Lessons Learned from Fukushima on Modeling of Severe Accidents and Future Research Directions for MAAP

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International Experts' Meeting on Strengthening R&D Effectiveness in the Light of the Accidents at the Fukushima Daiichi Nuclear Power Plant
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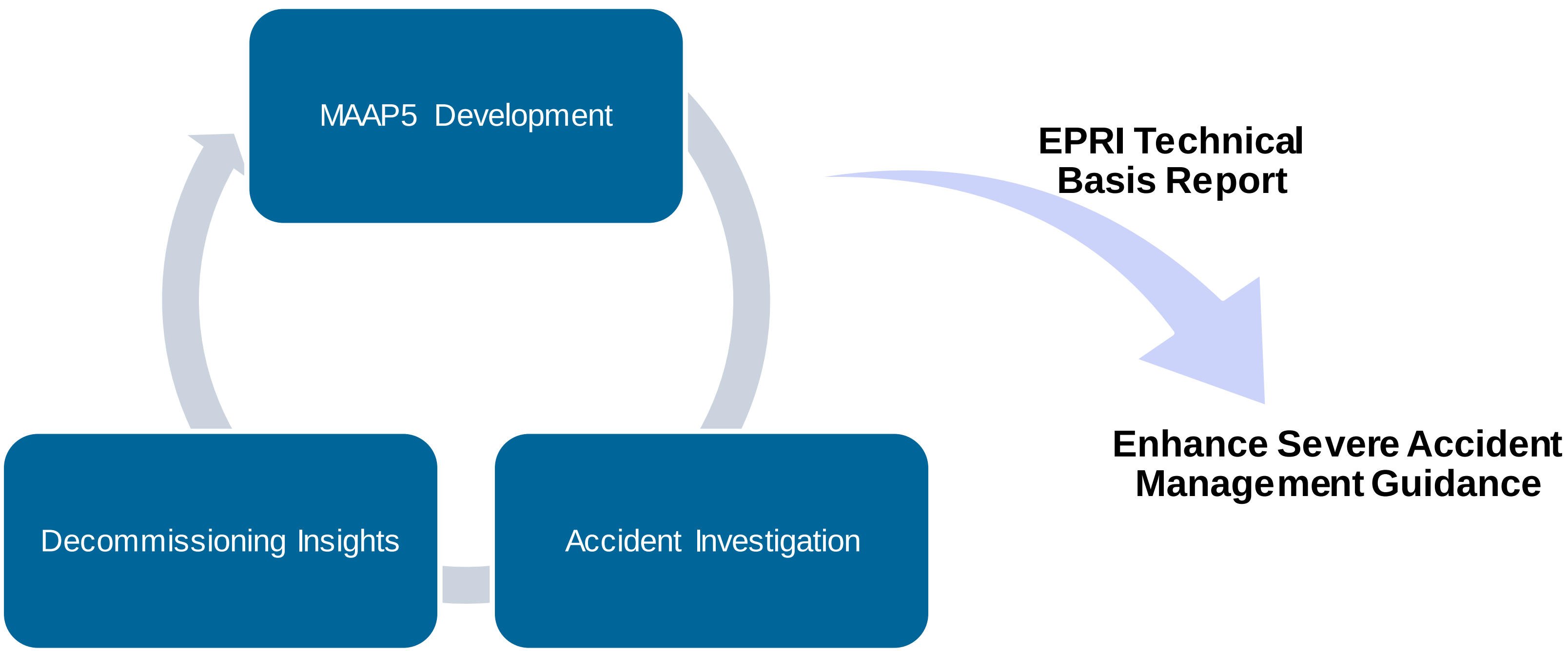
MAAP in light of Fukushima Daiichi

- Understanding accident progression critical to
  - Enhancing emergency procedures and guidelines
  - Identifying debris location to plan decommissioning activities



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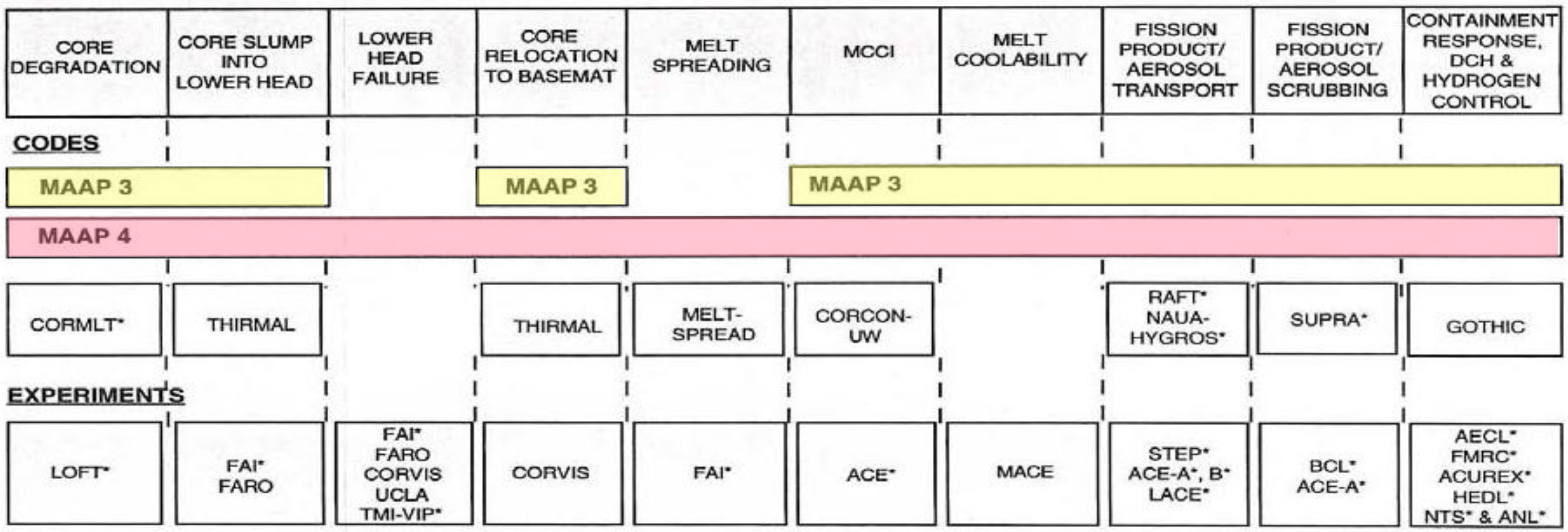
Key Experiments and Analyses used in MAAP Development



