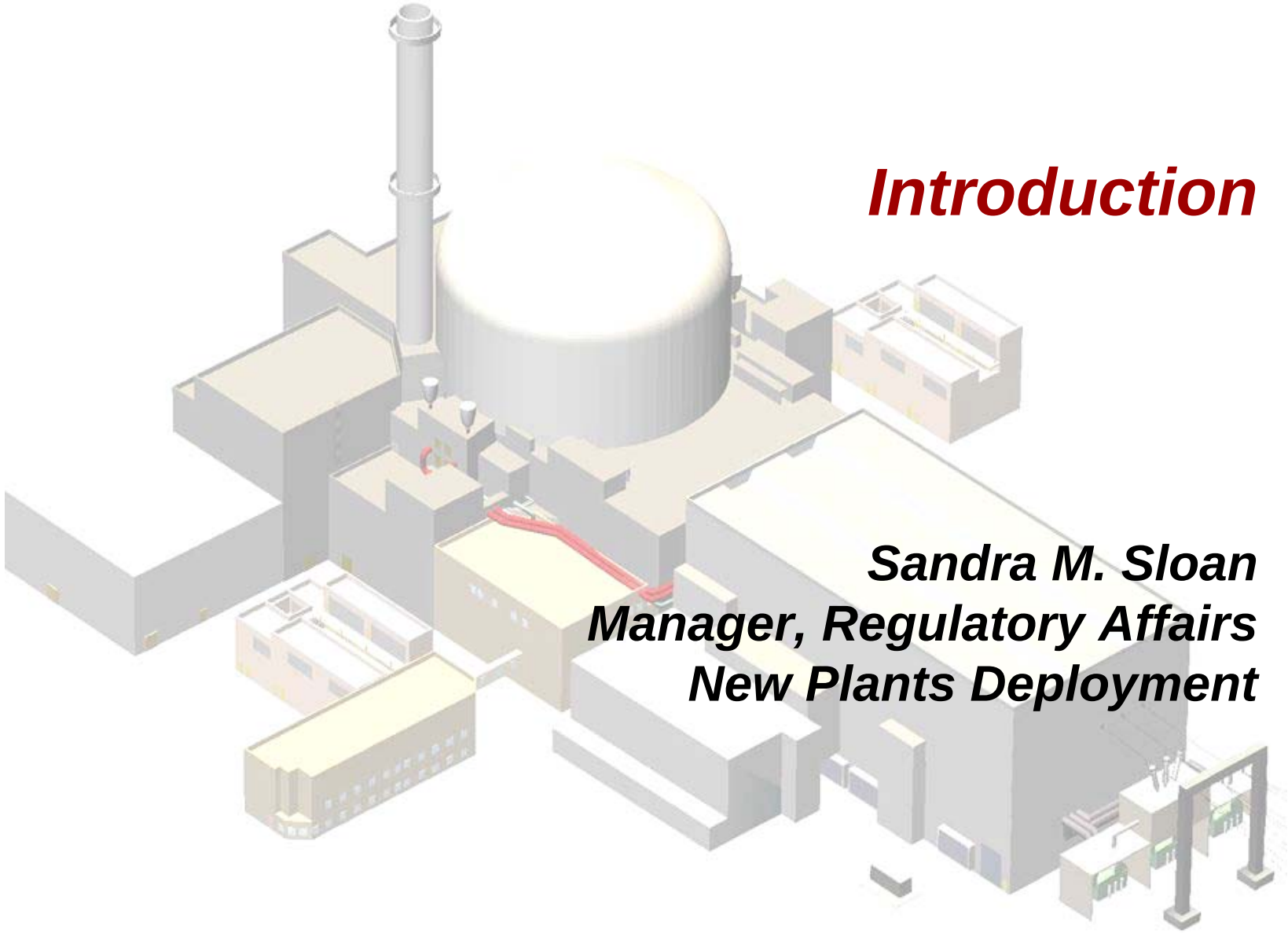
U.S. EPR Pre-Application Review Meeting:

Severe Accident Topical Report

AREVA NP and the NRC
July 25, 2006



Introduction

Sandra M. Sloan
Manager, Regulatory Affairs
New Plants Deployment

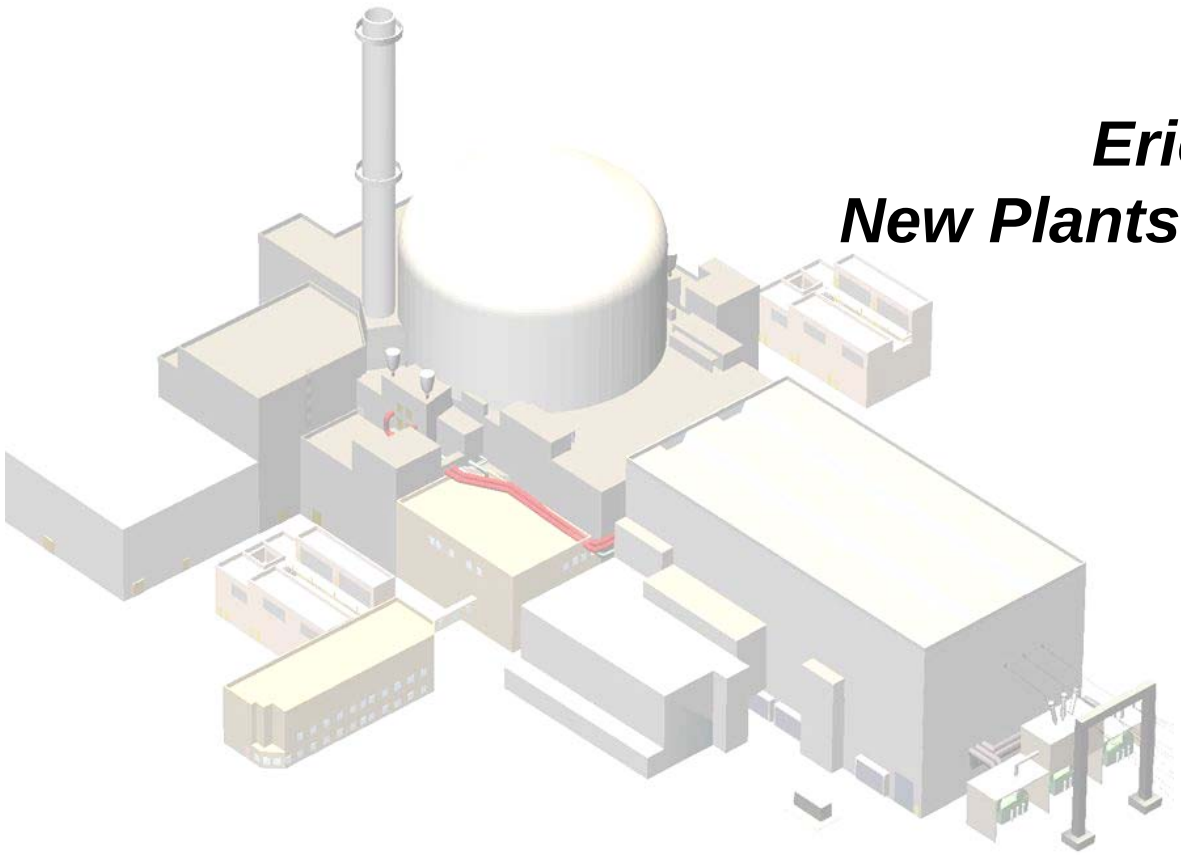
Meeting Objectives

- Review U.S EPR severe accident mitigation approach and design features
- Provide a preview of the U.S. EPR Severe Accident Topical Report, to be submitted in October 2006
- Provide an overview of the testing programs supporting the design and operation of U.S. EPR severe accident mitigation design features
- Provide an overview of the U.S. EPR severe accident analytical approach and selected preliminary results
- Solicit feedback from the NRC about the proposed content of the topical report

Outline

- Review of Severe Accident Mitigation (Eric Williams)
- Topical Report Organization and Severe Accident Testing Programs (Robert Martin)
- Severe Accident Analytical Approach and Preliminary Results (Eric Williams)
- Summary and Next Steps (Sandra Sloan)

Review of U.S. EPR Severe Accident Mitigation



Eric S. Williams
New Plants Engineering

U.S. EPR Safety Basis

- Safety philosophy includes deterministic consideration of defense-in-depth complemented by probabilistic analyses
  - Prevent deviations from normal operation
  - Detect deviations and prevent escalation to design basis accident (DBA) conditions
  - Control DBAs and prevent escalation into a severe accident (beyond DBA)
  - Mitigate the consequences of a severe accident

- Features included to limit radiological consequences
  - Design objective to minimize the need for countermeasures

Robust U.S. EPR design for severe accident mitigation

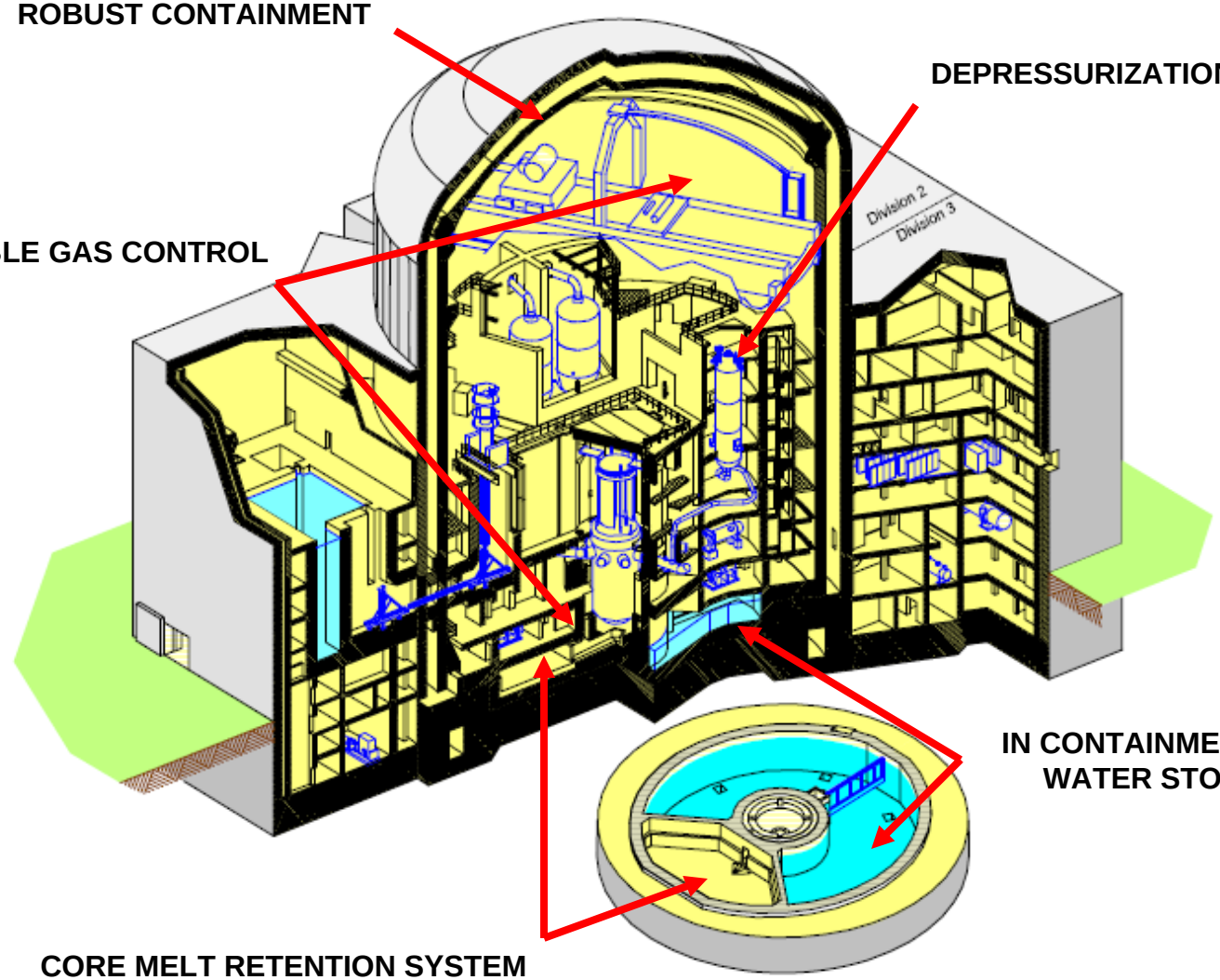
U.S. EPR Severe Accident Philosophy

- **The U.S. EPR is designed to account for a broad spectrum of severe accident phenomena**
  - **High pressure reactor coolant system (RCS) failure**
  - **Fuel coolant interactions (FCI)**
  - **Molten core concrete cnteraction (MCCI)**
  - **Hydrogen generation**
  - **Containment pressurization**

- **Robust design of severe accident mitigative features demonstrated through bounding sequences**

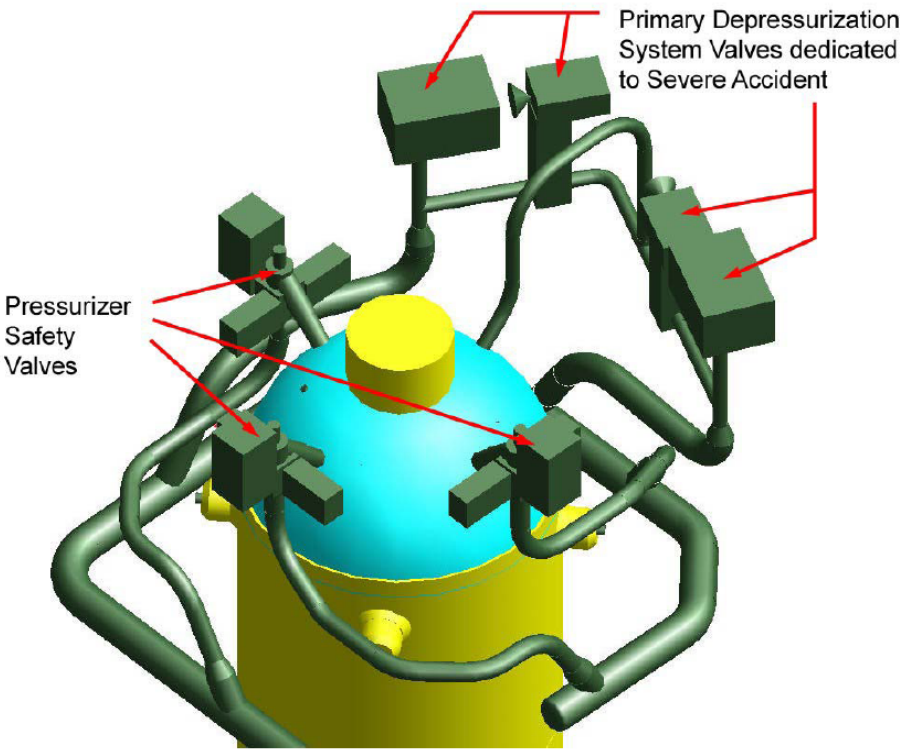
Severe accident mitigation philosophy is focused on maintaining containment integrity

