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Measurements of the isothermal, power and temperature reactivity coefficients of the IPR-R1 TRIGA reactor

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A B S T R A C T

The aim of this paper is to present the experimental results of the isothermal, power and temperature coefficients of reactivity of the IPR-R1 TRIGA reactor at the Nuclear Technology Development Center – CDTN in Brazil. The measured isothermal reactivity coefficient, in the temperature range measured, was −0.5 ¢/°C, and the reactivity measurements were performed at 10 W to eliminate nuclear heating. The reactor forced cooling system was turned off during the measurements. When the reactor is at zero power there is no sensible heat being released in the fuel, and the entire reactor core can be characterized by a single temperature. The power coefficient of reactivity obtained was approximately −0.63 ¢/kW, and the temperature reactivity coefficient of the reactor was −0.8 ¢/°C. It was noted that the rise in the coolant temperature has contributed only with a small fraction to the observed negative effect of the reactivity. The power defect, which is the change in reactivity taking place between zero power and full power (250 kW), was 1.6 $. Because of the prompt negative temperature coefficient, a significant amount of reactivity is needed to overcome temperature and allow the reactor to operate at the higher power levels in steady state.

1. Introduction

The TRIGA fuel elements are filled with homogeneous metallic mixture of the moderator zirconium-hydride combined with 20%-enriched uranium. The basic safety aspect for the TRIGA reactor system is the fuel temperature. The feature of these fuel-moderator elements is the prompt negative temperature coefficient of reactivity, which automatically limits the reactor power to a safe level in the event of a power excursion (General Atomic, 1970, 1961, 1958). Because of this coefficient, a significant amount of reactivity is needed to overcome temperature and allow the reactor to operate at high power levels.

Fuel temperature reactivity coefficient is important for reactivity and power excursion transient analysis where power feedback effects depend on the sign, rate and time delay of the fuel temperature reactivity effects. Three temperature coefficients are normally defined in respect to which temperature change is considered: fuel temperature reactivity coefficient, coolant/moderator temperature reactivity coefficient, and isothermal reactivity coefficient. Fuel temperature and power are related to each other. Although the fuel temperature is difficult to measure, the power coefficient of reactivity and the power defect are easily measured. This paper reports the results of a set of experiments to determine these coefficients of reactivity. The isothermal temperature coefficient was measured by observing the reactivity change when the core temperature is raised by other means while the reactor is operating at a very low, almost zero power level. When the reactor is at zero power there is no sensible heat being released in the fuel, and the entire reactor core can be characterized by a single temperature. The results obtained demonstrated that the fuel temperature coefficient is the main contributor to the reactivity power coefficient of the TRIGA reactor.

2. Methodology

Temperature is one of the operating conditions that affect the reactivity of a reactor core: a change in temperature will cause a change in reactivity. The direction of the change, whether it is positive or negative, and also its magnitude are of great importance to the reactor safety and control. If the reactivity effect of the increase in temperature is negative, the reactor will tend to level out at a new, higher power without external manipulation of controls. Such a reactor is stable and inherently safe. If, on the other

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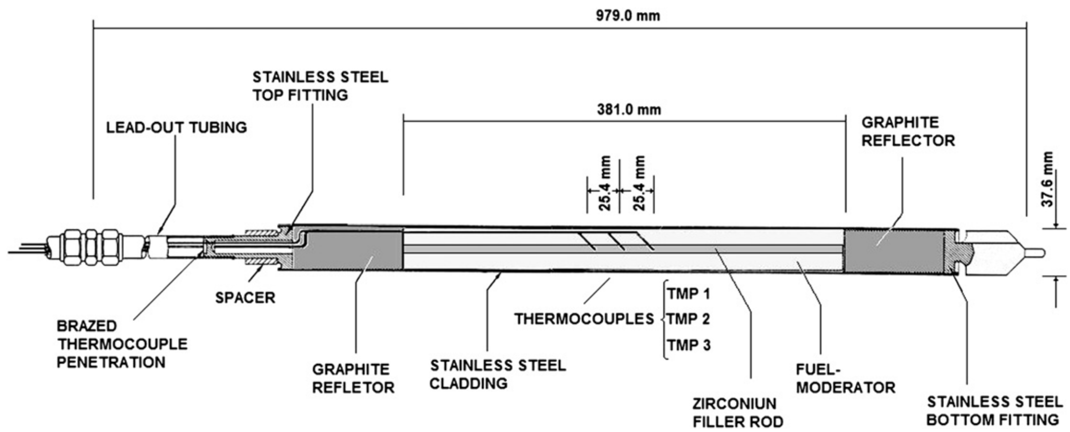

Fig. 1. Diagram of the instrumented fuel element (Gulf General Atomic, 1972).

hand, the reactivity effects are positive, the reactor will tend to "run away", and its safety will depend entirely on external control.

