



U.S. NUCLEAR REGULATORY COMMISSION

# STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

## 9.2.5 ULTIMATE HEAT SINK

### REVIEW RESPONSIBILITIES

Primary - Auxiliary Systems Branch (ASB)

Secondary - None

### 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 design of the UHS must satisfy the requirements of General Design Criteria 2, 5, 44, 45, and 46.

The ASB 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, accident, or shutdown condition 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 SRP Section 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, floods and hurricane winds on the availability of the source water. The UHS is also reviewed

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### USNRC STANDARD REVIEW PLAN

Standard review plans are prepared for the guidance of the Office of Nuclear Reactor Regulation staff responsible for the review of applications to construct and operate nuclear power plants. These documents are made available to the public as part of the Commission's policy to inform the nuclear industry and the general public of regulatory procedures and policies. Standard review plans are not substitutes for regulatory guides or the Commission's regulations and compliance with them is not required. The standard review plan sections are keyed to the Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants. Not all sections of the Standard Format have a corresponding review plan.

Published standard review plans will be revised periodically, as appropriate, to accommodate comments and to reflect new information and experience.

Comments and suggestions for improvement will be considered and should be sent to the U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Washington, D.C. 20555.

to assure that adverse environmental conditions including freezing will not preclude the safety function of the UHS.

- e. Sharing of cooling water sources in multiunit 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. ASB 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. ASB also performs the following reviews under the SRP sections indicated:
- a. Review of flood protection is performed under SRP Section 3.4.1,
  - b. Review of the protection against internally generated missiles is performed under SRP Section 3.5.1.1,
  - c. Review of the structures, system, and components to be protected against externally generated missiles is performed under SRP Section 3.5.2, and
  - d. Review of high- and moderate-energy pipe breaks is performed under SRP Section 3.6.1.

In addition, ASB will coordinate other branch evaluations that interface with the overall review of the system as follows: The Reactor Systems Branch (RSB) will confirm the heat loads transmitted to the UHS from the reactor coolant and emergency core cooling systems as part of its primary review responsibility for SRP Section 6.3. The Structural Engineering Branch (SEB) will determine 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 the tornado missiles as part of its primary review responsibility for SRP Sections 3.3.1, 3.3.2, 3.5.3, 3.7.1 through 3.7.4, 3.8.4, and 3.8.5. The Materials Engineering Branch (MTEB) verifies the inservice inspection requirements are met for system components and the compatibility of the materials of construction with the service conditions as part of its primary review responsibility for SRP Section 6.1.1. The Instrumentation and Control Systems Branch (ICSB) and Power Systems Branch (PSB) will verify the adequacy of the design, installation, inspection, and testing of all electrical systems (sensing, control, and power) required for proper operation as part of the primary review responsibilities for SRP Section 7.1 and Appendix 7-A for ICSB and SRP Section 8.3.1 for PSB. The Hydrologic and Geotechnical Engineering Branch (HGEB) verifies the ultimate heat sink water levels, meteorological and natural phenomena criteria, and transient analysis of the cooling water inventory as part of its primary review responsibility for SRP Section 2.4. The review for fire protection, technical specifications, and quality assurance are coordinated and performed by the Chemical Engineering Branch, Licensing Guidance Branch, and Quality Assurance Branch as part of their primary review responsibility for SRP Sections 9.5.1, 16.0, and 17.0, respectively.

For those areas of review identified above as being reviewed as part of the primary review responsibility of other branches, the acceptance criteria and their methods of application are contained in the SRP sections corresponding to those branches.

