Comparison of the MELCOR, MAAP4 and SCDAP/RELAP5 Severe Accident Codes for PWR Station Blackout Calculations

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Overview of Presentation

- Objectives of the Current Work
- Motivation for Code Comparison
- TMLB' (Station Blackout) Description
- Overview of the Three Codes
- Comparison of Code Input Decks
- Key Assumptions
- Comparison of Calculation Results
- Conclusions

Sponsorship by the US NRC for the work at Purdue and EPRI for the work at Creare, Inc. is gratefully acknowledged.

Objectives of the Current Work

- Compare the MELCOR, MAAP4 and SCDAP/RELAP5 codes in a consistent and unbiased manner
  - "comparison" vs. "validation"
- Produce an assessment of the relative state of modeling in each code
- Provide recommendations for code modifications to better meet severe accident modeling needs

Motivation for Code Comparison

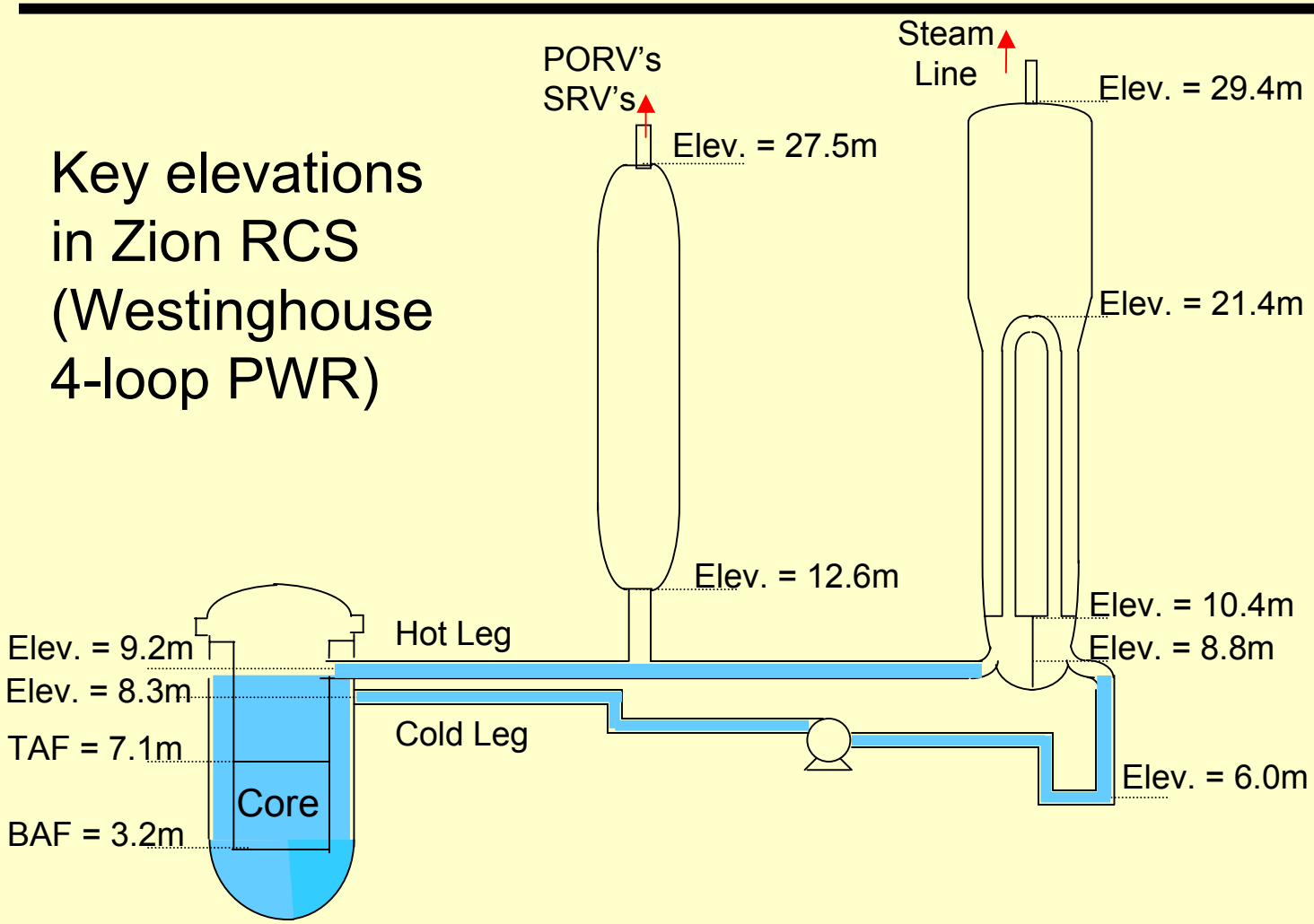
- Codes' capabilities and applications are converging
  - SCDAP/RELAP5
    - Initially a best estimate code for detailed calculations
  - MELCOR
    - Originally a PRA tool with many simple, empirical models and sensitivity coefficients
    - Incorporation of numerous physics-based models and improved numerical schemes
      - Increased detail in modeling and spatial nodalizations
  - MAAP4
    - Initially a severe accident code with simplified TH models
    - Often simpler SA models based on first principles

Motivation for Code Comparison (cont.)

- Severe accident modeling efforts will be more efficient if efforts are concentrated into a single code
  - SCDAP/RELAP5 and MELCOR are both supported by the US NRC and used by regulatory and research agencies
  - MAAP4 is the most-widely used code and is used by US utilities and vendors
- The regulatory agencies have an inherent interest in understanding codes used by the industry
- Utilities would like MAAP4 results to be accepted by the NRC (for SDP, etc.)
- Less information is publicly available about the MAAP4 code although its good performance record should be explained.

TMLB' (Station Blackout) Description

Key elevations in Zion RCS (Westinghouse 4-loop PWR)



TMLB' (Station Blackout) Description (cont.)

- Loss of AC power and feedwater to steam generator secondary side without any recovery
- Coast down of pumps, motors, etc.
- Net steam production and increase of primary-side pressure
- Water boiloff on SG secondary side
  → loss of heat sink
- Stuck-open SG PORV and rapid depressurization
- Release of primary coolant through pressurizer PORV
- Voiding in RCS and core heatup
- Potential for natural circulation core cooling by steam

TMLB' (Station Blackout) Description (cont.)

- Threat of heat up of structural components and failure of pressure boundary (e.g. hot leg nozzles, surge line, steam generator tubes)
- Continued core heat up, with potential for fuel failure
- Following any pressure boundary failure, radioactive materials may be released to the containment or environment
- Possibility of molten material relocation to vessel lower plenum and damage to lower head
- Upon failure of vessel head, release of molten fuel to the cavity

Overview of the Three Codes

- Code versions
  - MELCOR
    - base code version 1.8.5(A), Sept. 25, 2000
    - transmittal by MELCOR development team
  - MAAP4
    - MAAP4.05 run at Creare, Inc.
    - insurmountable code availability issues for Purdue
  - SCDAP/RELAP5
    - MOD3.3 transmittal by ISL for the US NRC, June 2001

Overview of the Three Codes (cont.)

- MELCOR Highlights
  - Great modeling flexibility afforded by control volume approach and control functions
  - Integral analysis of reactor systems out to the source term is possible
  - Sensitivity coefficients
    - Provide user ability to change modeling parameters and perform sensitivity studies on models
    - User expertise required to determine appropriate values of sensitivity coefficients

Overview of the Three Codes (cont.)

- MAAP4 Highlights
  - Extremely short run time produces real time results and promotes parametric studies
    - Run time is two or three orders of magnitude shorter than that of the other codes
  - Input file simpler to generate than for the other codes
    - "Generalized models" are employed for BWR and PWR nodalizations
  - Integral analysis of reactor systems out to the source term is possible
  - Standard version of MAAP4 limited to conventional reactors
    - Code versions have been created to model other NSSS's, including various ALWRs, CANDU and VVER designs

Overview of the Three Codes (cont.)

