SIGNIFICANCE OF THE OECD-MCCI PROGRAM IN RELATION TO SEVERE ACCIDENT UNCERTAINTIES EVALUATION

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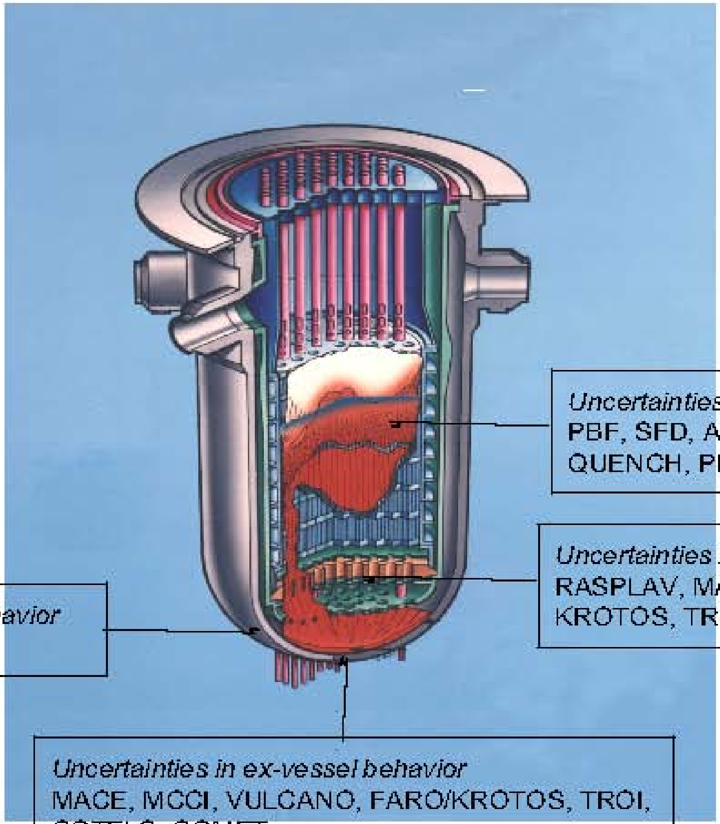
Presentation Outline

- Motivation
- Program Background and Objectives
- Elements of the Program
- Principal Findings
- Significance of Data to Uncertainties Evaluation
- Concluding Remarks

Motivation

- Epistemic Uncertainties in Severe Accidents and Level 2 Probabilistic Safety Analysis
  - Phenomenological uncertainty
  - Modeling uncertainty
  - Parameter uncertainty
- Parameter uncertainty addressed by sensitivity analysis and appropriate choice of parameters
  - Requires reliable model(s) for sensitivity analysis
- Modeling uncertainty reduced by improvement in model(s) of phenomena
  - Requires enhanced knowledge of severe accident phenomena
- Phenomenological uncertainty resolved through improved understanding of phenomena
  - Requires enhanced base of experimental data

Severe Accident - Phenomenological Uncertainties



Uncertainties in core degradation
PBF, SFD, ACRR, CORA, QUENCH, PHEBUS

Uncertainties in lower plenum behavior
RASPLAV, MASCA, COPO, ULPU, KROTOS, TROI

Uncertainties in lower head behavior
LHF, OLHF, FOREVER

Uncertainties in ex-vessel behavior
MACE, MCCI, VULCANO, FARO/KROTOS, TROI, COTELS, COMET

OECD-MCCI Program – Background and Objectives

- **The OECD-MCCI program is an internationally sponsored project investigating ex-vessel debris coolability and 2-D core-concrete interaction**

  4 year project: 01/02 - 01/06.

  U.S. is host country; program includes 12 international participants

- **The program is conducting reactor material experiments and associated analysis to achieve the following technical objectives:**

  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

  address phenomenological uncertainties related to ex-vessel debris coolability, as well as long-term 2-D core-concrete interactions under both wet and dry cavity conditions

- **Achievement of these objectives will provide the technical basis for improved SAMGs for existing plants, as well as better containment designs for advanced plants**

OECD-MCCI Program – General Approach

- **Debris Coolability: Separate effects tests to investigate various coolability mechanisms, thereby providing data for development and validation of models and codes for extrapolation to plant scale**

  Severe accident codes (e.g., MELCOR) generally have parametric treatment of debris coolability models

  Experiment results used for model development or improvement, and code assessment

- **2-D Core-Concrete Interaction: Prototypic material integral tests to provide 2-D CCI data for code verification and validation purposes**

  Reduce modeling uncertainties in lateral/axial power split; resolve differences between codes in calculated cavity erosion behavior

- **In general, test types and parameter ranges selected to validate models over the range of anticipated conditions in plant accident scenarios so that the codes can be used to extrapolate to plant conditions**

- **Severe accident uncertainties addressed through enhancement of knowledge base and improvement of models in codes**

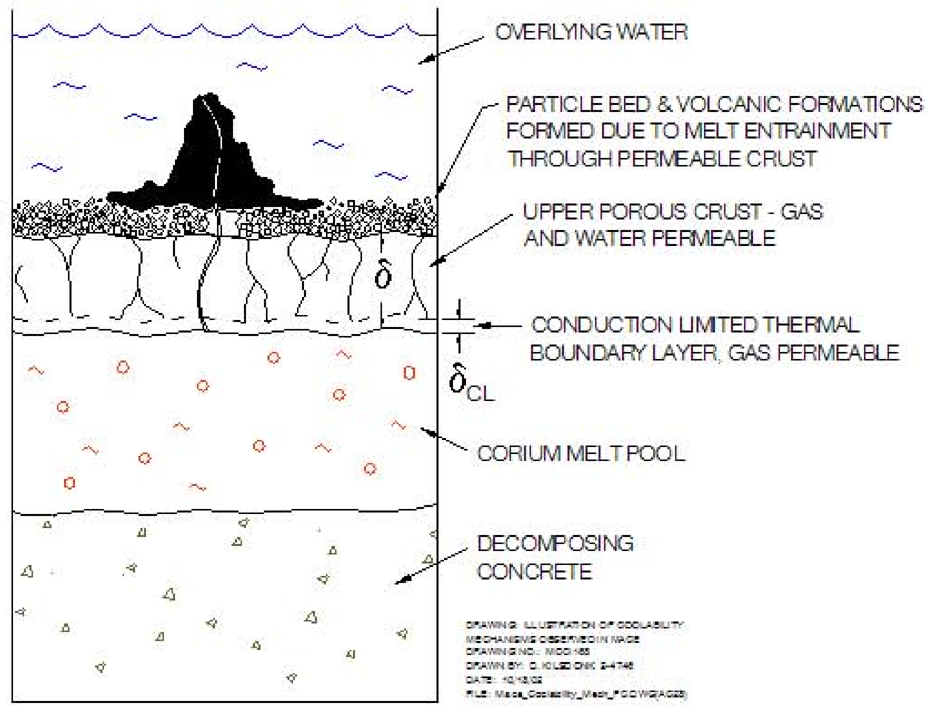
Coolability Mechanisms Under Investigation

