NUREG-75/087

U.S. NUCLEAR REGULATORY COMMISSION
STANDARD REVIEW PLAN
OFFICE OF NUCLEAR REACTOR REGULATION

SECTION 9.2.5 ULTIMATE HEAT SINK

REVIEW RESPONSIBILITIES

Primary - Auxiliary and Power Conversion Systems Branch (APCSB)

Secondary - Reactor Systems Branch (RSB)
Mechanical Engineering Branch (MEB)
Structural Engineering Branch (SEB)
Materials Engineering Branch (MTEB)
Site Analysis Branch (SAB)
Electrical, Instrumentation and Control Systems Branch (EICSB)

I. AREAS OF REVIEW

The ultimate heat sink (UHS) is the source of cooling water provided to dissipate reactor decay heat and essential cooling system heat loads after a normal reactor shutdown or a shutdown following an accident, including LOCA.

The APCSB reviews the water sources which make up the ultimate heat sink. This includes the size, type of cooling water supply (e.g., ocean, lake, natural or man-made reservoir, river, or cooling tower), makeup sources to the ultimate heat sink, and the capability of the heat sink to deliver the required flow of cooling water at appropriate temperatures for normal or accident condition shutdown of the reactor. The UHS is reviewed to determine that design code requirements, as applicable to the assigned quality classifications and seismic categories, are met. A related area of review is the conveying system, which is generally the service water pumping system. The service water system is reviewed under Standard Review Plan (SRP) 9.2.1.

1. The ultimate heat sink is reviewed with respect to the following considerations:

   a. The type of cooling water supply.

   b. The ability to dissipate the total essential station heat load.

   c. The effect of environmental conditions on the capability of the UHS to furnish the required quantities of cooling water, at appropriate temperatures and with any required chemical and purification treatment, for extended times after shutdown.

   d. The effect of earthquakes, tornadoes, missiles, and hurricane winds on the availability of the source water.

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e. Sharing of cooling water sources in multi-unit stations.

f. Applicable design requirements such as the high and low water levels of the source to determine their compatibility with the service water system.

2. APCSB reviews the station heat input provided in the SAR for the design of the UHS with respect to reactor system heat, sensible heat, and pump work, and station auxiliary system individual and total heat loads.

3. The proposed technical specifications are reviewed for operating license applications as they relate to areas covered in this review plan.

Secondary reviews will be performed by other branches and the results used by the APCSB to complete overall evaluation of the UHS. The secondary reviews are as follows. The RSB assures that seismic and quality group classifications established for the system components are acceptable. The RSB also confirms heat loads from the reactor coolant and emergency core cooling systems. The SEB determines the acceptability of the design analyses, procedures, and criteria used to establish the ability of seismic Category I structures housing the system and supporting systems to withstand the effects of natural phenomena such as the safe shutdown earthquake (SSE), the probable maximum flood (PMF), and tornado missiles. The MEB reviews the seismic qualification of components and confirms that the system is designed in accordance with applicable codes and standards. The MTEB verifies that inservice inspection requirements are met for system components and, upon request, verifies the compatibility of the materials of construction with service conditions. The EICSB determines the adequacy of the design, installation, inspection, and testing of electrical components and instrumentation required for UHS operation. The SAB verifies the ultimate heat sink water levels, meteorological and natural phenomena criteria and transient analysis of the cooling water inventory.

II. ACCEPTANCE CRITERIA

Acceptability of the design of the ultimate heat sink, as described in the applicant's safety analysis report (SAR), including related sections of Chapters 2 and 3 of the SAR, is based on specific general design criteria and regulatory guides and on independent calculations and staff judgments with respect to system adequacy. An additional basis for acceptability is the degree of similarity of the UHS design with that for previously reviewed plants with satisfactory operating experience.

The design of the ultimate heat sink is acceptable if the system and the associated complex of water sources, including retaining structures and canals or conduits connecting the sources with the station, are in accordance with the following criteria:

1. General Design Criterion 2, as related to structures housing the system and the system itself being capable of withstanding the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, and floods.

2. General Design Criterion 4, relative to structures housing the systems and the system itself being capable of withstanding the effects of external missiles and internally generated missiles, pipe whip, and jet impingement forces associated with high and moderate energy pipe breaks.

3. General Design Criterion 5, as related to shared systems and components important to safety being capable of performing required safety functions.

