.66E-05 | 6.32E-05 | 0.030 | 0.012 |
| 6 | 2.93E-06 | 3.66E-05 | 6.40E-05 | 0.036 | 0.016 |
| 7 | 3.41E-06 | 3.74E-05 | 7.09E-05 | 0.041 | 0.020 |
| 8 | 6.25E-06 | 4.31E-05 | 7.23E-05 | 0.047 | 0.024 |
| 9 | 6.28E-06 | 5.01E-05 | 7.26E-05 | 0.053 | 0.028 |
| 10 | 6.28E-06 | 6.00E-05 | 7.71E-05 | 0.059 | 0.033 |
| 11 | 7.80E-06 | 7.18E-05 | 1.03E-04 | 0.065 | 0.037 |
| 12 | 1.30E-05 | 7.67E-05 | 1.03E-04 | 0.071 | 0.042 |
| 13 | 1.40E-05 | 7.71E-05 | 1.51E-04 | 0.077 | 0.046 |
| 14 | 1.44E-05 | 1.04E-04 | 1.75E-04 | 0.083 | 0.051 |
| 15 | 1.56E-05 | 1.36E-04 | 1.78E-04 | 0.089 | 0.056 |
| 16 | 1.66E-05 | 1.49E-04 | 2.18E-04 | 0.095 | 0.061 |
| 17 | 2.37E-05 | 1.85E-04 | 2.27E-04 | 0.101 | 0.066 |
| 18 | 2.37E-05 | 1.87E-04 | 2.63E-04 | 0.107 | 0.070 |
| 19 | 2.63E-05 | 1.91E-04 | 2.79E-04 | 0.112 | 0.075 |
| 20 | 3.66E-05 | 1.93E-04 | 2.79E-04 | 0.118 | 0.080 |
| 21 | 3.92E-05 | 2.36E-04 | 3.30E-04 | 0.124 | 0.085 |
| 22 | 4.33E-05 | 2.55E-04 | 3.54E-04 | 0.130 | 0.090 |
| 23 | 5.71E-05 | 2.63E-04 | 5.03E-04 | 0.136 | 0.095 |
| 24 | 6.24E-05 | 3.03E-04 | 5.73E-04 | 0.142 | 0.101 |
| 25 | 7.11E-05 | 4.39E-04 | 7.27E-04 | 0.148 | 0.106 |
| 26 | 7.35E-05 | 4.78E-04 | 7.97E-04 | 0.154 | 0.111 |
| 27 | 7.93E-05 | 5.11E-04 | 8.36E-04 | 0.160 | 0.116 |
| 28 | 8.78E-05 | 7.03E-04 | 8.37E-04 | 0.166 | 0.121 |
| 29 | 9.48E-05 | 7.17E-04 | 8.74E-04 | 0.172 | 0.126 |
| 30 | 1.49E-04 | 7.50E-04 | 9.40E-04 | 0.178 | 0.132 |

Table 4: Comparison of Release Rates (continued)

| | R/P (a) (Ci/h*MW) | R3/P (b) (Ci/h*MW) | R3(2)/P (c) (Ci/h*MW) | Nominal (d) Prob. | 95% (e) Confid. |
|---|---|---|---|---|---|
| 31 | 1.56E-04 | 1.07E-03 | 1.07E-03 | 0.183 | 0.137 |
| 32 | 1.63E-04 | 1.16E-03 | 1.63E-03 | 0.189 | 0.142 |
| 33 | 1.88E-04 | 1.42E-03 | 1.71E-03 | 0.195 | 0.147 |
| 34 | 4.45E-04 | 1.55E-03 | 3.00E-03 | 0.201 | 0.153 |
| 35 | 8.60E-04 | 2.22E-03 | 3.71E-03 | 0.207 | 0.158 |
| 36 | 8.75E-04 | 3.21E-03 | 4.92E-03 | 0.213 | 0.163 |
| 37 | 1.07E-03 | 4.59E-03 | 5.15E-03 | 0.219 | 0.169 |
| 38 | 1.12E-03 | 4.60E-03 | 1.03E-02 | 0.225 | 0.174 |
| 39 | 1.45E-03 | 4.97E-03 | 1.08E-02 | 0.231 | 0.179 |
| 40 | 1.59E-03 | 5.07E-03 | 1.10E-02 | 0.237 | 0.185 |
| 41 | 1.65E-03 | 5.71E-03 | 1.12E-02 | 0.243 | 0.190 |
| 42 | 1.65E-03 | 6.04E-03 | 1.19E-02 | 0.249 | 0.196 |
| 43 | 1.73E-03 | 6.04E-03 | 1.19E-02 | 0.254 | 0.201 |
| 44 | 1.90E-03 | 6.14E-03 | 1.31E-02 | 0.260 | 0.207 |
| 45 | 1.97E-03 | 6.17E-03 | 1.32E-02 | 0.266 | 0.212 |
| 46 | 1.99E-03 | 7.09E-03 | 1.33E-02 | 0.272 | 0.218 |
| 47 | 2.17E-03 | 7.27E-03 | 1.41E-02 | 0.278 | 0.223 |
| 48 | 2.42E-03 | 8.82E-03 | 1.58E-02 | 0.284 | 0.229 |
| 49 | 2.93E-03 | 9.30E-03 | 1.60E-02 | 0.290 | 0.234 |
| 50 | 3.28E-03 | 9.88E-03 | 1.91E-02 | 0.296 | 0.240 |
| 51 | 3.38E-03 | 1.17E-02 | 1.93E-02 | 0.302 | 0.245 |
| 52 | 4.04E-03 | 1.22E-02 | 2.11E-02 | 0.308 | 0.251 |
| 53 | 4.10E-03 | 1.30E-02 | 2.25E-02 | 0.314 | 0.256 |
| 54 | 4.13E-03 | 1.46E-02 | 2.25E-02 | 0.320 | 0.262 |
| 55 | 4.23E-03 | 1.48E-02 | 2.30E-02 | 0.325 | 0.268 |
| 56 | 4.70E-03 | 1.60E-02 | 2.42E-02 | 0.331 | 0.273 |
| 57 | 4.81E-03 | 1.78E-02 | 2.45E-02 | 0.337 | 0.279 |
| 58 | 5.44E-03 | 1.86E-02 | 2.60E-02 | 0.343 | 0.284 |
| 59 | 5.60E-03 | 1.93E-02 | 2.72E-02 | 0.349 | 0.290 |
| 60 | 6.03E-03 | 2.01E-02 | 2.75E-02 | 0.355 | 0.296 |

Table 4: Comparison of Release Rates
(continued)

| | R/P (a) (Ci/h*MW) | R3/P (b) (Ci/h*MW) | R3(2)/P (c) (Ci/h*MW) | Nominal (d) Prob. | 95% (e) Confid. |
|---|---|---|---|---|---|
| 61 | 6.35E-03 | 2.07E-02 | 2.95E-02 | 0.361 | 0.301 |
| 62 | 6.61E-03 | 2.17E-02 | 3.48E-02 | 0.367 | 0.307 |
| 63 | 6.83E-03 | 2.21E-02 | 3.62E-02 | 0.373 | 0.313 |
| 64 | 7.22E-03 | 2.25E-02 | 4.20E-02 | 0.379 | 0.318 |
| 65 | 7.27E-03 | 2.45E-02 | 4.40E-02 | 0.385 | 0.324 |
| 66 | 7.42E-03 | 2.68E-02 | 4.78E-02 | 0.391 | 0.330 |
| 67 | 8.06E-03 | 2.88E-02 | 4.79E-02 | 0.396 | 0.335 |
| 68 | 8.50E-03 | 3.04E-02 | 5.05E-02 | 0.402 | 0.341 |
| 69 | 9.31E-03 | 3.08E-02 | 5.10E-02 | 0.408 | 0.347 |
| 70 | 9.64E-03 | 3.21E-02 | 5.11E-02 | 0.414 | 0.353 |
| 71 | 9.77E-03 | 3.65E-02 | 5.33E-02 | 0.420 | 0.358 |
| 72 | 1.01E-02 | 3.83E-02 | 5.43E-02 | 0.426 | 0.364 |
| 73 | 1.05E-02 | 3.94E-02 | 5.63E-02 | 0.432 | 0.370 |
| 74 | 1.23E-02 | 4.01E-02 | 5.82E-02 | 0.438 | 0.376 |
| 75 | 1.24E-02 | 4.07E-02 | 5.95E-02 | 0.444 | 0.381 |
| 76 | 1.25E-02 | 4.11E-02 | 6.12E-02 | 0.450 | 0.387 |
| 77 | 1.28E-02 | 4.13E-02 | 6.18E-02 | 0.456 | 0.393 |
| 78 | 1.28E-02 | 4.16E-02 | 6.22E-02 | 0.462 | 0.399 |
| 79 | 1.31E-02 | 4.40E-02 | 6.36E-02 | 0.467 | 0.405 |
| 80 | 1.35E-02 | 4.43E-02 | 6.48E-02 | 0.473 | 0.411 |
| 81 | 1.36E-02 | 4.70E-02 | 6.82E-02 | 0.479 | 0.416 |
| 82 | 1.37E-02 | 4.78E-02 | 6.87E-02 | 0.485 | 0.422 |
| 83 | 1.37E-02 | 4.79E-02 | 7.24E-02 | 0.491 | 0.428 |
| 84 | 1.41E-02 | 4.81E-02 | 7.33E-02 | 0.497 | 0.434 |
| 85 | 1.41E-02 | 4.83E-02 | 7.52E-02 | 0.503 | 0.440 |
| 86 | 1.46E-02 | 4.85E-02 | 7.53E-02 | 0.509 | 0.446 |
| 87 | 1.49E-02 | 4.86E-02 | 8.11E-02 | 0.515 | 0.452 |
| 88 | 1.52E-02 | 4.96E-02 | 8.35E-02 | 0.521 | 0.458 |
| 89 | 1.52E-02 | 5.01E-02 | 8.41E-02 | 0.527 | 0.463 |
| 90 | 1.55E-02 | 5.23E-02 | 8.58E-02 | 0.533 | 0.469 |

