1.0 Purpose

This procedure is to be used to interpret results from analysis of post-accident sampling system reactor coolant, torus liquid, and containment atmosphere samples. Where specified limits are exceeded, the procedure provides guidance on actions to be taken.

2.0 Discussion

The first two sections of the procedure (4.1 and 4.2) provide information on reactor coolant samples. Section 4.1 concerns the I-131 concentration in the reactor coolant, and Section 4.2 explains chemistry properties of the coolant.

The next two sections (4.3 and 4.4) concern samples from the primary and secondary containment atmospheres. Section 4.3 covers radioactive material concentrations while Section 4.4 is concerned with oxygen and hydrogen concentrations.

Section 4.5 provides a method of estimating the extent of core damage based on I-131 and Cs-137 concentrations in the reactor coolant. Core damage estimates are also made based on the observed concentrations of Xe-133 and Kr-85 in the containment gas samples. Core damage estimates based on Cs-137 and Kr-85 are optional and are most likely to be of value several weeks after reactor shutdown following the decay of the shorter lived isotopes.

The activity ratios of several isotopes are also calculated to determine if the observed activity is originating from the fuel cladding gap or from the fuel matrix. Although this method of estimating core damage contains significant uncertainty, it should be considered as more reliable than the method of PASAP 7.3 and should be used to confirm the quick estimates provided by that procedure.

The final two sections (4.6 and 4.7) are used only to provide necessary intermediate results for some of the preceding sections.

3.0 References

3.1 "Procedures for the Determination of the Extent of Core Damage Under Accident Conditions," General Electric Company.

4.0 Procedures

4.1 Reactor Coolant Iodine Equivalent Concentration

4.1.1 Obtain the data sheets and the isotopic analysis printout for small volume liquid samples of reactor coolant.

4.1.2 Fill out the blanks in lines 1.1 and 1.2 of Worksheet I with the sample volume (ml) and the iodine activities (μCi) for the reactor coolant sample. The sample volumes are obtained from the liquid sample results data sheets, and the iodine activities are obtained from the isotopic analysis printouts. Note, if a certain iodine isotope activity is missing in the isotopic analysis printout, enter zero for the measured activity of that nuclide.

4.1.3 Multiply the activities by the I-131 equivalent conversion factors to obtain the I-131 equivalent activities for each iodine radionuclide, and write down the results in line 1.2 of Worksheet I.

4.1.4 Sum all I-131 equivalent activities to obtain the total I-131 dose equivalent activity for each sample. Enter the results in line 1.3 of Worksheet I.

4.1.5 Divide the total I-131 equivalent activity by the sample volume to obtain the total I-131 equivalent concentration for the reactor coolant sample. Enter the results in line 1.4 of Worksheet I. It is assumed that the reactor coolant density is 1 gm/ml.

4.1.6 If C_{Ia} or $_b$ is greater than 300 μCi/gm, (1) check the box in line 2.1; (2) check the box in line 3.1, and notify the Emergency Coordinator of the status; the class of emergency is "ALERT"; (3) shut down the reactor, and immediately close the steamline isolation valves; (4) execute the emergency plan procedure for "ALERT" state (see EPIP 1.1). Otherwise, continue to the next step.

4.1.7 If C_{Ia} or $_b$ is greater than 1.2 μCi/gm, check the box (line 2.2) for reactor coolant I-131 equivalent concentration exceeding the Technical Specification limit; (2) check the box in line 3.2, and notify the Emergency Coordinator of the status; the class of emergency is "NOTIFICATION OF UNUSUAL EVENTS". Check the plant operation conditions. If the reactor has had a power transient within 48 hours, operation may continue. However, the plant may not be operated in this state for more than 5% of its yearly power operation (check the box in line 4.0).

4.2 Reactor Coolant Chemistry Properties

4.2.1 Obtain the data sheets of liquid sample results for reactor coolant liquid samples and gaseous sample results for the dissolved gas samples from reactor coolant.

4.2.2 Record in the blanks of Worksheet II. (1) the boron content line 1.1), (2) chloride contents (line 2.1), (3) conductivity (line 3.1), (4) pH level (line 4.1), (5) dissolved hydrogen content (line 5.1), and (6) dissolved oxygen content (line 6.1) for the reactor coolant sample from the data sheets.

4.2.3 If the reactor coolant boron content is less than 600 ppm after the addition of standby liquid (line 1.1), check the condition box in line 1.2. Notify the Emergency Coordinator of the limit exceeding condition of the reactor coolant boron content.

4.2.4 As for reactor coolant chloride content, conductivity, and pH level, refer to the Technical Specification for Coolant Chemistry, Section 3.6.2B.2a, for plant operation guidelines and exceptions depending upon the reactor operating status.

4.2.5 If the dissolved hydrogen content (cc/kg) in the reactor coolant exceeds 2000 cc/kg, check the condition box in line 5.2 of the data sheet. Notify the Emergency Coordinator of the limit-exceeding condition of the dissolved hydrogen content in the reactor coolant.

4.2.6 If the dissolved oxygen content (ppm) in the reactor coolant exceeds 20 ppm check the condition box in line 6.2 of the data sheet. Notify the Emergency Coordinator of the limit-exceeding condition of the dissolved oxygen content in the reactor coolant.

4.3 Containment Atmosphere Radioactivities

Secondary Containment Xe

4.3.1 Obtain the gas sample data sheets, its gaseous sample results, and its isotopic analysis printout for the secondary containment grab sample.

4.3.2 Follow the instructions of Section 4.6 and use Worksheet VI as the data sheet to obtain the total Xe-133 equivalent concentration. Enter the result in line 1.1 of Work-sheet III.

4.3.3 Calculate the total Xe-133 equivalent activity in the secondary containment by multiplying the concentration by the total volume of the containment (line 1.2 of Worksheet III).

Secondary Containment I

4.3.4 Obtain the iodine cartridge sample data sheets, gaseous sample results, and isotopic analysis printout for the secondary containment sample.

4.3.5 Follow the instructions of Section 4.7 and use Worksheet VII as the data sheet to obtain the total I-131 equivalent concentration. Write down the result in line 1.3 of Worksheet III.

4.3.6 Calulate the total I-131 equivalent activity in the secondary containment by multiplying the concentration by the total volume of the containment (line 1.4 of the worksheet).

Drywell Atmosphere Xe

4.3.7 Obtain the gas sample data sheets, gaseous sample results, and isotopic analysis printout for the drywell atmosphere grab samples.

4.3.8 Follow the instructions of Section 4.6 and use Worksheet VI as the data sheet to obtain the total Xe-133 equivalent concentration for the sample. Enter the results in line 2.1 of Worksheet III.

4.3.9 Calculate the total Xe-133 equivalent activity in the drywell atmosphere by multiplying the concentration by the total volume of the drywell, (line 2.2 of the worksheet).

Drywell Atmosphere I

4.3.10 Obtain the iodine cartridge sample data sheets, gaseous sample results, and isotopic analysis printout for the drywell atmosphere iodine cartridge.

4.3.11 Follow the instructions of Section 4.7 and use Worksheet VII as the data sheet to obtain the total I-131 equivalent concentration for the sample. Record the results in lines 2.3 of Worksheet III.

4.3.12 Calculate the total I-131 equivalent activity in the drywell atmosphere by multiplying the concentration by the total volume of the drywell (line 2.4 of the worksheet).

Torus Atmosphere Xe

4.3.13 Obtain the gas sample data sheets, gaseous sample results, and isotopic analysis printout for the torus atmosphere grab sample.

4.3.14 Follow the instructions of Section 4.6 and use Worksheet VI as the data sheets to obtain the total Xe-133 equivalent concentration for the sample. Record the result in lines 3.1 of Worksheet III.

4.3.15 Calculate the total Xe-133 equivalent activity in the torus gas space by multiplying the concentration by the total volume of the torus gas space (line 3.2 of the worksheet).

Torus Atmosphere I

4.3.16 Obtain the iodine cartridge sample data sheets, its gaseous sample results, and isotopic analysis printout for the torus atmosphere iodine cartridge.

4.3.17 Follow the instructions of Section 4.7 and use Worksheet VII as the data sheet to obtain the total I-131 equivalent concentration for the sample. Enter the results in lines 3.3 of Worksheet III.