## **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.

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. Acceptance is based on meeting the guidance of Regulatory Guide 1.29, Position C-1 and Regulatory Guide 1.27, Positions C-2 and C-3.
2. General Design Criterion 5, as related to shared systems and components important to safety being capable of performing required safety functions.
3. 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.
  - d. Acceptance is based upon meeting the guidance of Regulatory Guide 1.27, Positions C-2 and C-3 and Regulatory Guide 1.72, Positions C-1, C-4, C-5, C-6, and C-7, as well as Branch Technical Position ASB 9-2.
4. General Design Criterion 45, as related to the design provisions to permit inservice inspection of safety-related components and equipment.
5. General Design Criterion 46, as related to the design provisions to permit operation functional testing of safety-related systems or components.

## **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 subsection II of this SRP section. 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.

Upon request from the primary reviewer, the coordinated review branches will provide input for the areas of review stated in subsection I of this SRP section. The primary reviewer obtains and uses such input as required to assure that this review procedure is complete.

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 SRP section, 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 phenomena including freezing and to 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 including freezing and has provisions for cooling the unit (or units, including LOCA for one unit for a multiunit 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 of any man-made feature 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, floods, 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 basin. 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 including freezing, 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.
  - e. Cooling towers or spray ponds used as a UHS and designed to withstand the effects of tornado missiles need not be designed to seismic Category I if another UHS is also available that is designed to meet the seismic classification guidelines of Regulatory Guide 1.27.
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, tsunamis, seiches, and the SSE.
  - b. By reviewing the SAR preliminary 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. As indicated in subsection I of this SRP section, the review of seismic design is performed by SEB and the review for seismic and quality group classification is performed by MEB.

#### 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 has determined the adequacy of the applicant's proposed design criteria, design bases and safety classification for the ultimate heat sink and the requirements for delivering cooling water for a safe shutdown during normal and accident conditions. The UHS and its supporting systems meet seismic category I, Quality Group C requirements. The staff concludes that the design of the ultimate heat sink is acceptable and meets the requirements of General Design Criteria 2, 5, 44, 45, and 46. This conclusion is based on the following:

1. The applicant has met the requirement of General Design Criterion 2 with respect to being capable of withstanding the effects of earthquakes. Acceptance is based on meeting the guidance of Regulatory Guide 1.29, Position C-1.
2. The applicant has met the requirements of General Design Criterion 5 with respect to sharing of structures, systems, and components by demonstrating that such sharing does not affect the safe shutdown of either unit in the event of an active or passive failure.
3. The applicant has met the requirements of General Design Criterion 44 with respect to the ultimate heat sink. Acceptance is based on meeting the guidance of Regulatory Guides 1.27 and 1.72, as well as Branch Technical Position ASB 9-2.
4. The applicant has met the requirements of General Design Criterion 45 with respect to inservice inspection of the safety-related components and equipment by demonstrating the accessibility of the UHS system for periodic inspections.
5. The applicant has met the requirements of General Design Criterion 46 with respect to periodic pressure and functional testing to assure structural and leaktight integrity, operability, and performance of its active components, and operability of the system as a whole by demonstrating the capability to operate the system at full capacity during normal startup or shutdown procedures or during normal operation without degrading the system to provide for a safe shutdown or to mitigate the consequences of an accident.

## V. IMPLEMENTATION

The following is intended to provide guidance to the applicants and licensees regarding the NRC staff's plans for using this SRP section.

Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used by the staff in its evaluation of conformance with Commission regulations.

Implementation schedules for conformance to parts of the method discussed herein are contained in the referenced regulatory guides.

## VI. 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 5, "Sharing of Structures, Systems, and Components."
3. 10 CFR Part 50, Appendix A, General Design Criterion 44, "Cooling Water System."
4. 10 CFR Part 50, Appendix A, General Design Criterion 45, "Inspection of Cooling Water System."
5. 10 CFR Part 50, Appendix A, General Design Criterion 46, "Testing of Cooling Water System."
6. Regulatory Guide 1.27, "Ultimate Heat Sink for Nuclear Power Plants."
7. Regulatory Guide 1.29, "Seismic Design Classification."
8. Regulatory Guide 1.72, "Spray Pond Plastic Piping."
9. Branch Technical Position ASB 9-2, "Residual Decay Energy for Light Water Reactors for Long-Term Cooling."

