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Foreword

(This Foreword is not a part of American National Standard for Decay Heat Power in Light Water Reactors, ANSI/ANS-5.1-1979.)

The ANS Standards Subcommittee 5 proposed, in October 1971, the adoption of a standard entitled "Decay Energy Release Rates Following Shutdown for Uranium-Fueled Thermal Reactors." The Standards Committee approved the proposed standard and submitted it to the American National Standards Institute (ANSI). Following balloting and comments by those voting, minor revisions were made in October 1973.(1)* Although the required number of affirmative votes were received, ANSI tabled action on the standard pending resolution of a strong objection to its adoption that arose after the ANSI balloting. It has since remained in the status of a proposed ANS standard; however, the Atomic Energy Commission, now Nuclear Regulatory Commission (NRC), has used the proposed standard in the regulatory process.

The proposed ANS standard (1971 and 1973) was based on the curve recommended by K. Shure (2) for infinite irradiation of uranium and for cooling times from 0 to 10^9 seconds. The approach was simplistic in that a single curve was chosen to represent the decay heat power of "uranium-fueled thermal reactors." Many phenomena that make the decay heat power unique to each case were ignored and assumed to be included within the appropriately large uncertainties that were adopted. Uncertainty bands were chosen by the ANS-5.1 Working Group on the basis of comparison of available data (3-8) as follows:

Cooling Time	Uncertainty
$t_s < 10^3$ seconds	+ 20%, - 40%
10^3 seconds $< t_s < 10^7$ seconds	+ 10%, - 20%
$t_s > 10^7$ seconds	+ 25%, - 50%

where

t_s = cooling time in seconds

+ refers to the interval above the standard value within which the true value may reside.

An example of the use by AEC/NRC of the standard is the requirement (9) that for evaluation of Emergency Core Cooling System (ECCS) performance in hypothetical Loss of Coolant Accidents (LOCA), "the heat generation rates from radioactive decay of fission products shall be assumed equal to 1.2 times the values for infinite operating time in the ANS standard . . ." The factor 1.2 appears to have been based upon the ANS uncertainty for $t_s \leq 10^3$ seconds.

In 1974, new research programs were initiated under the auspices of the Energy Research and Development Administration, Nuclear Regulatory Commission, and Electric Power Research Institute to better quantify decay heat and its uncertainty for short cooling times. The ANS 5.1 Working Group was reconstituted to include those individuals engaged in the new research and representatives from industry and NRC who have knowledge of decay heat from those perspectives. The first objective of the Working Group was defined to be a revision of the ANS 5.1 standard for LOCA applications (cooling time up to 10^4 seconds) in LWR's. The present revision provides precise results, including detailed evaluation of the influence of neutron capture in fission products for this shutdown time range. It also covers the cooling times up to 10^9 seconds by use of an upper bound for the capture effect. Subsequently, it is planned to extend the revised standard to:

a. Improve the capture effect specification in cooling times $10^4 \leq t \leq 10^9$ sec
b. Address other thermal reactor fuel cycles
c. Address fast reactor fuel cycles.

*Numbers in parentheses refer to the Bibliography attached to this foreword.

The approach to developing the revised standard has been similar to that followed previously in that:

a. The standard prescribes fission product decay heat power and its uncertainty for reactor operating histories. Although the data adopted depend in part on the summation calculation method, the summation calculation itself is not chosen as the proposed standard.

b. The standard prescribes data that are applicable to Light Water Reactors of the type currently operating in the USA.

c. The standard prescribes the recoverable energy release rates from fission product decay but does not specify the spatial distribution of the deposition of the energy in reactor materials. This aspect of the problem is reactor specific and must be dealt with by the user of the standard.

d. Decay heat power from ^{239}U and ^{239}Np are separately prescribed and are to be added to the fission product decay heat power.

e. A method is prescribed for obtaining decay heat power for arbitrary reactor operating histories from the standard.

f. The decay heat power is related to the operating power of the reactor via the fission rate and the recoverable energy per fission during operation. The energy release per fission depends upon the energy spectrum of the neutron flux in the operating reactor and the composition of the reactor core. The standard requires the user to supply and justify this quantity.

g. Decay heat power from activation products in reactor materials is not specified in the standard.

