BRANCH TECHNICAL POSITION ASB 9-2

RESIDUAL DECAY ENERGY FOR LIGHT-WATER REACTORS FOR LONG-TERM COOLING

A. BACKGROUND

The Auxiliary Systems Branch has developed acceptable assumptions and formulations that may be used to calculate the residual decay energy release rate for light-water-cooled reactors for long-term cooling of the reactor facility.

Experimental data (Refs. 1 and 2) on total beta and gamma energy releases for long half-life (> 60 seconds) fission products from thermal neutron fission of U-235 have been considered reliable for decay times of 10^3 to 10^7 seconds. Over this decay time, even with the exclusion of short-lived fission products, the decay heat rate can be predicted to within 10% of experimental data (Refs. 3, 7, and 8).

The short-lived fission products contribute appreciably to the decay energy for decay times less than 10^3 seconds. Although consistent experimental data are not as numerous (Refs. 4 and 5) and the results of various calculations differ, the effect of all uncertainties can be treated in the zero to 10^3 second time range by a suitably conservative multiplying factor.

B. BRANCH TECHNICAL POSITION

1. Fission Product Decay

For finite reactor operating time (t_o) the fraction of operating power, $\frac{P}{Po}(t_o, t_s)$, to be used for the fission product decay power at a time t_s after shutdown may be calculated as follows:

$$\frac{P}{Po} \quad (\infty, t_s) = \frac{1}{200} \sum_{n=1}^{n=11} A_n \exp(-a_n t_s) \qquad (1)$$

$$\frac{P}{Po} \quad (t_o, t_s) = (1 + K) \ \frac{P}{Po} (\infty, t_s) - \frac{P}{Po} (\infty \ t_o + t_s) \qquad (2)$$

where:

$\frac{P}{Po}$ = fraction of operating power

t_o = cumulative reactor operating time, seconds

t_s = time after shutdown, seconds

K = uncertainty factor; 0.2 for $o \leq t_s < 10^3$ and 0.1 for $10^3 \leq t_s \leq 10^7$

A_n, a_n = fit coefficients having the following values:

n	A_n	a_n (sec^{-1})
1	0.5980	1.772×10^{0}
2	1.6500	5.774×10^{-1}
3	3.1000	6.743×10^{-2}
4	3.8700	6.214×10^{-3}
5	2.3300	4.739×10^{-4}
6	1.2900	4.810×10^{-5}
7	0.4620	5.344×10^{-6}
8	0.3280	5.716×10^{-7}
9	0.1700	1.036×10^{-7}
10	0.0865	2.959×10^{-8}
11	0.1140	7.585×10^{-10}

The expressions for finite reactor operation may be used to calculate the decay energy from a complex operating history; however, in accident analysis a suitably conservative history should be used. For example, end-of-first-cycle calculations should assume continuous operation at full power for a full-cycle time period, and end-of-equilibrium-cycle calculations should assume appropriate fractions of the core to have operated continuously for multiple-cycle times.

An operating history of 16,000 hours is considered to be representative of many end-of-first or equilibrium cycle conditions and is, therefore, acceptable. In calculating the fission produce decay energy, a 20% uncertainty factor (K) should be added for any cooling time less than 10^3 seconds, and a factor of 10% should be added for cooling times greater than 10^3 but less than 10^7 seconds.

