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Use of Modular Accident Analysis Program (MAAP) in Support of Post-Fukushima Applications

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Objective

- EPRI Report (3002001785) developed to address:
  - The quality assurance process under which MAAP analyses are expected to be performed
  - The capability of MAAP to support analyses such as those needed to support response to Order EA-12-049

MAAP code has been found to be acceptable for use in support of the industry response to Order EA-12-049. This judgment is based on extensive benchmarking, which is documented in the MAAP4 Applications Guidance document

Background

- Initial development of MAAP began in 1980s
  - Primary tool used for Individual Plant Examinations as required by Generic Letter 88-20
- Continued maintenance and development by EPRI
- With increasing demands for analysis of beyond design basis events, MAAP applications greatly increased over past 30 years
  - PRA support (e.g. success criteria, HRA, source term)
  - License Renewal Severe Accident Mitigation Alternatives
  - Extended Power Uprates
  - Significance Determination Process
  - Post-Fukushima activities
    - EA-12-049
    - EA-13-109
    - Filtering Strategy Rulemaking
    - Severe Accident Management Guidelines (NTTF Recommendation 8)
    - Stress Tests

MAAP4 Applications Guidance (EPRI report 1020236 – July 2010)

1. Overview
2. Introduction to MAAP4
3. Ensure Quality of MAAP4 Analyses
4. Uncertainty and Sensitivity Analysis
5. BWR Applications Guidance
6. PWR Applications Guidance
7. MAAP Benchmarks
8. Range of Applicability, Limitations, Precautions, and Issues for Future Consideration
9. References

Appendices

- A. Units and User-Defined Calculations
- B. BWR Systems and Events
- C. PWR Systems and Events
- D. Sample MAAP4 Analyst Certification Guide
- E. ASME Requirements for PRA Applicable to MAAP4
- F. Summaries of MAAP Benchmarks

Quality of Analysis

- MAAP code is developed and maintained in accordance with the EPRI Quality Assurance Program that fulfills the requirements of 10 CFR 50 Appendix B. MAAP is subject to 10 CFR Part 21
- Application Guidance document addresses:
  - Verification of Code Installation
  - Testing of plant parameter file
  - Planning and creating sequence input files
  - Confirmation of successful code execution
  - Control of files and documentation of runs
  - Review of results
  - Training and certification of code users
- Applications Guidance also provides “best practices” for using the code

Verification of Code Installation

- For accepted Windows operating systems
  - Digit-for-digit agreement with sample results
- For other operating systems
  - Timing of key events (e.g. core uncovery, relocation, vessel breach) agree to within 5%
  - Distributed masses of UO_2, CsI, and SrO agree to within 10%
  - Fraction of cladding reacted in-vessel agrees within 5%
- Recommended to document code installation and verification

Development and Testing of Plant Parameter File

- Steady-state testing
- Execution of standard sequences

Code	Parameter File Containment Type	Input File	Type of Sequence
BWR	Mark I	SBO1A1	Loss of AC and DC power
	Mark I	SLOCA1	Small LOCA, no injection
	Mark I	LLOCA1	Large LOCA, no low pressure injection
	Mark II	SBO1A2	Loss of AC and DC power, no injection
	Mark II	SLOCA2	Small LOCA, no injection
	Mark III	SBO1A1	Loss of AC and DC power, no injection
PWR	WLD	TMLB	Loss of AC power, seal LOCAs
	WLD	S2HF	Small LOCA
	WLD	AHF	Large LOCA
	B&W	TMI19F	Small LOCA, no injection
	WICE	CRA1AI	Large LOCA, no injection

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Preparation and Execution of Sequence File

- Preparation and Execution of Sequence File
  - Verification of local parameter changes
  - Successful execution of operator actions
  - Review of diagnostic messages

Training and Certification of Users

- Training courses conducted by EPRI
- Certification is a utility responsibility
  - Application Guidance document provides sample Certification Guide listing attributes for user qualifications