Table 4: Comparison of Release Rates (continued)

| | R/P (a) (Ci/h*MW) | R3/P (b) (Ci/h*MW) | R3(2)/P (c) (Ci/h*MW) | Nominal (d) Prob. | 95% (e) Confid. |
|---|---|---|---|---|---|
| 91 | 1.55E-02 | 5.31E-02 | 8.93E-02 | 0.538 | 0.475 |
| 92 | 1.58E-02 | 5.31E-02 | 9.22E-02 | 0.544 | 0.481 |
| 93 | 1.60E-02 | 5.32E-02 | 9.23E-02 | 0.550 | 0.487 |
| 94 | 1.60E-02 | 5.48E-02 | 9.32E-02 | 0.556 | 0.493 |
| 95 | 1.66E-02 | 5.62E-02 | 9.46E-02 | 0.562 | 0.499 |
| 96 | 1.73E-02 | 5.76E-02 | 9.79E-02 | 0.568 | 0.505 |
| 97 | 1.84E-02 | 6.18E-02 | 9.88E-02 | 0.574 | 0.511 |
| 98 | 1.85E-02 | 6.24E-02 | 9.95E-02 | 0.580 | 0.517 |
| 99 | 1.90E-02 | 6.42E-02 | 1.04E-01 | 0.586 | 0.532 |
| 100 | 1.95E-02 | 6.60E-02 | 1.12E-01 | 0.592 | 0.529 |
| 101 | 2.13E-02 | 6.87E-02 | 1.14E-01 | 0.598 | 0.535 |
| 102 | 2.18E-02 | 7.15E-02 | 1.15E-01 | 0.604 | 0.541 |
| 103 | 2.21E-02 | 7.38E-02 | 1.19E-01 | 0.609 | 0.547 |
| 104 | 2.30E-02 | 7.49E-02 | 1.26E-01 | 0.615 | 0.553 |
| 105 | 2.42E-02 | 7.55E-02 | 1.27E-01 | 0.621 | 0.559 |
| 106 | 2.48E-02 | 7.73E-02 | 1.27E-01 | 0.627 | 0.565 |
| 107 | 2.51E-02 | 7.85E-02 | 1.37E-01 | 0.633 | 0.571 |
| 108 | 2.56E-02 | 8.91E-02 | 1.40E-01 | 0.639 | 0.578 |
| 109 | 2.73E-02 | 8.98E-02 | 1.40E-01 | 0.645 | 0.584 |
| 110 | 2.74E-02 | 9.06E-02 | 1.48E-01 | 0.651 | 0.590 |
| 111 | 2.83E-02 | 9.12E-02 | 1.52E-01 | 0.657 | 0.596 |
| 112 | 2.87E-02 | 9.22E-02 | 1.53E-01 | 0.663 | 0.602 |
| 113 | 2.88E-02 | 9.43E-02 | 1.70E-01 | 0.669 | 0.608 |
| 114 | 2.97E-02 | 9.45E-02 | 1.81E-01 | 0.675 | 0.614 |
| 115 | 3.28E-02 | 9.98E-02 | 1.87E-01 | 0.680 | 0.620 |
| 116 | 3.32E-02 | 1.04E-01 | 1.95E-01 | 0.686 | 0.627 |
| 117 | 3.37E-02 | 1.06E-01 | 1.96E-01 | 0.692 | 0.633 |
| 118 | 3.50E-02 | 1.11E-01 | 1.97E-01 | 0.698 | 0.639 |
| 119 | 3.63E-02 | 1.13E-01 | 2.06E-01 | 0.704 | 0.645 |
| 120 | 3.73E-02 | 1.14E-01 | 2.14E-01 | 0.710 | 0.651 |

Table 4: Comparison of Release Rates (continued)

| | R/P (a) (Ci/h*MW) | R3/P (b) (Ci/h*MW) | R3(2)/P (c) (Ci/h*MW) | Nominal (d) Prob. | 95% (e) Confid. |
|---|---|---|---|---|---|
| 121 | 3.84E-02 | 1.19E-01 | 2.21E-01 | 0.716 | 0.658 |
| 122 | 3.91E-02 | 1.28E-01 | 2.21E-01 | 0.722 | 0.664 |
| 123 | 4.18E-02 | 1.39E-01 | 2.35E-01 | 0.728 | 0.670 |
| 124 | 4.37E-02 | 1.45E-01 | 2.42E-01 | 0.734 | 0.676 |
| 125 | 4.44E-02 | 1.50E-01 | 2.48E-01 | 0.740 | 0.683 |
| 126 | 4.89E-02 | 1.55E-01 | 2.58E-01 | 0.746 | 0.689 |
| 127 | 5.18E-02 | 1.63E-01 | 2.80E-01 | 0.751 | 0.695 |
| 128 | 5.27E-02 | 1.66E-01 | 2.80E-01 | 0.757 | 0.702 |
| 129 | 5.33E-02 | 1.72E-01 | 2.85E-01 | 0.763 | 0.708 |
| 130 | 5.91E-02 | 1.84E-01 | 3.07E-01 | 0.769 | 0.714 |
| 131 | 6.19E-02 | 1.87E-01 | 3.15E-01 | 0.775 | 0.721 |
| 132 | 6.22E-02 | 1.98E-01 | 3.25E-01 | 0.781 | 0.727 |
| 133 | 6.58E-02 | 2.04E-01 | 3.30E-01 | 0.787 | 0.733 |
| 134 | 6.65E-02 | 2.08E-01 | 3.34E-01 | 0.793 | 0.740 |
| 135 | 6.82E-02 | 2.11E-01 | 3.54E-01 | 0.799 | 0.746 |
| 136 | 7.18E-02 | 2.23E-01 | 3.63E-01 | 0.805 | 0.753 |
| 137 | 7.84E-02 | 2.45E-01 | 3.71E-01 | 0.811 | 0.759 |
| 138 | 8.10E-02 | 2.60E-01 | 3.74E-01 | 0.817 | 0.766 |
| 139 | 8.26E-02 | 2.64E-01 | 3.76E-01 | 0.822 | 0.772 |
| 140 | 8.54E-02 | 2.71E-01 | 3.84E-01 | 0.828 | 0.779 |
| 141 | 9.04E-02 | 2.72E-01 | 3.91E-01 | 0.834 | 0.785 |
| 142 | 9.30E-02 | 2.97E-01 | 4.04E-01 | 0.840 | 0.792 |
| 143 | 9.41E-02 | 3.09E-01 | 4.06E-01 | 0.846 | 0.798 |
| 144 | 1.00E-01 | 3.28E-01 | 4.23E-01 | 0.852 | 0.805 |
| 145 | 1.04E-01 | 3.28E-01 | 4.43E-01 | 0.858 | 0.812 |
| 146 | 1.08E-01 | 3.31E-01 | 4.68E-01 | 0.864 | 0.818 |
| 147 | 1.09E-01 | 3.32E-01 | 4.85E-01 | 0.870 | 0.825 |
| 148 | 1.15E-01 | 3.47E-01 | 5.89E-01 | 0.876 | 0.832 |
| 149 | 1.16E-01 | 3.60E-01 | 5.93E-01 | 0.882 | 0.838 |
| 150 | 1.19E-01 | 3.98E-01 | 5.94E-01 | 0.888 | 0.845 |