Features that distinguish the revised standard from the original version are:

a. The effect of neutron capture in fission products during reactor operation is accounted for in the revised standard. An upper bound for the effect of neutron capture in fission products that provides conservative values of decay heat power is given for the case of a long operation of a ^{235}U fueled LWR at high neutron flux. The given correction may be used for real operations for which none of the parameters of operation exceeds the parameters specified in the revised standard (Section 3.5) which were used in the computation of the correction due to neutron capture.

b. Data are prescribed for decay heat power from fission products from fissioning of the major fissionable nuclides present in LWR's, i.e., ^{235}U and ^{239}Pu thermal and ^{238}U fast, and methods are prescribed for evaluating the total fission product decay heat power from the data given for these specific fuel nuclides. The original standard gave one standard curve for "uranium-fueled reactors."

c. In the revised standard, the uncertainty is expressed in a statistical sense as one standard deviation in a normal distribution. The uncertainty specified in the original standard was ambiguous.

d. The standard values adopted for ^{235}U and ^{239}Pu are based upon a statistical evaluation of new experimental data and summation calculations. The latter contribution includes the most recent improvements in evaluated nuclear data (ENDF/B-IV) [10] at the time of issue of this revision. The corresponding adopted uncertainties are based on the same analysis but with uncertainties in the experimental data and summation calculations increased beyond quoted values to reflect small remaining inconsistencies. Beyond 10^5 seconds, the standard is based solely upon summation calculations and is supported by experimental data, including those of Gunst, Connor, and Conway. [14,37,38]

e. Due to paucity of direct experimental data for the time range of interest, the standard values adopted for ^{238}U are based solely on summation calculations. The corresponding adopted uncertainties are also based on summation calculations but are increased beyond calculated values to reflect known deviations between calculated and experimental values for ^{235}U and to acknowledge reliance on a single source of values.

f. In the revised standard, the formulations are based upon the assumption that the energy release per fission during operation, Q_i, for each nuclide, is independent of time. The user must provide and justify the values of Q_i in his application of the revised standard. Examples of evaluations of Q_i are those by Spinrad et al. [11] and Unik and

Gindler.[12] Low values of Q_i lead to conservative evaluation (high values) of the decay heat power.

Since the evaluation of the literature done by the ANS 5.1 Working Group leading to the 1971 version of the standard, some new publications have appeared that report additional work on both experimental methods and summation calculations. Experiments were performed by Johnston,[13] Gunst et al.,[14] and Lott et al.[15] using calorimetric techniques. Of these, only the data of Lott are in the short-time range of interest in LOCA, while the others are for longer times. More recent results have been obtained by Friesenhahn et al.[16] at IRT and Dickens et al.[17] at ORNL using radiation detection methods and by Yarnell et al.[18] at LASL and Schrock et al.[19] at the University of California, Berkeley, using calorimetry. These five experiments provide a new data base for short time decay of ^{235}U fission products. Since the more recent experiments and summation calculations have so much smaller uncertainties relative to the prior work, the more recent data dominate the uncertainty analysis and the prior works are statistically excluded. Data obtained prior to 1973 were evaluated by Perry et al.[20] and shown to have larger measurement uncertainty and apparent normalization spread than the new experiments. A summary of the new basis for the ^{235}U standard is given in the Proceedings of the ANS Topical Conference on Thermal Reactor Safety.[21] New experimental data for ^{239}Pu have since been reported by Yarnell and Bendt,[33] Dickens, et al.,[34] and Fiche, et al.[35] A summary of the basis for the new standard, including ^{238}U and ^{239}Pu, is given by England, et al[36] and in a review of the subject by Schrock.[39]

Using the ENDF/B-IV data file as a common basis, summation calculations have been performed by Kee, et al.[22] and others that have demonstrated that the same result is obtained using the well known codes ORIGEN,[23] CINDER,[24] and RIBD.[25] Systematic approaches to the evaluation of uncertainties in summation calculation results have been developed by Shay[26] and Schmittroth.[27] Although the methods differ, the error estimates are in close agreement.