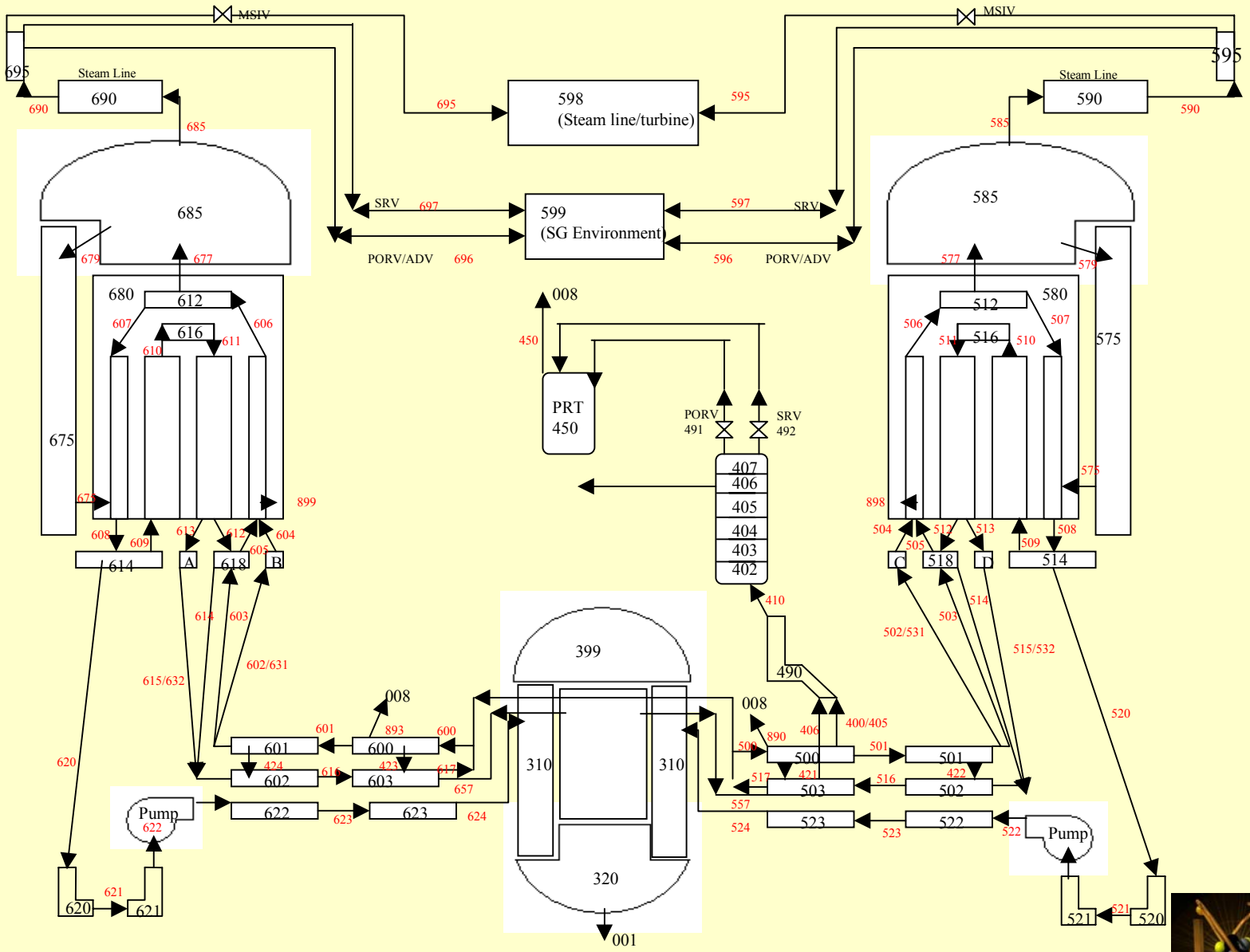
- SCDAP/RELAP5 Mod 3.3 Highlights
  - Mechanistic models for thermal hydraulic and severe accident phenomena have been extensively verified and documented
  - Robust thermal hydraulic modeling via the RELAP5 code
  - Few modeling parameters are determined via user input
    - Less reliance on user expertise
  - Detailed lower head model by finite element COUPLE code
  - Calculations not possible beyond the time of primary side pressure boundary failure
    - Fission product behavior evaluated by VICTORIA code
    - Containment behavior evaluated by CONTAIN code

Overview of the Three Codes (cont.)

- Integration of Thermal Hydraulics and Severe Accident Models
  - MELCOR and SCDAP/RELAP5 model core as “structures” within the thermal hydraulic nodalization
  - MELCOR and SCDAP/RELAP5 pass information between stand-alone thermal hydraulic and core solvers
  - MAAP4 includes the coolant in a core “node” along with core materials

Overview of the Three Codes (cont.)

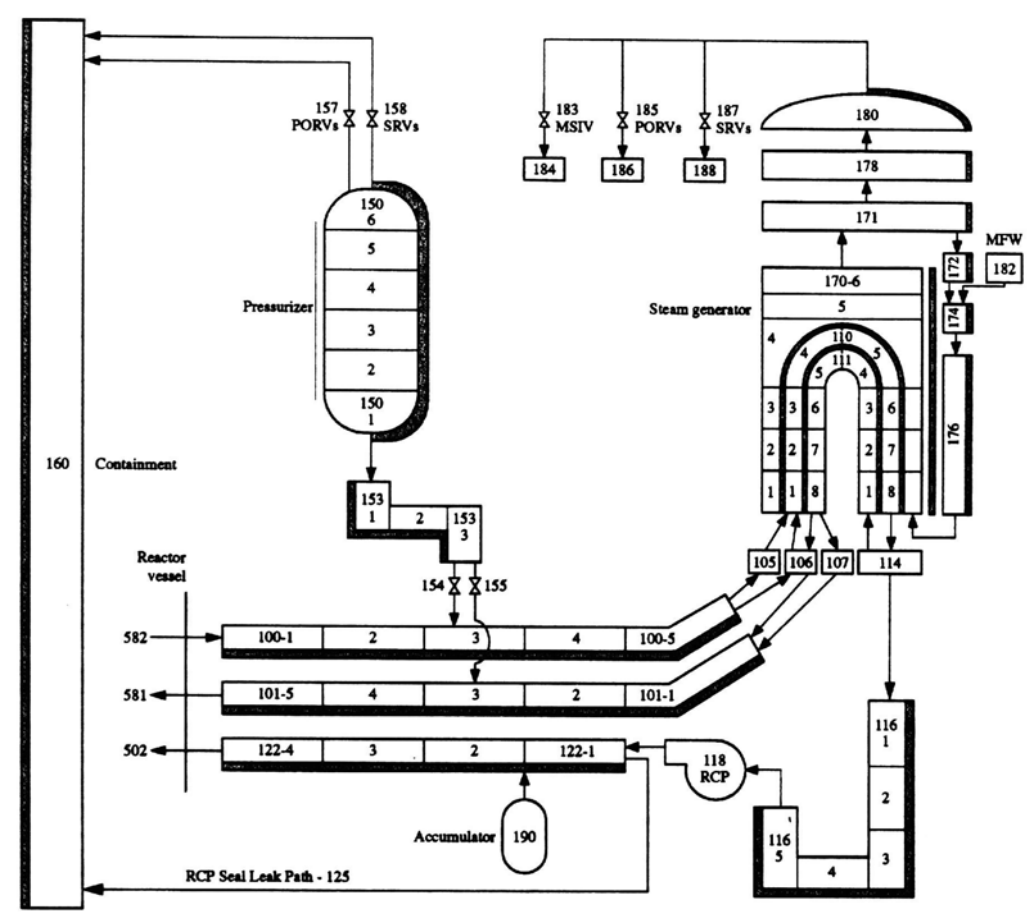
- Core Degradation
  - SCDAP/RELAP5 has the most detailed modeling for material interactions and relocation
    - SCDAP/RELAP5 components: porous debris, nonporous debris, molten or frozen ceramic pool
    - MELCOR components: particulate debris, particulate debris in the BWR bypass
    - MAAP4: lumped component of fuel, clad, control rod/blade, fuel all at the same temperature, water
  - MELCOR does not treat the liquified core in detail
    - Any liquified material not associated with a pool relocates to a lower cell and resolidifies within the current timestep
  - SCDAP/RELAP5 appears developed for a TMI-2 type relocation, while MELCOR and MAAP4 are not restricted to any specific relocation mode



