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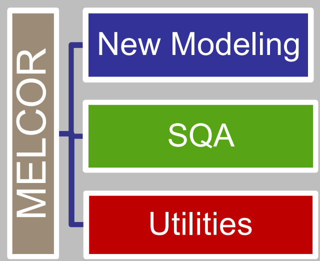

MELCOR Code Development Status
EMUG 2015

Presented by Larry Humphries

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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International Use of MELCOR

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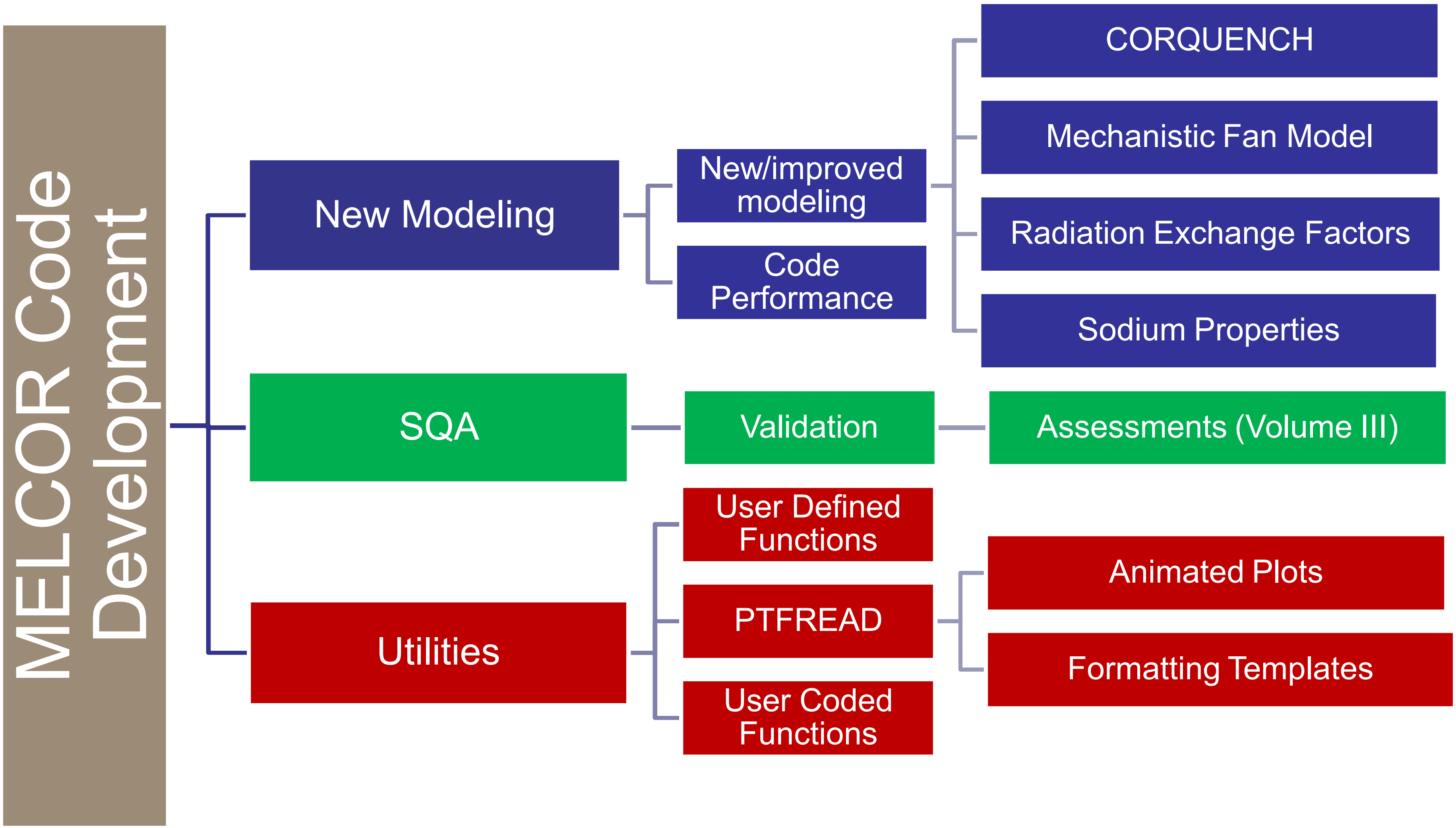
MELCOR Workshops & Meetings

- CSARP/MCAP/ MELCOR Workshop
  - September 8-12, 2014
  - Almost 100 registered
  - MELCOR full week Course
- MELCOR Code Assessment Program (MCAP)
  - September 18-19, 2014
- Asian MELCOR User Group (AMUG)
  - October 13-17th 2014, Republic of Korea
  - Weeklong workshop
- European MELCOR User Group (EMUG)
  - Bel V & Tractebel, Belgium 2015

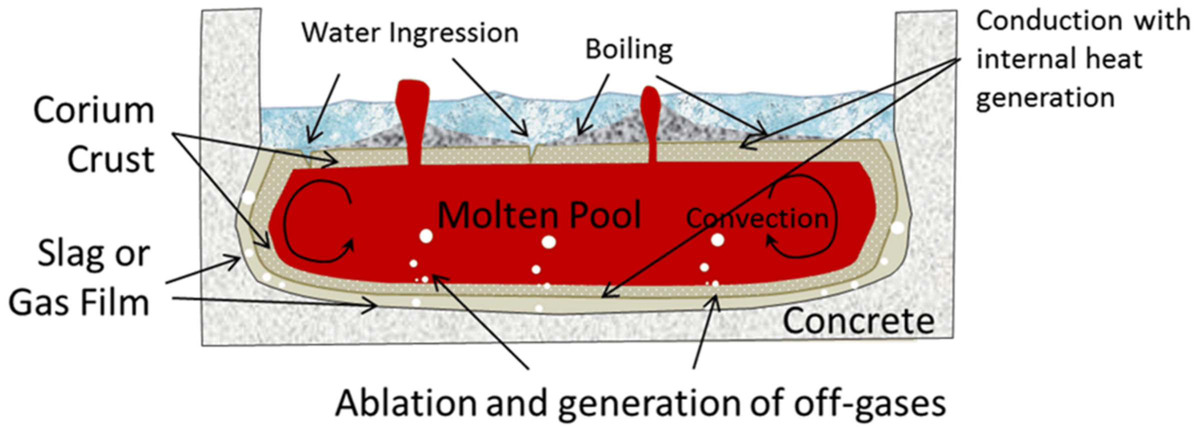
MELCOR Code Development



New Model Development Tasks (2013-2015)

- Completed
  - Mechanistic Fan Cooler Model
  - New debris cooling models added to CAV package
    - Water-ingression
    - Melt eruption through crust
  - Miscellaneous models and code improvements
    - LAG CF
    - MACCS Multi-Ring Release
    - Valve Flow Coefficient
- In Progress
  - Spreading model implemented into CAV package
  - CONTAIN/LMR models for liquid metal reactors
  - Multiple fuel rod types in a COR cell
  - CVH/FL Numerics
  - Core catcher model
  - Aerosol re-suspension model

