GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION

REVISION STATUS SHEET

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CONT ON SHEET 2 SH NO. 1

DOCUMENT TITLE Radioactive Decay Heat Power Data

☒ SPECIFICATION ☐ DRAWING ☐ OTHER

TYPE Design Bases

FMF General Use

MPL No. A12/A13-6451
Product Summary, Sect 7

LEGEND OR DESCRIPTION OF GROUPS

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1. SCOPE

1.1 This document specifies the values for the decay heat power from fission products and the heavy elements, U-239 and Np-239, following the shutdown of General Electric Boiling Water Reactors (BWR/2-6) containing U-235, U-238 and Pu. The decay heat power values for the fission products and heavy elements are presented in analytical and tabular form.

1.2 The decay heat power values in this document shall be applied after July 1, 1978 to all future analyses (including revisions) dependent on decay heat but shall not be backfitted. Based on BWR licensing commitments, plant equipment limitations and the ongoing revision to the Proposed ANS Standard (Oct 73 revision) the decay heat power values are specified for applications as follows:

a. For BWR/2-6 analyses governed by 10CFR50, Appendix K the decay heat power values derived from the Proposed ANS Standard shall be used as evaluated in sections 3.2 and 4.1 of this document.

b. For BWR/6 analyses not governed by 10CFR50, Appendix K the decay heat power values derived from the Proposed ANS Standard shall be used as evaluated in Sections 3.2 and 4.2 of this document.

c. For BWR/2-5 analyses not governed by 10CFR50, Appendix K the decay heat power values derived from the May-Witt curve shall be used as evaluated in sections 3.1 and 4.3 of this document.

1.3 The identical decay heat power values shall be applied for all reactor conditions and events, namely; normal, upset, emergency, and faulted.

1.4 The decay heat power values in this document are based on the shutdown of thermal reactors fueled with Uranium (U-235 and U-238 mixtures). An infinite irradiation period at maximum reactor power and a recoverable fission energy of 200 MeV/fission are assumed prior to shutdown. Neutron capture effects by the fission products are not considered. These assumptions result in conservative decay heat power values for BWR/2-6 plants containing fissile Pu and operating at average neutron flux levels $<5 \times 10^{13}$ neutrons/cm^2/sec. and an average fuel irradiation <20,000 hours.

1.5 This document does not specify pre-shutdown energy, delayed neutron fission energy, sensible heat release from the fuel or any spatial distribution.

2. APPLICABLE DOCUMENTS

2.1 GE Documents

a. G.J. Scatena and G.L. Upham, "Power Generation in a BWR Following Normal Shutdown or Loss-of-Coolant Accident Conditions", NEDO-10625, April 1973.

b. "General Electric Company Analytical Model for Loss-of-Coolant Analysis in Accordance with 10CFR50, Appendix K," NEDO-20566, January 1976.

2.2. Codes and Standards

a. Code of Federal Regulations, 10CFR50, Appendix K.

b. Proposed ANS Standard - "Decay Energy Release Rates Following Shutdown of Uranium-Fueled Thermal Reactors", October 1971 (revised October 1973).

3. DECAY HEAT POWER CALCULATIONS

3.1 May-Witt Curve (Ref. 2.1.a)

For an infinite irradiation period at maximum reactor power the fraction of operating power emitted by radioactive decay heat as calculated by:

a. $\frac{P}{P_o} (t_s) = M (t_s) + HE (t_s)$

where $M (t_s)$ = fraction of operating power due to decay of U-235 fission products.

$HE (t_s)$ = fraction of operating power due to heavy element decay.

P_o = maximum power level during reactor operation.

t_s = time in seconds since operation (cool down time).

For the approximate fraction of operating power due to decay of U-235 fission products:

b. $M (t_s) = A\, t_s^{-a}$

where the following table gives the values A and a, along with the appropriate time intervals.

CONSTANTS FOR FRACTION OF OPERATING POWER

Applicable time interval, sec.	A	a
$10^{-1} \leq t < 10^{1}$	.0603	0.0639
$10^{1} \leq t \leq 1.5 \times 10^{2}$	.0766	0.1507
$1.5 \times 10^{2} < t < 1 \times 10^{6}$	.1301	0.2834

The fraction of power for heavy element decay is:

c. $HE\ (t_s) = \frac{P(U\text{-}239)}{P_o}\ (t_s) + \frac{P(Np\text{-}239)}{P_o}\ (t_s)$

For the fraction of operating power due to U-239 decay:

d. $\frac{P(U\text{-}239)}{P_o}\ (t_s) = .0025 \quad e^{-\left(\frac{t_s}{2040}\right)}$

where 2040 is the mean life or reciprocal of the decay constant for U-239, and initially the U-239 contributes .25% of the operating power level.

For the fraction of operating power due to Np-239 decay:

e. $\frac{P(Np\text{-}239)}{P_o}\ (t_s) = .0024 \quad e^{-\left(\frac{t_s}{290,000}\right)}$

where 290,000 is the mean life or reciprocal of the decay constant for Np-239, and initially the Np-239 contributes .24% of the operating power level.