MELCOR Nodalization of Zion RCS

Laboratory for Nuclear Heat Transfer Systems, Purdue University

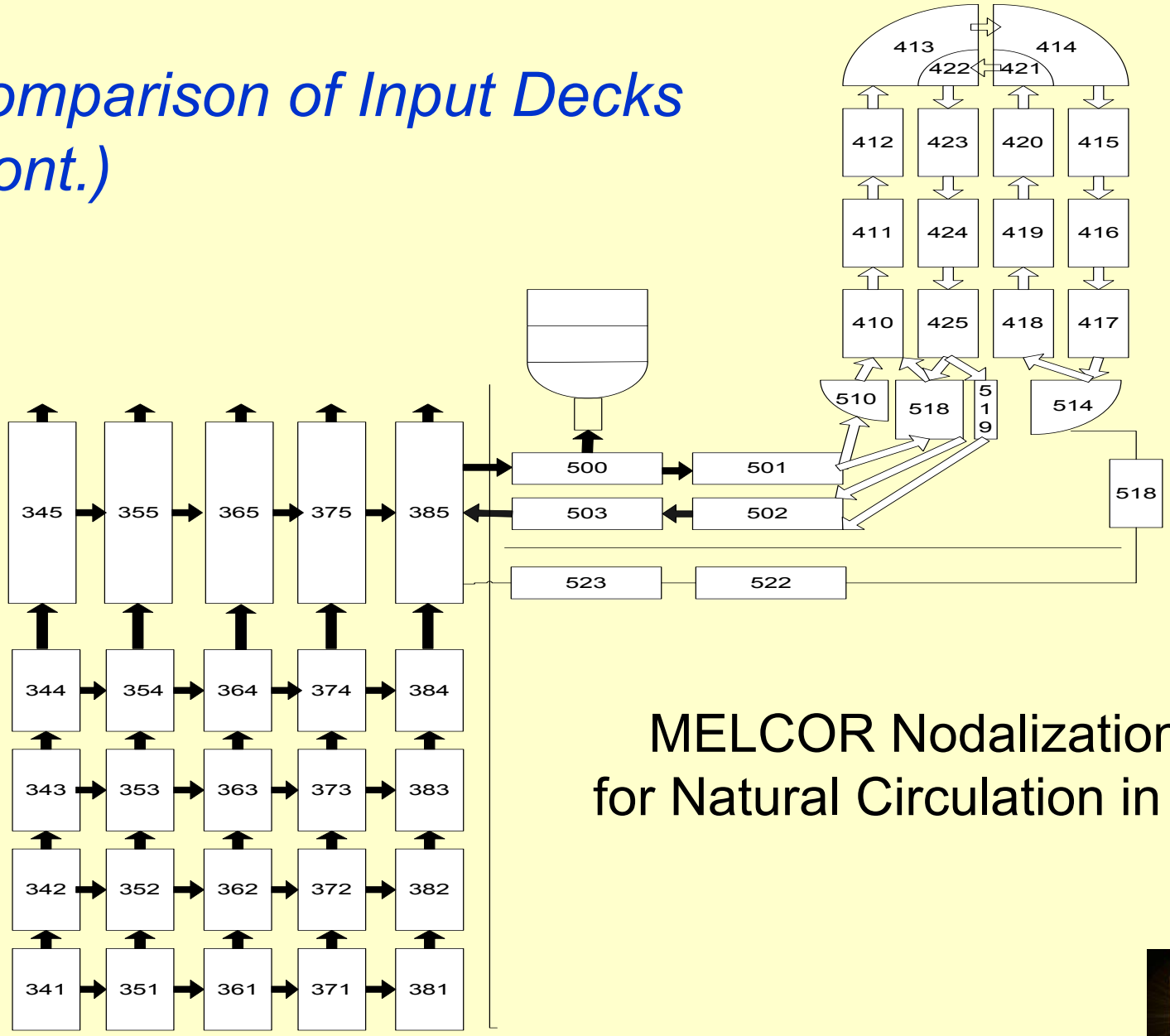
Comparison of Input Decks (cont.)



Ref: L. Ward, US NRC

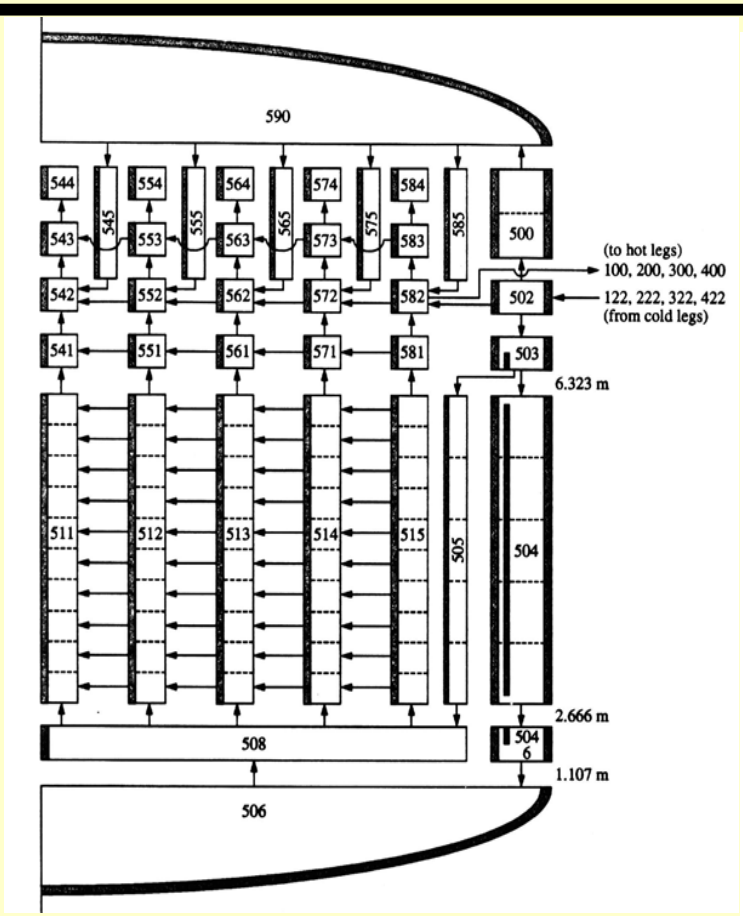
SCDAP/RELAP5 Nodalization of Zion RCS

Comparison of Input Decks (cont.)

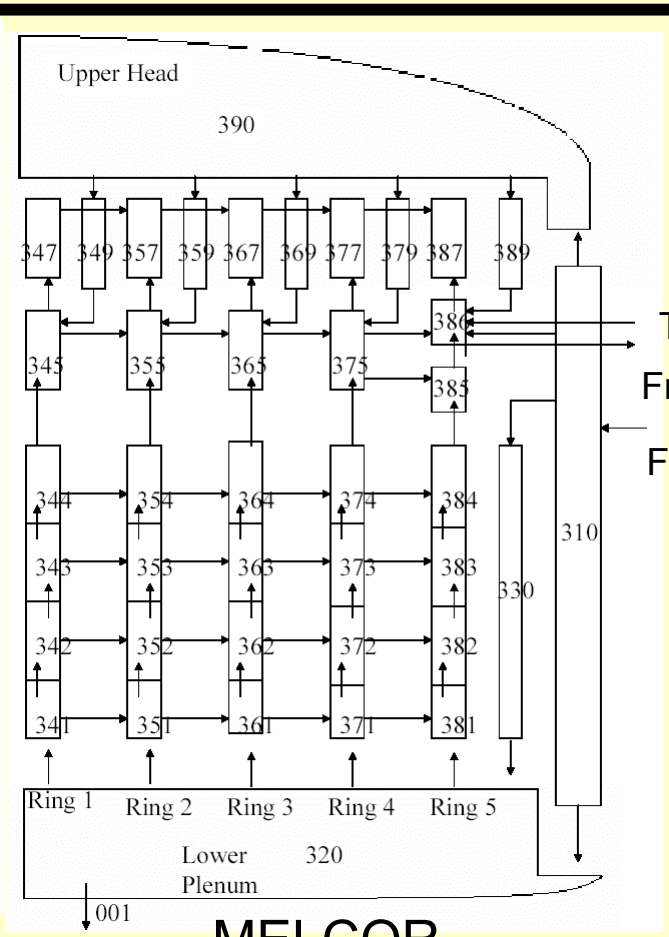


MELCOR Nodalization
for Natural Circulation in SG

Comparison of Input Decks (cont.)



