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JAMES A. FITZPATRICK NUCLEAR POWER PLANT

RADIOLOGICAL AND ENVIRONMENTAL SERVICES DEPARTMENT

PROCEDURE NO.: RTP-46

TITLE: CORE DAMAGE ESTIMATION, PASS

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CORE DAMAGE ESTIMATION, PASS

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CORE DAMAGE ESTIMATION, PASS

1.0 PURPOSE

The purpose of this procedure is to estimate the degree of reactor core damage using the measured fission product concentrations in either the water or gas samples taken from the primary system under accident conditions. The procedure involves calculations of fission product inventories in the core and the release of inventories into the primary system under postulated Loss Of Coolant Accident (LOCA) conditions. The fuel gap fission products are assumed to be released upon the rupture of fuel cladding. The majority of fission product inventories in the fuel rods would be released when the fuel is melted at higher temperatures. The estimation of core damage will be calculated by comparing the measured concentrations of major fission products in either gas or liquid samples, after appropriate normalization, with reference plant data from a BWR-6/238 with a Mark III containment.

2.0 REQUIREMENTS AND ACCEPTANCE CRITERIA

2.1 Technical Specifications

None

2.2 Plant

Compliance with NUREG-0737, Item II.B.3

3.0 SPECIAL EQUIPMENT

None

4.0 PROCEDURE

4.1 Plant Parameters

4.1.1 The pertinent plant parameters for the reference plant and the FitzPatrick Plant are given below:

	Reference Plant	FitzPatrick Plant
Rated Reactor Thermal Power	3579 MWt	2436 MWt
Number of Fuel Bundles	748 Bundles	560 Bundles
Total Primary Coolant Mass (Reactor Water plus Suppression Pool Water)	3.92E+9 g	3.21E+9 g
Total Torus Containment and Drywell Gas Space Volume	4.0E+10 cc	7.57E+9 cc

4.1.2 Fission product inventories in the primary system of the reference plant were calculated based on postulated LOCA conditions after three years (1,095 days) of continuous operation at 3,651 MWt, or 102% of rated power, by using a computer code developed at Los Alamos and adapted to the GE computer system. The inventories of some major fission products in the core at the time of reactor shutdown are given in Table 1.

4.1.3 The inventories of some major fission products in the core of the FitzPatrick Plant at the time of reactor shutdown are given in Table 2.

4.2 Estimation Procedure Preliminary Guides

4.2.1 Obtain samples from the Post Accident Sampling System (PASS), following the procedure outlined in PSP-17.

a. It is recommended that both the water and gas phase samples be taken and analyzed in order to reduce the uncertainty in core damage estimations.

b. Samples acquired for the estimation of core damage should be taken from locations that are consistent with break case and system conditions, as outlined in Table 3. This will ensure the viability of results reported and provide the best estimation of core damage.

4.2.2 Perform gamma ray spectrometry on the samples and determine the concentration, in μCi/g, of a fission product i, as outlined in CAP-41.

a. In water, the concentration is represented as Cw, and the recommended isotopes of interest are I-131 and Cs-137.

b. In gas, the concentration is represented as Cg, and the recommended isotopes of interest are Xe-133 and Kr-85.

c. In case the fission product concentrations are measured separately for the reactor water and suppression pool water or the drywell gas and the torus gas, the measured concentrations Cw or Cg would be averaged from the separate measurements:

$$Cw = \frac{\text{(Conc. in Rx Water) (Rx Water Mass)}}{\text{Reactor Water Mass + Pool Water Mass}}$$

$$+ \frac{(\text{Conc. in Pool})\ (\text{Pool Water Mass})}{\text{Reactor Water Mass} + \text{Pool Water Mass}}$$

$$Cg = \frac{(\text{Conc. in Drywell})(\text{Drywell Gas Vol})}{\text{Drywell Gas Volume} + \text{Torus Gas Volume}}$$

$$+ \frac{(\text{Conc. in Torus})(\text{Torus Gas Vol})}{\text{Drywell Gas Volume} + \text{Torus Gas Volume}}$$

4.3 Isotope Decay Correction

4.3.1 Supply the counting room technician time of shutdown for automatic isotope decay correction or else decay as in next step.

4.3.2 Correct the measured concentration (Cw or Cg) for decay to the time of reactor shutdown, using the following equations:

$$Cd = Cw\ e^{(-\lambda i\ t)} \quad \text{or} \quad Cd = Cg\ e^{(-\lambda i\ t)}$$

Where:

Cd = the corrected concentration (C/g).

λi = the decay constant of isotope i (day ^{1}) (given in Table 4).

t = the time between the reactor shutdown and the sample time (day).

$e^{(-\lambda i\ t)}$ = the decay correction to the time of reactor shutdown.

4.4 Gaseous Sample Temperature and Pressure Correction

4.4.1 Correct the gaseous activity concentration for temperature and pressure differences between the sample vial and the containment gas phase, if significant difference exists between sample and containment condition, using the following equation:

$$Cdc = Cd \times \frac{P2\ T1}{P1\ T2}$$

Where:

Cd = containment isotopic concentration (μCi/cc).

(P1,T1) = sample vial pressure and temperature (psia,°R).

(P2,T2) = containment pressure and temperature (psia,°R).

