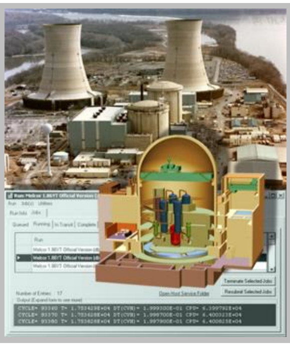
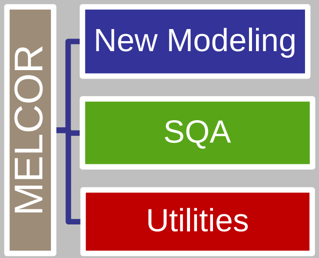
Exceptional service in the national interest

Sandia National Laboratories





MELCOR Validation

Prepared by
MELCOR Development Team

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Importance of Code Validation

- Code Developers
  - provide the necessary guidance in developing and improving models
  - Desirable to have validation test at time of model implementation
- Code Users
  - Increased confidence in applying code to real-world application
  - Improved understanding of modeling uncertainties

Presentation Objectives

- Discuss the objectives of the MELCOR validation program
  - Historical perspectives
  - Uses of validation
  - Available severe accident database
  - Future approach to validation
- Recent progress in MELCOR validation
  - Automation of existing validation cases
  - Samples of current validation cases
- Non-LWR validation

Historical Assessments

- **Validations should be performed by both**
  - **Developers**
    - **More intimate understanding of the model nuances**
  - **Code Users**
    - **Greater knowledge of real-world applications**
- **Validations should focus on what can be learned from the exercise**
  - **Should avoid trying to 'tune' results**

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Tills, J, Notafrancesco, A.,Longmire, P., "An Assessment of MELCOR 1.8.6: Design Basis Accident Tests of the Carolinas Virginia Tube Reactor (CVTR) Containment (Including Selected Separate Effects Tests)", SAND2008-1224 (2008).

Souto, F.J., Haskin, F.E., Kmetyk, L.N., "MELCOR 1.8.2 Assessment: Aerosol Experiments ABCOVE AB5, AB6, AB7, and LACE LA2," SAND94-2166 (1994),

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Selection of Validation Test Cases

- Separate Effects Tests
  - Designed to focus on an individual physical process
  - Eliminates complications from combined effects
  - May be difficult or impossible to design a single test to isolate a single process
  - Sometimes geometry or boundary conditions for SETs are difficult to model within an integral code
- Integral Tests
  - Examines relationships between coupled processes
  - Tests should be selected that are applicable to the calculation domain of the code.
- Actual Plant Accidents
  - TMI, Chernobyl, Fukushima, etc.
  - Captures all relevant physics
  - Poorly ‘instrumented’
- International Standard Problems
  - Well documented
  - Often there are code-to-code comparisons to compare modeling approaches

MELCOR Assessments

RN Physics / Transport

- ABCOVE
- ACE AA1, AA2, AA3
- AHMED
- CSE-A9
- DEMONA
- FALCON 1&2
- LACE LA1 & LA3
- LACE-LA4
- Marviken ATT-4
- Poseidon
- RTF ISP-41
- STORM
- VANAM-M3
- VERCORS
- VI (ORNL)

Core Heatup & Degradation

- CORA-13
- DF-4
- FPT1 & FPT3
- LHF/OLHF
- LOFT-FP2
- MP1 & MP2 (SNL)
- PBF-SFD
- Quench 11
- VERCORS
- VI (ORNL)

Integral / Accidents

- FPT1 & FPT3
- TMI-2
- Fukushima

RN Release

- VERCORS
- VI (ORNL))

RPV & Primary TH

- Bethsy
- Flecht-Seaset
- GE Level Swell
- LOFT-FP
- Marviken Blowdown Tests
- NEPTUN
- RAS MEI

Ex-Vessel Debris

- IET-DCH
- OECD-MCCI
- SURC

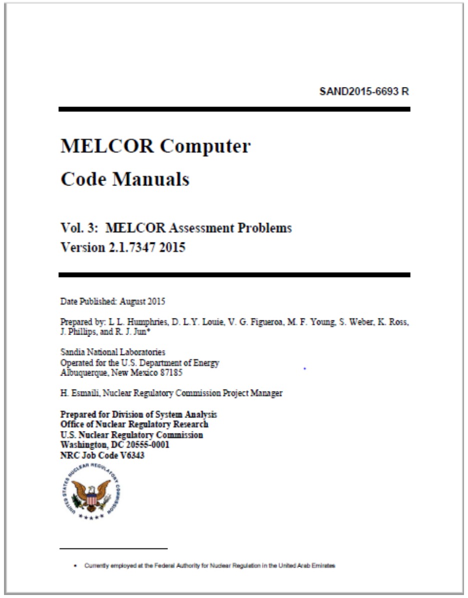
Containment

- CSE-A9
- CSTF Ice Condenser Test
- CVTR
- DEHBI
- GE Mark IISuppression Pool
- HDR E-11
- HDR V44
- IET 1 thogh IET7 and IET 9
- JAERI Spray Tests
- NST Hydrogen Burn
- NUPEC M-7-1, M-8-1, M-8-2
- PNL Ice Condenser Tests
- Wisconsin flat plate

Current Validation Effort

- Update Volume III of the MELCOR Documentation which includes a compilation of assessments to experiments
  - Initial release will provide an update a subset of assessments documented in previously published report
  - Expand number of assessments with each code release

- Develop an automation scheme which integrates well with current testing pipelines
  - Python scripts for managing automatic update of key plots.
  - Scripting of boiler plate description of experiment and model nodalization and assumptions
- Move away from comparing current code version results to previous code version results
  - Perform UA of key model parameters and compare with bounds of experiment uncertainty.



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MELCOR Computer

Code Manuals

Vol. 3: MELCOR Assessment Problems
Version 2.1.7347 2015

Date Published: August 2015

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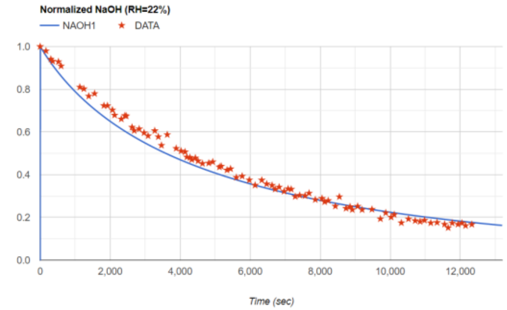
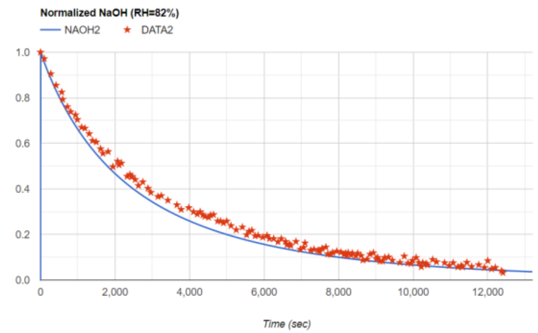
Washington, DC 20555-0001
NRC Job Code V6343

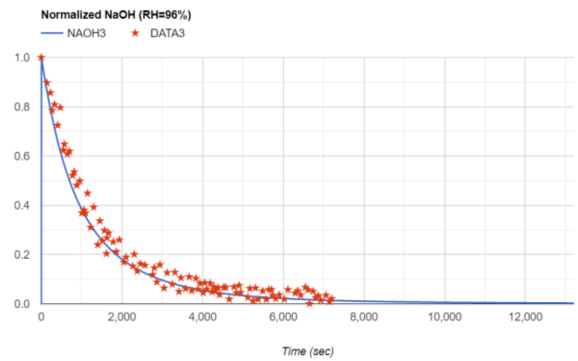
- Currently employed at the Federal Authority for Nuclear Regulation in the United Arab Emirates

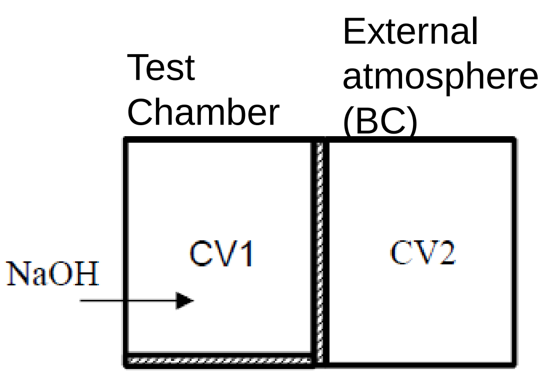
AHMED Tests

- The Aerosol and Heat Transfer Measurement Device (AHMED) facility
- Conducted in 1991 by VTT (Technical Research Center of Finland) .
- A series of aerosol experiments were conducted at the AHMED Test Facility by injecting NaOH in aerosol form into an atmosphere.
  - Data for hygroscopic and non-hygroscopic aerosol behavior
  - single as well as multi-component
  - under controlled temperature and humidity conditions.
- Relatively simple experiments providing a wealth of information.