Severe Accident Design Features



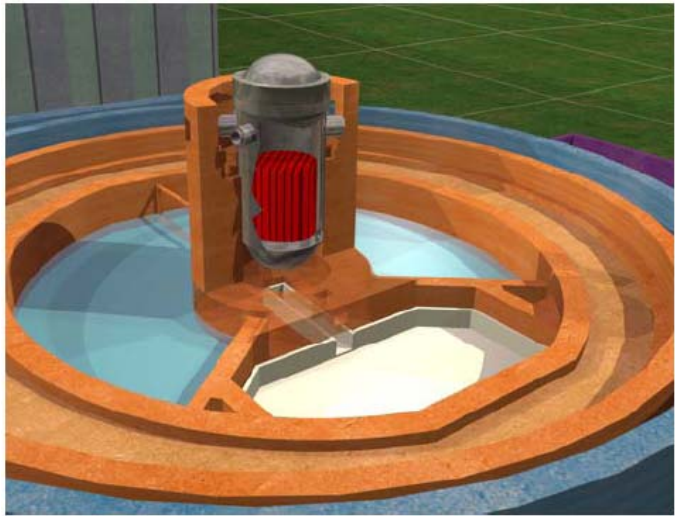
Severe Accident Depressurization Valves

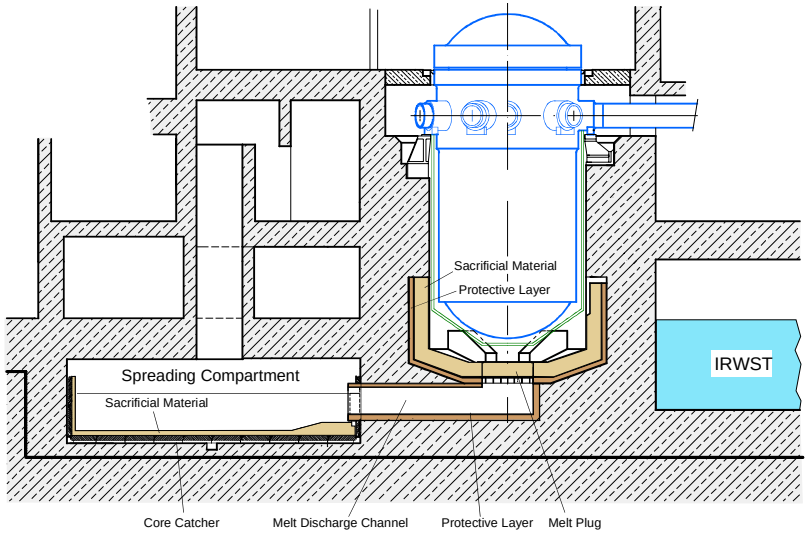
- Dedicated valves address high pressure RCS failure concerns
  - Manual actuation at 1200°F
- Valve sizing ensures rapid depressurization of RCS
- Benefits of depressurization
  - Avoid direct containment heating (DCH) due to high-pressure melt ejection (HPME)
  - Uplift forces
  - Cavity pressurization
  - Thermally-induced steam generator tube rupture



Core Melt Retention System (CMRS)

- CMRS designed to passively stabilize molten core debris
  - Decouples melt stabilization from uncertainties associated with in-vessel melt progression
- CMRS features address staged melt progression
  - In-vessel melt progression
  - RPV lower head failure
  - Melt retention and conditioning
  - Melt relocation and spreading
  - Melt quenching and stabilization



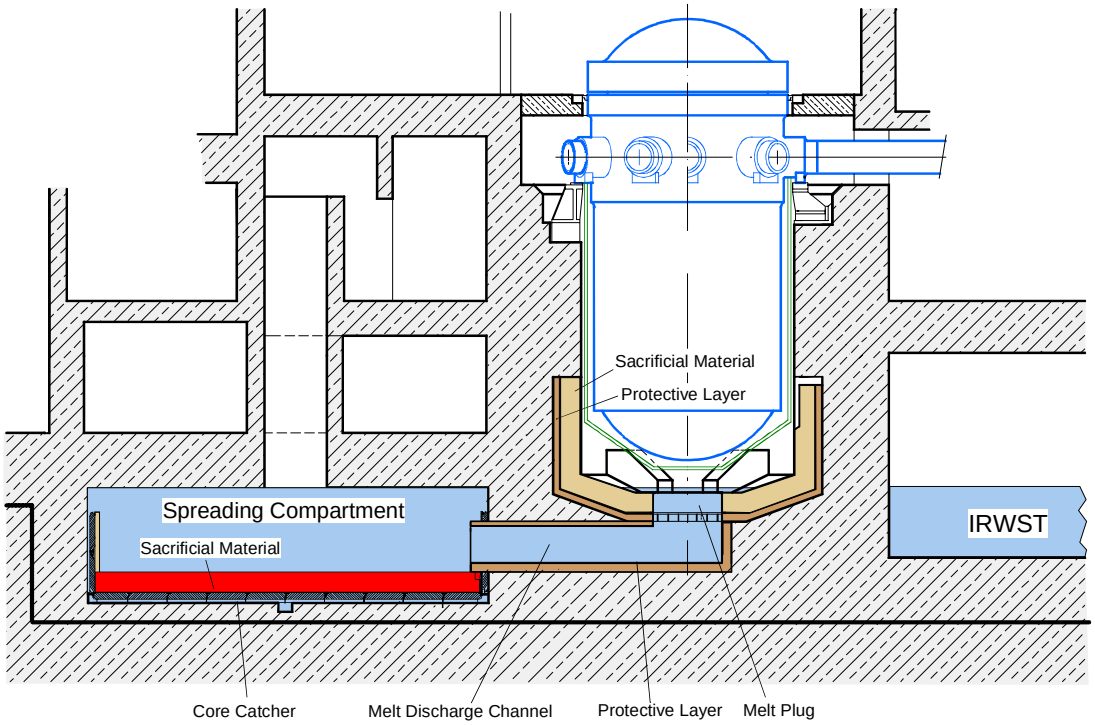


Melt Stabilization and Cooling

Passive melt cooling:

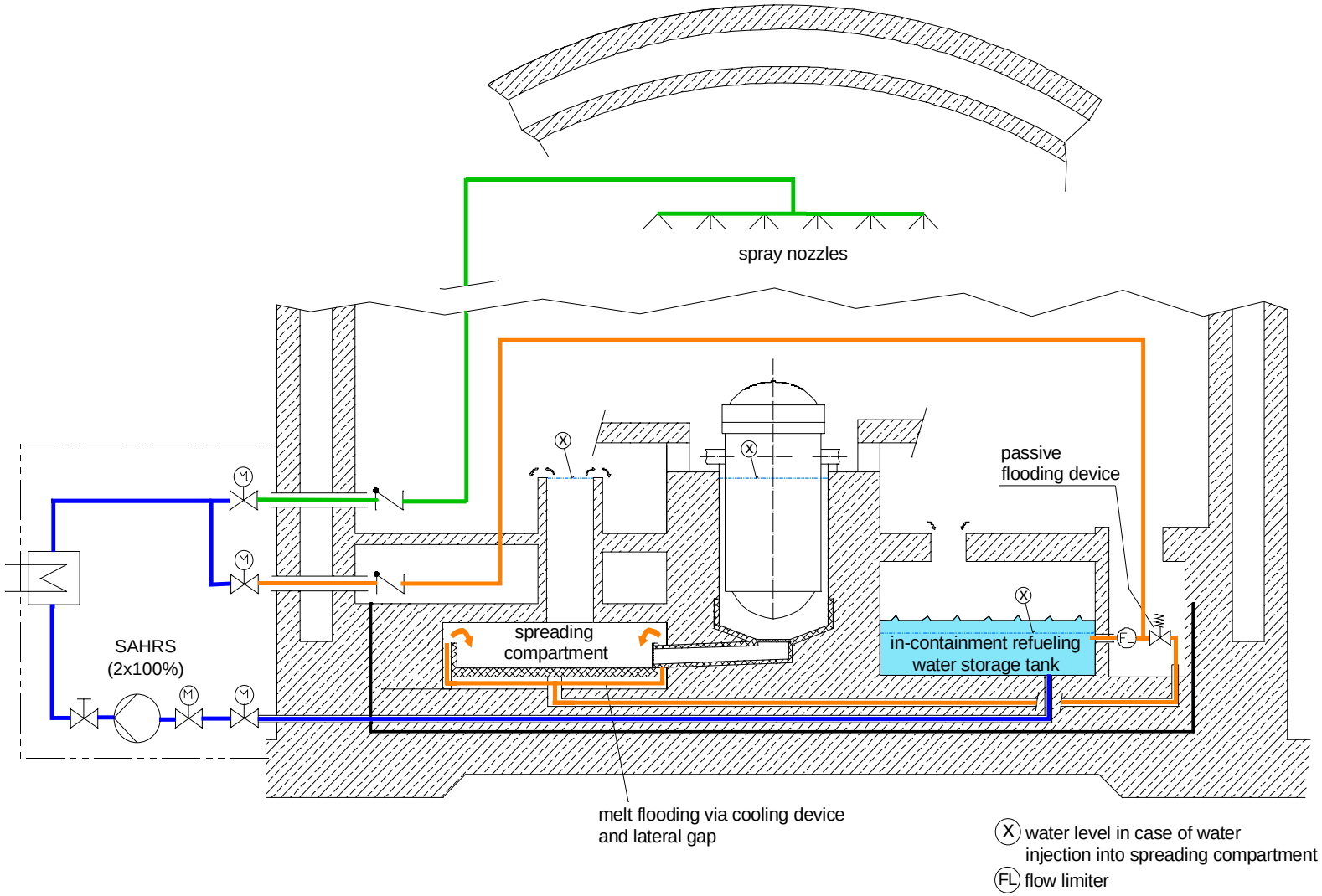
Gravity-driven overflow of water from the IRWST

At equilibrium water level, cooling is established also for debris remaining within transfer channel and lower pit



Containment design limits maintained for ~12 hours without operator action

Severe Accident Heat Removal System

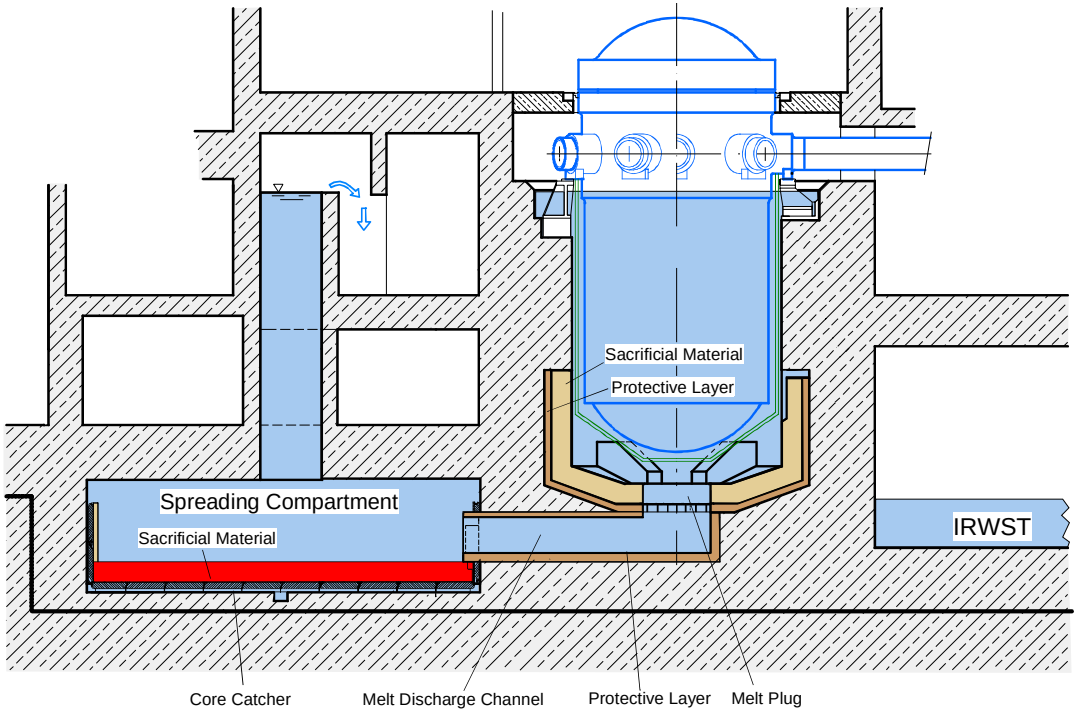


Long-Term Containment Heat Removal

Active melt cooling:

Water injection by the SAHRS into the spreading area with overflow into the IRWST

