Letters to the Editor

Comparison of the Response to Small Perturbations in Metal- and Oxide-Fueled Liquid-Metal-Cooled Reactors

In a recent paper,[1] Ott has clearly brought out the differences in the response of oxide- and metal-fueled liquid-metal-cooled reactor (LMR) cores to the unprotected loss-of-flow (ULOF) and unprotected loss-of-heat-sink (ULOHS) incidents. For the particular reactor design he considered, Ott's asymptotic analysis reveals that for the oxide-fueled core the asymptotic state is a zero reactivity state (stable low-power criticality), while for the metal-fueled core there exists a semiasymptotic subcritical state with zero fission power. This difference in behavior is basically due to the high thermal conductivity of metal fuel, resulting in a much smaller fuel-temperature-related reactivity feedback coefficient in comparison with oxide fuel. The reactivity coefficients of the considered cores, taken from p. 21 of Ref. 1, are reproduced here in Table I for clarity of the subsequent discussion.

From Table I, it is clear that the essential difference between the two cores is the order of magnitude smaller value of ρ_p for the metal-fueled core as compared to the oxide-fueled core. The purpose of this letter is to point out that, while such a distribution of coefficients appears to lead to a better response of the metal-fueled core in the case of low-probability incidents like ULOF or ULOHS, it leads to a larger sensitivity of the power plant to small perturbations during normal operation. While evaluation of the actual time behavior of the power plant after a small perturbation would require transient analysis, the larger sensitivity of the metal-fueled core to such perturbations can be easily established by analysis of asymptotic critical states as developed by Ott.[1]

First we consider the case of a reactivity perturbation with no change in flow or inlet temperature. Equation (16) of Ref. 1 shows that

$$\rho = a_i \delta T_i + \rho_{pf} \delta \Phi + \rho_p \delta p \ . \qquad (1)$$

When there is no change in flow, $\delta\Phi = \delta p$, and as $\delta T_i = 0$ then

$$\delta p = \frac{\rho}{\rho_{pf} + \rho_p} \ . \qquad (2)$$

Using this equation, the perturbation in power for a 10¢ change in reactivity is calculated for the metal- and oxide-fueled cores and is given in the first column of Table II.

TABLE I

Comparison of Reactivity Feedback Coefficients [900-MW(thermal) LMR]

LMR Type	Inlet Temperature Coefficient, a_i (¢/K)	Power Coefficient, ρ_p (¢)	Power-to-Flow Ratio Coefficient, ρ_{fp} (¢)
Oxide-fueled	−0.4	−170	−40
Metal-fueled	−0.3	−15	−30

Next we consider the case of an inlet temperature perturbation with no change in flow and zero input reactivity. For this case,

$$\delta p = -\frac{a_i \delta T_i}{\rho_{pf} + \rho_p} \ . \qquad (3)$$

The calculated values of perturbation in power for a 10 K change in inlet temperature is given in the second column of Table II. The much larger sensitivity of the power in metal-fueled LMRs to small perturbations is evident from the numbers in Table II.

In the future, with LMR power plants having load-following capabilities, it is possible that control instrumentation would link the flow to the power so as to have a constant power-to-flow ratio in normal operation. For the case of a constant power-to-flow ratio, Eqs. (2) and (3) become

$$\delta p = \rho / \rho_p \qquad (4)$$

and

$$\delta p = -a_i \delta T_i / \rho_p \ , \qquad (5)$$

respectively. The resulting perturbations are calculated and given in Table III. It is seen that, for the constant power-to-flow ratio case, while there is not much increase in the power

TABLE II

Percentage Perturbation in Power for Small Perturbations in Reactivity or Inlet Temperature (Constant Flow)

LMR Type	10¢ Change in External Reactivity (%)	10 K Change in Inlet Temperature (%)
Oxide-fueled	4.76	1.90
Metal-fueled	22.22	6.67

TABLE III

Percentage Perturbation in Power for Small Perturbations in Reactivity or Inlet Temperature (Constant Power-to-Flow Ratio)

LMR Type	10¢ Change in External Reactivity (%)	10 K Change in Inlet Temperature (%)
Oxide-fueled	5.88	2.35
Metal-fueled	66.67	20.00

perturbation in the oxide-fueled core, the power perturbations become very large in the metal-fueled LMR.