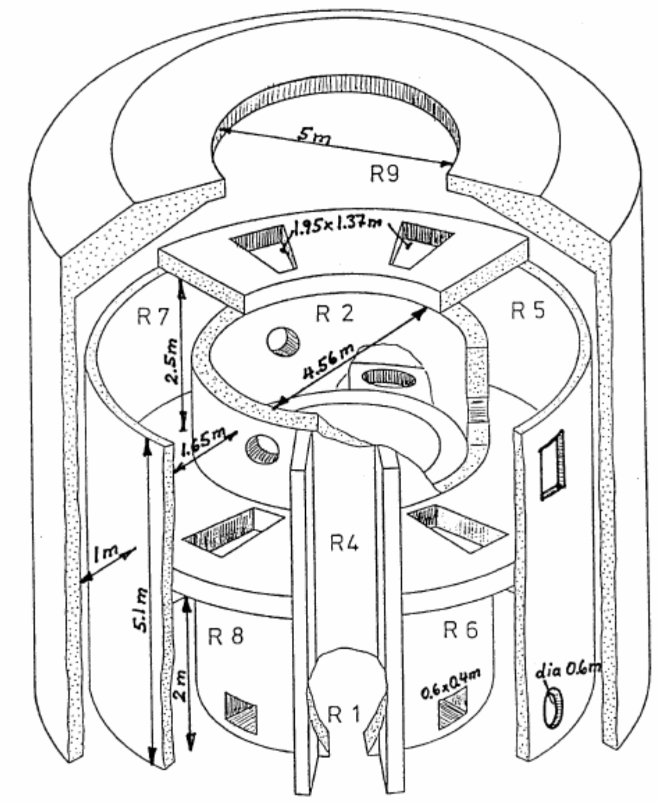






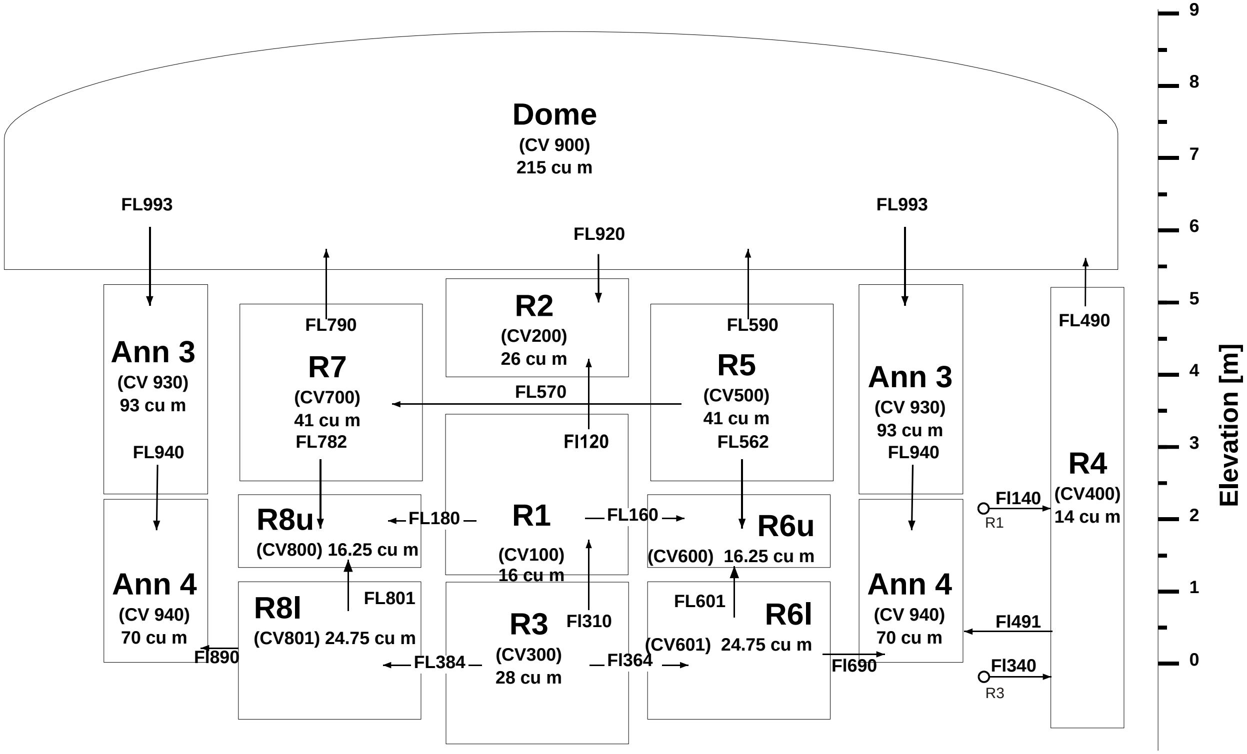
DEMONA

- The DEMONA-B3 test emphasized phenomena associated with steam condensation effects on aerosol settling.
- Test B3 was conducted over a period of 3 days in 1986
  - **Phase 1: Purge**
    - **purge air out to achieve a pure steam atmosphere (0.4-7.1 h).**
  - **Phase 2: Steam Injection**
    - **Inject steam over 2 days to heat up BMC structure, at a constant pressure of 1.7 bar.**
  - **Phase 3: Aerosol & air injection**
    - **Hot air and aerosol were injected from 48.4 to 49.3 h, raising the pressure to 3 bar (partial pressures, air 1.3 bar, steam 1.7 bar, & peak aerosol concentration was 9 g/m^3.**
  - **Phase 4: Aerosol depletion 49.3-71.1 h**
  - **Phase 5: Cooldown (this was ignored in modeling)**