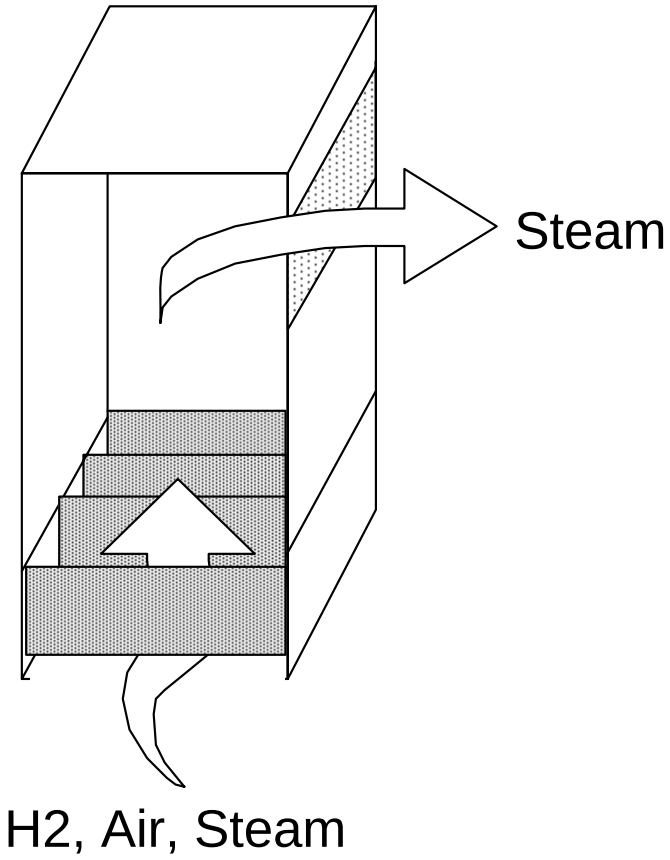
The elevated water level establishes long-term cooling for all debris that potentially remained in either the transfer channel, the pit, or the RPV



Formation of a sub-cooled water pool above the melt avoids the need for further containment spraying (atmospheric pressure)

Combustible Gas Control System

- CGCS includes passive autocatalytic recombiners (PARs)
  - H2 < 10% global
  - H2 < 4% global in 12 hours
  - AICCP < design pressure
- PARs distributed throughout containment
- AREVA PARs have increased efficiency, even in a steam saturated atmosphere
- Effectiveness demonstrated through testing programs

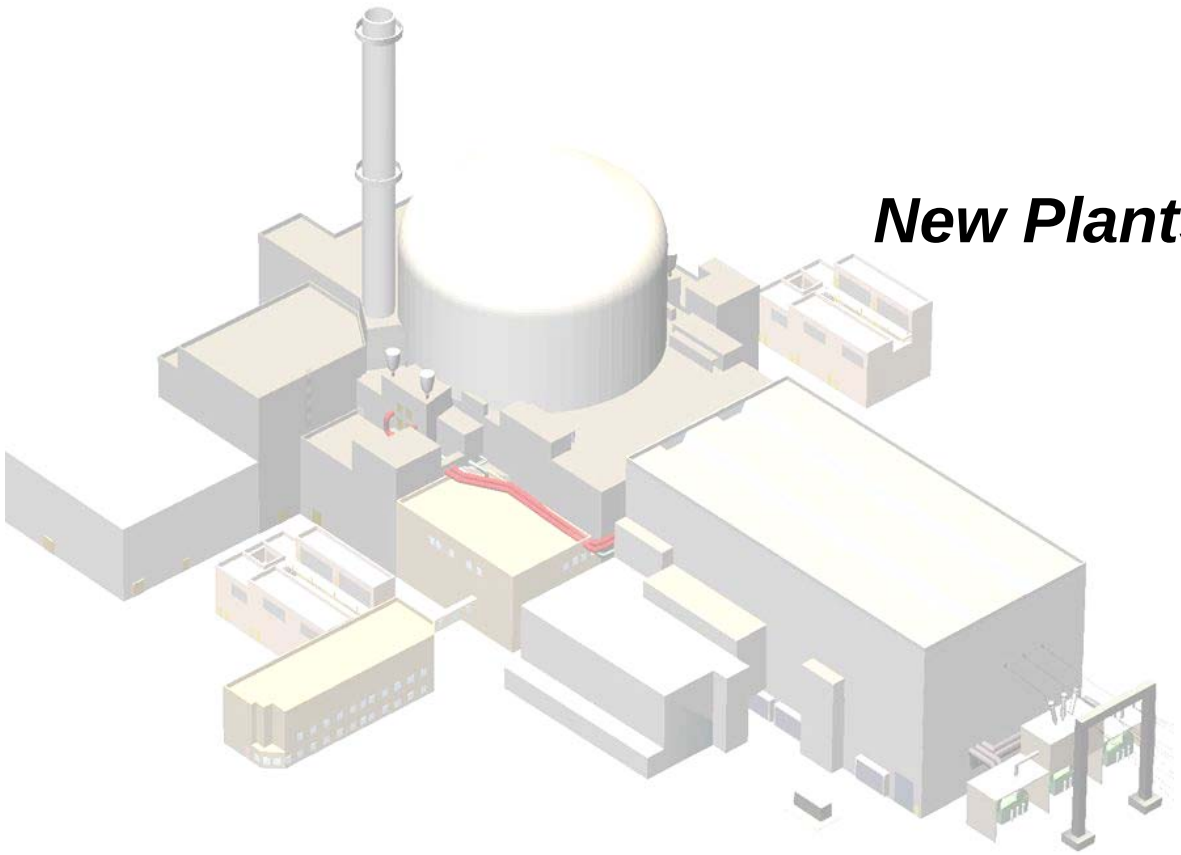


U.S. EPR Licensing Basis

> **Consideration of severe accidents is an integral part of an NRC licensing review but it is not part of the "design basis"**

> **NRC guidance for severe accident mitigation**
  - **Non-safety related systems**
  - **Not seismically qualified**
  - **Equipment survivability, not qualification**
  - **Consideration of single failure not required**

Technical Basis for U.S. EPR Severe Accident Design Features



Robert Martin
New Plants Engineering

Presentation Outline

- > General outline of U.S. EPR Severe Accident Topical Report
- > Identification of safety issues and relevant phenomena
- > Description of test programs and important results

The U.S. EPR will demonstrate conformance within the framework of existing severe accident regulatory guidance

Topical Report Table of Contents

- **Section 1: Introduction**
  - Regulatory guidance, acceptance criteria, analysis requirements
- **Section 2: Executive Summary**
- **Section 3: U.S. EPR Severe Accident Design Features**
  - Severe accident depressurization, CMRS, SAHRS, and CGCS
- **Section 4: Selection of Relevant Accident Scenarios**
  - Use of risk-informed insights to select representative scenarios
  - Consideration of bounding sequences to address uncertainties
- **Section 5: Technical Resolution of Severe Accident Safety Issues**
  - Methodology for treatment of relevant phenomena
- **Section 6: R&D Related to the U.S. EPR Severe Accident Concept**
  - Relevant testing programs and relationship to design decisions

Topical Report Table of Contents (continued)

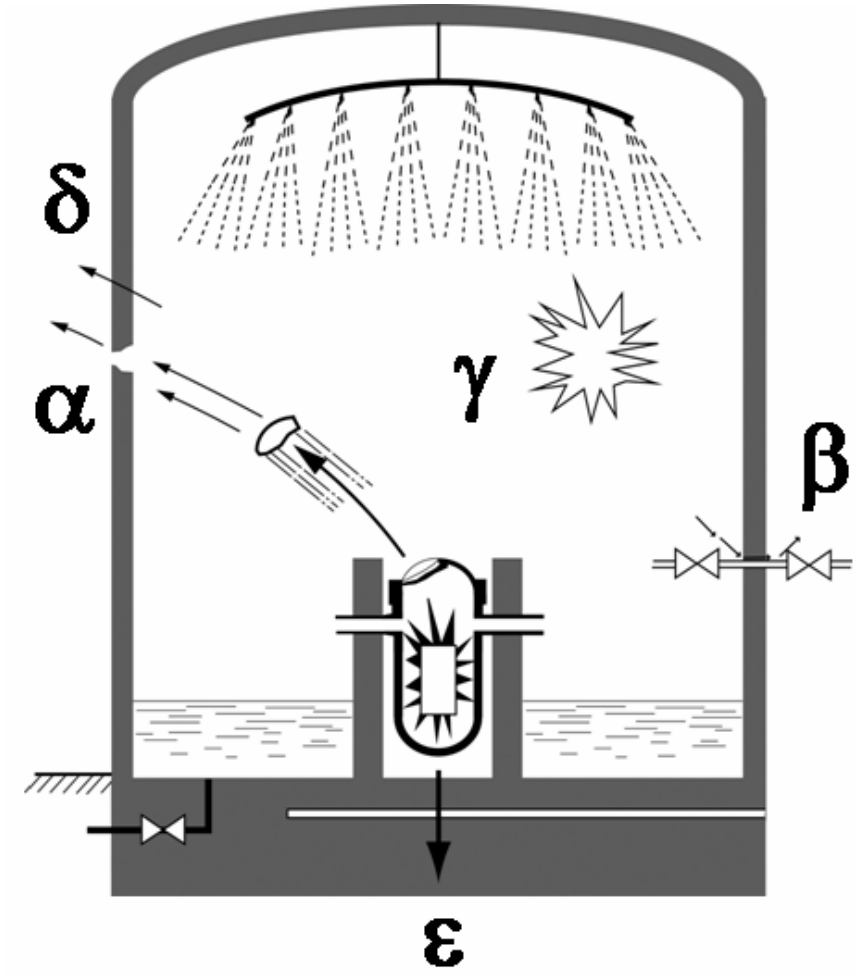
- **Section 7: Analytical Methodology**
  - **Code selection, applicability, and validation**
- **Section 8: Sample Analyses for U.S. EPR**
  - **Sample results for LOOP, LBLOCA, and SBLOCA scenarios**
- **Section 9: References**
- **Appendices**
  - **Relevant supporting information (as needed)**

Identification of Safety Issues

- Severe accident issues represent residual risk to public health and safety
- The U.S. EPR's robust treatment of severe accidents is based on a spectrum of developmental processes to address uncertainties
  - Establishment of aggressive safety goals
  - Identification of important physical processes and phenomena
  - Iterative design processes focused on risk reduction
  - Collaborative international testing programs
  - Expert elicitation on important technical issues
- The U.S. EPR severe accident philosophy focuses on maintaining containment integrity by addressing relevant failure modes

Identification of Safety Issues (continued)

- α Mode: Steam Explosion
- β Mode: Containment Bypass
- γ Mode: H_2 Explosion
- δ Mode: Overpressure Failure
- ε Mode: Basemat Ablation by MCCI



Identification of Safety Issues (continued)

- Within the U.S. EPR, containment failure modes are mitigated through dedicated design considerations

- SECY 93-087 (April 2, 1993) and 10 CFR 50.44 (September 16, 2003) provide guidance for the resolution of severe accident issues
  - High-pressure melt ejection (HPME)
  - Core debris coolability
  - Hydrogen control
  - Containment performance
    - FCI
    - General overpressurization
  - Equipment survivability

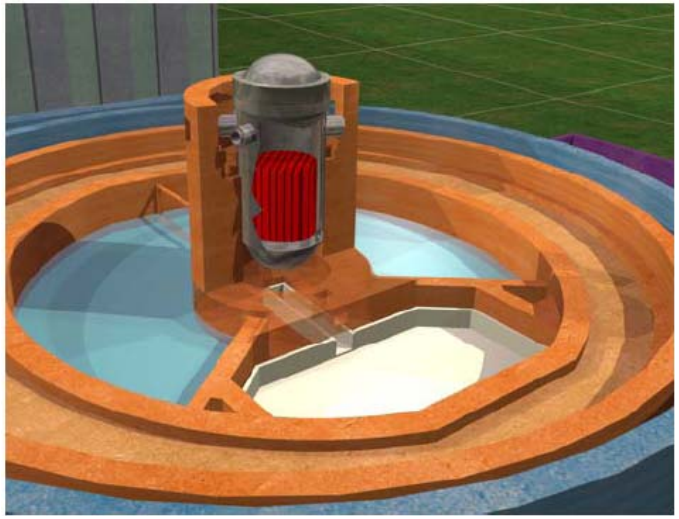
Identification of Safety Issues (continued)

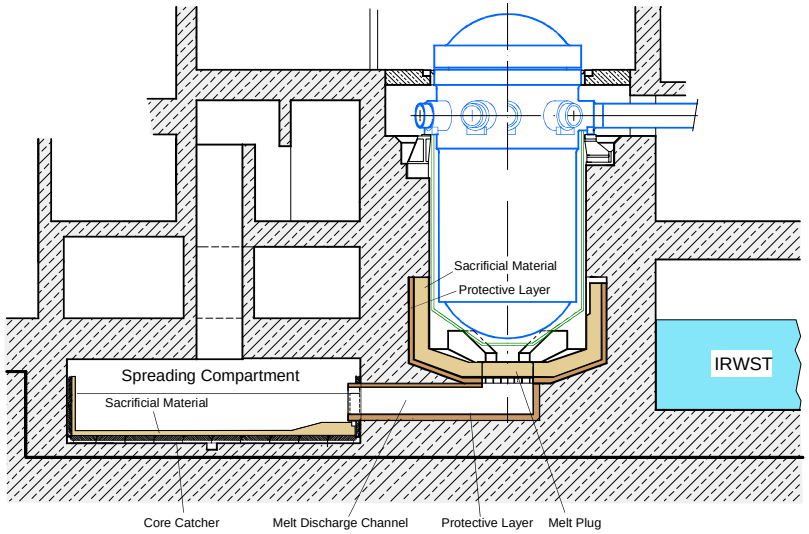
- **Hydrogen control**
  - 10 CFR 50.44, "Combustible Gas Control for Nuclear Reactors"
  - Capability to ensure a mixed atmosphere
  - Maintain atmospheric concentration of hydrogen below 10% by volume
  - Maintain containment integrity in the event of a deflagration
- **Core debris coolability**
  - Provisions to spread and quench molten core debris
  - Ensure that the environmental conditions (pressure and temperature) resulting from core-concrete interactions are within established criteria
- **Containment performance**
  - Maintain role as a leak-tight barrier for 24 hours following core damage
  - Post-24 hours, provide a barrier against uncontrolled fission product release
  - Consideration of in-vessel and ex-vessel steam explosion
- **High pressure melt ejection**
  - Reliable depressurization system
  - Features to decrease ejected debris in the upper containment
- **Equipment survivability**
  - Maintain reliability of functions during credible severe accident scenarios

Processes and Phenomena

- Identification of dominant processes and phenomena for the U.S. EPR encompasses
  - Broad R&D database
  - Elicitation of expert opinion
  - Defined analytical objectives

- Consider a (credible) bounding severe accident sequence
  - LBLOCA with no active ECCS
    - Maximize core damage
    - Bias early hydrogen production
    - Maximize decay heat





Processes and Phenomena (continued)