Bulk Cooling: **Gas sparging initially high enough to preclude stable crust formation. Thus, efficient heat transfer occurs across the agitated melt/water interface**

Water Ingression: **Cracks/fissures in solidifying corium form pathways for water to ingress, thereby increasing the heat transfer rate above the conduction- limitation**

Melt eruptions: **Sparging gases entrain corium through cracks and fissures in the crust to form an overlying porous particle bed**

Crust Breach: **Crust failure events lead to rapid water flooding beneath the crust, thereby providing a pathway for renewed bulk cooling, water ingression, and melt eruption**



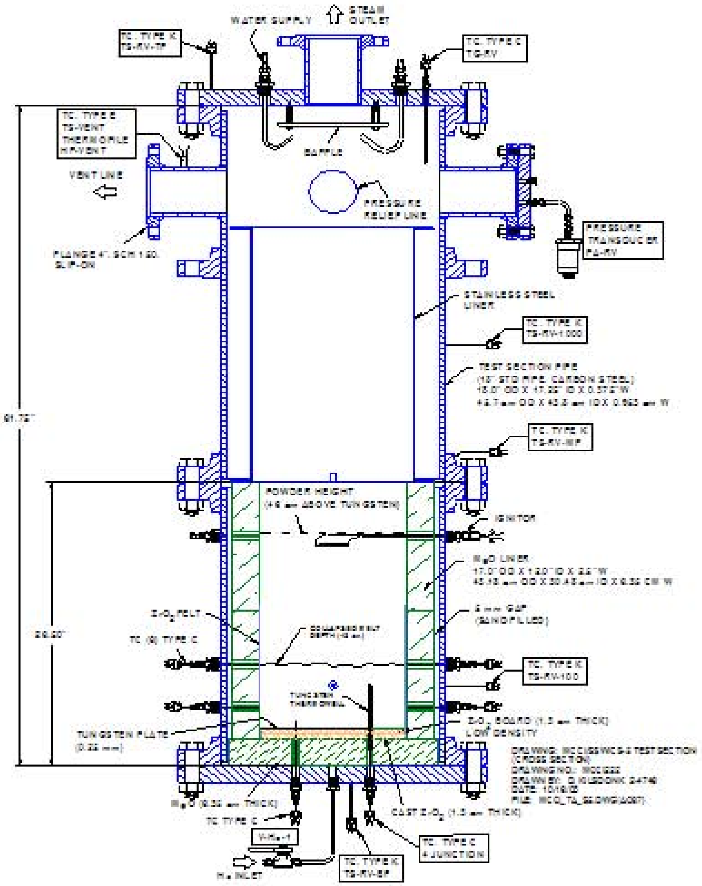
Water Ingression (SSWICS) Test Setup and Procedure

Corium melt generated through thermite reaction

Melt is flooded at the top of apparatus by four injection tubes that impact upon a baffle plate

Multi-junction Type C thermocouple assembly used for in-situ measurement of water penetration rate

