Single Rod Fuel-clad Mechanical Interaction

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Much of our FY07 Global Nuclear Energy Partnership (GNEP) activity involved performing a number of coupled physics calculations in 1D and 3D using a single rod with fluid channel on the outside. Our particular focus was to simulate mechanical interaction between the fuel and cladding in case of severe fuel swelling that squeezes out the gap. We handled this interaction in the computational hydrodynamics for advanced design (CHAD) code by defining a critical value of the gap thickness (a user input parameter) below which the gap is considered to be closed. When this happens we add equal and opposite momentum sources at the two gap interfaces to maintain this thickness so that the cladding can respond to the fuel motion and vice-versa. (Simulating a flow blockage in the fluid channel is much easier as CHAD has built-in fluid velocity constraints at each node, which can be set to zero when the fluid channel thickness goes below a critical value.)

Figure 1 shows the fuel-clad interaction in 1D. CHAD is a 3D code, and all calculations are done in full 3D mode. To simulate a 1D rod, we took a small radial segment of the rod that has only one azimuthal zone and is only one cell high. Energy was added to the fuel while the pressure was applied to the outside surface of the coolant. We continued adding energy to the fuel until the gap was considered closed at 20 s. The fuel-clad interaction is depicted in the frames starting at 20 s.

Figures 2 and 3 show the fuel-clad interaction in 3D. Instead of the applied pressure to the coolant, the coolant is modeled as a flow channel with a solid cylindrical wall on the outside. The outside diameter of the flow channel is defined so that the total flow area corresponds to the advanced burner test reactor (ABTR) hexagonal design. Figure 3 compares the initial fuel-clad-coolant configuration with that at 25 s. An incipient Rayleigh-Taylor type instability is observable at 25 s. Soon after 25 s, the instability grows and the code fails to run further. The primary reason for this instability is that the deviatoric part of the material stress tensor was not included in these calculations, without which the fuel and the cladding behave like a fluid with very high density. The reason for not including the material strength in these calculations is that the current semi-implicit implementation of these models in CHAD does not work satisfactorily for such low Mach number flows, which are of the order of about 1 x 10^{-8}. Work for fully implicitizing these models within the current implicit hydrodynamics scheme is in progress.

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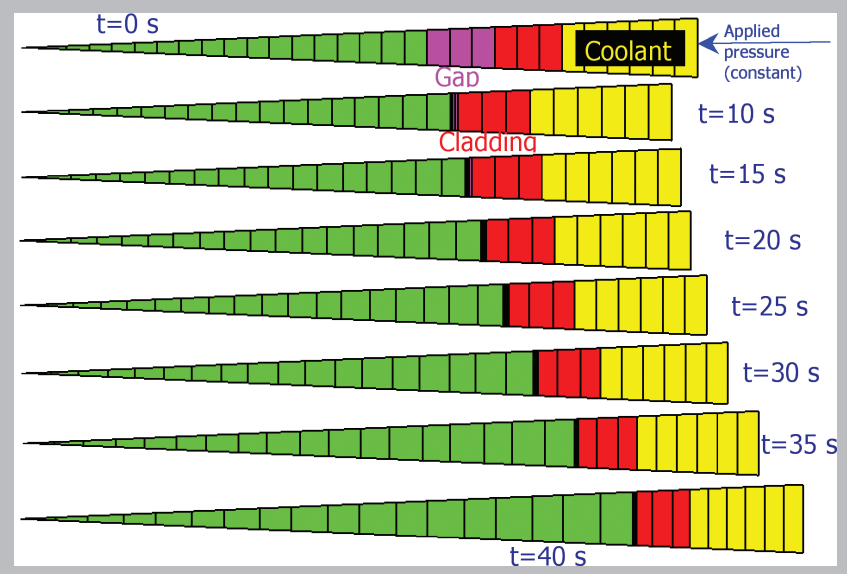

Fig. 1. Fuel-clad mechanical interaction in 1D cylindrical wedge.

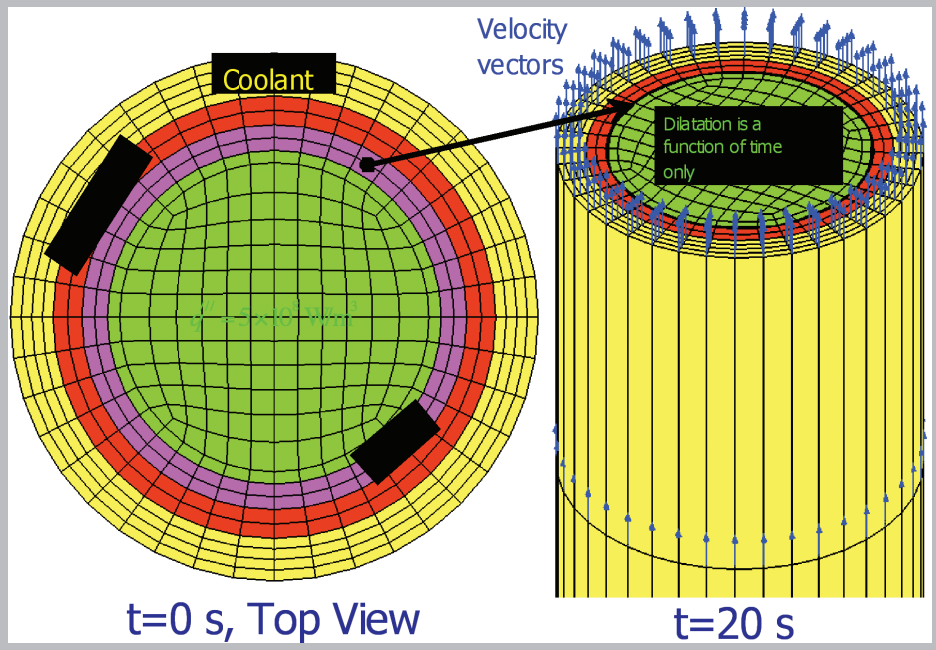

Fig. 2. Single-rod 3D calculation to 20 s, the time at which the gap is considered to be closed.

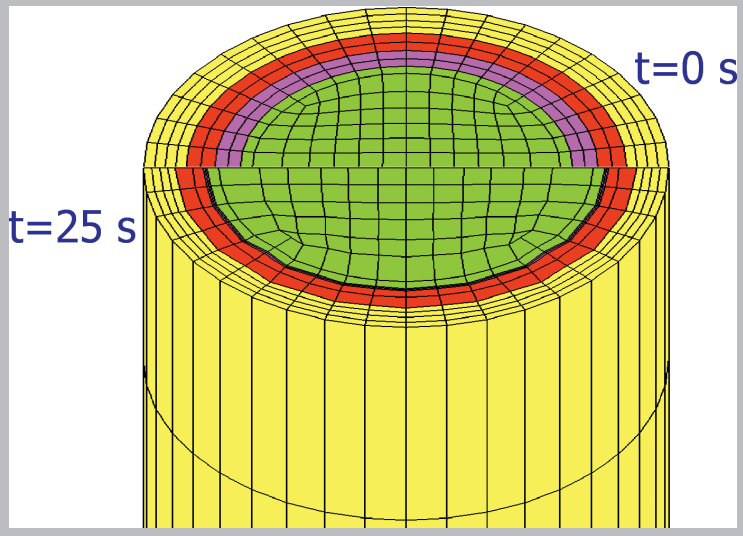

Fig. 3. Comparison of initial and final configurations. The cladding has been pushed significantly into the original flow channel.