Applicability of MAAP to EA-12-049

- MAAP4 Applications Guidance document includes over 30 benchmarks with:
  - Plant transient data
  - Integral codes
  - Integral experiments
  - Separate effects experiments
- Team of experts reviewed all code benchmarks
  - Determine if adequate information exists
  - Code was used in an appropriate manner
- In-depth review evaluated strength of conclusions
- Insights from benchmarks provided for code improvements

Major Modeling Areas Validated

- BWR primary system thermal hydraulics
  - Pressure and water level
- PWR primary system thermal hydraulics
  - Pressure and level in pressurizer and vessel
- Steam generator thermal hydraulics
  - Pressure and water level
- Core Heat-Up (BWR and PWR)
  - Maximum core temperature
- Containment thermal hydraulics
  - Pressure and temperature

BWR Sequences Supported by Benchmarks

Sequence Initiating Event	Type of Benchmark	Number and Types of Sequences	Overall Agreement	Sequence Time Frame
BWR transients (including SBOs, LOFW, and turbine trips)	Plant event: Oyster Creek (PE3)	1 LOFW	Very good	30 min
	Integral code comparison to TRACG02 (IC3)	2 LOOPs with LLOCAs	Good	8 min
	Integral code comparison to (IC11)—MAAP3B	4 LOFW	Good agreement with MAAP3B	15 min–2 hr
	Integral experiment comparison to FIST (IE11)—MAAP3B	2 LOFW	Good agreement with MAAP3B	15–50 min
	Integral code comparison to MELCOR (IC10)	1 SBO and 3 transients	Good: only a minor supporting benchmark for Level 1 applications	40 hr
BWR LLOCAs (excluding MSLBs)	Integral code comparison to TRACG02 (IC3)	2 LOOPs with LLOCA	Good	8 min
	Integral code comparison to SR5 and MELCOR (IC5)	1 LLOCA	Good	4 hr
	Integral code comparison to MELCOR (IC10)	1 LLOCA	Good: only a minor supporting benchmark for Level 1 applications	40 hr
BWR MLOCAs and SLOCAs -	Integral code comparison to (IC11)—MAAP3B	1 SLOCA	Good agreement with MAAP3B	1 hr
	Integral experiment comparison to FIST (IE11)—MAAP3B	1 MLOCA	Good agreement with MAAP3B	8 min
BWR MSLBs Can be considered a subset of LLOCAs	Integral code comparison to (IC11)—MAAP3B	1 MSLB	Good agreement with MAAP3B	7 min

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BWR Sequences Supported by Benchmarks

Sequence Initiating Event	Type of Benchmark	Number and Types of Sequences	Overall Agreement	Sequence Time Frame
BWR interfacing system LOCAs (discharge outside of containment)	No supporting benchmarks, but essentially covered by LLOCA and S/MLOCA benchmarks.			
BWR stuck-open SRVs	No supporting benchmarks with stuck-open SRVs as an initiator, but similar to SLOCAs if discharge is to the gas space (versus to the suppression pool). Sequences are also supported by benchmarks in which stuck-open or manually opened SRVs are subsequent conditions.			
BWR feedwater line breaks	No supporting benchmarks, but essentially covered by S/MLOCA benchmarks.			
BWR ATWS	No supporting benchmarks.			