New Modeling for Top-Quenched Debris in Cavity



- Quenching of the upper crust at the top of the corium debris can lead to a considerable density change (~18%volume) leading to cracking and formation of voids
  - Water ingression reduces conduction path to molten pool and increases surface area of contact
- Molten corium extruded through crust by entrainment from decomposition gases as they escape through fissures and defects in the crust.
  - Enhance the coolability of the molten corium
    - by relocating enthalpy from the internal melt through the crust
    - more coolable geometry that is more porous and permeable to water

MELCOR Debris Spreading Model

- By default, corium relocated to the cavity will spread instantaneously
- Users are able to specify a spreading radius through a CF or TF
- Current model development adds an internally calculated spreading radius.
  - Balance between gravitational and viscous forces

CAV_SP – Definition of Parametric Debris Spreading
Optional

This record may be used to model the spreading of debris in the cavity. Users can define a maximum debris radius as a function of time through a tabular function, control function, channel of an external data file, or an internal model.

(1) SOURCE

Source of data for maximum debris radius as a function of time

1 or 'TF'
Use data from tabular function.

-1 or 'CF'
Use data from control function.

2 or 'CHANNELEDF',
Use data from channel of external data file NameCF_TF_EDF.

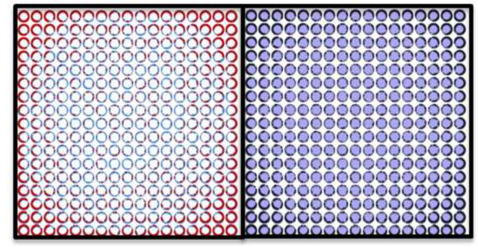
0 or 'MODEL',
This option allows the code to internally calculate the debris radius as a function of time. However, this option requires the initial debris radius (RADTINI).

If SOURCE = 0, the following record is required:

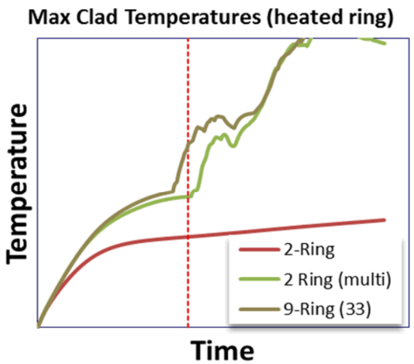
(2) RADTINI - Initial time-dependent debris radius for the internal model

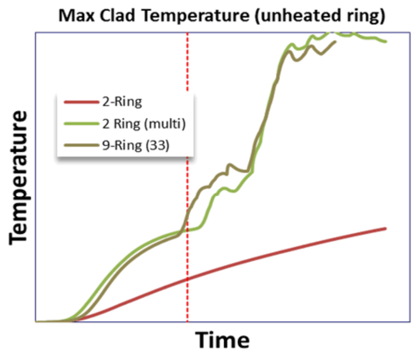
Multi-Rod Model

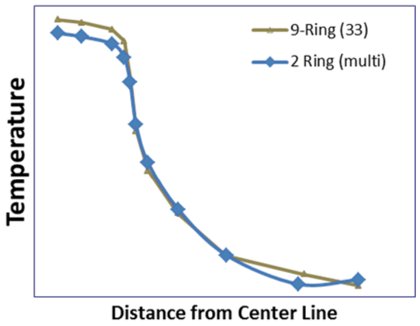
- Motivation
  - It is desirable to model an entire assembly within a single MELCOR ring
- Challenge
  - When hot assembly reaches ignition, heat transfer to cold assembly is problematic

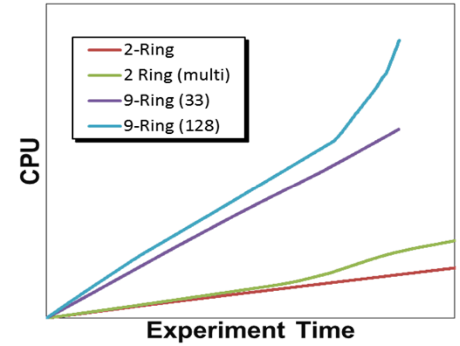


Hot Assembly Cold Assembly









- Validation
  - Validation was performed against the Sandia PWR Spent Fuel Pool Experiments
  - Comparisons between 2-ring (2 rods) model; 2-ring, (9 rods) model; and 9-ring model.
- CPU time is greatly reduced for multi-rod model
- Simplified input requirements

Miscellaneous New Models: Valve Flow Coefficient

- Description
  - Valve flow coefficients are typically used in characterizing flow properties of valves.
  - By definition, a valve has a C_v of 1 when a pressure of 1 psi causes a flow of 1 US gallon per minute of water at 60° F (i.e. SG = 1) through the valve.
  - Since the pressure drop through a valve is proportional to the square of the flow rate:

$$C_v = Q * \sqrt{\frac{SG}{\Delta P}}$$

    – Q=Flow in gpm
    – Cv = Valve flow coefficient
    – DP = Difference in pressure (psi)
    – SG = specific gravity of liquid relative to water at 60 F

- Implementation
  - The user indicates that the valve is a 'NoTRIPCV' and then supplies a CF for specifying the value of C_V for the valve
  - The valve must be on a single segment flowpath and takes the pipe diameter from this segment
  - Standard engineering units for flow coefficient are gpm/sqrt(psi) are expected.

```
fl_vlv   1
     1      'TestValve'       'VALVE'  NoTRIPCV       'CVvsTime'
```

Miscellaneous New Models: Lag Control Function

- The lag function type (designated by the short name LAG) is a basic control theory function for which a function that is passed as an argument, $a_1(t)$, is transformed through the following integral equation.

$$f(t) = \int^{t} \left(\frac{c_2 \cdot a_1(t) - f(t)}{c_1}\right) dt$$

- Where c_1 is the lag time (seconds) and c_2 is a scaling factor. In differential form, this integral is advanced using the following transform equation.

$$f^{n+1} = \frac{f^n\left(1 - \frac{dt}{2c_1}\right) + c_2\left(a_1^n + a_1^{n+1}\right)\frac{dt}{2c_1}}{1 + \frac{dt}{2c_1}}$$

