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Comparison of Effect of Insulating Blockages on Metal and Oxide Fuel Elements

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Comparision of Effect of Insulating Blockages on Metal and Oxide Fuel Elements

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The safety philosophy of the new liquid metal reactor (LMR) plant designs is oriented towards inherent protection against loss of coolable geometry and other entries to core disruption. One potenteal entry is via propagation of local faults (ref. 1). Within this category is a wide range of initiators which each require assessment of their probabaility and consequences in order to determine their contribution to plant risk. Local faults includes those initiators which cause local power/flow disturbances restricted either to a single subassembly or to a local region of the bundle. The concern is that these localized initiators may start a sequence of events in which fuel failure may propagate first within a subassembly envelope and finally cause loss of coolable geometry in adjacent subassemblies. These events do not have initiators which are readily detectable by instrumentation and amenable for use as automatic shutdown system inputs and the probilities associated with shutown have not been assessed. However low risk can be demonstrated by the inherent tolerance of the design to potential initiators, process inherencies which do not support propagation, and engineering inherencies which restrict the impact of initiators, enhance the other aspects of inherency, and provide redundant signals to the operator on a timely basis.

The basic event in all local sequences is cladding failure, irrespective of initiator. Since failure occurs when the applied stress exceeds the strength of the cladding, failure initiators generally can be classified as those which increase cladding stress or reduce cladding strength:

- strength reduction--increasing temperature (flow reduction, power increase, thermal resistance increase), thickness reduction,
- load increase--internal loading increase, external loading increase.

In an insulating blockage event both of these effects occur. For oxide fuel the increase in cladding temperature reduces the strength and increases the loading due to local thermal distortion. For metal fuel both of these effects occur but due to the higher thermal conductivity of the metallic fuel they are smaller. However there is also the potential for a reduction in effective cladding thickness because of an eutectic interaction between the fuel and cladding to be considered. The rate of eutectic penetration is a strong function of temperature and time to failure at a given temperature is a combination of eutectic penetration and creep (ref. 2). The change in emphasis due to an inherent safety approach is illustrated below.

The insulating blockage occurs inside a fuel bundle and does not bave a signature which is visible to instrumentation. For non-heatgenerating blockages, CRBRP licensing (ref. 3) emphasized the difficulty of blockage formation due to geometric factors and system cleanliness, the effect of wake residence times behind multi-channel planar blockages and the detectability of slowly developing failures without propagation. In this era of inherency the focus is on the limits of failure initiation parameters eventhough the above arguments still apply.

A model of a complete insulating blockage, i.e. total loss of heat transfer from the cladding surface due to any cause, was developed for a range of insulated arcs. The internal properties represented either metal or oxide fuels, both irradiated to a condition which closed the fuel-clad gap. The advantage of the high conductivity of the metal fuel is clearly evident; the maximum cladding temperatures are considerably lower than for the oxide elements with the same circumferential blockage extent. Also the minimum cladding temperature at the opposite side of the element is higher for the metal fuel thus providing more uniform heat rejection from the unblocked portion of the cladding. The cladding temperatures at the edge of the blockages for the oxide elements are directly proportional to the blockage angle, indicating that the cladding is the main path for heat rejection. For the metallic fuel this temperature is proportional to the blockage angle to a three-quarter (3/4) power law, showing that the temperature distribution in the fuel changes sufficiently to divert some of the heat from the blocked sector to the unaffected periphery. This agrees with the observation that the increase in minimum cladding temperature for the metallic fuel is much larger than the increase for oxide fuel.

One consequence of the higher cladding temperatures in the oxide fuel is that the circumferential temperature gradients are larger than for the metallic fuel elements. The larger local deformation (strain) and the increased gradients imposed on the cladding result in larger stresses in the cladding and an increased likelihood of failure.

Below about 715 degrees centigrade there is no uranium-iron eutectic formation (ref. 2), consequently a metallic fuel element can sustain an insulating blockage up to about 60 degrees azimuthal extent with less probability of failure than oxide fuel. Above this blockage size the consequences also depend upon the creep performance of the cladding and the internal pressurization of the fuel element.

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Figure 1. CLADDING TEMPERATURE PROFILES