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PWR Sequences Supported by Benchmarks

Sequence Initiating Event	Type of Benchmark	Number and Types of Sequences	Plant Type	Steam Generator Type and Model	Overall Agreement	Sequence Time Frame
PWR transients (including SBOs, LOFW, and turbine trips)	Plant event: -2 (PE1)	1 LOFW with stuck-open PORV	B&W	OTSG, one-region model	Very good	5 hr
	Plant event: Davis-Besse (PE2)	1 LOFW	B&W	—	Fair	30 min
	Plant event: Maanshan (PE5)	1 SBO	WLD	—	Good	3 hr
	Plant event: (PE6)	1 plant trip	B&W	—	Good	15 min
	Plant event: four-loop (PE7)—MAAP3B	1 and 1 plant trip	Westing-house	—	Good agreement with MAAP3B	3–5 min
	Integral code comparison to CENTS (IC1)	1 SBO and 1 LOFW with feed and bleed	CE	U-tube, two-region model	Good	3 hr
	Integral code comparison to SR5 (IC2)	3 LOFWs		U-tube, one-region model	Good	2 hr
	Integral code comparison to RELAP5 (IC4)	2 SBOs with feed and bleed	CE	U-tube, one-region model	Good	5–10 hr
	Integral code comparison to SR5 and MELCOR (IC5)	1 SBO	WLD	U-tube, region model not specified	Good	5 hr
	Integral code comparison to SR5 and MELCOR (IC8)	1 TMLB' (SBO, no RCP seal leak)	WLD	U-tube, one-region model	Good	5 hr
	Integral code comparison to RELAP5 (IC9)	1 LOOP with feed and bleed	CE	U-tube, one-region model	Good	3 hr

PWR Sequences Supported by Benchmarks

Sequence Initiating Event	Type of Benchmark	Number and Types of Sequences	Plant Type	Steam Generator Type and Model	Overall Agreement	Sequence Time Frame
	Integral code comparison to MELCOR (IC10)	1 TMLB (SBO with RCP seal leak)	WLD	—	Good: only a minor supporting benchmark for Level 1 applications	40 hr
	Integral code comparison to RELAP and RETRAN (IC12)—MAAP3B	2 transients	Westing-house	—	Good agreement with MAAP3B plus code changes that were incorporated into MAAP4	5 min–1.4 hr
	Integral experiment comparison to BETHSY (IE1)	2 LOFWs with feed and bleed	900 MWe EDF/ Framatome	U-tube, one-region model	Very good	1–2 hr
	Integral experiment to IIST (IE2)	1 SBO	WLD	U-tube, one-region model	Very good	3 hr
	Integral experiment comparison to MB-2 (IE3)	2 LOFWs	WLD	U-tube, two-region model	Very good	2–12 min
	Integral experiment comparison to Semiscale (IE10)—MAAP3B	2 LOOPs	Generic	—	Good agreement with MAAP3B	3–5 hr
PWR LLOCAs (excluding MSLBs)	Integral code comparison to MELCOR (IC10)	2 LLOCAs: location not identified	WLD	—	Good: only a minor supporting benchmark for Level 1 applications	40 hr

PWR Sequences Supported by Benchmarks

Sequence Initiating Event	Type of Benchmark	Number and Types of Sequences	Plant Type	Steam Generator Type and Model	Overall Agreement	Sequence Time Frame
PWR MLOCAs and SLOCAs	Integral code comparison to SR5 (IC2)	1 SLOCA: location not identified 1 MLOCA: location not identified		U-tube, one-region model	Good	2 hr
	Integral code comparison to CENTS (IC6)	1 MLOCA: break in the intermediate leg	WLD	U-tube, region model not specified	Inconclusive	5 hr
	Integral code comparison to CATHARE (IC7)	1 SLOCA: break in the hot leg 1 MLOCA: break in the hot leg 3 SLOCAs: breaks in the cold leg 1 MLOCA: break in the cold leg	900 MWe EDF/ Framatome	U-tube, one-region model	Good	2–12 hr
	Integral code comparison to MELCOR (IC10)	1 SLOCA: location not identified	WLD	—	Good: only a minor supporting benchmark for Level 1 applications	40 hr
	Integral code comparison to RELAP and RETRAN (IC12)—MAAP3B	2 SLOCAs: breaks in the cold leg	Westing-house	—	Good agreement with MAAP3B plus code changes that were incorporated into MAAP4	30 min–1 hr

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PWR Sequences Supported by Benchmarks