Important U.S. EPR Phenomena	Safety Issue
Thermal-hydraulics and fuel degradation	Hydrogen control Core debris coolability Equipment survivability
Core melt progression (degradation of core structures)	Hydrogen control Core debris coolability
Core melt relocation to lower head	Hydrogen control Core debris coolability
In-vessel fuel-coolant interaction	Containment performance High pressure melt ejection
Oxide-metal stratification	Core debris coolability
Crust formation and failure	Core debris coolability
In-vessel debris formation	Core debris coolability

Processes and Phenomena (continued)

Important U.S. EPR Phenomena	Safety Issue
RPV failure modes	Containment performance High pressure melt ejection
Melt conditioning in reactor pit o Molten core concrete interactions (MCCI) o Oxide-metal stratification o Integrity of ex-vessel protective structures	Hydrogen control Core debris coolability Containment performance
Melt spreading in spreading area	Core debris coolability
MCCI in spreading area o Oxide-metal stratification	Hydrogen control Core debris coolability Containment performance
Basemat cooling	Core debris coolability Equipment survivability
Melt flooding and quenching	Containment performance Equipment survivability

Processes and Phenomena (continued)

Important U.S. EPR Phenomena	Safety Issue
Steam/hydrogen transport	Containment performance Equipment survivability
Hydrogen recombination	Hydrogen control Equipment survivability
Hydrogen combustion	Hydrogen control Containment performance Equipment survivability
Long-term containment heat removal	Containment performance Equipment survivability
Fission product transport	Containment performance

Expert Opinion of Technical Issues

- **PRA supporting analysis methods – Risk-Oriented Accident Analysis Methodology (ROAAM) – Theofanous, 1996**
  - **To integrate risk factors and constraints imposed by design and phenomena to identify credible accident scenarios**

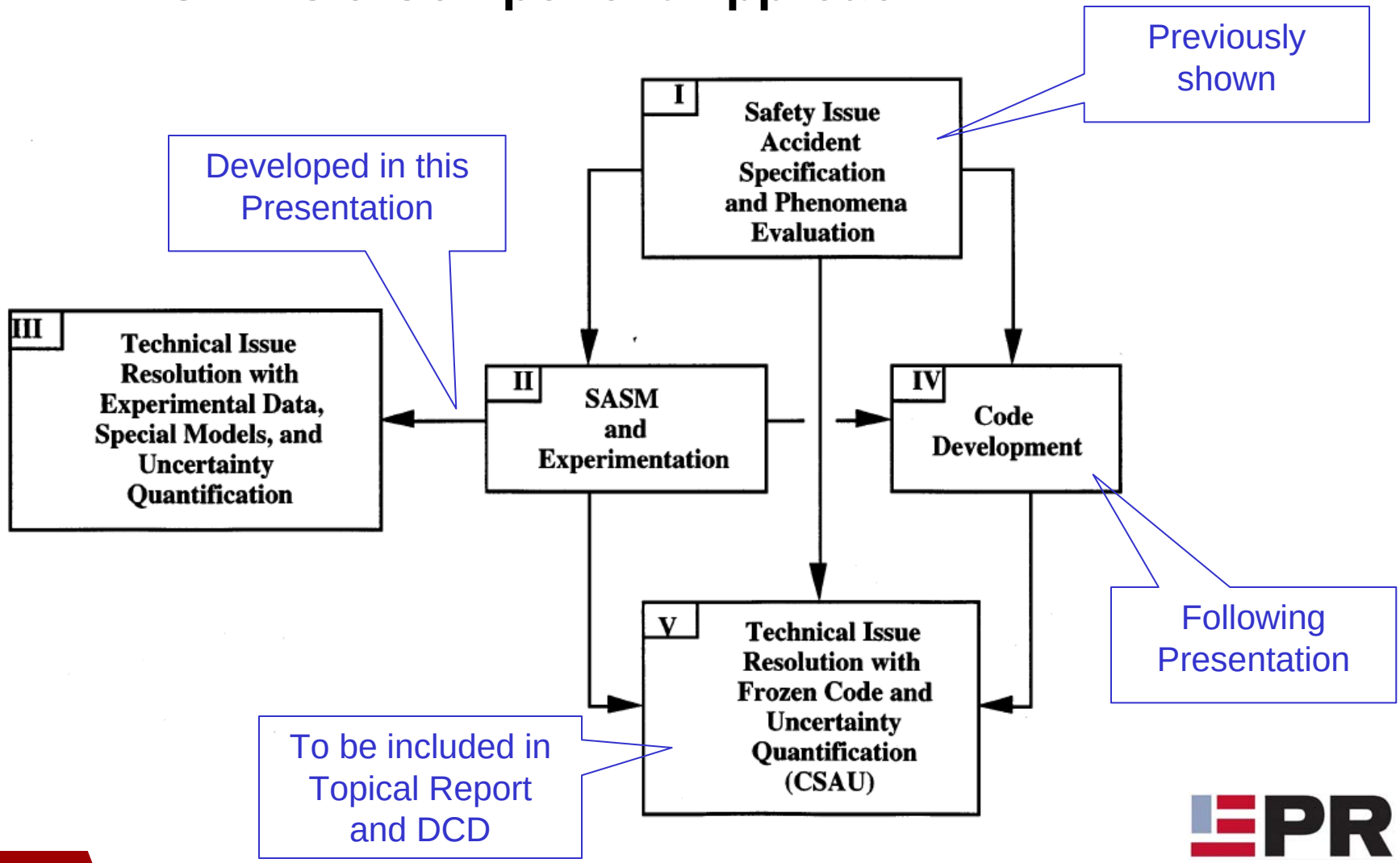
- **Analysis methods supporting PRA – Integrated Structure for Technical Issue Resolution (ISTIR) – TPG, 1993**
  - **To integrate experiments, analysis and uncertainty quantification by means of a methodology that is systematic, comprehensive, auditable, and practical**
  - **To ensure that computer codes and models used to resolve safety issues have the capability to scale-up processes to relevant plant conditions**

Expert Opinion of Technical Issues (continued)

- ROAAM uses Level 1 PRA to define major accident classes
- For all accidents not identified as "remote and speculative," analysis must show that containment failure is physically unreasonable
- Expect to show that this class is characterized as
  - Isolated containment (no bypass issue)
  - Full RCS depressurization
  - Passive protection of containment liner
  - Available active SAHRS
  - Hydrogen well-mixed in the containment
  - Hydrogen control available
  - No ex-vessel steam explosion

Expert Opinion of Technical Issues (continued)

> **ISTIR's 5-Component Approach:**



U.S. EPR Research & Development

- R&D supporting U.S. EPR severe accident features achieved through international collaborative efforts

- R&D performed in parallel with the various U.S. EPR development phases, has helped to
  - Facilitate understanding of the underlying phenomena
  - Identify initial and boundary conditions (e.g. RPV failure)
  - Support conceptual choices (e.g. melt spreading)
  - Confirm design solutions (e.g. steam explosion)
  - Improve analysis codes, models and data bases

Hydrogen Control R&D

- Identified phenomena of relevance to the U.S. EPR
  - Thermal-hydraulics and fuel degradation
  - Core melt progression (degradation of core structures)
  - Core melt relocation to lower head
  - Melt conditioning in reactor pit
  - MCCI in spreading area
  - Steam/hydrogen transport
  - Hydrogen recombination
  - Hydrogen combustion

- Phenomena of relevance can be broadly classified
  - Hydrogen production
  - Hydrogen distribution
  - Hydrogen combustion
  - Hydrogen recombination

Hydrogen Production

- The U.S. EPR is designed to maintain the average concentration of hydrogen in the containment atmosphere from complete clad oxidation below 10% (by volume)
- Hydrogen production serves as an initial condition for demonstrating the performance of the CGCS
- Hydrogen production mechanisms have been studied using analysis codes that show good agreement with test results
  - Dominant uncertainties relate to reflood and late phase core melt

Hydrogen Production Experiments

R&D Effort (Organization)	Description, Phenomena, Insights
CORA (FzK)	o Steam and argon flow through electrically heated PWR assembly o Parametric studies on reflooding conditions o Measured temperature, fuel damage and H_2 production
FLHT (PNNL)	o Nuclear heated full-length PWR assembly with coolant boil-off o Measured boil-off, temperature, fuel damage and H_2 production
PBF & LOFT Tests (INL)	o Nuclear heated PWR assembly with steam flow (w/ and w/o argon) o Measured temperatures, fuel damage and H_2 production
PHEBUS (CEA)	o Nuclear heat-up and steam flow through PWR fuel assembly o Measured temperatures, fuel damage and H_2 production o Analyses completed and documented for MAAP validation
QUENCH (FzK)	o Steam and argon flow through electrically heated PWR assembly o Parametric studies on reflooding conditions o Measured temperature, fuel damage and H_2 production o Oxidation of control rods containing B_4C

Uncertainties addressed by "realistic conservatism" in analyses

Hydrogen Distribution

- Most hydrogen distribution experiments have been instrumented to provide lumped-parameter measures
- The U.S. EPR addresses uncertainties with design features promoting atmospheric mixing
  - Severe accident depressurization
  - PARs
  - Hydrogen distribution subsystem

Hydrogen Distribution (continued)

R&D Effort (Organization)	Description, Phenomena, Insights
HDR (Germany)	o Full-scale containment study of steam and H_2 mixing o Focus on natural convection, heat absorption and gas distribution
NUPEC (MITI, Japan)	o H_2 mixing and distribution with high steam and sprays o Focus on natural convection, heat absorption and gas distribution
Battelle Model Containment (USA)	o Mixing and distribution of H_2 in containment. o Measured gas concentration, temperature and velocity o Measured structure temperature and heat transfer
KAEVER (GRS)	o Effect on atmospheric conditions from steam release and wall heating o Used to investigate aerosol transport and settling effects

Uncertainties examined relate to whether a local or global accumulation near the containment shell can occur at combustible concentrations

Hydrogen Combustion

- The combination of the CGCS and robust U.S. EPR containment design minimizes hydrogen risk of
  - Any deflagration with AICC pressure above design limits
  - Fast deflagration with transition to detonation
  - Local temperatures that may pose a threat to the containment
- Hydrogen combustion research facilitates understanding of phenomenon
  - Development of criteria to predict combustion modes
  - Validation of analysis codes predicting loads from combustion
- Uncertainties remain in the international state of knowledge relative to hydrogen combustion
  - Conditions for the development and stability of a standing flame
  - Application of combustion criteria to exclude fast deflagration and DDT

Goal is to control the consequences of potential combustion

Hydrogen Combustion Experiments

R&D Effort (Organization)	Description, Phenomena, Insights
Large View (University of Pisa)	o Visualization, ignition, opening location, jet ignition, and turbulence
Interconnected Vessel (AECL, Canada)	o Jet ignition, independent hydrogen concentration
Vented Containment (AECL, Canada)	o Vented combustion with different vent areas
Model Containment (Germany/Battelle)	o Slow and fast combustion, vented combustion, jet ignition, obstacles
PHDR (Germany/FzK)	o Slow and fast combustion, vented combustion, jet ignition, obstacles
NUPEC (Japan)	o Mixing/distribution, ignition location, spray, pressure, transients
RUT (Russia)	o Influence of mixtures sensitivity to detonation and DDT

Uncertainties examined relate to atmospheric conditions; concentrations of combustible gases, steam, and inertants; and ignition sources

Hydrogen Recombination

- The primary role of the U.S. EPR PARs is to minimize combustion risk by reducing hydrogen concentration
  - Prevents containment failure resulting from combustion
  - Combustion can occur in the form of deflagration
- Important uncertainties need to be addressed relative to hydrogen recombination
  - Recombination rates relative to production rates
  - Recombination efficiency vs. temperature
  - Time to start up

Catalytic Recombination Experiments

> **Recombiners qualified for various steam/inertant/hydrogen concentrations, poisoning and realistic flows**

R&D Effort (Organization)	Description, Phenomena, Insights
Model Containment (Germany/Battelle)	o Various experiments related to catalytic recombiners
Vented Containment (Canada/AECL)	o Various experiments related to catalytic recombiners
KALI (CEA)	o Various experiments related to AREVA NP PARs o PAR performance under spray conditions
H2PAR (CEA)	o Various experiments related to AREVA NP PARs o PAR performance up to 12% H_2 and subject to aerosols

Uncertainties examined relate to self-start capability, environment conditions and equipment survivability

Conclusions on Hydrogen Mitigation

- **The U.S. EPR hydrogen mitigation concept builds upon decades of research into hydrogen phenomena**
  - **Research has resulted in criteria predicting combustion potential**
  - **The AREVA NP PARs are reliable, well qualified components**
- **Experience has demonstrated that analysis codes are sufficiently mature for use as a decision tool**
  - **Provide capability for meaningful accident analysis**
  - **Justification and optimization of hydrogen mitigation concept**

Core Debris Coolability R&D

- Identified phenomena of relevance to the U.S. EPR
  - Core melt progression (degradation of core structures)
  - Core melt relocation to lower head
  - Oxide-metal stratification
  - Crust formation and failure
  - In-vessel debris formation
  - RPV failure modes
  - Melt conditioning in reactor pit
  - MCCI in spreading area
  - Basemat cooling
  - Melt flooding and quenching