ACE — Advanced Containment Experiments
ACUREX — Acurex Corp.
AECL — Atomic Energy of Canada, Ltd.
ANL — Argonne National Laboratory
BCL — Battelle Columbus Laboratories Experiments
CORCON — Molten Core–Concrete Interaction Code
CORVIS — Corium Reactor Vessel Interaction Studies
DCH — Direct Containment Heating
FAI — Fauske and Associates, Inc.
FARO — CEC Fuel Coolant Interaction Facility
FMRC — Factory Mutual Research Corp.
GOTHIC — Generation of Thermal-Hydraulic Information in Containments
HEDL — Hanford Engineering Development Laboratory
*Completed

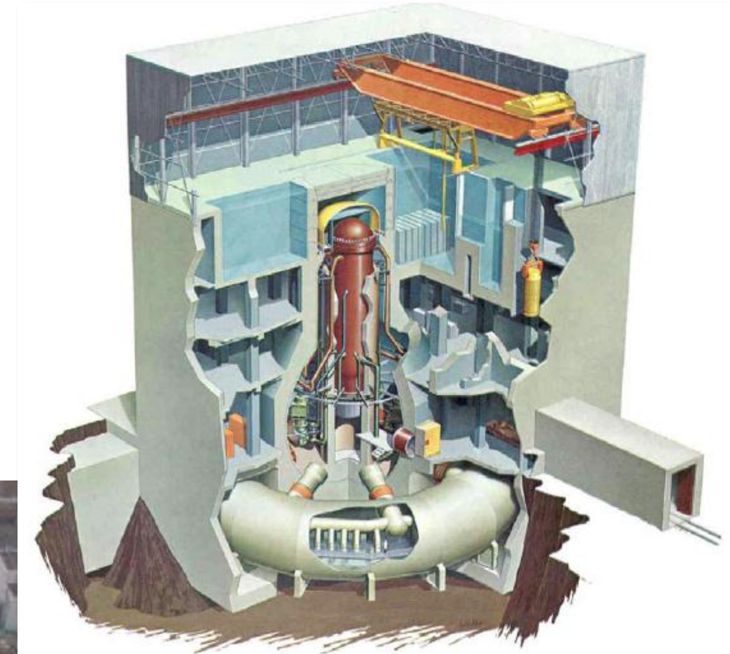
LACE — LWR Aerosol Containment Experiments
LOFT — Loss of Fluid Test Facility
MAAP — Modular Accident Analysis Program
MACE — Melt Attack and Coolability Experiments
MCCI — Molten Corium–Concrete Interaction
MELTSPREAD — Melt Spreading Code
NAUAHYGROS — Nachunfallaerosalverhaltens-Hygroscopic Aerosols
NTS — USDOE Nevada Test Site
RAFT — Reactor Aerosol Formation and Transport
STEP — Source Term Experiments Project
SUPRA — Suppression Pool Retention Analysis
THIRMAL — Thermal-Hydrodynamic Interaction and Reaction of Melt and Liquid
TMI-VIP — Three Mile Island Vessel Investigation Project
UW — University of Wisconsin

Ref: Technical Foundation of Reactor Safety, Rev1, EPRI 1022186, Oct 2010

Limited reactor scale information available

Accident Analysis – Focus on Root Causes and Safety Lessons Learned

- Core Damage
- Containment Impairment
- Hydrogen Explosion
- Off-site Consequence