Table 4: Comparison of Release Rates (continued)

| | R/P (a) (Ci/h*MW) | R3/P (b) (Ci/h*MW) | R3(2)/P (c) (Ci/h*MW) | Nominal (d) Prob. | 95% (e) Confid. |
|---|---|---|---|---|---|
| 151 | 1.32E-01 | 4.03E-01 | 6.08E-01 | 0.893 | 0.852 |
| 152 | 1.32E-01 | 4.03E-01 | 6.79E-01 | 0.899 | 0.859 |
| 153 | 1.46E-01 | 4.49E-01 | 7.10E-01 | 0.905 | 0.866 |
| 154 | 1.50E-01 | 4.52E-01 | 7.32E-01 | 0.911 | 0.873 |
| 155 | 1.53E-01 | 4.62E-01 | 7.32E-01 | 0.917 | 0.880 |
| 156 | 1.54E-01 | 4.68E-01 | 8.12E-01 | 0.923 | 0.887 |
| 157 | 1.58E-01 | 4.85E-01 | 8.93E-01 | 0.929 | 0.894 |
| 158 | 2.03E-01 | 6.14E-01 | 1.09E+00 | 0.935 | 0.901 |
| 159 | 2.17E-01 | 7.31E-01 | 1.28E+00 | 0.941 | 0.908 |
| 160 | 3.45E-01 | 1.06E+00 | 1.53E+00 | 0.947 | 0.916 |
| 161 | 4.05E-01 | 1.23E+00 | 2.08E+00 | 0.953 | 0.923 |
| 162 | 4.45E-01 | 1.36E+00 | 2.11E+00 | 0.959 | 0.931 |
| 163 | 5.32E-01 | 1.62E+00 | 2.13E+00 | 0.964 | 0.938 |
| 164 | 5.46E-01 | 1.66E+00 | 2.29E+00 | 0.970 | 0.946 |
| 165 | 6.35E-01 | 1.91E+00 | 3.39E+00 | 0.976 | 0.954 |
| 166 | 6.35E-01 | 1.91E+00 | 3.42E+00 | 0.982 | 0.963 |
| 167 | 7.02E-01 | 2.13E+00 | 3.70E+00 | 0.988 | 0.972 |
| 168 | 9.98E-01 | 3.04E+00 | 6.62E+00 | 0.994 | 0.982 |

a. Nominal release rate based on measured concentration and time
b. Release rate based on nominal time and estimated maximum concentration
c. Release rate based on estimated maximum concentration and 2 h time differential
d. Nominal probability
e. 95% confidence probability

distribution were calculated using binomial distribution statistical analysis methods. The statistical methods used are described briefly below.

The release rate must be normalized to account for differences in reactor size. This is because the amount of iodine being released from the fuel into the RCS will be a function of the number of fuel rods in the core. The SRP normalizes this number to the steady state release rate by specifying that the release rate during the transient be 500 times larger than that which, in steady state, results in an RCS concentration of 1.0 $\mu$Ci/g. This approach is difficult to assess because the number of reactor trips which occur with an RCS concentration near 1.0 $\mu$Ci/g is too small to be used in this analysis. Using the ratios (bounded post-trip to actual steady-state release rates) from all trips results in extremely large ratios, not because the absolute post-trip release rate is high but rather because the steady-state release rate is so low. This is illustrated in Figures 6 and 7, which show the release rate ratio (R3/Ro) plotted against the initial iodine concentration (note: the transient release rate is that based on the bounded maximum concentration and the measured time). All of the very large ratios result from initial concentrations which are less than 0.3 $\mu$Ci/g. Therefore, a different normalization method is proposed, namely the core power (in MW(e)). Thus, each release rate is divided by the core electric power prior to the trip.

The estimated cumulative probability distribution for the iodine release rate divided by the core power prior to trip is tabulated in Table 4 and shown in Figure 8. This is the release rate based on the bounded maximum concentration. Figure 9 is the same as Figure 8 with the vertical axis expanded to illustrate the upper portion. The other two values for the release rate (release rate based on the measured concentration and time difference and the release rate based on the bounded maximum concentration and a 2 h time differential) are also shown in Table 4. Figures 10 and 11 illustrate the first and Figures 12 and 13, the second calculation.