4.5 Fission Product Inventory Correction

4.5.1 Calculate the fission product inventory correction factor FIi for each isotope of interest, using the following equation:

$$FIi = \frac{\text{Inventory in Reference Plant}}{\text{Inventory in FitzPatrick Plant}}$$

$$= \frac{3651\ (1-e^{-1095}\lambda i)}{\Sigma\ Pj(1-e^{\gamma-\lambda i\ Tj\sim})e^{(-\lambda i\ Tj)}}$$

Where:

FIi = inventory correction factor for isotope i.

Pj = steady reactor power operated in period j (MWt)

Tj = duration of operating period j (day).

Tj0 = time between the end of operating period j and time of the last reactor shutdown (day).

4.5.2 Pj, Tj, and the time of reactor shutdown for each operating period j, excluding the operating period just concluded, are provided in Table 5.

4.5.3 Pj, Tj, and the time of reactor shutdown for the most recent operating period must be obtained. Tj0 must be calculated for each operating period.

4.5.4 The information given in Table 5 should be updated to include the most recent operating period following each reactor shutdown.

4.5.5 For a particular short-lived isotope i, a calculation for only a period of ~ six half-lives of reactor operation time before reactor shutdown should be accurate enough.

4.5.6 The correction factor calculated from this equation may not be entirely accurate, but the error is insignificant in comparison to the uncertainties in the fission product release fractions (Table 6) and other assumptions.

4.6 Plant Parameter Correction Factor

4.6.1 Calculated plant parameter correction factors were developed using the equations below:

$$Fw = \frac{\text{FitzPatrick Plant Coolant Mass (3.21E+9 g)}}{\text{Reference Plant Coolant Mass (3.92E+9 g)}}$$

$$Fg = \frac{\text{FitzPatrick Plant Containment Gas Volume (7.57E+9 cc)}}{\text{Reference Plant Containment Gas Volume (4.0E+10 cc)}}$$

Ehere:

Fw = primary coolant mass correction factor.

Fg = containment gas volume correction factor.

These equations reduce to the following for normal plant operation:

Fw = 0.819 (AND) Fg = 0.189

4.7 Normalized Isotopic Concentrations

Calculate the normalized concentrations, Cnw and Cng using the equations below. These are the concentrations in the reference plant equivalent to the concentrations in the FitzPatrick Plant.

Cnw = Cd x F x Fw (OR) Cng = Cdc x F x Fg

4.8 Interpretation of Normalized Isotopic Information

4.8.1 If the normalized concentrations, Cn are higher than the baseline concentrations shown in Table 7, the extent of fuel or cladding damage (or both) can be estimated directly from Figures 1 through 4. These are graphs of each isotope's concentration versus % cladding failure and % fuel meltdown. They yield a best estimate for core damage, as well as a range of possible values.

4.8.2 If the normalized concentrations fall into a range where release of the fission product from the fuel gap or the molten fuel cannot be definitely determined, the presence of Sr, Ba, La and Ru should be established. Fission products 27 hr Sr-92 (1.385 MeV) and 40 hr La-140 (1.597 MeV) are relatively easy to identify and measure from a gamma ray spectrum and are indicative of fuel meltdown. These results should be compared to baseline reactor water concentrations.

4.9 Identification of Release Source, Core or Fuel Gap

4.9.1 From the samples obtained using the PASS, determine the concentrations of the following short-lived isotopes by gamma spectroscopy:

Kr-87
Kr-88
Kr-85m
Xe-133
I-134
I-132
I-135
I-133
I-131

4.9.2 Correct the measured fission products to the time of reactor shutdown, using the following equation:

$$Ci = Ci(sample)e^{-\lambda i\ t}$$

Where:

i = the isotope measured.

Ci = the concentration corrected for the time of reactor shutdown (μCi/g).

Ci (sample) = the measured concentration in the sample (μCi/g).

λi = the decay constant of isotope i (day $^{-1}$) (given in Table 4).

t = the time between the reactor shutdown and the sample time (day).

4.9.3 Calculate the isotopic activity ratios from the following equations:

$$\text{Noble gas ratio} = \frac{\text{Noble Gas Isotopic Concentration}}{\text{Xe-133 Concentration}}$$

$$\text{Iodine ratio} = \frac{\text{Iodine Isotopic Concentration}}{\text{I-131 Concentration}}$$

4.9.4 Compare these ratios to the ratios supplied in Table 8 to determine the release source (the core or the fuel gap). Fuel cladding rupture is assumed if the source is the fuel gap, and some core melting is assumed if the source is the core.

4.10 Integration of Other Parameters into the Estimate

These methods are only outlined briefly here, and no exact procedure for estimations is provided. Also, these methods are used for the confirmation of estimates obtained earlier in this procedure, and not to make original estimates.

4.10.1 Containment Radiation Levels

The level of containment radiation is an indication of the inventory of airborne fission products (i.e. noble gases, a fraction of the halogens, and a much smaller fraction of the particulates) released from the fuel to the containment, and as such, and indication of the degree of core damage sustained.

4.10.2 Reactcr Vessel Water Level

Reactor vessel water level readings indicating significant periods during which the core is uncovered would mean core damage is likely. Bulk core damage situations could be caused by loss of coolant to the entire core, while localized core damage situations could be caused by a flow blockage to some part of the core.

