REACTOR PHYSICS STANDARDS IN THE NEW MILLENNIUM

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ABSTRACT

Recent advances in reactor physics standards currently in use throughout the nuclear industry as well as standards under development are discussed. These standards provide guidance for performing, qualifying and validating a wide range of reactor physics calculations and measurements. Developed by experts in specific reactor physics areas, under the auspices of the American Nuclear Society (ANS), these standards cover a wide range of calculations and measurements and are intended for applications to both research and power reactors of all types. When fully developed by the respective working groups and reviewed and approved by the proper technical committees, these standards, in their final form, are adopted by the American National Standards Institute (ANSI) and become formal U.S. national standards. Eight ANSI/ANS reactor physics standards have been developed to date covering the following areas: (1) nuclear data sets for reactor design calculations; (2) determination of reaction rate distribution and reactivity of nuclear reactors; (3) determination of thermal energy deposition rates in nuclear reactors; (4) a guide for acquisition and documentation of reference power reactor physics measurements for nuclear analysis verification; (5) requirements for reference reactor physics measurements; (6) reload startup physics tests for pressurized water reactors; (7) moderator temperature coefficient in pressurized water reactors; and (8) decay heat power in light water reactors. Proposed standards in various stages of development, in the areas of (1) fission product chain yields, (2) delayed neutrons and (3) fast neutron fluence in the pressure vessels of pressurized water reactors, are also discussed.

1. INTRODUCTION

The multitude and diversity of reactor physics methods used in core design and analysis and the broadening of the ranks of users of these methods in the last decade, have enhanced significantly

the role and usefulness of the Reactor Physics Standards. Reactor Physics Standards provide guidance for performing and validating a wide range of nuclear reactor calculations and measurements. These standards are currently in widespread use by the nuclear industry. While reactor physics standards are specifically intended for use in the U.S. by the nuclear industry, these standards are being increasingly used abroad. The purpose of this paper is to summarize recent advances in reactor physics standards, to present an overview of the overall reactor physics standards program and to report on the status of those standards which are currently being developed.

The effort on the development of reactor physics standards started in the mid-1970's as the nuclear industry was entering into an expansion phase. Operating under the aegis of the American Nuclear Society (ANS), the ANS-19, Reactor Physics Standards Committee is composed of a number of experts representing users, vendors, national laboratories, universities and government. Members of ANS-19 lead their respective working groups, in developing, maintaining, reaffirming, updating and revising standards for determining key reactor physics parameters used in reactor design calculations and measurements. A proposed standard is reviewed by potential users and other interested parties and must be approved by the ANS-19 Reactor Physics Standards Committee, by the Consensus and the Steering committees, with each level of review providing comments and questions for resolution by the Working Groups. With all comments and questions satisfied, the Working Group will bring the proposed standard into final form for adoption by the American National Standards Institute (ANSI), as a formal U.S. national standard. The eight ANSI/ANS reactor physics standards and their designations, (Refs. 1-9), developed to date, are listed in Table 1.

TABLE 1
ANSI/ANS REACTOR PHYSICS STANDARDS

Designation of Standard	Title of ANSI/ANS Standard	Reference
ANSI/ANS-19.1	Nuclear Data Sets for Reactor Design Calculations	1,2
ANSI/ANS-19.3	Determination of Reaction Rate Distribution and Reactivity of Nuclear Reactors	3
ANSI/ANS-19.3.4	Determination of Thermal Energy Deposition Rates in Nuclear Reactors	4
ANSI/ANS-19.4	A Guide for Acquisition and Documentation of Reference Power Reactor Physics Measurements for Nuclear Analysis Verification	5
ANSI/ANS-19.5	Requirements for Reference Reactor Physics Measurements	6
ANSI/ANS-19.6.1	Reload Startup Physics Tests for Pressurized Water Reactors	7
ANSI/ANS-19.11	Moderator Temperature Coefficient in Pressurized Water Reactors	8
ANSI/ANS-5.1	Decay Heat Power in Light Water Reactors	9

Reactor physics standards under development (Refs. 10-12) are shown in Table 2.

TABLE 2
PROPOSED ANS-19 REACTOR PHYSICS STANDARDS IN PROGRESS

Proposed Standard Designation	Title of Proposed Standard	References
ANS-19.8	Fission Product Chain Yields	10
ANS-19.9	Delayed Neutron Parameters	11
ANS-19.10	Fast Neutron Fluence in the Pressure Vessel of PWRs	12, 14

These standards cover a wide range of reactor physics and shielding design calculations as well as measurements.