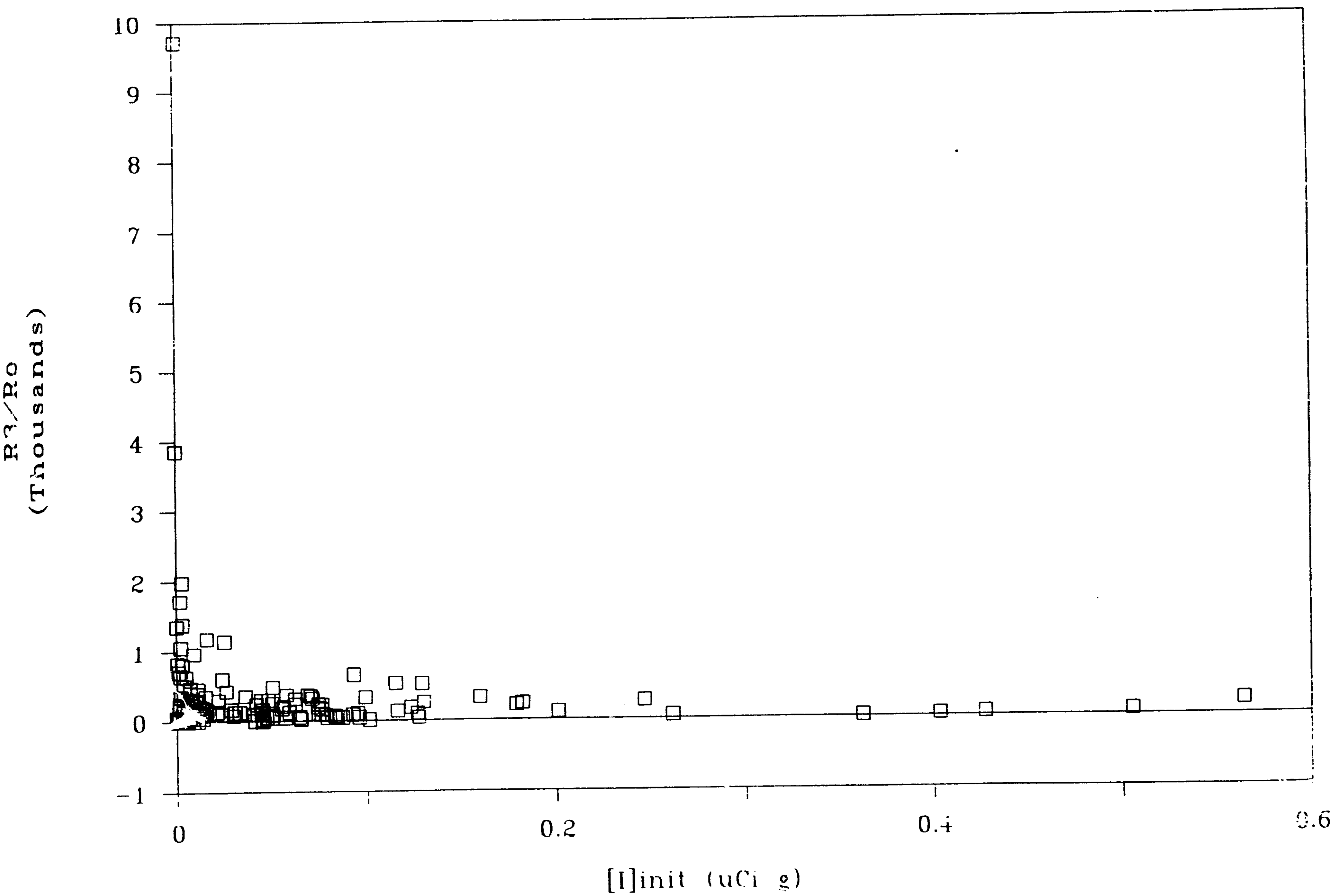


Figure 6: Release rate ratio (R3/Ro) versus the initial iodine concentration

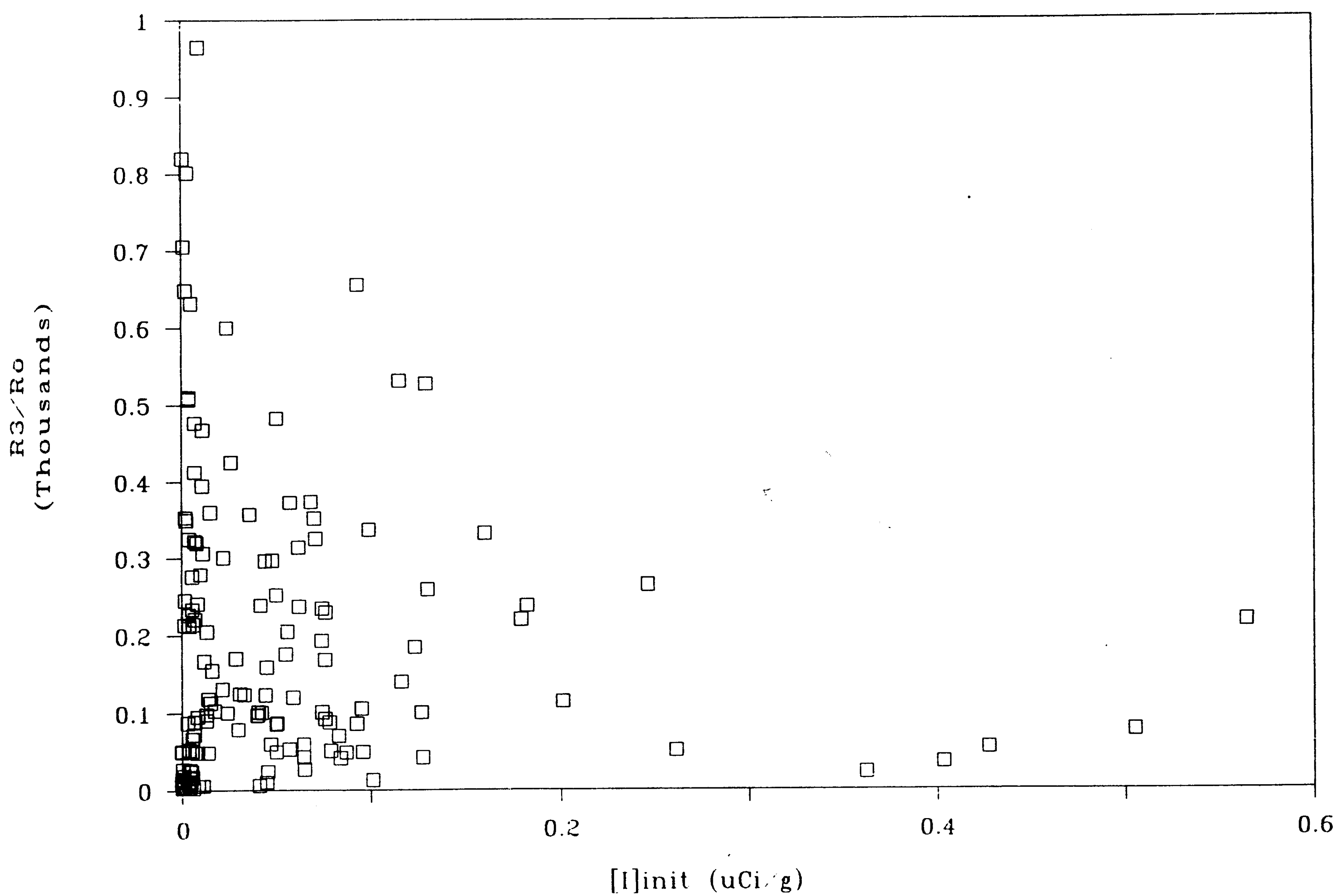


Figure 7: Release rate ratio (R3/Ro) versus the initial iodine concentration (expanded)

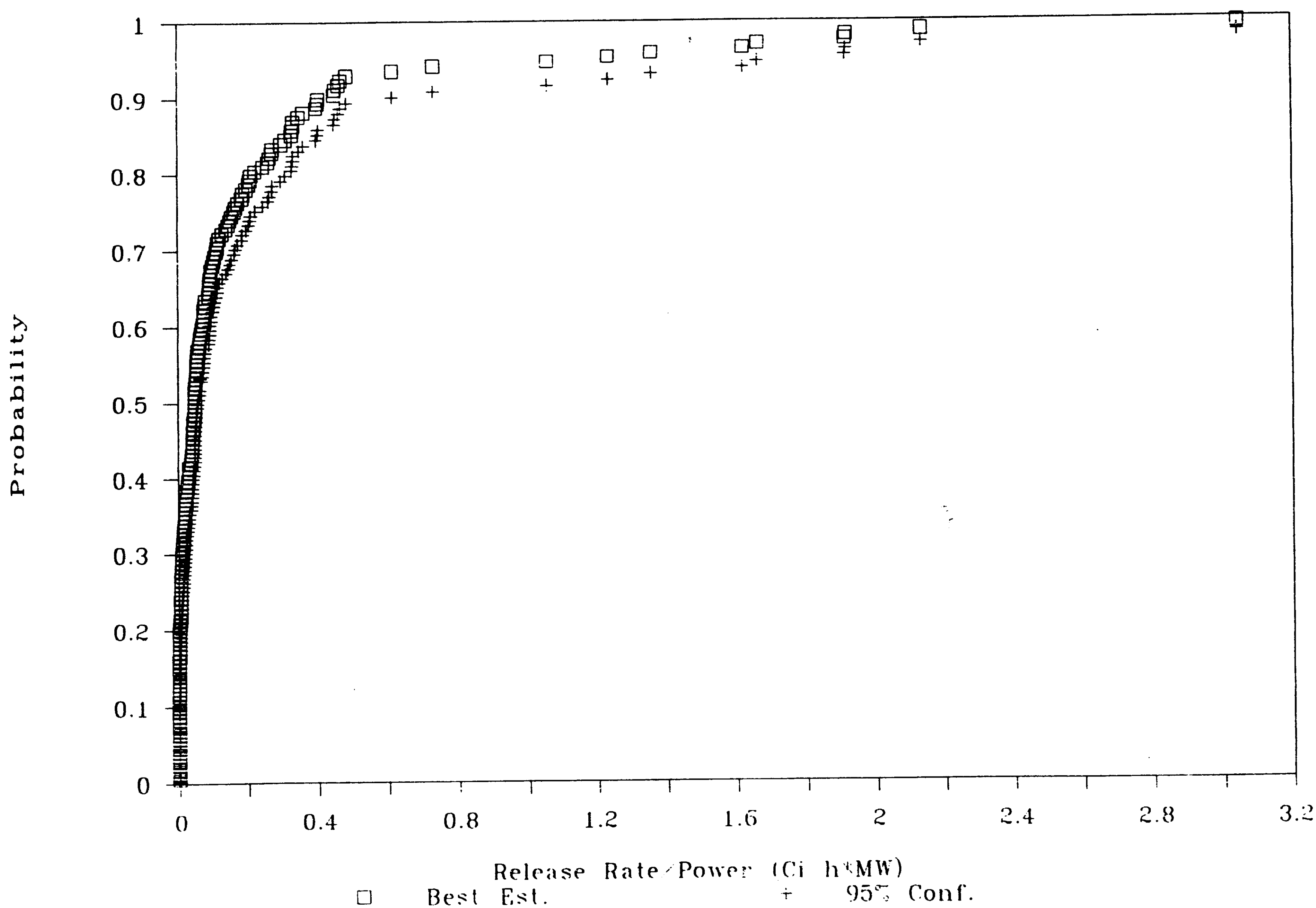


Figure 8: Cumulative probability distribution for the release rate based on the bounded maximum iodine concentration