2. Heavy Element Decay Heat

The decay heat generation due to the heavy elements U-239 and N_p-239 may be calculated according to the following expressions (Ref. 6):

$$\frac{P\ (U\text{-}239)}{Po} = 2.28 \times 10^{-3}\ C\ \frac{\sigma_{25}}{\sigma_{f25}} [1 - \exp(-4.91 \times 10^{-4}\ t_o)]\ [\exp(-4.91 \times 10^{-4}\ t_s)] \quad (3)$$

$$\frac{P(N_p\text{-}239)}{Po} = 2.17 \times 10^{-3}\ C\ \frac{\sigma_{25}}{\sigma_{f25}} \quad (4)$$

$$\{1.007\ [1 - \exp(-3.41 \times 10^{-6}\ t_o)]\ \exp(-3.41 \times 10^{-6}\ t_s)$$

$$- 0.007\ [1 - \exp(-4.91 \times 10^{-4}\ t_o)]\ \exp(-4.91 \times 10^{-4}\ t_s)\}$$

where:

$\frac{P\ (U\text{-}239)}{Po}$ = fraction of operating power due to U-239

$\frac{P\ (N_p\text{-}239)}{Po}$ = fraction of operating power due to N_p-239

t_o = cumulative reactor operating time, seconds

t_s = time after shutdown, seconds

C = conversion ratio, atoms of Pu-239 produced per atom of U-235 consumed

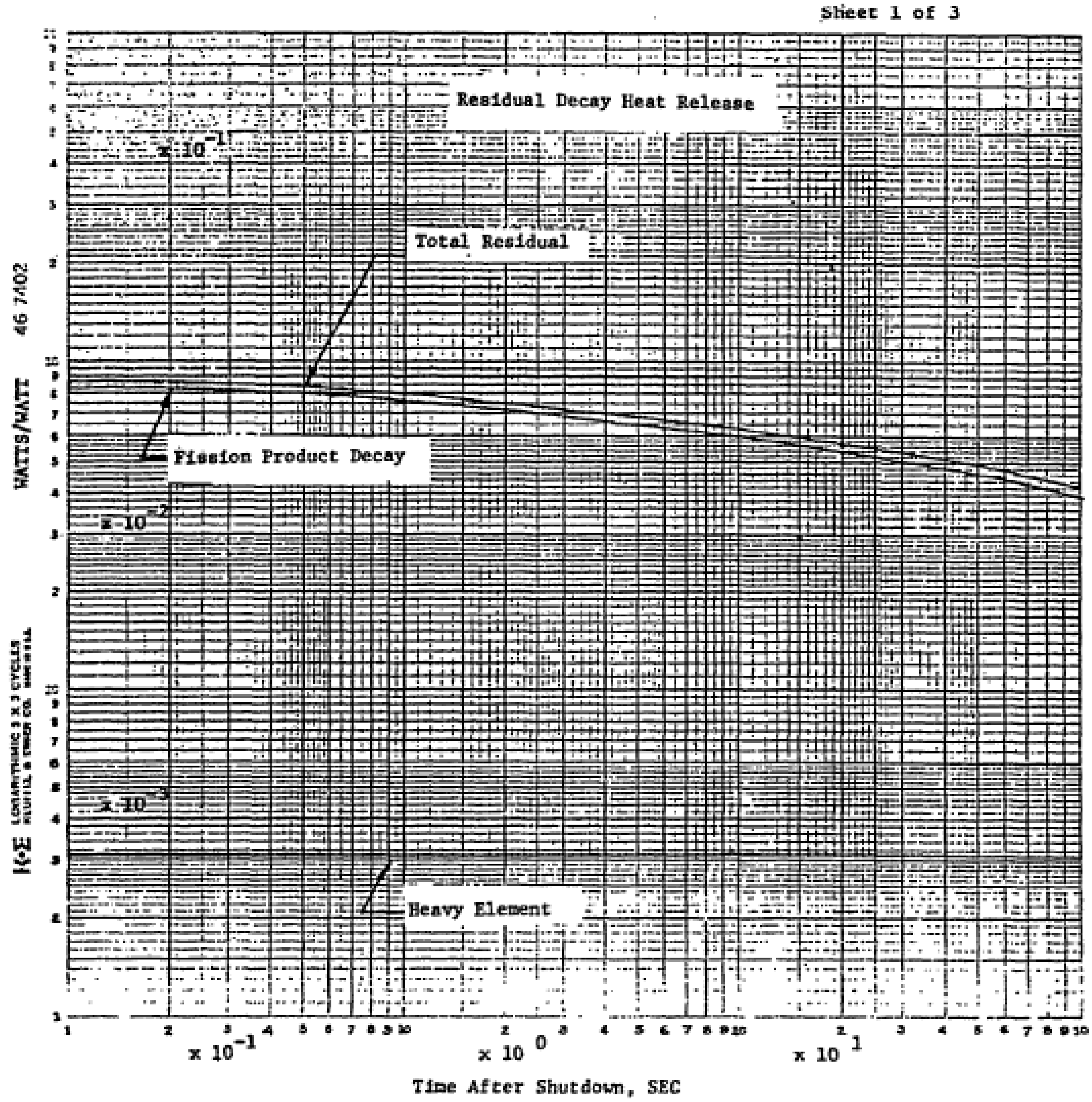
σ_{25} = effective neutron absorption cross section of U-235