4.10.3 Main Steam Line Radiation Level

High main steam line radiation levels indicate some core damage may have occurred. The usefulness of the method is limited, however, because the main steam line radiation monitors are downstream of the main steam isolation valves and would be unavailable following vessel isolation.

4.10.4 Reactor Vessel Pressure

High reactor vessel pressure may indicate a core damage event has occurred. This indication is ambiguous, however, as there are many non-degraded core events which could also produce a high reactor vessel pressure.

4.10.5 Containment Hydrogen Concentration

Hydrogen concentrations may be obtained from either the containment hydrogen monitors or from the PASS sample analysis. Curves have been developed which relate this concentration, after appropriate normalization, to the % metal-water reaction undergone, and thus to the % cladding failure sustained.

4.11 <u>Development of a Final Estimate</u>

4.11.1 From the estimates developed in section 4.8, assign one or more categories of core damage to the core from those listed in Table 9.

4.11.2 Using the release sources identified in section 4.9, narrow down the range of categories assigned above as far as possible.

4.11.3 Use any or all of the methods summarized in section 4.10 to assign the final core damage estimate. More than one category may be assigned (For example, in order for fuel melt to occur, some fuel overheat and cladding failure must have occurred).

5.0 REFERENCES

5.1 NEDO-22215, Procedures for the Determination of the Extent of Core Damage Under Accident Conditions, August, 1982.

5.2 Memo RES 83-0279, NUREG-0737 Item II.B.3, BWRDG-8324 (June 17, 1983) Attachment 2, Integration of Other Plant Parameters into Core Damage Estimate.

5.3 PSP-17, PASS Operating Procedure.

5.4 CAP-41, Post Accident Sample Analysis.

6.0 ATTACHMENTS

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

6.2 Figure 2, Relationship Between Cs-137 Concentration in the Primary Coolant (Reactor Water + Pool Water) and the Extent of Core Damage in Reference Plant.

6.3 Figure 3, Relationship Between Xe-133 Concentration in the Containment Gas (Drywell + Torus Gas) and the Extent of Core Damage in the Reference Plant.

6.4 Figure 4, Relationship Between Kr-85 Concentration in the Containment Gas (Drywell + Torus Gas) and the Extent of Core Damage in Reference Plant.

6.5 Figure 5, Core Damage Estimation Data Sheet.

6.6 Table 1, Core Inventory of Major Fission Products in a Reference Plant Operated at 3651 MWt for Three Years.

6.7 Table 2, Core Inventory of Major Fission Products in the FitzPatrick Plant Operated at 2436 MWt for Three Years.

6.8 Table 3, Samples Most Representative of Core Conditions During an Accident for the Estimation of Core Damage.

6.9 Table 4, Decay Constants of Some Radioactive Isotopes.

6.10 Table 5, Fission Product Inventory Correction Data.

6.11 Table 6, Best-Estimate Fission Product Release Fractions.

6.12 Table 7, Fission Product Concentrations in Reactor Water and Drywell Gas Space During Reactor Shutdown Under Normal Conditions.