SCDAP/RELAP5



MELCOR

Ref: L. Ward, US NRC

Vessel Nodalization

Comparison of Input Decks (cont.)

- SCDAP/RELAP5 input
  - Based on plant data
  - Taken as reference input deck
  - Models all 4 loops separately
    - The 3 loops without a pressurizer showed nearly identical behavior, so they are grouped together in the other codes' input
- MAAP4 input
  - Modified at Creare, Inc. to have consistent volumes, flow areas and initial conditions with SCDAP/RELAP5 input
  - Set points on the SRV's and PORV's, boundary conditions, etc. matched to those of the SCDAP/RELAP5 analysis

Comparison of Input Decks (cont.)

- MELCOR input
  - Modified at Purdue to be more consistent with SCDAP/RELAP5 input
  - Core renodalized as 5-ring, 12-axial levels
  - Pressurizer nodalization increased from 1 to 6 control volumes
  - Steam generator-related input
    - Steam generator tubes on the unique loop and grouped 3 loops were nodalized similar to the SCDAP/RELAP5 tubes
    - Steam generator inlet plenum geometries were made similar to those of SCDAP/RELAP5
  - Set points on the SRV's and PORV's, boundary conditions, etc., were matched to those of the SCDAP/RELAP5 analysis
  - Piping was renodalized

Key Assumptions

- Conservative assumptions were made in the SCDAP/RELAP5 analysis to place the most challenging conditions on the SG tubes
  - PORV on secondary side steam line of unique-loop SG fails open upon first opening
  - Pressurizer PORV functions when AC power is not available, assuming that battery power is available
  - Depressurization of primary system following any tubing or piping failure is not allowed
  - RCP seals do not leak

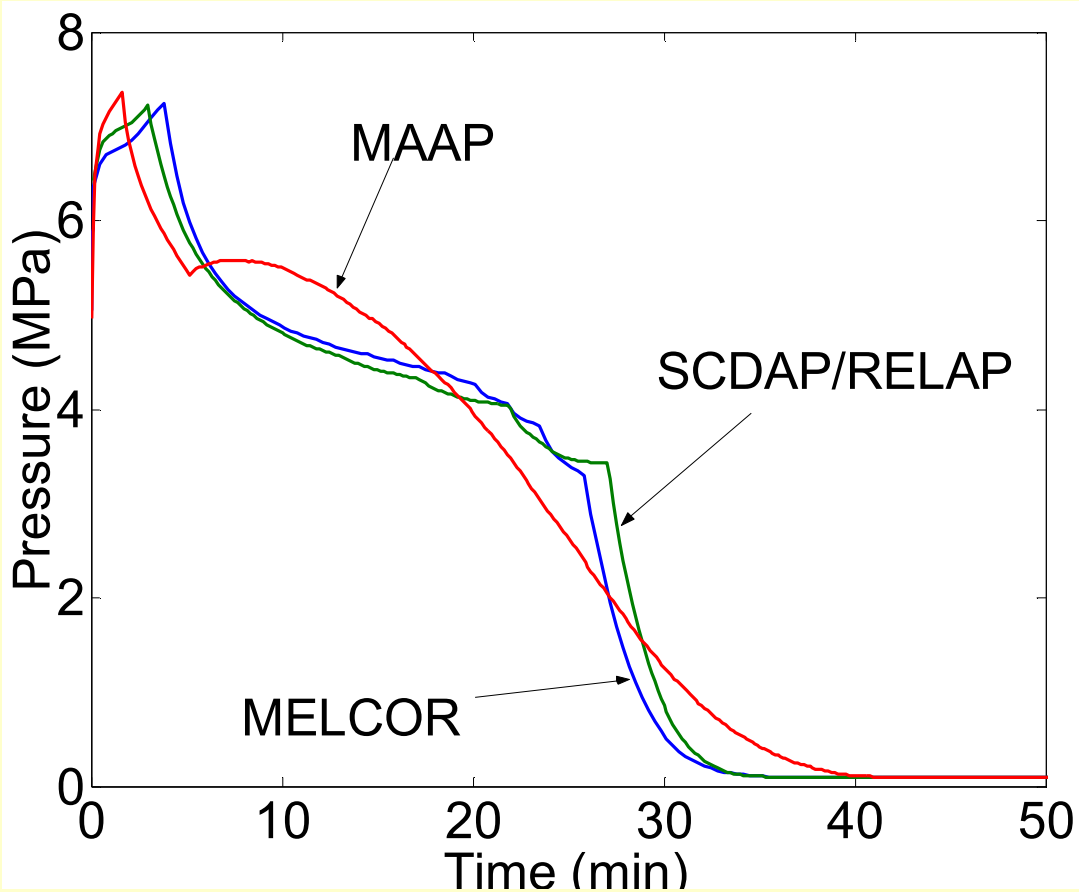
Key Assumptions (cont.)

- Additional assumptions were made to reconcile large difference in calculation results that arise due to known modeling differences
  - Steam generator and hot leg natural circulation flow rates were set in MELCOR and MAAP4 to approximately match those in SCDAP/RELAP5
  - The recirculation ratio (ratio of flow rate into steam generator tubes)/(flow rate from hot leg to steam generator inlet) was set to be about 2
    - based on data from the 1/7th scale PWR testing (Boyd, 2004)
  - Initial core-to-upper plenum natural circulation flow rates were set in MAAP4 to approximately match those in SCDAP/RELAP5 and MELCOR

Key Assumptions (cont.)