Sequence Initiating Event	Type of Benchmark	Number and Types of Sequences	Plant Type	Steam Generator Type and Model	Overall Agreement	Sequence Time Frame
	Integral experiment comparison to BETHSY (IE1)	1 SLOCA: break in the cold leg	900 MWe EDF/ Framatome	U-tube, two-region model	Very good	2 hr
	Integral experiment comparison to OSU (IE4)	2 SLOCAs: breaks in an injection line	AP600	U-tube, two-region model	Very good	Not provided
	Integral experiment comparison to Semiscale (IE10)—MAAP3B	4 SLOCAs: breaks in the cold leg	Generic	—	Good agreement with MAAP3B	13–50 min
	Integral experiment comparison to MIST (IE12)—MAAP3B	2 SLOCAs: breaks in the cold leg	B&W	—	Good agreement with MAAP3B	1–12 hr
PWR interfacing system LOCAs (discharge outside of containment)	No supporting benchmarks, but essentially covered by LLOCA and S/MLOCA benchmarks.					
PWR stuck-open PORVs	Integral code comparison to RELAP and RETRAN (IC12)—MAAP3B	1 failed-open PORV	Westing-house	—	Good agreement with MAAP3B plus code changes that were incorporated into MAAP4	8 min
	Integral experiment comparison to OSU (IE4)	2 failed-open PORVs	AP600	U-tube, two-region model	Very good	Not provided

PWR Sequences Supported by Benchmarks

Sequence Initiating Event	Type of Benchmark	Number and Types of Sequences	Plant Type	Steam Generator Type and Model	Overall Agreement	Sequence Time Frame
PWR SGTR	Plant event: (PE4)	1 SGTR	WLD	—	Good	8 min
	Integral code comparison to RELAP and RETRAN (IC12)—MAAP3B	2 SGTRs	Westing-house	—	Good agreement with MAAP3B plus code changes that were incorporated into MAAP4	50 min
	Integral experiment comparison to Semiscale (IE10)—MAAP3B	3 SGTRs	Generic	—	Good agreement with MAAP3B	5–40 min
PWR MSLBs	Integral code comparison to RELAP and RETRAN (IC12)—MAAP3B	1 MSLB	Westing-house	—	Good agreement with MAAP3B plus code changes that were incorporated into MAAP4	5 min
	Integral experiment comparison to MB-2 (IE3)	2 MSLBs 1 MSLB with SGTR	WLD	U-tube, two-region model	Very good	2–3 min 17 min for SGTR
PWR feedwater line breaks	No supporting benchmarks, but similar to LOCAs and, to a lesser extent, MSLBs.					
PWR mid-loop operation	No supporting benchmarks.					
PWR ATWS	No supporting benchmarks, but typically a very low contributor to core damage frequencies.					

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ERI/NRC "Compendium of Analysis to Investigate Select Level 1 Probabilistic Risk Assessment End-State definition and Success Criteria Modeling Issues – Draft report for Comment."

- NRC MELCOR analysis performed to confirm success criteria assumptions in PRA models
- Comparison to MAAP for a variety of PWR bleed and feed scenarios
- Comparison included investigation of uncertainties in:
  - Power level at start of accident
  - Steam generator level set points
  - Time of reactor trip
  - Number of pressurizer PORVs used
  - Number of available HPSI and charging trains
  - HPSI pump flow characteristics
  - Pressurizer PORV flow characteristics
  - Aux FW failure time
  - Reactor coolant pump trip
  - Time of HPSI injection
  - Temperature defining core damage