4.3.18 Calculate the total I-131 equivalent activity in the torus gas space by multiplying the concentration by the total volume of the torus gas space (line 3.4 of the worksheet).

Total Primary Containment Atmosphere (Drywell & Torus) Xe and I

4.3.19 Calculate the total Xe-133 activity in the primary containment atmosphere by summing the total Xe-133 activities of both the drywell (line 2.2) and torus gas space (line 3.2) (line 4.1 of the worksheet).

4.3.20 Calculate the total I-131 activity in the primary containment atmosphere by summing the total I-131 activities of both the drywell and torus gas space (line 4.2 of the worksheet).

4.3.21 Complete section 5.0 of Worksheet III to compare the total containment noble gases and iodine release potentials (total Xe-133 and I-131 equivalent activities in curies in either the primary or secondary containment) to the EPIP 1.1 release potential limits. Use the primary containment limits to classify the emergency only if the integrity of the secondary containment is lost. That is, if the secondary containment integrity is lost (obtain this information from the Emergency Coordinator), use lines 5.3 and 5.4 of the data sheet. Otherwise, use lines 5.1 and 5.2 only. Check the appropriate boxes (lines 5.1, 5.2 or 5.3, 5.4) for the limit-exceeding conditions and the class of emergency (line 6.0). Notify the Emergency Coordinator of the status, that the class of emergency is as indicated in the data sheet, Section 6.0.

4.4 Containment Atmosphere Gas Contents

4.4.1 Obtain the 10 ml gas sample results data sheets for the five gas samples. Record the values of the hydrogen and oxygen percent volumes (gas contents) in Section 1.0 of Worksheet IV.

4.4.2 Calculate the gas contents in the primary containment (drywell and torus gas space) by using the equations in Section 2.0 of the worksheet.

4.4.3 Check hydrogen content (% volume) in the secondary containment against the Technical Specification limit (Section 3.0). Check the box for the limit-exceeding condition, and perform the necessary procedure as indicated in the section.

4.4.4 Check oxygen content (% volume) in the secondary containment against that required to support life (Section 4.0). Check the box if the limit is less than 19.5% and contact the Emergency Coordinator.

4.4.5 Check hydrogen content (% volume) in the primary containment against the Technical Specification limit (Section 5.0). Check the box for the limit-exceeding condition, and perform the necessary procedure as indicated in the section.

4.4.6 Check oxygen content (% volume) in the primary containment against the Technical Specification limit (Section 6.0). Check the box for the limit-exceeding condition, and perform the necessary procedure as indicated in the section.

4.5 Estimation of Extent of Core Damage

4.5.1 Obtain the data sheets of liquid sample results and isotopic analysis printout for small volume liquid samples of (1) reactor coolant, and (2) torus liquid.

4.5.2 Complete Section 1.0 of Worksheet V with the operating plant parameters: (1) number of operating periods N_p, (2) percent rated power of steady reactor power for each operating period E_j, (3) duration of each operating period (days) T_j, and (4) time between the end of each operating period and the time of reactor shutdown (days) T_{sj}. Note that each operating period should have less than +/- 20% variation of steady power. These values can be obtained from the Technical Support Monthly Report (File A-118d or TE-5) for preceding months and from Operations Records for the current month.

4.5.3 Insert in line 2.1 of Section 2.0 of Worksheet V the sample volume and the measured I-131 and Cs-137 activities (μCi) for each of the samples from the liquid sample results worksheets and the isotopic analysis printouts.

4.5.4 Calculate the I-131 and Cs-137 concentrations (μCi/gm) of the samples by dividing the activities by the respective sample volumes (line 2.1).

4.5.5 Calculate the average I-131 and Cs-137 concentration in the primary coolant water which consists of reactor coolant water and torus liquid by completing line 2.2 of the worksheet.

4.5.6 Calculate the inventory correction factor for I-131 and Cs-137 by completing Section 3.0 of the worksheet.

4.5.7 Complete Section 4.0 to calculate the normalized I-131 and Cs-137 concentration of the operating plant primary coolant water with respect to the reference plant parameters by (1) using the inventory correction factor, (2) using coolant mass correction factor, and (3) by making decay correction to the time between the reactor shutdown and the sampling time. (If the sample was not decay corrected during analysis.)

4.5.8 Estimate the % cladding failure and % fuel meltdown by intersecting the normalize I-131 concentration with the "upper release limit," "lower release limit," and "best estimate" lines for cladding failure and fuel meltdown in Figure 7.2-1. Estimate the % cladding failure and % fuel meltdown using the normalized Cs-137 concentration and figure 7.2-3. Insert the percent cladding failure and percent fuel meltdown values for upper release limit, best estimate, and lower release limit in Section 5.0 of the data sheet. If the concentration is below the lower limits of the lines' ranges, indicate that the percent cladding failure and percent fuel meltdown are less than 0.1% and 1.0%, respectively.

4.5.9 Insert in lines 6.1 and 6.2 of Worksheet V the sample volume V_1, pressure P_1, temperature T_1, and the measured Xe-133 and Kr-85 activity (µCi) for each of the samples from the 10 ml gas sample results data sheets and the isotopic analysis printouts. Insert in line 6.1 the sample source pressure P_2, and temperature T_2. Refer to line 4.6.b. of this procedure for P_2 and T_2.

4.5.10 Make correction to the sample volume for temperature and pressure difference in the sample vial and the sample source (drywell and torus) gas phase by using the equation in line 6.1 of the data sheet.

4.5.11 Calculate the Xe-133 and Kr-85 concentrations (µCi/cc) of the samples by completing line 6.2; i.e., divide the activities by the respective temperature and pressure corrected sample volumes.

4.5.12 Calculate the average Xe-133 and Kr-85 concentration in the primary containment atmosphere, which consists of drywell and torus gas, by completing lines 6.3 of the worksheet.

4.5.13 Calculate the inventory correction factor for Xe-133 and Kr-85 using the equation and data in Section 7.0 and the data in Worksheet V.

4.5.14 Complete Section 8.0 to calculate Xe-133 and Kr-85 concentration of the operating plant primary containment atmosphere normalized with respect to the reference plant parameters by (1) using the inventory correction factor, (2) using the containment volume correction factor, and (3) by making decay correction to the time between the reactor shutdown and the sampling time, (if not decay corrected during analysis).

4.5.15 Estimate the percent cladding failure and percent fuel meltdown by intersecting the normalized Xe-133 concentration with the "upper release limit," "lower release limit," and "best estimate" lines for cladding failure and fuel meltdown in Figure 7.2-2. Estiamte the % cladding failure and the % fuel meltdown using the normalized Kr-85 concentration and Figure 7.2-4. Insert the percent cladding failure and percent fuel meltdown values for upper release limit, best estimate, and lower release limit in Section 9.0 of the data sheet. If the concentration is below the lower limits of the lines' ranges, indicate that the percent cladding failure and percent fuel meltdown are less than 0.1% and 1.0%, respectively.

4.5.16 Complete Section 10.0 to find the conservative values of percent cladding failure and percent fuel meltdown values estimated by both reactor coolant and containment atmosphere nuclide concentrations as the final extent of core damage.

4.5.17 Compare the value of percent cladding failure (line 10.1) with that from the last calculation. If its increase is greater than 0.1% cladding failure within 30 minutes, check the "NOTIFICATION OF UNUSUAL EVENTS" box in line 11. If its increase is greater than 1% within 30 minutes or there is a 5% total cladding failure, check the "ALERT" box in line 11. If the cladding failure is greater than 5% and either or both of the following conditions exist: (1) loss of primary coolant boundary; (2) high potential for loss of containment, check the "GENERAL EMERGENCY" box in line 11.

4.5.18 Notify the Emergency Coordinator of the class of Emergency, as given in line 11 of Worksheet V (Refer to EPIP 1.1 for other appropriate actions).

4.5.19 Using the liquid sample results and the isotopic analysis printout, record the Observed activities for I-131, I-133 and I-135. (From Worksheet I line 1.2)

4.5.20 Decay correct the reported activity from the time of the sample count to the time of reactor shut down. This is done using the equations given in Section 12.1 of Worksheet V. and the decay time in days from line 4.1.