If the moderator and fuel temperature changes are the same throughout the core, as it would be in a homogeneous reactor, the temperature effect on the reactivity can be expressed by a simple temperature coefficient, α_{ISO}, defined as the change in reactivity due to change in temperature (Duderstadt and Hamilton, 1976):

$$\alpha_{ISO} = \frac{\Delta\rho}{\Delta T} \quad (1)$$

The negative reactivity feedback, $\Delta\rho_T$, produced by a temperature increase ΔT is then

$$\Delta\rho_T = \alpha_{ISO}\Delta T \quad (2)$$

assuming that α_{ISO} is constant over the range of temperature ΔT. The α_{ISO} is called the isothermal temperature coefficient or the zero power temperature coefficient (Duderstadt and Hamilton, 1976):

In a heterogeneous reactor like a TRIGA, the changes in temperature during operation are not uniform, that is, they are not the same in the moderator and in the fuel. In such a reactor we have to distinguish between the reactivity arising in the coolant, or moderator, and that arising in the fuel, and, accordingly, define a coolant temperature coefficient, α_T(M), and a fuel temperature coefficient, α_T(F). These coefficients, which depend on different factors, will in general be different in magnitude and in response time. Effects that depend on the instantaneous state of the fuel, for instance, resonance absorption (Doppler effect) or thermal distortion of fuel elements, are regarded as prompt, while effects that depend on the moderator or coolant are delayed (e.g., neutron energy spectrum and thermal expansion of moderator material).

The coefficient α_T(M) in a reactor is not measured as a separate quantity, since it is not possible to raise the temperature of the coolant without raising the temperature of the fuel. The quantity that can readily be determined is the isothermal temperature coefficient, measured by observing the reactivity change when the core temperature is raised by other means while the reactor is operating at a very low power level (zero power). Under such conditions the temperatures of the coolant and the fuel are the same. The isothermal temperature coefficient is a meaningful quantity in power reactor operation. It is a measure of the excess reactivity required for the transition from cold conditions to hot operating conditions.

In practice, it is difficult to measure α_T(F) directly, in the core, since the effective fuel temperature can not easily be measured. However, α_T(F) is the main contributor to the power coefficient of reactivity, which can be measured. To understand the effect of the operating power level on reactivity of the core, it is assumed that the mean temperature of the coolant and its rate of flow are kept the same at all power levels. An increase in power level must then cause an increase in the fuel temperature. Under these conditions, an increase in power level will cause a negative change in the reactivity. The power coefficient of reactivity is defined as the equation below, where ΔP is the change in power (Duderstadt and Hamilton, 1976):

$$\alpha_P = \frac{\Delta\rho}{\Delta P} \quad (3)$$

thus, in a change of the power level the change in the reactivity is

$$\Delta\rho_P = \alpha_P\Delta P \quad (4)$$

To obtain the contribution of the fuel to $\Delta\rho_P$ and thus the fuel power coefficient, α_P(F), in a reactor, it is necessary to subtract $\Delta\rho_T$(M) from $\Delta\rho_P$, where $\Delta\rho_T$(M) is the effect arising in the moderator due to the change in coolant temperature, ΔT(M). Approximate values for $\Delta\rho_T$(M) and $\Delta\rho_P$(F) are:

$$\Delta\rho_T(\mathrm{M}) = \alpha_{ISO}\Delta T(\mathrm{M}) \quad (5)$$

$$\Delta\rho_P(\mathrm{F}) = \Delta\rho_P - \Delta\rho_T(\mathrm{M}) \quad (6)$$

Then, the fuel power coefficient of reactivity is given by

$$\alpha_P(\mathrm{F}) = \frac{\Delta\rho_P(\mathrm{F})}{\Delta P} \quad (7)$$

3. The IPR-R1 TRIGA reactor

The IPR-R1 TRIGA reactor core consists of a lattice of cylindrical fuel-moderator elements, in which the zirconium-hydride moderator is homogeneously combined with 20% ^{235}U, and graphite

Table 1
Instrumented fuel element features (Mesquita, 2005).

Parameter	Quantity
Heated length	38.1 cm
Outside diameter	3.76 cm
Active outside area	450.05 cm^2
Fuel outside area (U-$ZrH_{1.6}$)	434.49 cm^2
Fuel element active volume	423.05 cm^3
Fuel volume (U-$ZrH_{1.6}$)	394.30 cm^3
Power (total of the core = 250 kW)	4.262 kW