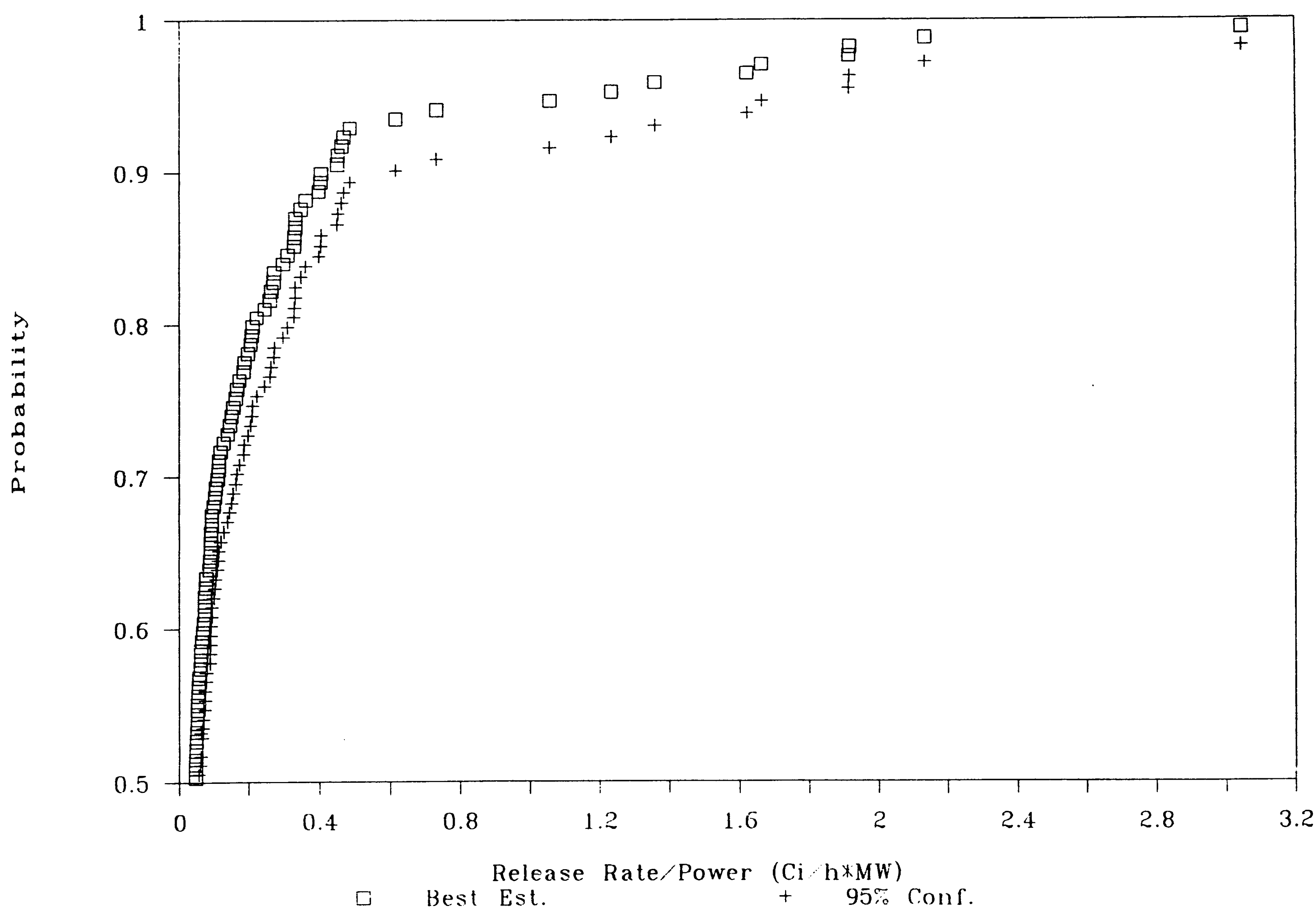


Figure 9: Cumulative probability distribution for the release rate based on the bounded maximum iodine concentration (expanded)

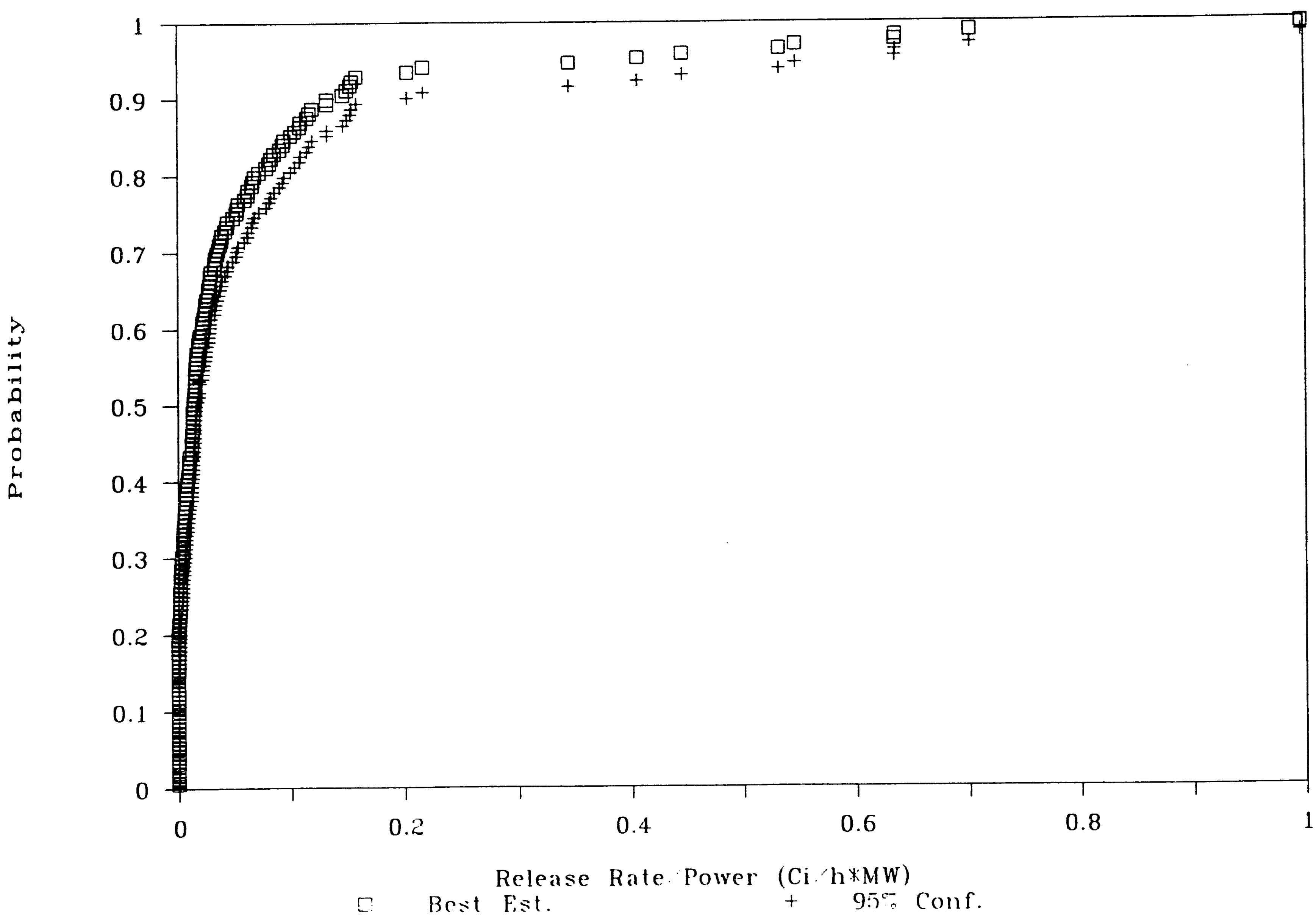


Figure 10: Cumulative probability distribution for the release rate based on the nominal iodine concentration and time