## 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 ( $t_0$ ) the fraction of operating power,  $\frac{P}{P_0}(t_0, t_s)$ , to be used for the fission product decay power at a time  $t_s$  after shutdown may be calculated as follows:

$$\frac{P}{P_0}(\infty, t_s) = \frac{1}{200} \sum_{n=1}^{n=11} A_n \exp(-a_n t_s) \quad (1)$$

$$\frac{P}{P_0}(t_0, t_s) = (1 + K) \frac{P}{P_0}(\infty, t_s) - \frac{P}{P_0}(\infty, t_0 + t_s) \quad (2)$$

where:

$\frac{P}{P_0}$  = fraction of operating power

$t_0$  = cumulative reactor operating time, seconds

$t_s$  = time after shutdown, seconds

$K$  = uncertainty factor; 0.2 for  $0 \leq t_s < 10^3$  and 0.1 for  $10^3 \leq t_s \leq 10^7$

$A_n, a_n$  = fit coefficients having the following values:



<u>n</u>	<u>A<sub>n</sub></u>	<u>a<sub>n</sub> (sec<sup>-1</sup>)</u>
1.	0.5980	1.772 x 10 <sup>0</sup>
2	1.6500	5.774 x 10 <sup>-1</sup>
3	3.1000	6.743 x 10 <sup>-2</sup>
4	3.8700	6.214 x 10 <sup>-3</sup>
5	2.3300	4.739 x 10 <sup>-4</sup>
6	1.2900	4.810 x 10 <sup>-5</sup>
7	0.4620	5.344 x 10 <sup>-6</sup>
8	0.3280	5.716 x 10 <sup>-7</sup>
9	0.1700	1.036 x 10 <sup>-7</sup>
10	0.0865	2.959 x 10 <sup>-8</sup>
11	0.1140	7.585 x 10 <sup>-10</sup>

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<sup>3</sup> seconds, and a factor of 10% should be added for cooling times greater than 10<sup>3</sup> but less than 10<sup>7</sup> seconds.

## 2. Heavy Element Decay Heat

The decay heat generation due to the heavy elements U-239 and N<sub>p</sub>-239 may be calculated according to the following expressions (Ref. 6):

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

$$\begin{aligned} \frac{P(N-239)}{P_o} = & 2.17 \times 10^{-3} C \frac{\sigma_{25}}{\sigma_{f25}} \\ & \{1.007 [1 - \exp(-3.41 \times 10^{-6} t_o)] \exp(-3.41 \times 10^{-6} t_s) \\ & - 0.007 [1 - \exp(-4.91 \times 10^{-4} t_o)] \exp(-4.91 \times 10^{-4} t_s)\} \end{aligned} \quad (4)$$

where:

