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Reactors - General

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MODERATOR TEMPERATURE COEFFICIENTS IN HEAVY WATER REACTORS

by

D. S. St. John

Theoretical Physics Division

December 1959

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ABSTRACT

Reactors that are moderated with heavy water differ from those that are moderated with graphite in that (1) the moderator temperature is lower than it may be in graphite reactors, (2) when the moderator temperature is raised, the moderator-to-fuel ratio decreases, and (3) circulation in the moderator introduces local, random changes in reactivity that distort the flux distribution. The large negative contributions to the moderator temperature coefficient from leakage and resonance capture overshadow any positive contribution from eta that may accompany the buildup of plutonium with exposure. The effect of the coefficient on reactor safety depends upon the manner in which the D_2O circulation couples the reactor power to the moderator temperature.

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MODERATOR TEMPERATURE COEFFICIENTS IN HEAVY WATER REACTORS

INTRODUCTION

This report contains information that was discussed at a meeting held between representatives of the United Kingdom and of the United States on the subjects of graphite temperature coefficients and xenon instability. This meeting was held at Argonne National Laboratory on July 24 and 25, 1958. Since the primary interest at the meeting was in moderator temperature coefficients in reactors moderated with graphite, the following discussion of the temperature coefficients for reactors moderated with heavy water considers the differences between the two systems. The differences are such that the control and safety implications of the coefficients have a different emphasis in reactors moderated with heavy water. Thus a comparison may bring out points that are of interest to the graphite system but that are masked in that system by other effects.

In this report, the following topics are discussed.

1. The differences between reactors moderated with graphite and those moderated with heavy water, with respect to the origin and magnitude of the moderator coefficients

2. The method of measurement of effective moderator coefficients

3. Some of the control and safety problems introduced by the moderator coefficient

DISCUSSION

MODERATOR TEMPERATURE COEFFICIENT IN REACTORS MODERATED WITH D_2O

The differences between graphite-moderated and heavy-water-moderated systems arise principally from the following effects.

1. When the temperature of heavy water increases, the density decreases, and heavy water is forced out of the fixed core volume. The moderator-to-fuel ratio is reduced, the moderating power is reduced, and leakage is markedly increased. In a graphite reactor, on the other hand, expansion of the graphite blocks merely fills the interstices, with no large net change in moderator-to-fuel ratio or in moderating power.

2. In the Savannah River reactors, the temperature is maintained below the boiling point of water, whereas the moderator temperature in graphite reactors may be much higher and undergo much larger temperature variations.

3. There is hydraulic circulation of the moderator in a heavy water reactor, so that heat is transmitted from one point to another by mass flow of the moderator and the moderator temperature at a given point can change rapidly. In a graphite reactor, the moderator temperature can change only slowly.

The methods used at the Savannah River Laboratory for calculation of moderator temperature coefficients have been published[1,2]. Typical values for the coefficients in heavy water reactors, with the moderator temperature at about 80°C, are made up of the following contributions:

Increased resonance capture	-6 to -8×10^{-5} k/°C
Increased leakage	-6 to -8
Change in η	-5 to 0
TOTAL	-12 to -20×10^{-5} k/°C

In the above tabulation, it is seen that the large negative contributions of the leakage and resonance absorption terms overshadow the change in η. Thus, even though the η term becomes more positive as plutonium builds in with exposure, it only reaches a value of zero at about 2000 MWD/T, and does not materially affect the safety or control of a heavy water reactor.

EFFECTIVE MODERATOR COEFFICIENTS

In the Savannah River reactors, the D_2O flows through the coolant channels and then out into the bulk of the moderator space. When the power is raised, the coolant moderator heats up rapidly, but the bulk moderator heats up more slowly at a rate that depends upon the degree of mixing of the coolant with the bulk before leaving the tank. This mixing depends upon the details of the flow pattern within the tank and changes as changes occur in power level, moderator temperature, or any detail of the hydraulic system.

Thus there is an effective moderator temperature coefficient with a value that depends upon the steady-state moderator coefficient and upon the statistical weight of that fraction of the bulk moderator that mixes effectively with the coolant moderator. It acts with a characteristic time constant that depends upon the degree of mixing, the heat capacity of the moderator, and the amount by which the moderator temperature exceeds the ambient temperature per unit power.

The effective moderator temperature coefficient is measured in the reactor under conditions of full reactor power and flow by a control rod oscillation technique[3]. A calibrated amount of reactivity is introduced by moving the control rods with a trapezoidal waveform. During the portion of the waveform in which the rods are moving, the response of the reactor is primarily dictated by prompt multiplication of the additional reactivity and by changes in the power distribution. During the period in which the rods remain stationary, however, the response is characteristic of the amount of reactivity added by the control rods and by the temperature coefficients; it is this response that is analyzed to give the temperature coefficients. Varying the length of time during which the rods remain stationary makes possible good resolution of temperature coefficients arising from various sources and having different characteristic times. Measurements are repeated when appreciable changes in the flow pattern in the tank or in the power level are made.

This measured effective moderator temperature coefficient is used in the calculation of the response of the system to hypothetical reactor accidents.

CONTROL AND SAFETY IMPLICATIONS

In a heavy water reactor, the moderator temperature is not uniform everywhere, and it is not constant with time at any one point. Small random fluctuations in the flow pattern and larger fluctuations associated with more or less stagnant regions that become overheated are continually introducing small local changes in reactivity. In a large reactor these result in tilts in the power distribution, so that the neutron flux measured at any one point outside the reactor will exhibit random fluctuations with an amplitude of perhaps 0.5% in a reactor with a stable forced circulation pattern or of several per cent in a reactor with large semistagnant areas in the moderator. These fluctuations at one point are not correlated with those measured at a point on another side of the pile. Thus, from an operational standpoint, good mixing of the moderator is required to prevent moderator overheating and large fluctuations in the flux pattern.

From the reactor safety standpoint, too, good mixing of the coolant with the moderator is indicated, because this allows the negative moderator temperature coefficient to act rapidly in overcoming any accidental insertion of reactivity.

A large negative temperature coefficient is not an unmixed blessing, however. First, the random fluctuations in moderator temperature throughout the tank can introduce relatively large fluctuations in reactivity; second, the possibility of the "cold water" accident is introduced, and third, oscillations in the reactor power may be made possible through a coupling of the reactor coolant loop with the neutron kinetics.

The "cold water" accident could occur during tests in the reactor in which the reactor moderator is heated at low pile power with the secondary coolant system throttled down. If the secondary coolant is then suddenly started, the sudden cooling of the primary system introduces a slug of cold water and, hence, positive reactivity into the reactor.

Oscillations associated with the delays in the coolant loop and in the neutron kinetics will have periods of the order of magnitude of the time required for coolant to be pumped through the coolant loop. This is usually long enough that such oscillations can be controlled easily. The oscillations are damped for systems with small negative moderator temperature coefficients but could become troublesome for systems with large negative coefficients.

In graphite reactors, by contrast, the moderator is not mixed with the coolant at all. This implies that the moderator coefficient acts with a time constant so long that it will have little or no effect during the short times of concern during a reactor accident. Also, the moderator stays in one place so that reactivity cannot be carried about the pile as it can in the heavy water systems. This means that the distribution of moderator temperatures will tend to follow the power distribution.

The systems do have in common, however, a large size and an easily distorted power distribution. The primary control problem in each is to maintain a good distribution of power in spite of reactivity that may be introduced locally through the moderator temperature coefficients.

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