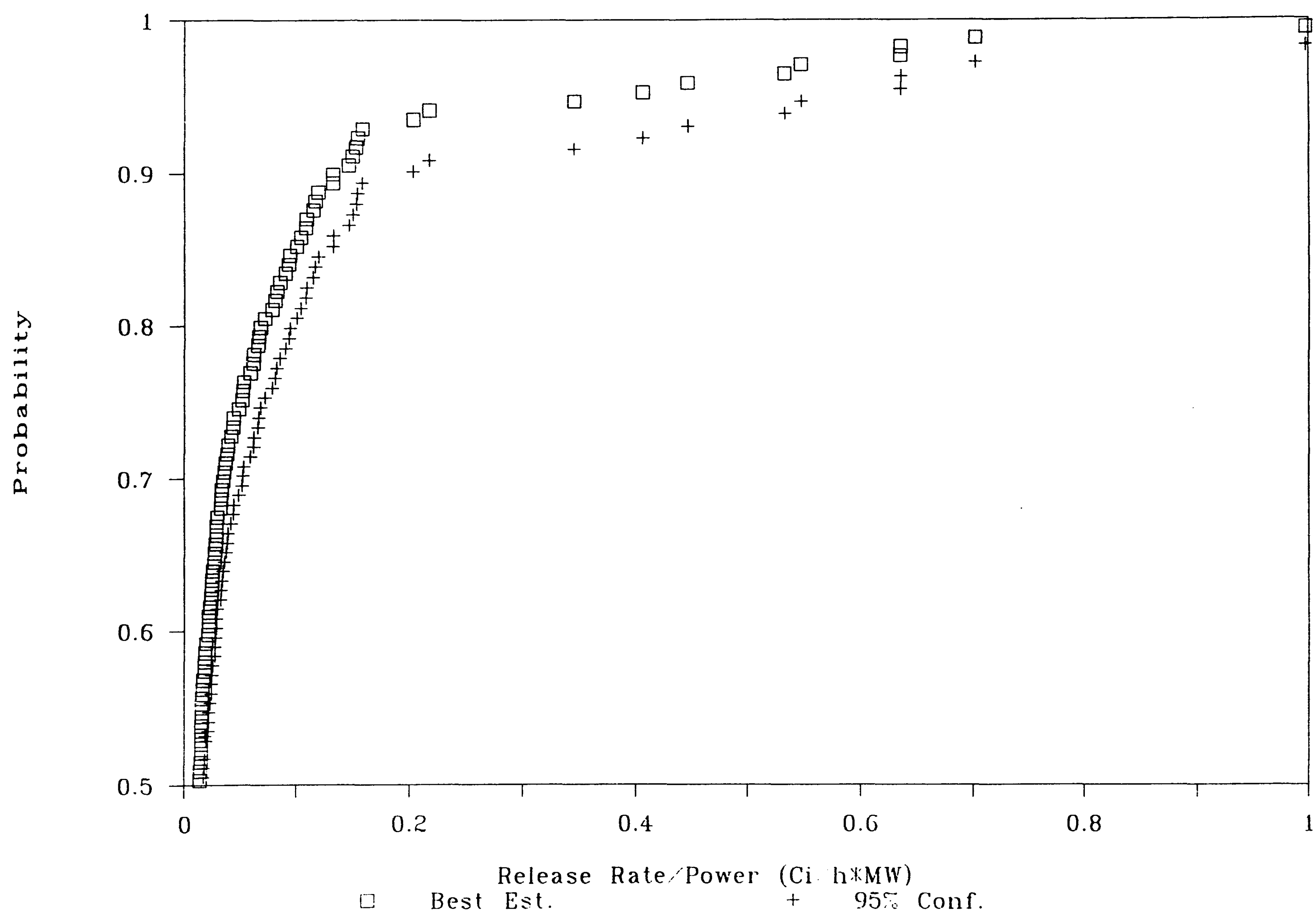


Figure 11: Cumulative probability distribution for the release rate based on the nominal iodine concentration and time (expanded)

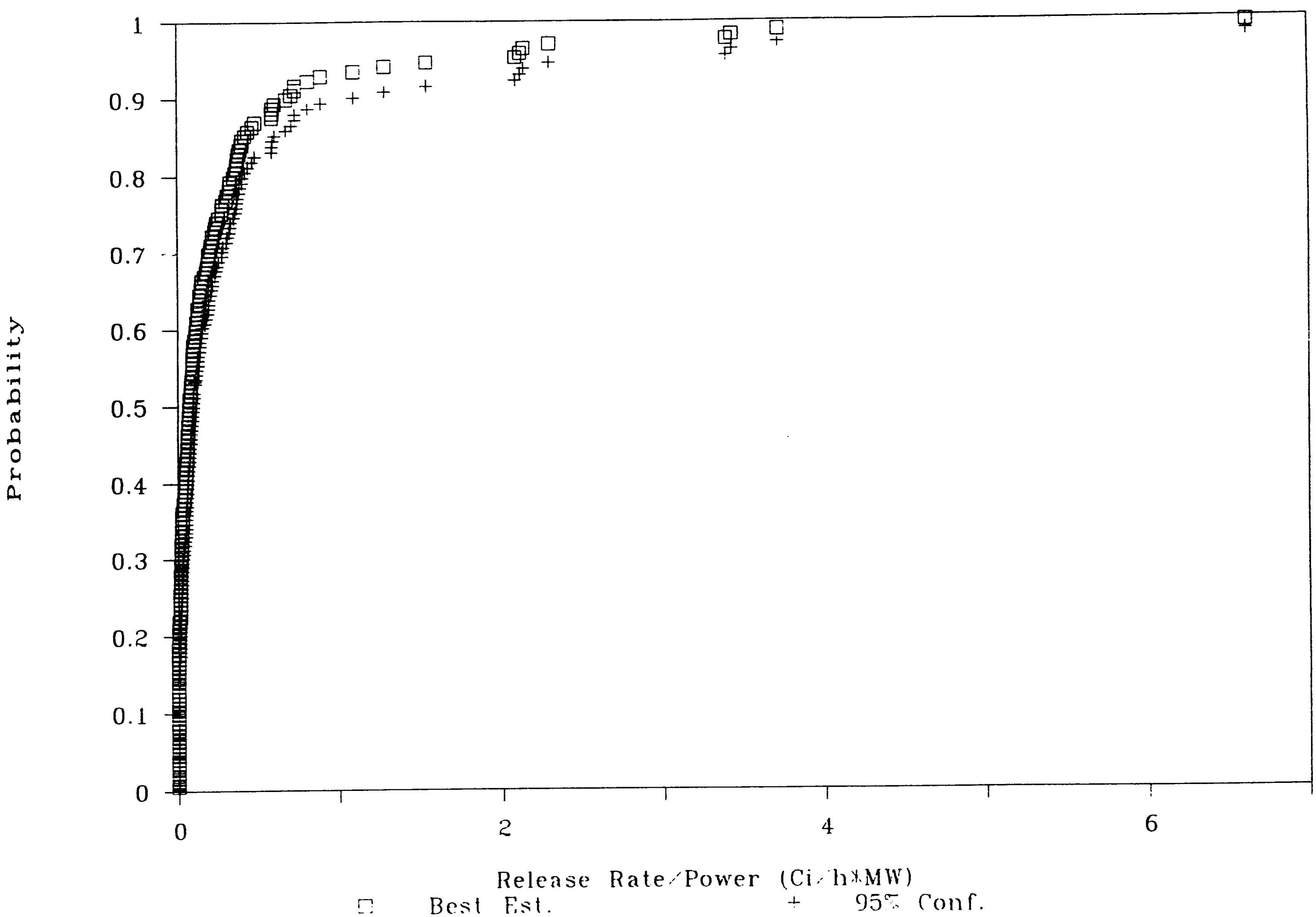


Figure 12: Cumulative probability distribution for the release rate based on the bounded iodine concentration and 2 hour assumption

