ANSI/ANS-19.11-2017

Calculation and Measurement of the Moderator Temperature Coefficient of Reactivity for Pressurized Water Reactors

An American National Standard

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American Nuclear Society
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Calculation and Measurement of the Moderator Temperature Coefficient of Reactivity for Pressurized Water Reactors

Secretariat
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Working Group ANS-19.11

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American National Standard

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Foreword

(This foreword is not a part of American National Standard "Calculation and Measurement of the Moderator Temperature Coefficient of Reactivity for Pressurized Water Reactors," ANSI/ANS-19.11-2017.)

It is the intent of this American National Standard to provide guidance and specify criteria for the calculation and measurement of the moderator temperature coefficient of reactivity (MTC) in pressurized water reactors (PWRs). The MTC is a major designed-in safety feature in PWRs. These reactors are designed to maintain a negative MTC over a large range of operating conditions. Although most off-nominal conditions benefit from a large negative MTC, some cooldown accidents are aggravated by the temperature feedback. For this reason it is important to determine the MTC accurately. This standard provides guidance and specifies criteria for determining the MTC in a PWR. Measurement of the isothermal temperature coefficient of reactivity (ITC) at hot-zero-power (HZP) conditions is covered in ANSI/ANS-19.6.1-2011 (R2016), "Reload Startup Physics Tests for Pressurized Water Reactors." The current standard therefore addresses the calculation of the ITC at HZP and the calculation and measurement of the MTC at power.

Major differences between the current edition and the earlier edition of this standard are the following:

- The basis/reason for adding the section regarding the use of precalculated coefficients for the boron exchange test method are discussed;
- Editorial changes were made to reflect a consistent format throughout the standard, and equations were renumbered to accommodate the addition of a data reduction technique using precalculated coefficients in the measurement of MTC using the boron exchange test method;
- The term "fuel assembly" is not used in the standard and was removed from the definitions of terms in Sec. 3.4. The term "full power" was replaced with "hot full power" as its acronym "HFP" is used throughout the standard;
- The statepoint equations used in the test simulation method for calculating the correction terms used in data reduction of the boron exchange method were revised because they erroneously contained the measured total temperature coefficient of reactivity and were double counted for the reactivity change;
- The "Advantages" and "Disadvantages" associated with each test method in the standard are illustrative in nature and do not represent requirements and were moved to the Appendices to facilitate clarity regarding the technical detail and requirements for each test method. The advantages and disadvantages deal primarily with cost and time associated with each method that the user may wish to consider in selecting one test method over another.

This standard might reference documents and other standards that have been superseded or withdrawn at the time the standard is applied. A statement has been included in the reference section that provides guidance on the use of references.

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.

This standard was developed by the ANS-19.11 Working Group of the American Nuclear Society. During the period the standard was revised, the working group had the active participation of the following members:

M. Mahgerefteh (Chair), *Exelon Generation LLC*

S. P. Baker, *Transware Enterprises*
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The membership of the Reactor Physics Subcommittee (ANS-19) at the time of its review and approval of this standard was the following:

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

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The Safety and Radiological Analysis Consensus Committee had the following membership at the time it reviewed and approved this standard:

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1 Introduction

The moderator temperature coefficient of reactivity (MTC) relates a change in core reactivity to a change in reactor moderator temperature: A positive MTC means that reactivity increases with increasing moderator temperature while a negative MTC means that reactivity decreases with increasing moderator temperature. The MTC is a major designed-in safety feature in pressurized water reactors (PWRs). These reactors are designed to maintain a negative MTC over a large range of operating conditions. Therefore, an increase in the moderator temperature will cause the reactivity to decrease, so that the moderator temperature tends to return to its initial value. Reactivity increases that cause an increase in moderator temperature thus will be self-limiting, and stable power operation will result. Although most off-nominal conditions benefit from a large negative MTC, some cooldown accidents are aggravated by the temperature feedback. For this reason it is important to determine the MTC accurately.

The value of the MTC is determined by competing effects. The decrease in the density of water that accompanies an increase in temperature leads to a reduction in neutron moderation, which tends to make the MTC more negative. The MTC is made more positive, however, by the addition of soluble boron to the water. Boron is a strong neutron absorber, and because the density of the boron is directly proportional to the density of the water, the absorption rate due to boron decreases as the water density decreases.

A change in moderator temperature affects core reactivity both directly and indirectly. It affects core reactivity directly at a macroscopic level through the change in moderator density that accompanies a change in the moderator temperature, as discussed above. It also affects neutron moderation directly at a microscopic level because the neutron scattering kernel for the water molecule is weakly temperature dependent. Furthermore, these changes in moderation have secondary effects, such as redistribution of the flux shape.

For the purposes of this standard, the MTC is defined to include all such effects, whether direct or indirect:

$$\mathrm{MTC} \equiv \left(\frac{\partial \rho}{\partial T_{ave}}\right)_{\mu} + \left(\frac{\partial \rho}{\partial \mu_{ave}}\right)_{p} \times \left(\frac{\partial \mu_{ave}}{\partial T_{ave}}\right)_{p} + \left(\frac{\partial \rho}{\partial \phi}\right)_{p} \times \left(\frac{\partial \phi}{\partial T_{ave}}\right)_{p},$$

(Eq. 1)

where:

ρ is the reactivity;