Shay,[26,28] England,[29] Shure,[32] and Tasaka[40] have evaluated the effect of neutron capture from summation calculations and have shown that the effect is on the order of only a few percent even for the longest practical reactor operating times in LWR's for $t < 10^4$ seconds. Spinrad[31] has completed a parametric study of the influence and formulated an empirical representation for short times. England, et al.,[29] have shown that the correction for long times can be large and is dependent upon a larger number of reactor parameters.

Schmittroth and Schenter[30] have developed and applied a generalized least-square method to obtain the best value and uncertainty of decay heat power from the experimental data[15-19] and summation calculation results.[29] This method is the basis of the decay heat power data chosen for the revised standard data for ^{235}U and ^{239}Pu thermal fission for $t < 10^5$ seconds. All other data in the revised standard are from summation calculations only and have been assigned a slightly inflated uncertainty.

The revised standard presents decay heat power for two irradiation conditions: (a) a fission pulse and (b) infinite reactor operation. For convenience, the Working Group chose 10^{13} seconds (about 3×10^5 years) as the practical definition of "infinite" operating time in the revised standard. In the absence of neutron capture in fission products, these two cases are related to one another by an exact mathematical expression. This makes it possible to obtain the decay heat power and its uncertainty, in the absence of neutron capture in fission products, from either the pulse or infinite irradiation data. The equivalence of the two sets of tabulated data has been verified.

The new standard for ^{235}U and its uncertainty (2σ) is compared with the 1973 ANS 5.1 standard and its nominal value plus its uncertainties in Figure F-1.