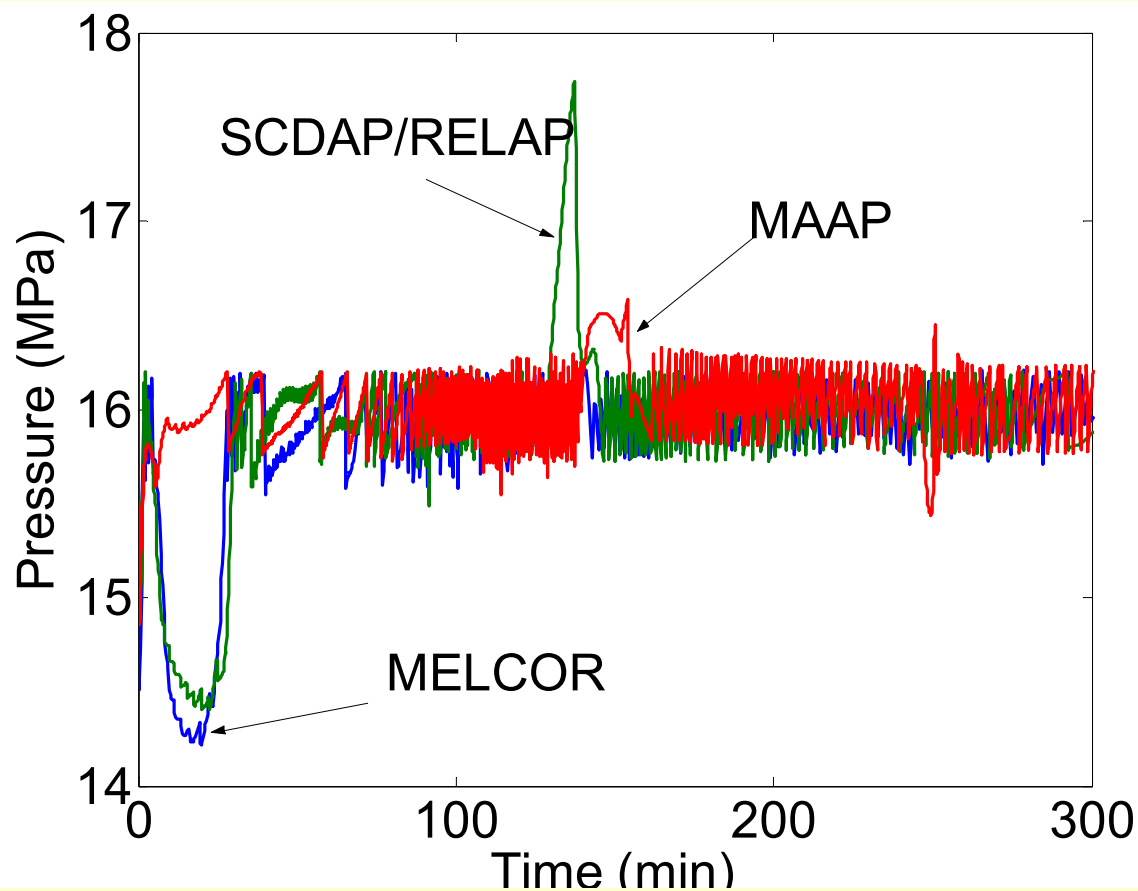
- Some models typically used in MAAP4 analysis were disabled for code consistency
  - Gas/wall radiation heat transfer model
    - Not available in current version of SCDAP/RELAP5
    - Significant delay in the calculated time of hot leg rupture in MAAP4.
  - Hot leg to containment heat transfer model.
    - Only minor impact on hot leg rupture time.

Comparison of Calculation Results



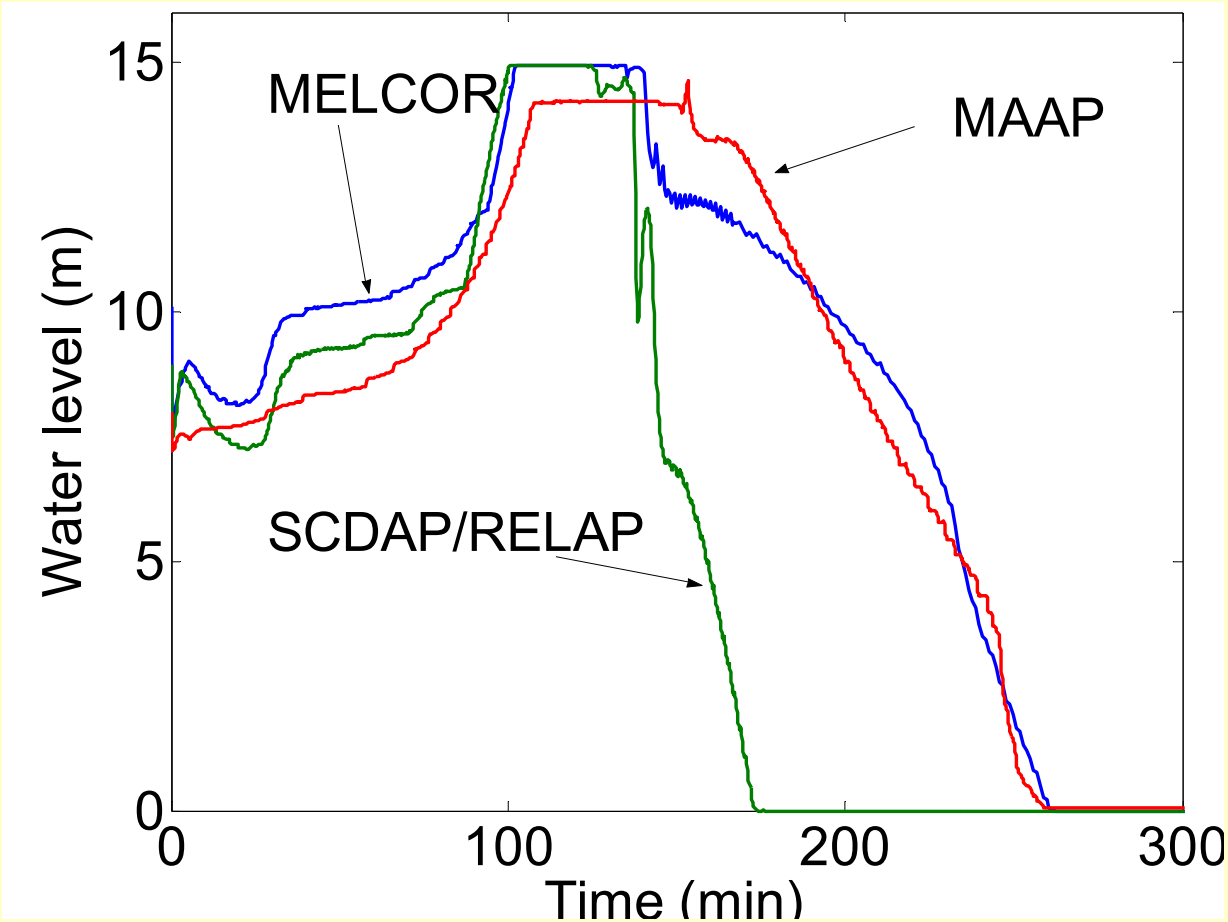
SG Secondary Side Pressure in Faulted Loop

Comparison of Calculation Results (cont.)