6.13 Table 8, Ratios of Isotopes in Core Inventory and Fuel Gap.

6.14 Table 9, Categories of Core Damage Events.

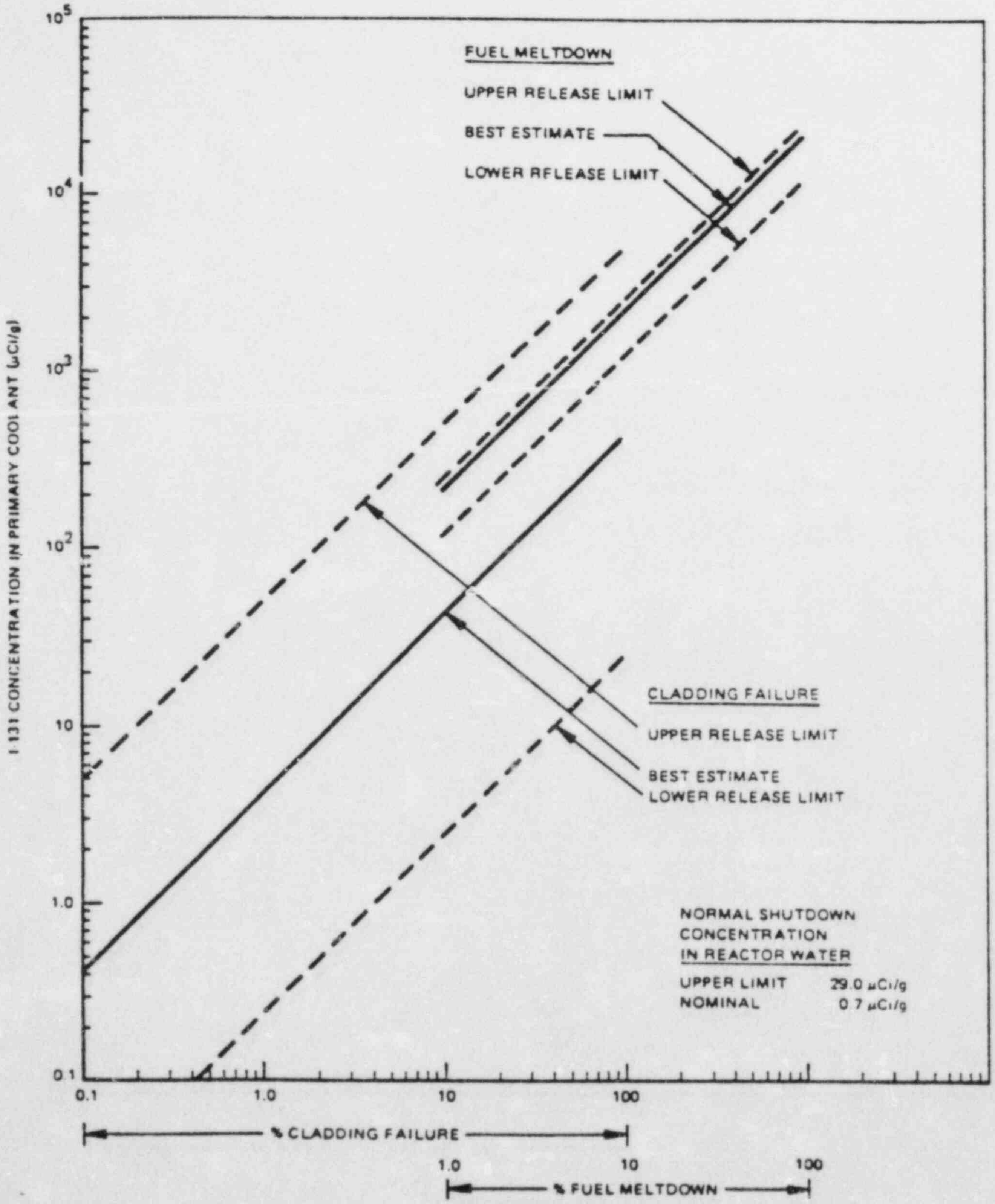

Figure 1. Relationship Between I-131 Concentration in the Primary Coolant (Reactor Water + Pool Water) and the Extent of Core Damage in Reference Plant

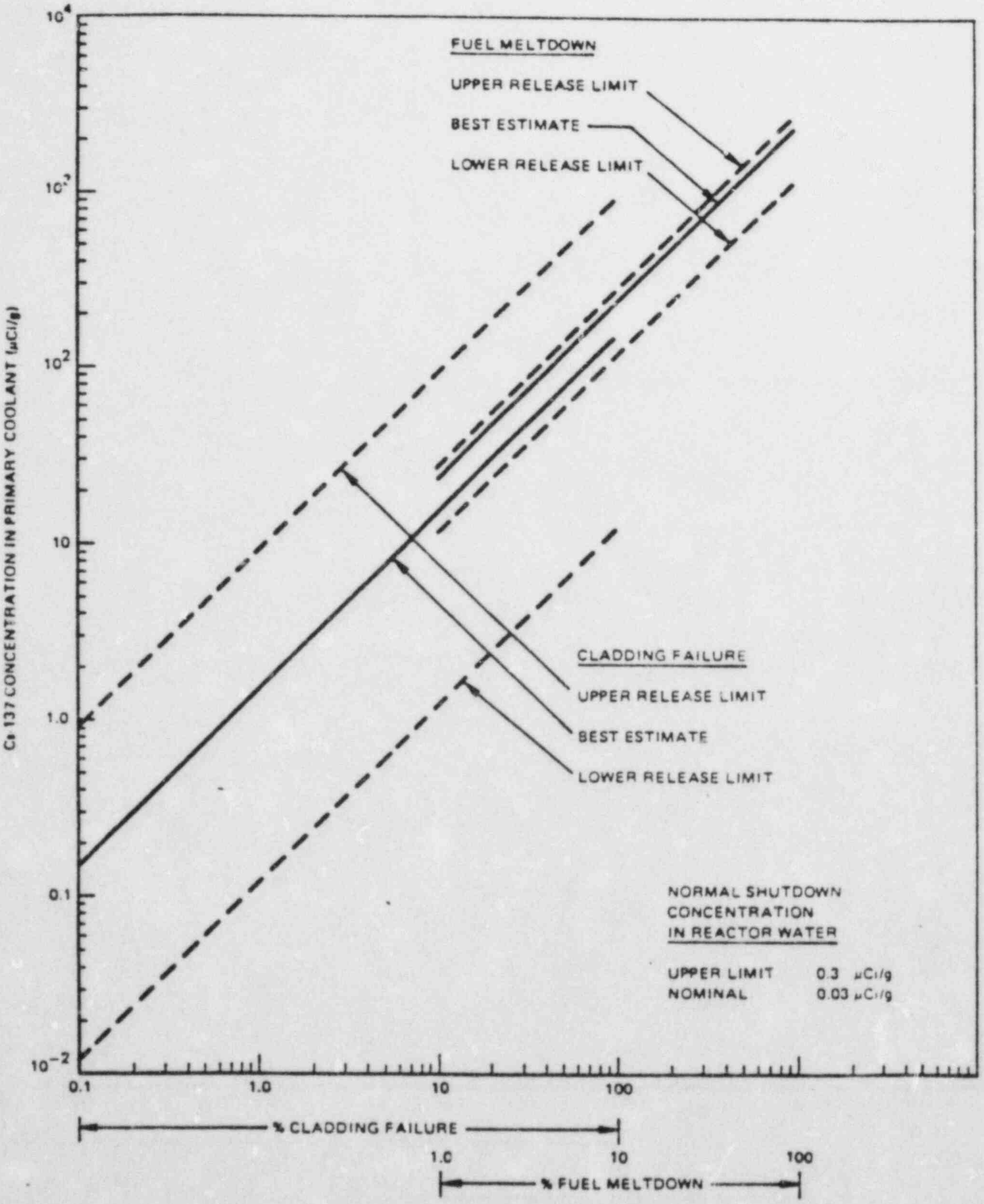

Figure 2. Relationship Between Cs-137 Concentration in the Primary Coolant (Reactor Water + Pool Water) and the Extent of Core Damage in Reference Plant