2. ANSI/ANS REACTOR PHYSICS STANDARDS

To keep standards current and to ensure that they meet the needs of the user community, ANS-19 regularly monitors the use of its standards and updates their applicability. As reactor technology evolves, standards are reviewed and revised. Revisions to the standards are made at regular intervals. When no revisions are required, the standards are reaffirmed at the required intervals. The following sections discuss the eight existing ANSI/ANS standards.

2.1 A STANDARD FOR NUCLEAR DATA

Criteria and specifications for creating and documenting nuclear data sets for reactor design calculations are presented in Standard ANSI/ANS-19.1,*"Nuclear Data Sets for Reactor Design Calculations*" (Ref. 1, 2) which has just been revised and is being published. This standard establishes three major classes of nuclear data used in reactor design calculations: (1) Evaluated nuclear data sets, derived from basic experimental and theoretical data specified over broad energy ranges; (2) processed continuous data sets, derived from evaluated data sets intended for calculations where continuous energy representations, are required, such as in Monte Carlo transport codes and (3) averaged data sets, also derived from evaluated or processed continuous data sets. This latter class of nuclear data consists of group parameters obtained from the evaluated data sets or from the processed continuous data sets by averaging with appropriate weighting functions over a given group structure. Application of the data to a wide range of benchmark experiments and other reference measurements forms the basis of testing of the nuclear data. In addition to the well known ENDF/B-VI nuclear data files, other evaluated data sets, (Chinese, European, Japanese and Russian nuclear data files) are cited in the Appendix of this standard

2.2 CORE PHYSICS STANDARD

The recently revised ANSI/ANS-19.3 standard (Ref. 3) covers the most fundamental aspects of reactor design. This standard provides guidance for performing and qualifying the complex sequence of reactor physics calculations aimed at determining spatial reaction rate distributions, reactivities and changes in isotopic compositions with burnup in light water, heavy water, high temperature gas cooled, fast breeder and research reactors. It also includes guidance in the selection of methods, criteria for the verification of calculational methods and for the evaluation of the accuracy and range of applicability of the data and methods. The nuclear data standard, (Ref.1, 2), discussed in the previous section, plays an important role in the use of this standard. The standard also includes an extensive compilation of state-of-the-art computer codes.

2.3 THERMAL ENERGY DEPOSITION

Guidance for performing and validating the sequence of calculations to evaluate thermal energy deposition rates in nuclear reactors and criteria for demonstrating the adequacy of the design calculations are presented in the newly revised ANSI/ANS-19.3.4 standard, *"Determination of Thermal Energy Deposition Rates in Nuclear Reactors"* (Ref. 4). This is a broad-based standard and covers the energy deposition calculations for all classes of reactors from fast to thermal and from research to power reactors. The previously mentioned standards, ANSI/ANS-19.1, (Ref. 1, 2) and ANSI/ANS-19.3, (Ref. 3), provide the basis for determining the distributions of neutron reaction rates and photon and beta particle emitter distributions.

2.4 POWER REACTOR MEASUREMENTS FOR ANALYSIS VERIFICATION

Verification of nuclear methods used to predict the performance characteristics of a power reactor is an important step in the validation of those methods and in establishing their reliability. A useful technique in assessing the effectiveness of a calculational system in evaluating performance characteristics of a reactor is to use that system to calculate performance characteristics for which measurements are available. Criteria for performing and documenting measurements and experimental data for light water power reactors are specified in the revised ANSI/ANS-19.4 standard, (Ref. 5*), "American National Standard: A Guide for Acquisition and Documentation of Reference Power Reactor Physics Measurements for Nuclear Analysis Verification".* The standard identifies the types of parameters, test conditions, and experimental data needed for such reference measurements. Considerable confidence is gained in the nuclear analysis methodology when performance characteristics, measured in a light water reactor in accordance with the criteria and guidelines of this standard, are successfully calculated.

2.5 REQUIREMENTS FOR REFERENCE DATA

Criteria for the qualification of reference reactor physics measurements obtained from subcritical, critical or other relevant experiments for purposes of verifying nuclear design and analysis methods are specified in standard ANSI/ANS19.5, *"Requirements for Reference Reactor Physics Measurements"* (Ref. 6). In general, measurements carried out in an operating power reactor consist of integral data and it is not always possible, on the basis of such measurements, to

extract specific parameter values without making various assumptions and/or approximations, which results in increased uncertainties of the target values. However, such integral data can still be valuable since they can be used to compare against the end result of the calculational stream. Measured versus calculated control rod worths and radial assembly-wise power distribution are just two examples of such comparisons. Special measurement procedures are required to verify parameters calculated at intermediate steps of the calculational process.