4.5.21 Calculate the Iodine activity ratios for I-133 and I-135 and compare these values to those given in Figure 7.2-5.

The comparison of the calculated values with those listed in Figure 7.2-5 should indicate the activity source as predominently 1) gap activity; 2) gap and fuel activity; and 3) fuel activity.

4.5.22 Check the appropriate box and report the findings to the emergency coordinator.

4.6 Determination of Noble Gases Concentrations

4.6.1 Obtain the gaseous sample results data sheet and the isotopic analysis printout for the specified gas sample.

4.6.2 Obtain the temperature and pressure in the specified gas sample source (torus, drywell loop, or secondary containment atmosphere) at the time when the sample was taken. Enter the values in Worksheet VI.

4.6.3 Make correction to the sample volume used for isotopic analysis to account for the pressure and temperature difference in the sample vial and the sample source gas phase. Use the equation given in the Worksheet and record the corrected sample volume.

4.6.4 Enter the sample nuclide activities (μCi from the isotopic printout) in the activity column of Worksheet VI. For nuclides not found in the isotopic printout, enter zero in the appropriate entries in the activity column of the worksheet.

4.6.5 Calculate the Xe-133 equivalent concentrations by multiplying by the Xe-133 equivalent conversion factors for each noble gas nuclide (as indicated in worksheet).

4.6.6 Sum all Xe-133 equivalent concentrations of the noble gas nuclides to obtain the total Xe-133 equivalent concentration in the specified gas sample. Divide the sum by the temperature and pressure corrected sample volume (V_2) and enter the result in the worksheet.

4.7 Determination of Iodine/Particulate Concentrations

4.7.1 Obtain the iodine/particulate sampling data sheet, the gaseous sample results data sheet, and the isotopic analysis printouts for the iodine cartridge sample and the particulate filter paper sample.

4.7.2 Obtain total sample period from the iodine/particulate sampling data sheet complete while using PASAP 2.3. For timed sampling, use the indicated sample period and convert it to minutes. For untimed sampling, subtract the start time from the final stop time to obtain the sample period and then convert it to minutes. Enter the sample period in minutes in Worksheet VII.

4.7.3 Calculate the sample volume, V_1 (amount of gas), flowing through the filter paper and the cartridge using the equation in the worksheet. The sample flow in scfm is taken from the iodine/particulate sampling data sheet, Item FI-8746. Note that the sample volume so calculated is under standard atmospheric condition (i.e., 530 R, 14.7 psia).

4.7.4 Obtain the temperature and pressure in the specified gas sample source (drywell, torus (RHR) gas space, or secondary atmosphere containment) at the time when the samples were taken. Enter the values in the worksheet.

4.7.5 Correct the sample volume for the pressure and temperature difference in the standard condition and in the specified sample source gas phase by using the equation for V_2 in the worksheet.

4.7.6 Enter the nuclide activities (Ci) from the isotopic printout in the appropriate blanks of the worksheet. For those iodine nuclides which are not found in the isotopic printout, enter zero in the corresponding blanks of the nuclide activity column of the worksheet.

4.7.7 Calculate the I-131 equivalent concentrations by multiplying by the I-131 equivalent conversion factors for each iodine radionuclide (as indicated in the worksheet). The I-131 equivalent conversion factors are based on the thyroid dose commitment factors for iodine nuclides from the inhalation pathway for a one-year old child.

4.7.8 Sum all I-131 equivalent concentrations of the iodine nuclides to obtain the total I-131 equivalent concentration for the specified iodine cartridge sample. Divide the sum by the volume (V_2) and enter the result in the worksheet.

5.0 Terminology

$C_{Ia \text{ or } b}$ = Total I-131 equivalent activity concentration in jet pump A or B sample (uCi/gm).

B = Boron content in reactor coolant (ppm).

Cl = Chloride content in reactor coolant (ppm).

D = Conductivity in reactor coolant (umho/cm).

pH = pH level in reactor coolant.

H_z = Dissolved hydrogen content in reactor coolant (cc/Kg).

O_2 = Dissolved oxygen content in reactor coolant (ppm).

$C_{Xe,s}$ = Total Xe-133 equivalent concentration in secondary containment atmosphere (uCi/cc).

$A_{Xe,s}$ = Total Xe-133 equivalent activity in secondary containment atmosphere (Ci).

$C_{I,s}$ = Total I-131 equivalent concentration in secondary containment atmosphere (uCi/cc).

$A_{I,s}$ = Total I-131 equivalent activity in secondary containment atmosphere (Ci).

$C_{Xe,d}$ = Total Xe-133 equivalent concentration in drywell loop A or B atmosphere (uCi/cc).

$A_{Xe,d}$ = Total Xe-133 equivalent activity in drywell atmosphere (Ci).

$C_{I,d}$ = Total I-131 equivalent concentration in drywell loop A or B atmosphere (uCi/cc).

$A_{I,d}$ = Total I-131 equivalent activity in drywell atmosphere (Ci).

$C_{Xe,t}$ = Total Xe-133 equivalent concentration in torus (RHR) loop A or B atmosphere (uCi/cc).

$A_{Xe,t}$ = Total Xe-133 equivalent activity in torus atmosphere (Ci).

$C_{I,t}$ = Total I-131 equivalent concentration in torus (RHR) loop A or B atmosphere (uCi/cc).

$A_{I,t}$ = Total I-131 equivalent activity in torus atmosphere (Ci).

$A_{Xe,p}$ = Total Xe-133 equivalent activity in primary containment atmosphere (Ci).

$A_{I,p}$ = Total I-131 equivalent activity in primary containment atmosphere (Ci).

$A_{Xe,c}$ = Containment noble gas release potential (Xe-133 equivalent) in curies.

$A_{I,c}$ = Containment iodine release potential (I-131 equivalent) in curies.

$V_{h,s}$ = Hydrogen content in secondary containment atmosphere (% volume).

$V_{o,s}$ = Oxygen content in secondary containment atmosphere (% volume).

$V_{h,d}$ = Hydrogen content in drywell atmosphere (% volume).

$V_{o,d}$ = Oxygen content in drywell atmosphere (% volume).

$V_{h,t}$ = Hydrogen content in torus (RHR) atmosphere (% volume).

$V_{o,t}$ = Oxygen content in torus (RHR) atmosphere (% volume).

$V_{h,p}$ = Hydrogen content in primary containment atmosphere (% volume).

$V_{o,p}$ = Oxygen content in primary containment atmosphere (% volume).

E_j = % steady reactor power (% rated power) in operating period j.

T_j = Duration of operating period j (days).

T_s = Time between the end of operating period and time of reactor shutdown (days).

T_d = Time between reactor shutdown and sampling time (days).

$C_{I,r}$ = I-131 concentration in reactor coolant (uCi/gm).

$C_{I,s}$ = I-131 concentration in suppression pool water (uCi/gm).

C_{Iw} = Average I-131 concentration in primary coolant (uCi/gm).

FI_I = Inventory correction factor for I-131.

F_w - Coolant mass correction factor.

C_{Iw} = Normalized I-131 concentration in primary coolant (uCi/gm).

$C_{cs,r}$ = Cs-137 concentration in reactor coolant (uCi/gm).

$C_{cs,s}$ = Cs-137 concentration in suppression pool water (uCi/gm).

$C_{cs,w}$ = Average Cs-137 concentration in primary coolant (uCi/gm).

FI_{cs} = Inventory correction factor for Cs-137.

$C_{cs,w}$ = Normalized Cs-137 concentration in primary coolant (uCi/gm).

$C_{Xe,d}$ = Xe-133 concentration in drywell (uCi/cc).

$C_{Xe,t}$ = Xe-133 concentration in torus gas space (uCi/cc).

C_{Xeg} = Average Xe-133 concentration in primary containment (uCi/cc).

FI_{Xe} = Inventory correction factor for Xe-133.

F_g = Containment volume correction factor.

C_{Xeg}' = Normalized Xe-133 concentration in primary containment atmosphere.

$C_{Kr,d}$ = Kr-85 concentration in drywell atmosphere (uCi/cc).

$C_{Kr,t}$ = Kr-85 concentration in torus atmosphere (uCi/cc).

$C_{Kr,g}$ = Average Kr-85 concentration in primary containment atmosphere (uCi/cc).