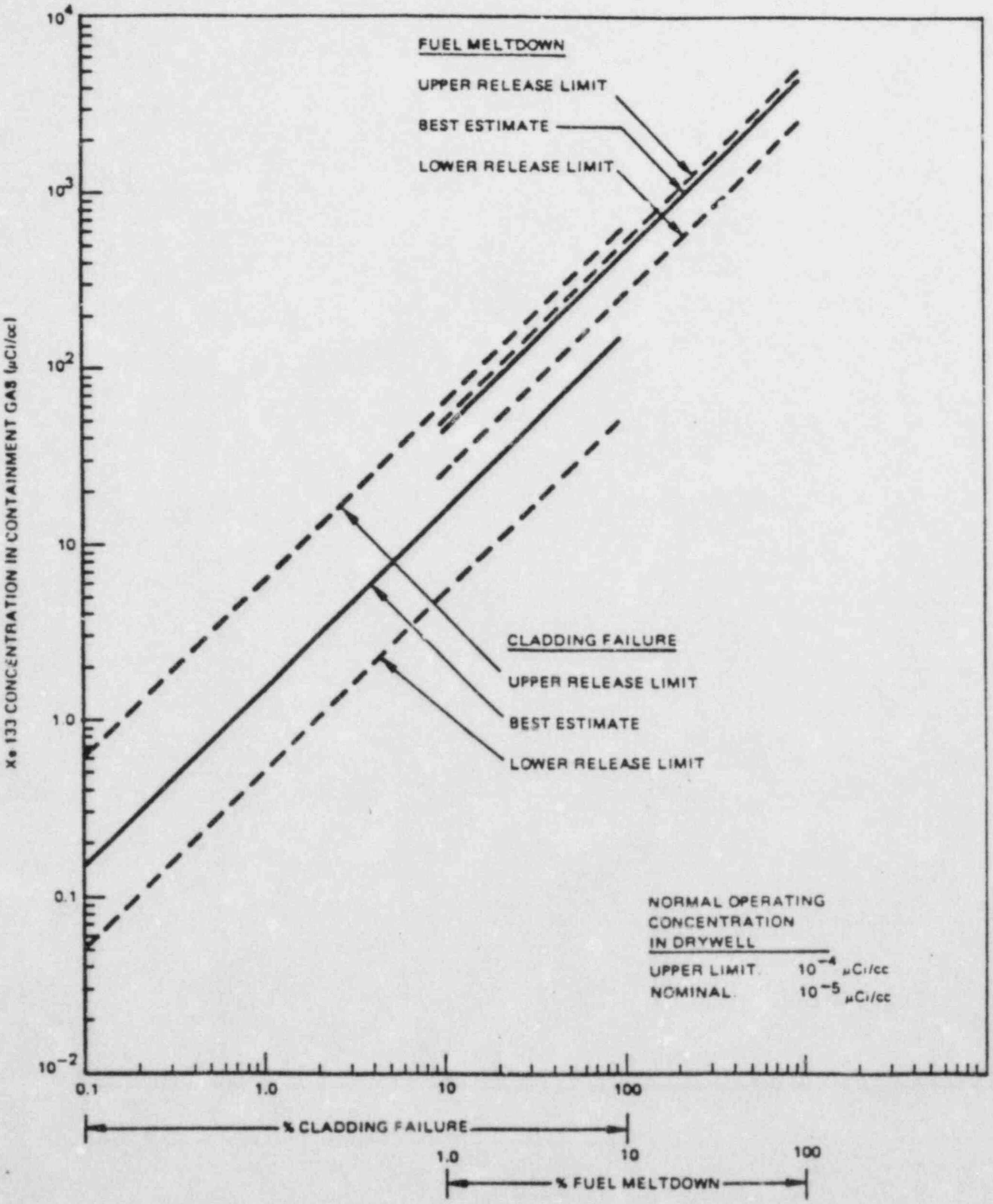

Figure 3. Relationship Between Xe-133 Concentration in the Containment Gas (Drywell + Torus Gas) and the Extent of Core Damage in Reference Plant