Conclusions from NRC MELCOR Evaluation

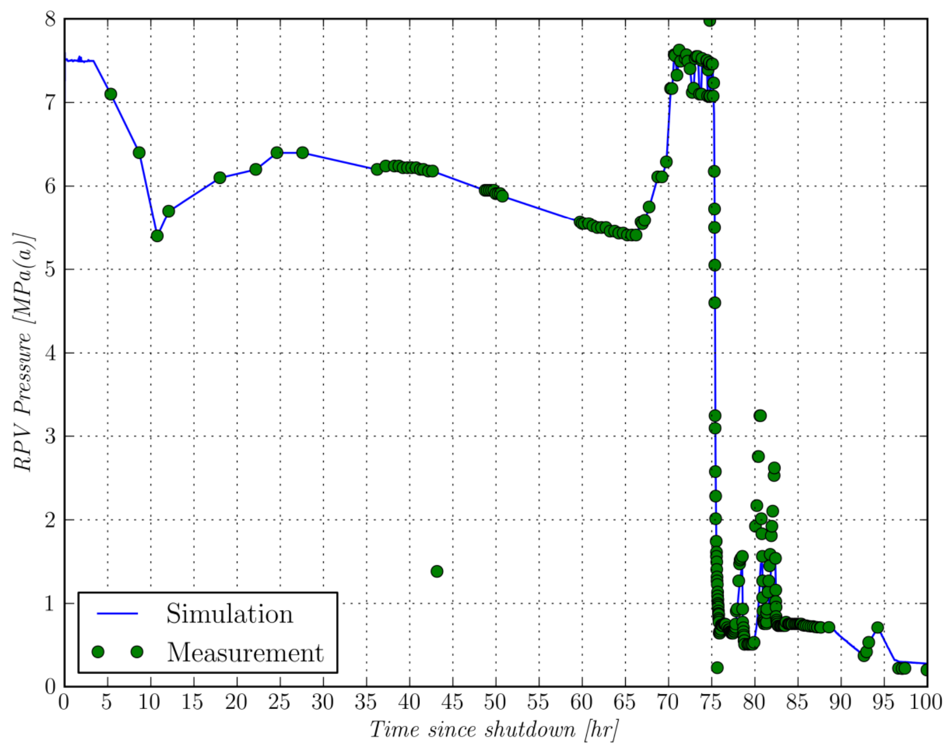
- Distribution ranges established for all uncertainty parameters
- 100 samples using Latin Hypercube Sampling
- Computed the probability of core damage

	MELCOR	MAAP
1 PORV	0.57	0.61
2 PORVs	0.15	0.22

Demonstrates good agreement in the calculation of peak core temperature

EPRI Fukushima Technical Evaluation

- Dai-ichi Unit 2 maintained adequate core cooling using RCIC for extended period of time
- Similar scenario initially to EA-12-049 application



