Find erratum inside front cover.
Contact standards@ans.org with questions.

AMERICAN NUCLEAR SOCIETY ANS

Decay Heat Power in Light Water Reactors

ANSI/ANS-5.1-2014

An American National Standard

Published by the
American Nuclear Society
555 N. Kensington Ave
La Grange Park, IL 60526

ERRATUM

ANSI/ANS-5.1-2014

Decay Heat Power in Light Water Reactors

A typographical error was identified on page 30, formula (28). Time should be 10^4 s not 10^{-4} s." The corrected formula is provided below:

6 Total decay heat power

The total decay heat power from the fission products and actinides is calculated as

$$P_T(t,T) = P_d'(t,T) + P_{dC}(t,T) + P_{dHE}(t,T) + P_{dA}(t,T), \quad (27)$$

where

$$P_{dC}(t,T) = \begin{cases} P_d'(t,T) \cdot G(t), & t \leq 10^4 \text{ s} \\ P_{dCs}(t,T) + P_{dE}(t,T), & t > 10^4 \text{ s} \end{cases}. \quad (28)$$

The total uncertainty is determined from the uncertainty in the fission product decay heat power without neutron capture in fission products, $\Delta P_d'(t,T)$, as described in Eq. (6), and the uncertainty in the operating power, ΔP, as described in Eq. (7). The other terms in Eq. (27) are defined to provide conservative overestimates of their contributions to the decay heat power, and the uncertainties in these terms are therefore not included in the total uncertainty.

ANSI/ANS-5.1-2014

American National Standard Decay Heat Power in Light Water Reactors

Secretariat
American Nuclear Society

Prepared by the
American Nuclear Society
Standards Committee
Working Group ANS-5.1

Published by the
American Nuclear Society
555 North Kensington Avenue
La Grange Park, Illinois 60526 USA

Approved November 4, 2014
by the
American National Standards Institute, Inc.

American National Standard

Designation of this document as an American National Standard attests that the principles of openness and due process have been followed in the approval procedure and that a consensus of those directly and materially affected by the standard has been achieved.

This standard was developed under the procedures of the Standards Committee of the American Nuclear Society; these procedures are accredited by the American National Standards Institute, Inc., as meeting the criteria for American National Standards. The consensus committee that approved the standard was balanced to ensure that competent, concerned, and varied interests have had an opportunity to participate.

An American National Standard is intended to aid industry, consumers, governmental agencies, and general interest groups. Its use is entirely voluntary. The existence of an American National Standard, in and of itself, does not preclude anyone from manufacturing, marketing, purchasing, or using products, processes, or procedures not conforming to the standard.

By publication of this standard, the American Nuclear Society does not insure anyone utilizing the standard against liability allegedly arising from or after its use. The content of this standard reflects acceptable practice at the time of its approval and publication. Changes, if any, occurring through developments in the state of the art may be considered at the time that the standard is subjected to periodic review. It may be reaffirmed, revised, or withdrawn at any time in accordance with established procedures. Users of this standard are cautioned to determine the validity of copies in their possession and to establish that they are of the latest issue.

The American Nuclear Society accepts no responsibility for interpretations of this standard made by any individual or by any ad hoc group of individuals. Requests for interpretation should be sent to the Standards Department at Society Headquarters. Action will be taken to provide appropriate response in accordance with established procedures that ensure consensus on the interpretation.

Comments on this standard are encouraged and should be sent to Society Headquarters.

Published by

American Nuclear Society
555 North Kensington Avenue
La Grange Park, Illinois 60526 USA

Printed in the United States of America

Inquiry Requests

The American Nuclear Society (ANS) Standards Committee will provide responses to inquiries about requirements, recommendations, and/or permissive statements (i.e., "shall," "should," and "may," respectively) in American National Standards that are developed and approved by ANS. Responses to inquiries will be provided according to the Policy Manual for the ANS Standards Committee. Nonrelevant inquiries or those concerning unrelated subjects will be returned with appropriate explanation. ANS does not develop case interpretations of requirements in a standard that are applicable to a specific design, operation, facility, or other unique situation only and therefore is not intended for generic application.

Responses to inquiries on standards are published in ANS's magazine, *Nuclear News*, and are available publicly on the ANS Web site or by contacting the ANS Standards Administrator.

Inquiry Format

Inquiry requests shall include the following:

(1) the name, company name if applicable, mailing address, and telephone number of the inquirer;

(2) reference to the applicable standard edition, section, paragraph, figure, and/or table;

(3) the purpose(s) of the inquiry;

(4) the inquiry stated in a clear, concise manner;

(5) a proposed reply, if the inquirer is in a position to offer one.