3.2 Proposed ANS Standard (Reference 2.2.b).

For an infinite irradiation period at maximum reactor power the fraction of operating power emitted by radioactive decay heat shall be calculated by:

a. $\frac{P}{P_o}\ (t_s) = K\ (t_s)\ M\ (t_s) + HE\ (t_s)$

Where $K\ (t_s)$ = Multiplier defined in sections 4.1 and 4.2

$M\ (t_s)$ = fraction of operating power due to decay of U-235 fission products.

HE (t_s) = fraction of operating power due to heavy element decay.

P_o = maximum power level during reactor operation.

t_s = time in seconds since operation (cool down time).

The Proposed ANS Standard allows using equation 3.1.b to calculate the approximate fraction of operating power due to decay of U-235 fission products. However, in this document the tabulated decay heat power fractions M (t_s) are used as reproduced in Table 3-1.

The fraction of power for heavy element decay is:

b. $HE(t_s) = \frac{P(U\text{-}239)}{P_o}(t_s) + \frac{P(Np\text{-}239)}{P_o}(t_s)$

Where the fractions of operating power due to U-239 and Np-239 decay are:

c. $\frac{P(U\text{-}239)}{P_o} = .456 \frac{(C\,\Sigma a)}{Y\,\Sigma_f}\, e^{(-4.91 \times 10^{-4} t_s)}$

d. $\frac{P(Np\text{-}239)}{P_o} = .434 \frac{C\,\Sigma a}{Y\,\Sigma_f}\left[1.007\, e^{(-3.41 \times 10^{-6} t_s)} - 0.007\, e^{(-4.91 \times 10^{-4} t_s)}\right]$

and the lattice parameter from reference 2.2.b for BWRs is approximately:

$\frac{C\,\Sigma a}{Y\,\Sigma_f} = 3.28 \times 10^{-3} \frac{1}{MeV}$

TABLE 3-1

PROPOSED ANS STANDARD (Revised 1973)

FISSION PRODUCT DECAY HEAT POWER FRACTIONS

INFINITE REACTOR OPERATING TIME

COOLING TIME t_s, seconds	FISSION PRODUCT POWER FRACTION $M(t_s)$	COOLING TIME t_s, seconds	FISSION PRODUCT POWER FRACTION $M(t_s)$
1×10^{-1}	0.0675	6×10^4	0.00566
1×10^0	0.0625	8	0.00505
2	0.0590	1×10^5	0.00475
4	0.0552	2	0.00400
6	0.0533	4	0.00339
8	0.0512	6	0.00310
1×10^1	0.0500	8	0.00282
2	0.0450	1×10^6	0.00267
4	0.0396	2	0.00215
6	0.0365	4	0.00166
8	0.0346	6	0.00143
1×10^2	0.0331	8	0.00130
2	0.0275	1×10^7	0.00117
4	0.0235	2	0.00089
6	0.0211	4	0.00068
8	0.0196	6	0.00062
1×10^3	0.0185	8	0.00057
2	0.0157	1×10^8	0.000550
4	0.0128	2	0.000485
6	0.0112	4	0.000415
8	0.0105	6	0.000360
1×10^4	0.00965	8	0.000303
2	0.00795	1×10^9	0.000267
4	0.00625		

4.0 REQUIREMENTS

4.1 10CFR50, Appendix K Analysis. For 10CFR50 Appendix K analysis the Proposed ANS Standard described in Section 3.2 shall be used with a 1.2 multiplier times the fission product power values for the total cool down period for all BWR/2-6 plants. The resultant decay heat power values for the first 1000 seconds of cool down are tabulated in Table 4-1. Interpolation in Table 4-1 shall be done on a log - log or linear basis.

4.2 BWR/6 Analyses (except 10CFR50, Appendix K)

For BWR/6 analyses not governed by 10CFR50 Appendix K, the Proposed ANS Standard described in Section 3.2 shall be used with a 1.2 multiplier times the fission product power values for the first 1000 seconds of cooling time and a 1.1 multiplier thereafter for cooling times $\leq 10^9$ seconds. The resultant decay heat power values are tabulated in Table 4-1. Interpolation in Table 4-1 shall be done on a log - log or linear basis.

4.3 BWR/2-5 Analyses (except 10CFR50, Appendix K)

For BWR/2-5 analyses (except late BWR 4/5s) not governed by 10CFR50, Appendix K, the May-Witt curve described in Section 3.1 shall be used for cooling times $\leq 1\times10^4$ seconds. The resultant decay heat power values are tabulated in Table4-2. For cooling times $>1\times10^4 \leq 10^9$ seconds the decay heat power values specified in Section 4.2 shall be used. For late BWR 4/5s analyses, specifically Limerick 1,2, Nine Mile Point 2, Shoreham, Susquehanna 1,2, Zimmer, Bailly, and LaSalle 1,2, the decay heat power values specified in Section 4.2 shall be used. Interpolation in Table 4-2 shall be done on a log - log or linear basis.