Type C TCs at melt bottom surface used to detect arrival of saturation isotherm

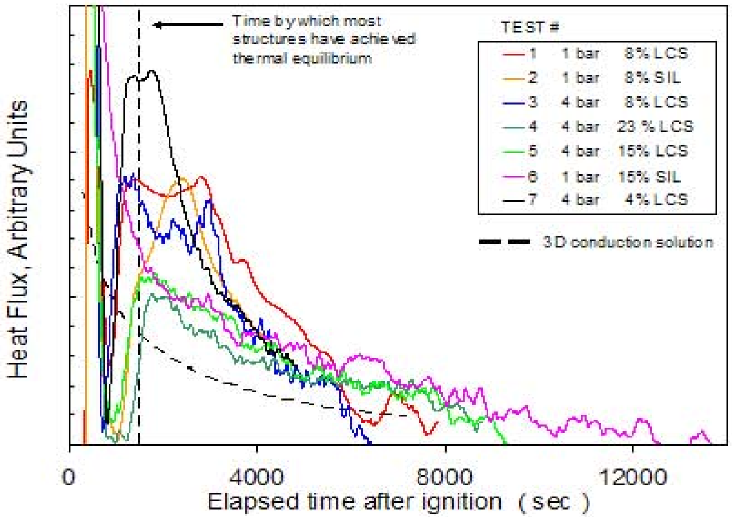


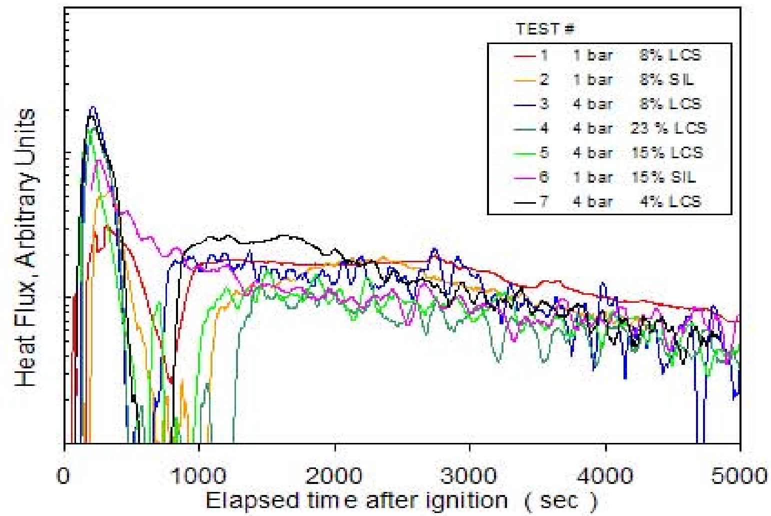
SSWICS Test Specifications

Parameter	SSWICS-1	SSWICS-2	SSWICS-3	SSWICS-4	SSWICS-5	SSWICS-6	SSWICS-7
Test Section ID (cm)	30.5	30.5	30.5	30.5	30.5	30.5	30.5
Melt Composition (wt % UO_2/ZrO_2/Cr/Concrete)	61/25/6/8	61/25/6/8	61/25/6/8	48/20/9/23	56/23/7/14	56/23/7/14	64/26/6/4
Concrete Type	LCS	SIL	LCS	LCS	LCS	SIL	LCS
Melt Mass (kg)	75	75	75	60	68	68	80
Melt Depth (cm)	15	15	15	15	15	15	15
Initial Melt Temperature (°C)	~2300	~2100	~2100	~2100	~2100	~2000	~2100
Basemat Type	Inert	Inert	Inert	Inert	Inert	Inert	Inert
System Pressure (bar)	1	1	4	4	4	1	4
Water Injection Flowrate (lpm)	4	4	12	13	6	14	13
Water Injected (liters)	33	39	34	40	61	47	40

SSWICS Tests - Summary Results

Heat Flux Measured in SSWICS Tests



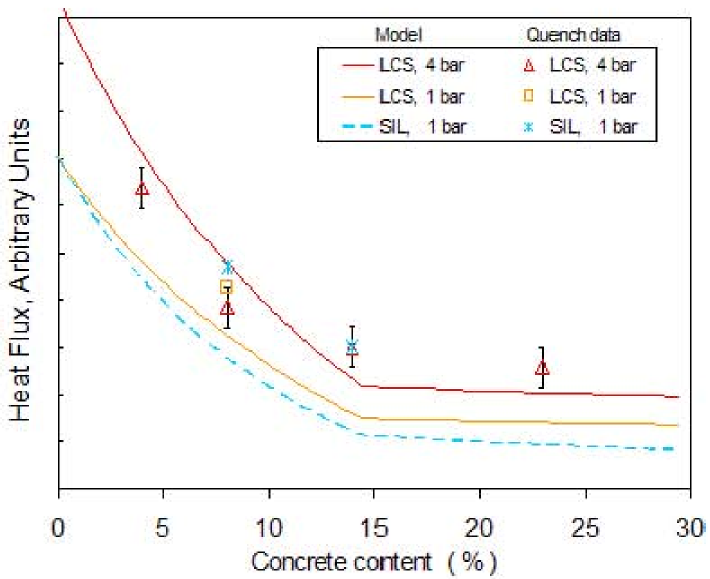


Trends indicated by heat flux data:

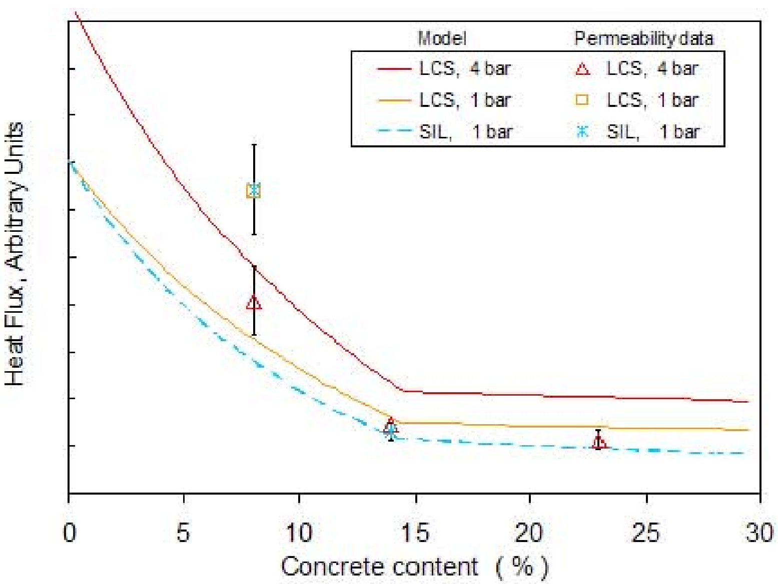
- Quench rate decreases with increasing concrete content in the melt
- Quench rate does not increase appreciably with system pressure
- Quench rate is a weak function of concrete type

Dryout Heat Flux from Quench and Permeability

Quench-based Heat Flux Data



Permeability-based Heat Flux Data



SSWICS Posttest Debris Configuration (SSWICS-3)