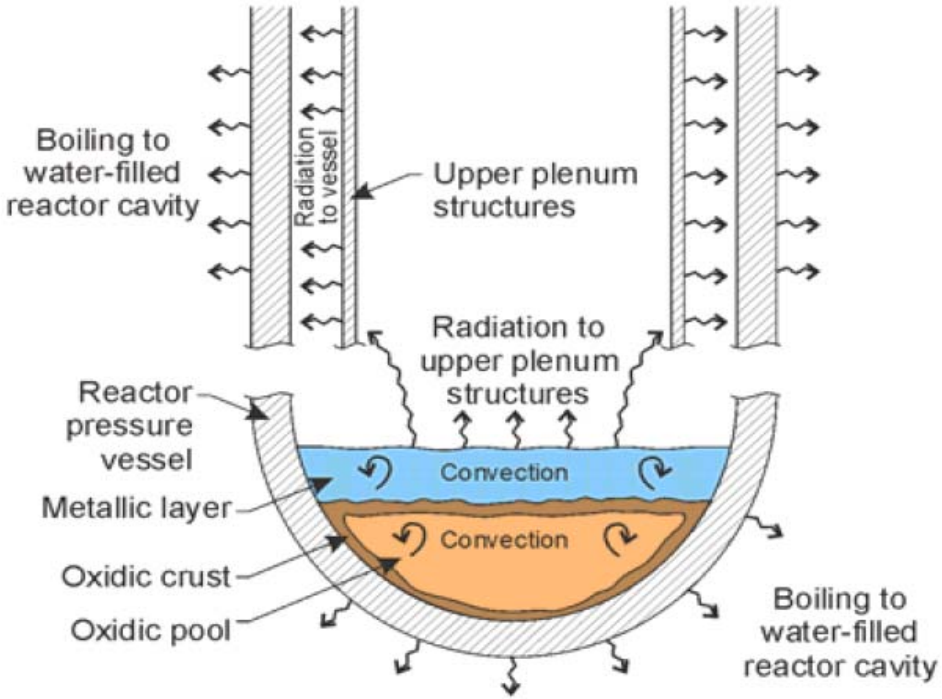
- Phenomena of relevance can be broadly classified
  - In-vessel melt progression
  - RPV failure modes
  - Ex-vessel melt stabilization

In-vessel Melt Progression

- U.S. EPR design decouples melt stabilization from the inherent uncertainties associated with in-vessel melt progression
- In-vessel melt progression provides the boundary conditions for the U.S. EPR melt retention strategy
- In-vessel melt progression has been studied in the framework of validating the in-vessel retention concept
  - Useful in assessing the spectrum of potential RPV failure modes

In-vessel Melt Progression (continued)

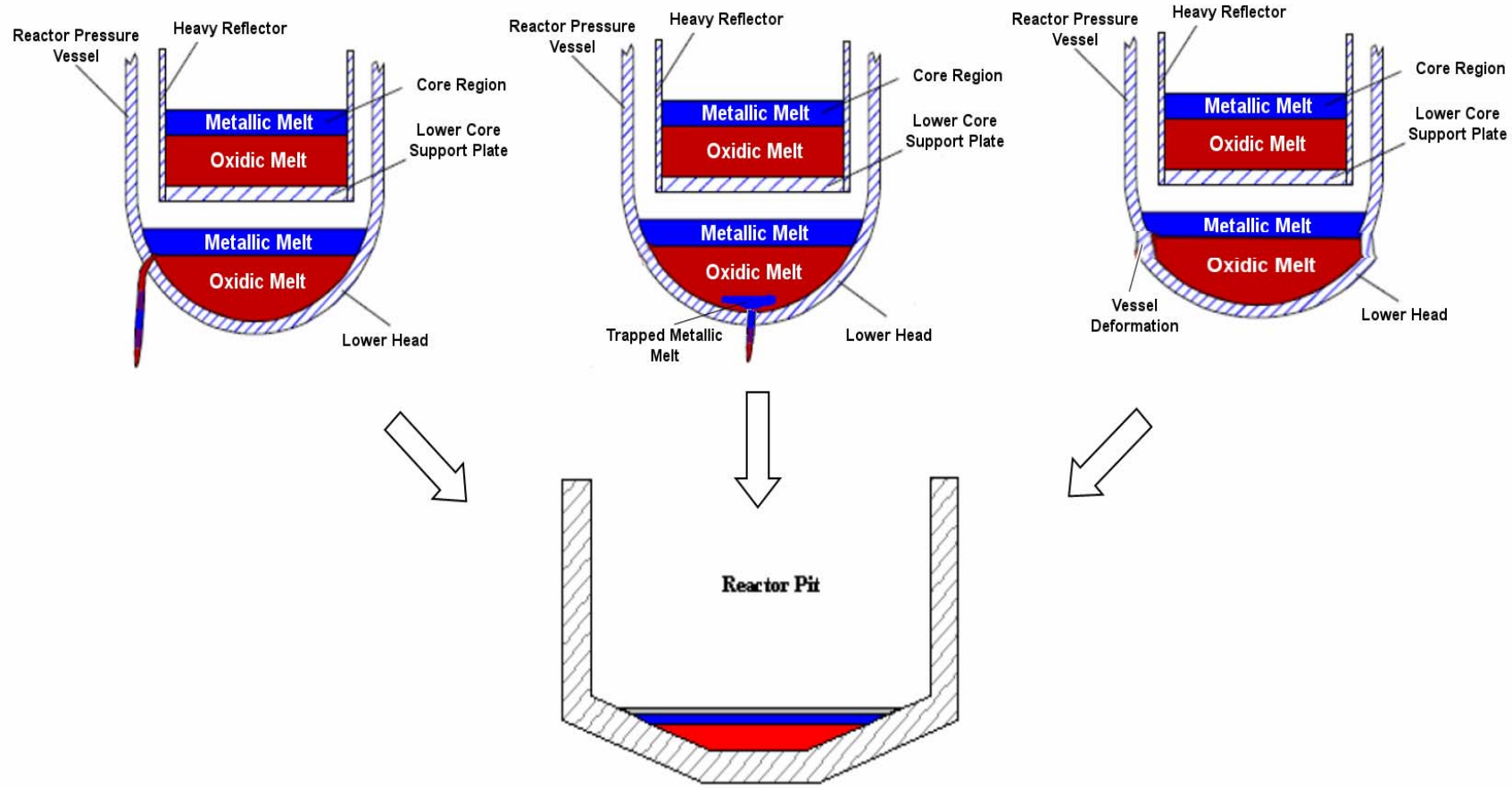
- FIBS (UCSB)
- COPO (IVO)
- ACOPO (UCSB)
- BALI (CEA)
- RASPLAV/MASCA (OECD)
  - Corium melt behaved comparable to simulant materials



RPV Failure Modes

- The RPV can fail locally or globally and dictate the conditions to which the containment is exposed
  - Local failure: non-uniform heat distribution in conjunction with mechanical loads
  - Global failure: uniform exposure to high stress
- The U.S. EPR melt retention concept accounts for a complete spectrum of RPV failure modes
  - No penetrations in the lower portion of the RPV
  - Melt retention facilitates global failure of the lower head

RPV Failure Modes (continued)



The U.S. EPR melt retention concept accounts for a complete spectrum of RPV failure modes

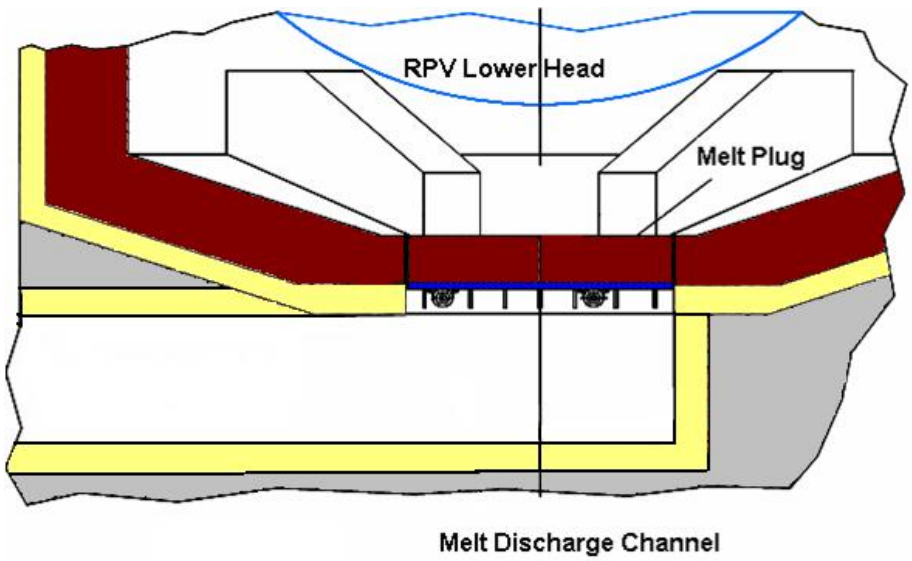
RPV Failure Modes (continued)

R&D Effort (Organization)	Description, Phenomena, Insights
LHF (SNL)	o Prediction of RPV failure for given heat load and pressure
SCWR Materials (INL)	o High temperature thermal diffusivity for SA533 and SS304
TMI-2 Vessel Investigation (OECD)	o Potential for localized and global RPV failure modes
Lower Head Failure Program (NRC)	o High temperature creep and tensile data for key materials

Uncertainties examined relate to the spectrum of RPV failure modes

Ex-vessel Melt Stabilization
Melt Conditioning

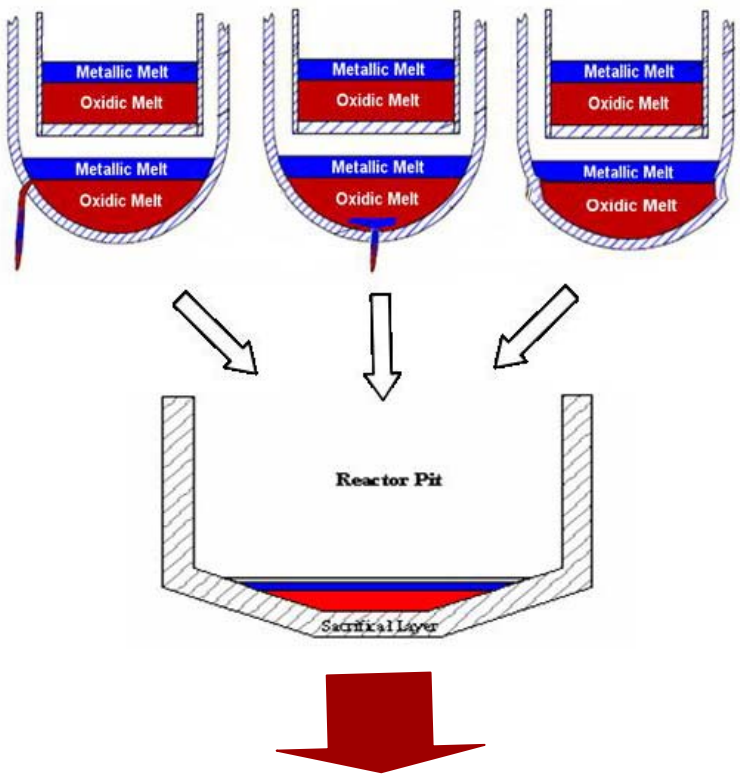
- Temporary melt retention is important to melt stabilization
- Initial conditions for stabilization are subject to the uncertainties of in-vessel melt progression
- Tolerance to uncertainties is provided by a preceding phase or retention prior to stabilization



Ex-vessel Melt Stabilization

Melt Conditioning

- Reactor pit is designed to promote temporary retention
- Sacrificial concrete provides delay time to account for time dependent release from RPV
- Admixture of concrete constituents during MCCI conditions melt to facilitate spreading
- Refractory layer ensures melt discharge from cavity only occurs at the gate



Ex-vessel Melt Stabilization
Melt Conditioning

> **U.S. EPR melt retention concept has many benefits**
- **Use of concrete builds upon a large MCCI database**
- **MCCI experiments indicate an isotropic heat flux distribution and moderate cooling of oxidic melts**
- **Ensures a low melt viscosity that facilitates spreading**
- **Flexibility in selecting aggregates to support conditions**

Ex-vessel Melt Stabilization

Melt Conditioning

R&D Effort (Organization)	Description, Phenomena, Insights
BETA (FZK)	o 2D-interaction of concrete with heated metallic melts
ACE (ANL)	o 1D-MCCI with oxidic melts and various concrete types
MACE (ANL)	o 1D/2D-MCCI with oxidic melts/concretes under flooded conditions
BALI (CEA Grenoble)	o Heat flux distribution in a volumetrically heated, bubble agitated fluid
BALISE (CEA Grenoble)	o Gas-driven mixing of density stratified non-freezing liquids
CORESA (SNT, AREVA)	o MCCI of metallic/oxidic melts in lab- and industrial-scale
MCCI OECD (ANL Chicago)	o Large-scale 2D-MCCI experiments using prototypic melts
AREVA Experiments	o Lab-scale investigation of EPR-specific concrete ablation

Uncertainties examined relate to melt state, thermal/chemical reaction rates, and heat transfer

AREVA NP MCCI Tests

AREVA NP MCCI Tests

Ex-vessel Melt Stabilization
Melt Conditioning

- The melt plug is an important component to U.S. EPR concept
  - Concrete plug backed by a composite steel/aluminium gate
- The melt plug is a predefined failure location for the pit
  - Melt will accumulate atop the plug
  - Gate will essentially fail instantaneously when contacted by melt
  - Gate design ensures a large failure size to promote melt spreading
- Melt plug is essentially identical to surrounding concrete
- Melt plug uncertainties equivalent to MCCI
  - MCCI test programs confirm performance

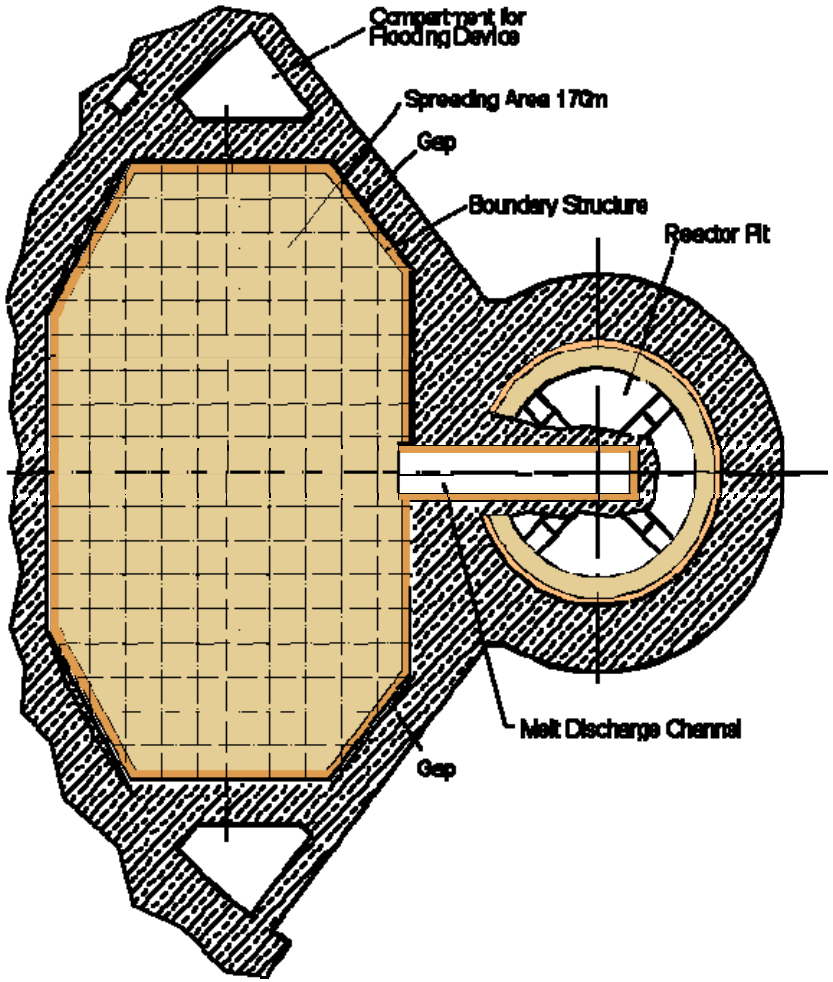
Ex-vessel Melt Stabilization

Melt Conditioning

Ex-vessel Melt Stabilization

Melt Spreading

- The spreading area provides a large surface over which to spread and cool the conditioned melt
- Spreading increases the surface-to-volume ratio of the melt and promotes effective cooling
- Melt relocates from the pit through a transfer channel
  - Channel blockage is not credible
  - Experiments demonstrate good spreading characteristics
  - Refractory lining limits heat loss