FI_{Kr} = Inventory correction factor for Kr-85.

$C_{Kr,g}$ = Normalized Kr-85 concentration in the primary containment atmosphere (uCi/cc).

Worksheet I

Reactor Coolant I-131 Equivalent Calculations

Worksheet Record ID: ______________________ Date: ______________

Worksheet Prepared By: ______________________ Date: ______________

1.0 Reactor Coolant Sample (from Jet Pump or RHR Shutdown Cooling Mode) (Circle One)

1.1 Sample Volume: V = ______________ ml.

1.2 I-131 Equivalent Activities: (based on inhalation path way for a one year old child)

Iodine Nuclide	Measured Activity (uCi)		Conversion Factor		I-131 Equivalent Activities (uCi)
I-129	____________	X	0.975	=	____________
I-130	____________	X	0.114	=	____________
I-131	____________	X	1.0	=	____________
I-132	____________	X	1.19E-2	=	____________
I-133	____________	X	0.237	=	____________
I-134	____________	X	3.12E-3	=	____________
I-135	____________	X	4.88E-2	=	____________

1.3 Sum of I-131 Equivalent Activities: A_I = ______________ uCi.

1.4 Total I-131 Equivalent Activity Concentration:

$C_I = A_I/V$ = ____________ uCi/gm.

2.0 Emergency Plan Limits Check (refer to EPIP1.1):

2.1 Yes ☐ - C_I is greater than 300 uCi/gm.

2.2 Yes ☐ - C_I is greater than 1.2 uCi/gm. (the reactor coolant Tech. Spec. limit)

3.0 Class of Emergency to Declare:

3.1 ☐ - "ALERT". (Check if line 2.1 is checked).

3.2 ☐ - "NOTIFICATION OF UNUSUAL EVENTS". (Check if line 2.2 is checked).

4.0 ☐ - Limited Plant Operation (not more than 5% of the yearly power operation).

Worksheet II

Reactor Coolant Chemistry Properties

Worksheet Record ID: ______________________ Date: ________________

Worksheet Prepared By: ____________________ Time: ________________

Reactor Coolant Sample: Jet Pump or RHR Shutdown Cooling Sample (Circle One)

1.0 Boron Content:

1.1 Boron content in reactor coolant sample: B = ______ ppm.

1.2 Yes ☐ - B is less than 600 ppm (Tech. Spec. Limit after the addition of Standby liquid).

2.0 Chloride Content:

2.1 Chloride content in reactor coolant sample:

Cl = ________ ppm.

2.2 Yes ☐ - Cl is greater than 0.1 ppm (Tech. Spec. Limit).

3.0 Conductivity:

3.1 Conductivity in reactor coolant sample:

D = _______ umho/cm.

3.2 Yes ☐ - D is greater than 5 umho/cm (Tech. Spec. Limit).

4.0 pH level:

4.1 pH level in reactor coolant sample: pH = ______________

4.2 Yes ☐ - pH is out of range of 5.6 to 8.6 (Tech. Spec. Limit).

5.0 Dissolved Hydrogen Content:

5.1 Dissolved hydrogen content in reactor coolant sample:

H_2 = _______ cc/kg.

5.2 Yes ☐ - H_2 is greater than 2000 cc/kg. (Tech. Spec. Limit).

6.0 Dissolved Oxygen Content:

6.1 Dissolved oxygen content in reactor coolant sample:

O_2 = __________ ppm.

6.2 Yes ☐ - O_2 is greater than 20 ppm (Tech. Spec. Limit).

Worksheet III

Containment Atmosphere Radioactivities Calculations

Worksheet Record ID: ____________________ Date: __________

Worksheet Prepared By: ____________________ Date: __________

1.0 Secondary Containment Atmosphere Noble Gases and Iodines Activities:

1.1 Total Xe-133 equivalent concentration:

$C_{Xe,s}$ = __________ uCi/cc.

1.2 Total Xe-133 equivalent activity:

$A_{Xe,s} = C_{Xe,s} \times 3.1E3$ = __________ Curies.

1.3 Total I-131 equivalent concentration:

$C_{I,s}$ = __________ uCi/cc.

1.4 Total I-131 equivalent activity:

$A_{I,s} = C_{I,s} \times 3.1E3$ = __________ Curies.

2.0 Drywell Atmosphere Noble Gases and Iodines Activities: Loop A or B (circle one)

2.1 Total Xe-133 equivalent concentration in drywell:

$C_{Xe,d}$ = __________ uCi/cc.

2.2 Total Xe-133 equivalent activity in drywell:

$A_{Xe,d} = (C_{Xe,d}) \times 2.9E3$ = __________ Curies.

2.3 Total I-131 equivalent concentration in drywell:

$C_{I,d}$ = __________ uCi/cc.

2.4 Total I-131 equivalent activity in drywell:

$A_{I,d} = (C_{I,d}) \times 2.9E3$ = __________ Curies.

3.0 Torus Atmosphere Noble Gases and Iodines Activities: Loop A or B (circle one)

3.1 Total Xe-133 equivalent concentration in torus:

$C_{Xe,t}$ = ____________ uCi/cc.

3.2 Total Xe-133 equivalent activity in torus:

$A_{Xe,t} = (C_{Xe,t}) \times 2.6E3$ = ____________ Curies.

3.3 Total I-131 equivalent concentration in torus:

$C_{I,t}$ = ____________ uCi/cc.

3.4 Total I-131 equivalent activity in torus:

$A_{I,t} = (C_{I,t}) \times 2.6E3$ = ____________ Curies.

4.0 Total Primary Containment Atmosphere (Drywell and Torus) Noble Gas and Iodine Activities:

4.1 Total Xe-133 equivalent activity in primary containment.

$A_{Xe,p} = A_{Xe,d}$ (line 2.2) + $A_{Xe,t}$ (line 3.2)

= ____________________ Curies.

4.2 Total I-131 equivalent activity in primary containment:

$A_{I,p} = A_{I,d}$ (line 2.4) + $A_{I,t}$ (line 3.4)

= ____________________ Curies.

5.0 Release Potential Limits Check and Class of Emergency Assessment (refer to NUREG 0654, Rev. 0):

5.1 Yes ☐ - Either $A_{Xe,s}$ (line 1.2) is greater than 1.0E6 Ci or $A_{I,s}$ (line 1.4) is greater than 1000 Ci.

If yes, check "GENERAL EMERGENCY" box in line 6.1.

5.2 Yes ☐ - Either $A_{Xe,s}$ (line 1.2) is greater than 1.0E4 Ci or $A_{I,s}$ (line 1.4) is greater than 10 Ci.

If yes, check "SITE EMERGENCY" box in line 6.2.

* Note: lines 5.3 and 5.4 are used only if the integrity of secondary containment is lost. If the integrity of secondary containment has not been lost, go to 6.0.

5.3 Yes ☐ - Either $A_{Xe,p}$ (line 4.1) is greater than 1.0E6 Ci or $A_{I,p}$ (line 4.2) is greater than 1000 Ci.

If Yes, check "GENERAL EMERGENCY" box in line 6.1.

5.4 Yes ☐ - Either $A_{Xe,p}$ (line 4.1) is greater than 1.0E4 Ci or $A_{I,p}$ (line 4.2) is greater than 10 Ci.

If Yes, check "SITE EMERGENCY" box in line 6.2.

6.0 Class of Emergency to Declare:

6.1 ☐ - "GENERAL EMERGENCY"

6.2 ☐ - "SITE EMERGENCY"

Worksheet IV

Containment Atmosphere Gas Contents

Worksheet Record ID: ______________________ Date: ______________

Worksheet Prepared By: ______________________ Time: ______________

1.0 Measured Gas Contents:

1.1 Hydrogen content in secondary containment:

$V_{h,s}$ = ______________% volume.

1.2 Oxygen content in secondary containment:

$V_{o,s}$ = ______________% volume.

1.3 Hydrogen content in drywell atmosphere, loops A or B (circle one):

$V_{h,d}$ = ______________% volume.

1.4 Oxygen content in drywell atmosphere, loops A or B (circle one):

$V_{o,d}$ = ______________% volume.

1.5 Hydrogen content in torus atmosphere loops A or B (circle one):

$V_{h,t}$ = ______________% volume.