$\frac{P(U-239)}{P_0}$  = fraction of operating power due to U-239

$\frac{P(N_p-239)}{P_0}$  = fraction of operating power due to  $N_p$ -239

$t_0$  = 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

$\sigma_{25}$  = effective neutron absorption cross section of U-235

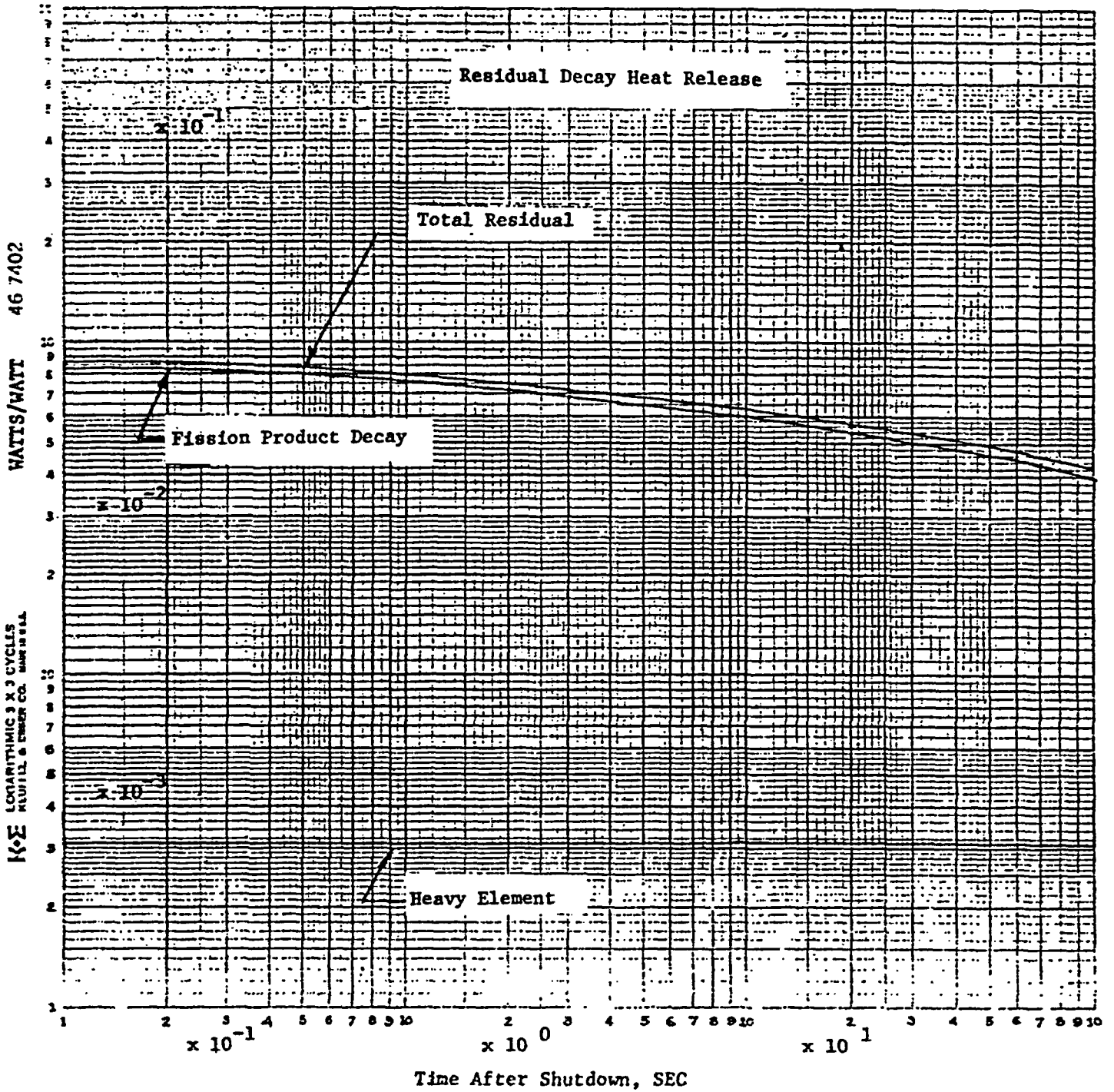
$\sigma_{f25}$  = effective neutron fission cross section of U-235

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.