Ex-vessel Melt Stabilization

Melt Spreading

R&D Effort (Organization)	Description, Phenomena, Insights
CORINE (CEA)	o Dry and wet 1D-spreading tests with low temperature simulant melts o Different fluids and various inflow conditions and geometries
KATS (FZK)	o 1D/2D-spreading tests with high temperature simulant melts o Spreading performed under dry and wet conditions
COMAS (SNU)	o 1D-spreading test with large melt masses (several tons) o High temperature prototypic melts under dry conditions
COMAS-EU (SNU)	o 1D/2D-spreading test with large melt masses (several tons) o High temperature prototypic melts under dry conditions
VULCANO (CEA)	o 1D-spreading tests with high temperature simulants and prototypic melts (oxide) under dry conditions
FARO (JRC - Ispra)	o 1D-spreading tests with high temperature prototypic melts (oxide composition without added concrete) under dry and wet conditions
S3E (RIT)	o 1D/2D-spreading tests with medium temperature simulant melts (molten salts) under both dry and wet conditions
ECOKATS (FzK)	o 2D-demonstration test for the EPR o 3 tons of high-temperature simulant melt, subsequent flooding

Uncertainties examined relate to initial melt state, multi-dimensional spreading and heat transfer

Ex-vessel Melt Stabilization

Basemat Cooling

Ex-vessel Melt Stabilization

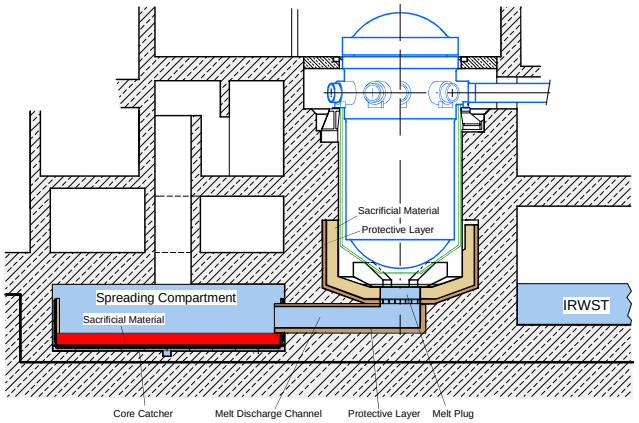
Basemat Cooling

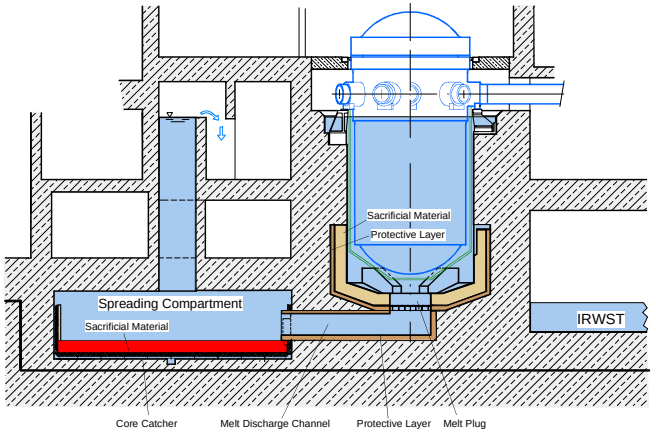
BENSON Test Results

Ex-vessel Melt Stabilization

Melt Quenching and Stabilization

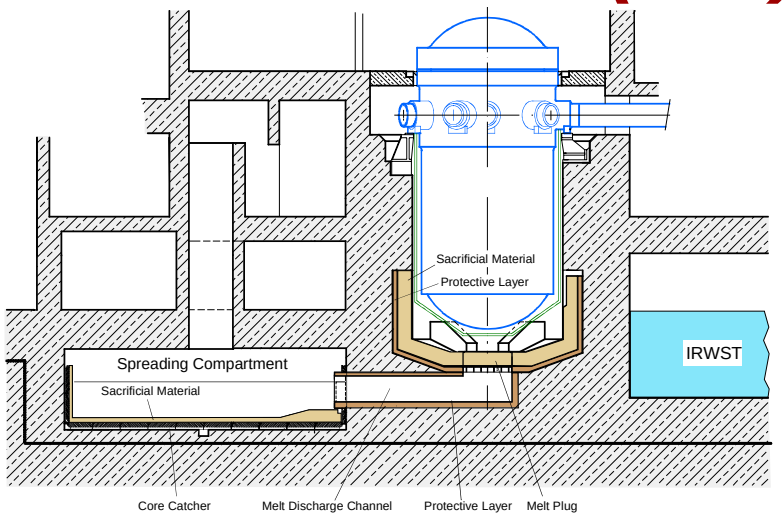
- Melt stabilization is based on cooling and crust formation
- The spreading process has prepared the melt to be cooled by increasing surface-to-volume ratio (~0.04 m^2/MWth)
- Melt stabilization is passively actuated by thermally sensitive initiators
- Water from the IRWST fills the cooling channels and overflows onto the melt
  - Decay heat removal by steaming to the containment atmosphere
- MACE (ANL) and ECOKATS (FzK) showed that flooding will lead to bulk cooling, creating an oxidic crust at the top of the melt
- Solidification of metallic melt is expected within a few hours; oxidic melt within days

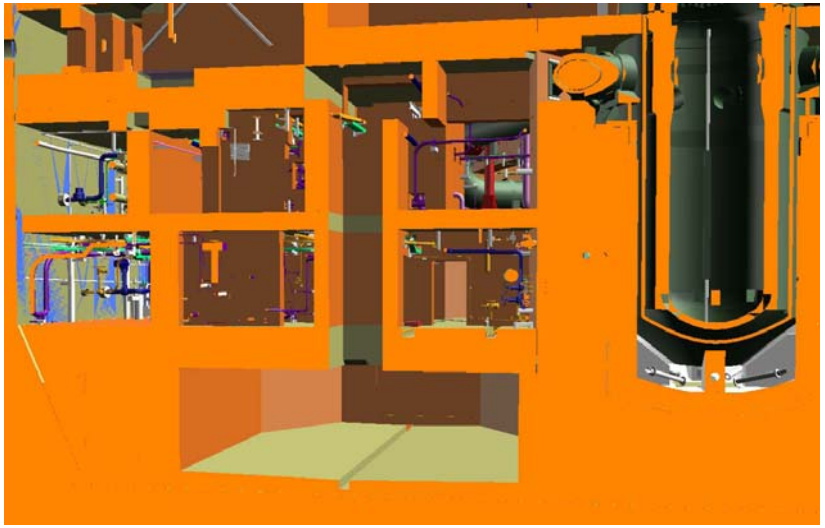




Containment Performance – Fuel Coolant Interactions (FCI)

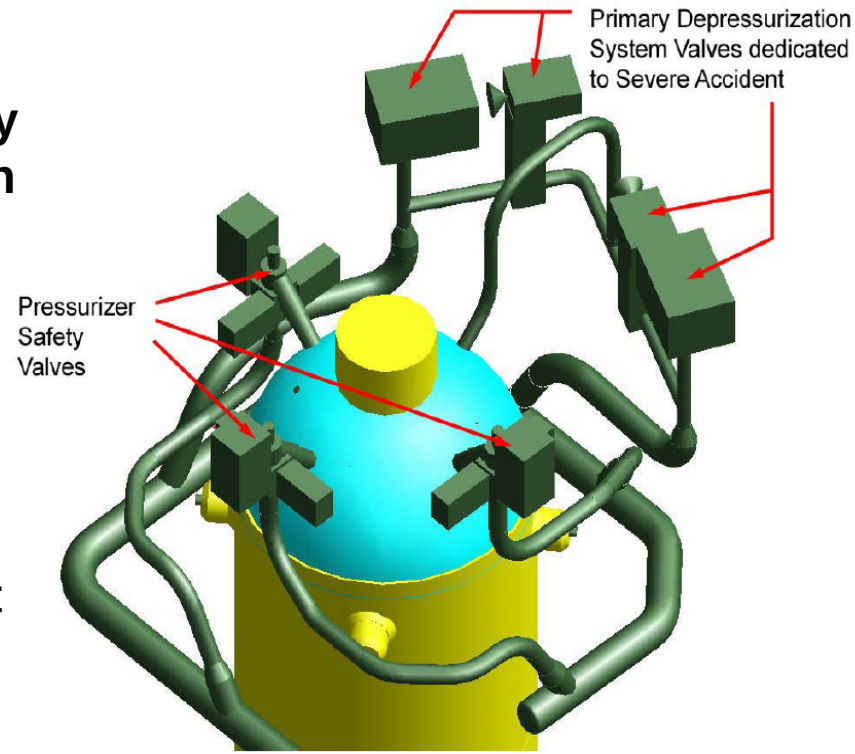
- FCI can result in an energetic steam explosion
  - Pouring contact mode
  - Stratified contact mode
- In-vessel steam explosion has a negligible risk
- Ex-vessel steam explosion is precluded by containment features that ensure a dry reactor pit and spreading area
- Melt quenching is performed at low flow rates





High Pressure Melt Ejection

- Prevent the progression of core damage under high pressure
- U.S. EPR credits the availability of 1 of 2 100% depressurization trains
  - goal is to reduce pressure to < 20 bars (~300 psia) prior breach for all events
- Reactor cavity designed with features minimizing the impact from a high pressure melt scenario

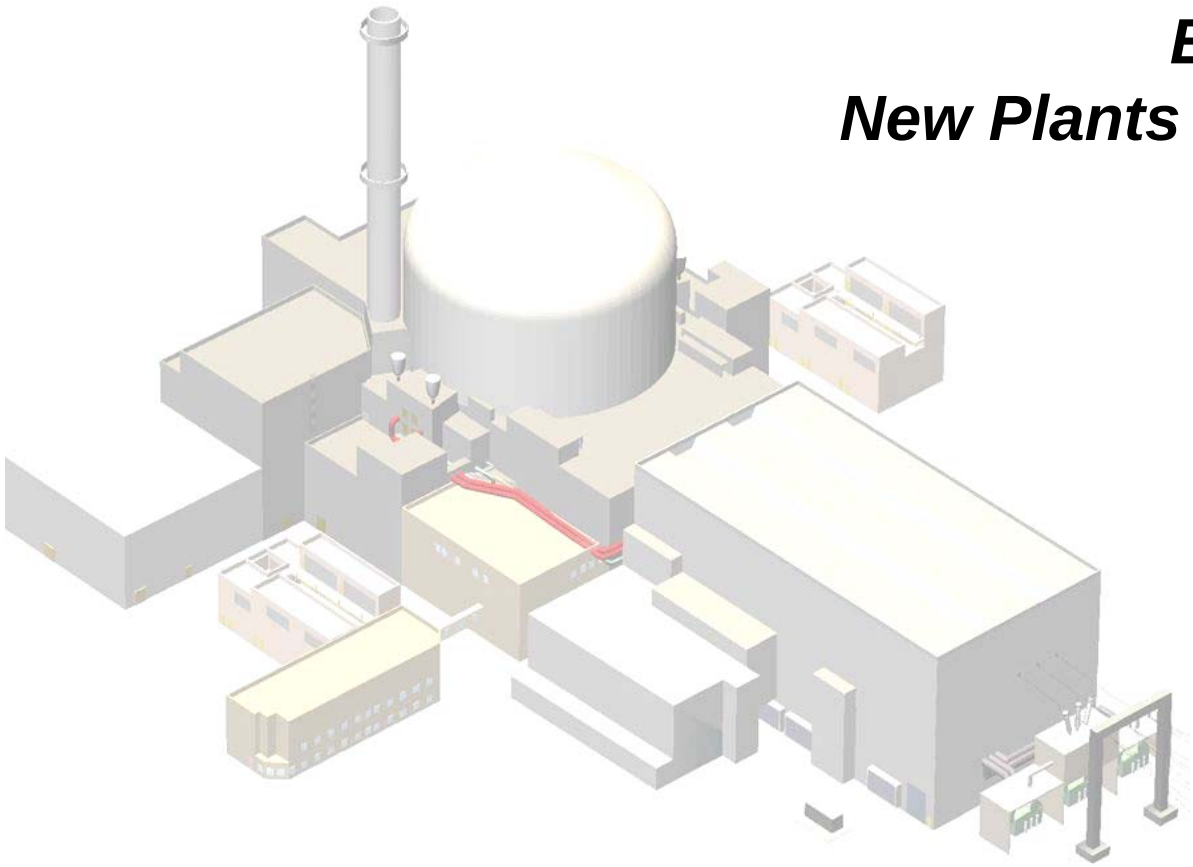


Summary

- A report is being prepared as outlined, presenting AREVA NP's approach to technical issue resolution considering
  - Expert opinion
  - Research & development – test program results
  - Assessment of risk
  - Analysis capability
- The analysis of relevant phenomena is sufficient to support accident management decision making and demonstrate consistency with regulatory expectations