Top Surface of Solidified Debris

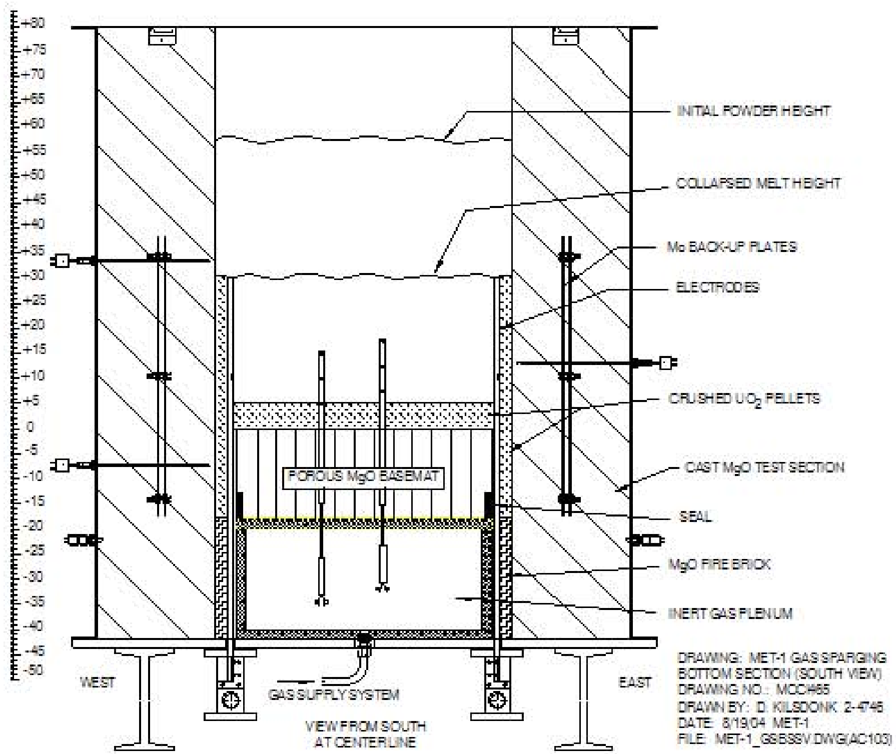
Crack Structure at Axial Midplane

MET Test Setup and Procedure

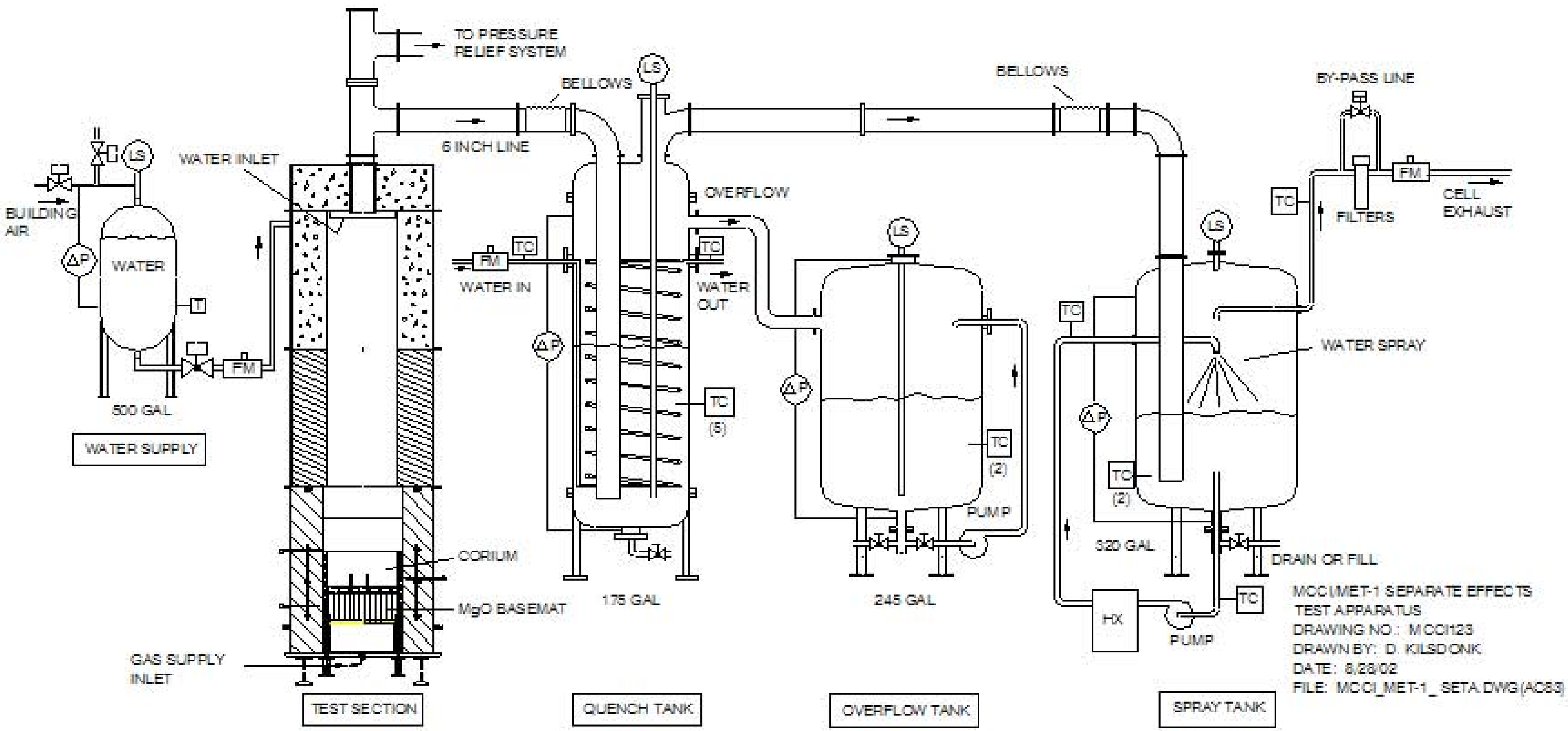
Tests are conducted with an inert (MgO) basemat and controlled gas sparging

The melt gas sparging rate is systematically increased over the course of the experiment; corresponding melt ejection rate is measured.

The gas sparging rate and the corresponding melt ejection rates provide the data needed to develop correlations for the melt entrainment rate.