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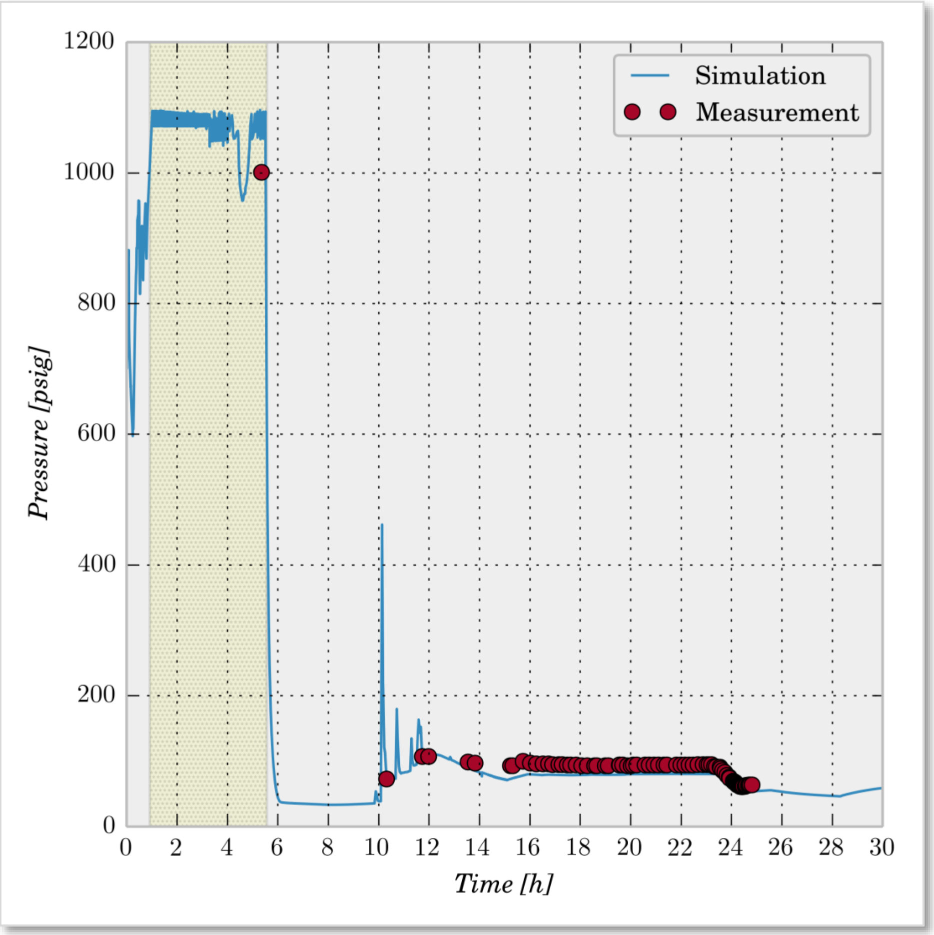
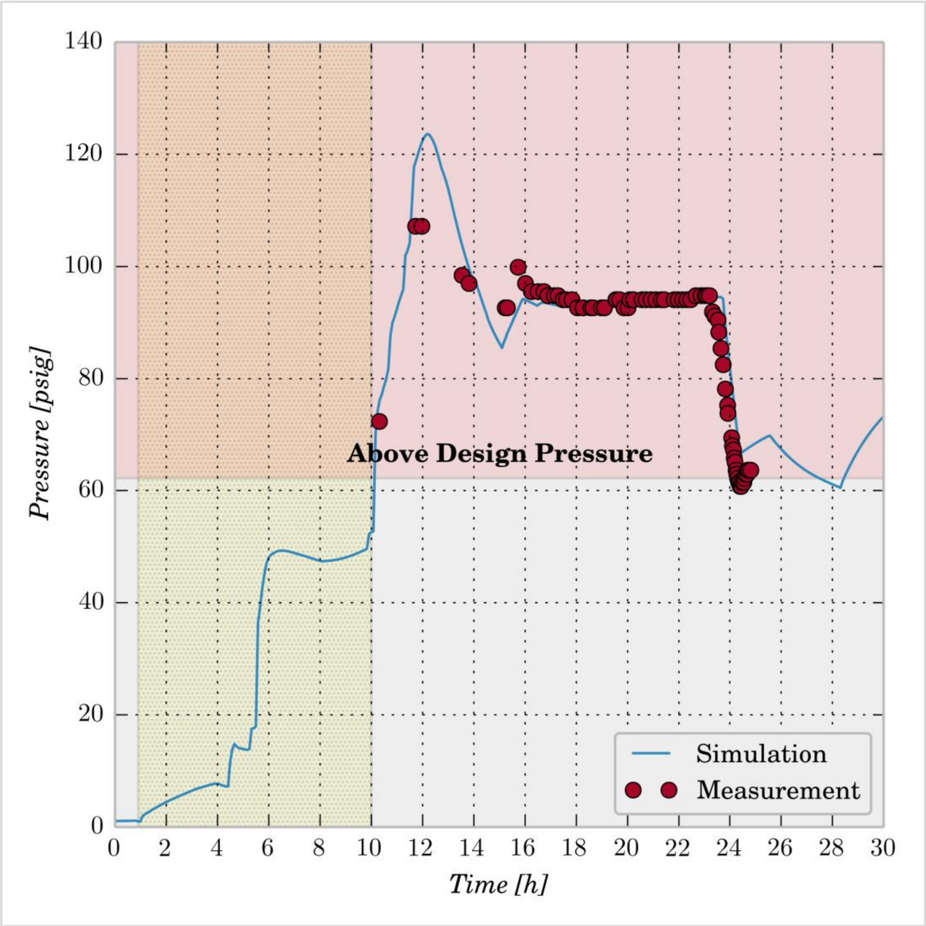
Enhancing Assessment of Accident Progression





- Limited data available from event
- Analytical methods aid in forensic evaluation
- Fukushima Technical Evaluation: EPRI 1025750, April 2013

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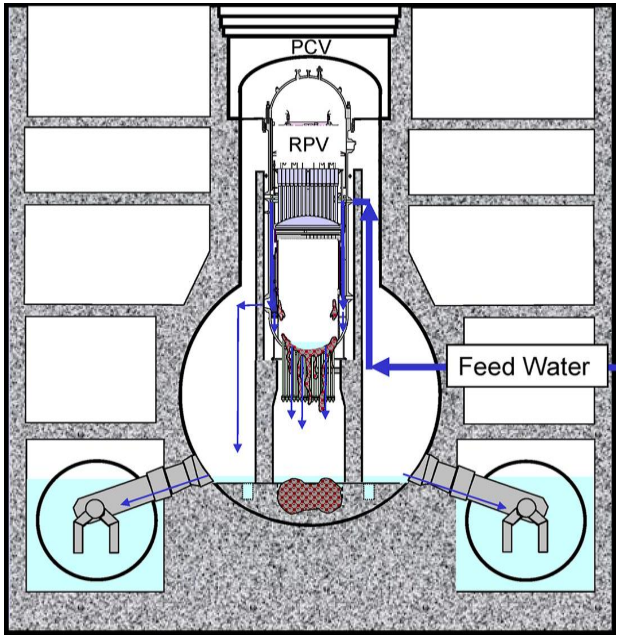
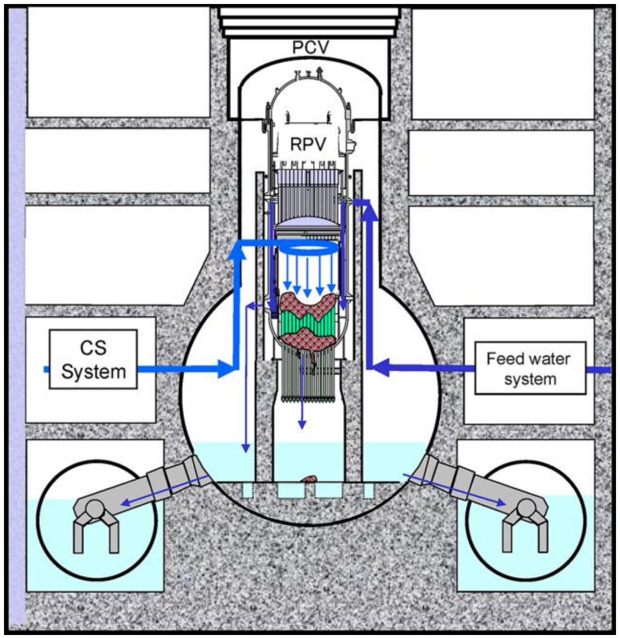
Uncertainty in Evaluation of Core Status