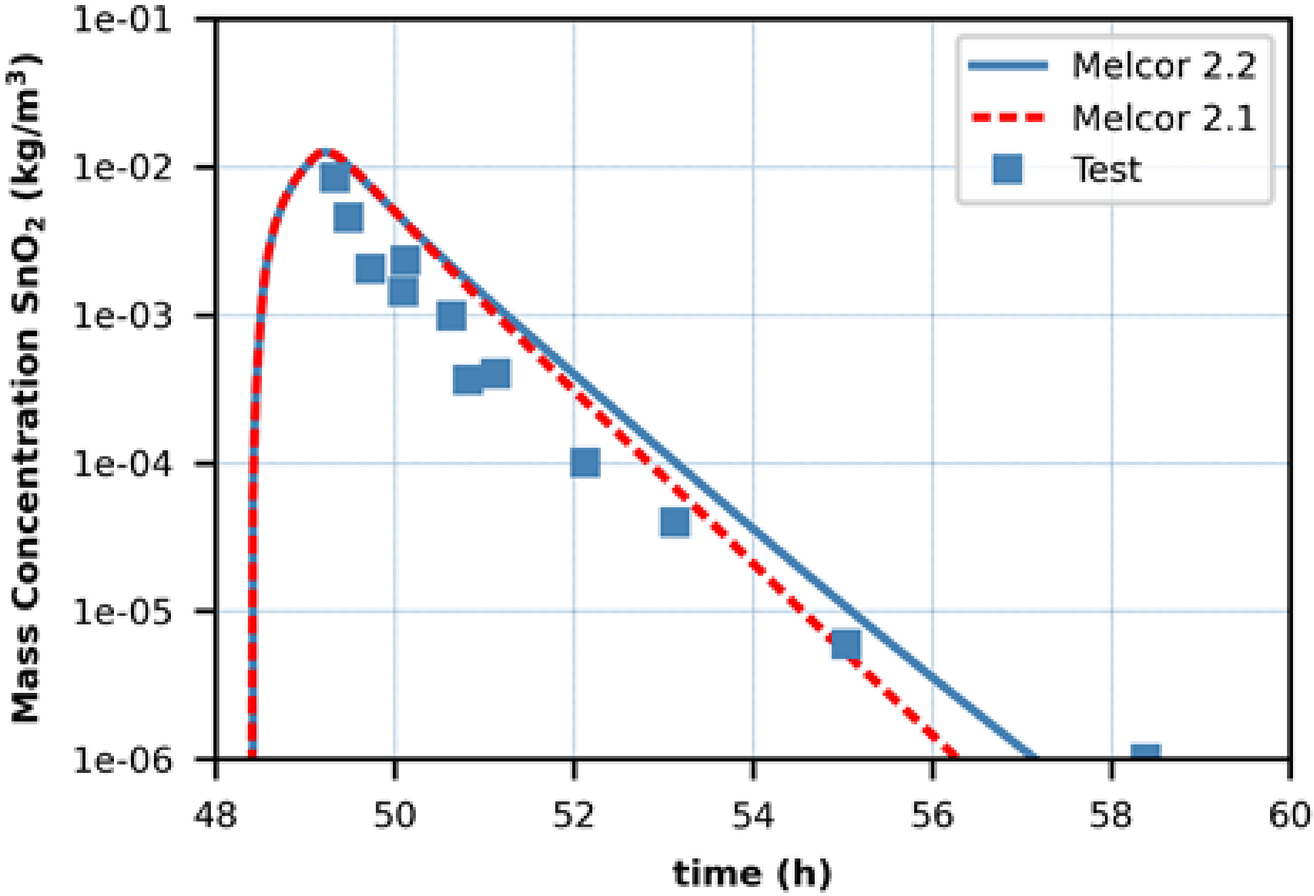


DEMONA

- MELCOR Nodalization



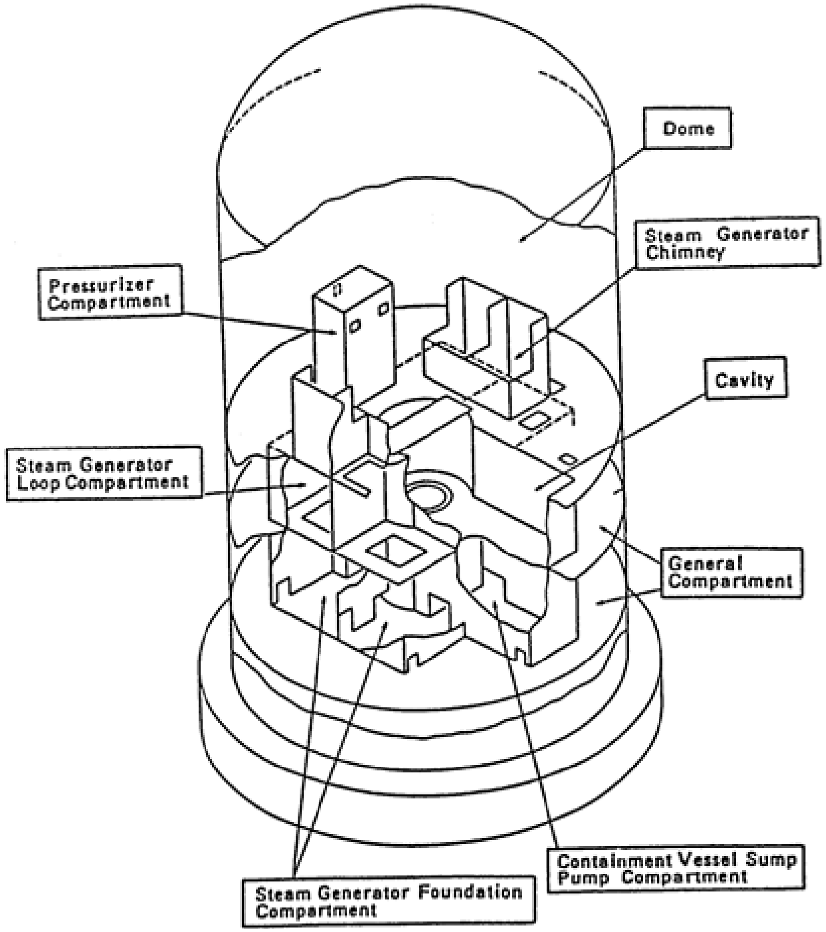
DEMONA



Mass Concentration SnO_2 (kg/m^3)
1e-01
1e-02
1e-03
1e-04
1e-05
1e-06
48
50
52
54
56
58
60
time (h)
Melcor 2.2
Melcor 2.1
Test

NUPEC M-7-1, M-8-1, and M-8-2

- Validation objectives
  - Pressure response;
  - Temperature distribution and stratification
  - Hydrogen mixing
  - Spray modeling
  - Film Tracking Model
- ¼ Scale Containment
  - 10.8 m OD domed cylinder,
  - 17.4 m high
  - 25 interconnected compartments (28 total)
- Sprays
  - M-8-1 No Sprays
  - M-7-1 and M-8-2 Sprays modeled

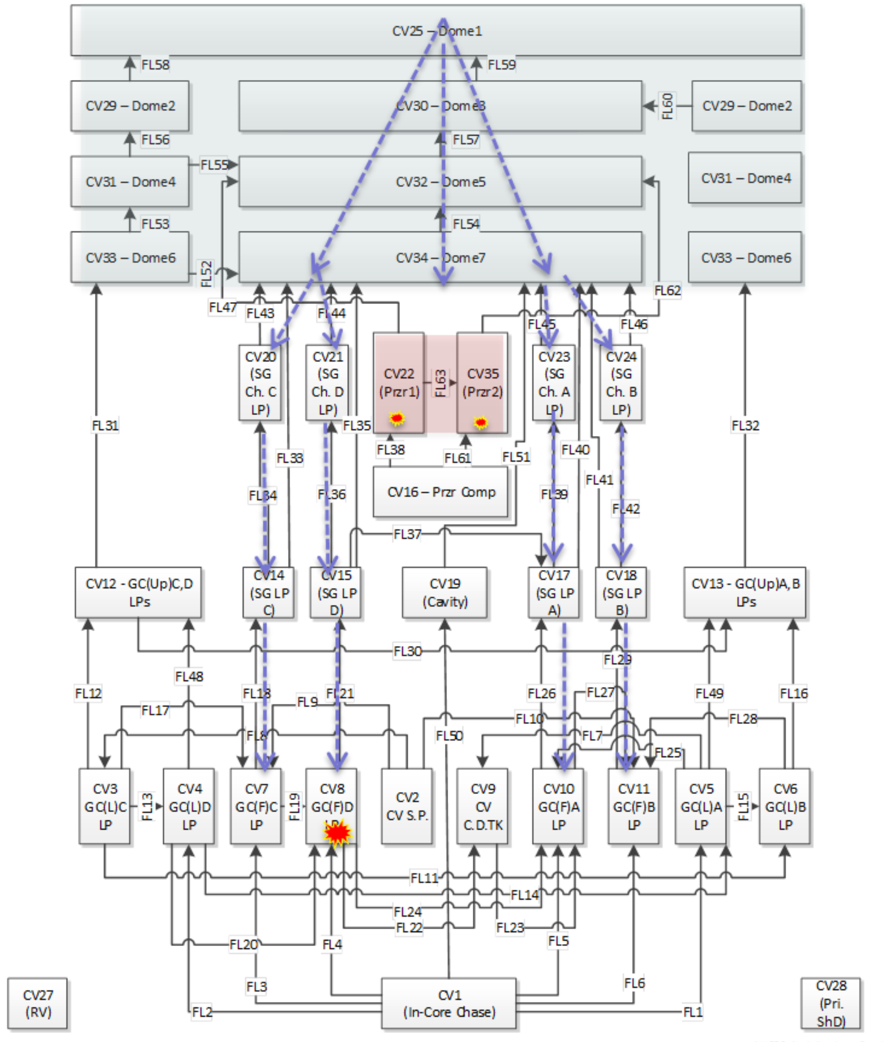


NUPEC Tests

Test	Injection Location	Initial Conditions	Relative Humidity	Helium Source	Steam Source	Containment Sprays
M-7-1	Bottom of SG Comp D (8)	343 K, 146 kPa	0.95	0→0.03 kg/s→0 283 K	0.08 kg/s→0.03 kg/s 383 K	19.4 m^3/s 313 K
M-8-1	Upper Pressurizer Comp (22)	303 K, 101 kPa	0.7	0.027 kg/s 283 K	0.33 kg/s, 388 K	*None*
M-8-2	Upper Pressurizer Comp (22)	343 K, 146 kPa	0.95	0→0.03 kg/s→0 283 K	0.08 kg/s→0.03 kg/s 363 K	19.4 m^3/s 313 K

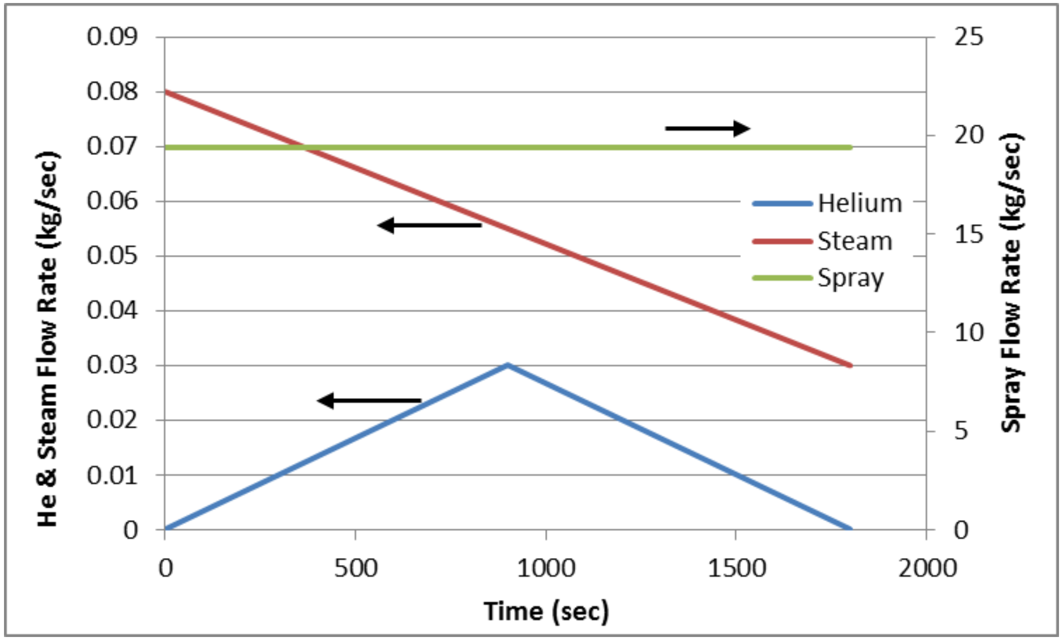
NUPEC MELCOR Nodalization

- Total of 35 CVs
  - Dome compartment subdivided into 7 CVs (green)
    - Allows convection loops
  - Upper pressurizer subdivided into two CVs (red)
    - Allows circulation from upper pressure compartment to lower compartment (dead end)
  - All other compartments represented by a single CV
- M-8-1 & M-8-2 He source in Pressurizer Compartment (CV 22 and CV 35)
- M-7-1 He source in CV8
- Spray junctions (M-8-2) shown by dashed arrows
  - Sprays not active in M-8-1