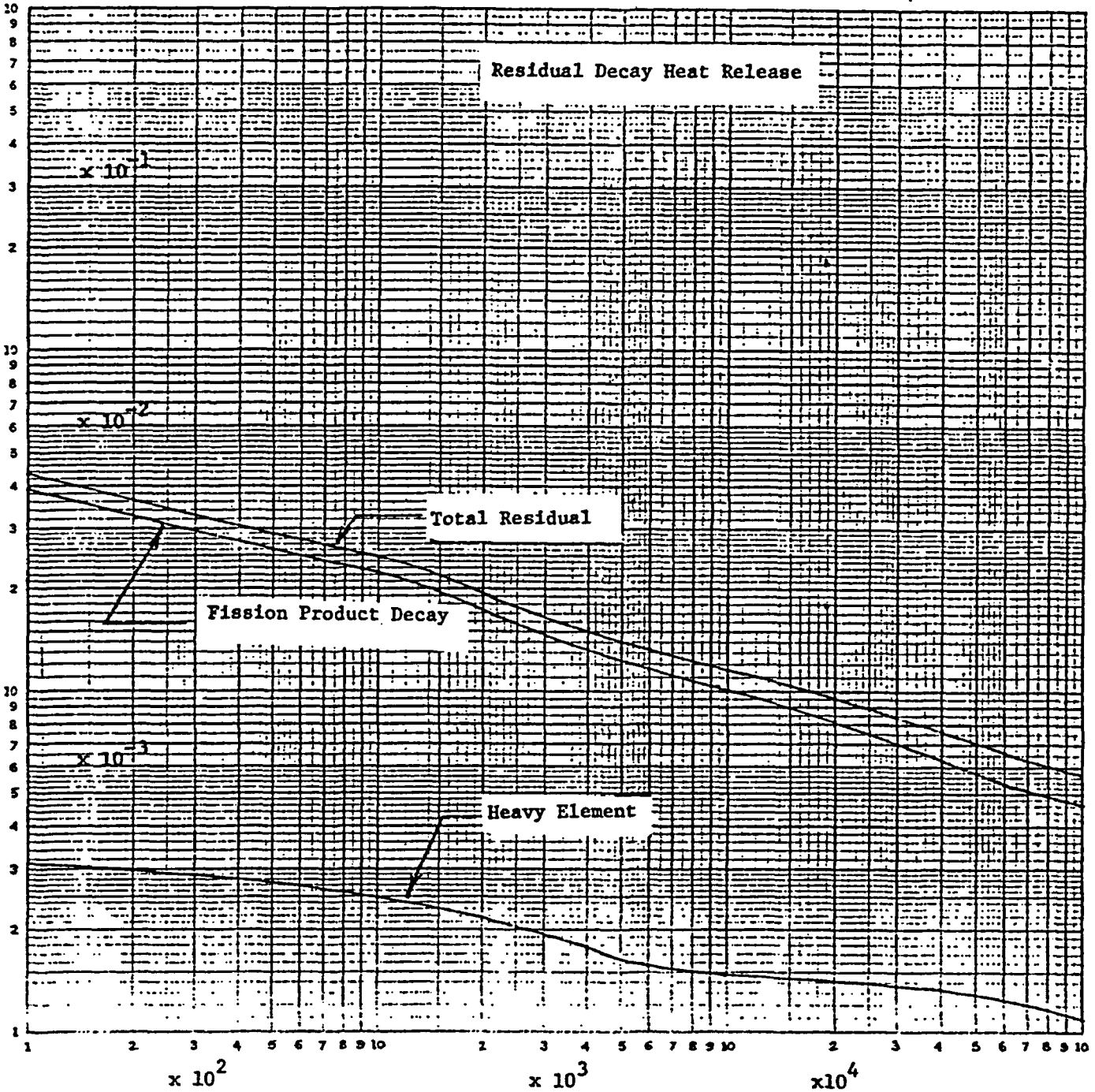
- Figures 1, 2, and 3 give the residual decay heat release in terms of fractions of full reactor operating power based on a reasonably realistic reactor operating time of 16,000 hours.