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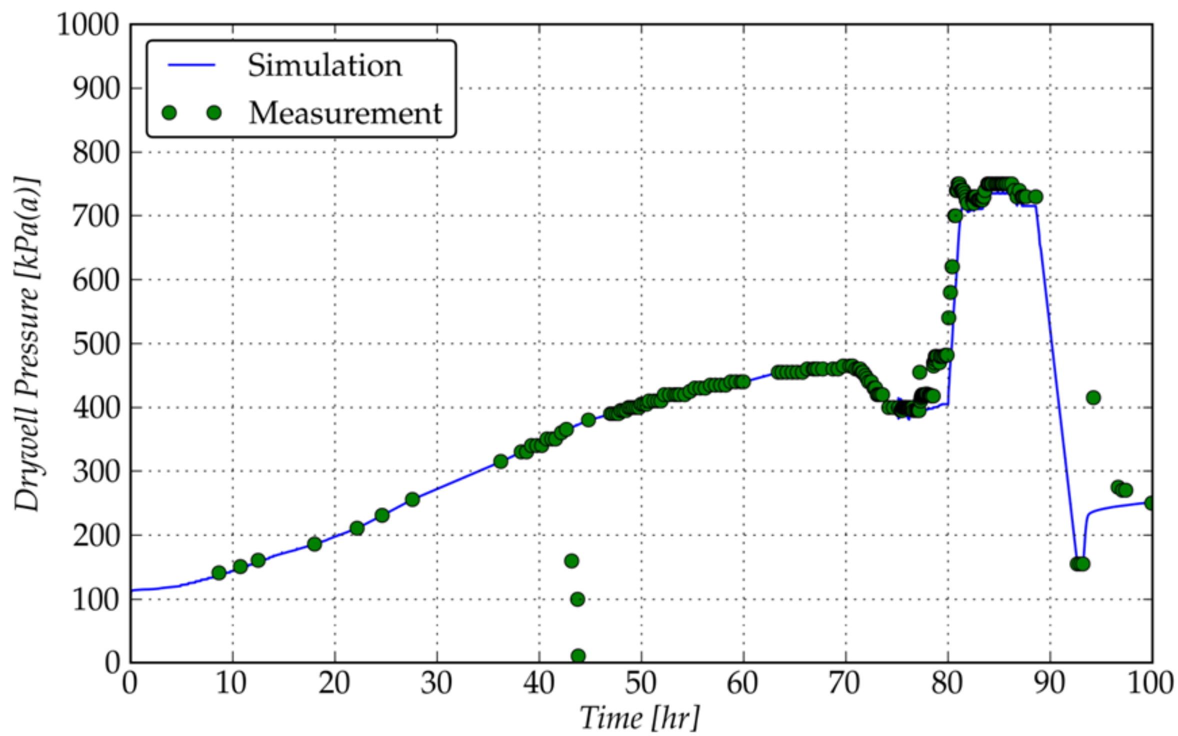
EPRI Fukushima Technical Evaluation

- Based on best available information and supported by numerous sensitivity analyses
- MAAP5 demonstrates good agreement with data



BWR MAAP/MELCOR Comparison

- NUREG-1953 : Confirmatory Thermal-Hydraulic Analysis to Support Specific Success Criteria in the Standardized Plant Analysis Risk Models- Surry and Peach Bottom
- Purpose is to strengthen the basis for SPAR models through targeted analysis
- Comparison made use of MELCOR 1.8.6 and MAAP 4.0.6
- Two cases analyzed
  - **IORV** with variations in injection type, timing of 2nd CRD pump initiation and timing of reactor trip
  - **SBO** with variations in injection, operator actions (HCTL depress.), SRV behavior, recovery time and DC power availability

SBO Results MELCOR (MAAP)

Case	RCIC	HPCI	ac/dc	SRV sticks open	HCTL Depress	Core Uncovery hrs	Core Damage hrs
1	No	No	-	No	No	0.5 (0.76)	1.2 (1.2)
1a	No	No	ac recovery at 1.2hr	No	No	0.5 (0.76)	1.2 (1.2)
2	No	No	-	t = 0	No	0.3 (0.5)	0.8 (0.8)
3	Yes	No	infinite dc	No	No	17.7 (17.1)	19.4 (18.0)
7	No	Yes	infinite dc	No	No	17.5 (16.3)	19.3 (17.2)
10	No	Yes	infinite dc	187 lifts	No	9.2 (7.8)	10.7 (8.6)