4. General Design Criterion 44, as related to:

    a. The capability to transfer heat loads from safety-related structures, systems, and components to the heat sink under both normal operating and accident conditions.

    b. Suitable component redundancy so that safety functions can be performed assuming a single active component failure coincident with loss of offsite power.

    c. The capability to isolate components, systems, or piping if required so that safety functions are not compromised.

5. General Design Criterion No. 45, as related to the design provisions to permit inservice inspection of safety-related components and equipment.

6. General Design Criterion No. 46, as related to the design provisions to permit operation functional testing of safety-related systems or components.

7. Regulatory Guide No. 1.26, as related to quality group classification of system components.

8. Regulatory Guide No. 1.27, as related to the design and functional requirements of the ultimate heat sink.

9. Regulatory Guide No. 1.29, as related to the seismic design classification of system components.

10. Branch Technical Position APCSB 9-2, as related to the methods for calculating heat release due to fission product and heavy element decay.

III. REVIEW PROCEDURES

The procedures below are used during the construction permit (CP) review to determine that the design criteria and bases and the preliminary design as set forth in the preliminary safety analysis report meet the acceptance criteria given in Section II of this plan. For operating license (OL) reviews, the procedures are used to verify that the initial design criteria and bases have been appropriately implemented in the final design as set forth in the final safety analysis report.

The review procedures for OL applications include a determination that the content and intent of the technical specifications prepared by the applicant are in agreement with the requirements for system testing, minimum performance, and surveillance developed as a result of the staff's review.

Availability of an adequate supply of water for the ultimate heat sink is a basic requirement for any nuclear power plant. There are various methods of satisfying the requirement, e.g., a large body of water such as an ocean, lake, or natural or man-made reservoir, a river, or cooling ponds or towers, or combinations thereof. The design of the ultimate heat sink tends to be unique for each nuclear plant, depending upon its particular geographical location. For the purpose of this plan, typical procedures are established for use in identifying the essential features of an ultimate heat sink. For installations where these general procedures are not completely adequate, the reviewer supplements them as necessary.

1. The SAR is reviewed for the overall arrangement and type of ultimate heat sink proposed. The reviewer verifies that the UHS is designed so that system function is maintained as required when subjected to adverse environmental phenomenon or a loss of offsite power. The reviewer evaluates the system to determine that:

   a. The heat inputs that are used in the design of the UHS are conservative. The reviewer makes an independent evaluation of the applicant's calculated heat loads. The UHS heat loads include heat due to decay of radioactive material, sensible heat, pump work, and the heat load from the operation of the station auxiliary systems serving and dependent upon the UHS.

   b. Operational data from plants of similar design confirm, where possible, the heat input values given for sensible heat, pump work, and station auxiliary systems.

2. The reviewer verifies that:

   a. The total essential station heat load and system flow requirements of the service water system are compatible with the heat rejection capability of the UHS.

   b. The UHS has the capability to dissipate the maximum possible total heat load, including LOCA under the worst combination of adverse environmental conditions and has provisions for cooling the unit (or units, including LOCA for one unit for a multi-unit station with one heat sink) for a minimum of 30 days without makeup unless acceptable makeup capabilities can be demonstrated. This capability is verified by independent check calculations.

   c. The connecting channels, structures, man-made embankments and dams, and conduits to and from the UHS are capable of withstanding design basis natural phenomena in combination with other site-related events and that a single failure resulting from such phenomena or events cannot prevent adequate cooling water flow or adversely effect the temperature of the water from the sink.

3. Plants utilizing cooling towers as the ultimate heat sink are reviewed as described above and in addition the reviewer determines that:

   a. The tower structure and basin design bases in the SAR include requirements for withstanding design basis natural phenomena or combinations of such phenomena at historically observed intensities. The natural phenomena to be considered include tornadoes, tornado missiles, hurricane winds, and the SSE.

   b. The results of failure modes and effects analyses show that the mechanical systems (fans, pumps, and controls) can withstand a single active failure in any of these systems, including failure of any auxiliary electric power source, and not prevent delivery of water in the quantities and at temperatures required for safe shutdown.

   c. Adequate net positive suction head (NPSH) can be provided to all essential pumps considering variations of water level in the basis. This is verified by performing independent calculations.

   d. The towers can provide the design cooling water temperature under the worst combination of adverse environmental conditions, and that the supply of water in the basins can provide a 30-day capability for long-term cooling at the required temperature without makeup unless acceptable makeup capabilities can be demonstrated. This is verified by independent calculations.