Figure 4

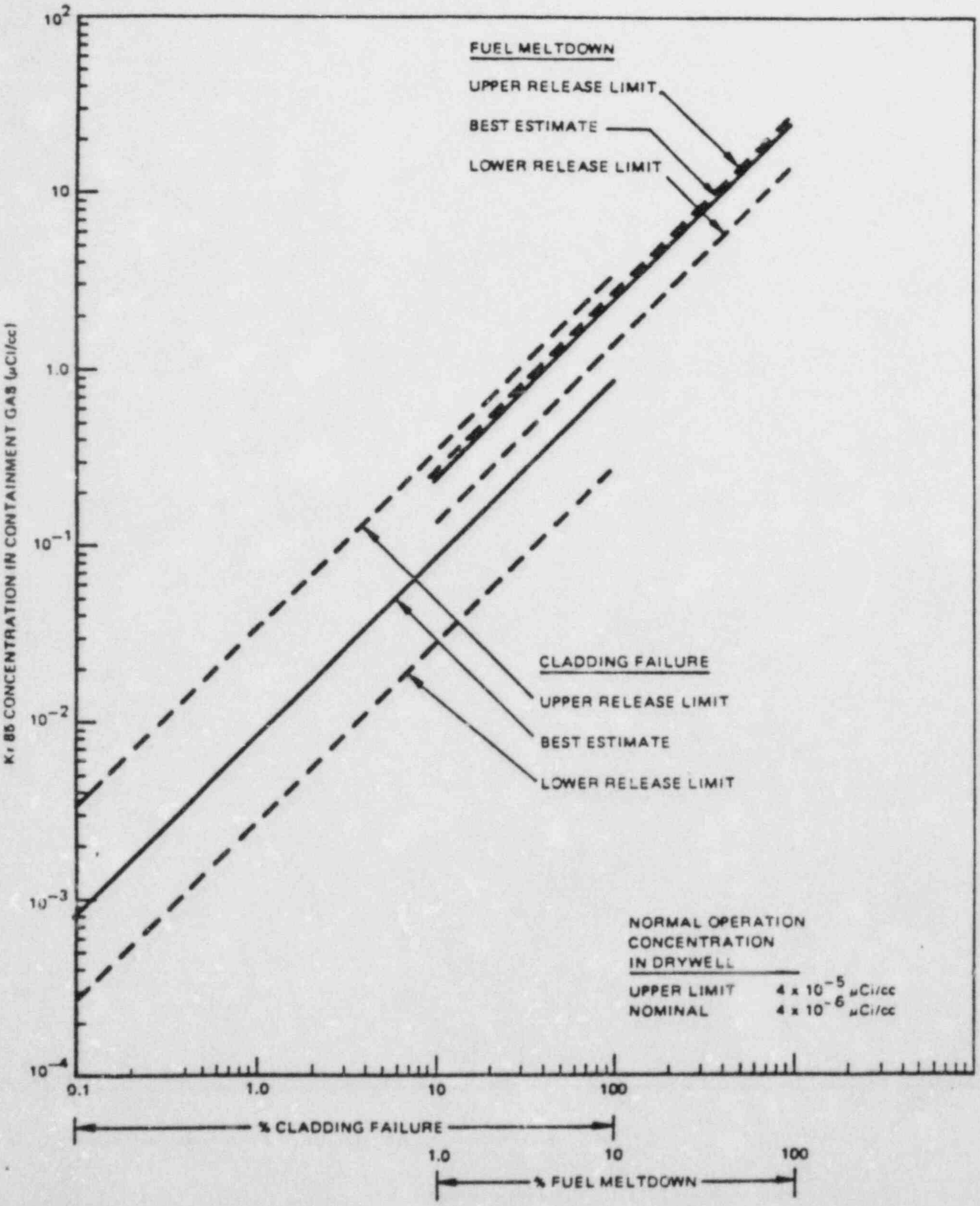

Figure 4. Relationship Between Kr-85 Concentration in the Containment Gas (Drywell + Torus Gas) and the Extent of Core Damage in Reference Plant

Figure 5

CORE DAMAGE ESTIMATION DATA SHEET

1. Name ______________________ Date ________________

   Date of Shutdown ______

   Time of Shutdown ______

2. Isotopic Information

   a. Liquid Sample Identification: ______________

      Sample Date and Time: ______________

      Sample decayed to Shutdown YES or NO (circle one)

      I - 131 μCi/g ______________________

      Cs - 137 μCi/g ______________________

   b. Gaseous Sample Identification: ______________

      Sample Date and Time: ______________

      Sample decayed to Shutdown YES or NO (circle one)

      Xe - 133 μCi/cc ______________________

      Kr - 85 μCi/cc ______________________

      Sample Vial Temperature $^oR(^oF + 460)T1$ = ________

      Pressure psia (psig + 14.7)P1 = ________

      Containment Temperature $^oR(^oF +460)$ T2 = ________

      Pressure psia (psig + 14.7)P2 = ________

   c. Isotopic Data Decayed to Shutdown

      Cd ; I - 131 (Liquid) μCi/g ______________

      Cd ; Cs- 137 (Liquid) μCi/g ______________

      Cd ; Xe- 133 (Gas) μCi/cc ______________

      Cd ; Kr- 85 (Gas) μCi/cc ______________

d. Fission Product Inventory Correction Factors

Operation Period	Days of Operation	Days between period S/D and current S/D	Average Power MWTh
1	448	670(to 9/1/83)	1985
2	455	89 (to 9/1/83)	2087
3A			
B			
C			
D			

F(I - 131) ____________

F(Cs -137) ____________

F(Xe - 133) ____________

F(Kr - 85) ____________

e. Plant Parameter Correction Factor

Fw = 0.819 and Fg = 0.189

f. Gaseous Temperature and Pressure Correction

Cdc = Cd x (P2 x T1) ÷ (P1 x T2)