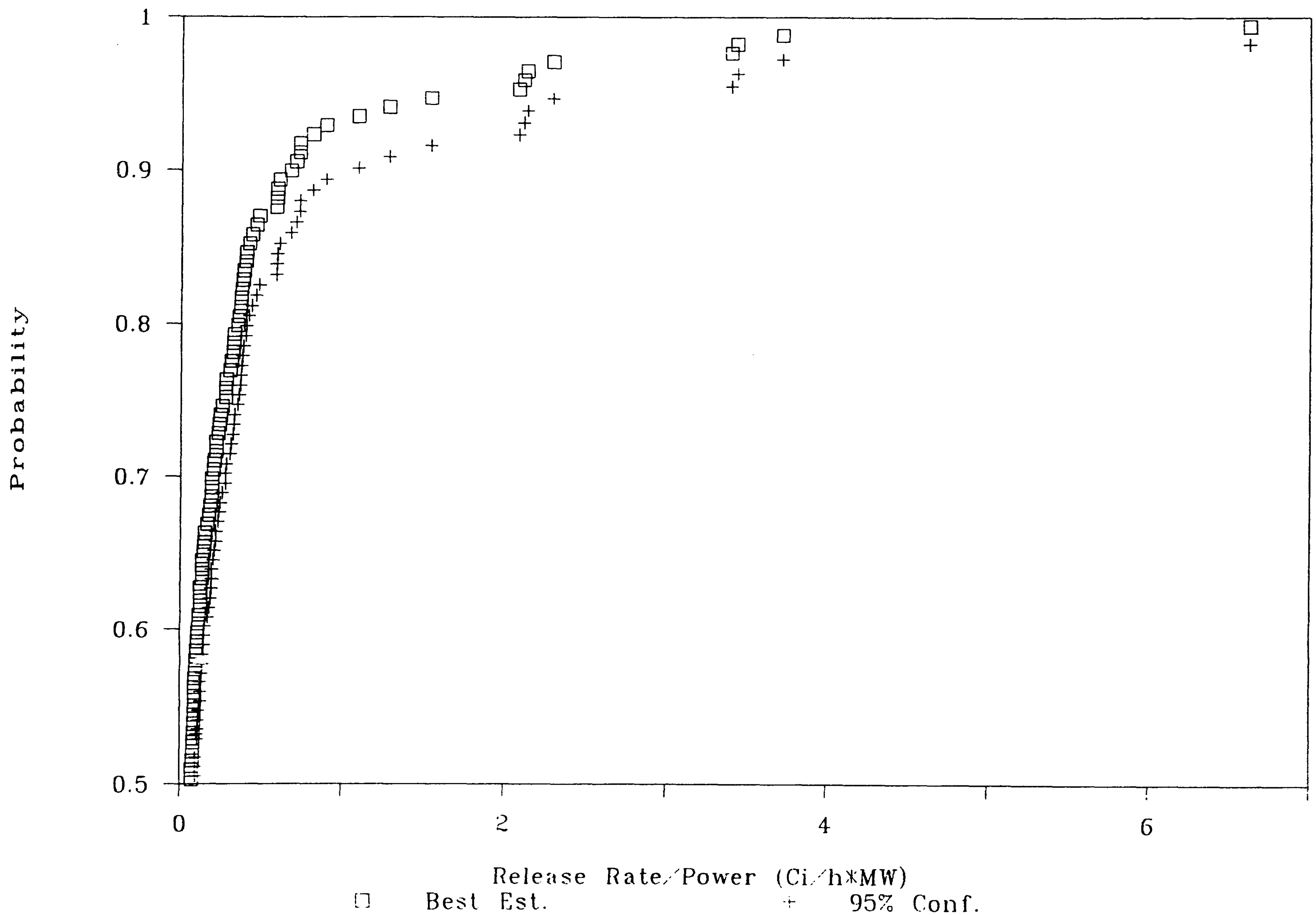


Figure 13: Cumulative probability distribution for the release rate based on the bounded iodine concentration and 2 hour assumption (expanded)

The interpretation of the table can be illustrated by examining event Number 126 (note: the event number is merely used as an indicator for the specific table - identical event numbers on different tables do not imply the same event). The (nominal) probability that an SGTR would result in a release rate less than 0.258 Ci/h*MW(e) is 75%. With 95% confidence, it is expected that an SGTR will result in a release rate less than 0.258 Ci/h*MW(e) 69% of the time. Thus, the use of the data to determine the probability of concentrations resulting from future events depends on the desired level of confidence. If nominal probability values suffice, they can be used (e.g. 90% value). If a higher degree of confidence is required, the 95% confidence probability distribution may be used.

The statistical calculations for constructing the tables are as follows. The nominal estimate of the cumulative probability at level x is the number of measured values that are less than or equal to x divided by the total number of measured values plus 1. The 95% confidence lower bound on the cumulative probability at any one point is found from Reference 8. The interpretation as a bound in the horizontal direction (i.e. on the iodine release rate) is described in Reference 9. The method results in a 95% confidence upper bound on any one percentile of interest, such as the 90th or 95th. It does not, however, give a bound on the entire curve with 95% confidence. The results are independent of any assumption regarding the shape of the probability distribution of iodine concentrations or of iodine release rates.

The 90th percentile release rate is .710 Ci/h*MW(e) which results in an absolute release rate of 710 Ci/h for a 1000 MW(e) plant. This release rate is that calculated using the bounded maximum concentration in the RCS and an assumed 2 h peak time after trip. As such, this value should be adequately conservative for this probability level. The 95% confidence bound on the 90th percentile is 1.09 Ci/h*MW(e) which results in an absolute release rate of 1090 Ci/h for a 1000 MW(e) plant. The SRP value for this rate (based on an initial RCS concentration of 1.0 $\mu$Ci/g and a 500 fold increase in release rate) is calculated in Reference 3 as

16,300 Ci/h. This appears to be overly conservative and could be reduced, per this analysis, by approximately a factor of 10 and could still provide adequate protection to the public if the 90th percentile iodine spike is an acceptable probabilistic bound. If a higher level of assurance is deemed appropriate, a higher percentile could be used.

Rather than rely on a ratio and initial concentration as currently specified, it is recommended that an absolute release rate be used, based on the plant power. This release rate is shown in Table 4 and Figures 8 - 13.

## CONCLUSIONS

An in-depth study of the radioiodine response of a PWR to a reactor trip has been presented. This is based on data from a wide variety of PWRs including all NSSS vendors and all sections of the country. The data indicate that the iodine release rate assumed in calculation of an SGTR event is overly conservative and could be reduced substantially without undue risk to the public. The formalism required by the SRP in determining the release rate is judged to be inappropriate and an absolute release rate, based on plant power, is recommended as a replacement. A value of 0.710 Ci/h*MW(e) is recommended for consideration as a replacement for the current iodine release rate specification for an SGTR with coincident iodine spike.

# REFERENCES


1. Title 10 of the Code of Federal Regulations, Part 50.

2. U.S.N.R.C. Standard Review Plan. NUREG-0800, Rev. 2, 1981.

3. J. P. Adams, Iodine Spiking Data from Commercial PWR Operations, EGG-NERD-8395, February 1989.

4. Standard Technical Specification for Westinghouse PWRs, NUREG-0452, Rev.2, 1980.

5. Standard Technical Specification for Combustion Engineering PWRs, NUREG-0212, Rev. 2, 1980.

6. Standard Technical Specification for Babcock and Wilcox PWRs, NUREG-0103, Rev. 3, 1979.

7. R. J. Lutz, Jr., Iodine Behavior Under Transient Conditions in the Pressurized Water Reactor, WCAP-8637, 1975.

8. N. L. Johnson and S. Kotz, Discrete Distributions, New York, John Wiley & Sons, 1969, Section 3.7.2, Equation 28.

9. M. Hollander and D. Wolfe, Nonparametric Statistical Methods, New York, John Wiley and Sons, 1973, p. 56.

# APPENDIX A
# DATA FOR BOUNDING IODINE CONCENTRATIONS

# APPENDIX A. DATA FOR BOUNDING IODINE CONCENTRATIONS

The data used in the bounding analysis for maximum iodine concentrations are presented here in Table A-1. There are 24 events listed, 23 extracted from Licensee Event Reports (LERs), and one, the last, obtained from examination of plant records. The events are listed in an arbitrary order, but are then assigned sequential event numbers that are referred to in the body of this report. Some LERs gave iodine concentrations measured before the trip as well as after the trip. These values are listed in Table A-1 for completeness, although they are not used anywhere in this report.

As mentioned in the body of this report, events are excluded from Table A-1 if there were no more than two measured concentrations before 14 hours, or if there were no measured concentrations before 6 hours.

TABLE A-1. Data Used for Bounding Magnitudes of Maximum Iodine Concentrations

| Event No. | Plant | Date | Time after Trip (h) | $^{131}I$ Concentration ($\mu Ci/g$) |
|---|---|---|---|---|
| 1 | Surry 1 | 850804 | | |
| | | | -18.17 | 0.061 |
| | | | 0.33 | 1.08 |
| | | | 2.67 | 1.79 |
| | | | 4.17 | 1.89 |
| | | | 4.67 | 1.83 |
| | | | 5.17 | 1.84 |
| | | | 5.67 | 1.61 |
| | | | 6.67 | 1.68 |
| | | | 8.67 | 1.46 |
| | | | 10.67 | 1.51 |
| | | | 12.67 | 1.35 |
| | | | 14.67 | 1.11 |
| | | | 15.67 | 0.922 |
| 2 | Surry 1 | 850911 | | |
| | | | -9.67 | 0.053 |
| | | | 2.5 | 1.24 |
| | | | 4.75 | 1.16 |
| | | | 6.5 | 1.43 |
| | | | 8.58 | 1.25 |
| | | | 10.58 | 1.00 |
| | | | 12.92 | 0.765 |
| 3 | Crystal R. | 770624 | | |
| | | | -4.47 | 0.206 |
| | | | 3.95 | 1.517 |
| | | | 9.37 | 1.957 |
| | | | 12.62 | 1.443 |
| | | | 16.62 | 0.864 |
| 4 | Crystal R. | 790117 | | |
| | | | 2.75 | 3.61 |
| | | | 5.75 | 4.19 |
| | | | 9.75 | 4.50 |
| | | | 13.80 | 3.79 |
| | | | 15.50 | 3.58 |
| | | | 18.50 | 2.84 |
| | | | 22.58 | 3.21 |
| | | | 26.75 | 2.52 |
| | | | 30.50 | 1.96 |
| | | | 34.50 | 1.32 |
| | | | 38.50 | 0.96 |
| | | | 42.25 | 0.69 |
| 5 | Crystal R. | 790106 | | |
| | | | -23.42 | 0.172 |
| | | | -4.42 | 0.237 |
| | | | 2.00 | 4.60 |
| | | | 4.08 | 4.40 |
| | | | 10.08 | 4.60 |
| | | | 14.08 | 4.59 |
| | | | 18.00 | 4.39 |