- May improve numerical uncertainty

Miscellaneous New Models: COR_HTR extended to HS

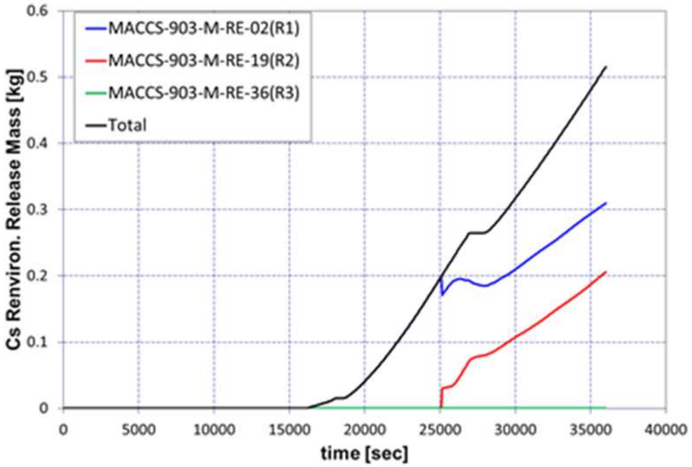
- This feature has been extended to allow specification of a heat transfer path from a COR component to a heat structure. The heat transfer path must be defined 'From' a valid COR component and the heat structure must not have a user specified boundary condition (i.e., IBCL = 0,20,30,80, or 90). Furthermore, if a radiation path is defined, the emissivity must be defined by the user on the appropriate HS Boundary Surface Radiation Data record (HS_LBR or HS_RBR).

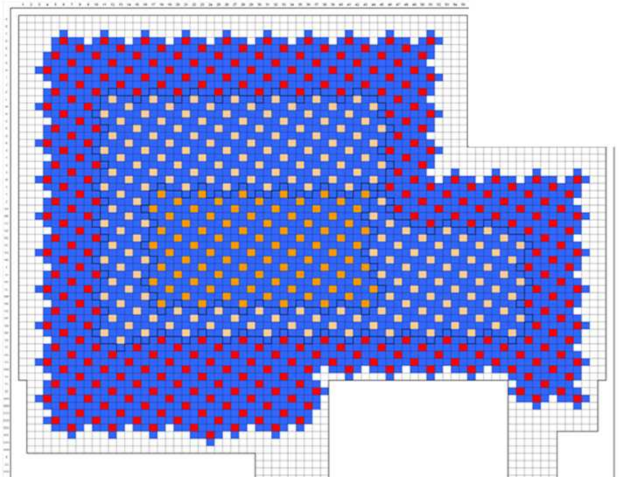
Example

```
COR_HTR 2  !From: IA IR IC To: IA IR IC FLAG        COEFF
            1  2  4   SS     3     3      SH    CONDUCT-CONST  0.0818
            2  2  4   SS   HS#  LEFT  HS    CONDUCT-CONST  0.0818
```

Miscellaneous New Models: MACCS Multi-ring release

- Motivation
  - Burnup and therefore activity for distinct rings may be vastly different. Recently, MACCS has been modified to allow it to distinguish masses provided by MELCOR by batch (ring). MACCS then will associate different activities for a class, dependent on the ring of origination
  - The problem is that once RN mass is released, it can no longer be distinguished by originating ring.
- New variable for approximating mass release by offload batch (ring)
  - Not really a new model
  - Creation of a plot variable in the binary plot file
  - This is an approximation in obtaining a plot variable
- Previously implemented by KC Wagner through use of control functions.
  - Control function description can be quite lengthy even for a two-ring model





DOE Models: CONTAIN/LMR Models for

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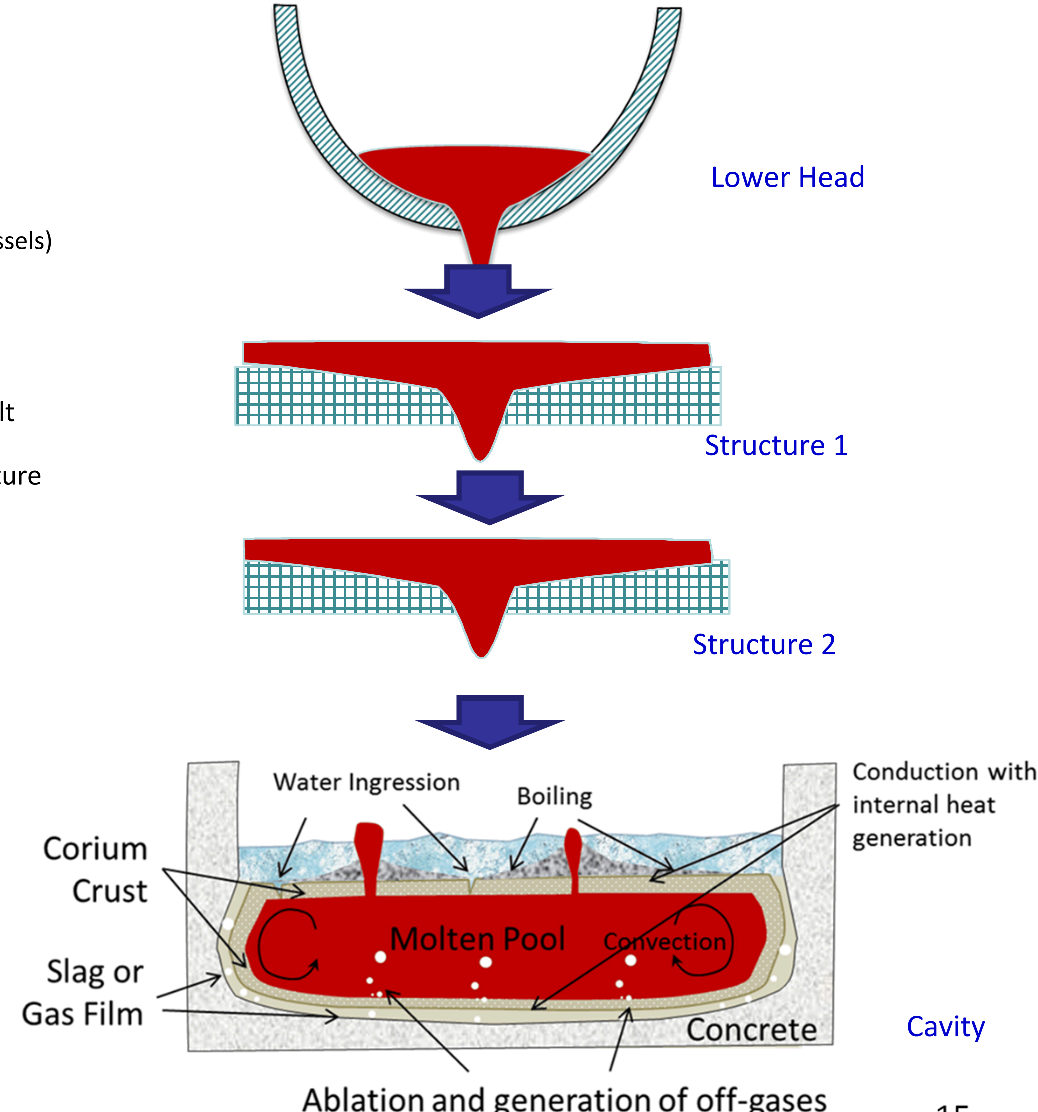
- Phase 1 – Implement sodium as replacement to the working fluid for a MELCOR calculation
  - Implement properties & Equations Of State (EOS) from the fusion safety database
  - Implement properties & EOS based on SIMMER-III
- Phase 2 – Review of CONTAIN/LMR and preparation of design documents
  - Detailed examination of LMR models with regards to implementation into MELCOR architecture
  - Condensation of sodium
- Phase 3 – Implementation and Validation of:
  - Sodium spray fires
  - Upper cell chemistry
  - Sodium pool chemistry
- Phase 4 – Implementation and Validation of:
  - Sodium pool modeling,
  - Sodium pool fire models
  - Debris bed/concrete cavity interactions.