Severe Accident Code Validation

Eric Williams
New Plants Engineering



Objectives

> **Description of topical report content related to MAAP4.07 development:**
- New models for the U.S. EPR in MAAP4.07
- Verification/validation strategy of new MAAP4.07 models
- U.S. EPR modelling approach
- Results of representative MAAP4.07 analyses

> **Obtain feedback from NRC on:**
- Proposed level of detail
- Scope of content
- Verification/validation strategy

Outline

- Current status of MAAP4.07 development
- Description of MAAP4.07 modifications
  - Modifications to source code
  - U.S. EPR modelling approach
- As part of MAAP4.07 discussion, the following items will be addressed:
  - Validation & verification of new models
  - Results of preliminary integral analyses

Current Status of MAAP4.07 Development

> **Fauske and Associates, Inc. (FAI) scope of work**
- All models needed to represent the U.S. EPR have been implemented and successfully tested
- Currently undergoing final FAI review process

> **AREVA NP scope of work**
- MAAP4.07 U.S. EPR parameter file development complete
- Representative scenarios (LOOP, LBLOCA, SBLOCA) are currently being analyzed
- MAAP4.07 MCCI validation studies complete
- MELCOR 1.8.6 U.S. EPR model in final preparation
- Code comparison studies between MAAP4.07 and MELCOR 1.8.6 are planned

MAAP4.07 Source Code Modifications

Core Heavy Reflector

Core Heavy Reflector

Core Heavy Reflector

B_4C Oxidation

B_4C Oxidation

Ex-vessel Thermal Radiation

Ex-vessel Thermal Radiation

Molten Core-Concrete Interaction

Molten Core-Concrete Interaction

Molten Core-Concrete Interaction

Adiabatic Isochoric Complete Combustion

Passive Autocatalytic Recombiners

Passive Autocatalytic Recombiners

MAAP4.07 U.S. EPR Models

Reactor Pit Melt Retention

Passive Melt Cooling

Active Melt Cooling

Crust Fragmentation

Miscellaneous MAAP4.07 Modifications

Preliminary Integral Analyses

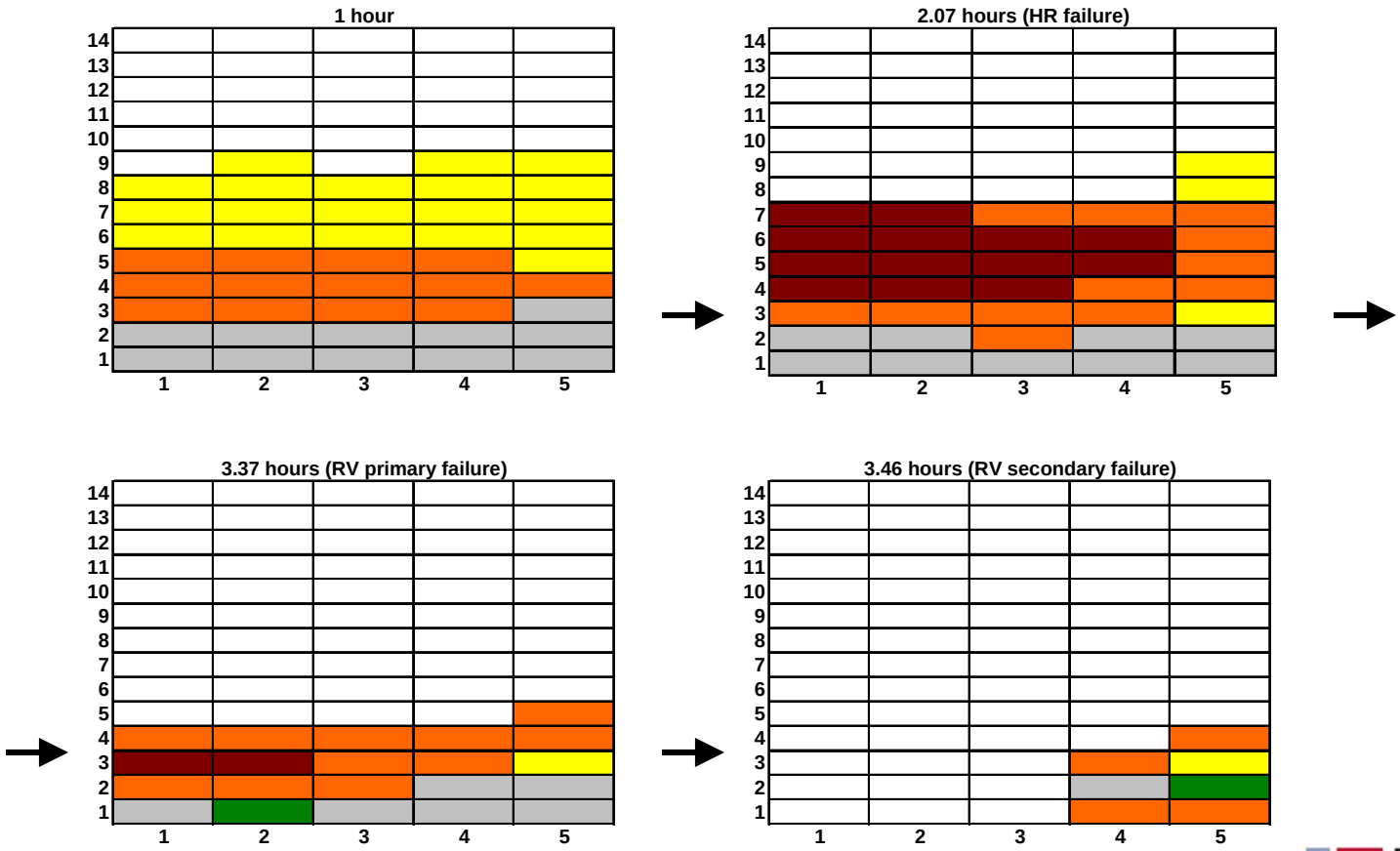
MAAP4.07 Results of LBLOCA

Event	Time
Reactor scram, MSIV closure, isolation of MFW, start AFW	5.3 seconds
Pressurizer empty	11 seconds
Reactor coolant pump trip	18 seconds
Start of core uncovery	108 seconds
Accumulator injection onset	121 seconds
Accumulator depletion	243 seconds
Core outlet temperature = 550 ºC	0.40 hours
Core outlet temperature = 600 ºC	0.42 hours
Core outlet temperature = 650 ºC	0.44 hours
Actuation of severe accident depressurization valves	0.45 hours
Onset of core oxidation	0.45 hours
Start of core melt	0.51 hours
Relocation of core material to lower head	2.07 hours
Dryout of lower plenum	2.55 hours
Local RPV failure	3.37 hours
Global RPV failure	3.46 hours
Corium relocation to spreading room	4.17 hours

PRELIMINARY RESULTS

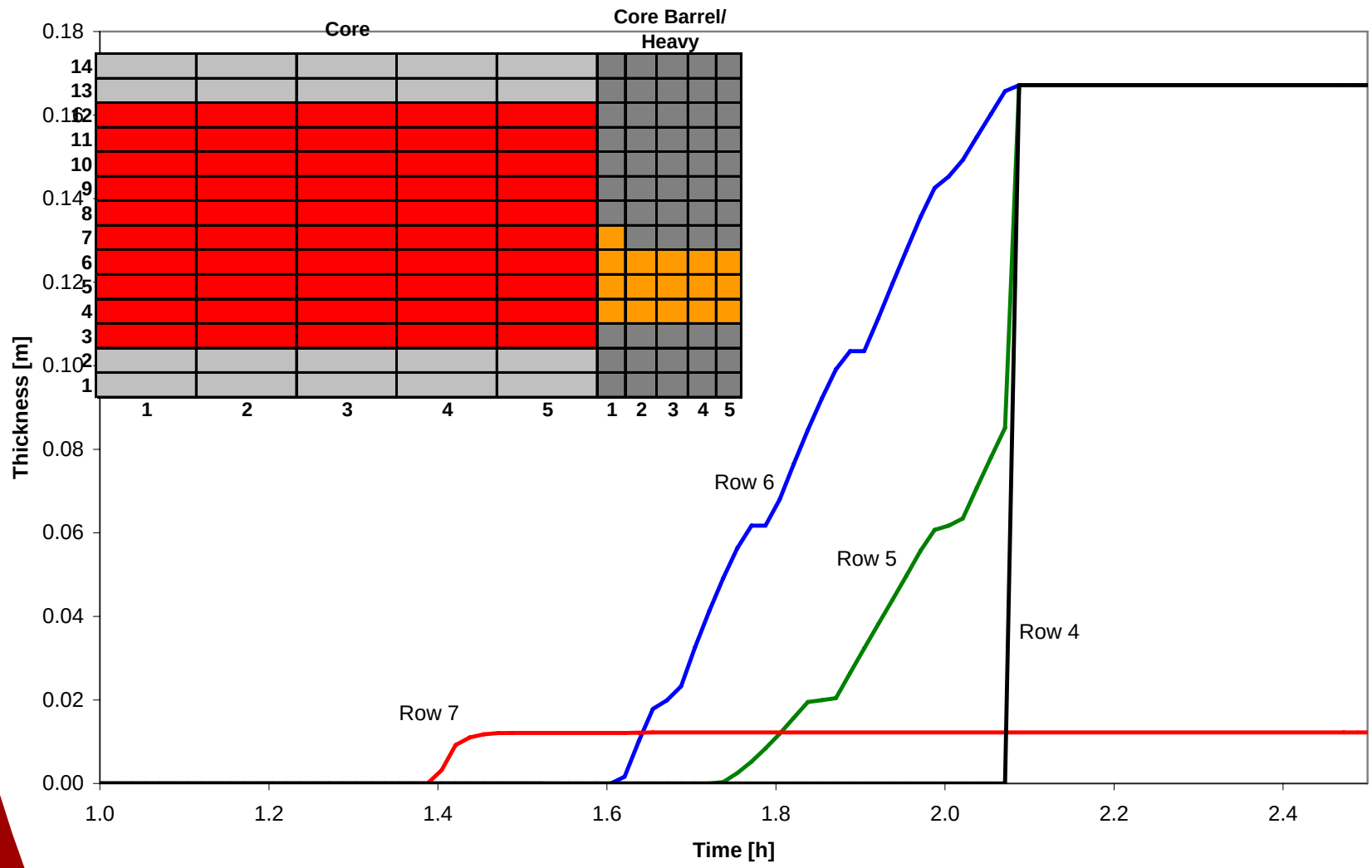
MAAP4.07 Results of LBLOCA

	Empty
	Intact fuel pin configuration
	Collapsed fuel pin configuration
	Thickened fuel pin configuration due to downward relocation
	Filled to a user-specified porosity and no longer considered a fuel pin configuration
	Fully molten



