REVISIONS TO THE DECAY HEAT STANDARD: ANSI/ANS 5.1

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Abstract

This paper presents a summary of the 2005 revision to ANSI/ANS-5.1, Decay Heat Power for Light Water Reactors. The 2005 revision to ANSI/ANS-5.1[1] represented an important milestone for this Standard. The reconstitution of the working group, incorporation of ENDF/B-VI data, and revisions to the "simplified method" are the most significant accomplishments realized in the approval and publication of this Standard. A discussion comparing the content of the 2005 revision to the previous version of the Standard[2] is provided. In addition, an outline of the current activities of the working group and goals for the next revision is presented.

KEYWORDS: Decay Heat, Standards, ANSI/ANS-5.1. Fission Products

Introduction

The previous revision to the decay heat standard was published in 1994 and briefly withdrawn in 2004 as a result of inactivity. The reconstitution of an active working group has been a significant achievement. The incorporation of ENDF/B-VI data in place of the ENDF/B-VI data in the previous revision demonstrates an active interest in the standard. A review of scientific and technical literature indicated that few new decay heat measurements have been reported in the interim between the release of the 1994 Standard and the 2005 revision. Therefore, the coefficients for calculating decay heat after fission remain unchanged in the 2005 revision. At the time the current revision was completed, these interim data had been integrated into the JENDL files [3]. These new data were not incorporated into the fission yield evaluations for ENDF/B-VI since they were direct fission yield measurements and ENDF/B fission yield evaluations are based on cumulative fission yields. However, decay heat values and their uncertainties calculated using the updated JENDL libraries have been compared[4] with the recommended decay-heat values and uncertainties in the 1994 Standard and were found to agree within the

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uncertainties cited.

The 2005 Standard contains the main features of the 1994 Standard except that the specific "simplified method" as described in the 1994 Standard is incorporated in the 2005 Standard in a new Appendix D as one example of a simplified model. The text of the 2005 Standard was revised to permit other approaches to a "simplified model" based on the user's discretion under defined guidelines provided. A correction for Eq. (D.2) (formerly Eq. (13) in the 1994 Standard) is included in the Appendix D example. Section 3.6 has been modified to permit substitution of a user-provided simplified model under the conditions specified. Minor corrections have also been made to Equation 10, Equation C.6 and the text in Section 3.5. The Gmax(t) values reported in Table 13 have been recalculated using CINDER-90 and ENDF/B-VI data.[5] The 1994 Gmax values[6] were based on calculations performed with ENDF/B-IV data. The empirical representation of the correction factor for short times (Eq. 11) is based on a parametric study of the influence of neutron capture on fission products as reported by Spinrad and Tripathi[7] and is not changed from the 1994 version of the Standard. All of the example problems have been recalculated.

The 2005 Standard is the same as the previous versions of the standard in that:

a. The Standard prescribes fission product decay heat power and its uncertainty for reactor operating histories.
b. The Standard prescribes data that are applicable to Light Water Reactors (LWRs) 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.
d. Decay heat power for ^{239}U and ^{239}Np are separately prescribed and are to be added to the fission product decay heat power.
e. In the Standard, the uncertainty is expressed in a statistical sense as one standard deviation in a normal distribution.
f. The Standard presents decay power for two irradiation conditions: (a) a fission pulse and (b) an irradiation of 10^{13} seconds to represent infinite reactor operation.
g. 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.
h. For cooling times greater than 10^5 seconds, the Standard is based solely upon summation calculations rather than combined with empirical data and summation calculations as done for shorter decay times.
i. The formulations are based upon the assumption that the energy release per fission during operation, Q_i, for each nuclide, is independent of time.
j. A method is prescribed for obtaining decay heat power for arbitrary reactor operating histories from the Standard.
k. 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.
l. Decay heat power from activation products in reactor materials is not specified in the Standard.

Summary of Revisions

Features that distinguish the revised Standard from the 1979 Standard but are consistent with the 1994 Standard are:

a. The cooling-time region of validity has been extended to 10^{10} seconds. In the 1979 Standard the time region of validity was 10^9 seconds.
b. Data are prescribed for decay heat power from fission products from fissioning of the major fissionable nuclides present in LWRs, i.e., ^{235}U, ^{239}Pu, and ^{241}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 1979 Standard gave standard curves for ^{235}U and ^{239}Pu thermal, and ^{238}U fast.
c. The Standard values adopted for ^{238}U are based upon an evaluation of new experimental data and summation calculations. In the 1979 Standard, the values for ^{238}U were obtained solely from summation calculations.
d. The Standard values adopted for ^{241}Pu are based upon evaluation of experimental data and summation calculations. The 1979 Standard did not give a separate set of values and prescribed that ^{235}U values should be used for contributions from all other fissioning actinides other than ^{239}Pu and ^{238}U.
e. Standard values and uncertainties for pulse thermal fission of ^{235}U have been revised for times after shutdown of 1.0, 1.5, and 2.0 seconds, based upon a 1989 evaluation published by Tobias[8] of all available experimental data for ^{235}U. These changes involve increases of decay heat power of 16.2%, 8.0%, and 3.3%, respectively. Corresponding uncertainties have been reduced for these values from those given in the 1979 Standard, also based on the Tobias evaluation.
f. Standard values and uncertainties for pulse thermal fission of ^{235}U have been revised for times after shutdown longer than 1.5 x 10^9 s. These changes reflect improved nuclear data and uncertainties used in summation calculations for long-lived fission products, principally ^{99}Tc and ^{126}Sn.
g. Standard uncertainties for pulse thermal fission of ^{239}Pu have been revised for times after shutdown of 1.0, 1.5, 2.0, and between 20 and 15,000 seconds, based on the Tobias evaluation[8] of all available experimental data for ^{239}Pu, as well as the excellent agreement of the experimental results of Akiyama et al.[9] with the results of Dickens et al.[10]
h. Standard values and uncertainties for pulse thermal fission of ^{239}Pu have been revised for times after shutdown greater than 5 x 10^9 seconds, reflecting improved nuclear data and uncertainties used in summation calculations for long-lived fission products, principally ^{99}Tc and ^{126}Sn.

The formal presentation of the revised Standard is the same as for the 1994 Standard, thus allowing ease in upgrading computer programs. Users applying the Standard to reactor safety analysis should justify that the inputs (e.g., the recoverable energy Q) to the Standard are appropriate.

Future Activities

Further revisions of the Standard are already under consideration. Revisions to (a) improve the capture effect specification, (b) include contributions from actinides not already included, and (c) specify total recoverable energy Q for major elements are carried over from recommendations by Dickens et al.[11]

A review of the treatment of the neutron capture effect in the international decay heat standard[12], ISO 10645, will be performed to identify and develop potential approaches for addressing the desired improvements. For example, in its approach to accounting for the capture effect, the ISO standard treats Cs-134 explicitly and then lumps the remainder of the fission products into a single correction factor. This practice has been shown to greatly reduce conservatism in treating the capture effect as a single parameter, G(t) in the current version of ANS 5.1. This would encourage us to utilize sensitivity analyses to identify specific fission products whose contribution to decay heat may be significant and to develop correlations to specifically include those effects.

Revising the treatment of actinide contributions is essential to expanding the applicability of the Standard to the storage and disposal of spent fuel. Developing representations of the actinide content of the fuel without making them overly cumbersome will present a challenge. One of the objectives of the Standard has always been to enable decay heat power to be calculated to the precision of summation methods without requiring the need for complicated calculations. Currently, the Standard explicitly considers decay heat power from ^{239}U and ^{239}Np explicitly but makes no attempt to include other actinides, either explicitly or in some lumped form. The limited treatment of actinide contributions is the primary reason that ANSI/ANS-5.1 should not be used at cooling times greater than 10^{10} seconds. This limitation actually makes the use of the Standard not practical beyond much shorter times. Beyond typically 30-50 year (10^9 sec) cooling time the actinide contribution can exceed that of the fission products which is why the uncertainties given in the Standard are large for these cooling times.

The working group would also like to readdress the representation of uncertainties. The intent would be to represent the uncertainties in the same way that the f(t) values are by developing fit coefficients for the uncertainty rather than requiring the user to interpolate the uncertainties from the tables of f(t) and F(t, ∞).

The interpolation required with using the tabular data in the Standard (particularly the F-values) can make the method sensitive to the interpolation scheme used at longer decay times. The working group will also give consideration to providing the tabular data in an Appendix for reference and cross-checking and retain only the fitted parameters in the body of the Standard. This issue will be addressed separately relative to f(t) and F(t, ∞).

Any future revision to this Standard should include a review of available experimental data for new measurements or revised evaluations. In order to facilitate these reviews, consideration is given to creating a database wherein the experimental data used in generating existing decay heat coefficients can be compiled. If new measurements were to be acquired for incorporation into future revisions of the Standard, they could be entered into the compiled database until needed. Currently, the experimental data used are identified only by reference. The exact experiments that were ultimately selected, and the data evaluation methods used to generate coefficients and uncertainties for each fissionable nuclide are also available only by reference. Because of the heavy reliance on these data and the fact that much of the U.S. expertise in evaluating decay heat measurements is reaching retirement, it seems prudent that this activity be undertaken in the near term.

Conclusion

In conclusion, the foundations of this Standard are deeply rooted in experimental data. Maintaining the active management of this Standard is important to preserve a reference for comparison with decay heat calculations performed using more complex reactor physics codes. The Standard is widely implemented as a method used to calculate decay heat in many physics codes that do not explicitly track the extensive number of fission product concentrations that contribute to decay heat. ANSI/ANS-5.1 is a direct link to the measured data and has close ties with the evaluated nuclear data files. Plans for the future of this Standard include maintaining the tie to measured data and expanding the applicability and accuracy of the Standard for longer cooling times.

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