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A DIRECT HEATING CONTAINMENT VESSEL INTERACTIONS CODE (DHCVIC) AND* PREDICTION OF SNL "SURTSEY" TEST DCH-1

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High-pressure melt ejection from PWR vessels has been identified as a severe core accident scenario which could potentially lead to "early" containment failure.[1] Melt ejection, followed by dispersal of the melt by high velocity steam in the cavity beneath the PWR vessel could, according to this scenario, lead to rapid transfer of energy from the melt droplets to the containment atmosphere. This paper describes DHCVIC, an integrated model of the thermal, chemical and hydrodynamic interactions which are postulated to take place during high-pressure melt ejection sequences. The model, which characterizes interactions occurring within the reactor cavity, as well as in the containment vessel (or building), is applied to prediction of the Sandia National Laboratory "SURTSEY" Test DCH-1 and a (post-test) prediction of that test is made.

DHCVIC is, at present, a three-region integrated model, consisting of descriptions of interactions within: (i) a pressure vessel containing the melt and driver gas, (ii) a (reactor) cavity beneath the pressure vessel and (iii) a large containment volume. Figure 1 shows the three-regions which comprise the SURTSEY 1/10-scale simulation of the (ZION) containment system. The mass, momentum and energy balances which are solved for the three regions lead to predictions of the rate of discharge of gas from the pressure vessel, of the chemical and thermal exchange processes occurring within the cavity and within the containment volume.

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Melt, consisting of metallic and non-reacting oxidic components, ejected from the vessel, is assumed to fragment into droplets due to the relative velocity between gas and liquid in the cavity. These droplets, which are produced continuously throughout the melt ejection process, are then tracked during their pathway through the cavity and containment volume using a Lagrangian methodology. With this technique, packets of droplets are tracked and their position, velocity, temperature, composition and size are continuously computed.

The gas velocity and temperature within the cavity are computed as a function of position using a quasi-steady continuity equation and an energy equation which accounts for particle-gas heat transfer. Thermal and chemical interactions within the cavity are considered.

Droplets and gas which enter the containment volume from the cavity are treated as a two-phase jet. The gas velocity along the jet is assumed to vary along its axis according to the behavior of a turbulent jet.[2] The particles are tracked using the Lagrangian approach through the containment. When they reach the vessel head they are assumed to bounce and are allowed to continue to travel to the bottom of the vessel where they are removed from the flow field. The containment volume is treated as a single control volume for pressure and gas temperature calculations. The containment atmosphere contains oxygen which can react with metallic constituents of the melt.

DHCVIC was used to simulate the SNL "SURTSEY" Test DCH-1. Figure 1 presents the initial conditions assumed in the calculation. A major uncertainty at the present time in analysis of the direct heating sequence is specification of the rate of melt ejection (or entrainment) from the reactor cavity, given the rate of gas blowdown from the melt pressure vessel. For the present calculation, it was assumed that the 10.2 kg was ejected from the cavity during a period of 0.30 second, a time which corresponds approximately to the point when the Kutateladze number of the gas-liquid system within the cavity falls below 10.[3] Melt droplet sizes were computed assuming a critical Weber number of 6.0. The calculation was performed using 400 droplet packets and an integration time step of 2 milliseconds. The calculation was carried out to the time of peak pressure.

The calculated containment volume pressure-time history is shown in Fig. 2. The calculation indicates that the peak pressure rise of 0.12 MPa is reached in approximately 2 seconds, as compared with a measured pressure change of 0.92-0.103 MPa (except for one transducer, which indicated 0.134 MPa) in a time period of 2-3 seconds. The calculation indicates a mass mean droplet diameter of 0.65 mm, as compared with 0.55 mm as measured from debris recovered from DCH-1. The iron-oxygen reaction is predicted to go to about 90% completion, and approximately 50% of the initial inventory of thermal and chemical energy is predicted to be transferred to the containment volume gas. Gas temperatures at the exit of the cavity structure are predicted to be as high as 2000K, and accompanying gas velocities (strongly varying with time) at the exit are correspondingly high, up to 800 m/s for a brief time interval. Droplet velocities at the cavity exit are predicted to lag the gas by about 100 m/s. It is noted that the experimental results are preliminary, and were obtained from discussions with the investigators.[4]

The above comparisons were the first to be made with DHCVIC. Evaluation against experimental data is continuing. The code contains a description of many interacting phenomena. The physics of several of these phenomena is uncertain at this time. DHCVIC will be used as a tool to gain an understanding of the phenomena so that, eventually, prediction of direct heating under accident conditions can be realistically assessed.