Overall Facility Layout for MET and CCI Tests



CCI Test Setup and Procedure

A 400 kg core melt is formed *in-situ*

by a thermite-type chemical reaction

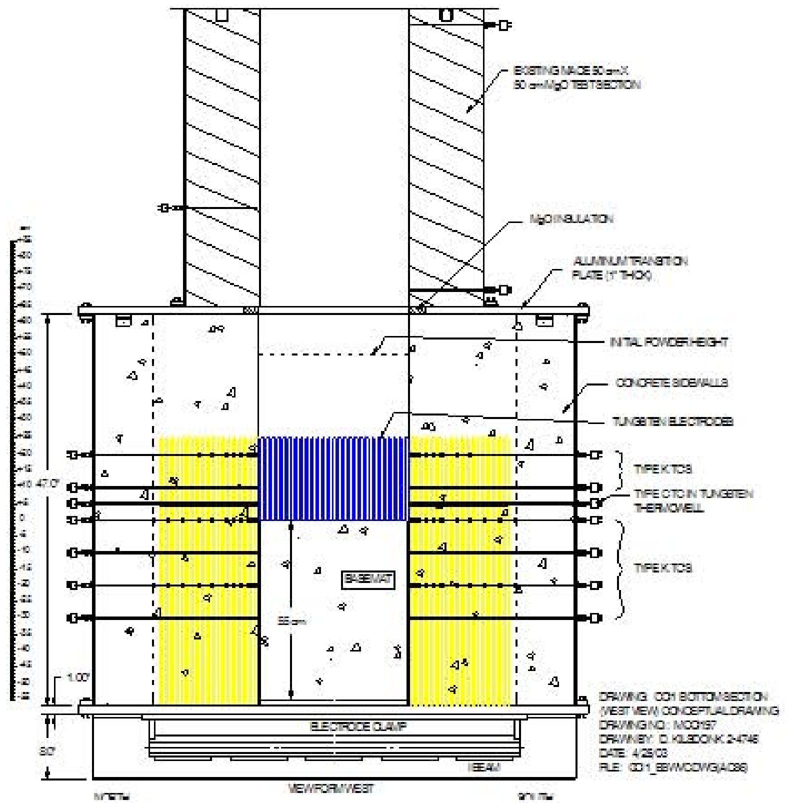
The melt is then resistance heated through two banks of tungsten electrodes to simulate decay heat

CCI proceeds to 30 cm ablation depth in either radial or axial directions

- Objective is to quantify radial-axial power split

Melt is then flooded to provide coolability data following late-phase flooding

- Crust formed at the melt/water interface is then failed with a lance to obtain data on the crust breach cooling mechanism

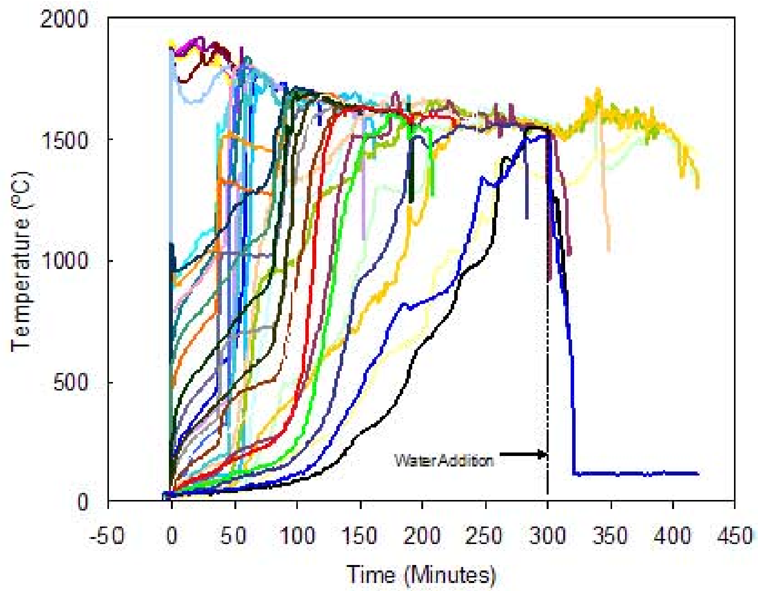


CCI Test Specifications

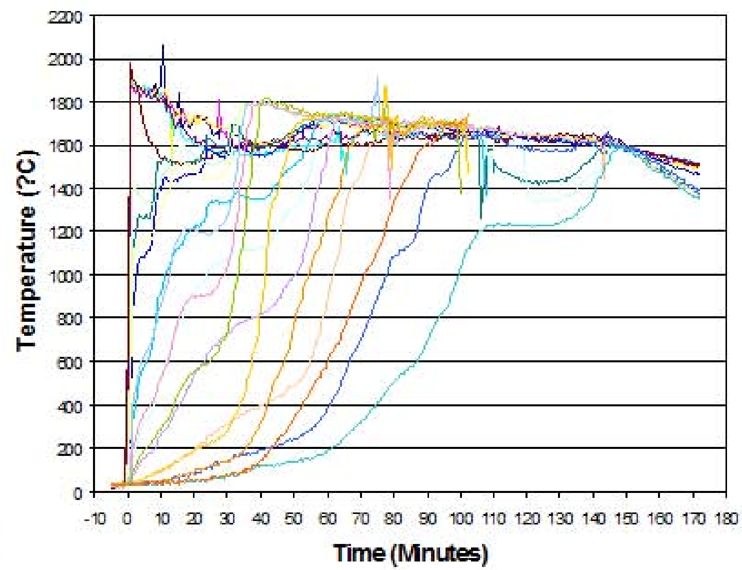
Parameter	Specification
Corium	100 % oxidized PWR with 8 wt % concrete
Concrete type	CCI-1: Siliceous CCI-2: Limestone/common sand CCI-3: LCS variety with gas content between CCI-1 and CCI-2
Initial basemat dimension	50 cm x 50 cm
Initial melt mass (depth)	400 kg (25 cm)
Test section sidewall construction	Nonelectrode walls: concrete Electrode walls: MgO protected by UO_2 pellet layer
Radial ablation limit	35 cm
Axial ablation limit	35 cm
Initial melt temperature	1800 °C
Melt heating technique	Thermite burn followed by direct electrical (Joule) heating
Power supply operation-dry cavity phase	CCI-1: Constant power at 150 kW CCI-2: Constant power at 120 kW CCI-3: Constant power at 120 kW