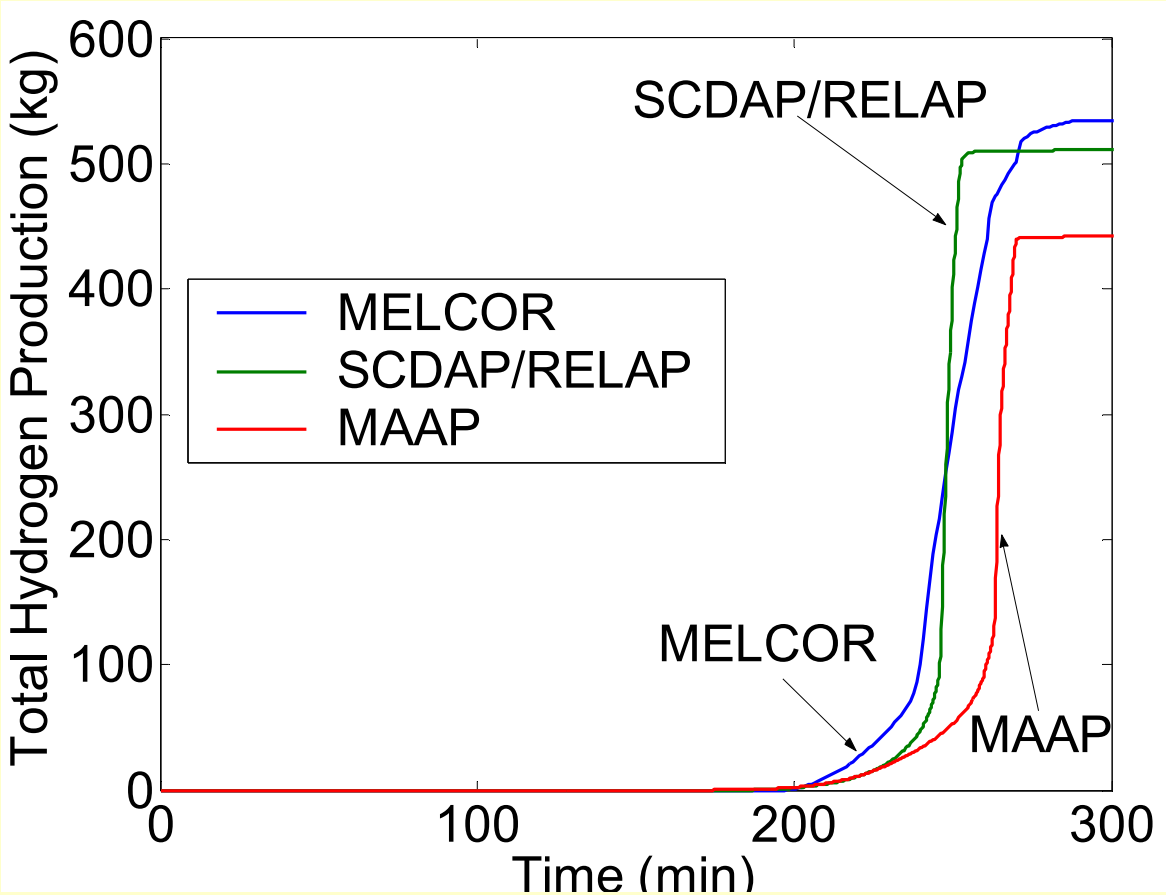
Pressurizer Pressure

Comparison of Calculation Results (cont.)



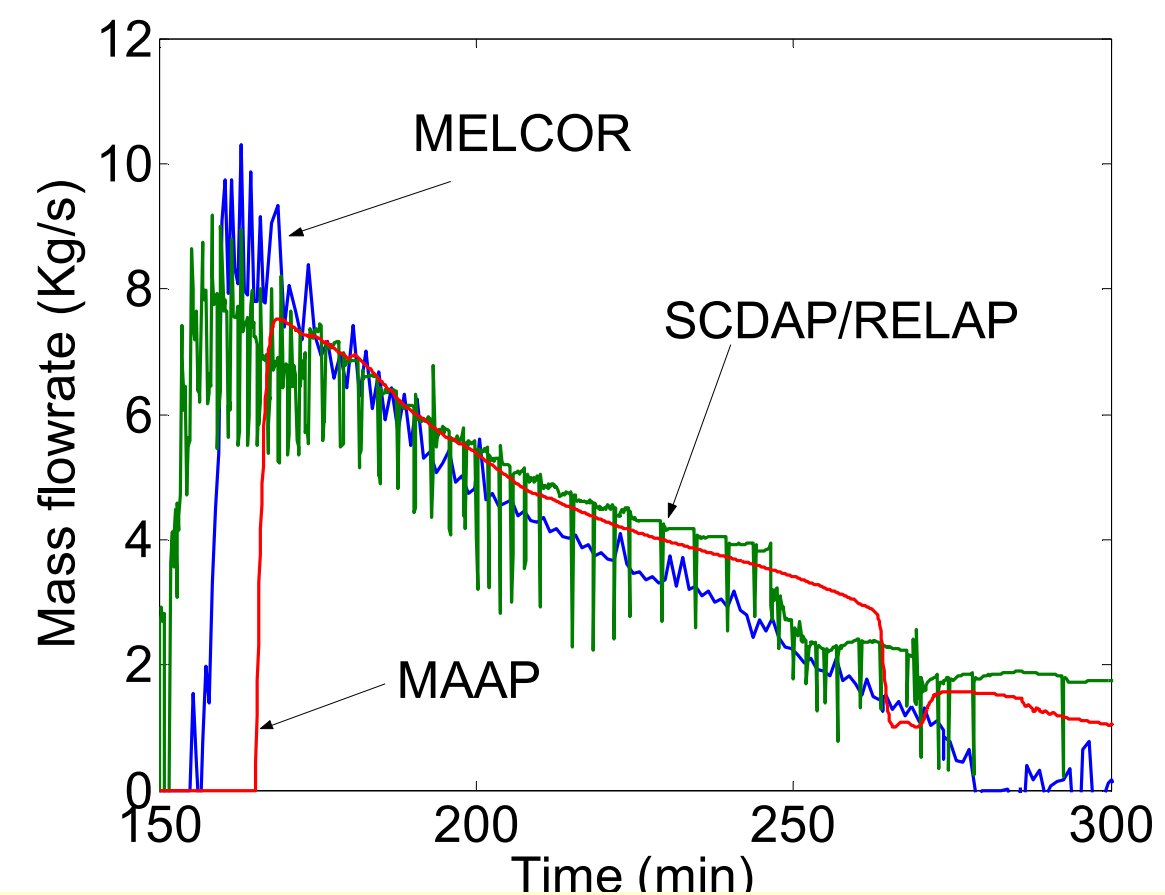
Collapsed Water Level in Pressurizer

Comparison of Calculation Results (cont.)



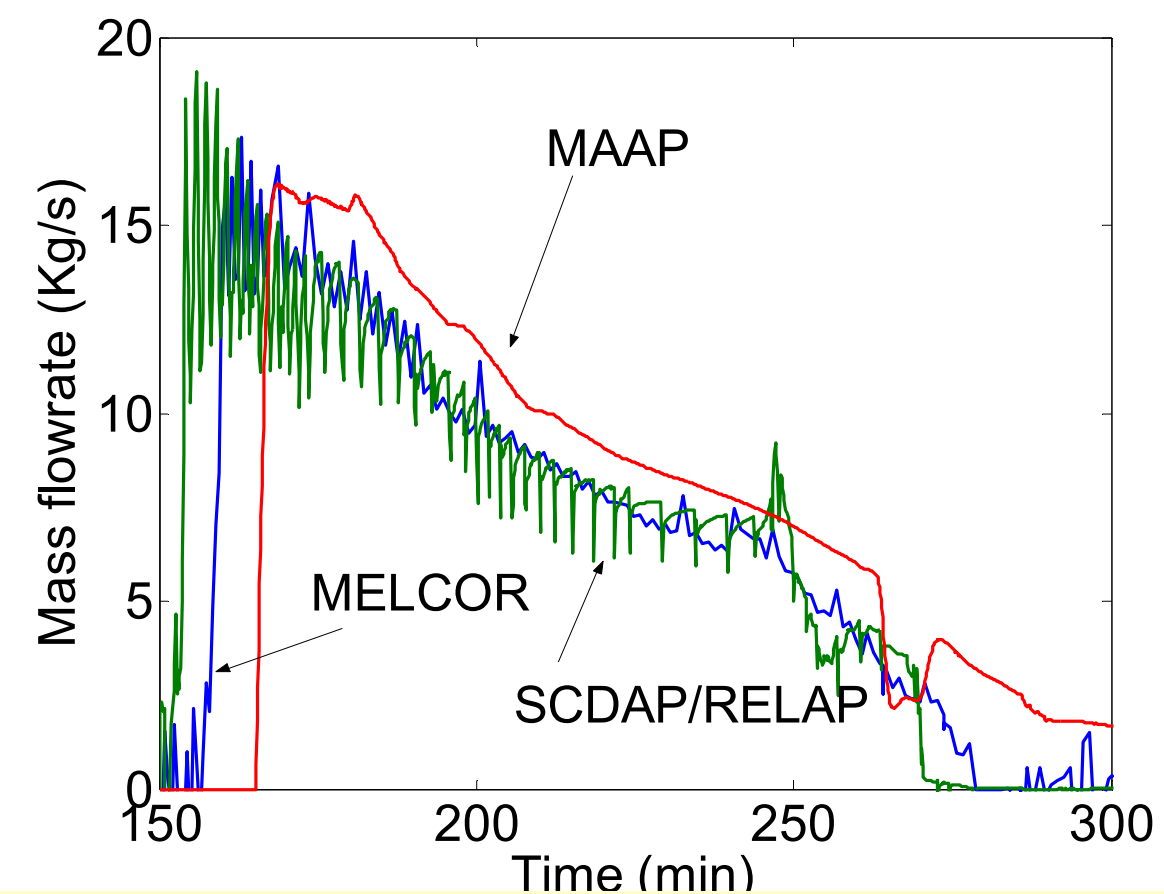
Hydrogen Generation

Comparison of Calculation Results (cont.)



