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Numerical Simulations of the Nonlinear Dynamic Response of the CRBRP Head Assembly*

by

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Summary

The head assembly of a liquid metal fast breeder reactor's (LMFBRs) vessel provides the topside barrier for radioactive core materials and coolant. Events that challenge the structural integrity of this barrier must be taken into account in the safety analysis of LMFBRs because a breach of the topside closure would permit a substantial inventory of sodium to enter into the secondary containment. One such accident, which is very unlikely but potentially severe, is a hypothetical core disruptive accident (HCDA), which has the mechanical consequence of propelling a slug of high velocity sodium against the head assembly. The numerical simulation of the dynamic response of the Clinch River Breeder Reactor Plant's (CRBRP) head closure during a 661 MJ HCDA and a qualitative comparison of deformation modes with a static loading test, which was performed by SRI International, are described here.

The CRBRP is a loop-type LMFBR with a triple, rotatable plug head closure. The head closure consists of head plates, biological shield plates, support skirts, risers and bearing sets, and thermal reflector plates. The small rotatable plug (SRP) is supported by the intermediate rotatable plug (IRP); the IRP is supported by the large rotatable plug (LRP); and the LRP is supported by the reactor vessel flange. Each plug supports its respective shielding from the underside.

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A three-dimensional finite-element model was developed that includes structural representation for the head plates, shield plates, spacer rings, and skirts. Because of symmetry, a 180-degree model was adequate. Along the outer periphery of the LRP, simply supported boundary conditions that permit radial motion were applied. Gap-impact elements, which were arranged in a geometric configuration to simulate the mechanics of translational and rotational gaps, were located along all the plug-to-plug junctions. In addition, tetrahedral gap-impact elements were located between the lower and middle shield plates. The NEPTUNE system of codes was used to simulate the response of the head assembly to slug impact.

Results from our numerical simulation showed that the largest vertical displacement of the head plates occurred at the LRP-IRP juncture at the wide side of the LRP, and it had a value of 8 cm. These deformations were large enough to cause the bottom edges in the LRP-IRP and IRP-SRP junctions to contact each other, thus, causing these plugs to translate in a somewhat horizontal direction. The translational motion caused failure, in the sense that a sodium leak path is created when the LRP shear ring slips off the IRP shear-ring-bearing surface.

Examination of the deformations of the components of the head clearly show that the largest deformation has occurred in the lower shield plate of the IRP. Also, a comparison between the deformed shapes of the IRP's head plate and the IRP lower shield plate shows substantial differences; the IRP's head plate deformed into a "conical shape", whereas the IRP's lower shield plate deformed into a "dome" shape. These differences can be explained by examining the load path within the head assembly. The head is designed with a series of spacer rings (1) between the head and upper shield plate and (2) between the shield plates themselves. During slug loading, the entire underside of the lower shield plate is subjected to the impact pressure. The loading is transmitted to the head through the spacer rings. Thus, the head plates only feel the line loading of the spacer rings. In contrast to the lower shield plate, there is no pressure loading acting on the underside of the headplates. The pressure loading deforms the IRP lower shield plate into a "dome" shape, while the spacer rings line loads deform the IRP head plate into a "conical" shape. The calculations also indicate that the IRP's lower shield plate impacted against the IRP's middle shield plate. Note, the above predictions were made prior to the SRI International test of the head assembly, which is mentioned below.

In conjunction with our numerical simulations of the response of the head assembly, SRI International was given a contract, from the Clinch River Breeder Reactor Project office, to conduct a series of 1/20th scale model tests in support of the design and to provide us with data for code validation. Only one static test was completed before the cancellation of the Clinch River Project; no dynamic tests were performed, and no report was written. Examination of posttest photographs of the head assembly indicated that the NEPTUNE predicted deformed shapes are qualitatively in very good agreement with the SRI test results. A verbal communication with the SRI Research Engineer, who conducted this test, indicated that the middle and lower shield plates of the IRP contacted each other, which is also in agreement with the numerical simulation.