DOE Models: Core Catcher / Ex-Vessel Structure Model

- New model for simulating core catcher assembly (assemblies) outside the lower head.
  - Can also be used to simulate multiple lower heads or secondary pressure vessels
    - Debris relocated from lower head to core catcher via transfer process
    - Allow for multiple core catcher objects (pressure vessels) connected via transfer processes
- 2-D core catcher nodalized through the wall
  - Through-wall and transverse heat conduction
  - CV volumes serve as boundary conditions
  - Available volume between structures can constrain melt relocation
  - Heat transfer between debris and 'upper' (inner) structure
    - Radiation
    - Possible contact
  - Material composition of structure varies through mesh
  - Allow for vessel structure to melt and molten material become part of molten debris.
    - Simple eutectics
  - Homogeneous molten debris
  - Crust between molten debris and structure
  - Same RN release modeling as in COR package
  - Penetrations not modeled
- Multiple failure criteria
    - Failure by melt-through
    - Failure by control function
    - Secondary Pressure Vessel
      - Larson-Miller Creep
      - Yield Stress
- Work begins in October
  - To be completed in 2015



DOE Models: Re-suspension Model

- Re-suspension modeling approaches
  - Static Methods
    - Force balances or force ratio model assert that liftoff is determined by a balance between aerodynamic and adhesive forces. Incorporates moments and distribution of forces
    - Calculates amount removed (no rate information)
    - Reeks-Hall removal force
  - Dynamic or kinetic models
    - Attempts to improve on static methods by adding various dynamic features into the model, such as resonances, energy storage, rolling, force moments, surface deformation, etc.
    - Rates of re-suspension are calculated.
    - Rock ‘n’ roll model
- MELCOR approach
  - Simplest model that is supported by the data (static methods).
  - Other models (dynamic) can be incorporated later if validation supports such model improvements.
- Validation against STORM tests (SR11 and SR12)

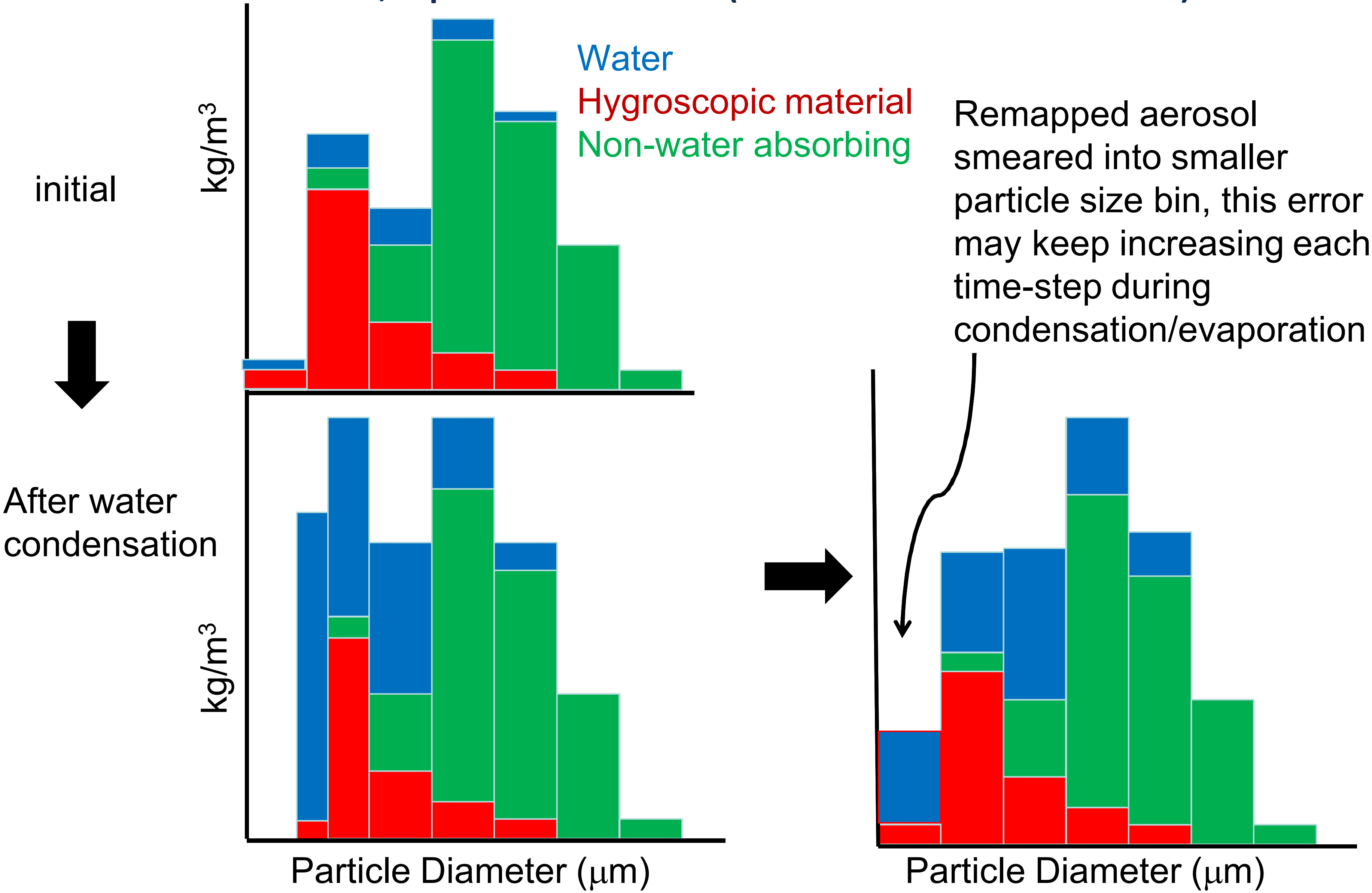
Improved CVH/FL Numerics

- Retain same physics and basic equation set
- Revise code to improve stability and efficiency of explicit coupling and time integration
  - Introduce "temporal" filter on all flux rate terms
  - Improved and consistent treatment of "small value threshold" situations
- Revise code to cast all implicit equations (e.g. CVH-FL) in residual form
  - Enables use of Modern Solver libraries (e.g. Trilinos, PETSc)
  - Better separation of Computer Science from the Physics/Models

