INTRODUCTION

In some nuclear reactor core melt accidents, a potential exists for molten core debris to be dispersed into the containment under high pressure. Resulting energy transfer to the containment atmosphere can pressurize the containment. This process, known as direct containment heating (DCH), has been the subject of extensive experimental and analytical programs sponsored by the U.S. Nuclear Regulatory Commission (NRC). DCH modeling has been a major focus for the development of the CONTAIN code.¹ Results of a detailed independent peer review of the CONTAIN code were published recently.² In support of the peer review, extensive analyses of DCH experiments were performed in order to assess the CONTAIN code’s DCH models and improve understanding of DCH phenomenology. The present paper summarizes this assessment effort.

EXPERIMENTS ANALYZED

High-temperature melts generated by the iron oxide/aluminum thermite reaction were expelled by high-pressure steam into scaled reactor cavities that were connected to pressure vessels simulating to various degrees the reactor containment building. Chromium metal was added to the thermite reaction mixture to enhance chemical reactivity of the melt with steam. Pressure rise (ΔP), temperature distributions, amounts of hydrogen produced and burned, and debris transport parameters were among the experimental results measured in these tests.

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Experiments analyzed included the Limited Flight Path (LFP) Series (six experiments),\textsuperscript{3} the Wet Cavity (WC) series (three experiments),\textsuperscript{4,5} the Sandia National Laboratories Zion geometry Integral Effects Tests (SNL/IET Zion) series\textsuperscript{6} (seven experiments analyzed), the Argonne National Laboratory Zion geometry IET (ANL/IET Zion) series (three experiments analyzed),\textsuperscript{7} and SNL IET Surry geometry (SNL/IET Surry) series\textsuperscript{8} (three experiments analyzed). The IET experiments included detailed scale models of containment structures as well as scaled reactor cavities, while the others had nonprototypic containment geometries. The SNL/IET Surry experiments were performed at 1/6-scale, the ANL/IET Zion experiments were 1/40-scale, and all others were 1/10-scale. The three ANL/IET Zion cases analyzed were scaled counterparts of corresponding SNL/IET experiments and provide a test of model scalability. The Zion IET experiments all had a small amount of water in the cavity and one WC experiment (WC-2) had a wet cavity. Cavities were dry in all other cases.

**CONTAIN DCH MODELING**

DCH-related phenomena modeled in the CONTAIN code include debris transport and trapping, debris-gas heat transfer, metal-steam and metal-oxygen chemical reactions, atmosphere-structure heat transfer, interactions between nonairborne debris and blowdown steam, potential effects of debris-water interactions, and hydrogen combustion under DCH conditions. Detailed mechanistic models are provided where phenomenological understanding is sufficiently advanced to justify a mechanistic model. For poorly understood phenomena, simple models together with input flexibility are provided to permit studying the effect of modeling uncertainties upon the results of interest. Models for nonairborne debris interactions and debris-water interactions fall in this category.

In the assessment of CONTAIN DCH models, a standard input prescription for use of the DCH models was defined and "frozen" while the code was applied to analyze the experiments without varying the code input except as dictated by the experimental initial and boundary conditions.
RESULTS

Figure 1 compares calculated and experimental results for $\Delta P$ and hydrogen production. Hydrogen results are plotted after scaling up to plant scale in order to facilitate comparison of experiments performed at different scales. Plot symbols distinguish experiments performed in open geometry, the LFP series, the SNL/IET (Zion) experiments with and without hydrogen combustion, the ANL/IET (Zion) experiments, and SNL/IET (Surry) experiments.

The CONTAIN $\Delta P$ and hydrogen production results reproduce the overall trends of the experimental data reasonably well. Comparison of the ANL/IET and SNL/IET Zion results reveals no obvious scale distortion. Comparison of the SNL/IET (Zion) results with and without combustion of DCH-produced hydrogen illustrates the importance of hydrogen combustion to DCH loads, and also shows that CONTAIN reproduces this effect reasonably well. The least favorable comparisons are with some of the LFP experiments, in which the code overpredicted debris transport to the dome and hence overpredicted $\Delta P$.

Extensive sensitivity studies were performed to assess strengths and weaknesses of specific model features. Findings included:

- Sensitivity was fairly low to particle size and to variations within empirically established limits for debris dispersal fractions and for the time-dependence of debris dispersal.

- Contributions of nonairborne debris interactions were important; $\Delta P$ and hydrogen production were significantly underpredicted in many instances if nonairborne interactions were omitted.

- Co-dispersed cavity water appeared to contribute significantly to hydrogen production and to $\Delta P$ in the Zion experiments.
Figure 1. Comparison of CONTAIN predictions with results of DCH experiments.
Atmosphere-structure heat transfer combined with hydrogen holdup in oxygen-starved subcompartment volumes is a very important mitigation effect.

CONCLUSIONS

A standardized input prescription for CONTAIN DCH analysis has been developed that is useful in achieving consistency in DCH analyses. Using this standard prescription, CONTAIN analyses of DCH experiments reproduce the major trends of DCH integral test results, including containment pressurization and hydrogen production, reasonably well. Despite the progress made, there remain significant modeling uncertainties that can be important in some instances. Sensitivity studies can be performed in order to define a reasonable representation of the uncertainty range.

References


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