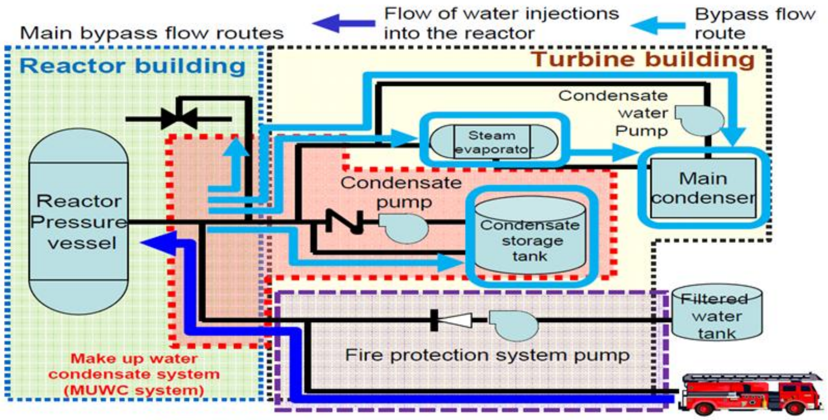
Unit 1



Units 2 & 3



Extensive core melting due to degraded water injection



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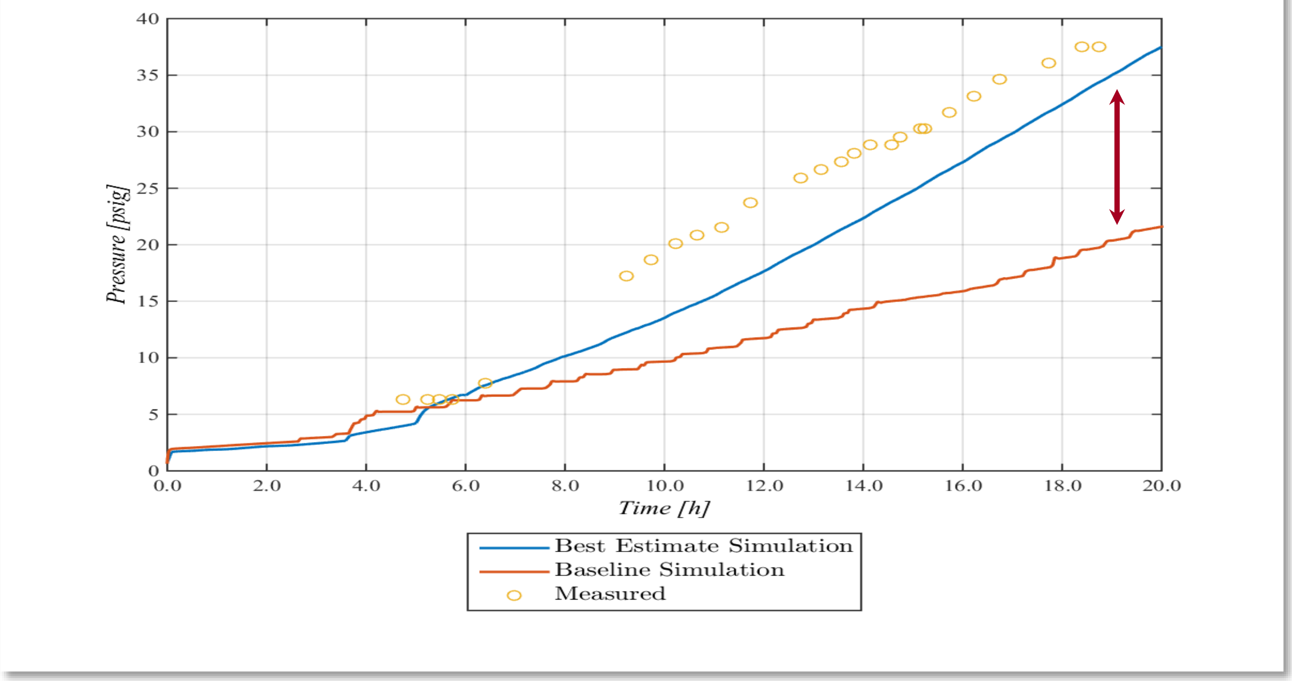
Uncertainty in Evaluation of Containment Response

Unit 3 containment response – prior to core damage



- Enhanced containment pressurization prior to core damage
- ELAP scenarios bring in additional physics
  – Buoyancy can dominate gas and water flows in containment