TABLE 4-1
BWR/6 ANALYSES APPLICATIONS (1)
FISSION PRODUCT and HEAVY ELEMENT
DECAY HEAT POWER VALUES

COOLING TIME t_s (sec)	FISSION PRODUCT POWER VALUES (2) $F(t_s)$ $M(t_s)$	HEAVY ELEMENT POWER VALUES $HE(t_s)$	DECAY HEAT POWER VALUES P/Po (t_s)
0	.0810	.00292	.0839
$1x10^{-1}$	.0810	.00292	.0839
$1x10^{0}$	.0750	.00292	.0779
2	.0708	.00292	.0737
4	.0662	.00292	.0692
6	.0640	.00292	.0669
8	.0614	.00291	.0644
$1x10^{1}$	.0600	.00291	.0629
2	.0540	.00291	.0569
4	.0745	.00289	.0504
6	.0438	.00288	.0467
8	.0415	.00286	.0444
$1x10^{2}$	[illegible]	.00285	.0426
2	.0330	.00278	.0358
4	.0282	.00265	.0309
6	.0253	.00254	.0279
8	.0235	.00243	.0260
$1x10^{3}$	.0222	.00234	.0245
1.001	.0204	.00234	.0227
2	.0173	.00198	.0192
4	.0141	.00162	.0157
6	.0123	.00147	.0138
8	.0116	.00142	.0130
$1x10^{4}$	.0106	.00139	.0120
2	.00875	.00132	.0101
4	.00688	.00124	.00812
6	.00623	.00116	.00739
8	.00556	.00109	.00664
$1x10^{5}$	.00523	.00101	.00624
2	.00440	.00072	.00512
4	.00373	.00037	.00409
6	.00341	.00018	.00360
8	.00310	.00009	.00320

TABLE 4-1
BWR/6 ANALYSES APPLICATIONS (1)
FISSION PRODUCT and HEAVY ELEMENT
DECAY HEAT POWER VALUES

COOLING TIME t_s (sec)	FISSION PRODUCT POWER VALUES (2) $K(t_s)$ $M(t_s)$	HEAVY ELEMENT POWER VALUES $HE(t_s)$	DECAY HEAT POWER VALUES P/Po (t_s)
$1x10^6$	.00294	.00005	.00298
2	.00237	-	.00237
4	.00183	-	.00183
6	.00157	-	.00157
8	.00143	-	.00143
$1x10^7$	.00129	-	.00129
2	.000979	-	.000979
4	.000748	-	.000748
6	.000682	-	.000682
8	.000627	-	.000627
$1x10^8$	.000605	-	.000605
2	.000534	-	.000534
4	.000457	-	.000457
6	.000396	-	.000396
8	.000333	-	.000333
$1x10^9$	.000294	-	.000294

(1) For 10CFR50, Appendix K analysis see Section 4.11

(2) Includes multipliers per Section 4.2.

(3) These values are not to be used to calculate finite irradiation values.

TABLE 4-2
BWR/2-5 ANALYSES APPLICATIONS (1)
FISSION PRODUCT and HEAVY ELEMENT
DECAY HEAT POWER VALUES

COOLING TIME t_s (sec)	FISSION PRODUCT POWER VALUES M (t_s)	HEAVY ELEMENT POWER VALUES HE (t_s)	DECAY HEAT POWER VALUES P/Po (t_s)
0	.0743	.00490	.0792
$1x10^{-1}$	.0699	.00490	.0748
$1x10^{0}$	.0603	.00490	.0652
2	.0577	.00490	.0626
4	.0552	.00490	.0601
6	.0538	.00489	.0587
8	.0528	.00489	.0577
$1x10^{1}$	.0505	.00489	.0554
2	.0446	.00488	.0495
4	.0393	.00485	.0442
6	.0366	.00483	.0414
8	.0347	.00480	.0395
$1x10^{2}$	.0333	.00478	.0381
2	.0290	.00467	.0337
4	.0238	.00445	.0283
6	.0212	.00426	.0258
8	.0196	.00405	.0237
$1x10^{3}$	.0184	.00392	.0223
2	.0151	.00332	.0184
4	.0124	.00272	.0151
6	.0111	.00248	.0135
8	.0102	.00238	.0126
$1x10^{4}$	.00957	.00234	.0119

(1) For exceptions, cooling times $>10^4$ and 10CFR50, Appendix K analysis see Sections 4.3 and 4.1.

RAI Number: 950.23

Question:

Provide the test plan and the final hardware configuration for the PANTHERS facility.

GE Response:

The Test Plan and Procedures document for the PANTHERS-PCC test is enclosed. The hardware configuration will be contained in the document "PANTHERS-PCC TEST FACILITY DESCRIPTION" which is scheduled to be issued on November 15, 1993. Similar documentation for the PANTHERS-IC test is not scheduled to be available until mid-1994.