4. Reactor sites that utilize large natural or man-made water sources which for all practical purposes have an infinite supply of water are reviewed as described in items 1 and 2, above, and in addition the reviewer determines:

   a. By evaluation of the SAR information or independent calculations, that the water source is adequate taking into account the effects of design basis natural phenomena such as tornadoes, hurricane winds, probable maximum floods, tsunami, seiches, and the SSE.

   b. By reviewing the SAR prelimin y site and plant arrangement sketches (CP) and (OL) site drawings and plant arrangement drawings that the design of the intake and outlet conduits (open or closed type) are properly separated to prevent recirculation or water temperature stratification.

   c. That man-made earth dam, dike, or other structure design bases in the SAR include requirements for withstanding the design basis natural phenomena or combinations of such phenomena at historically observed intensities. In the event of failure of a dam, dike, or other structure not designed to withstand the design basis natural phenomena (particularly the SSE), sufficient water must remain in the source pool to assure a cooling water supply for a minimum of 30 days, with adequate cooling capability so that the required cooling water temperature to the service water system inlet is not exceeded.

5. The reviewer verifies that essential portions of the UHS are classified seismic Category I Quality Group C, or higher and are tornado missile protected.

IV. EVALUATION FINDINGS

The reviewer verifies that sufficient information has been provided and his review supports conclusions of the following type, to be included in the staff's safety evaluation report:

> "The ultimate heat sink review included the size, type of cooling supply [i.e., large body of water, ocean, lake, natural or man-made reservoir, river, pond, or cooling tower], and makeup sources to the ultimate heat sink. The review for the ___________ plant included layout drawings, piping and instrumentation diagrams, process flow diagrams [if any], and descriptive information on the supporting systems that are essential to safe operation. [The review has determined the adequacy of the applicant's proposed design criteria and design bases for the ultimate heat sink and the requirements for delivering cooling water during normal, abnormal, and accident conditions. (CP)] [The review has determined that the design of the ultimate heat sink and supporting systems is in conformance with the proposed design criteria and design bases. (OL)]
>
> "The basis for acceptance in the staff review has been conformance of the applicant's designs, design criteria, and design bases for the ultimate heat sink and supporting systems to the Commission's regulations as set forth in the general design criteria, and to applicable regulatory guides, branch technical positions, and industry standards.
>
> "The staff concludes that the design of the ultimate heat sink conforms to all applicable regulations, guides, staff positions, and industry standards, and is acceptable."

V. REFERENCES

1. 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena."
2. 10 CFR Part 50, Appendix A, General Design Criterion 4, "Environmental and Missile Design Bases."
3. 10 CFR Part 50, Appendix A, General Design Criterion 5, "Sharing of Structures, Systems, and Components."
4. 10 CFR Part 50, Appendix A, General Design Criterion 44, "Cooling Water System."
5. 10 CFR Part 50, Appendix A, General Design Criterion 45, "Inspection of Cooling Water System."
6. 10 CFR Part 50, Appendix A, General Design Criterion 46. "Testing of Cooling Water System."
7. Regulatory Guide 1.26, "Quality Group Classifications and Standards for Water-, Steam-, and Radioactive-Waste-Containing Components of Nuclear Power Plants."

8. Regulatory Guide 1.27, "Ultimate Heat Sink for Nuclear Power Plants," Revision 1.

9. Regulatory Guide 1.29, "Seismic Design Classification," Revision 1.

BRANCH TECHNICAL POSITION APCSB 9-2

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

A. BACKGROUND

The Auxiliary and Power Conversion 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 percent 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:

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

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

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 $0 \le t_s \le 10^3$ and 0.1 for $10^3 \le t_s \le 10^7$

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 percent uncertainty factor (K) should be added for any cooling time less than 10^3 seconds, and a factor of 10 percent 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):

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

$$\frac{P(N_p\text{-239})}{Po} = 2.17 \times 10^{-3}\ C\ \frac{\sigma_{25}}{\sigma_{f25}} \Big\{ 0.007\ [1 - \exp(-4.91 \times 10^{-4}\ t_o)] \cdot [\exp(-3.41 \times 10^{-6}\ t_s) - \exp(-4.91 \times 10^{-4}\ t_s)] + [1 - \exp(-3.41 \times 10^{-6}\ t_o)]\ [\exp(-3.41 \times 10^{-6}\ t_s)] \Big\} \qquad (4)$$