Inquiries should be addressed to

American Nuclear Society
ATTN: Standards Administrator
555 N. Kensington Avenue
La Grange Park, IL 60526

or standards@ans.org

Foreword

(This Foreword is not a part of American National Standard “Decay Heat Power in Light Water Reactors,” ANSI/ANS-5.1-2014.)

This American National Standard provides values for the decay heat power from fission products and actinides following the shutdown of light water reactors operated with nuclear fuel consisting of uranium. The energy released in the fission process is divided into (1) prompt energy from the kinetic energy of fission fragments, neutrons, and gamma rays from prompt de-excitation of fission products and (2) delayed energy from beta particles and gamma rays emitted from the decay of fission products.

The development of this standard was initiated due to the importance of energy release after reactor shutdown and the need for accurate data to evaluate fuel rod heating during a loss-of-coolant accident. The ANS Standards Subcommittee first proposed the adoption of a new standard on decay heat power in October, 1971. Following minor revisions in 1973, it was submitted to the American National Standards Institute but remained as a draft standard. After significant technical developments based on data from new experimental programs, the draft standard was revised and approved and released as the 1979 standard. Since then, it was reaffirmed in 1985, revised in 1994, and revised again in 2005. The revisions since 1979 have been guided largely by recommendations made by Dickens, England, and Schenter on future improvements to the standard.[1)] A detailed technical summary of the development of the standard and revisions is provided as an Appendix to this standard.

The standard prescribes methods that enable the calculation of fission product decay heat power and uncertainty with accuracies comparable to those of summation codes but without the need for complex calculations. Fission product decay heat values are provided for thermal neutron-induced fission of ^{235}U, ^{239}Pu, and ^{241}Pu and fast fission of ^{238}U.

As revised, this standard provides better guidance on methods and implementation, an improved representation of uncertainties in the fission product decay heat values, and an improved method for the neutron capture correction. Also included, for the first time, is a complete estimate of all actinide contributions to decay heat power. The changes in this revision do not alter the tabular data for standard fission product decay heat power and uncertainty values from the 1994 and 2005 standards, but they do include several recommendations for near-term improvements to the standard identified by Dickens, England, and Schenter.

Relationship to Other Standards

ANSI/ANS-19.3.4-2002 (R2008), “Determination of Thermal Energy Deposition Rates in Nuclear Reactors”

Proposed American National Standard ANS-19.8, “Fission-Product Yields for ^{235}U, ^{238}U, and ^{239}Pu” (in draft form)

ANSI/ANS 19.1-2002 (R2011), “Nuclear Data Sets for Reactor Design Calculations”

This standard might reference documents and other standards that may have been superseded or withdrawn at the time this standard is applied.

[1)] J. K. Dickens, T. R. England, and R. E. Schenter, “Current Status and Proposed Improvements to the ANSI/ANS-5.1 American National Standard for Decay Heat Power in Light Water Reactors,” *Nucl. Safety*, **32**, 209 (1991).

This standard does not incorporate the concepts of generating risk-informed insights, performance-based requirements, or a graded approach to quality assurance. The user is advised that one or more of these techniques could enhance the application of this standard.

The working group acknowledges the substantial efforts of earlier working groups in establishing and maintaining this standard. The working group specifically acknowledges the significant contributions made to the standard by the late J. Kirk Dickens and Robert Schenter, who passed away before this standard was issued. Both of these working group members played key roles in the development and advancement of the standard and provided a roadmap for future improvements of the standard that was used to guide this revision.

Working Group ANS-5.1 of the Standards Committee of the American Nuclear Society had the following membership at the time of its approval of this revision of the standard:

I. C. Gauld (Chair), *Oak Ridge National Laboratory*
M. C. Brady Raap (Past Chair for ANSI/ANS-5.1-2005), *Pacific Northwest National Laboratory*
W. B. Wilson (Past Chair for ANSI/ANS-5.1-1994), *Los Alamos National Laboratory*

M. Aissa, *U.S. Nuclear Regulatory Commission*
D. Carpenter, *Bettis Atomic Power Laboratory*
R.-T. Chiang, *AREVA Inc.*
J. K. Dickens, *Individual*
A. H. Fero, *Westinghouse Electric Company, LLC*
J. Katakura, *Nagaoka University of Technology*
J. Klingensmith, *Westinghouse Electric Company, LLC*
E. R. Knuckles, *Individual*
R. Schenter, *Individual*
H. Trellue, *Los Alamos National Laboratory*
S. Wang, *Westinghouse Electric Company, LLC*
T. Yoshida, *Musashi Institute of Technology*
D. Ziabletsev, *AREVA Inc.*