1.6 Oxygen content in torus atmosphere loops A or B:

$V_{o,t}$ = ______________% volume.

2.0 Average Gas Content in the Primary Containment Atmosphere:

2.1 Average hydrogen content in the primary containment atmosphere:

$$V_{h,p} = 0.5 \times (V_{h,d} + V_{h,t})$$

= ______________________ % volume.

2.2 Average oxygen content in the primary containment atmosphere:

$$V_{o,p} = 0.5 \times (V_{o,d} + V_{o,t})$$

= ______________________ % volume.

3.0 Secondary Containment Atmosphere Hydrogen Content Limit Check and Status of Secondary Containment Integrity:

Yes ☐ - $V_{h,s}$ (line 1.1) is greater than 4 % volume.

If yes, notify the Emergency Coordinator that there has been a detection of potential for secondary containment breach and/or explosion due to high hydrogen content.

4.0 Secondary Containment Atmosphere Oxygen content Limit Check and Status of Secondary Containment Integrity:

Yes ☐ - $V_{o,s}$ (line 1.2) is less than 19.5% volume.

If Yes, notify the Emergency Coordinator that the oxygen level in secondary containment may not be sufficient to support life.

5.0 Primary Containment Atmosphere Hydrogen Content Limit Check and Status of Primary Containment Integrity:

Yes ☐ - $V_{h,p}$ (line 2.1) is greater than 4% volume.

If Yes, notify the emergency Coordinator that there has been a detection of potential for primary containment breach and/or explosion due to high hydrogen content. Refer to Operation Instruction (OI 73/74) Containment Atmosphere Control and Dilution System for hydrogen control in the primary containment.

6.0 Primary Containment Atmosphere Oxygen Content Limit Check and Status of Primary Containment Integrity:

Yes ☐ - $V_{o,p}$ (line 2.2) is greater than 4.0% volume.

If Yes, notify the Emergency Coordinator that there has been a detection of potential for primary containment breach and/or explosion due to high oxygen content. Refer to Operating Instruction (OI 73/74) Containment Atmosphere Control and Dilution System for oxygen control in the primary containment.

Worksheet V

Estimation of Extent of the Core Damage

Worksheet Record ID: ______________ Date: ______________

Worksheet Prepared By: ______________ Date: ______________

1.0 Operating Plant Parameters:

1.1 Number of operating periods: N_p = ______________.

Period j	Reactor Power E_j (% rated power) (<20% variation)	Operating Period T_j (days)	Decay Time T_{sj} (days)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

NOTE: Obtain these values from the Technical Support Monthly Report (File A-118d or TE-5) for the preceding months and from Operations Records for the current month.

2.0 Liquid Samples: (Cs-137 calculations are optional)

2.1 Liquid concentrations:

Sample Source	Measured I-131 Activity (uCi)		Sample Volume (ml)		I-131 Concentration (uCi/gm)
Reactor Coolant Sample: Jet Pumps or RHR Shutdown Cooling (circle one)	________	÷	________	=	________ $(C_{I,r})$
Torus Liquid Sample: RHR Suppression Pool Cooling: (circle one)	________	÷	________	=	________ $(C_{I,s})$

Sample Source	Measured Cs-137 Activity (uCi)		Sample Volume (ml)		Cs-137 Concentration (uCi/gm)
Reactor Coolant Sample:					
Jet Pump or RHR Shutdown Cooling (circle one)	________	÷	________	=	________ $(C_{cs,r})$
Torus Liquid Sample: RHR Suppression Pool Cooling: (circle one)	________	÷	________	=	________ $(C_{cs,s})$

2.2 Average concentration in primary coolant (reactor water + suppression pool water):

$$C_{Iw} = (C_{I,r} \times 7.99E-2) + (C_{I,s} \times 9.20E-1) = \_\_\_\_\_\_ \text{ uCi/gm.}$$

$$C_{cs,w} = (C_{cs,r} \times 7.99E-2) + (C_{cs,s} \times 9.20E-1) = \_\_\_\_\_\_ \text{ uCi/gm.}$$

3.0 Inventory Correction Factor for coolant sample:

I-131 Factor:

$$FI_I = \frac{224.67}{\sum_{j=1}^{N_p} E_j \times (1.0-\exp(-8.62E-2 \times T_j)) \times \exp(-8.62E-2 \times T_{sj})}$$

$$= \_\_\_\_\_\_\_\_.$$

Cs=137 Factor:

$$FI_{cs} = \frac{14.96}{\sum_{j=1}^{N_p} E_j \times (1.0-\exp(-6.29E-5 \times T_j)) \times \exp(-6.29E-5 \times T_{sj})}$$

= ________________.

where E_j, T_j, and T_{sj} for j=1 to N_p are from the table of Section 1.1.

4.0 Normalized Concentration in Primary Coolant:

4.1 Time between reactor shutdown and sampling time:

T_d = ________ _______ days,

4.2 Coolant mass correction factor: F_w = 0.463,

4.3 Normalized I-131 Concentration in Primary Coolant:

C_{Iw}' = C_{Iw} (line 2.2) x exp(8.62E-2 x T_d(line 4.1))

x FI_I (line 3.0) x 0.463

= ________________ uCi/gm.

Normalized Cs-137 Concentration in primary coolant:

$C_{cs,w}$ = $C_{cs,w}$ (line 2.2) x exp.(6.29E-5xTd(line 4.1))

x FI_{cs} (line 3.0) x 0.463

= ________________ uCi/gm.

5.0 Extent of Core Damage estimated from Primary coolant I-131 Concentration (use normalized concentration from line 4.3 and Figure 7.2-1):

5.1 % Cladding Failure = ________________ % (Best Estimate),

5.2 % Fuel Meltdown = ________________ % (Best Estimate),

5.3 % Cladding Failure = ________________ % (Upper Release Limit),

5.4 % Fuel Meltdown = ________________ % (Upper Release Limit),

5.5 % Cladding Failure = ________________ % (Lower Release Limit),

5.6 % Fuel Meltdown = ________________ % (Lower Release Limit),

Extent of Core Damage estimated from primary coolant Cs-137 concentration (Use normalized concentration from line 4.3 and figure 7.2-3).

(Optional):

5.7 % Cladding Failure = ________________ % (Best Estimate),

5.8 % Fuel Meltdown = ________________ % (Best Estimate),

5.9 % Cladding Failure = ________________ % (Upper Release Limit),

5.10 % Fuel Meltdown = ________________ % (Upper Release Limit),

5.11 % Cladding Failure = ________________ % (Lower Release Limit),

5.12 % Fuel Meltdown = ________________ % (Lower Release Limit),

6.0 Gas Samples:

6.1 Temperature and pressure corrected sample volumes V2:

Use the equation: $$V_2 = V_1 \times \frac{P_1 \times (T_2 + 460)}{P_2 \times (T_1 + 460)}$$, and

where V_1 = sample volume (cc),

P_1 = sample pressure (psia),

T_1 = sample temperature (F),

P_2 = pressure in the sample source (psia),

T_2 = temperature in the sample source (F),

V_2 = temperature and pressure corrected sample volume (cc).

Sample	V_1	P_1	T_1	P_2	T_2	V_2
Drywell Atmosphere	______	______	______	______	______	______
Torus Atmosphere	______	______	______	______	______	______

6.2 Gas Concentrations:

Sample Source	Measured Xe-133 Activity (uCi)		Corr. Sample Vol. V_2(cc)		Xe-133 Concentration (uCi/cc)
Drywell Atmosphere	______	÷	______	=	______ $(C_{Xe,d})$
Torus Atmosphere	______	÷	______	=	______ $(C_{Xe,t})$

Sample Source	Measured Kr-85 Activity (uCi)		Corr. Sample Vol. V_2(cc)		Kr-85 Concentration (uCi/cc)
Drywell Atmosphere	______	÷	______	=	______ $(C_{Kr,d})$
Torus Atmosphere	______	÷	______	=	______ $(C_{Kr,t})$

6.3 Average Gas concentration in primary containment atmosphere (drywell + torus gas space):

$C_{Xeg} = (C_{Xe,d} + C_{Xe,t}) \times 0.5$

= ____________________ uCi/cc of Xe-133.

$C_{kr,g} = (C_{Kr,d} + C_{Kr,t}) \times 0.5$

= ____________________ uCi/cc of Kr-85.

