Models to Support Industry Efforts in the Implementation of Severe Accident Water Management (SAWM) Strategies for Boiling Water Reactors

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For boiling water reactor (BWR) plants (see Figure 2), accident management guidance prior to the Fukushima Daiichi accident called for flooding the reactor cavity to a level of approximately 1.2 m above the drywell floor once the vessel breach has been determined. While this action would achieve the accident management objective of cooling the core debris and scrubbing the fission products, it could also result in flooding the wetwell, thereby rendering the wetwell vent path unavailable. Further venting would then require use of the drywell vent path that is unfiltered. In response to the U.S. Nuclear Regulatory Commission (NRC) capable vent Order EA-13-109 [2], the industry has developed an alternative Severe Accident Water Management (SAWM) strategy [3] in which the drywell flooding rate would be throttled to achieve a stable wetwell water level while preserving the wetwell vent path. The Nuclear Energy Institute (NEI) has estimated [4] that this approach will save the industry in excess of 1 billion dollars in costs associated with the installation of filters on drywell vents if the SAWM approach were to be taken.

The objective of this research is to improve existing models for ex-vessel core melt spreading (MELTSPREAD) and debris coolability (CORQUENCH) [5,6] to provide flexible, analytically capable, and validated tools to support industry efforts in the implementation of plant-specific SAWM strategies that focus on keeping core debris covered with water while preserving the wetwell vent path. Specifically, there are gaps in analysis capability for evaluating melt relocation and cooling behavior, which account for several important factors including: (1) the influence of below vessel structure and pre-existing water on the containment floor on melt stream breakup and subsequent spreading behavior (see Figure 3); and (2) the effect of water injection on spreading and long-term debris coolability. These gaps were identified by an industry-lab advisory group as high-priority items needing to be addressed [7]. The importance of modeling the melt interaction with a below vessel structure has been reinforced by recent findings at Fukushima Daiichi, which indicate significant debris interaction and holdup on this structure [8].

An important factor impacting flooding strategy is the spatial distribution of core debris in containment following vessel failure and melt spreading. For instance, a localized accumulation of melt in the pedestal region may require a more specific flooding approach in comparison to the situation in which the core melt is spread uniformly over the pedestal and drywell floor areas. In the former case, the localized core melt accumulation could form a dam preventing adequate debris flooding and cooling if the water is not injected directly on top of the material, while in the latter case, effective debris flooding is expected

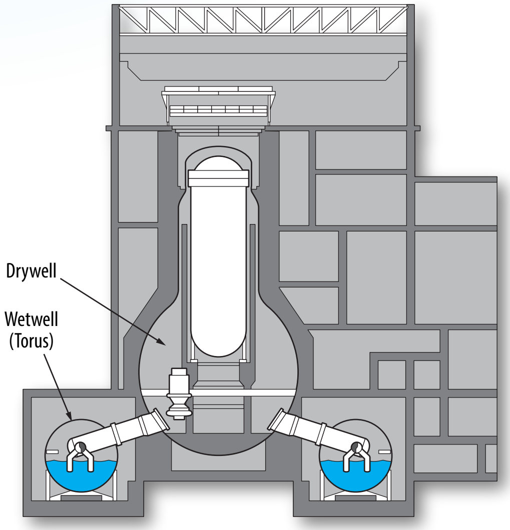

Figure 2. Plan View of a Typical Mark I Containment [1].

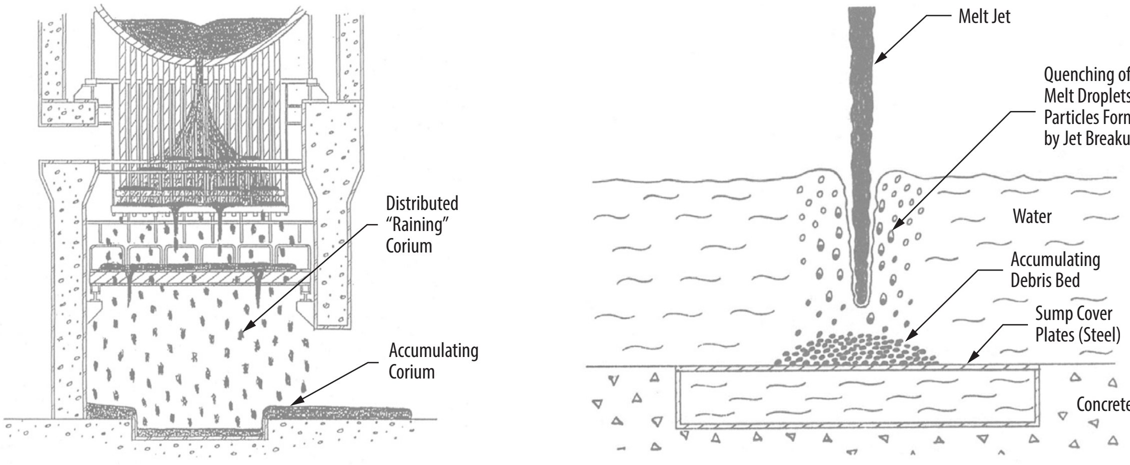

Figure 3. Illustration of Melt Stream Interaction with BWR Below-Vessel Structure (left) and Water Present on Pedestal Floor (right).

regardless of injection point(s), as long as the injection flowrate is high enough to remove both sensible energy and decay heat. Questions of melt spatial distribution, coupled with the overall effectiveness of the debris cooling process, impact the water injection requirements for achieving a balance between the injection flowrate versus water boil-off, thereby minimizing extraneous spillover into the wetwell.

In order to adequately address these questions, an additional modeling need was identified (i.e., to develop a multi-nodal modeling capability) to address localized core-concrete interaction behavior given actual containment features (e.g., sumps and compartments) coupled with a realistic water inventory model, which can be used to evaluate water injection strategies. Thus, a further aim of this work has been to implement a multi-nodal analysis capability within CORQUENCH, which is coupled to a realistic water inventory model, to provide an integrated modeling capability for assessing SAWM strategies for BWRs.

A key element of this work has been collaboration with industry in the development of these tools to ensure they will meet industry needs. Specifically, with support from the Electric Power Research Institute (EPRI), Jensen Hughes has extensively exercised MELTSPREAD for various reactor cases and provided feedback on the adequacy of the modeling, as well as on usability and performance. A similar activity is being initiated for the upgraded version of CORQUENCH. These efforts are contributing to the development of reliable and vetted tools that industry can utilize to support the implementation of SAWM strategies moving forward. The improvements to MELTSPREAD and CORQUENCH are wrapping up this year with both codes Open Sourced to expedite the transition to full industry utilization. Additional work this year includes: (1) a scoping study with the upgraded tools to analyze SAWM strategies in the Peach Bottom plant geometry using melt pour data obtained with MAAP5 by Jensen Hughes and MELCOR by Sandia National Laboratories; and (2) the completion of a melt interaction model for evaluating the extent of core debris holdup on the below vessel structure.

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