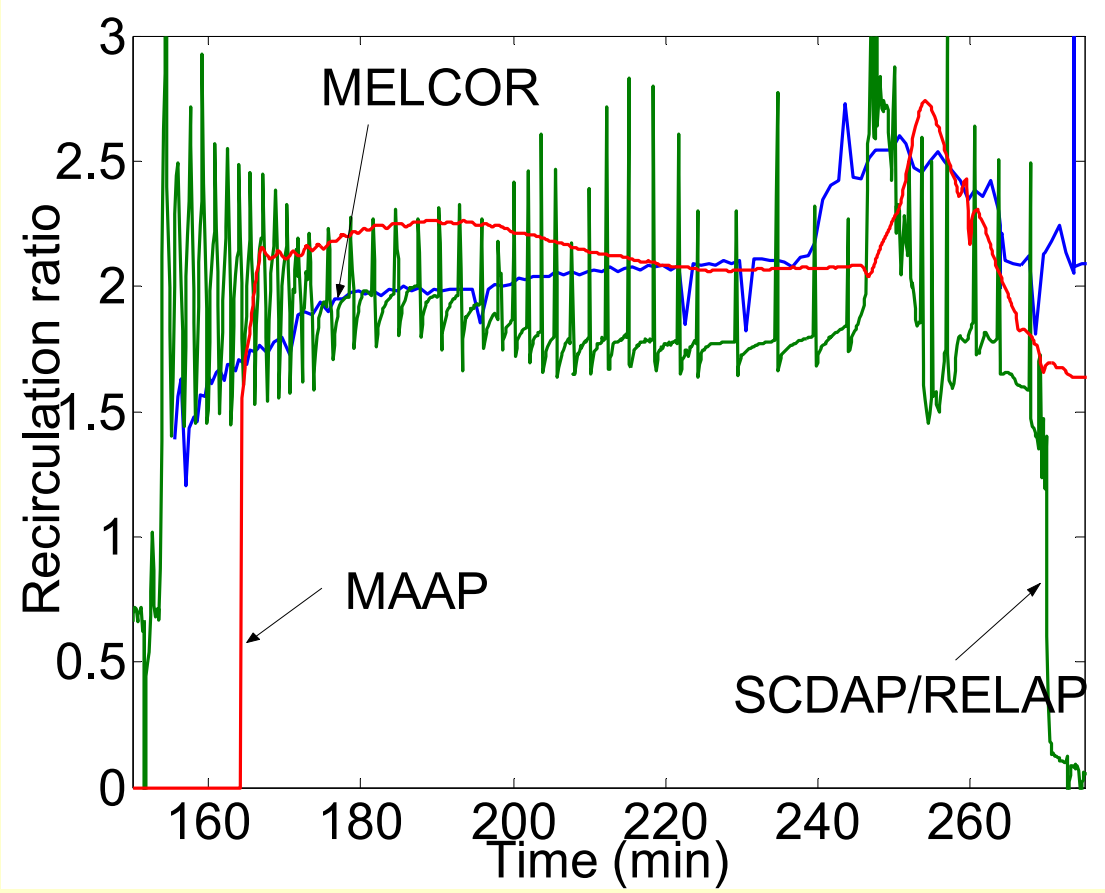
Hot Leg Flow Rate

Comparison of Calculation Results (cont.)



Flow Rate into SG Tubes

Comparison of Calculation Results (cont.)

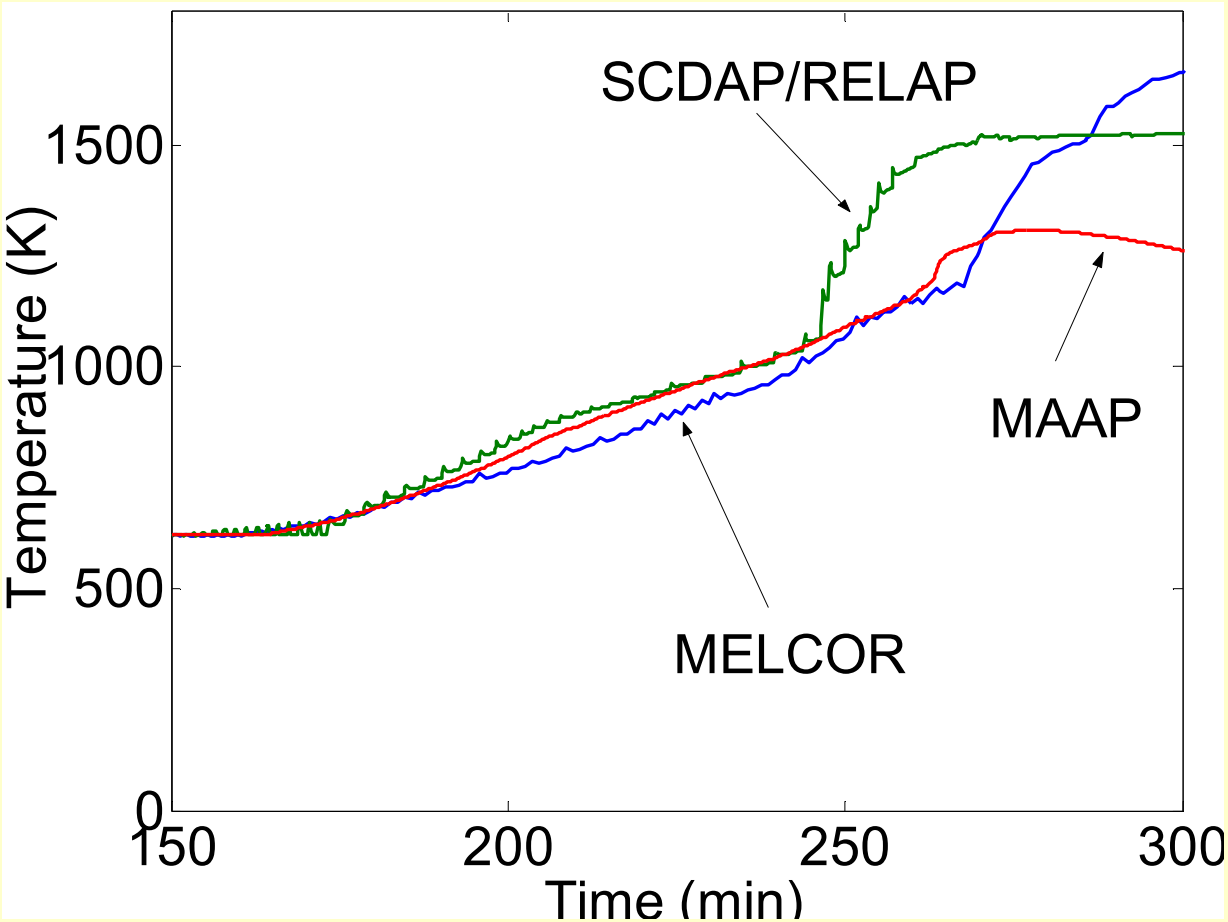


Recirculation Ratio

Comparison of Calculation Results (cont.)