Improvements to MAEROS Aerosol Particle Growth by Condensation and Hygroscopic Absorption of Water Vapor

- **Current Status in MELCOR and Reason for Needed Advancement**
  - When excess steam introduced into a cell, condensed water drops are placed into smaller particle size bin instead of condensing on existing aerosol.
  - When steam condenses on hygroscopic particles, numerical diffusion leaves some particles in bins that should have been depleted of these particles.
- **Proposed Enhancements to MELCOR**
  - Steam will condense on aerosol based on particle concentration, surface area, and chemical composition.
  - Numerical diffusion to be minimized by also tracking number concentration of particles in addition to mass concentration of each chemical in aerosol.
- **Expected Completion Time**
  - Stand-alone implementation and testing (June 2015)
  - MELCOR implementation and testing (Aug 2015)
  - Documentation (Sept 2015)

Basic Concept: Remapping aerosol mass to bins after condensation, spreads mass (numerical diffusion)



Solution: Increase order of mass concentration approximation from constant to linear within a bin

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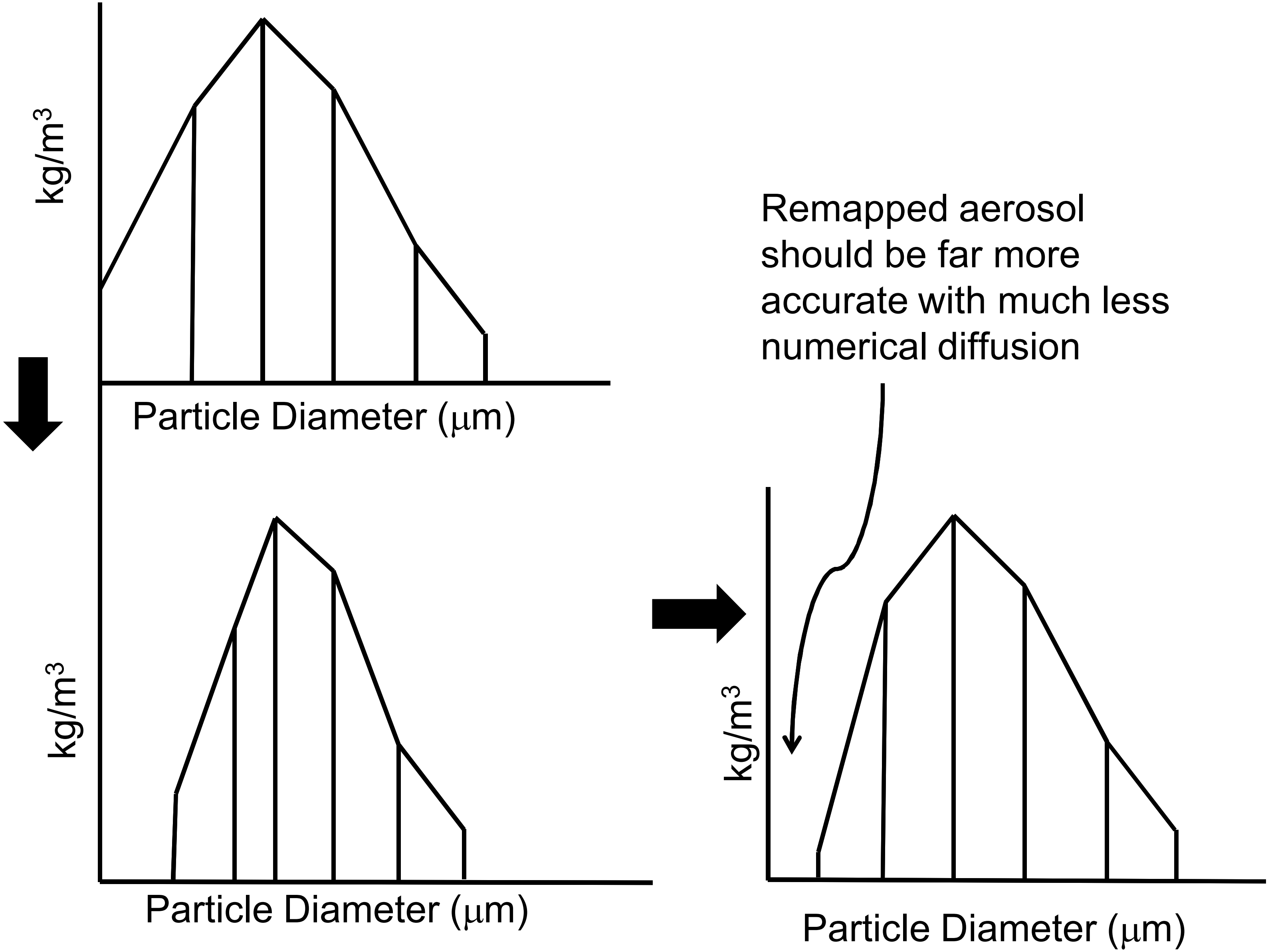


Importance of Code Validation

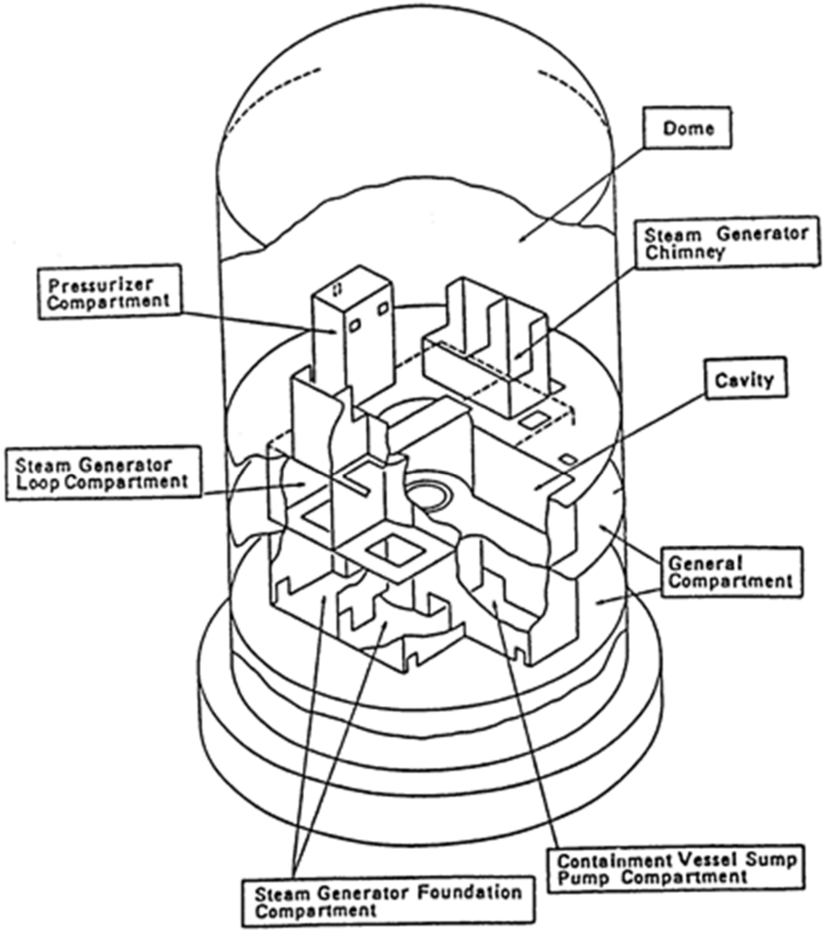
- Code Developers
  - provide the necessary guidance in developing and improving models
  - Desirable to have validation test at time of model implementation
- Code Users
  - Increased confidence in applying code to real-world application
  - Improved understanding of modeling uncertainties