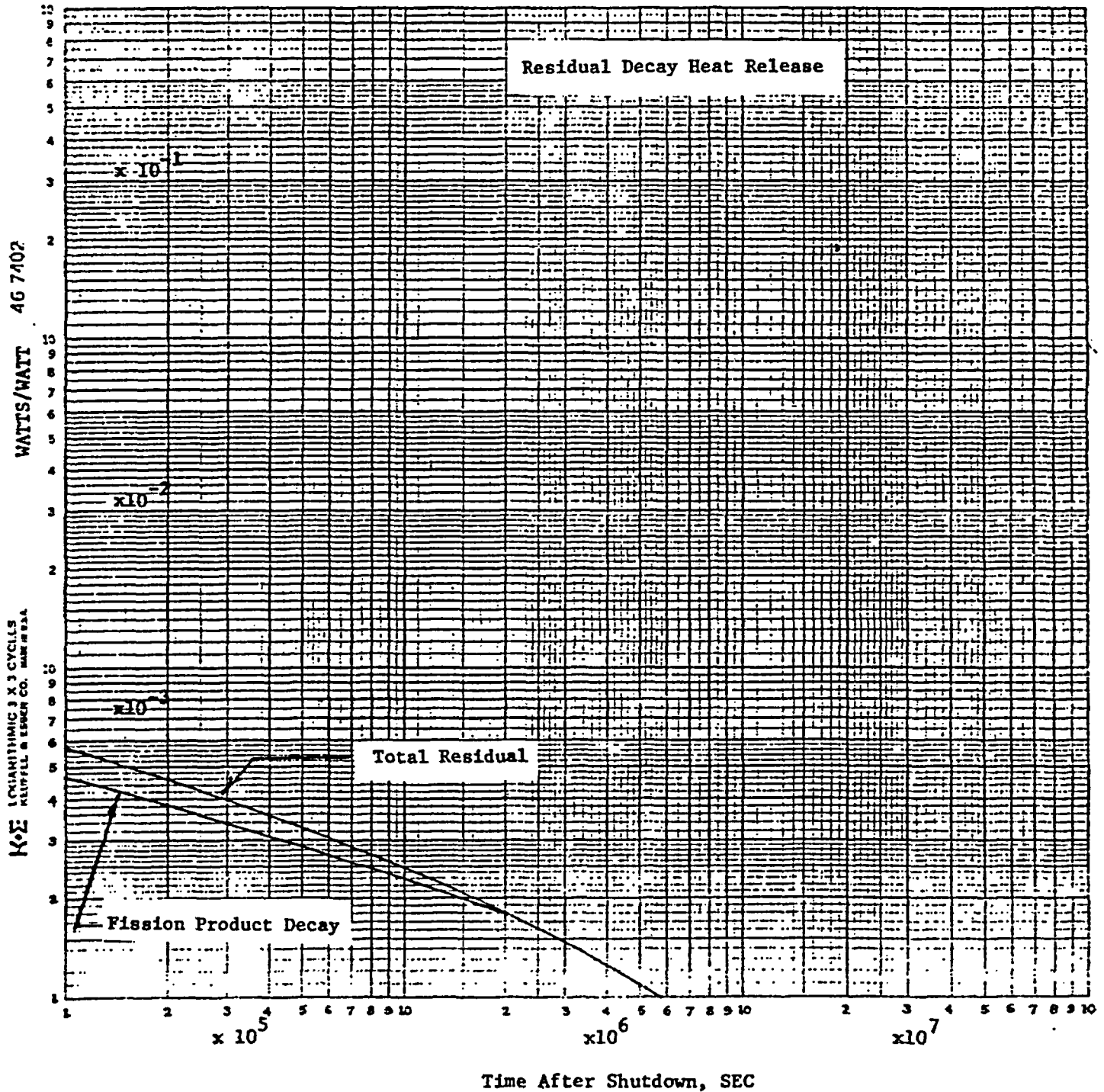


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7. J. Scobie and R. D. Scott, "Calculation of Beta Energy Release Rates Following Thermal Neutron Induced Fission of  $^{238}\text{U}$ ,  $^{235}\text{U}$ ,  $^{239}\text{Pu}$ , and  $^{241}\text{Pu}$ ," Journal of Nuclear Energy, Vol. 25, 339 (1971).
8. K. Shure, "Fission Product Decay Energy," WAPD-BT-24, Westinghouse Electric Corporation, December 1961.