Thermal stratification in containment for ELAP scenarios

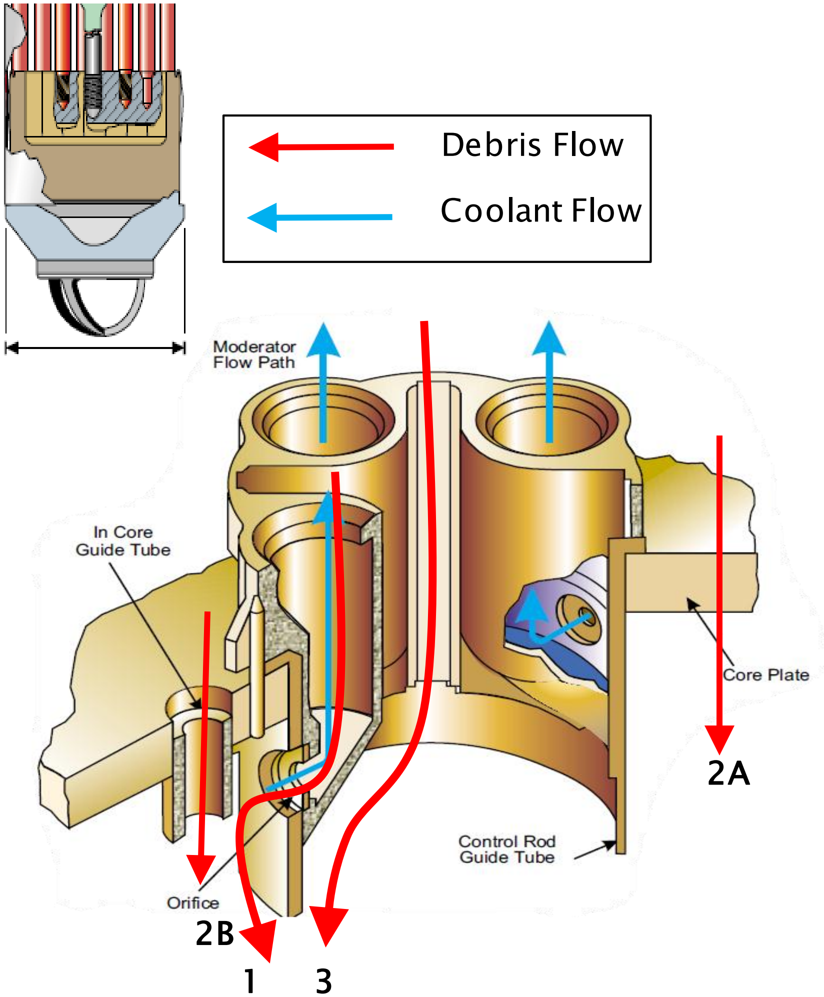
Key Model Improvements for MAAP5

- Enhanced BWR core melt progression
- More detailed BWR lower plenum model
- BWR penetration and ex-vessel control rod drive structure models
- Debris behavior in containment
  - Molten Core-Concrete Interaction (MCCI) enhancement
  - Ex-vessel debris coolability
- BWR Thermal Hydraulics
- Containment Stratification Model

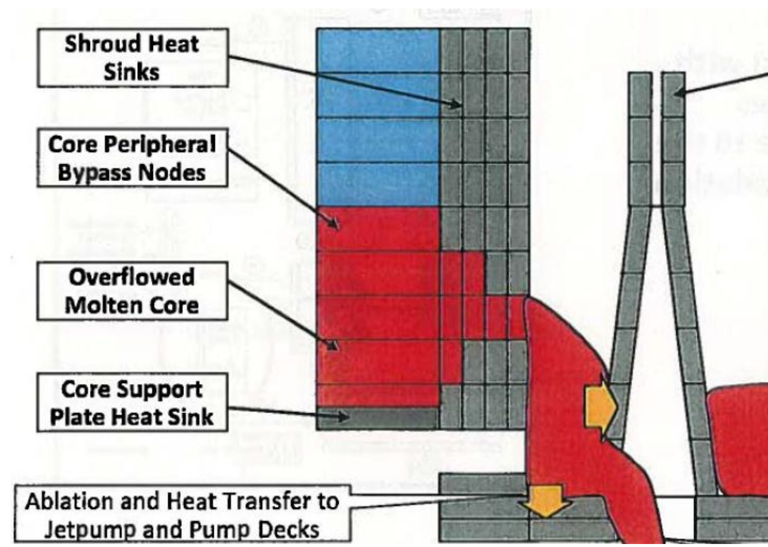
METI funding obtained for MAAP5 enhancements

Enhanced Core Relocation Modeling

▪ Conceivable Melt Relocation Paths to Lower Plenum



- **Path 1**: Through open coolant inlet channels
- **Path 2A**: Through core plate due to creep rupture/collapse
- **Path 2B**: Through core support plate holes for in-core instrument tubes due to tube melting
- **Path 3**: Through gap in the control blade opening inside the fuel support piece
- **Path 4**: Through shroud wall breach due to thermal attack from molten pool



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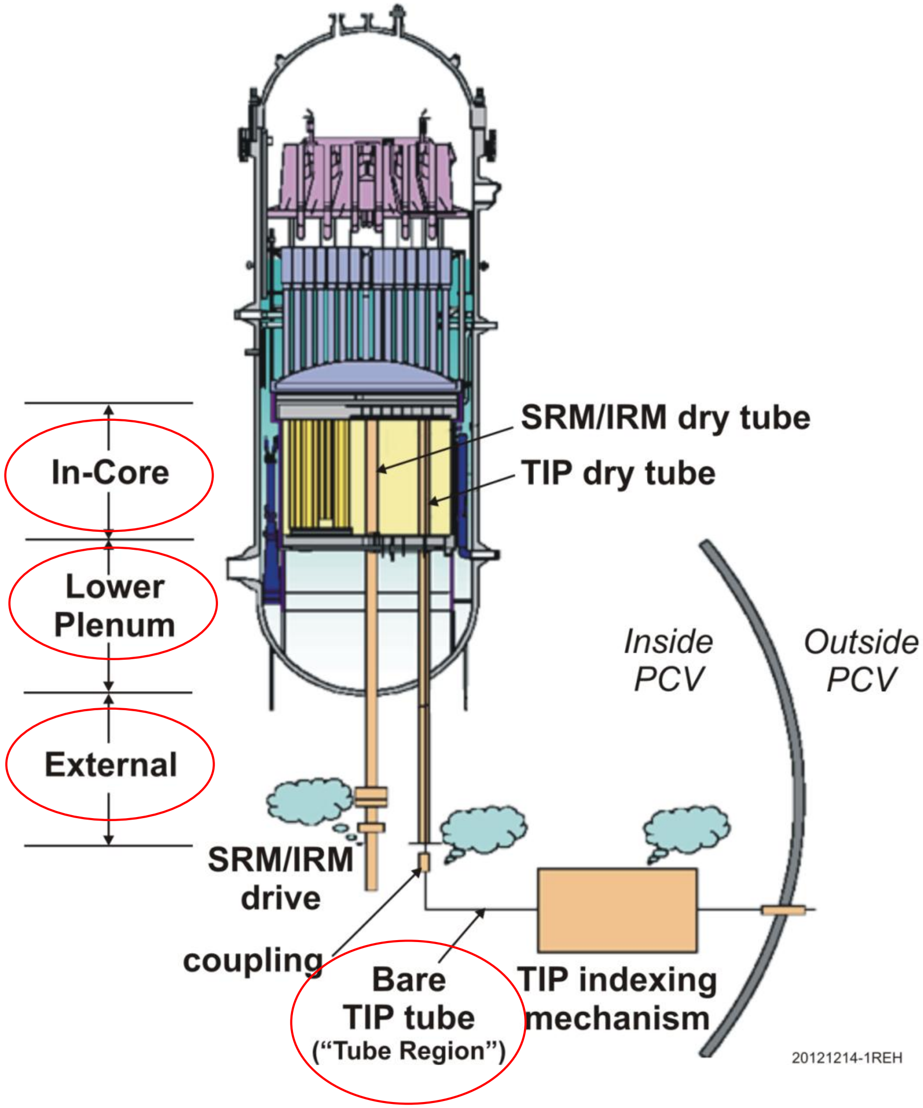
Modeling of Instrument Tube Degradation