CCI Melt Temperature Data

CCI-2 Test

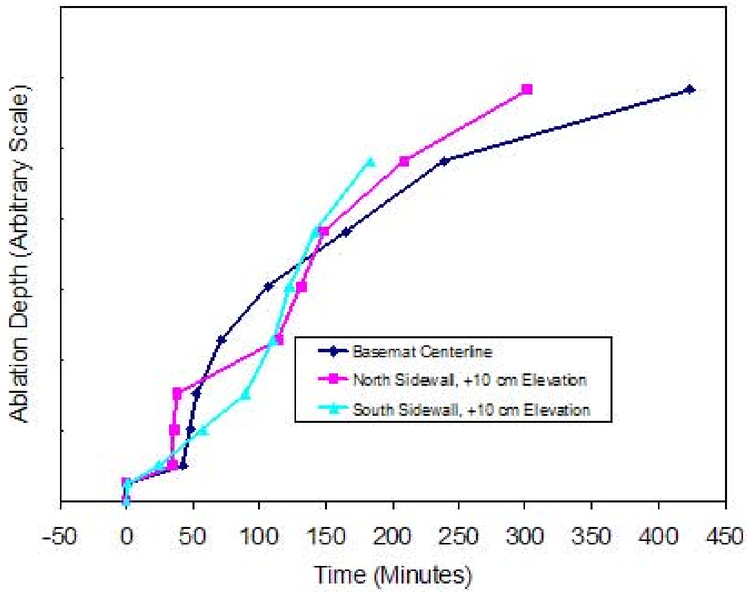


CCI-3 Test

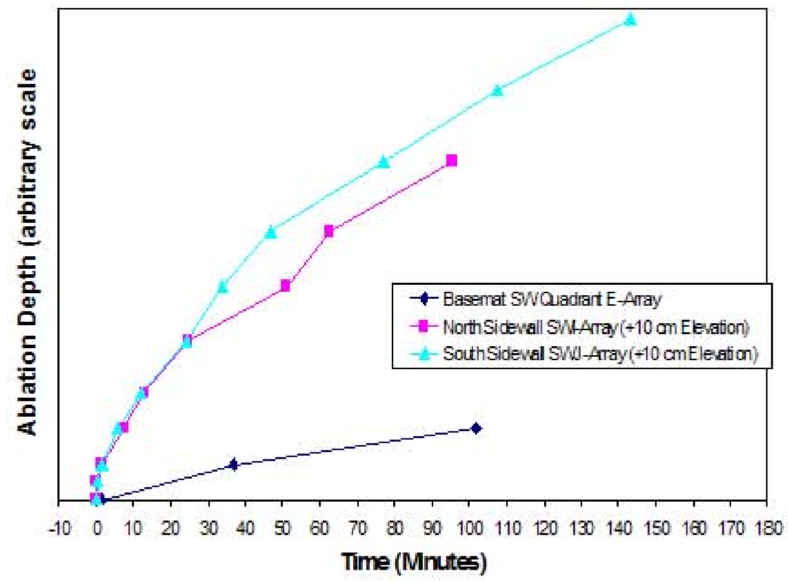


CCI Concrete Ablation Data

CCI-2 Test



CCI-3 Test



Posttest Debris Configuration (CCI-2 Test)

Corium and Concrete Walls

Solidified Corium over Basemat

Principal Findings of the OECD-MCCI Program

SSWICS test series

1. Water is able to ingress into cracks/fissures that form during quench, thereby augmenting the debris cooling rate
2. Water ingression is more effective at the early phase when the concrete content in the melt is low
3. Crusts are mechanically weak, indicating that the crust will likely breach at plant scale providing pathways for significant water ingression

MET and CCI test series

1. Tests exhibiting melt eruption showed high melt entrainment rates indicating effective augmentation of cooling
2. Radial erosion is an important factor in the overall cavity erosion process

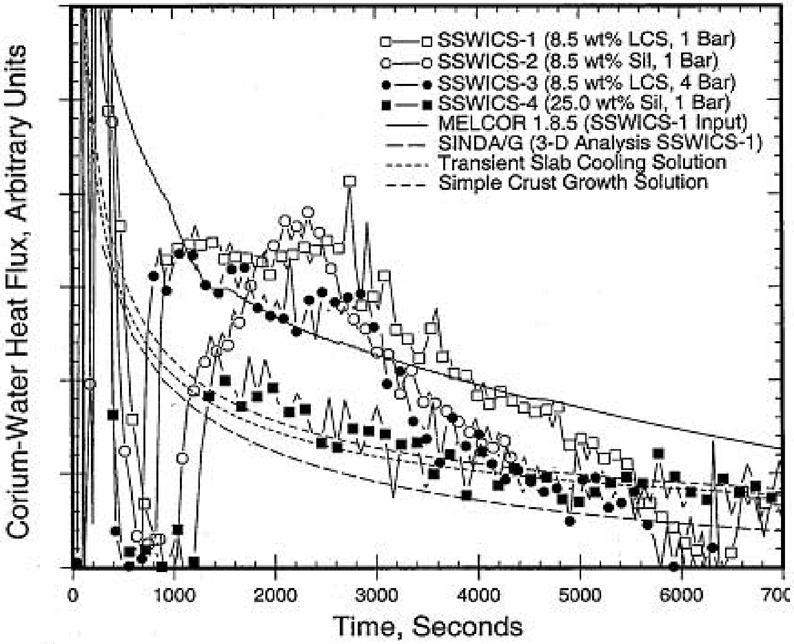
Ramifications for accident management

1. Early containment flooding is effective in cooling core debris during early phase of core-concrete interaction
2. Late phase flooding is effective in cooling core material in certain geometries and for certain concrete types