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

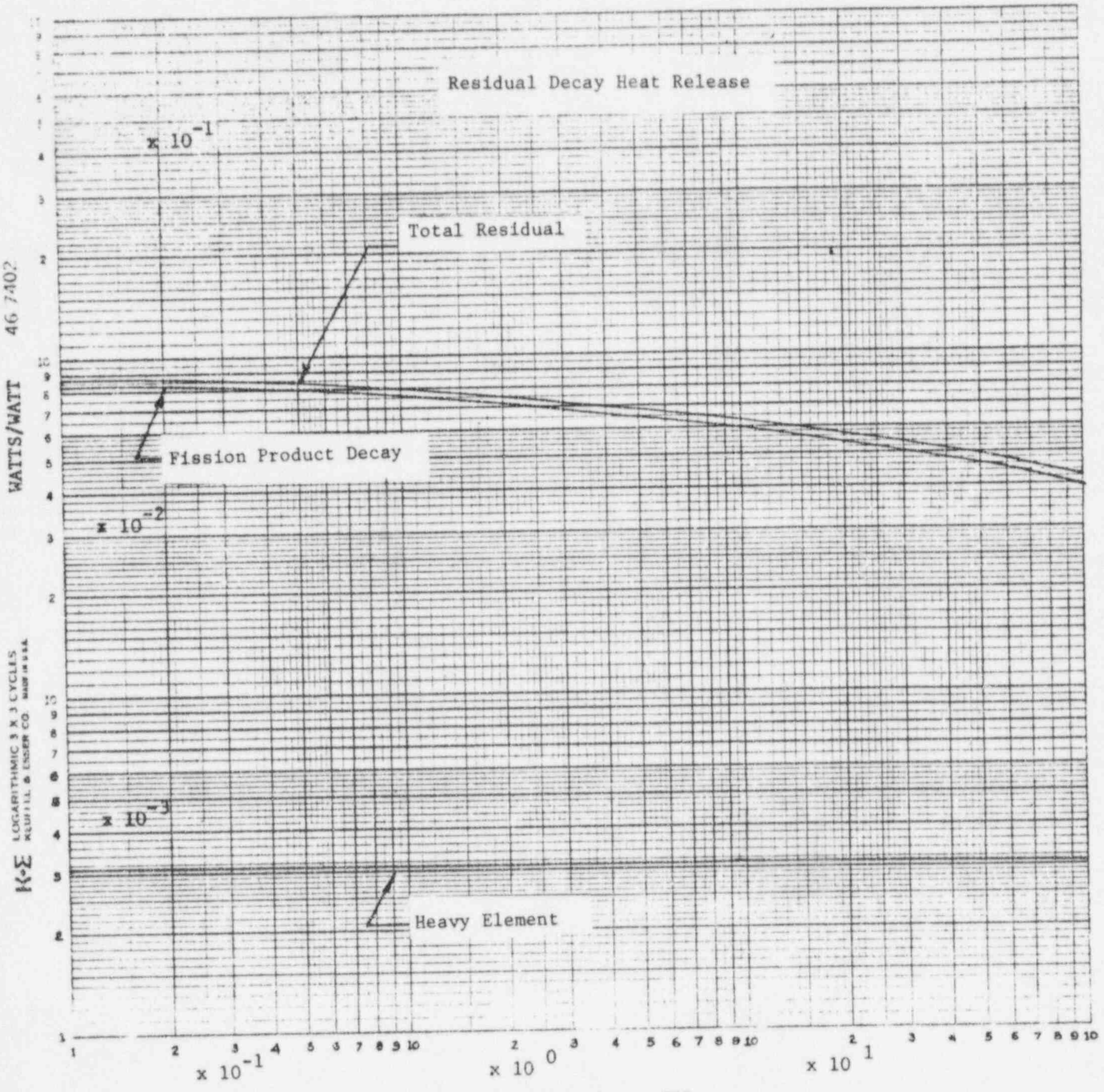
σ_{f25} = effective neutron fission cross section of U-235