TABLE A-1. (Continued)

| Event No. | Plant | Date | Time after Trip (h) | $^{131}I$ Concentration ($\mu Ci/g$) |
|---|---|---|---|---|
| | | | 23.83 | 4.33 |
| | | | 27.83 | 2.64 |
| | | | 31.83 | 1.46 |
| | | | 40.00 | 1.16 |
| | | | 44.00 | 0.769 |
| | | | 48.00 | 0.331 |
| | | | 52.00 | 0.564 |
| | | | 58.33 | 0.484 |
| 6 | Crystal R. | 790130 | | |
| | | | 0.97 | 2.46 |
| | | | 4.97 | 3.69 |
| | | | 8.88 | 4.74 |
| | | | 12.80 | 3.08 |
| | | | 16.97 | 2.37 |
| | | | 20.97 | 2.10 |
| | | | 24.97 | 1.39 |
| | | | 28.97 | 1.16 |
| | | | 33.05 | 0.832 |
| | | | 37.97 | 0.650 |
| 7 | Maine Yankee | 791105 | | |
| | | | -3.18 | 0.268 |
| | | | 2.3 | 2.75 |
| | | | 6.3 | 2.34 |
| | | | 10.3 | 1.66 |
| | | | 14.3 | 1.25 |
| | | | 18.3 | 1.13 |
| | | | 22.3 | 1.02 |
| | | | 26.08 | 0.883 |
| | | | 45.5 | 0.366 |
| 8 | North Anna | 810710 | | |
| | | | 1.25 | 1.35 |
| | | | 7.20 | 1.08 |
| | | | 10.95 | 0.746 |
| 9 | North Anna | 810712 | | |
| | | | 1.20 | 1.17 |
| | | | 5.12 | 1.04 |
| | | | 9.20 | 0.678 |
| 10 | Surry 1 | 811129 | | |
| | | | 1.22 | 1.80 |
| | | | 2.22 | 2.47 |
| | | | 4.22 | 3.27 |
| | | | 8.22 | 2.01 |
| | | | 12.22 | 1.78 |
| | | | 21.63 | 1.56 |
| | | | 29.22 | 0.360 |
| 11 | St. Lucie 1 | 810908 | | |
| | | | -29.95 | 0.045 |
| | | | 4.62 | 1.193 |
| | | | 7.20 | 1.287 |
| | | | 9.87 | 1.287 |

TABLE A-1. (Continued)

| Event No. | Plant | Date | Time after Trip (h) | $^{131}I$ Concentration ($\mu Ci/g$) |
|---|---|---|---|---|
| | | | 12.87 | 1.187 |
| | | | 16.87 | 0.915 |
| | | | 84.95 | 0.10 |
| | | | 105.12 | 0.036 |
| 12 | St. Lucie 1 | 811219 | | |
| | | | -85.73 | 0.039 |
| | | | -67.23 | 0.043 |
| | | | -19.40 | 0.10 |
| | | | 3.35 | 1.09 |
| | | | 7.35 | 1.127 |
| | | | 11.35 | 0.87 |
| 13 | Surry 1 | 820413 | | |
| | | | -8.37 | 0.158 |
| | | | 1.5 | 4.59 |
| | | | 3.8 | 6.75 |
| | | | 5.8 | 5.46 |
| | | | 7.55 | 5.21 |
| | | | 9.55 | 4.54 |
| | | | 14.13 | 2.87 |
| | | | 17.80 | 2.10 |
| | | | 21.88 | 2.51 |
| | | | 28.55 | 2.24 |
| | | | 32.72 | 2.00 |
| | | | 35.05 | 1.86 |
| | | | 38.47 | 1.69 |
| | | | 45.55 | 0.965 |
| 14 | Surry 1 | 820425 | | |
| | | | -2.17 | 0.191 |
| | | | 2.50 | 4.86 |
| | | | 5.58 | 4.04 |
| | | | 8.67 | 4.14 |
| | | | 13.08 | 3.59 |
| | | | 17.67 | 2.10 |
| | | | 21.75 | 1.33 |
| | | | 25.58 | 0.89 |
| 15 | Surry 1 | 820105 | | |
| | | | -0.88 | 0.350 |
| | | | 3.12 | 5.63 |
| | | | 7.03 | 5.55 |
| | | | 11.03 | 5.09 |
| | | | 15.03 | 3.25 |
| | | | 19.03 | 2.44 |
| | | | 23.03 | 1.71 |
| | | | 27.12 | 1.31 |
| | | | 31.12 | 0.94 |
| 16 | Surry 1 | 820325 | | |
| | | | -2.50 | 0.218 |
| | | | 0.92 | 3.61 |
| | | | 1.72 | 5.50 |
| | | | 2.92 | 7.46 |

TABLE A-1. (Continued)

| Event No. | Plant | Date | Time after Trip (h) | $^{131}I$ Concentration (μCi/g) |
|---|---|---|---|---|
| | | | 4.92 | 6.88 |
| | | | 6.92 | 5.96 |
| | | | 8.92 | 5.96 |
| | | | 10.92 | 5.17 |
| | | | 12.83 | 4.11 |
| | | | 14.95 | 4.37 |
| | | | 17.17 | 3.99 |
| | | | 19.00 | 3.10 |
| | | | 22.95 | 2.02 |
| | | | 27.58 | 1.29 |
| | | | 31.17 | 0.944 |
| 17 | Crystal R. | 870702 | | |
| | | | -52.53 | 0.073 |
| | | | -4.67 | 0.065 |
| | | | 3.7 | 1.275 |
| | | | 6.95 | 0.937 |
| | | | 10.92 | 0.680 |
| | | | 19.42 | 0.398 |
| 18 | Surry 1 | 840118 | | |
| | | | -8.32 | 0.121 |
| | | | 2.85 | 1.89 |
| | | | 4.93 | 1.84 |
| | | | 6.93 | 1.60 |
| | | | 10.93 | 1.23 |
| | | | 12.93 | 0.997 |
| 19 | Surry 1 | 840206 | | |
| | | | -18.53 | 0.125 |
| | | | 2.47 | 2.15 |
| | | | 4.47 | 1.98 |
| | | | 8.47 | 1.54 |
| | | | 10.47 | 1.49 |
| | | | 12.38 | 1.15 |
| | | | 14.63 | 0.838 |
| 20 | Surry 1 | 840106 | | |
| | | | -12.82 | 0.113 |
| | | | 2.1 | 1.57 |
| | | | 4.1 | 1.32 |
| | | | 6.1 | 1.03 |
| | | | 8.1 | 0.891 |
| 21 | Point Beach | 830308 | | |
| | | | 1.7 | 0.907 |
| | | | 5.07 | 1.47 |
| | | | 5.90 | 1.41 |
| | | | 9.83 | 1.02 |
| | | | 11.07 | 0.963 |
| 22 | Surry 1 | 860108 | | |
| | | | -11.07 | 0.061 |
| | | | 3.43 | 2.26 |
| | | | 5.35 | 2.13 |
| | | | 7.52 | 1.83 |

TABLE A-1. (Continued)

| Event No. | Plant | Date | Time after Trip (h) | $^{131}I$ Concentration ($\mu Ci/g$) |
|---|---|---|---|---|
| | | | 9.35 | 1.59 |
| | | | 11.43 | 1.22 |
| | | | 13.43 | 1.05 |
| | | | 15.43 | 0.901 |
| 23 | Surry 1 | 860124 | | |
| | | | -1.17 | 0.091 |
| | | | 0.58 | 1.02 |
| | | | 2.83 | 1.04 |
| | | | 4.33 | 1.22 |
| | | | 6.42 | 0.95 |
| 24 | San Onofre 3 | 880219 | | |
| | | | 1.08 | 0.331 |
| | | | 4.08 | 0.564 |
| | | | 7.25 | 0.562 |

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