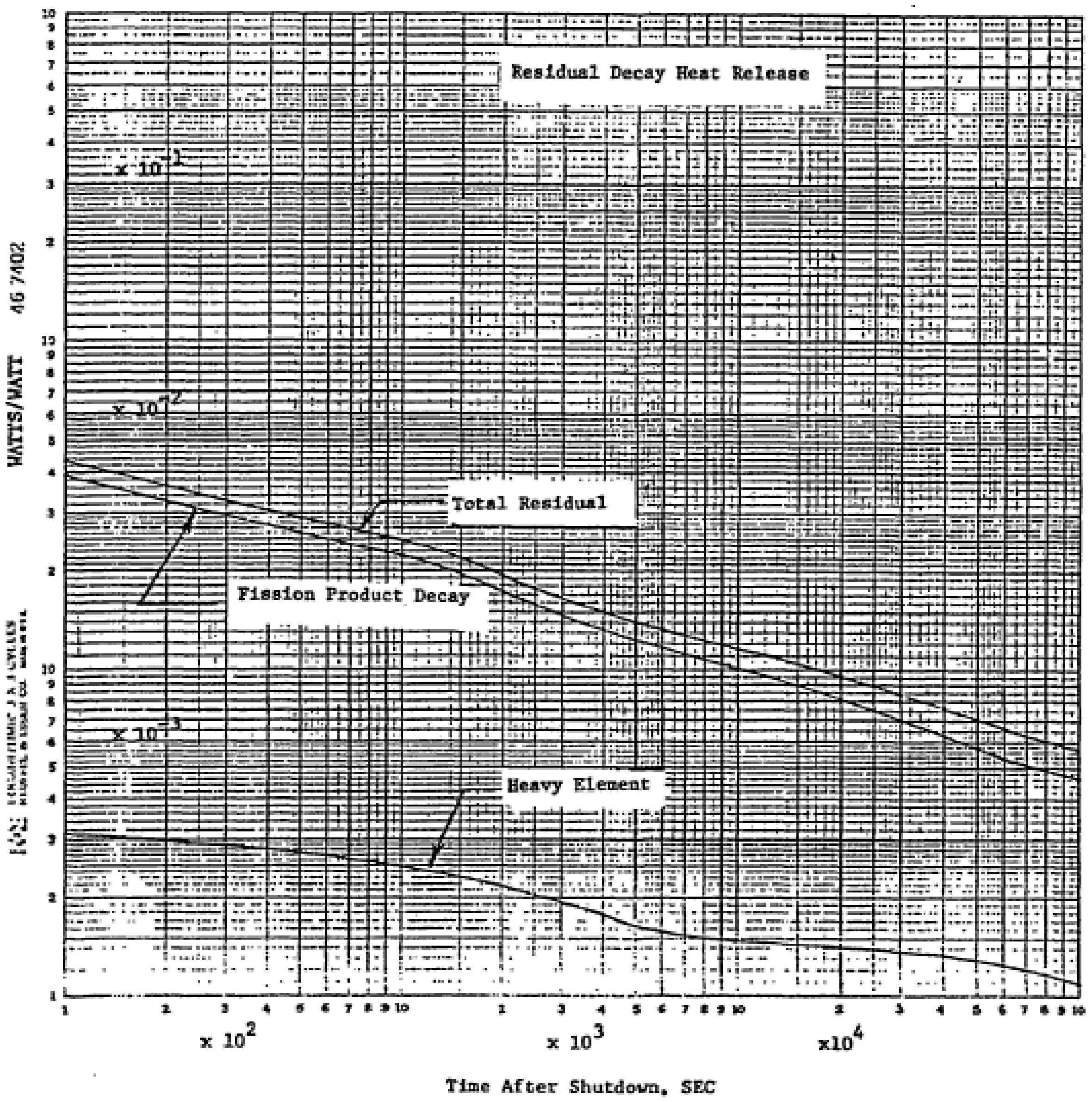
σ_{f25} = effective neutron fission cross section of U-235