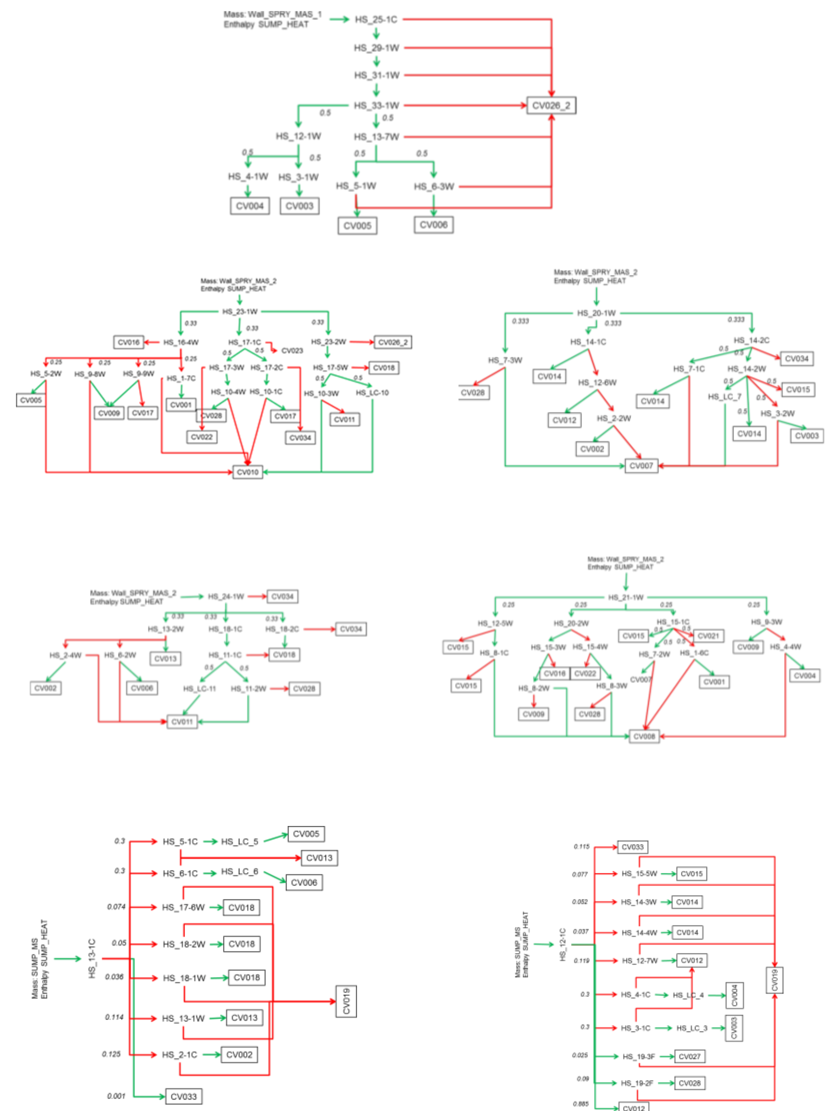
He, Steam, and Spray Sources

- Steam released into a compartment to simulate break of a steam generator system. Total helium volume was decided by volumetric scaling of hydrogen release from 10% Zr-H2O reaction
  - CVH mass and energy sources in a CV
- At the same time, containment spray was activated to simulate the impact of spray water on mixing.



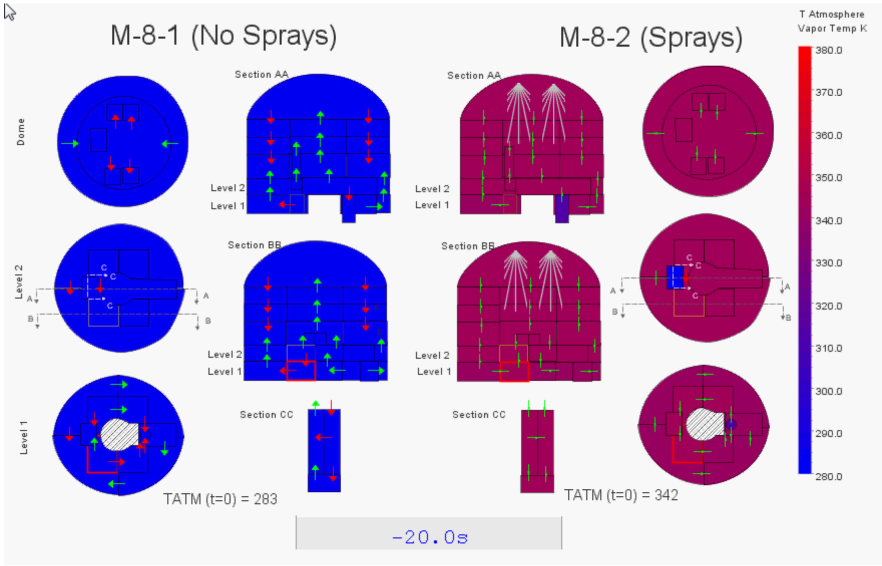
HS Film-Tracking Networks

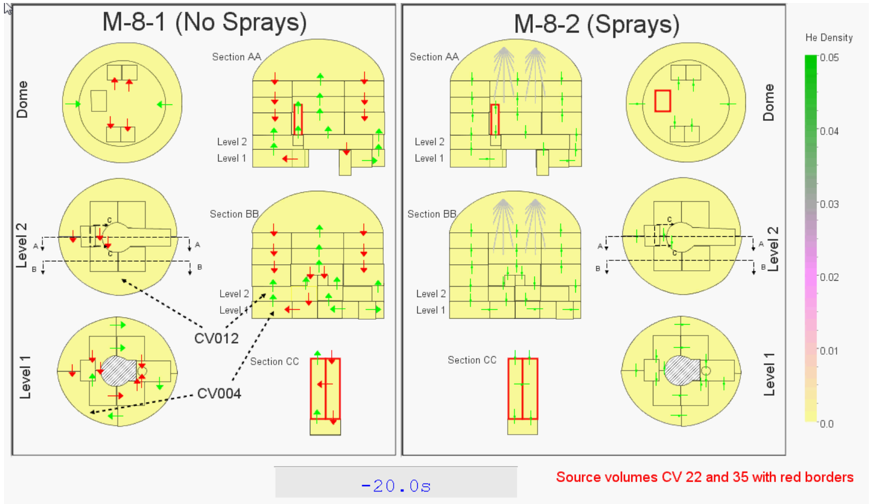
- Spray water is diverted onto seven separate film flow networks
  - Allows flow down each of the four steam generator compartments
  - Also models water draining down the containment walls from the dome
- Motivation: Since the heat structure film temperature and the spray temperature were close, it was expected that this model would better represent the uniform cooling of both structures and gases observed in the test



Temperature and He Concentration Distributions

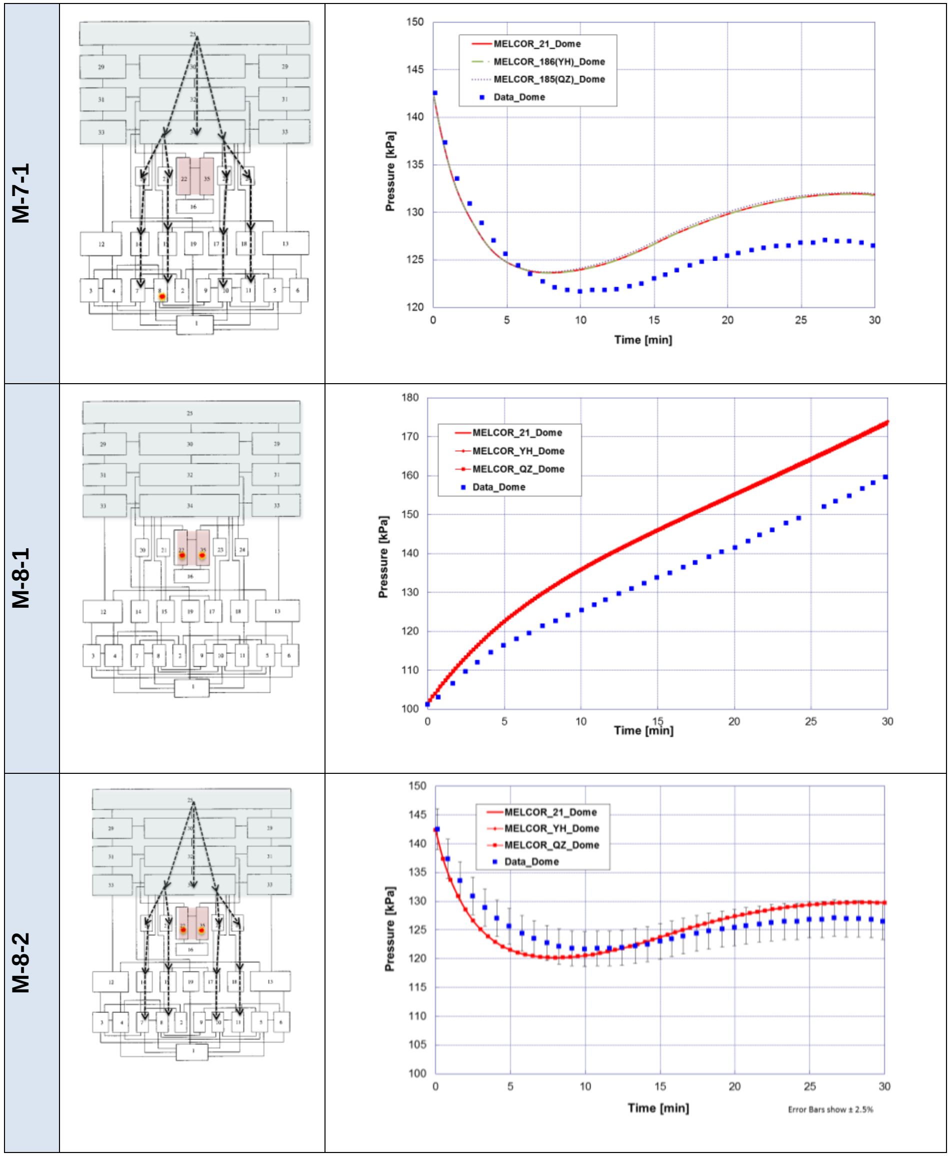
- SNAP representation based on MELCOR nodalization and NUPEC drawings.
- Temperature stratification occurs for M-8-1
  - No sprays
- Enhanced mixing for M-8-2
  - Sprays active
- Similarly, stratification of helium in the upper dome is much more significant for M-8-1 than M-8-2
- Mixing is greater for central compartments where the spray is active and is less effective in outer, lower compartments