7.0 Gas Inventory Correction Factors

Xe-133 Factor

$$FI_{Xe} = \frac{224.67}{\sum_{j=1}^{N_p} E_j \, x(1.0- \exp(-0.132x\ T_j))x\ \exp(-0.132 \times T_{sj})}$$

= ________________.

Kr-85 Factor

$$FI_{Kr} = \frac{39.61}{\sum_{j=1}^{N_p} E_j \times (1.0 - \exp(-(1.77E-4) \times T_j)) \times \exp(-(1.77E-4) \times T_{sj})}$$

= ________________.

where E_j, T_j, and T_{sj} for j = 1 to N_p are from the table of Section 1.1.

8.0 Normalized Gas Concentration in Primary containment atmosphere:

8.1 Time between reactor shutdown and sampling time:

T_d = ________________ days,

8.2 Containment volume correction factor: F_g = 0.133,

8.3 Normalized Xe-133 Concentration in Primary Containment atmosphere:

C_{Xeg}' = C_{Xeg} (line 6.3) x exp (0.132 x T_d(line 8.1))

x FI_{Xe} (line 7.0) x 0.133

= ________________ uCi/cc,

Normalized Kr-85 concentration in the primary containment atmosphere:

$C_{Kr,g}'$ = $C_{Kr,g}$(line 6.3) x exp(1.77E-4)xTd(line 8.1))

x FI_{Kr} (line 7.0) x 0.133

= ________________ uCi/cc.

9.0 Extent of Core Damage Estimated from Containment Atmosphere Xe-133 Concentration (use normalized concentration from line 8.3 and Figure 7.2-2):

9.1 % Cladding Failure = ________________% (Best Estimate),

9.2 % Fuel Meltdown = ________________% (Best Estimate),

9.3 % Cladding Failure = ________________% (Upper Release Limit),

9.4 % Fuel Meltdown = ________________ % (Upper Release Limit),

9.5 % Cladding Failure = ________________ % (Lower Release Limit),

9.6 % Fuel Meltdown = ________________% (Lower Release Limit),

Extent of Core Damage estimated from containment atmosphere Kr-85 concentration (use normalized concentration from line 8.3 and figure 7.2-4)(optional):

9.7 % Cladding Failure = ________________% (Best Estimate),

9.8 % Fuel Meltdown = ________________% (Best Estimate),

9.9 % Cladding Failure = ________________% (Upper Release Limit),

9.10 % Fuel Meltdown = ________________ % (Upper Release Limit),

9.11 % Cladding Failure = ________________ % (Lower Release Limit),

9.12 % Fuel Meltdown = ________________% (Lower Release Limit),

10.0 Conservative Extent of Core Damage (take larger values from Section 5.0 and 9.0):

10.1 Final % Cladding Failure = ________________ % (Best Estimate),

10.2 Final % Fuel Meltdown = ________________ % (Best Estimate),

10.3 Final % Cladding Failure = ________________ % (Upper Release Limit),

10.4 Final % Fuel Meltdown - ________________ % (Upper Release Limit),

10.5 Final % Cladding Failure = ________________% (Lower Release Limit),

10.6 Final % Fuel Meltdown = ________________% (Lower Release Limit),

11.0 Class of Emergency to Declare:

☐ - "NOTIFICATION OF UNUSUAL EVENTS"

☐ - "ALERT"

☐ - "GENERAL EMERGENCY".

12.0 Activity ratio Determination

12.1 Decay correction

(Note: Decay time is from count time to reactor shutdown in days.)

Observed Activity x exp. (.693/(T 1/2) x Decay Time) = Corrected Activity (uCi)

(I-131) __________ x exp. (0.0862 x _______) = ________________ (uCi)

(I-133) __________ x exp. (0.7998 x _______) = ________________ (uCi)

(I-135) __________ X exp. (2.517 x _______) = ________________ (uCi)

12.2 Activity Ratios

I-133 to I-131 ratio = ________________________

I-135 to I-131 ratio = ________________________

12.3 The predominate source of the observed activity as indicated by comparison of the activity ratios to Figure 7.2-5 is (check one):

☐ Fuel Gap

☐ Fuel Gap and Core Inventory

☐ Core Inventory

Worksheet VI

Noble Gas Concentrations Calculations

Worksheet Record ID: ______________________________ Date: ________________

Worksheet Prepared By: ____________________________ Time: ________________

<u>Gas Sample Source:</u> Sample Location ______________________________

Sample Volume (from gaseous sample results data sheet):

V_1 = ______________ cc.

Final Sample Pressure: P_1 = ____________ psia.

Sample Temperature: T_1 = ______________ F.

Sample Source Pressure: P_2 = ______________ psia.

Sample Source Temperature: T_2 = ______________ F

Temperature and Pressure Corrected Sample Volume:

$$V_2 = V_1 \times \frac{P_1 \times (T_2 + 460)}{P_2 \times (T_1 + 460)} = \_\_\_\_\_\_\_\_\_\_\_\_ \text{ cc.}$$

TITLE: INTERPRETATION OF POST ACCIDENT SAMPLING SYSTEM RESULTS

Noble Gas Nuclide	Nuclide Activity (uCi)		Xe-133 Conv. Factor		Xe-133 Equiv. Concen. (uCi)
Kr-83m	______	x	2.57E-4	=	______
Kr-85m	______	x	3.98	=	______
Kr-85	______	x	5.48E-2	=	______
Kr-87	______	x	20.1	=	______
Kr-88	______	x	50.0	=	______
Kr-89	______	x	56.5	=	______
Kr-90	______	x	53.1	=	______
Xe-131m	______	x	0.311	=	______
Xe-133m	______	x	0.854	=	______
Xe-133	______	x	1.0	=	______
Xe-135m	______	x	10.6	=	______
Xe-135	______	x	6.16	=	______
Xe-137	______	x	4.83	=	______
Xe-138	______	x	30.0	=	______
Ar-41	______	x	30.1	=	______

Sum: ______

Total Xe-133 Equivalent Concentration C_{Xe} = _____ sum ÷ _____ V_2 = _____uCi/cc.

Worksheet VII

Iodine Concentrations Calculations

Worksheet Record ID: ______________________ Date: __________

Worksheet Prepared By: ______________________ Date: __________

Iodine/Particulate Sample Source:

Total Sample Period: T_s = ______________ minutes.

Sample Flow (from FI-8746 of iodine/particulate sample data sheet):

F_s = __________ scfm.

Sample Volume: $V_1 = F_s \times T_s$ = __________ cu. ft.

Sample Source Pressure: P_2 = ____________ psia.

Sample Source temperature: T_2 = ___________ F.

Temperature and pressure Corrected Sample Volume:

$$V_2 = V_1 \times \frac{T_2 + 460}{P_2} \times 785.39 = \_\_\_\_\_\_\_\_\_\_ \text{cc.}$$

Iodine Nuclide	Nuclide Activ. (uCi)		I-131 Conv. Factor		I-131 Equiv. Concen. (uCi)
I-129	________	x	0.975	=	________
I-130	________	x	0.114	=	________
I-131	________	x	1.0	=	________
I-132	________	x	1.19E-2	=	________
I-133	________	x	0.237	=	________
I-134	________	x	3.12E-3	=	________
I-135	________	x	4.88E-2	=	________
				Sum:	________

Total I-131 Equivalent Concentration: C_I = _____ sum ÷ _____ V_2 = _______ uCi/cc.