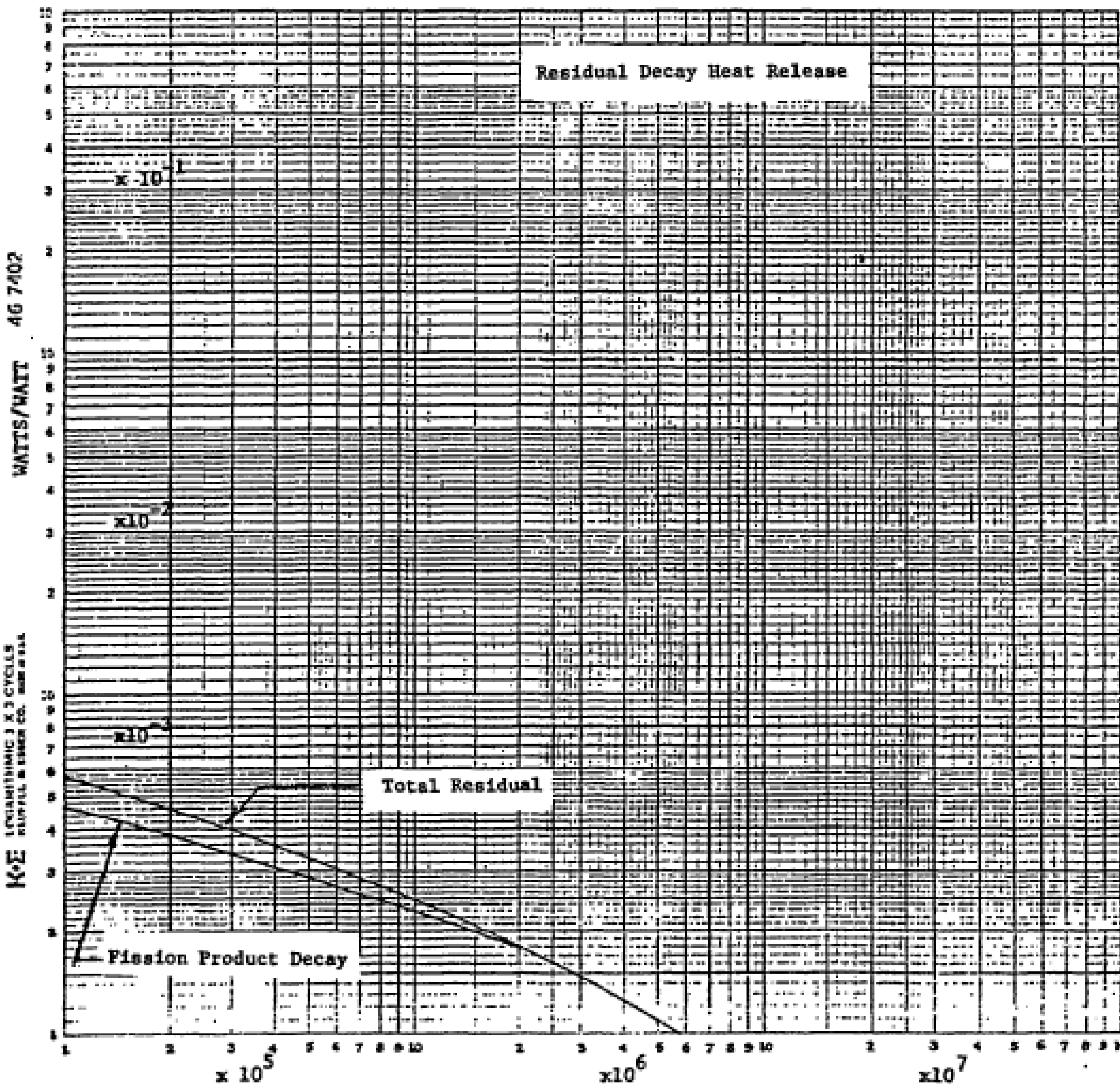
The product of the terms $C \cdot \frac{\sigma_{25}}{\sigma_{f25}}$ can be conservatively specified as 0.7.