Direct RPV leakage into drywell

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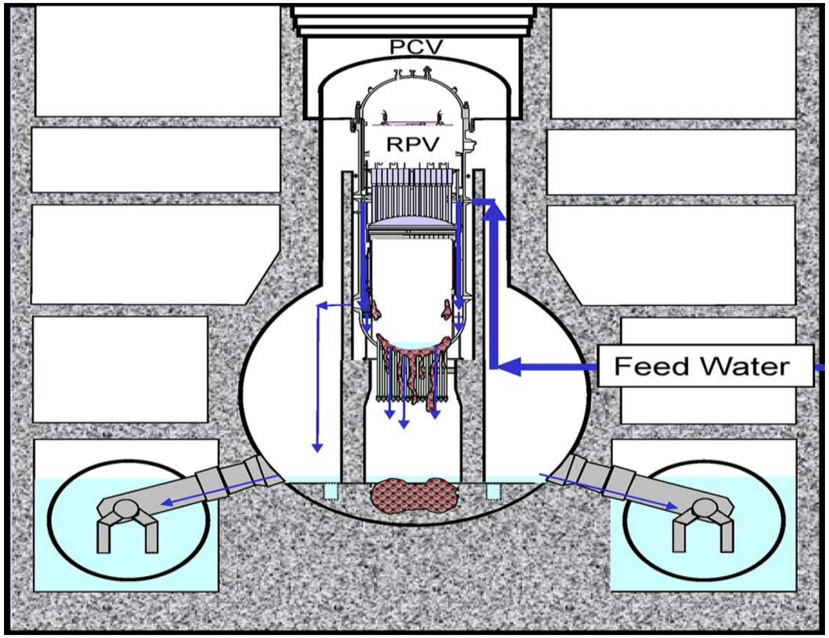
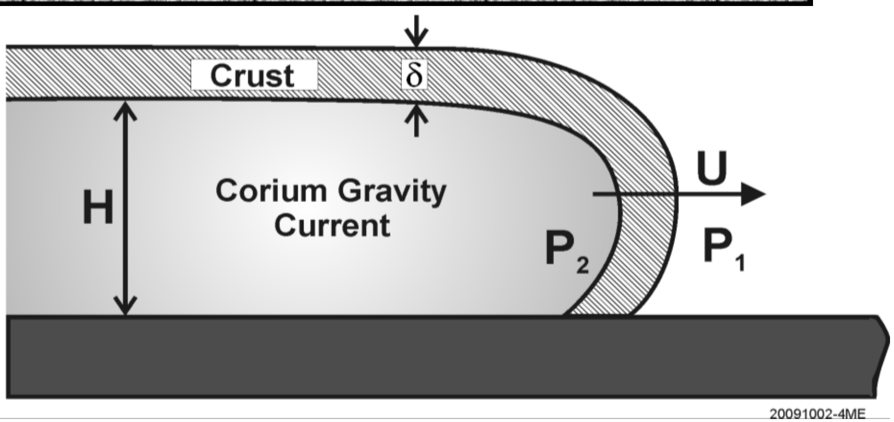
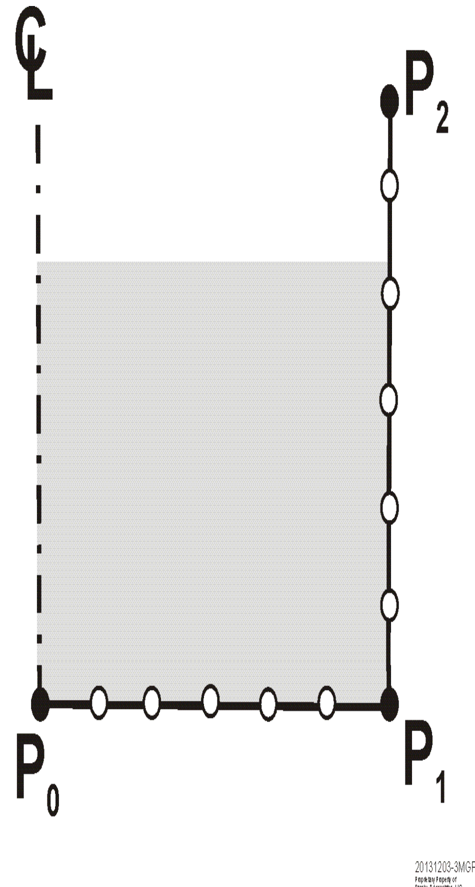
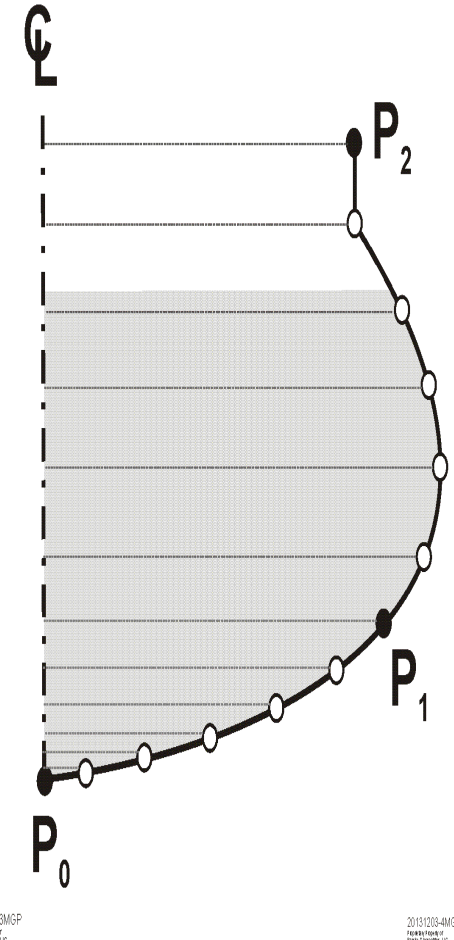
Enhanced containment pressurization