REFERENCES

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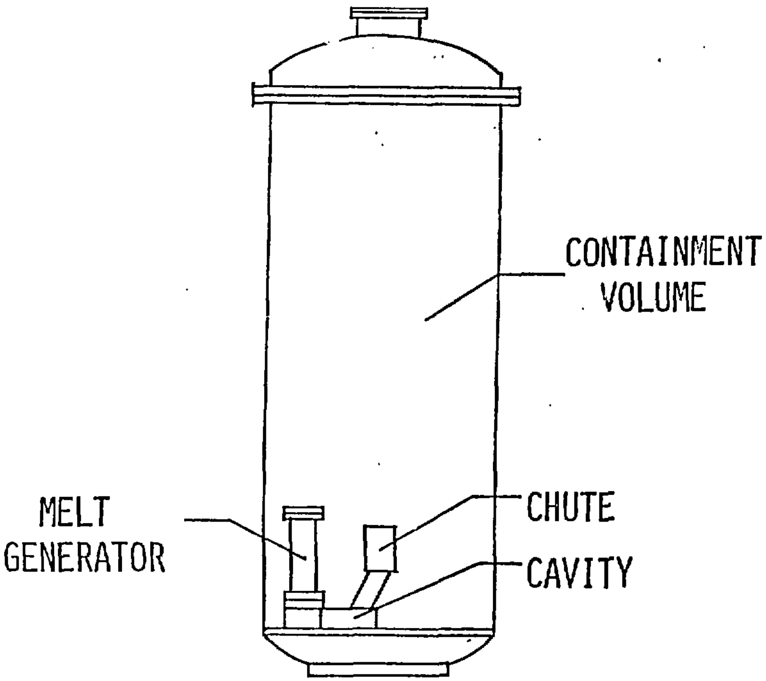

MELT COMPOSITION: 55% (WEIGHT) ALUMINA
45% IRON

MASS MELT: 10.2 KG

MELT TEMPERATURE (IN MELT PRESSURE VESSEL): 2500K

MELT VESSEL PRESSURE: 2.64 MPA

MELT FLOWRATE: 34.0 KG/S (FOR 0.30 S)

INITIAL CONTAINMENT VOLUME PRESSURE: 0.082 MPA

INITIAL CONTAINMENT VOLUME TEMPERATURE: 300K

DRIVER GAS: NITROGEN

Figure 1 "SURTSEY" Vessel and Initial Conditions

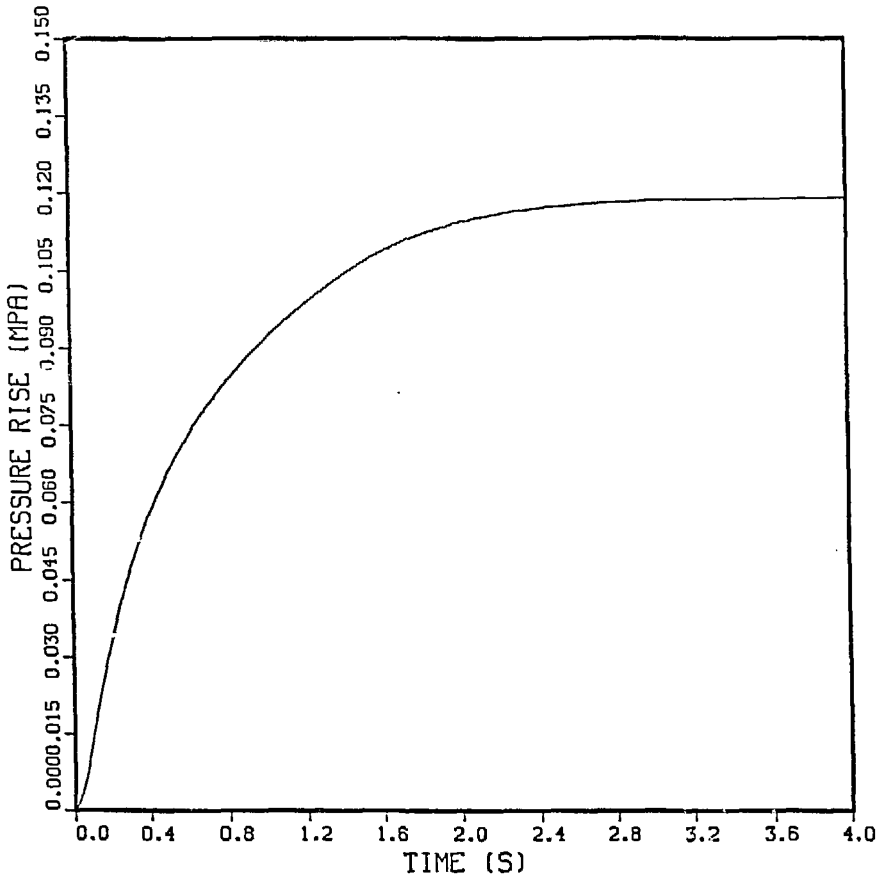

Figure 2 DHCVIC Computed Pressure Rise Transient