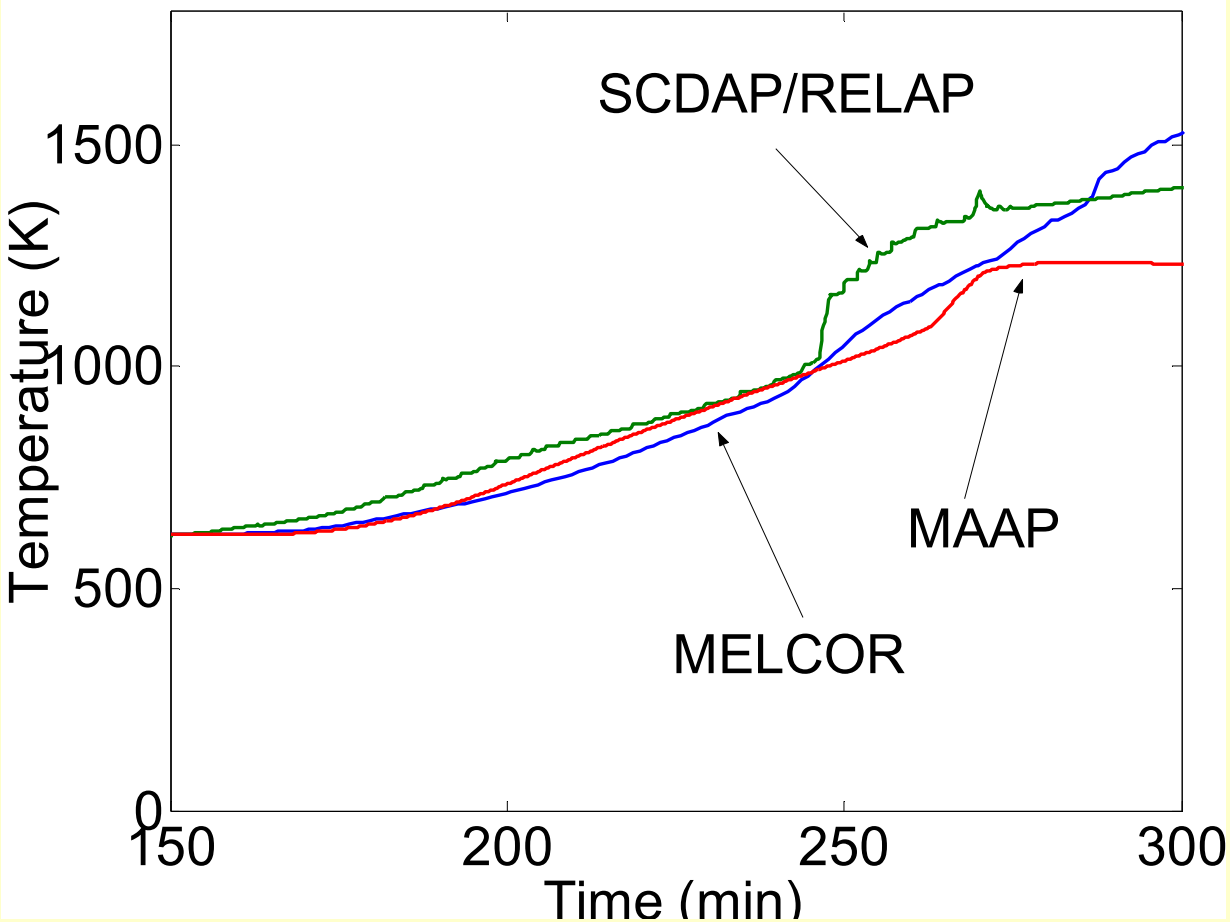
Event	MELCOR (sec.)	SCDAP/ RELAP5 (sec.)	MAAP4 (sec.)
Onset of natural circulation	9300	9000	9720
Failure of surge line	16287	14955	14860
Failure of hot leg with PRZ	16464	15720	15267
Failure of SG tubes	16553	15210	14913

Comparison of Calculation Results (cont.)



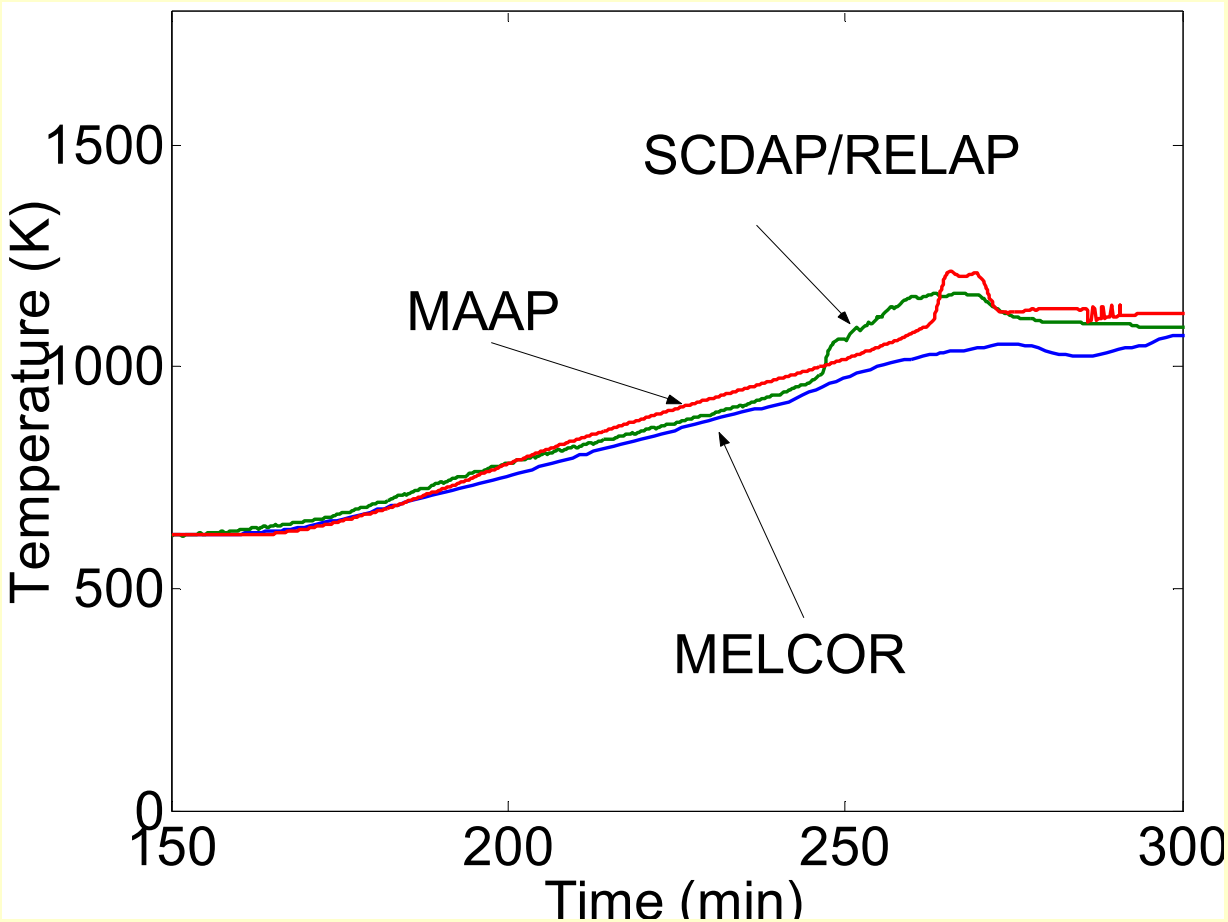
Surge Line Heat Structure Temperature

Comparison of Calculation Results (cont.)



Hot Leg Heat Structure Temperature

Comparison of Calculation Results (cont.)



Steam Generator Tube Temperature

Comparison of Calculation Results (cont.)

Event	MELCOR (sec.)	SCDAP/ RELAP5 (sec.)	MAAP4 (sec.)
Start of core uncovery	7680	7160	9615
Core completely voided	11620	9950	14500
5% cladding oxidized	13780	14806	13800
Slumping to lower head	16189	16130	21944

Conclusions

- MELCOR, MAAP4 and SCDAP/RELAP5 calculations of a Zion TMLB' station blackout were compared
- The codes provide very similar results for most phenomena if several key known modeling differences are accounted for
- Accident progression differs from about 15,000 sec, due to differences in core degradation progression
- The code comparison and code validation are continuing at Purdue for:
  - Investigating additional details of core degradation and FP behavior
  - Evaluating significance of known modeling differences
  - Comparison and validation against TMI-2 plant data
  - Comparison of MELCOR and MAAP4

Journal Publication

- The contents of this presentation have been accepted for publication in Nuclear Engineering & Design.
  - Authors are the same as for this presentation
  - Volume number is not yet known