APPROVED BY: Greg Taylor DATE: 5-14-84
Chemistry Coordinator

APPROVED BY: [signature] DATE: 5-15-84
Radiation Protection Supervisor

REVIEWED BY: [signature] DATE: 5-15-84
ALARA Coordinator

REVIEWED BY: [signature] DATE: 5/22/84
Chairman, Operations Committee

APPROVED BY: [signature] DATE: 5-24-84
Plant Superintendent-Nuclear

Figure 7.2-1 Relationship between I-131 Concentration in the Primary Coolant (Reactor Water + Pool Water) and the Extent of Core Damage in Reference Plant

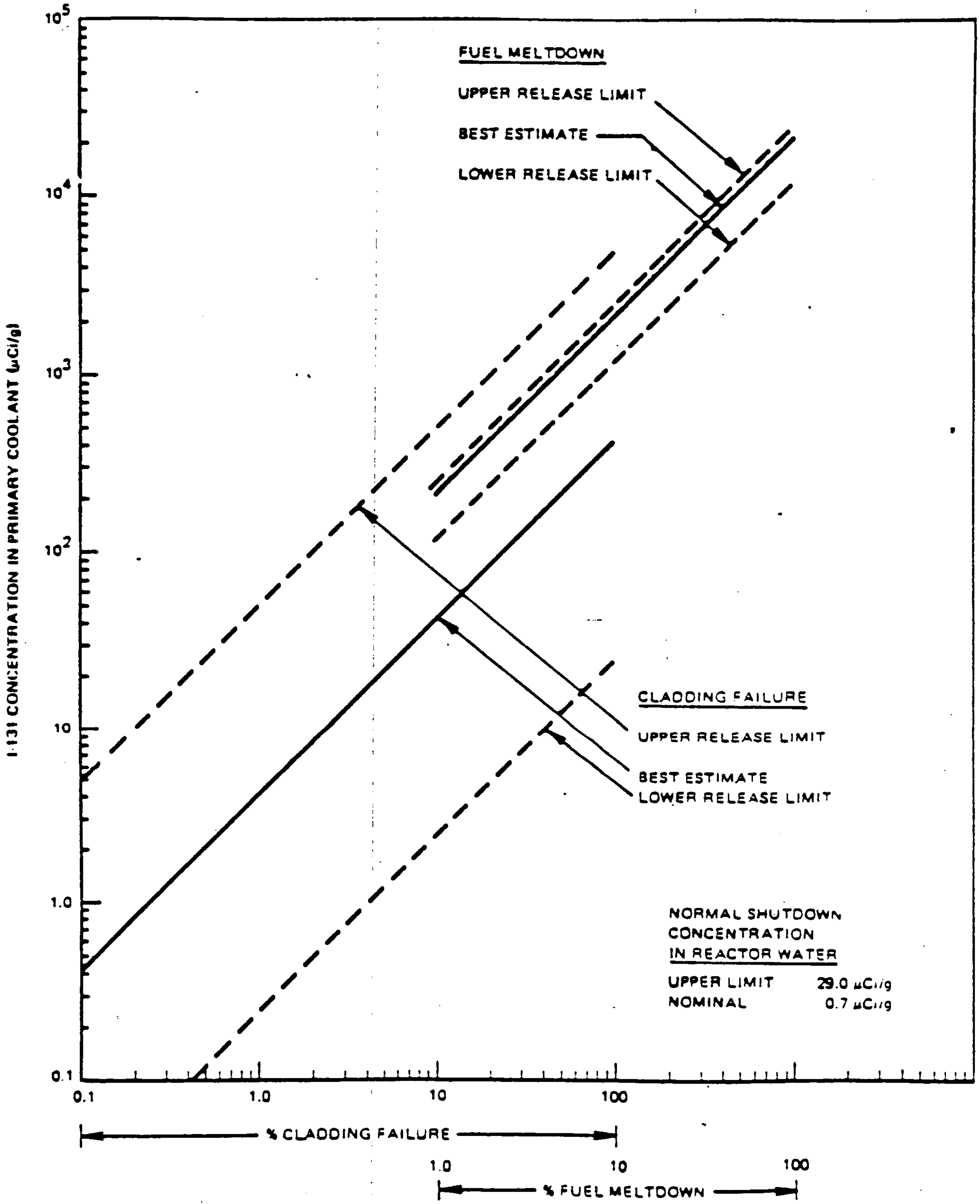

Figure 7.2-2 Relationship between Xe-133 Concentration in the Containment Gas (Drywell + Torus Gas) and the Extent of core damage in Reference Plant

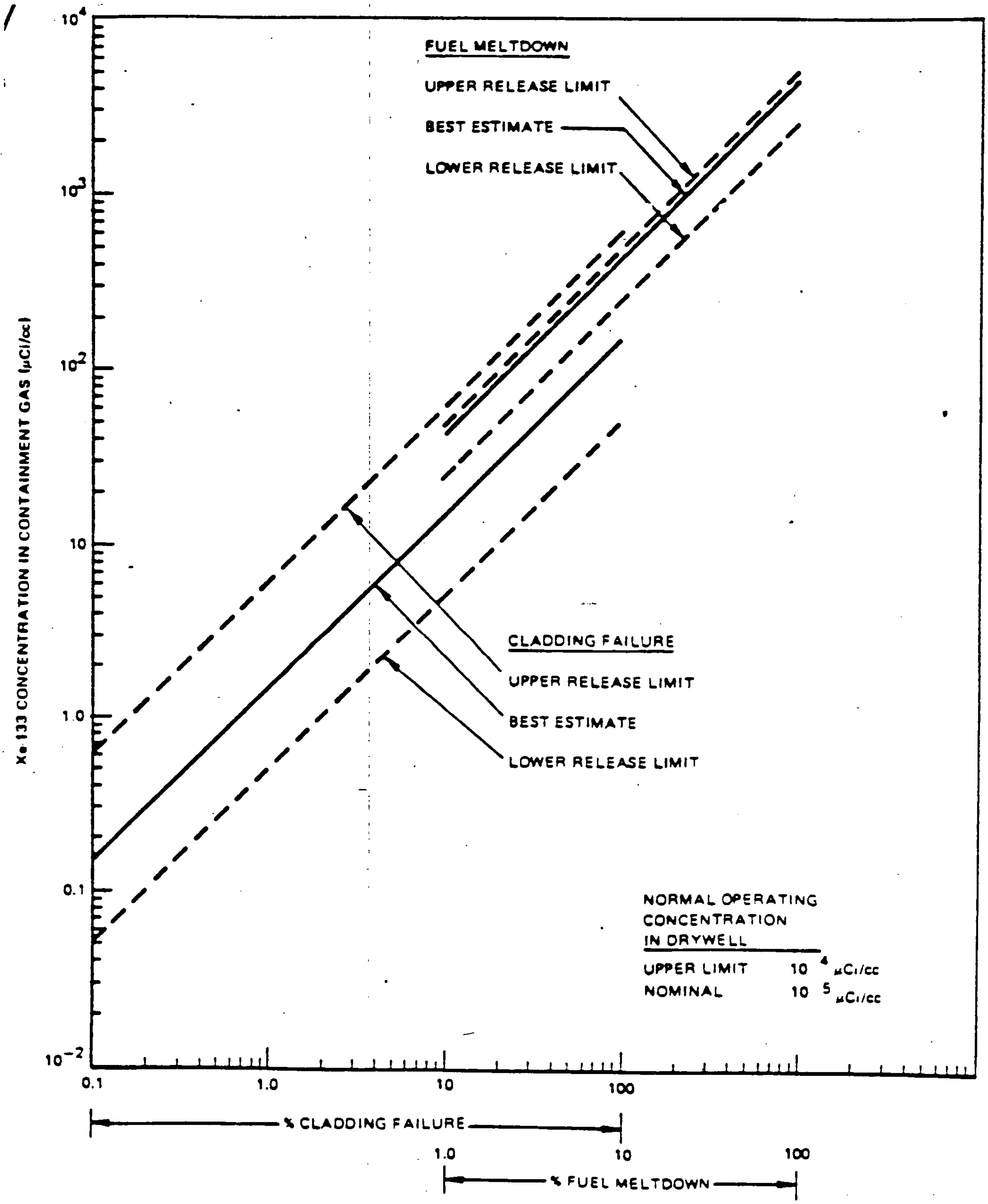

Figure 7.2-3 Relationship between Cs-137 Concentration in the Primary Coolant (Reactor Water + Pool Water) and the Extent of Core Damage in Reference Plant