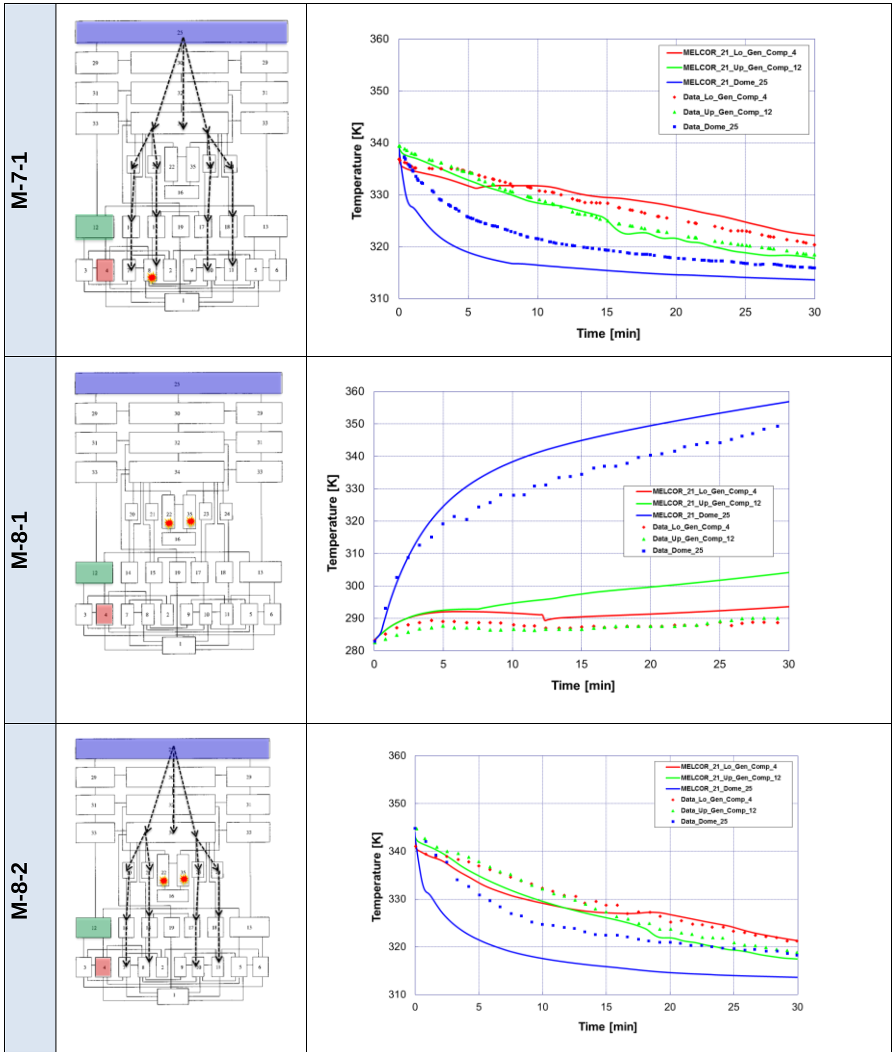
Pressure Response

- Pressure calculated for M-7-1 exceeds experiment pressure
- M-8-1 without sprays shows excessive pressure



Temperature distribution vert. distribution of general region

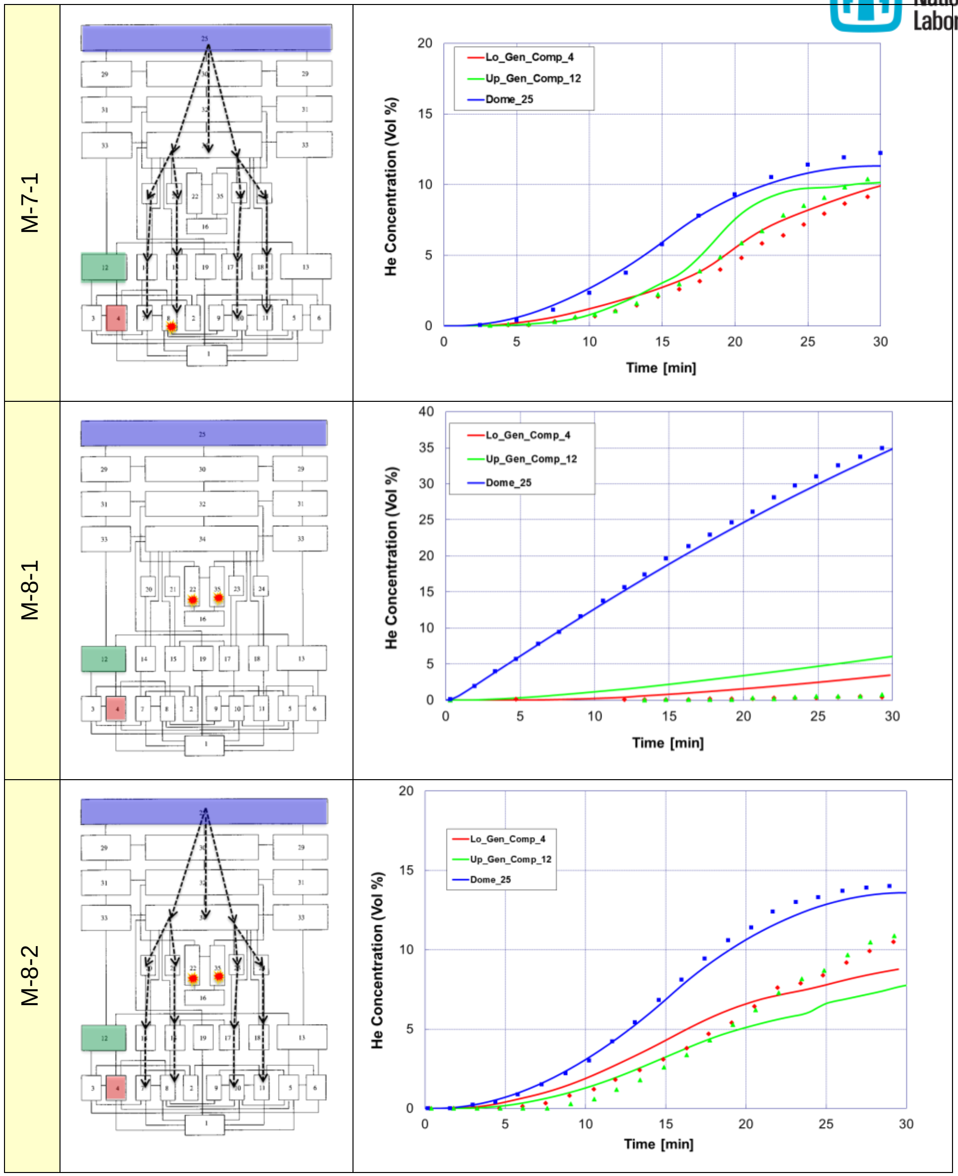
- Calculated temperature in dome is less than measured data for spray tests
  - Cooling from spray is overpredicted slightly by MELCOR
- Calculated temperature in dome is greater than data without sprays.
  - Stratification may be slightly overpredicted.



Color indicates CV

He Concentrations for vert. distribution of general region

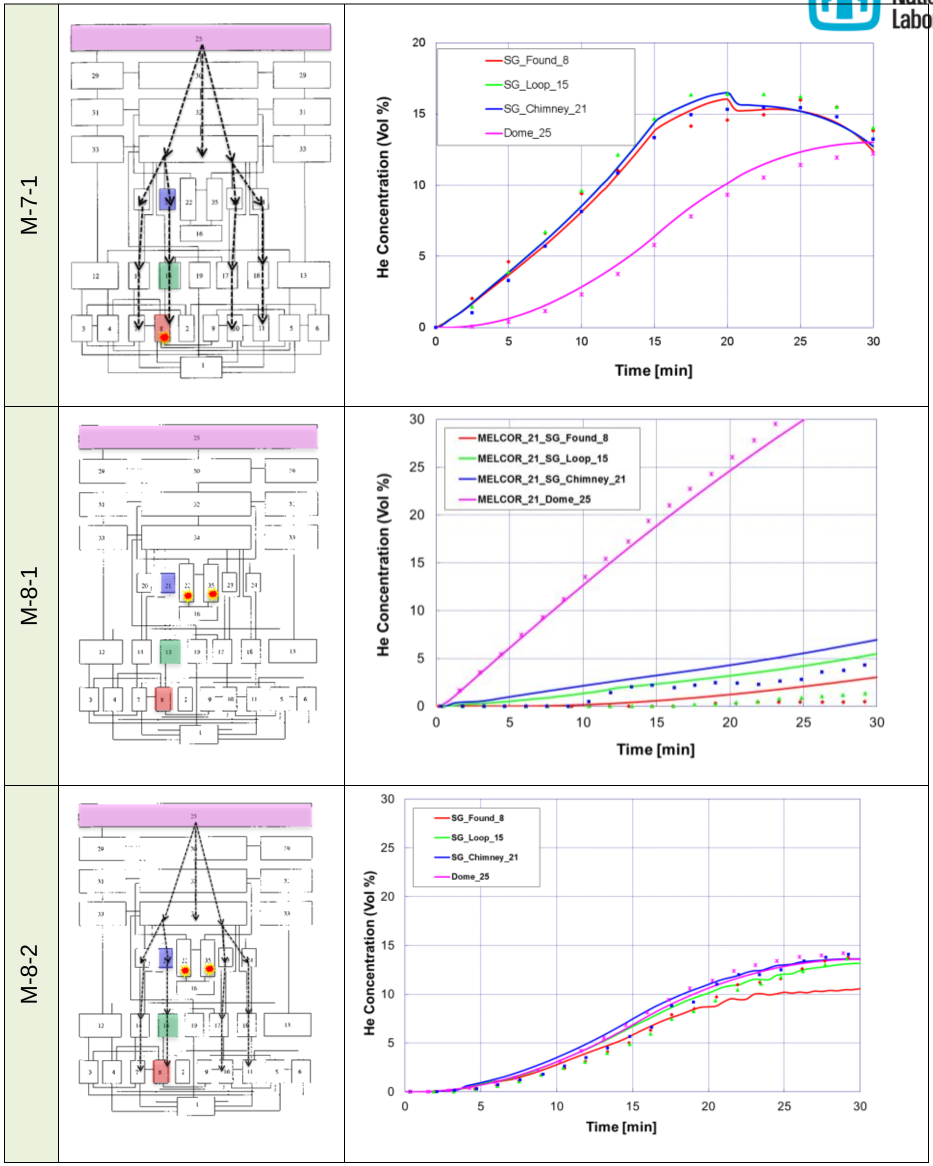
- Without sprays
  - MELCOR significantly overpredicts concentration in lower general compartments
- With sprays
  - He concentration well-predicted for all compartments