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

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	Containmen t 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

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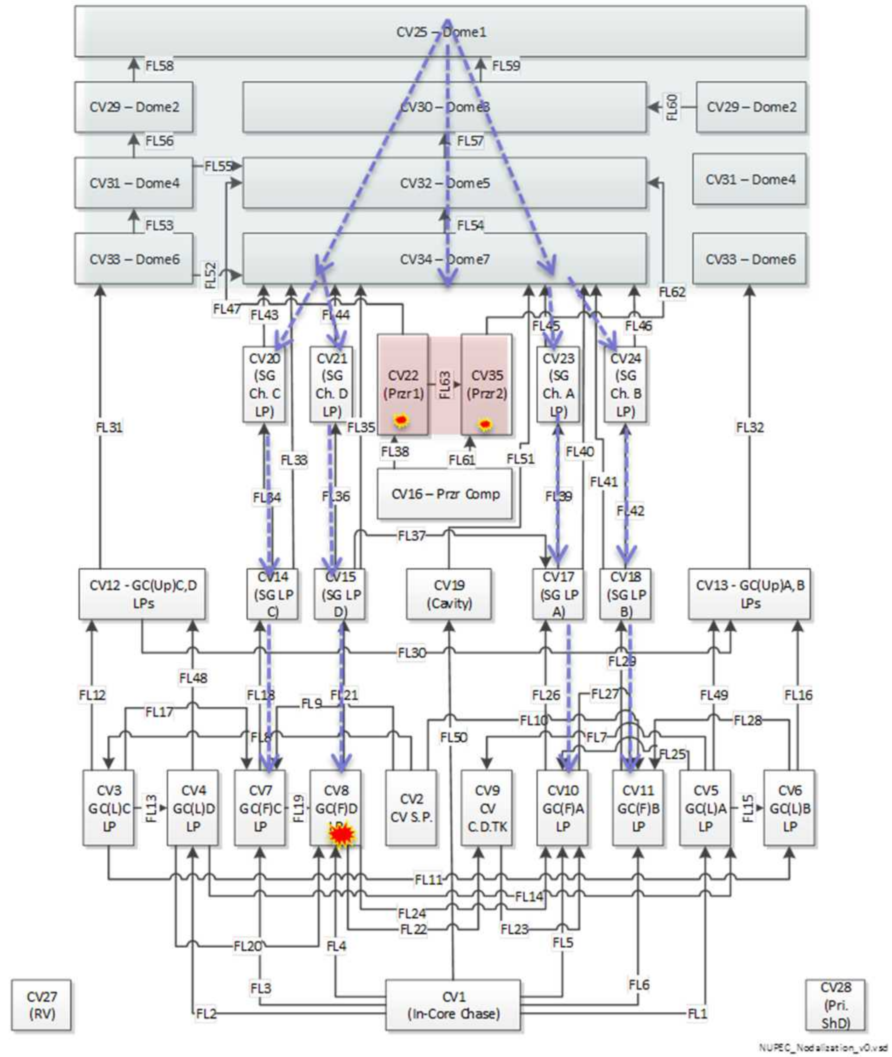
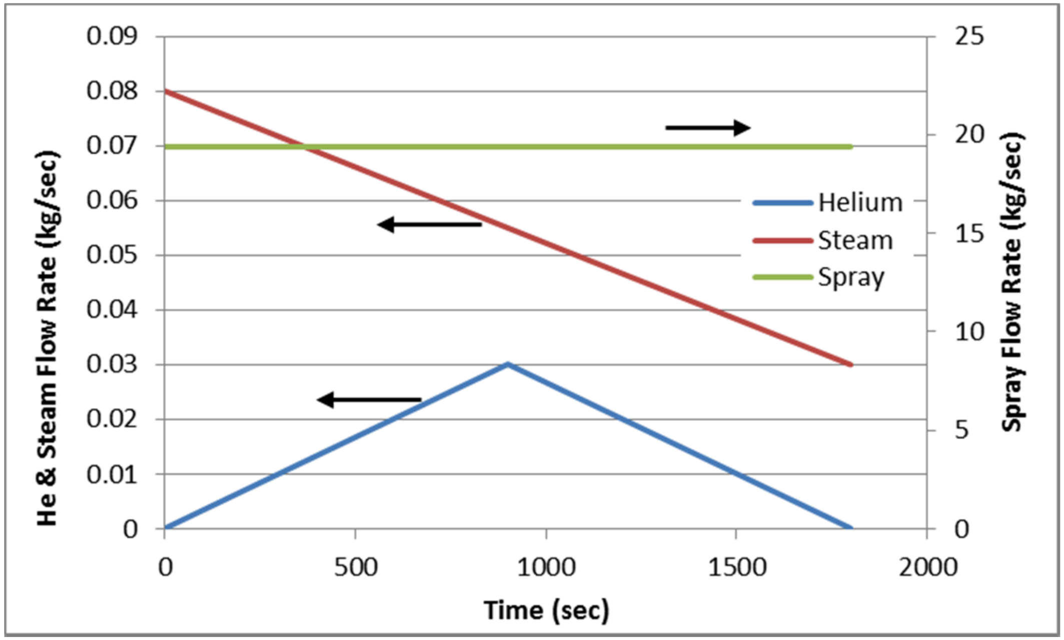
- Total of 35 CVs
  - Dome compartment subdivided into 7 CVs (green)
    - Allows convection loops
  - Upper pressurizer subdivided into two CVs (red)
    - Allows circulation from upper pressure compartment to lower compartment (dead end)
  - All other compartments represented by a single CV
- M-8-1 & 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