Cdc Xe - 133 μCi/cc = ________________

Cdc Kr - 85 μCi/cc = ________________

g. Normalizing Isotopic Data

Cnw = Cd x F x Fw

Cng = Cdc x F x Fg

Cn(I - 131) = Cd x F(I - 131) x 0.819

___ x ________ x 0.819 = _____ μCi/g

Cn(Cs- 137) = Cd x F(Cs -137) x 0.819

___ x ________ x 0.819 = _____ μCi/g

Cn(Xe- 133) = Cdc x F(Xe-133) x 0.189

___ x ________ x 0.189 = _____ μCi/g

Cn(Kr - 85) = Cdc x F(Kr- 85) 0.189

___ X ________ X 0.189 = _____ μCi/g

Figure 5 (con't)

3. Interpretation of Normalized Isotopic Data

a. I - 131

1. Within normal range 0.7 → 29μC/g YES or NO
2. Cladding Failure, % Failure

Upper ________ Best ________ Lower ________

3. Fuel Meltdown, % Meltdown

Upper ________ Best ________ Lower ________

b. Cs - 137

1. Within normal range, 0.03 to 0.3 μCi/g YES or NO
2. Cladding failure, % Failure

Upper ________ Best ________ Lower ________

3. Fuel Meltdown, % Meltdown

Upper ________ Best ________ Lower ________

c. Xe - 133

1. Within normal range, 1E-5 to 1E-4 μCi/cc Y or N
2. Cladding failure, % Failure

Upper ________ Best ________ Lower ________

3. Fuel meltdown, % meltdown

Upper ________ Best ________ Lower ________

d. Kr - 85

1. Within normal range, 4E-6 to 4E-5 YES or NO
2. Cladding failure, % Failure

Upper ________ Best ________ Lower ________

3. Fuel Meltdown, % Meltdown

Upper ________ Best ________ Lower ________

Table 1

CORE INVENTORY OF MAJOR FISSION PRODUCTS IN A REFERENCE PLANT OPERATED AT 3651 MWt FOR THREE YEARS

CHEMICAL GROUP	ISOTOPE*	HALF-LIFE	INVENTORY 10^6 Ci	MAJOR GAMMA RAY ENERGY (INTENSITY) KeV (γ/d)
Noble gases	Kr-85m	4.48h	24.6	151(0.755)
	Kr-85	10.72y	1.1	514(0.0043)
	Kr-87	76. m	47.1	403(0.494)
	Kr-88	2.84h	66.8	196(0.203),1530(0.109)
	Xe-133	5.25d	202.	81(0.371)
	Xe-135	9.09h	26.1	250(0.906)
Halogens	I-131	8.04d	96.	364(0.824)
	I-132	2.29h	140	668(0.99),773(0.762)
	I-133	20.8 h	201	530(0.87)
	I-134	52.6 m	221	847(0.954),884(0.653)
	I-135	6.59h	189	1132(0.2[illegible]1),1250(0.293)
Alkali Metals	Cs-134	2.06y	19.6	605(0.98),796(0.88)
	Cs-137	30.17y	12.1	662(0.85)
	Cs-138	32.2 m	2990.**	463(0.267),1436(0.75)
Tellurium Group	Te-132	78. h	138	228(0.88)
Noble Metals	Mo-99	66.02h	183	740(0.138)
	Ru-103	39.4 d	155	497(0.9)
Alkaline Earths	Sr-91	9.52h	115	750(0.24)
	Sr-92	2.71h	123	1385(0.9)
	Ba-140	12.8 d	173	537(0.238)
Rare Earths	Y-92	58.6 d	118	934(0.137)
	La-140	40.2 h	184	487(0.453),1597(0.953)
	Ce-141	32.5 d	161	145(0.49)
	Ce-144	284.4 d	129	134(0.108)
Refractories	Zr-95	46. d	161	724(0.435),757(0.543)
	Zr-97	16.8 h	166	743(0.933)

*Only the representative isotopes which have relatively large inventory and considered to be easy to measure are listed here.

**1 hr after shutdown

Table 2

CORE INVENTORY OF MAJOR FISSION PRODUCTS
IN THE FITZPATRICK PLANT OPERATED AT 2436 MWt FOR THREE YEARS

Chemical Group	Isotope	T1/2	Inventory (10^6 Curies)
Noble Gases	Kr-85m	4.48h	16.4
	Kr-85	10.72y	0.73
	Kr-87	76.30m	31.4
	Kr-88	2.84h	44.6
	Xe-133	5.25d	134.8
	Xe-135	9.11h	17.4
Halogens	I-131	8.04d	64.1
	I-132	2.30h	93.4
	I-133	20.80h	134.1
	I-134	52.60m	147.4
	I-135	6.61h	126.1
Alkali Metals	Cs-134	2.06y	13.1
	Cs-137	30.17y	8.1
	Cs-138	32.20m	1973.
Noble Metals	Mo-99	66.02h	122.1
	Ru-103	39.40d	103.4
Alkaline Earths	Sr-91	9.50h	76.7
	Sr-92	2.71h	82.1
	Ba-140	12.8 d	115.4
Rare Earths	Y-92	58.6 d	82.7
	La-140	40.20h	122.8
	Ce-141	32.50d	107.4
	Ce-143	284.30d	86.1
Refractories	Zr-95	64.00d	107.4
	Zr-97	16.90h	110.8

