

American Nuclear Society

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**calculation and measurement of the
temperature coefficient of reactivity
for water moderated power reactors**

an American National Standard

REAFFIRMED

**June 17, 2011
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**American National Standard
Calculation and Measurement of the
Modular Temperature Coefficient of Reactivity
for Water Moderated Power Reactors**

Secretariat
American Nuclear Society

Prepared by the
**American Nuclear Society
Standards Committee
Working Group ANS-19.11**

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Foreword

(This Foreword is not a part of American National Standard for the Calculation and Measurement of the Moderator Temperature Coefficient of Reactivity for Water Moderated Power Reactors, ANSI/ANS-19.11-1997.)

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 water moderated power reactors. At present, this standard addresses the calculation and measurement of the MTC only in pressurized water reactors (PWRs), because PWRs are the only type of power reactor currently sited in the United States for which measurement of the MTC is required.

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

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Contents	Section	Page
	1. Introduction	1
	2. Scope	1
	3. Definitions	2
	3.1 Limitations	2
	3.2 Glossary	2
	4. Moderator Temperature and Reactivity	3
	4.1 Moderator Temperature	3
	4.2 Moderator Temperature Coefficient of Reactivity	4
	5. Calculation of the Moderator Temperature Coefficient of Reactivity	4
	5.1 Numerics and Convergence	4
	5.2 Zero Power Calculation	5
	5.3 At-Power Calculation	6
	6. Measurement of the Moderator Temperature Coefficient of Reactivity at Power	6
	6.1 Measurement Techniques for PWRs	6
	6.2 Extrapolation	16
	7. Documentation	16
	8. References	17

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

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 fuel cycle 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 cool-down 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:

$$MTC \equiv \left(\frac{\partial \rho}{\partial T_{ave}} \right)_{\mu} + \left[\left(\frac{\partial \rho}{\partial \mu_{ave}} \right)_p \times \left(\frac{\partial \mu_{ave}}{\partial T_{ave}} \right)_p \right] + \left[\left(\frac{\partial \rho}{\partial \phi} \right)_p \times \left(\frac{\partial \phi}{\partial T_{ave}} \right)_p \right] \quad (\text{Eq. 1})$$

where ρ is reactivity, T_{ave} is the average moderator temperature, p is the pressure, μ_{ave} is the average moderator density, and ϕ is the neutron flux. The first term in this equation represents the reactivity effect due to the moderator temperature itself, while the second term represents the reactivity effect due to the associated change in moderator density. Both of these terms include the indirect effects of the resulting spectral change upon the absorption cross sections of other isotopes (fuel, burnable poisons, etc.). The contribution from the first term is negative and is nearly constant. Its magnitude typically is a few pcm per °C. The second term usually is the dominant contributor to the MTC, and it may be positive or negative, depending upon the specific core conditions. The third term represents the reactivity effects associated with the spatial redistribution of the flux that occurs in response to the change in the moderator temperature, and it also can be either positive or negative.

2. Scope

This standard provides guidance and specifies criteria for determining the MTC in water moderated power reactors. Measurement of the isothermal temperature coefficient of reactivity (ITC) at hot zero power (HZP) conditions is covered in American National Standard Reload Startup Physics Tests for Pressurized Water Reactors, ANSI/ANS-19.6.1-1997 [1].¹ This standard therefore addresses the calculation of the ITC at HZP and the calculation and measurement of the MTC at power. At present, this standard addresses the calculation and measurement of the MTC only in PWRs, because that is the only

¹ Numbers in brackets refer to corresponding numbers in Section 8, References.