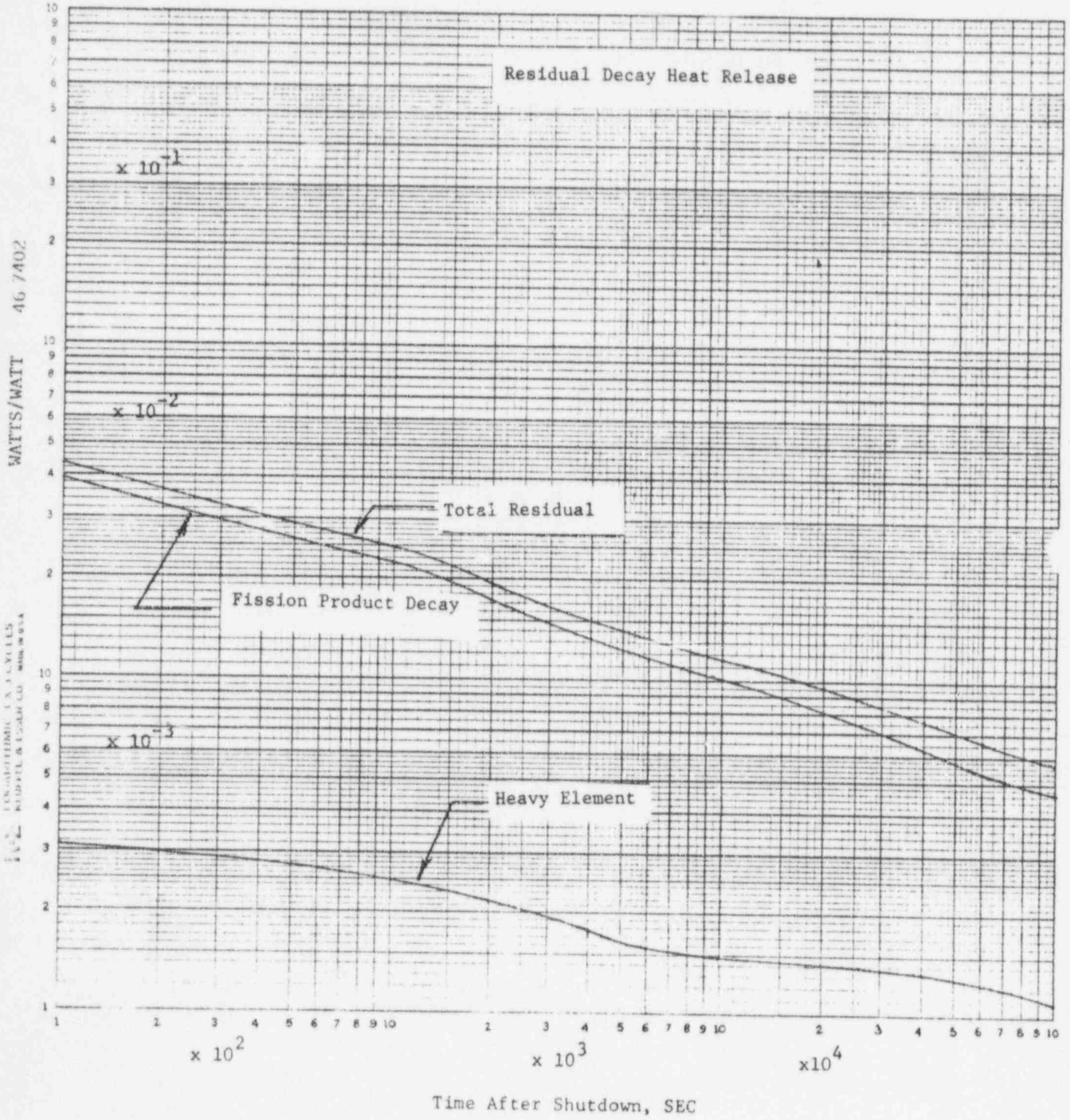
The product of the terms $C \cdot \frac{\sigma_{25}}{\sigma_{f25}}$ can be conservatively specified as 0.7.

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.