Significance of Data to Uncertainties Evaluation

SSWICS Database Utilization for Model Development

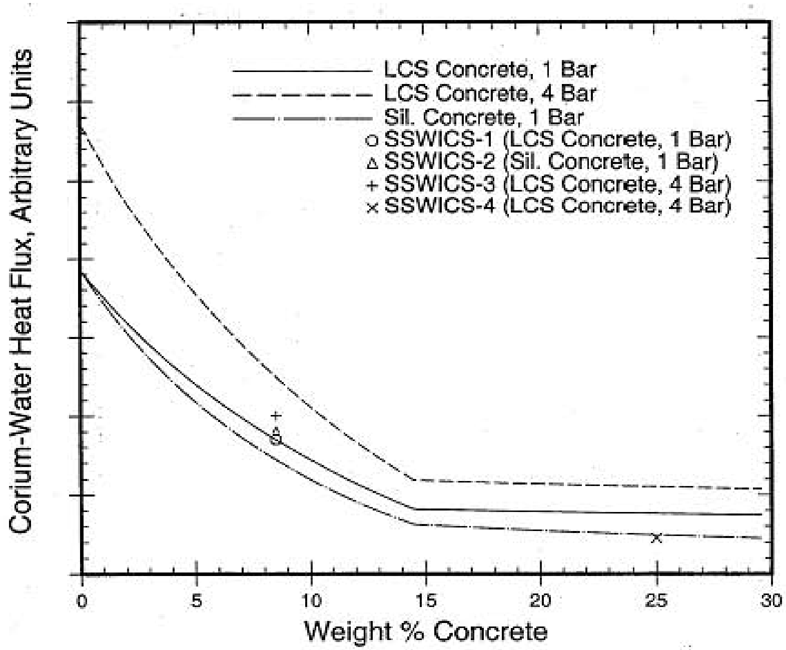
Heat Flux Data Compared With Conduction-Limited Cooling Solution



Significance of Data to Uncertainties Evaluation

SSWICS Database Utilization for Model Development

Crust Dryout Heat Flux Modeling



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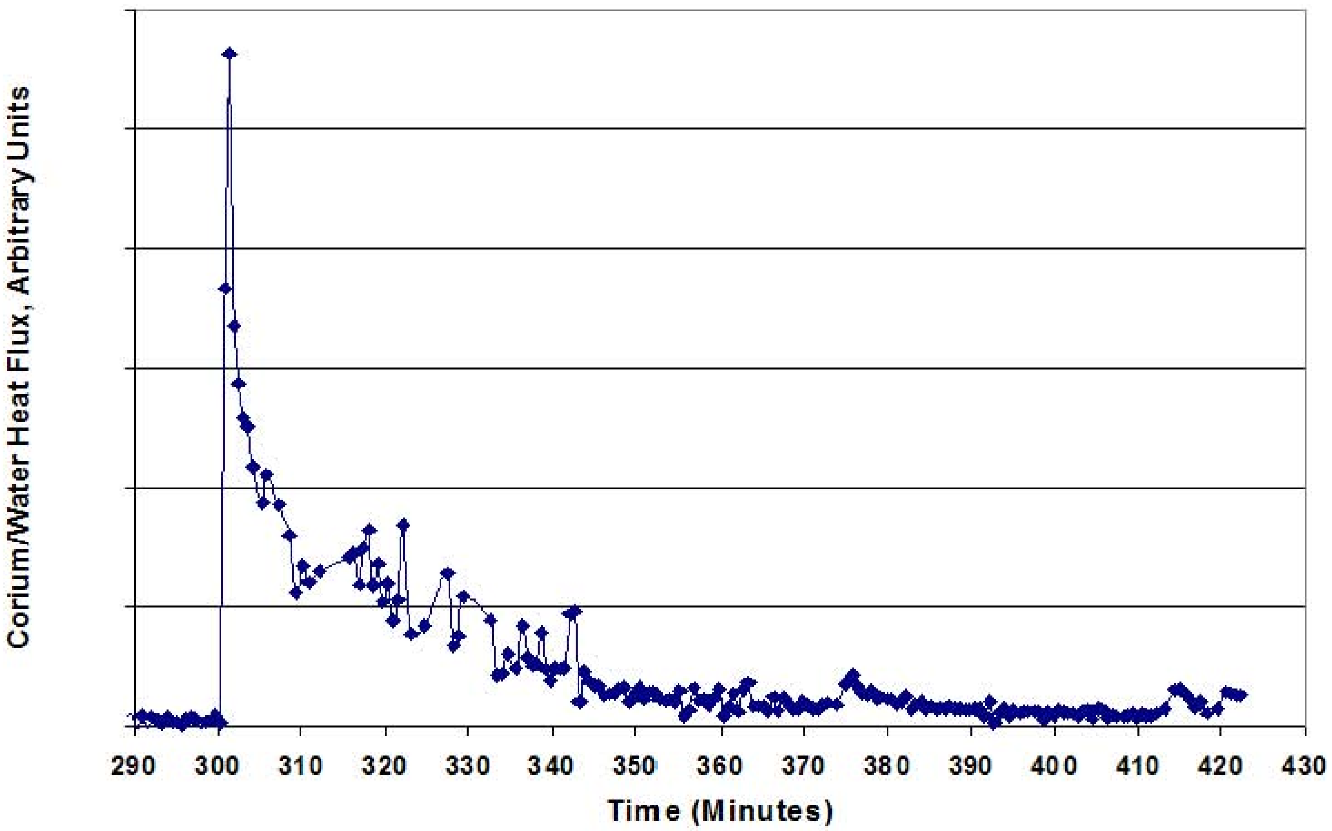
CCI Database Utilization for Model Development