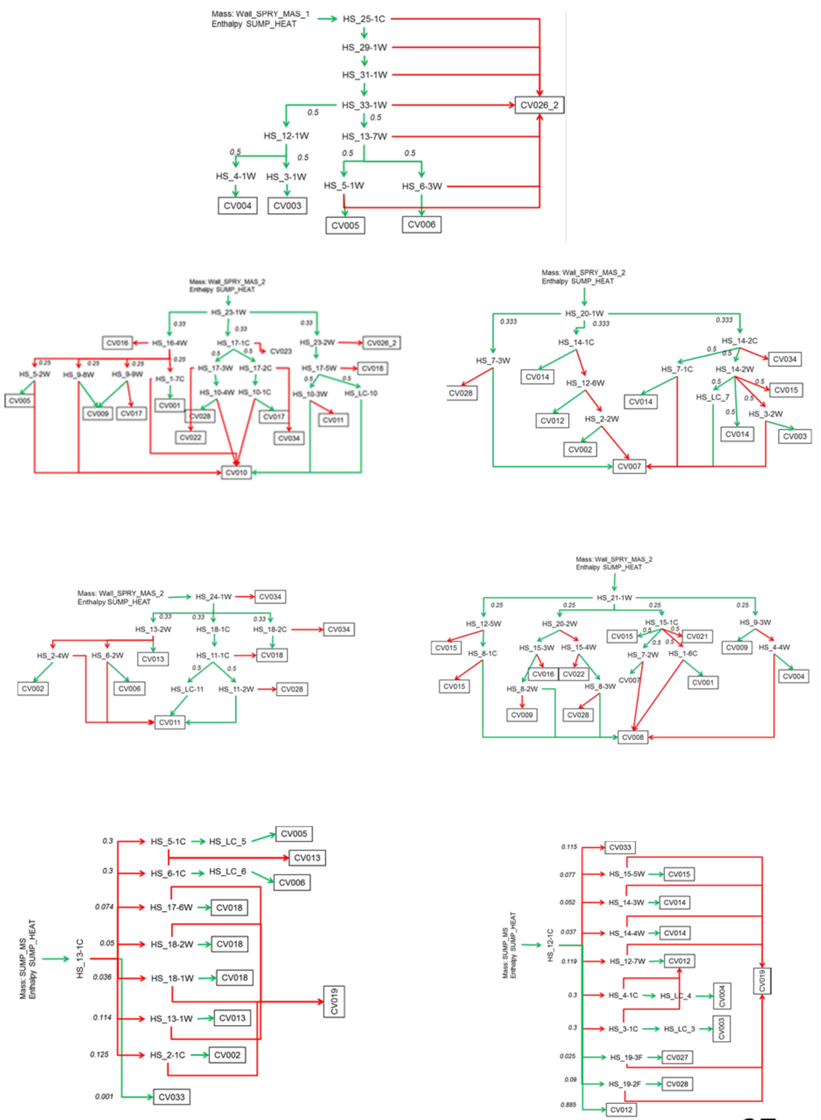
He, Steam, and Spray Sources

- 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.