To summarize, the oxide-fueled core appears to have a desirable highly damped response to small perturbations during normal operation, whereas the metal-fueled core is much more sensitive to such perturbations. Note that this difference in response to perturbations is prominent only for large cores. In small test fast reactors like Experimental Breeder Reactor II (metal) and RAPSODIE (oxide), the Doppler contribution is small and the dominating coefficient is ρ_{pf}, which makes the responses of the differently fueled cores to small perturbations similar.

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REFERENCE

1. K. O. OTT, *Nucl. Sci. Eng.*, **99**, 13 (1988).

Response to "Comparison of the Response to Small Perturbations in Metal- and Oxide-Fueled Liquid-Metal-Cooled Reactors"

The letter by Lee[1] addresses the response to small perturbations in inlet temperature (T_i) and externally applied reactivity (ρ_x) in metal- and oxide-fueled liquid-metal-cooled reactors (LMRs). As his analysis makes use of the steady-state reactivity formula of Ref. 2 ($\rho = 0$), his results have to be considered the asymptotic response to small perturbations. The two types of perturbations are discussed separately in Secs. I and II.

I. INLET TEMPERATURE PERTURBATIONS

Lee's Eq. (3) follows directly from Eq. (22) or (23) of Ref. 2, i.e.,

$$\delta T_i = \frac{\rho_{pf} + \rho_p}{a_i}\,\delta p = \begin{cases} -525\,\mathrm{K}\,\delta p\ \text{(oxide)} \\ -150\,\mathrm{K}\,\delta p\ \text{(metal)} \end{cases} , \tag{1}$$

using the coefficient values of Ref. 2. In Eq. (1), δp and δT_i are both unknown. If Eq. (1) is applied to an unprotected loss-of-heat-sink (ULOHS) incident, the required second equation comes from the asymptotic equality of power (p_{as}) and heat rejection rate p_{ras}. As p_{ras} is much smaller than $p_0 = 1$, δp_{as} is close to -100% (i.e., $\delta p_{as} \approx -1$).

Equation (1) is then solved in Ref. 2 for the remaining unknown, δT_{ias}:

$$\delta T_{ias} = 525\ \mathrm{K}\ \text{(oxide)}$$

and

$$\delta T_{ias} = 150\ \mathrm{K}\ \text{(metal)}\ . \tag{2}$$

Thus,

$$\delta T_{ias})_{metal}/\delta T_{ias})_{oxide} = 1/3.50\ , \tag{3}$$

with the inference that in a ULOHS incident metal cores have a considerably smaller and thus more desirable temperature response than oxide cores.

Lee treats δT_i in Eq. (1) as a given input and finds the δp response by inversely applying Eq. (1), giving

$$\delta p)_{metal}/\delta p)_{oxide} = 3.50\ , \tag{4}$$

with the inference that metal-fueled cores are much more sensitive to small perturbations than oxide-fueled cores, which have a highly desirable damped response.

While the numerical value on the right side of Eq. (4) is correct, we believe that Lee's conclusion with respect to desirability is mistaken. In discussing this question, it is important to consider the power level at which a perturbation is applied.

At nominal power T_i changes are more likely on the up side resulting from a deterioration of the heat rejection capability, leading to a *decrease* in power, that is, a factor of 3.5 stronger for metal than for oxide. The maximum T_i decrease that can be experienced at nominal power (either by a sudden increase in power demand or by accident) is quite limited. The consideration of the corresponding power increase is subject of the safety design.

Below nominal power, T_i changes may be effected in both directions, bringing into play the strong sensitivity of the power response. This opens up the intriguing possibility of controlling the reactor with the balance of plant (BOP) as discussed in some detail in Ref. 3. Of course, changing the inlet temperature in an LMR pool design is a very slow process as one needs to effect a temperature change in several thousand tons of metal. This novel control approach would hardly be possible if the core response to a T_i change would be "highly damped."

II. REACTIVITY PERTURBATIONS

Reactivity perturbations and the overpower transients (TOP) are not discussed in Ref. 2. A companion paper to Ref. 2 on TOP has been prepared for submittal to *Nuclear Science and Engineering*. Therefore only some general comments are presented here:

1. In case of a longer term, or asymptotic response, the power is determined by the heat rejection capability of the BOP and not by Lee's Eq. (2). The input reactivity is fully compensated by feedback resulting from a temperature change in the system.

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