The nuclear parameters for energy production by the heavy elements U-239 and N_p-239 are relatively well known. Therefore, the heavy element decay heat can be calculated with a conservatively estimated product term of $C \cdot \frac{\sigma_{25}}{\sigma_{f25}}$ without applying any other uncertainty correction factor.

3. Figures 1, 2, and 3 give the residual decay heat release in terms of fractions of full reactor operating power based on a reasonably realistic reactor operating time of 16,000 hours.


Residual Decay Heat Release
Total Residual
Fission Product Decay
Heavy Element
x 10^-1
x 10^-2
x 10^-3
WATTS/WATT
46 7402
K+E LOGARITHMIC 3 X 3 CYCLES
x 10^-1
x 10^0
x 10^1
Time After Shutdown, SEC


Residual Decay Heat Release
Total Residual
Fission Product Decay
Heavy Element
WATTS/WATT
46 7402
x 10^{-1}
x 10^{-2}
x 10^{-3}
x 10^2
x 10^3
x10^4
Time After Shutdown, SEC



Time After Shutdown, SEC

C. REFERENCES

1. J. F. Perkins and R. W. King, "Energy Release From the Decay of Fission Products, Nuclear Science and Engineering," Vol. 3, 726 (1958).

2. A. M. Perry, F. C. Maienschein, and D. R. Vondy, "Fission-Product Afterheat: A Review of Experiments Pertinent to the Thermal-Neutron Fission of ^{235}U," ORNL-TM-4197, Oak Ridge National Laboratory, October 1973.

3. A. Tobias, "The Energy Release From Fission Products," Journal of Nuclear Energy, Vol. 27, 725 (1973).

4. J. Scobie, R. D. Scott, and H. W. Wilson, "Beta Energy Release Following the Thermal Neutron Induced Fission of U and ^{235}U," Journal of Nuclear Energy, Vol. 25, 1 (1971).

5. L. Costa and R. de Tourreil, "Activite β et α Des Products d'une Fission de ^{235}U et ^{239}Pu," Journal of Nuclear Energy, Vol. 25, 285 (1971).

6. Proposed ANS Standard, "Decay Energy Release Rates Following Shutdown of Uranium-Fueled Thermal Reactors," American Nuclear Society, October 1973.

7. J. Scobie and R. D. Scott, "Calculation of Beta Energy Release Rates Following Thermal Neutron Induced Fission of ^{233}U, ^{235}U, ^{239}Pu, and ^{241}Pu," Journal of Nuclear Energy, Vol. 25, 339 (1971).

8. K. Shure, "Fission Product Decay Energy," WAPD-BT-24, Westinghouse Electric Corporation, December 1961.