Effect of Radiation Heat Transfer in Loss-Of-Offsite Power (LOOP) Transients for Material Irradiation Capsules in the HFIR

Juan J. Carbajo
Oak Ridge National Laboratory
P.O. Box 2008, MS-6074, Oak Ridge, TN 37831, carbajojj@ornl.gov

INTRODUCTION

Before capsules with materials are irradiated in the High-Flux-Isotope-Reactor (HFIR), a 85 MWth research reactor located at Oak Ridge National Laboratory, several safety studies must be completed to demonstrate that the capsules will not exceed defined limits for postulated off-normal operating conditions. One such safety study is the Loss-Of-Offsite Power (LOOP) transient, during which there is a transition from full coolant flow to low flow generated by a single pony motor in combination with a reactor scram delayed 1.27 s. This is a very limiting transient, because the coolant surrounding the irradiated capsule may reach saturation temperature and may start boiling, conditions that are not permitted during HFIR operation. This paper investigates the effect of *radiation* heat transfer in LOOP transient calculations.

LOOP transient calculations can be performed using the thermal-hydraulic transient code RELAP5, Mod.3.3 (Ref. 1). Simplifications that yield conservative results are permitted and often used in order to complete the calculation in a reasonable amount of time.
Neglecting radiation heat transfer across the internal surfaces of the capsule is one of the simplifications commonly employed. Generally, if the temperatures of the materials inside the capsule are not very high, radiation effects are not important and this approximation is valid. However, when the temperatures of the capsule materials are high, (>1300 K) radiation effects are important, and it is not clear if neglecting radiation heat transfer is conservative. In principle, the full-power calculated temperatures in the capsule without radiation will be much higher than when radiation is used. These higher temperatures before the LOOP starts are conservative as the stored energy inside the capsule will be higher than the values with radiation. On the other hand, the lack of radiation heat transfer models will transfer heat to the coolant at a slower rate, which may not be conservative. The overall effect of neglecting radiation depends on which of these two effects is more important: the higher stored energy or the slower release of the stored energy to the coolant.

METHOD AND RESULTS

In order to investigate the effect of radiation heat transfer, two separate calculations were completed for the RB-18J capsule to be irradiated in the HFIR. The calculations were completed with the code RELAP5 Mod3.3 (Ref. 1). This capsule contains three subcapsules with silicon carbide specimens that will be irradiated at temperatures of 800, 1000, and 1300 ºC. The capsule specimens are contained in graphite holders, which are inside stainless-steel sleeves and housing. There are gaps between the holders and the sleeves, and between the sleeves and the housing. The gaps are filled with mixtures of helium and argon. The gaps can be treated as pure conductive media (no radiation) or with conduction and radiation combined through the gap. Instead of using the radiation heat transfer model of RELAP5 which is very cumbersome, a *corrected* gap thermal conductivity is used, adding a radiation term to the conduction term as the following equations indicate:

$$\text{Radiation } Q = \frac{A\sigma(T_1^4 - T_2^4)}{(1/\varepsilon_1 + 1/\varepsilon_2 - 1)} \cong \frac{AF\sigma T_{avg}^{\ 3}(T_1 - T_2)}{(1/\varepsilon_1 + 1/\varepsilon_2 - 1)}$$

$$\text{Total } Q = A\frac{(T_1 - T_2)}{\Delta x}\left[k + \frac{\sigma F T_{avg}^{\ 3}\Delta x}{(1/\varepsilon_1 + 1/\varepsilon_2 - 1)}\right]$$

where **A** is the heat transfer area, **σ** is the Stefan-Boltzman constant, **T** absolute temperatures of the surfaces, **ε** surface emissivities, **Δx** the gap distance, and **k** the thermal conductivity of the gas in the gap. The factor **F** is 4 or larger, depending on the temperatures. For this analysis, a value of F=4.25 is appropriate based on results from separate steady state analyses. The second term inside the brackets of the last equation is the *radiation contribution,* to be added to *k*. This contribution is implemented in the thermal conductivity tables, part of the code input.