Color indicates CV

He Concentrations for vertical distribution of SG loop D

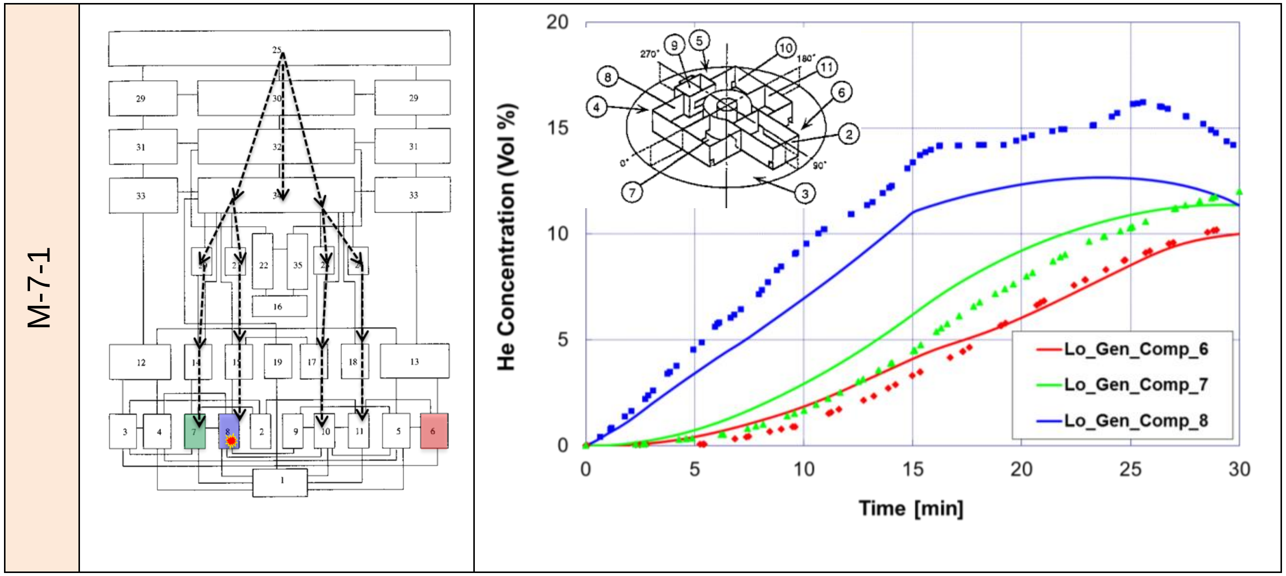
- Concentration in dome is well-predicted for all cases
- M-7-1 shows underprediction of He in mid-level compartments for source in lower level
- Slight under-prediction of concentration for lower compartments in M-8-2 otherwise, well predicted



Color indicates CV

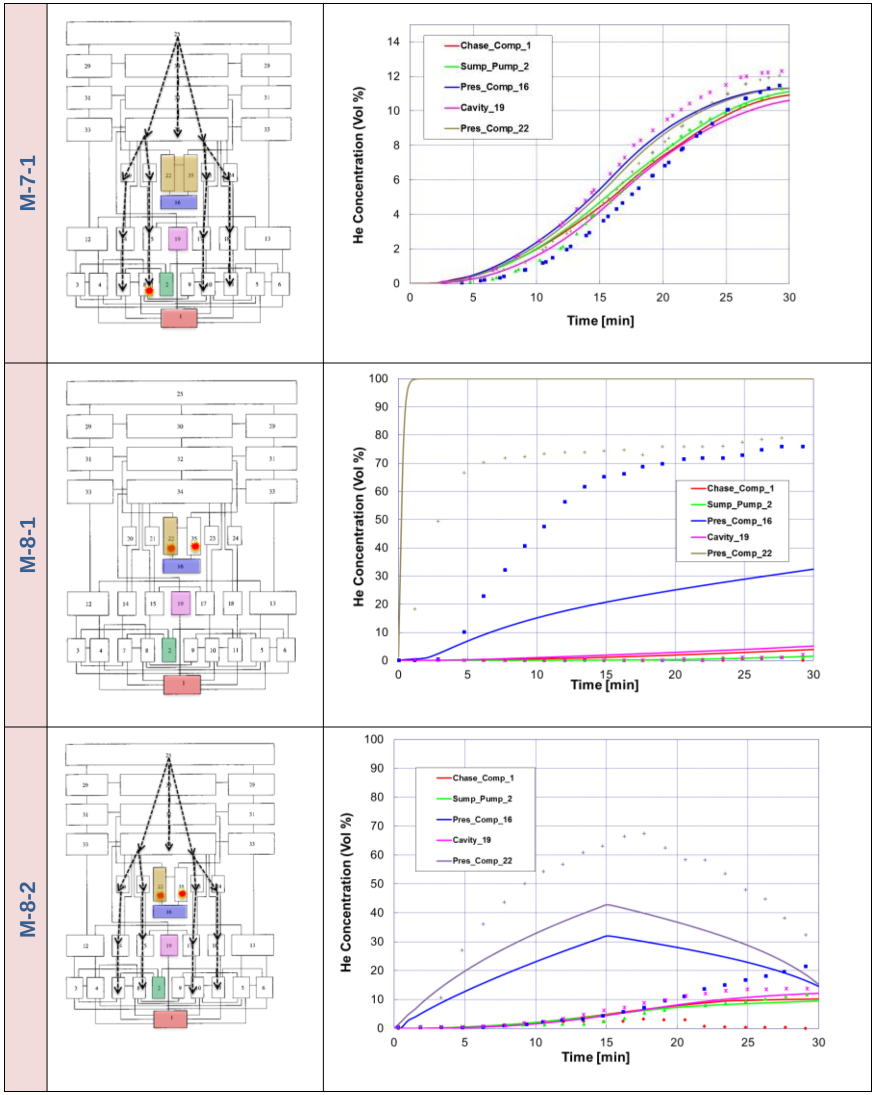
He Concentrations for 1st floor horizontal distribution

- MELCOR predicts concentrations for all lower compartments with reasonable accuracy
- MELCOR predicts concentration in source cell well



He Concentrations for vertical distribution of SG loop D

- Problems in calculating concentration in source volume and dead-end volume adjacent to source volume
- Best agreement in M-7-1 where He source was in a lower CV and sprays were active



Color indicates CV

AB1/AB5

- Performed at Containment Systems Test Facility at Hanford Engineering Development Laboratory
  - AB1 – 1979
  - AB5 – 1983
- Experiments investigated aerosol behavior under liquid metal fast breeder reactor accident conditions
  - Provided experimental basis for evaluating adequacy of aerosol behavior codes
- Aerosols generated by sodium fires
  - AB1 – pool fire
  - AB5 – spray fire

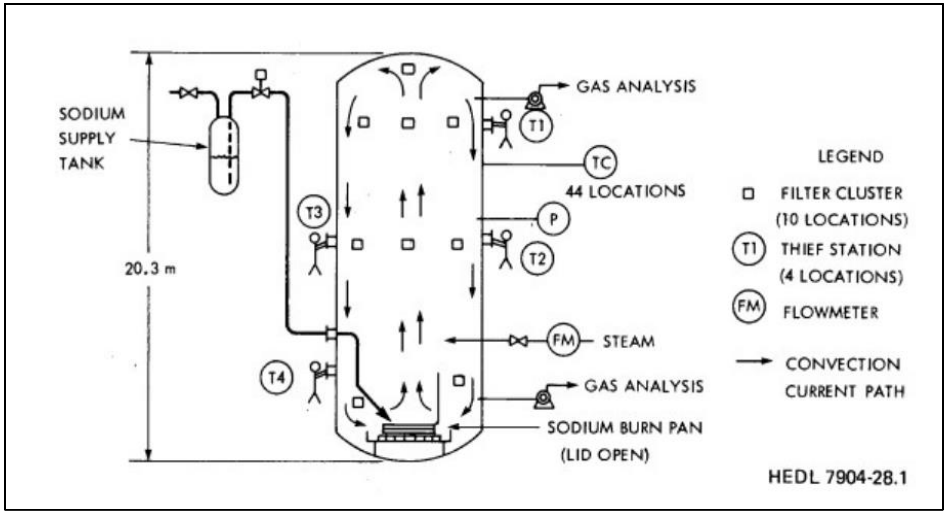
AB1/AB5

- All experiments performed in CSTF Test Vessel

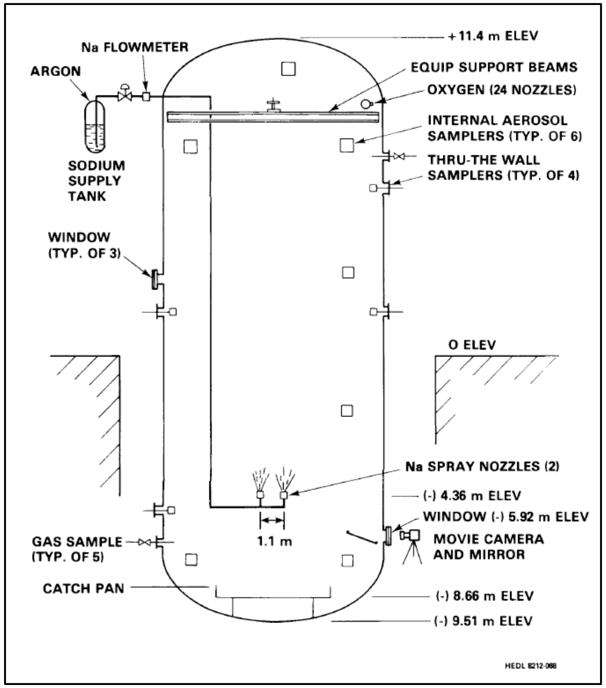
- AB1
  - Sodium pool fire initiated in burn pan at 0 s
  - Burn pan covered by lid at 3600 s terminating aerosol generation
  - Experiment ended at 50000 s when vessel opened

