Melt Coolability and Concrete Interaction (MCCI) Program

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MCCI Program Technical Basis

• Regulatory requirement for ultimate debris coolability for advanced LWR systems (2010 initiative).

- These advanced systems generally rely on In-Vessel Retention (IVR) as the approach for terminating the accident sequence.

- However, for current designs (e.g., AP1000), thermal margins on IVR have basically disappeared.

• Ex-vessel debris coolability needs to be considered as a back-up position to IVR to meet the regulatory requirement of assuring ultimate debris coolability.

• The issue being addressed in the OECD-MCCI program is to what extent is water added to the cavity as part of SAM able to quench and thermally stabilize core melt that has breached the RPV.
Program Objectives

• The MCCI project is conducting reactor material experiments and associated analysis to achieve the following technical objectives:

1. resolve ex-vessel debris coolability issue through a program that focuses on providing both confirmatory evidence and test data for cooling mechanisms identified in MACE integral effects tests, and

2. address remaining uncertainties related to long-term 2-D core-concrete interactions under both wet and dry cavity conditions.

• Achievement of these objectives will lead to improved SAMGs for existing plants, and improved containment designs for advanced plants.
**Approach**

- Separate effects tests are being conducted to provide the technical basis for development and validation of coolability models that can be integrated into system codes such as MELCOR for regulatory analysis.
  - MELCOR currently does not have debris coolability models.

- Program is focused on regulatory applications.
  - Test types and parameter ranges selected to validate models over the range of anticipated conditions in plant accident scenarios so that the codes can extrapolated to plant conditions.
Melt-Water Heat Transfer Mechanisms Under Investigation

- **Bulk Cooling**: Gas sparging rate from core-concrete interaction is initially high enough to preclude stable crust formation. As a result, efficient heat transfer occurs due to conduction and, predominately, radiation across the agitated melt/water interface.

- **Water Ingression**: Cracks/fissures form in the core material during quench. Water penetration into these cracks augments what would otherwise be a conduction-limited cooling process.

- **Melt eruptions**: Sparging gases entrain corium through cracks/fissures in the crust to form an overlying, porous particle bed that is readily coolable.

- **Crust Breach**: Periodic crust failure events lead to rapid water flooding beneath the crust. These events provide a pathway for renewed bulk cooling, water ingression, and melt eruption cooling mechanisms.
Project Status Summary

The first two year’s workscope consisted of:

- Conduct Small Scale Water Ingression and Crust Strength (SSWICS) tests to provide data on the water ingression cooling mechanism, as well as crust mechanical strength, and
- Conduct long-term 2-D Core-Concrete Interaction (CCI) tests to obtain data on radial vs. axial power split, including water addition late in the experiment sequence to obtain coolability data.

• Technical Progress:

- 6 successful SSWICS tests completed and documented.
- CCI-1 successfully completed and documented.
- 15 TRs generated to document test plans and experiment results
- Two phenomenological modeling reports published.
Future Project Plans

• Third (current) year workscope consists of:
  - Conduct and document 7th SSWICS test, effectively completing test series.
  - Conduct and document CCI-2 (test successfully conducted 24 August 2004).
  - Begin setup of first separate effects Melt Eruption Test (MET-1).

• Fourth year workscope consists of:
  - Conduct and document two MET’s
  - Produce a melt eruption phenomenological modeling report to support MELCOR development activities.
  - Generate program final report, which includes an assessment of the potential for achieving ex-vessel debris coolability based on validated model results.
**SSWICS Tests**

- Address the ability of water to ingress into cracks and/or fissures in the debris, thereby augmenting the otherwise conduction-limited heat flux.
- Generic phenomenology issue that is applicable to both in-vessel and ex-vessel accident sequences.
- Crack formation and propagation is property-sensitive, and therefore melt composition is the primary parameter in the test matrix.
- The effect of system pressure on the water ingestion rate also addressed in the test matrix.
SSWICS Test Facility

Test Vessel in Containment Cell

Experiment Control Room
SSWICS Posttest Debris
Radial Slice Through Solidified Corium Showing Crack Structure That Provides the Pathway for Water Ingression

SSWICS-3 (8 wt % Limestone/Sand Concrete)  SSWICS-4 (25 wt % Limestone/Sand Concrete)
CCI-1 Test Apparatus

DRAWING: CCI1 TEST APPARATUS
DRAWING NO.: MCCI198
DRAWN BY: D. KILSDONK
DATE: 12/11/02
FILE: CCI1_TA.DWG(AC86)
CCI Test Procedure

- A 400 kg fully oxidized PWR core melt at ~ 2200 °C is formed in ~ 30 seconds through a “thermite-type” exothermic chemical reaction.

- Thereafter, the melt is resistance heated with a 560 kW AC power supply with tungsten electrodes to simulate decay heat at ~ 2 hours after scram.

- The core-concrete interaction is allowed to proceed to 30 cm of ablation in either the radial or axial directions.
  - Objective is to obtain data on radial/axial power split during core-concrete interaction.

- Thereafter, the melt is flooded to obtained debris coolability data following late-phase flooding.
  - The crust formed at the melt/water interface is then failed with an insertable lance to obtain data on the postulated “crust breach” cooling mechanism.
Concrete Surfaces After Test

Concrete Sidewalls

Sintered UO₂ Pellets

Tungsten Electrodes
Close Up of North Sidewall

- Void Opening
- Light Oxide Phase
- Heavy Oxide Phase
- Ablation Boundary
Principal MCCI Program Results To Date

Principal Findings from SSWICS tests:

1. Water is able to ingress into cracks/fissures that form during debris quench, thereby augmenting what would otherwise be a conduction-limited cooling process.
   - However, the water ingression rate (or crust dryout limit) systematically decreases as more concrete enters the melt.

2. Crust strength measurements indicate that the crust is very weak and will not be mechanically stable at plant scale, so that transient crust breach cooling mechanism may be expected.

Principal findings from CCI-1 tests:

1. Radial erosion is an important factor in the overall cavity erosion process.

2. Crust breach is highly effective in increasing the debris cooling rate.

Ramifications for Accident Management:  i) water addition is effective in mitigating the consequences of core-concrete interaction, and ii) flood the containment early, since concrete incorporated into the melt from the interaction degrades coolability.