2.6 RELOAD STARTUP PHYSICS TESTS

A reactor physics standard enjoying widespread use both domestically and internationally is ANSI/ANS-19.6.1, *"Reload Startup Physics Tests for Pressurized Water Reactors"*, (Ref. 7). This standard prescribes the startup test procedures, which must be followed in order to ensure that the operating characteristics of the core are consistent with design predictions. As is the case with most standards, the working group responsible for this standard regularly updates and revises its contents while receiving useful feedback from the user community. Work is in progress for the revision of this standard.

2.7 DECAY HEAT

Due to regulatory and licensing requirements, the ANSI/ANS-5.1 standard, *"Decay Heat Power in Light Water Reactors",* (Ref. 9) is one of the most frequently used standards in the nuclear industry. It sets forth values for the decay heat power from fission products and U239 and Np239 following shutdown of light water reactors containing U235, U238 and plutonium. Data are presented in tables and in analytical form. The revised ANSI/ANS-5.1 includes the latest results of summation calculations using ENDF/B-VI files. It is noteworthy that the format and approach used by ANSI/ANS-5.1 is increasingly used by foreign nuclear utilities.

2.8 MODERATOR COEFFICIENT

The ANSI/ANS-19.11 standard, *"Moderator Coefficient of Reactivity in Pressurized Water Reactors",* (Ref. 8), is a relatively new standard initiated in the last few years. It provides guidelines and criteria for the calculation of the moderator temperature coefficient in PWRs. Here, the relevance of the nuclear data standard, ANS-19.1, and the core physics standard, ANS-19.3, is noted. This standard, as are the other standards, is being constantly reviewed and its use monitored by the Moderator Coefficient Working Group for possible updates or revisions.

3.0 PROPOSED STANDARDS

Over the past few years, three new standards have been proposed and work on their development has been initiated within the ANS-19 Reactor Physics Standards committee. The areas covered by these proposed standards are "Fission Product Yields", "Delayed Neutrons" and "Fast Neutron Fluence in the Pressure Vessel of PWRs". These proposed standards, are currently in various stages of development.

3.1 FISSION PRODUCT CHAIN YIELDS

Work on the development of the proposed standard *"Fission Product Chain Yields",* ANS-19.8, (Ref. 10), has been ongoing for the past several years, primarily at Los Alamos National Laboratory, and an extensive amount of information has been generated. The proposed standard includes a huge compilation of mass chain yields and related uncertainties for U-233, U-235, U-238, Pu-239, Pu-240, Pu-241, Th-232 and Cf-252. While most of the required material exists, some additional effort is needed to integrate and fully document the work before the proposed standard can be reviewed by ANS-19 Committee.

3.2 DELAYED NEUTRONS

Because of the importance of the effect of delayed neutrons on reactor transients, ANS-19 has initiated an effort aimed at developing a proposed *"Delayed Neutron Parameter Standard"*, designated as ANS-19.9, (Ref. 11). The proposed standard will provide delayed neutron yield data as a function of energy for reactor design and control including spectra for beta-effective calculations. It should be pointed out that preliminary experiments and recent work on the proposed standard tend to reaffirm the validity of Keepin's (Ref. 13) delayed neutron data.

3.3 FAST NEUTRON FLUENCE IN THE PRESSURE VESSEL OF PWRs

Safety concerns in the last twenty years about PWR pressure vessel embrittlement resulting from neutron irradiation, has prompted ANS-19 to initiate work leading to the development of a standard which would provide technical guidance for determining fast neutron fluence in the vessel. To accomplish this goal, the proposed standard, ANS-19.10, *"Fast Neutron Fluence in the Pressure Vessel of PWRs",* (Ref. 12, 14), consists of three major areas each corresponding to the specific steps involved in the determination of fast neutron fluence. Guidance is also provided for cases when no measured data are available. Again, the relevance here of the nuclear data standard, ANS-19.1 is noted. A first draft of the proposed standard, for review by ANS-19, is expected in the near future.

CONCLUSIONS

The reactor physics standards program is a multifaceted program that supports and guides the reactor physicist's technical effort to achieve safe design of a wide range of types of nuclear reactor cores. The standards produced thus far and those in progress cover major neutronic areas involved in the design process. These areas range from cross section libraries, (ANSI/ANS-19.1), to the detailed evaluation of physical parameters such as power distributions (ANSI/ANS-19.3), reactivities (ANSI/ANS-19.3 and ANSI/ANS-19.11), energy deposition (ANSI/ANS-19.3.4), fission yields (ANS-19.8), delayed neutrons (ANS-19.9), decay heat (ANSI/ANS-5.1), and fast neutron transport to the pressure vessel, (ANS-19.10). The standards also provide guidance for verifying nuclear analyses (ANSI/ANS-19.4 and ANSI/ANS-19.5).

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