The membership of Subcommittee ANS-19 at the time of the review and approval of this standard was as follows:

D. M. Cokinos (Chair), *Brookhaven National Laboratory*
C. T. Rombough (Secretary), *CTR Technical Services*

A. Attard, *Individual*
S. Baker, *Transware*
W. H. Bell, *South Carolina Electric & Gas Co.*
J. Bess, *Idaho National Laboratory*
R. J. Borland, *First Energy Corp.*
M. C. Brady Raap, *Pacific Northwest National Laboratory*
R.-T. Chiang, *AREVA Inc.*
M. DeHart, *Idaho National Laboratory*
D. J. Diamond, *Brookhaven National Laboratory*
I. C. Gauld, *Oak Ridge National Laboratory*
A. Haghighat, *Virginia Tech Research Center*
D. J. Harris, *Individual*
M. Mahgerefteh, *Exelon Corporation*

J. Katakura, *Nagaoka University of Technology*
E. R. Knuckles, *Individual*
B. Rouben, *Individual*
A. Weitzberg, *Individual*

The membership of the Safety and Radiological Analyses Consensus Committee at the time of the review and approval of this standard was as follows:

A. O. Smetana (Chair), *Savannah River National Laboratory*
A. Weitzberg, (Vice Chair), *Individual*

F. A. Alpan, *Westinghouse Electric Company, LLC*
R. S. Amato, *Bechtel Marine Propulsion Corporation*
M. C. Brady Raap, *Pacific Northwest National Laboratory*
R. R. Brey, *Health Physics Society (Employed by Idaho State University)*
R. E. Carter, *Individual*
D. M. Cokinos, *Brookhaven National Laboratory*
M. L. Corradini, *National Council on Radiation Protection and Management (Employed by University of Wisconsin-Madison)*
D. J. Dudziak, *Los Alamos National Laboratory*
I. C. Gauld, *Oak Ridge National Laboratory*
M. K. Gupta, *URS-Professional Solutions*
N. E. Hertel, *Georgia Institute of Technology*
K. A. Morrell, *Savannah River Nuclear Solution*
C. T. Rombough, *CTR Technical Services, Inc.*
C. E. Sanders, *University of Nevada, Las Vegas*

Contents

Appendices

Decay Heat Power in Light Water Reactors

1 Scope and purpose

1.1 Scope

This standard sets forth values for the decay heat power from fission products and actinides following shutdown of light water reactors (LWRs) using nuclear fuel initially containing ^{235}U and ^{238}U. The decay heat power from fission products is presented in tables and equivalent analytical representations. Contributions from the decay of ^{239}U and ^{239}Np and the contributions from all other actinides are represented separately. Methods are described that account for the reactor operating history, for the effect of neutron capture in fission products, and for assessing the uncertainty in the resultant decay heat power.

The standard applies to decay times of up to 10^{10} s after shutdown.

1.2 Purpose and application

This standard provides bases for determining the decay heat power and its uncertainty following shutdown of LWRs. The information in this standard can be used in the design, performance evaluation, and assessment of the safety of LWRs.

The methods prescribed in this standard enable the calculation of fission product decay heat power with accuracies comparable to those of summation codes but without the need for complex calculations. The fission product decay heat power values in this standard have the advantage of being developed directly from experimental measurements for time periods $<10^5$ s after fission. Therefore, this standard can be used as the basis for comparison with results of alternate methods for determining fission product decay heat power.[1)]

2 Range of application

2.1 Limitations

The standard methods for evaluating decay heat described herein are applicable to LWRs containing ^{235}U as the initial major fissile material and ^{238}U as the fertile material. The contributions from the fission of ^{235}U, ^{238}U, ^{239}Pu, and ^{241}Pu are treated explicitly; other fissionable nuclides are accounted for by treating them as ^{235}U. The application of this standard to mixed oxide or other recycled nuclear fuels is not supported.

Decay heat power from activation products in structural materials and fission power from delayed neutron–induced fission are not included in this standard and shall be evaluated by the user and appropriately included in any analysis of decay heat power.

2.2 Standard decay heat power representation

Standard fission product decay heat power values are provided in tabular form and as analytical representations of the thermal reactor neutron spectrum fission of ^{235}U, ^{239}Pu, and ^{241}Pu and for fast fission of ^{238}U at various times after fission. Uncertainties are provided for each shutdown time for each of the tabulations.

1) Examples of the use of the standard methods are presented in Appendix B.