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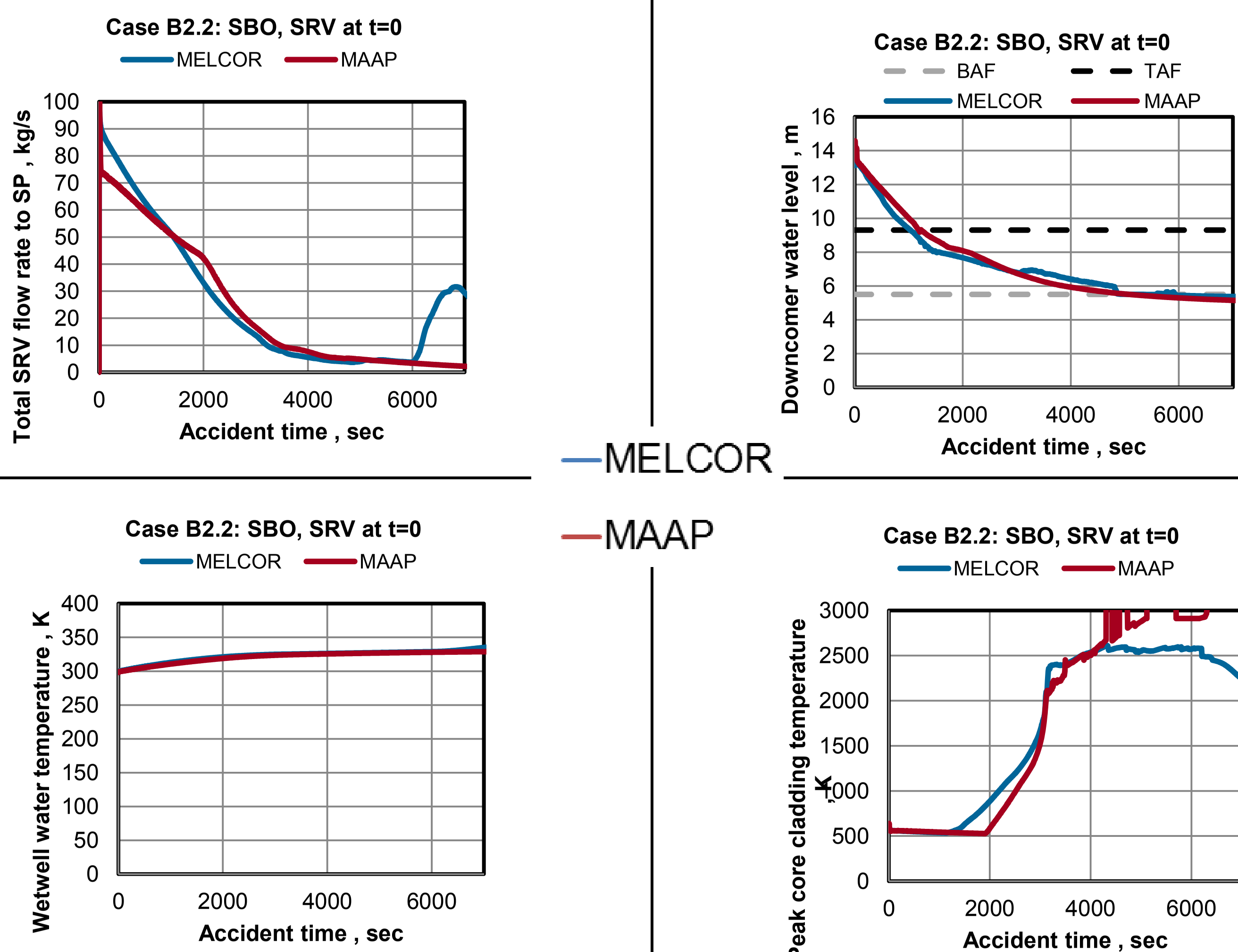
Case B2.2: SBO, SRV open at t = 0



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Conclusions from BWR MAAP/MELCOR Comparison

- Codes show good agreement
- Differences normally attributed to boundary conditions
  - <u>Not due to fundamental modeling differences</u>
- MAAP reaches the same conclusions regarding success criteria

Summary

- MAAP continues to benefit from extensive validation
  - Provides valuable input on code enhancements
- Differences encountered with benchmarks normally attributed to differences in boundary conditions
  - <u>Not due to modeling deficiencies</u>
- MAAP4 Applications Guidance document provides users with guidance for executing the code successfully, consistent framework for reviewing the results, and clear identification of limitations and precautions
- User qualifications provided by individual utilities with substantial training and guidance by EPRI

MAAP is an appropriate tool to use in support of post-Fukushima analysis including responses to EA-12-049

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