The capsule is surrounded by an aluminum liner. The capsule and the liner are located inside a cylindrical hole of the large beryllium reflector of the HFIR. Cooling water flows into two separate channels around the liner: the primary channel, between the capsule housing and the liner, and the secondary channel, outside the liner. The calculation was run for 500 s at full power in order to reach steady state conditions before the LOOP transient is initiated. As expected, the temperatures calculated inside the capsule prior to the initiation of the LOOP are significantly higher (several hundred degrees) in the case without radiation models. Therefore, the capsule stored energy in the case without radiation is also significantly higher than in the case with radiation. The calculated temperatures after the LOOP was initiated at 500 s are shown in Fig. 1 for the coolant exiting the primary and the secondary channels. The calculated temperatures are well below saturation in both calculations. During the first 18 s of the transient, the temperatures of both calculations are basically the same. After that time, the coolant temperatures are higher (by a few degrees) for the case without radiation models, due to the larger amount of energy stored in the capsule and released into the coolant.

CONCLUSIONS

A model was developed to treat the radiation heat transfer between surfaces as a component added to the thermal conduction of the gap. In the case analyzed, neglecting radiation heat transfer in high temperature capsules is conservative for LOOP transients, because the lack of radiation heat transfer increases the internal temperatures (and the energy stored) of the materials inside the capsule prior to the LOOP transient, resulting in slightly higher coolant temperatures after the LOOP is initiated. Including radiation heat transfer is a more accurate representation of the problem, but involves more extensive modeling.

REFERENCE

1.- *RELAP5/MOD3.3 Code Manual Volume II: User's Guide And Input Requirements*, NUREG/CR-5535/Rev 1, prepared for the Division of Systems Research, Office of Nuclear Regulatory Research, USNRC by Information Systems Laboratories, Inc., Rockville, Maryland, December 2001.

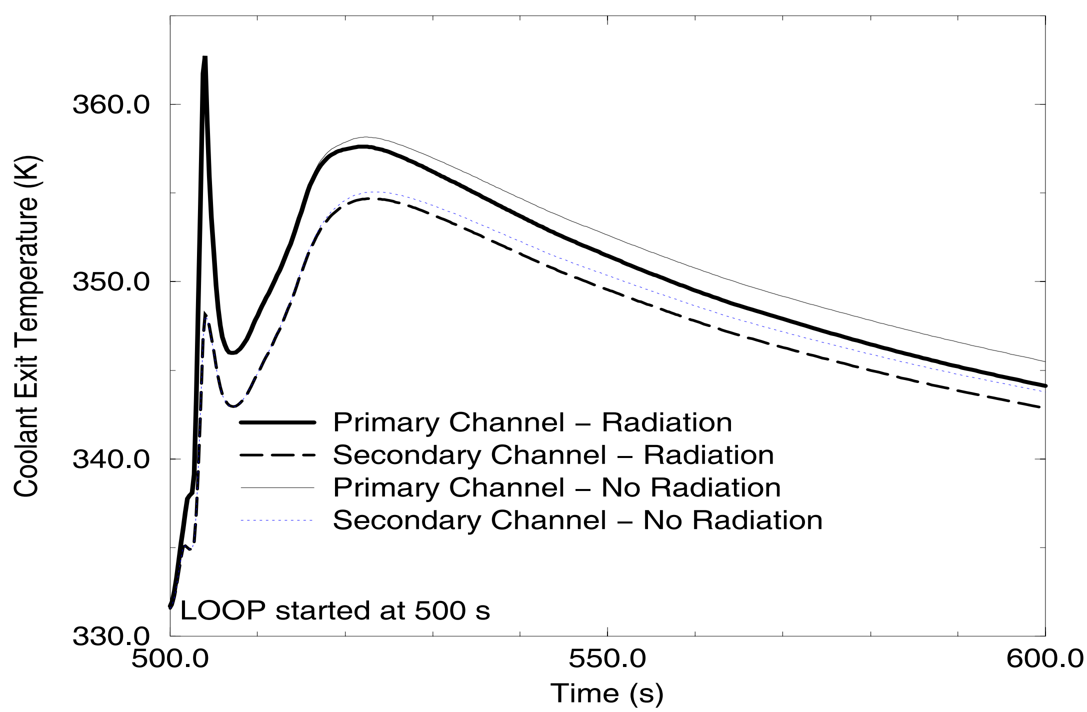

Fig. 1. Coolant exit temperatures calculated with and without radiation models during a LOOP transient in the RB-18J capsule.