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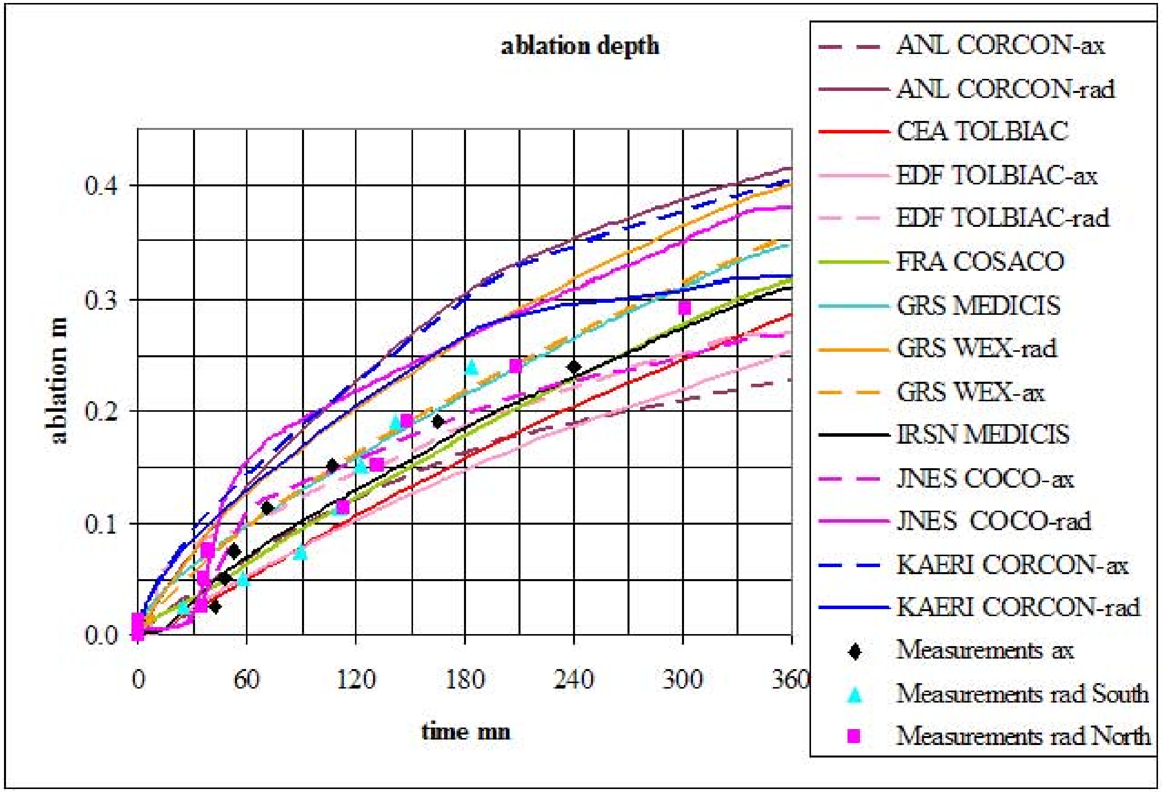

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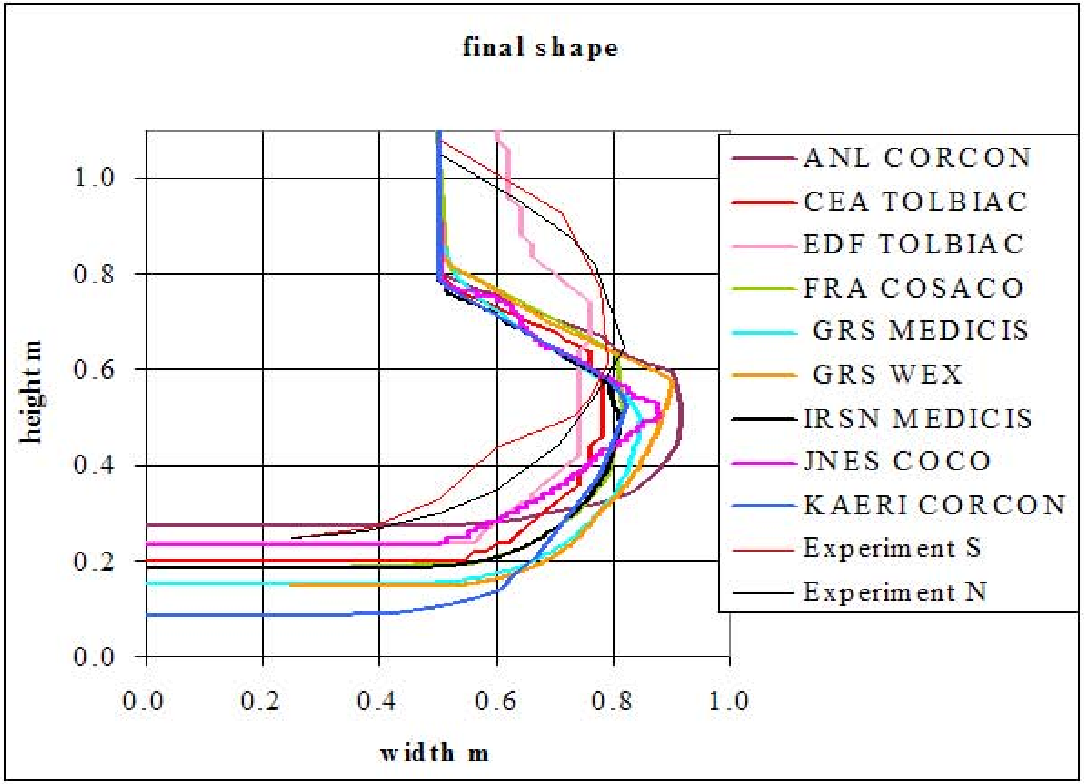

Concluding Remarks

- MCCI program provided data that can be used to develop coolability models and reduce uncertainties in assessing ex-vessel coolability

- SSWICS tests provided dryout heat flux data that can be used for water ingression model and assess a more precise heat flux partitioning at the melt-water interface

- Entrainment data obtained from MET and CCI experiments can be used to develop models for evaluating the effect of melt eruption on ex-vessel coolability

- CCI tests addressed uncertainties related to long-term two-dimensional core-concrete interaction under dry and flooded cavity conditions

- In general, MCCI program demonstrated the relative effectiveness of various cooling mechanisms in acheiving ex-vessel coolability, and reduced uncertainties in the knowledge base