THEORETICAL CHARACTERIZATION OF A DUAL-PURPOSE GAMMA THERMOMETER

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ANS Summary

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The local heat generation rate (LHGR) in a Pressurized water Reactor is typically inferred from measurements of the thermal neutron flux. However, since the thermal neutron flux exhibits a large amount of structure positionally within a PWR fuel assembly, an alternate instrument, the gamma thermometer (GT),[1-2] has been proposed as a means of improving the LHGR inference. Since the gamma flux is related to the fission rate, and since the gamma flux exhibits very little structure within a fuel assembly, the use of a gamma-based LHGR detector could significantly improve the measurement accuracy. More recently, a further application of the gamma thermometry principle has been advanced; that of a fluid level indicator for in-core measurements.[3] The results of a two-part study directed at establishing the feasibility of such a device, are the subject of this paper. The twin objectives of the study were to establish and characterize the basic LHGR to GT response relationship, and to verify the inital contention that a slightly modified version of the GT could be used as a fluid level indicator without compromise to the power level function.

The proposed GT (See Fig. 1) consists of a hollow, cylindrical stainless steel rod of length roughly equal to the reactor core height. Annuli of material are removed at intervals along the rod, and a cladding is swaged onto the exterior in an inert atmosphere. The thermocouples and associated leads are contained in the rods central core. Basically, the idea behind the dual-purpose application of the GT is to utilize the temperature difference between the hot and cold junctions as an indication of the LHGR, and to utilize the shape of the temperature distribution to infer the thermal hydraulic environment exterior to the device. Analytic approximations indicate that the two proposed responses are given by

$$\text{Power Level:}\quad (T_{Hot} - T_{Cold}) = \frac{\dfrac{qL_1^2}{2k} + \dfrac{qL_1R_1^2}{kmR_2^2}\left[(1 + e^{-2mL_2}) - 2e^{-mL_2}\right]}{(1-e^{-2mL_2})}$$

$$\text{Fluid Level:}\quad \frac{(T_{Hot} - T_{Mid})}{(T_{Mid} - T_{Cold})} = \frac{\dfrac{mL_1R_2^2}{2R_1^2}(1 - e^{-2mL_2})}{\left[(1 + e^{-2mL_2}) - 2e^{-mL_2}\right]}$$

where $m=\frac{hp}{kA}$, and the various dimensions are indicated in Figure 1. As evident from Eq. 1 and 2, the proposed power level response is anticipated to be a linear function of the LHGR (via q) but only a weak function of the thermal-hydraulic environment. Conversely, the proposed fluid level re-ponse is independent of the power level, but dependent on the external heat transfer coefficient.

Analogous to the dual functions of the proposed GT, the computational effort directed at characterizing the response in detail proceeded along two parallel paths. The discrete ordinates transport code DOT-IV[4] was employed to characterize the radiation transport from the fuel pins to the GT and to determine the subsequent heat deposition. A two-dimensional x-y geometric model of a prototypic PWR fuel assembly consisting of 288 fuel pins in a square lattice (17 x 17), with the GT in the central instrumented location was utilized. The results of the DOT-IV calculations indicated that the average GT response (i.e. the energy deposition rate) attributable to all gammas is found to be approximately 7.28 W/cm^3. The GT response was analyzed as to the origin of the particles which contributed to the response as well as the type of neutron interactions producing the gamma rays. It was found that (1) 95% of the GT response was due to particles originating in the instrumented fuel assembly (72% being from the first three rows of fuel pins surrounding the GT), and (2) 22% of the GT response was due to gamma rays from fission-product decay while only 3% of thermal power was due to same. The first finding indicates that the GT response is very representative of the Local Heat Generation Rate. The second indicates that the power level calibration will depend on burnup since the fission product gamma-ray spectrum changes with burnup. However, since the fission-product gamma source reaches equilibrium within a few full power days,[5] such an effect will represent only a transient at initial startup or following a restart.

The characterization of the response of the GT to changes in the thermal hydraulic environment was accomplished by using the HEATING -5[6] code to calculate the spatial and time dependence of the GT response. The analyses considered the behavior of the GT response for both normal operating conditions, as well as the behavior during and subsequent to various reactor transients. The results for an instantaneous loss of coolant accident are presented in Figure 1.

The results indicate that the power level response will return to the initial value after a short delay time, whereas the fluid level response decreases by approximately a factor of two. Similar results were observed for an instantaneous reactor scram with the fluid level response remaining constant and the power level response decreasing by a factor of four.

The conclusions of this preliminary study indicate that the GT is a feasible dual purpose instrument capable of providing both power level information and fluid level indication with neither function expected to compromise the effectiveness of the other function.

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Fig 1. GAMMA THERMOMETER RESPONSE TO AN INSTANTANEOUS LOCA