- AB5
  - Spray initiated at 13 s, terminated at 885 s
  - Experiment ended at ~50000 s when vessel opened

AB1/AB5



AB1



AB5

AB1/AB5

- CSTF vessel modeled with 1 CV and 6 HS
  - HS represent vessel top, walls, floor, vertical/horizontal deposition surfaces, burn pan

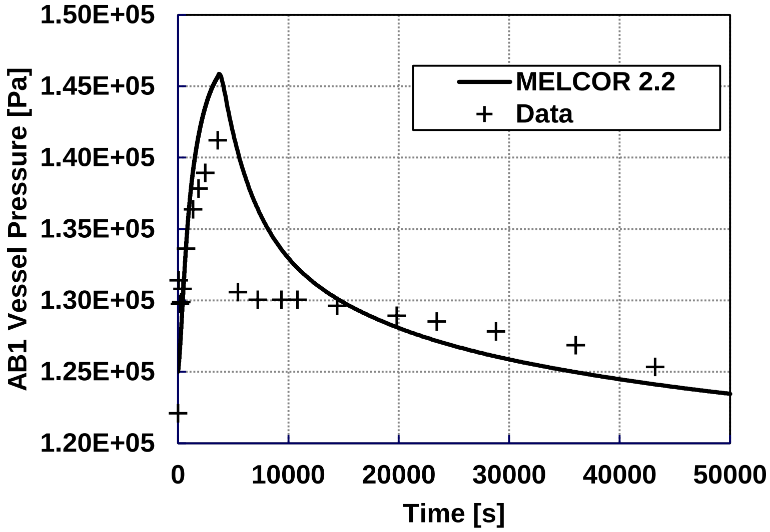
- Sodium fires modeled using NAC package
  - Boundary conditions inferred using test data
  - AB1
    - All sensible heat assumed to transfer to pool
    - 66% of O2 assumed to form Na2O
    - 100% of Na_2O, 12% of Na_2O_2 retained in pool
  - AB5
    - Spray fire produced 100% Na2O2

AB1/AB5

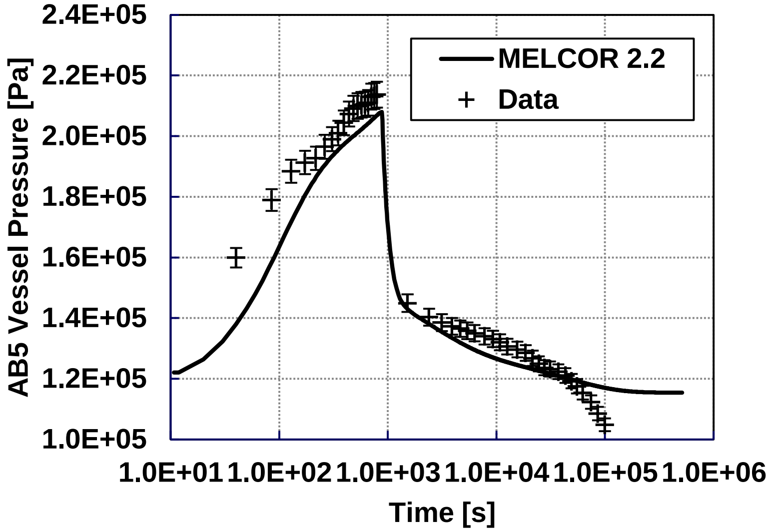
- CSTF vessel modeled with 1 CV and 6 HS
  - HS represent vessel top, walls, floor, vertical/horizontal deposition surfaces, burn pan

- Sodium fires modeled using NAC package
  - Boundary conditions inferred using test data
  - AB1
    - All sensible heat assumed to transfer to pool
    - 66% of O2 assumed to form Na2O
    - 100% of Na_2O, 12% of Na_2O_2 retained in pool
  - AB5
    - Spray fire produced 100% Na2O2

AB1/AB5

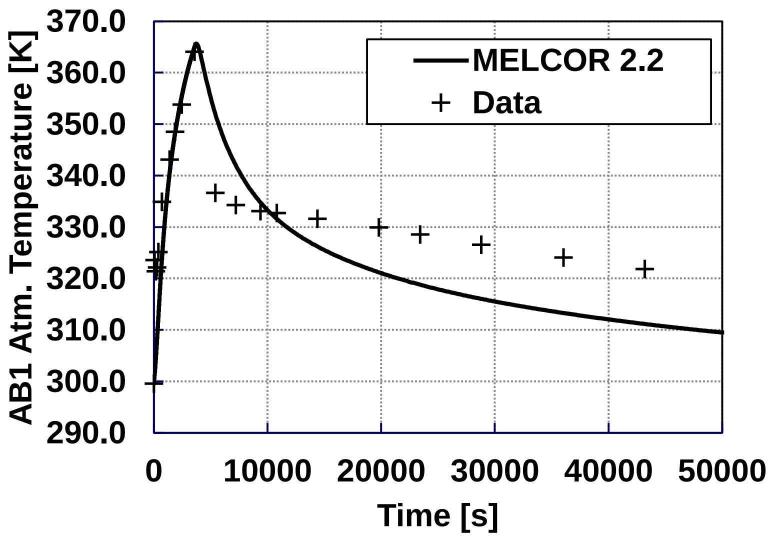


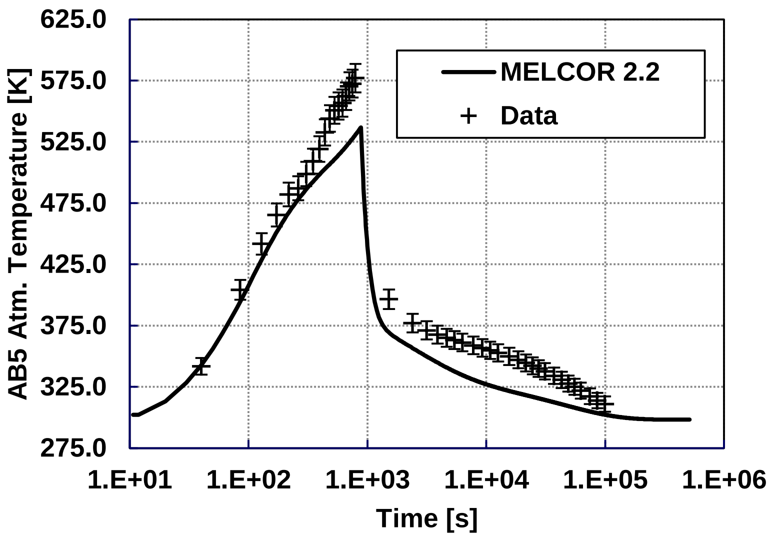
1.50E+05
1.45E+05
1.40E+05
1.35E+05
1.30E+05
1.25E+05
1.20E+05
AB1 Vessel Pressure [Pa]
0
10000
20000
30000
40000
50000
Time [s]
MELCOR 2.2
Data



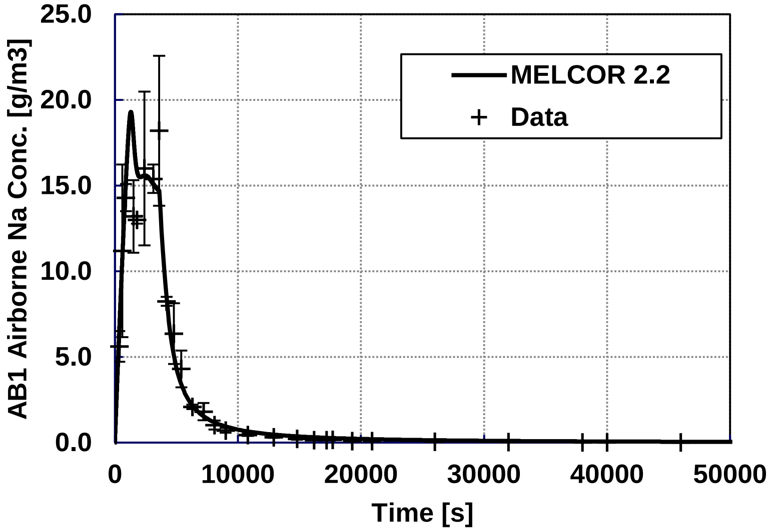
2.4E+05
2.2E+05
2.0E+05
1.8E+05
1.6E+05
1.4E+05
1.2E+05
1.0E+05
AB5 Vessel Pressure [Pa]
1.0E+01
1.0E+02
1.0E+03
1.0E+04
1.0E+05
1.0E+06
Time [s]
MELCOR 2.2
Data