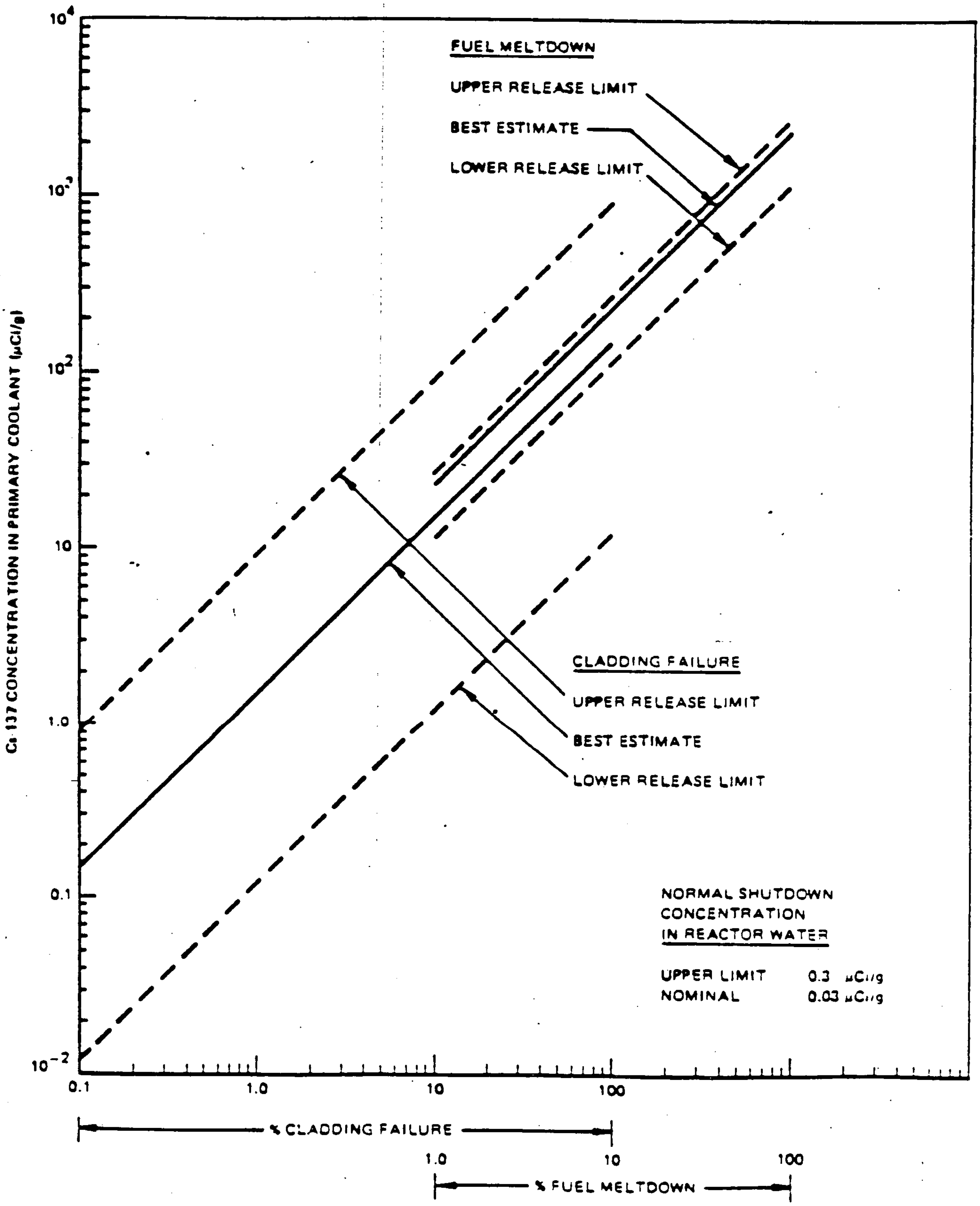

Figure 7.2-4 Relationship between Kr-85 Concentration in the Containment Gas (Drywell + Torus Gas) and the Extent of core damage in Reference Plant

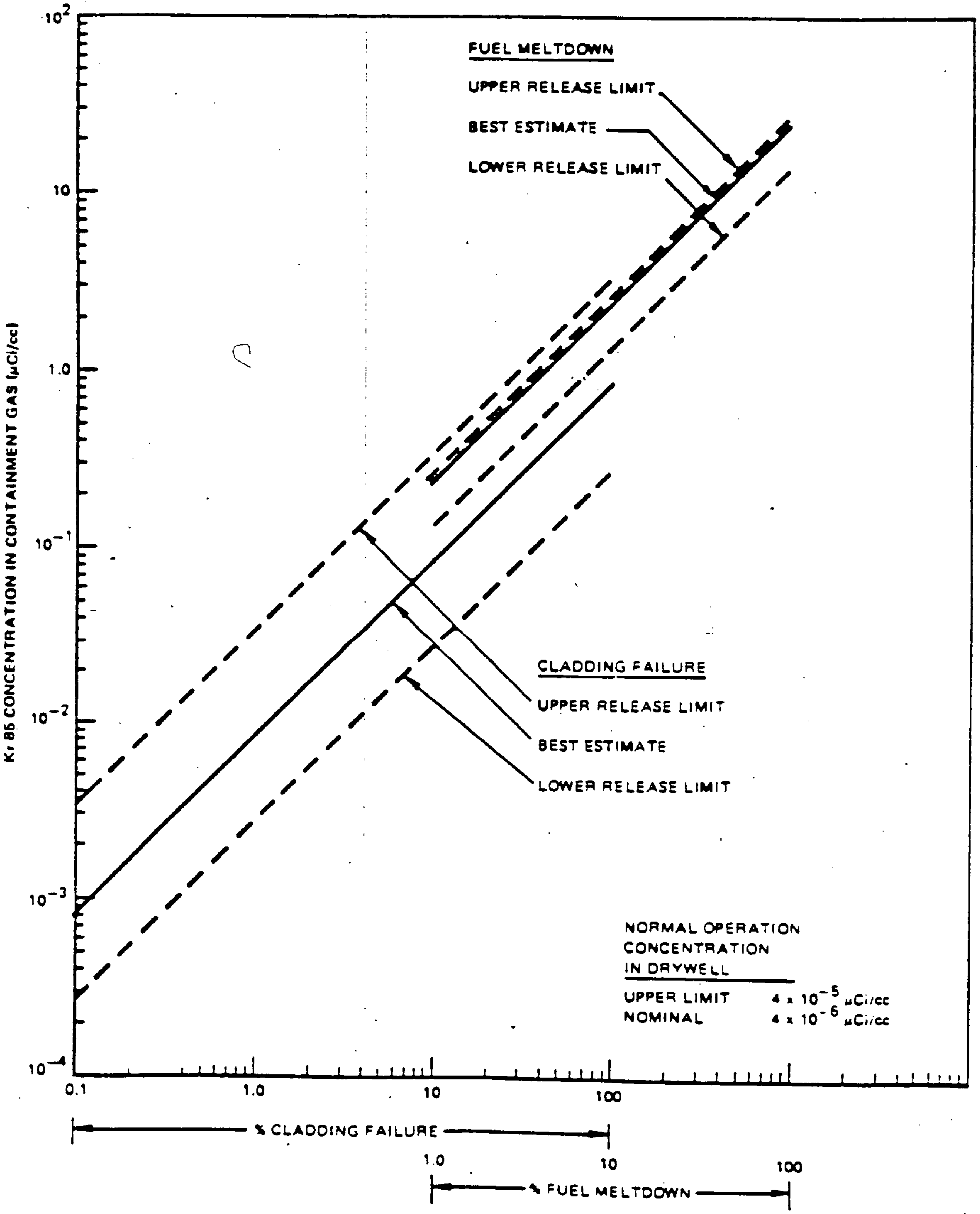

Figure 7.2-5

RATIOS OF ISOTOPES IN CORE INVENTORY AND FUEL GAP

Isotope	Half-Life	Activity Ratio* in Core Inventory	Activity Ratio* in Fuel Gap
Kr-87	76.3 m	0.233	0.0234
Kr-88	2.84h	0.33	0.0495
Kr-85m	4.48h	0.122	0.023
Xe-133	5.25d	1.0*	1.0*
I-134	52.6 m	2.3	0.155
I-132	2.3 h	1.46	0.127
I-135	6.61h	1.97	0.364
I-133	20.8 h	2.09	0.685
I-131	8.04d	1.0*	1.0*

$$*\text{Ratio} = \frac{\text{noble gas isotope concentration}}{\text{Xe-133 concentration}} \quad \text{for noble gases}$$

$$= \frac{\text{Iodine isotope concentration}}{\text{I-131 concentration}} \quad \text{for iodines}$$