Sheet 1 of 3


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^-1
x 10^0
x 10^1
Time After Shutdown, SEC
K+E LOGARITHMIC 3 X 3 CYCLES KEUFFEL & ESSER CO. MADE IN U.S.A.
1 2 3 4 5 6 7 8 9 10


Residual Decay Heat Release
WATTS/WATT
46 7402
LOGARITHMIC 3 X 3 CYCLES
KEUFFEL & ESSER CO.
x 10^-1
x 10^-2
x 10^-3
Total Residual
Fission Product Decay
Heavy Element
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x 10^2
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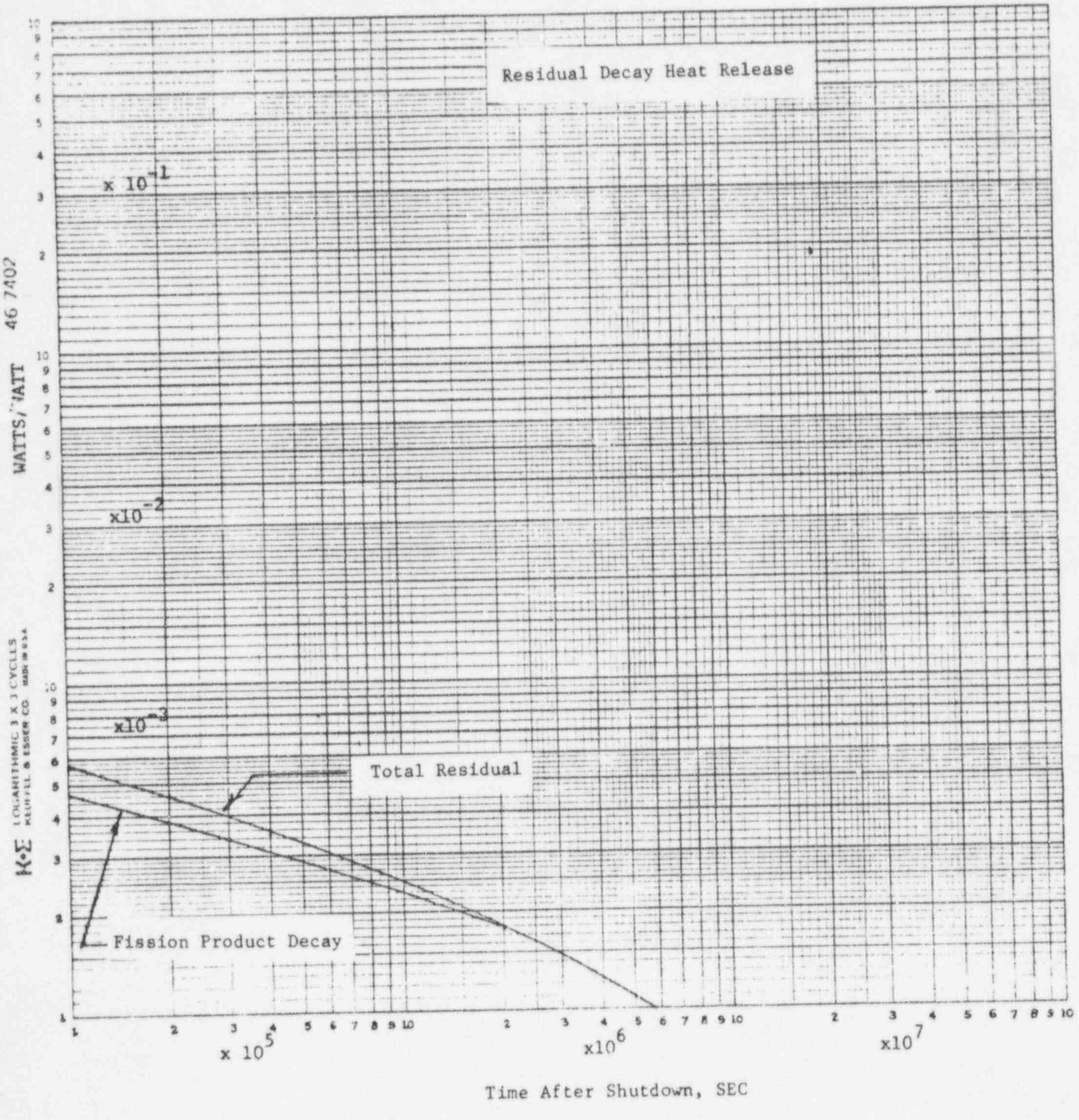
Time After Shutdown, SEC

Sheet 3 of 3


Residual Decay Heat Release
WATTS/WATT
x 10^-1
x10^-2
x10^-3
Total Residual
Fission Product Decay
x 10^5
x10^6
x10^7
Time After Shutdown, SEC
46 7402
K&E LOGARITHMIC 3 X 3 CYCLES KEUFFEL & ESSER CO. MADE IN U.S.A.

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 ^{233}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.

SRP 9.2-6