AB1/AB5

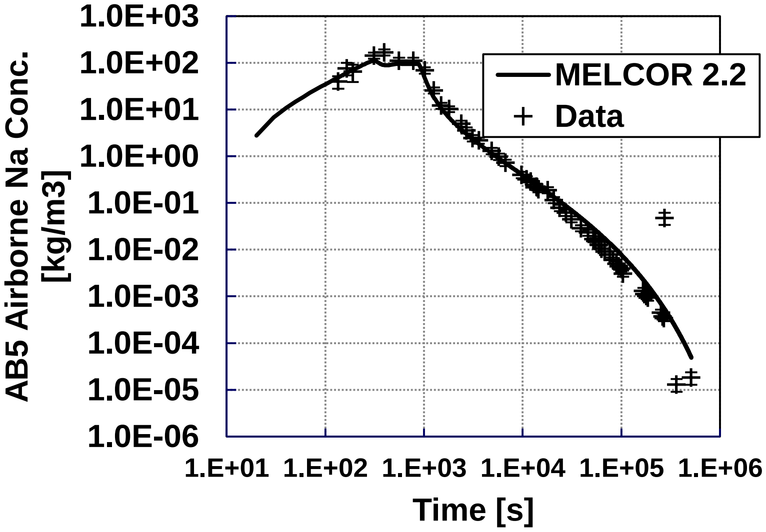

AB1 Atm. Temperature [K]
370.0
360.0
350.0
340.0
330.0
320.0
310.0
300.0
290.0
0
10000
20000
30000
40000
50000
Time [s]
MELCOR 2.2
Data


AB5 Atm. Temperature [K]
625.0
575.0
525.0
475.0
425.0
375.0
325.0
275.0
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
Time [s]
MELCOR 2.2
Data

AB1/AB5

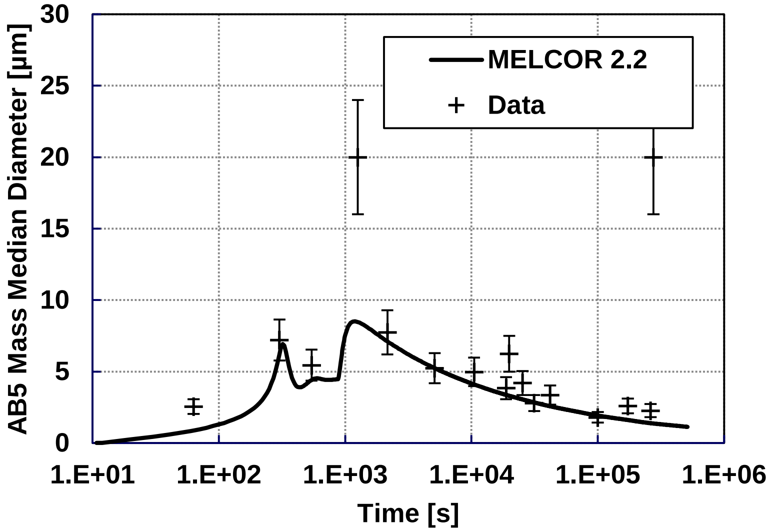


AB1 Airborne Na Conc. [g/m3]
25.0
20.0
15.0
10.0
5.0
0.0
0
10000
20000
30000
40000
50000
Time [s]
MELCOR 2.2
Data

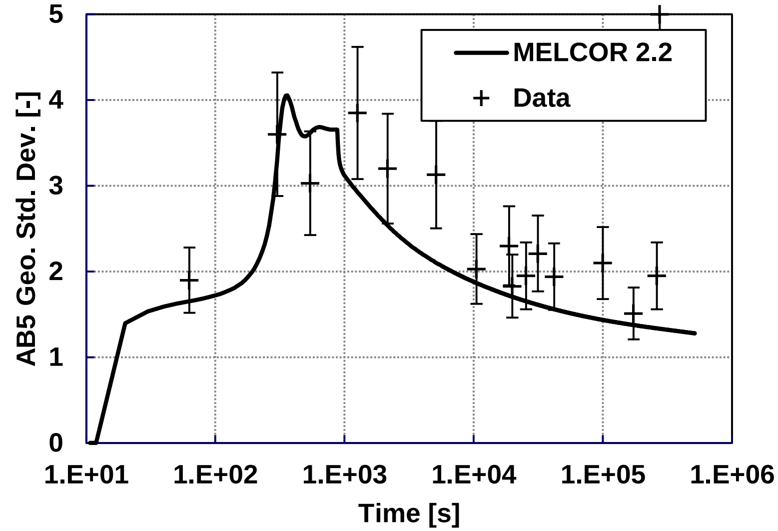


AB5 Airborne Na Conc. [kg/m3]
1.0E+03
1.0E+02
1.0E+01
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
Time [s]
MELCOR 2.2
Data

AB1/AB5



MELCOR 2.2
Data
AB5 Mass Median Diameter [µm]
30
25
20
15
10
5
0
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
Time [s]

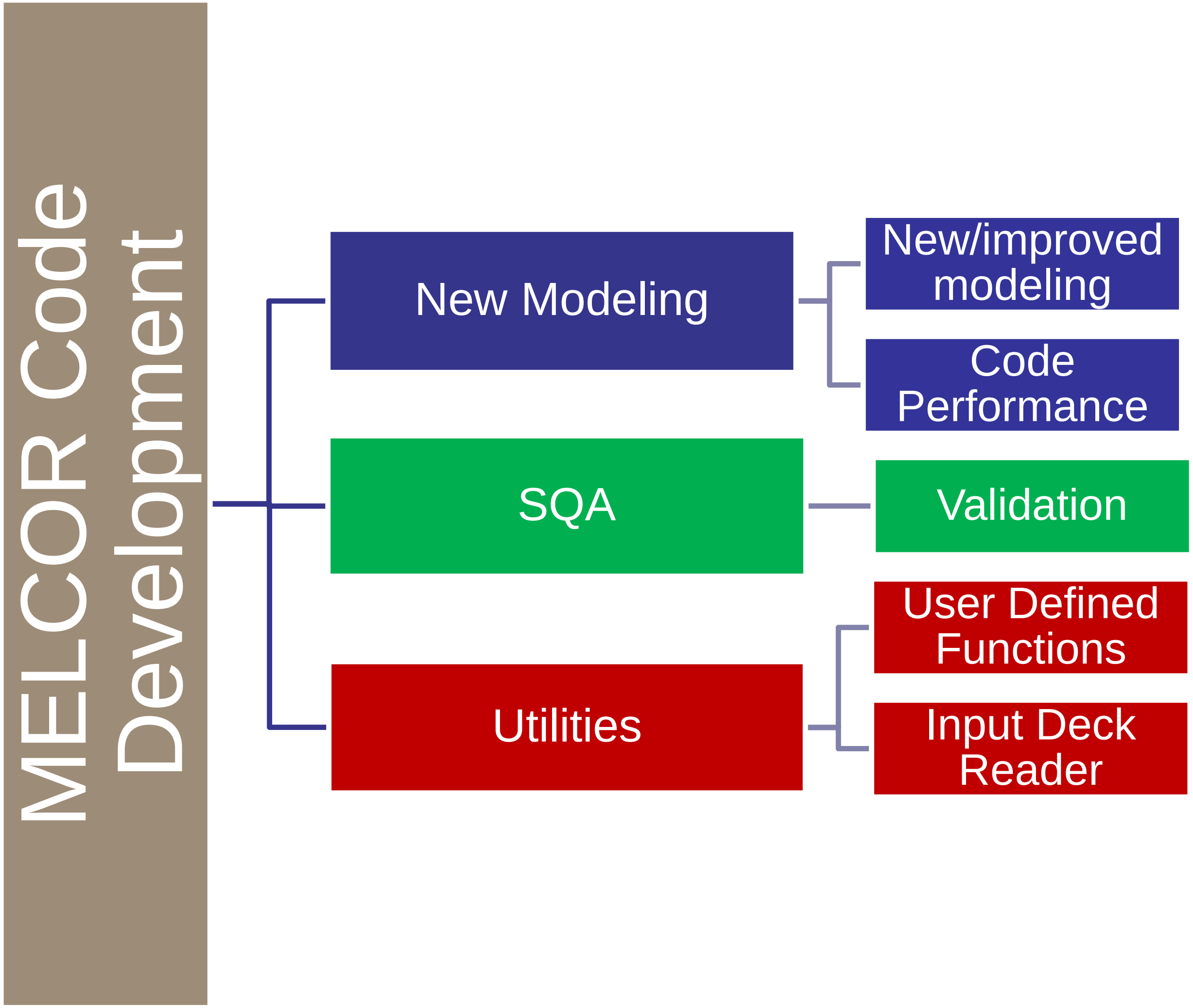


MELCOR 2.2
Data
AB5 Geo. Std. Dev. [-]
5
4
3
2
1
0
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
Time [s]

Challenges Going Forward

- Updating older validation models with current best practice
  - CORA-13 models the outer shroud as canister with modified candling properties. Should use the PWR shroud component
  - Radiation heat transfer from inner rods to boundaries not modeled in models for fuel bundle tests
  - Eutectics/time-at-temperature collapse modeling needs to be examined closely
    - Multiple failure models attempting to capture the same effects
    - Timing of collapse can severely impact simulation
      - MELCOR does not have a mechanical fuel pin failure model
  - Non-LWR Vallidation
    - Validation against existing LWR database is a good start
    - Severe accident data set is extremely sparse
    - Models in MELCOR can be used to assess the sensitivity in data which may or may not need to be refined. Calculations can guide experimental needs

Questions?



MELCOR Code Development
New Modeling
New/improved modeling
Code Performance
SQA
Validation
Utilities
User Defined Functions
Input Deck Reader