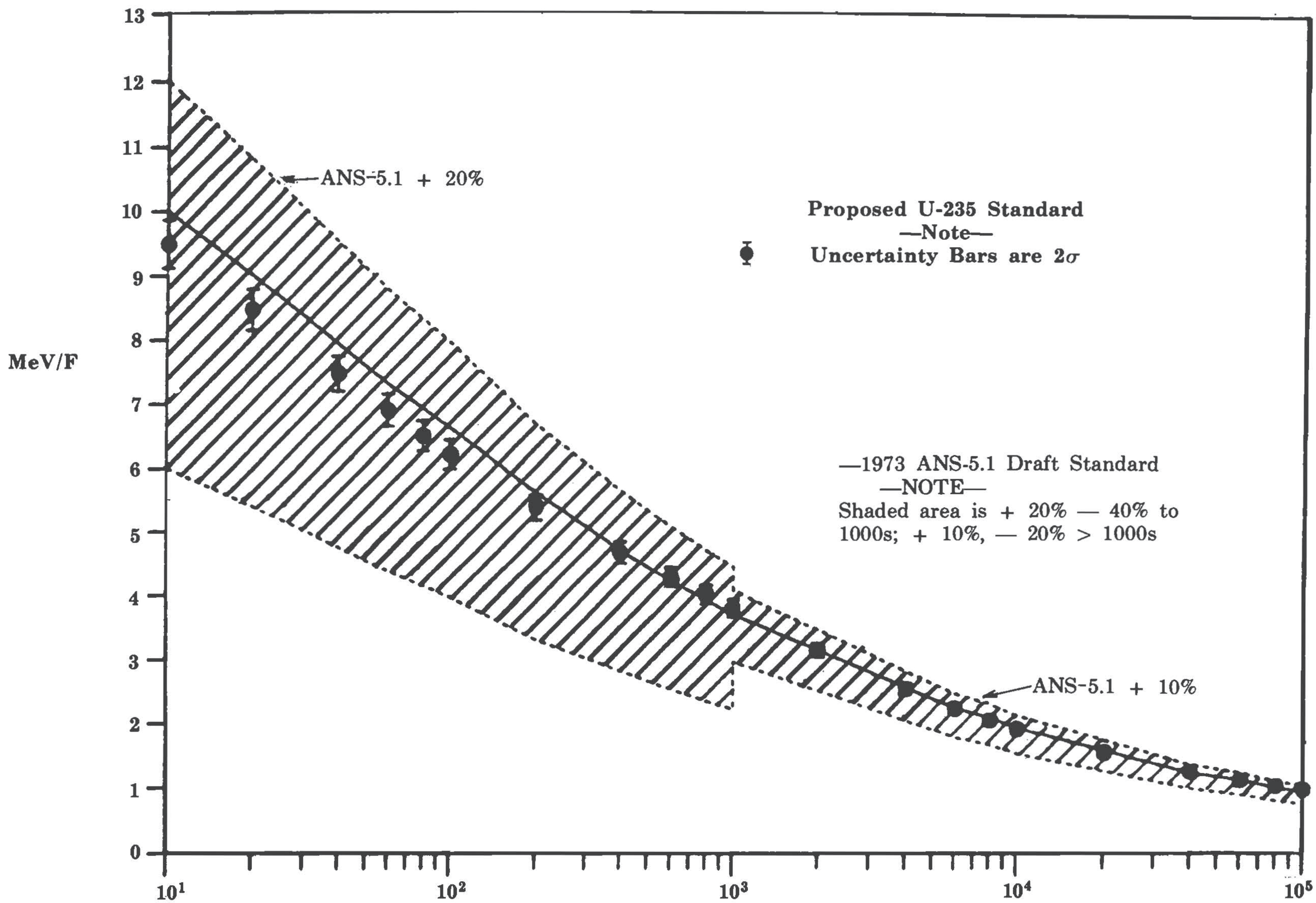

Figure F-1. Comparison of Revised Standard F(t,∞) for ^{235}U (1979) with 1973 Standard

In addition to the formulations provided for evaluating decay heat power from mixtures of ^{235}U, ^{239}Pu, and ^{238}U, a simplified method is provided that uses only the ^{235}U data. A multiplying factor of 1.02 conservatively accounts for the increase over ^{235}U decay heat power from ^{238}U fission products at typical ^{238}U fission rates in LWR's while the lower decay heat power from ^{239}Pu compared to ^{235}U results in conservatism in the simplified method.

The correction for neutron capture in fission products for $t < 10^4$ seconds is dependent upon neutron flux and operating time (alternatively burnup and operating time). To avoid difficulties in defining flux (or burnup), the revised standard specifies the correction factor in terms of the fraction of initial fissile atoms fissioned denoted by ψ. The advantage of this parameter is discussed by Spinrad. (31)

The NRC staff has indicated that the statistical combination of decay heat and power uncertainties (Equation 5a) does not correspond to current NRC approved models (1978) and LOCA analysis, and this situation may continue in the future when this standard may become part of NRC approved LOCA models.

Relationship to Other Standards

American National Standard ANS-19.3.4 (N676-1976), "Determination of Thermal Energy Deposition Rates in Nuclear Reactors," addresses the energy generation and deposition rates for all types of nuclear reactors where the neutron reaction rate distribution and photon and beta emitter distributions are known.

The 1973 Revision of the Proposed Standard ANS-5.1[1] is superseded by the present revision.

Working Group ANS-5.1 of the Standards Committee of the American Nuclear Society had the following membership:

V. E. Schrock, Chairman, *University of California, Berkeley*
J. C. Connor, *Westinghouse PWR Systems Division*
J. K. Dickens, *Oak Ridge National Laboratory*
R. DiSalvo, *U.S. Nuclear Regulatory Commission*
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F. Schmittroth, *Westinghouse Hanford Company*
K. Shure, *Westinghouse Bettis Laboratory*
B. I. Spinrad, *Oregon State University*
M. G. Stamatelatos, *Science Applications, Inc.*
C. R. Weisbin, *Oak Ridge National Laboratory*
S. Weiss, *U.S. Nuclear Regulatory Commission*
J. L. Yarnell, *Los Alamos Scientific Laboratory*

Subcommittee ANS-5, Fission Product Release, had the following membership at the time of its approval of this standard:

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Brent J. Buescher, *Babcock and Wilcox Company*
J. R. Davis, *Babcock and Wilcox Company*
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V. E. Schrock, *University of California, Berkeley*
S. E. Turner, *Southern Science Applications*

The American Nuclear Society Power Plant Standards Committee (NUPPSCO) had the following membership at the time it balloted this standard in October 1978:

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General Atomic Company	G. L. Wessman
American Society of Mechanical Engineers (Southern Company Services)	J. E. Windhorst
NUS Corporation	E. R. Wiot

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