SAMPLES MOST REPRESENTATIVE OF CORE CONDITIONS DURING AN ACCIDENT
FOR THE ESTIMATION OF CORE DAMAGE

Break Category/System Conditions	SAMPLE LOCATION					Other Instructions
	Jet Pump	Supp. Pool Liquid	Supp. Pool Atmos.	RHR	Drywell	
Small Liquid Line Break, Reactor Power ≥1%	Yes	---	Yes[1]	---	Yes[2]	
Small Liquid Line Break, Reactor Power <1%	---	---	Yes[1]	Yes	Yes[2]	a. RHR must be in shutdown cooling mode. b. Reactor water level must be raised and flow from moisture separators.
Small Steam Line Break, Reactor Power ≥1%	Yes	---	Yes[1]	---	Yes[2]	
Small Steam Line Break, Reactor Power <1%	---	---	Yes[1]	Yes	Yes[2]	a. RHR must be in shutdown cooling mode. b. Reactor water level must be raised and flow from moisture separators.
Large Liquid Line Break, Reactor Power ≥1%	Yes[3]	Yes[4]	Yes[1]	---	Yes[2]	a. Suppression pool must be in suppression cooling mode.
Large Liquid Line Break, Reactor Power <1%	---	Yes[4]	Yes[1]	Yes[3]	Yes[2]	a. RHR must be in shutdown cooling mode. b. Suppression pool must be in suppression cooling mode. c. Reactor water level must be raised and flow from moisture separators.

Superscripts on the Sample Location indicate system sample order of preference.

Table 4

DECAY CONSTANTS OF SOME RADIOACTIVE ISOTOPES

Isotope	Decay Constant (λi) (day $^{-1}$)
I-131	8.62E-2
I-132	7.23
I-133	8.00E-1
I-134	1.90E+1
I-135	2.52
Cs-137	6.29E-5
Xe-133	1.32E-1
Kr-85	1.77E-4
Kr-87	1.31E-1
Kr-88	5.86
Kr-85m	3.71

Table 5

FISSION PRODUCT INVENTORY CORRECTION DATA

Operating Period	Pj(MWt)	Tj(day)	Time of Shutdown
1	1985	448	10/31/81 (670 days to 09/01/83)
2	2087	455	06/04/83 (89 days to 09/01/83)

BEST-ESTIMATE FISSION PRODUCT RELEASE FRACTIONS

	Gap Release			Meltdown Release			Oxidation Release			Vaporization Release		
	Nominal	Lower Limit	Upper Limit	Nominal	Lower Limit	Upper Limit	Nominal	Lower Limit	Upper Limit	Nominal	Lower Limit	Upper Limit
Noble Gases (Xe,Kr)	0.030	0.010	0.12	0.873	0.485	0.970	0.087	0.078	0.097	0.010	0.010	0.010
Halogens (I,Br)	0.017	0.001	0.20	0.885	0.492	0.983	0.088	0.078	0.098	0.010	0.010	0.010
Alkali Metals (Cs,Rb)	0.050	0.004	0.30	0.760	0.380	0.855	---	---	---	0.190	0.190	0.190
Tellurium Group (Te,Se,Sb)	0.0001	3×10^{-7}	0.04	0.150	0.05	0.250	0.510	0.340	0.680	0.340	0.340	0.340
Noble Metals (Ru,Rh,Pd,Mo,Tc)	---	---	---	0.030	0.01	0.10	0.873	0.776	0.970	0.005	0.001	0.024
Alkaline Earths (Sr,Ba)	1×10^{-6}	3×10^{-9}	0.0004	0.100	0.02	0.20	---	---	---	0.009	0.002	0.045
Rare Earths (Y,La,Ce,Nd,Pr, Eu,Pm,Sm,Np,Pu)	---	---	---	0.003	0.001	0.01	---	---	---	0.010	0.002	0.050
Refractories (Zr,Nb)	---	---	---	0.003	0.001	0.01	---	---	---	---	---	---

Table 7

FISSION PRODUCT CONCENTRATIONS IN REACTOR WATER
AND DRYWELL GAS SPACE DURING REACTOR SHUTDOWN UNDER NORMAL CONDITIONS

	Reactor Water, µCi/g		Drywell Gas (µCi/cc)	
Isotope	Upper Limit	Nominal	Upper Limit	Nominal
I-131	29	0.7	---	---
Cs-137[c]	0.3[a]	0.03[b]	---	---
Xe-133	---	---	10^{-4}[a]	10^{-5}[b]
Kr-85	---	---	4×10^{-5}[a]	4×10^{-6}[b]

[a] Observed experimentally, in an operating BWR-3 with MK I containment, data obtained from GE unpublished document, DRF 268-DEV-0009.

[b] Assuming 10% of the upper limit values.

[c] Release of Cs-137 activity would strongly depend on the core inventory which is a function of fuel burnup.

Table 8

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*

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

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

Table 9

CATEGORIES OF CORE DAMAGE EVENTS

Degree of Degradation	Minor (<10%)	Intermediate (10% - 50%)	Major (>50%)
No Fuel Damage	←	1	→
Cladding Failure	2	3	4
Fuel Overheat	5	6	7
Fuel Melt	8	9	10

NEW YORK POWER AUTHORITY

JAMES A. FITZPATRICK NUCLEAR POWER PLANT

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ATTACHMENT C