Enhanced Ex-Vessel Debris Modeling





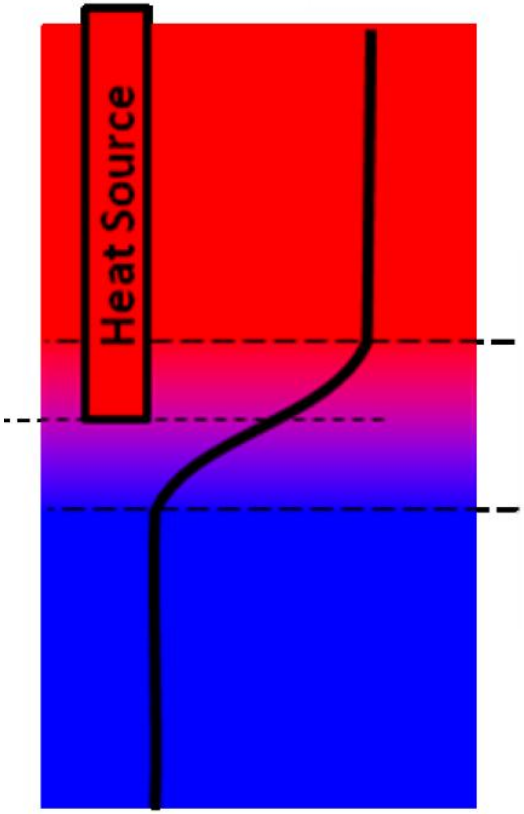




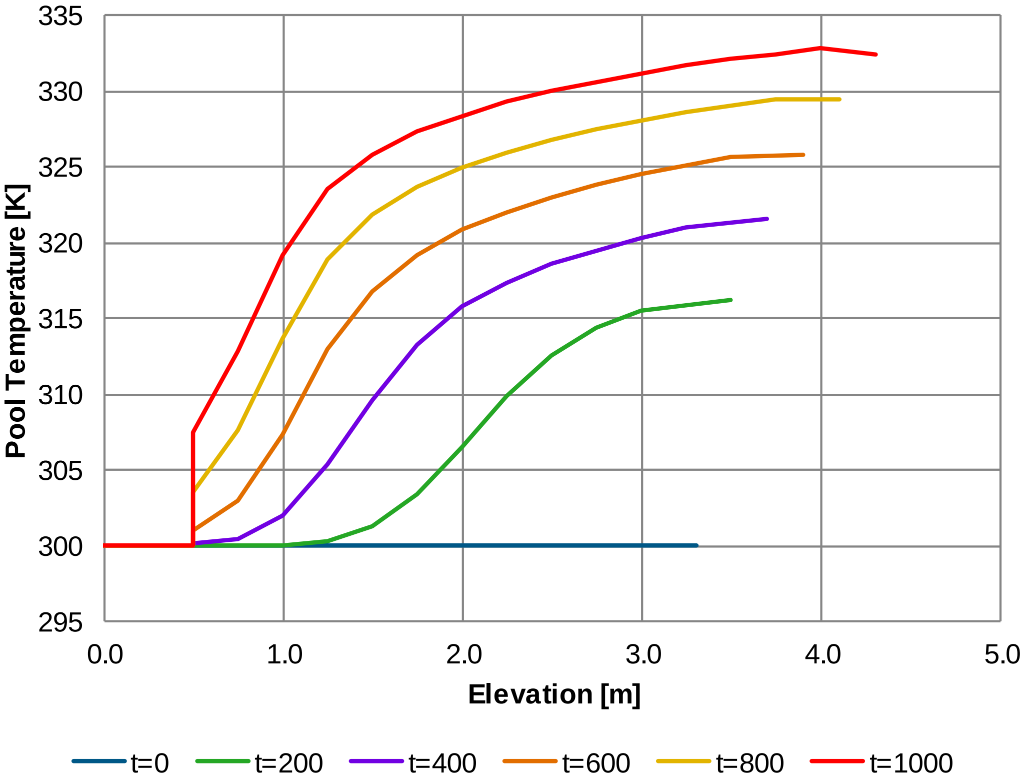
Enhanced evaluation of potential for drywell liner melting following RPV failure

Enhanced Containment Modeling – Stratification Phenomena

- Development of thermal stratification in suppression pool
  - Relevance to containment pressurization
  - Key safety insight from Fukushima Daiichi



Example Simulation – MAAP5 Model Enhancement



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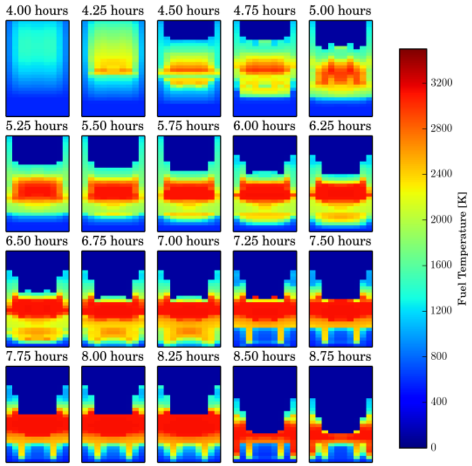
Core Damage Progression – Future R&D

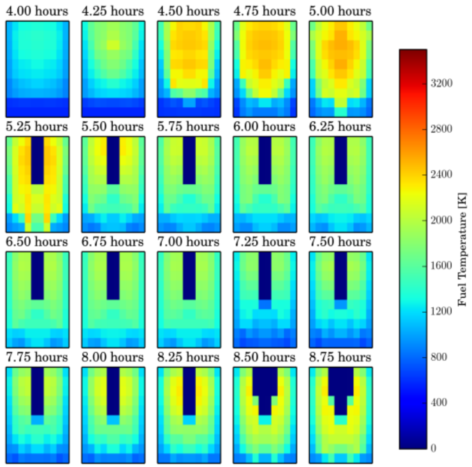
- Computer model validation
  - Separate effect tests
- MAAP-MELCOR Crosswalk first phase
  - Distinct core damage progression modeling
  - Established framework for identifying key gaps in knowledge base
- Key area of divergence between models
  - Representation of progression at reactor scale
- DOE/EPRI gap analysis
  - Identified as a high priority area

