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ABSTRACT

SIMMER is a coupled neutronics, two-phase, multicomponent hydrodynamics code that includes modeling of many heat, mass, and momentum exchange processes. SIMMER-I has predicted that the conversion of fission energy to sodium kinetic energy following LMFBR disassembly is very inefficient. This paper reports the result of a thorough sensitivity study of this process using SIMMER-II.

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INTRODUCTION

The application of SIMMER-I[1] to the analysis of the postdisassembly expansion phase of Hypothetical Core Disruptive Accidents (HCDAs) in Liquid Metal Fast Breeder Reactors (LMFBRs) predicted a large reduction (a few percent of ideal) in the fluid dynamic loading of the primary system.[2] These calculations provided an integrated and interactive assessment of the nonuniform two-phase core expansion, the intracore mixing of hot and cold fuel, the influence of both internal structures and heat exchange processes, and the effect of condensation on the internal structures. These analyses with SIMMER-I were of an exploratory nature and gave insight into both the expansion and the magnitude of the combined effects.

These results have led to a major effort[3] in evaluating the calculational validity of the code by a combined analytical and experimental approach using the SIMMER predictions as a focal point. To limit the scope of the effort and to maximize its cost-effectiveness, SIMMER-II[4] is being used to assess the sensitivity of the calculated results to initial conditions, to

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material properties, to modeling assumptions such as liquid breakup, to empirical data such as heat transfer coefficients, and to model deficiencies such as interfacial mixing. SIMMER-II provides greater flexibility than SIMMER-I in accommodating modeling variations, in representing physical processes, in operating efficiently, and in assessing the dynamic neutronic state during the expansion.

POSTDISASSEMBLY EXPANSION SENSITIVITY STUDY

This sensitivity study is based on a statistical approach providing a measure of the relative sensitivity of the results to the variables or uncertainties indicated previously. Relatively few (on the order of 15) code calculations are required. By randomly selecting complete, independent sets of variables for each SIMMER-II calculation, each code result represents an independent observation of a random system. These observations are then statistically analyzed to correlate the results or outputs and the input variables. Not only can the mean result be identified, but the probability of any other result falling outside the maximum and the minimum results can be established within confidence limits.

The calculational model used for the study is based on the Clinch River Breeder Reactor (CRBR) and encompasses the entire reactor vessel and its internal structures. The core initial conditions are taken from the state of the system following disassembly. The nominal calculation assumes both the core and upper pin structure to be void of sodium. The fuel, uniformly distributed in the core, is assumed to be in saturated equilibrium with its vapor and to have a temperature distribution consistent with the power distribution. The nominal case has an initial average core fuel temperature of 4200 K. The subassembly can walls in the active core are assumed to have disintegrated, hence offering no resistance to radial flow. Best estimates are used for the empirical data and material property data in the nominal case.

Compared to the work energy available in an isentropic expansion of the high temperature fuel, the system kinetic energy predicted by SIMMER-II for the nominal case is small at the time of sodium impact with the reactor head. For the initial fuel state selected for the nominal problem and the geometry of the CRBR system, SIMMER-II predicts approximately 5 MJ, compared with about 100 MJ for the isentropic expansion, a difference resulting from a number of mitigating effects. In the early portion of the expansion, the fuel in the core region is driven to the core extremities by the large initial pressure gradients. This results in the intermixing of hot and cold liquid fuel and in the early reduction of the peak fuel temperature and pressure. Hence, the driving force for the expansion is quickly reduced from about 25 MPa to about 3 MPa. The molten core material expands primarily upward through the intact pin structure of the upper axial blanket and fission gas plenum regions. Because this path is extremely resistive to high-velocity and high-density fluid flow, the expansion is throttled, producing both a substantially increased expansion time and decreased quantity of hot core material injected into the sodium pool. The longer expansion time permits the heat transfer processes in the core to reduce the driving force further for the expansion. The primary cause for the kinetic energy developed in the system is the heat transfer from fuel and steel to the sodium directly above the subassemblies. Although the heat transfer rate is large, this fuel-coolant interaction is relatively mild because the quantity of hot core material escaping from the subassemblies is small.

SUMMARY

The nominal results were found to be consistent with basic principles and phenomenological considerations. The parameters selected for variation in the sensitivity study were those which influenced the kinetic energy in the nominal calculation to the greatest extent. The sensitivity study indicates that the major contributors to the uncertainty in the kinetic energy at sodium impact with the reactor head are the degree of intracore mixing, liquid-fuel-to-liquid-steel heat transfer in the core, the initial sodium distribution in the core, the frictional characteristics of the upper pin bundle, the strength of the liquid-fuel-to-sodium heat transfer, and the strength of the condensation in the pin bundle and at the pool interface.

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