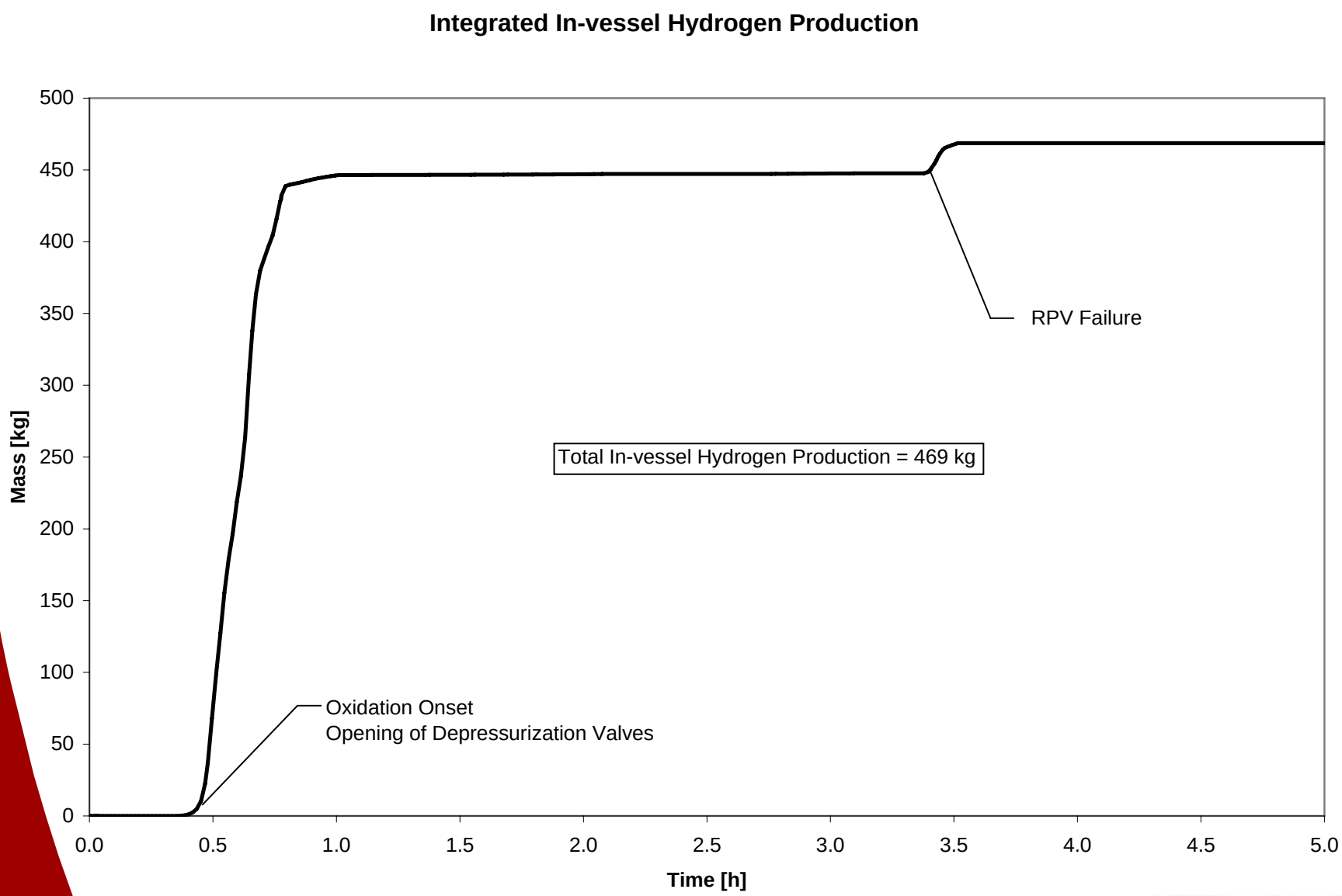
PRELIMINARY RESULTS

MAAP4.07 Results of LBLOCA



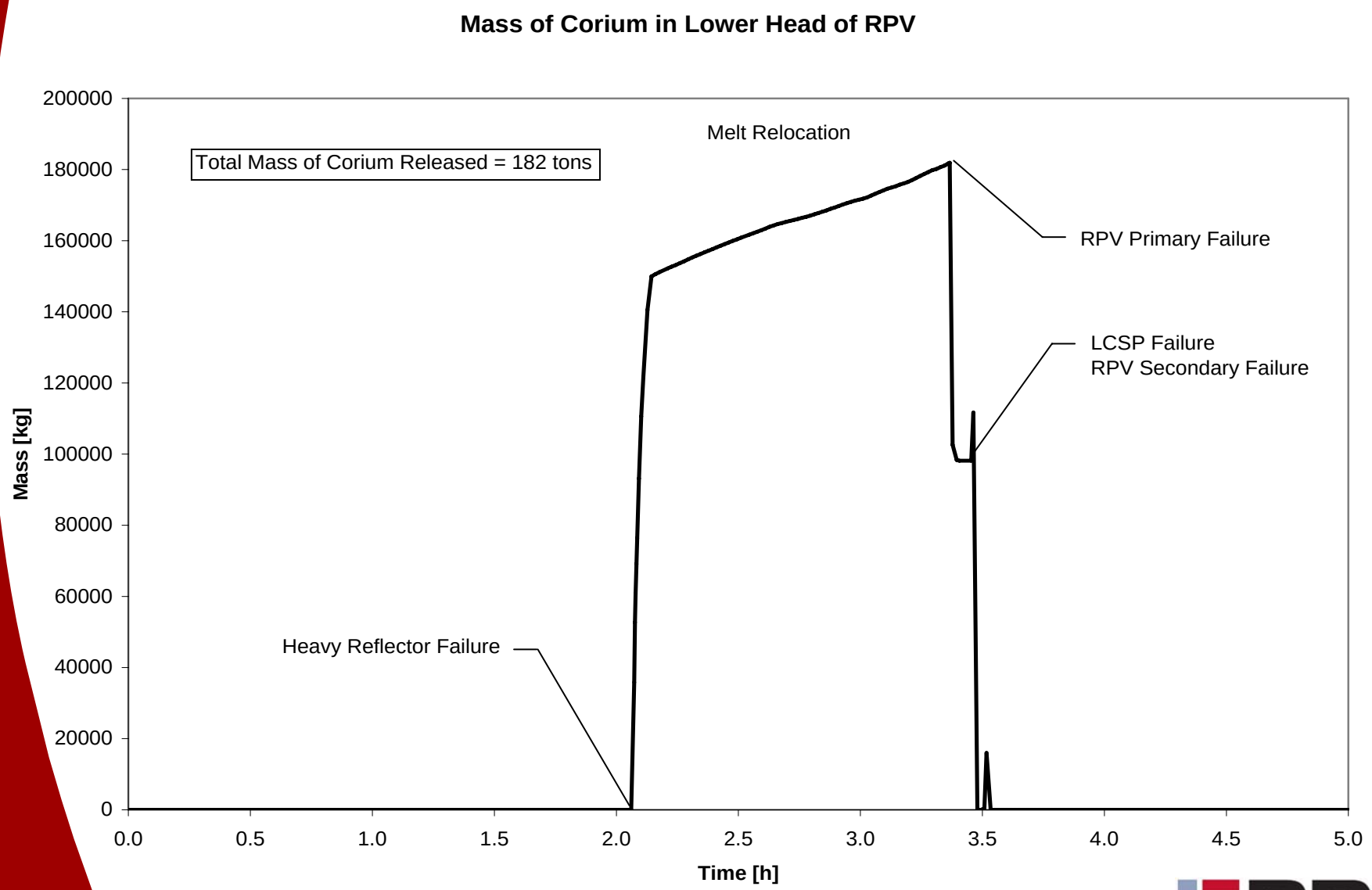
PRELIMINARY RESULTS

MAAP4.07 Results of LBLOCA



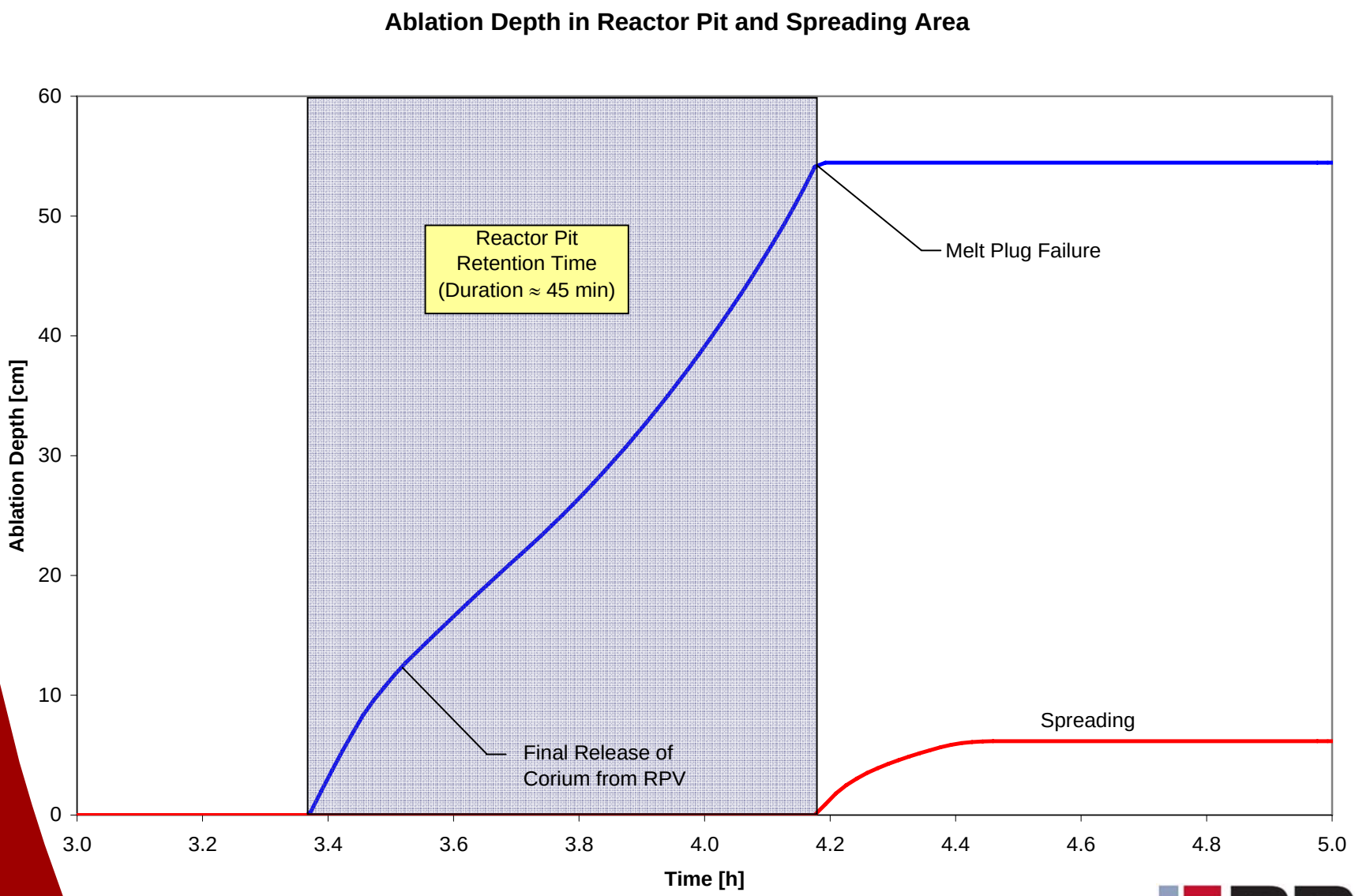
PRELIMINARY RESULTS

MAAP4.07 Results of LBLOCA



PRELIMINARY RESULTS

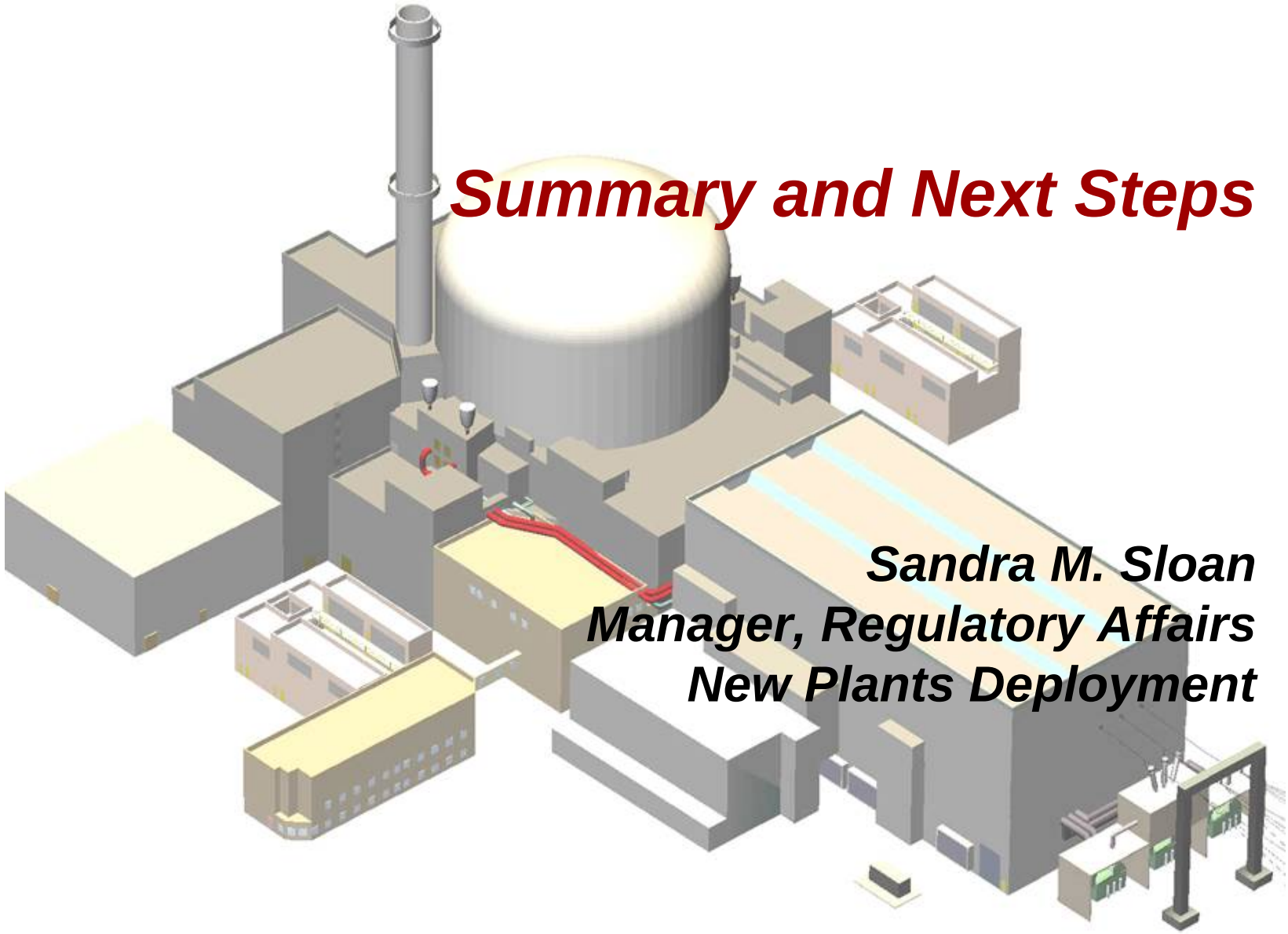
MAAP4.07 Results of LBLOCA



PRELIMINARY RESULTS

Conclusions

- MAAP4.07 has the capabilities necessary for a best estimate analysis of severe accidents in the U.S. EPR
- Newly incorporated models in MAAP4.07 have been verified and validated
- The proposed topical report content outlined relative to MAAP4.07 development will describe codes and methods used for severe accidents



Summary and Next Steps

Sandra M. Sloan
Manager, Regulatory Affairs
New Plants Deployment

Summary

- U.S. EPR includes robust severe accident mitigation features
- Technical basis for design of severe accident mitigation systems is founded on extensive testing experience, including design-specific AREVA tests
- Severe accident analytical approach with MAAP4.07 includes new U.S. EPR-specific models, and is benchmarked against MELCOR 1.8.6

Severe Accident Topical Report will provide a comprehensive technical basis, demonstrate conformance with regulatory guidance, and support development of U.S. EPR PRA

Next Steps

> **Submit Severe Accident Topical Report in October 2006**

> **Next meeting**

- **August 1, 2006, U.S. EPR Transient and Accident Analysis Code Applicability Topical Report**

Handouts

Acronyms

AFW	Auxiliary feedwater
AICC	Adiabatic isochoric complete combustion
CGCS	Combustible gas control system
CHF	Critical heat flux
CMRS	Core melt retention system
DCH	Direct containment heating
DDT	Deflagration-to-detonation transition
FCI	Fuel-coolant interaction
HPME	High-pressure melt ejection
IRWST	In-containment refueling water storage tank
ISTIR	Integrated Structure for Technical Issue Resolution
LCSP	Lower core support plate
MCCI	Molten core concrete interaction
MFW	Main feedwater
NURETH	Nuclear Reactor Thermal Hydraulics (Conference)
PAR	Passive Autocatalytic Recombiner

Acronyms

POR	Passive outflow reducer
RCS	Reactor coolant system
RPV	Reactor pressure vessel
ROAAM	Risk-Oriented Accident Analysis Methodology
SADV	Severe accident depressurization valve
SAHRS	Severe accident heat removal system
SASM	Severe Accident Scaling Methodology
TPG	Technical Program Group