Key uncertainty in extrapolation of models to reactor scale

MAAP5



MELCOR

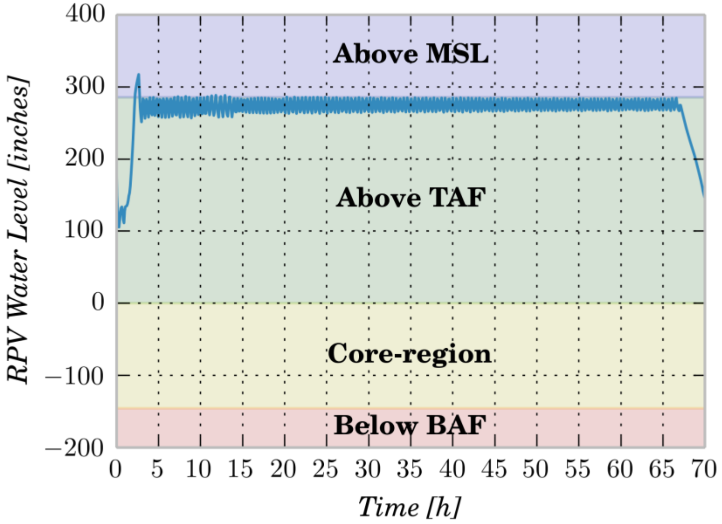


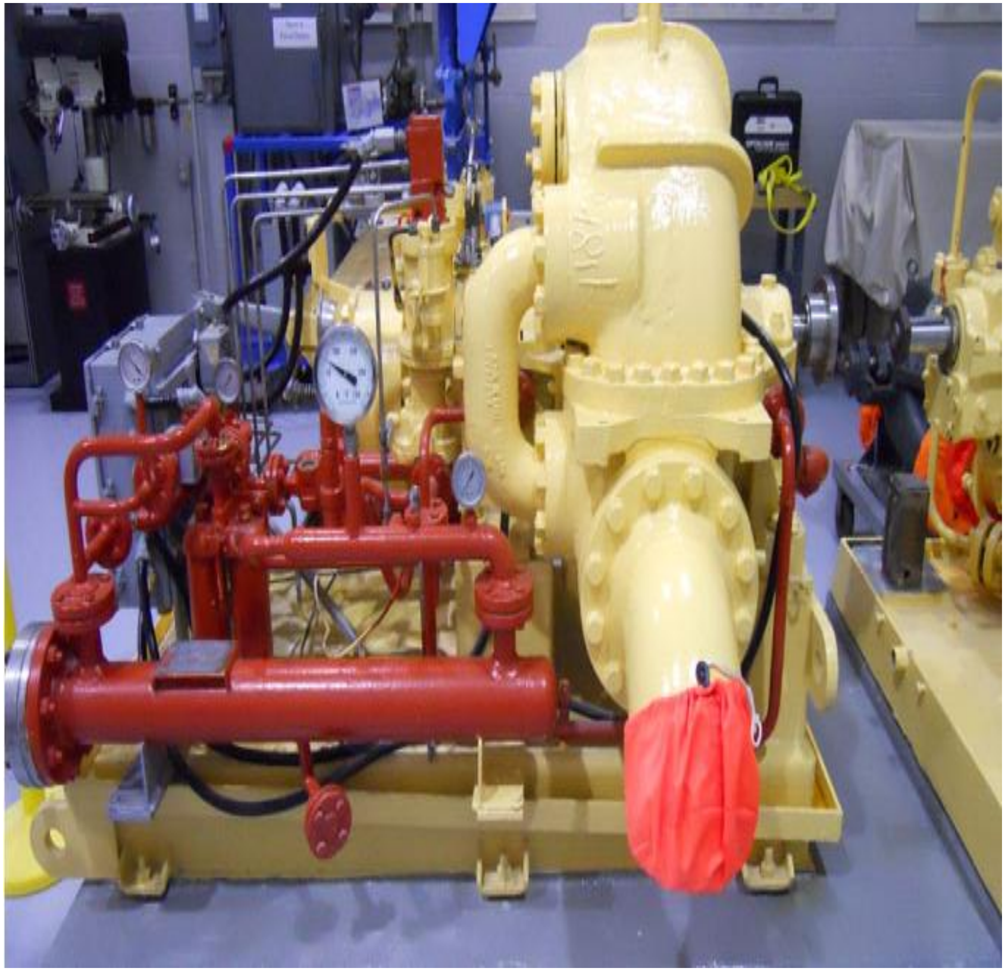
MAAP-MELCOR Crosswalk: EPRI 3002004449, November 2014

Beyond Design Basis RCIC Operation – Future R&D

How should RCIC be operated outside design basis?

Unit 2





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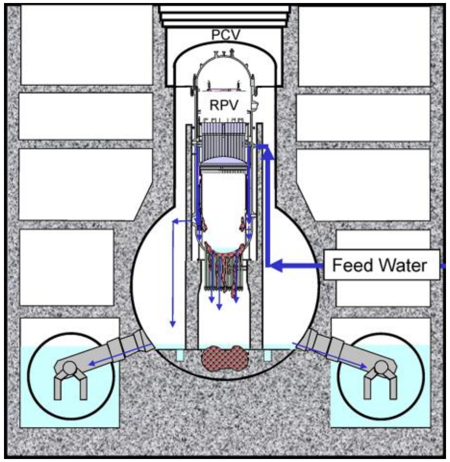
Severe Accident R&D – Looking Forward

- Good representation of overall plant response
  - Fukushima root cause evaluation
  - Robust PRA conclusions
- Uncertainties in core damage progression details
  - Highly relevant to assessing impact of mitigation measures
- Substantial insights to be developed from Fukushima
  - Interplay between decommissioning and accident evaluation
  - Insights to refine future experimental programs

Unit 1



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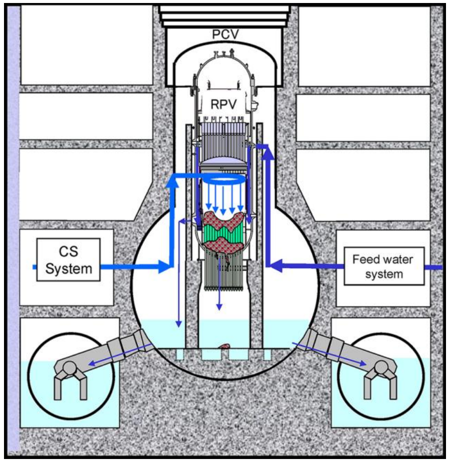

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