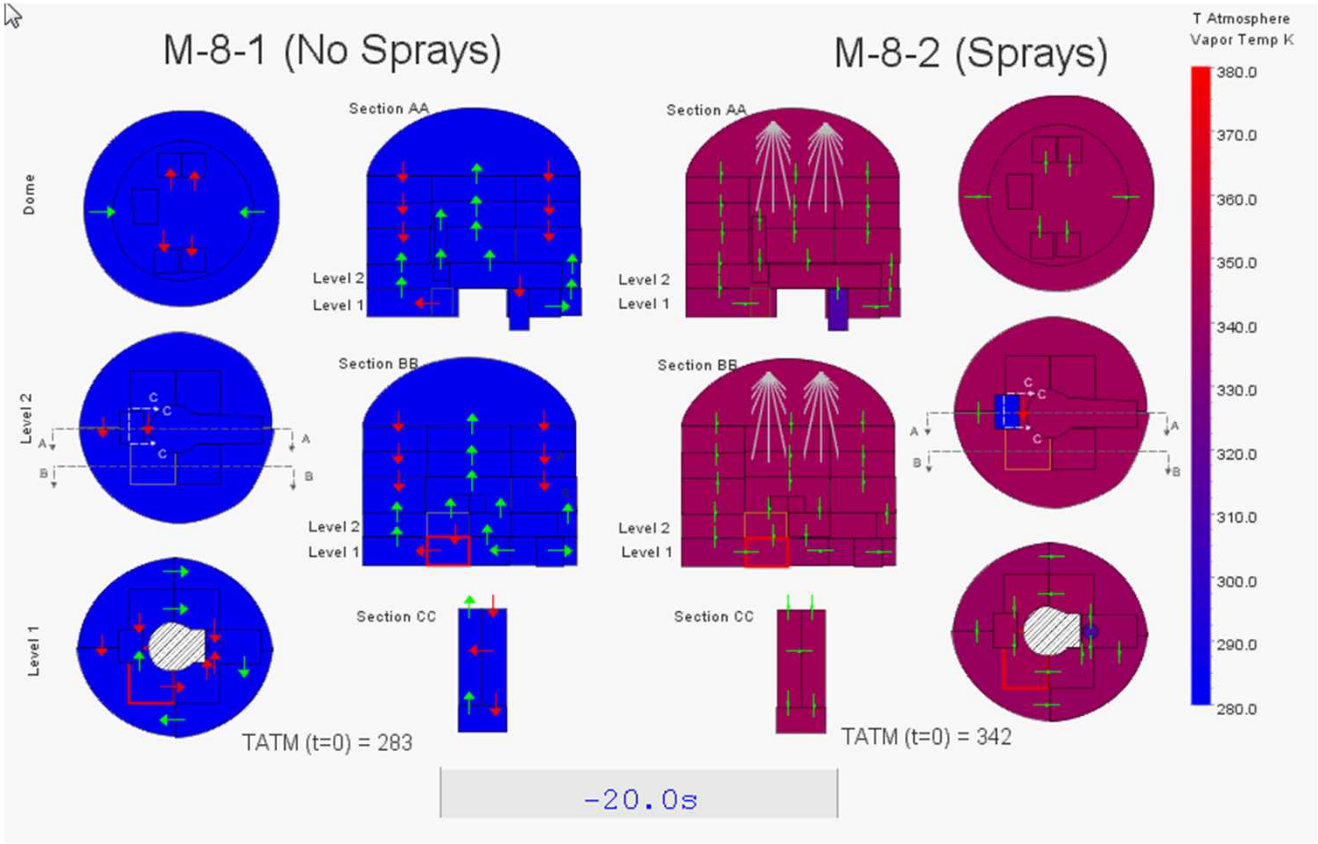


HS Film-Tracking Networks

- 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

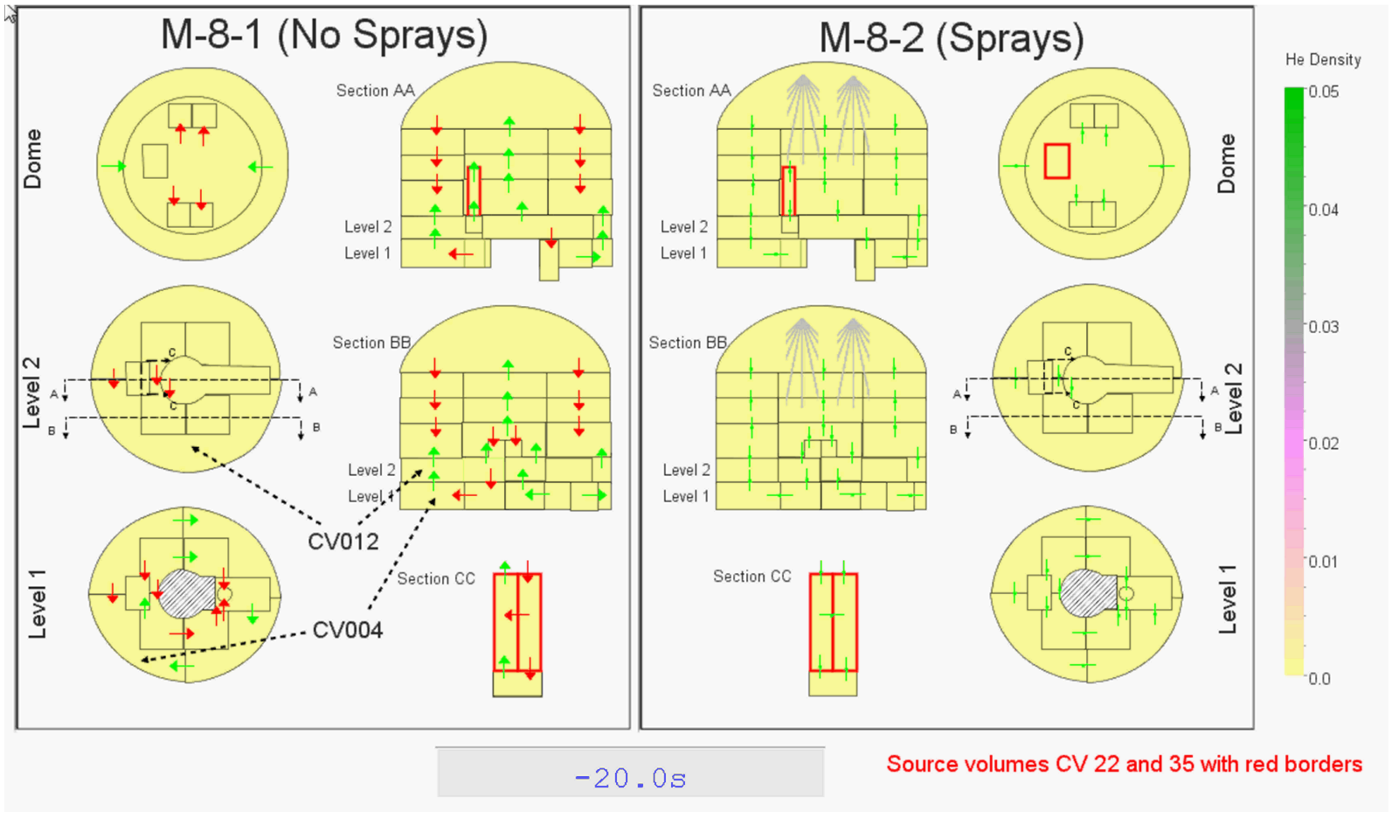


Temperature Distributions



- 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

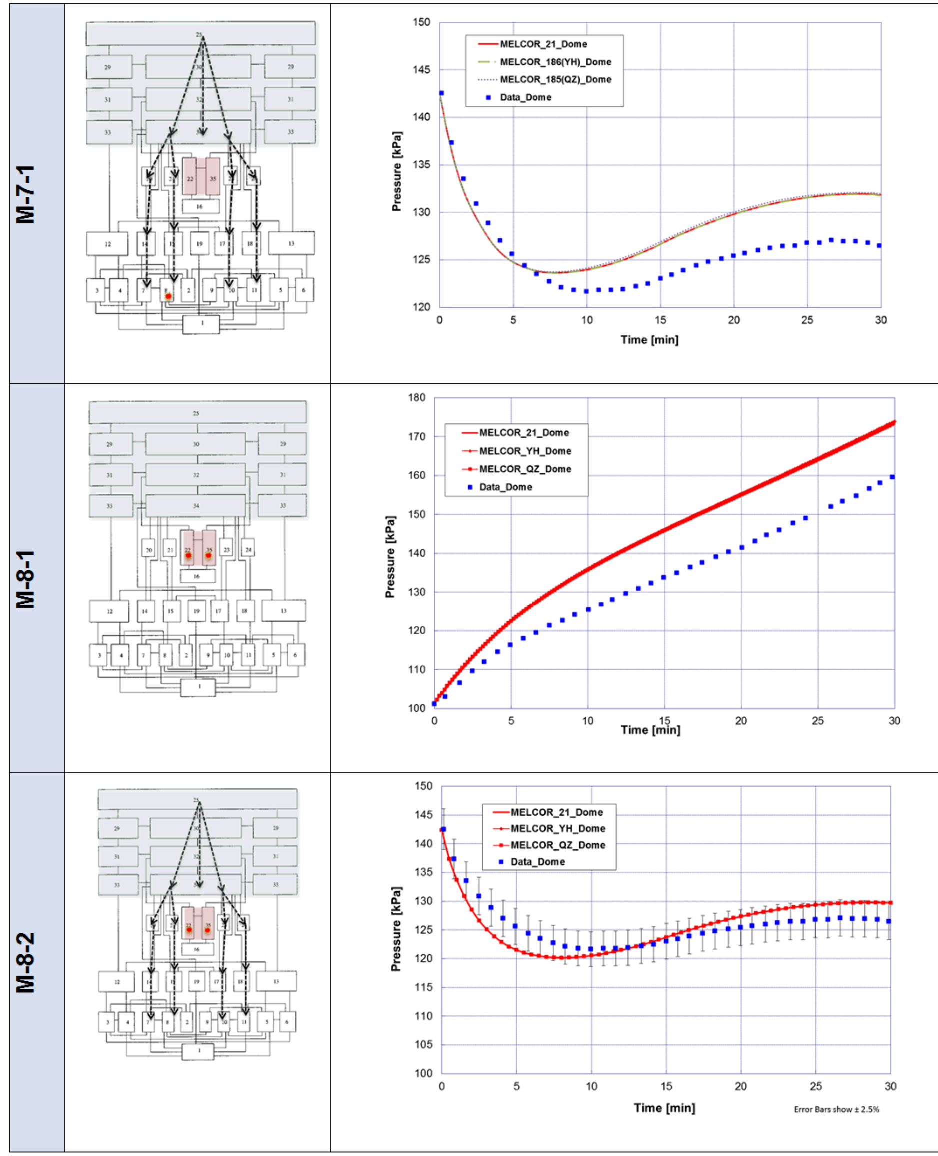
He Concentration Distributions



- Similarly, stratification of helium in the upper dome is much more significant for M-8-1 than M-8-2
- Stratification by floor 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

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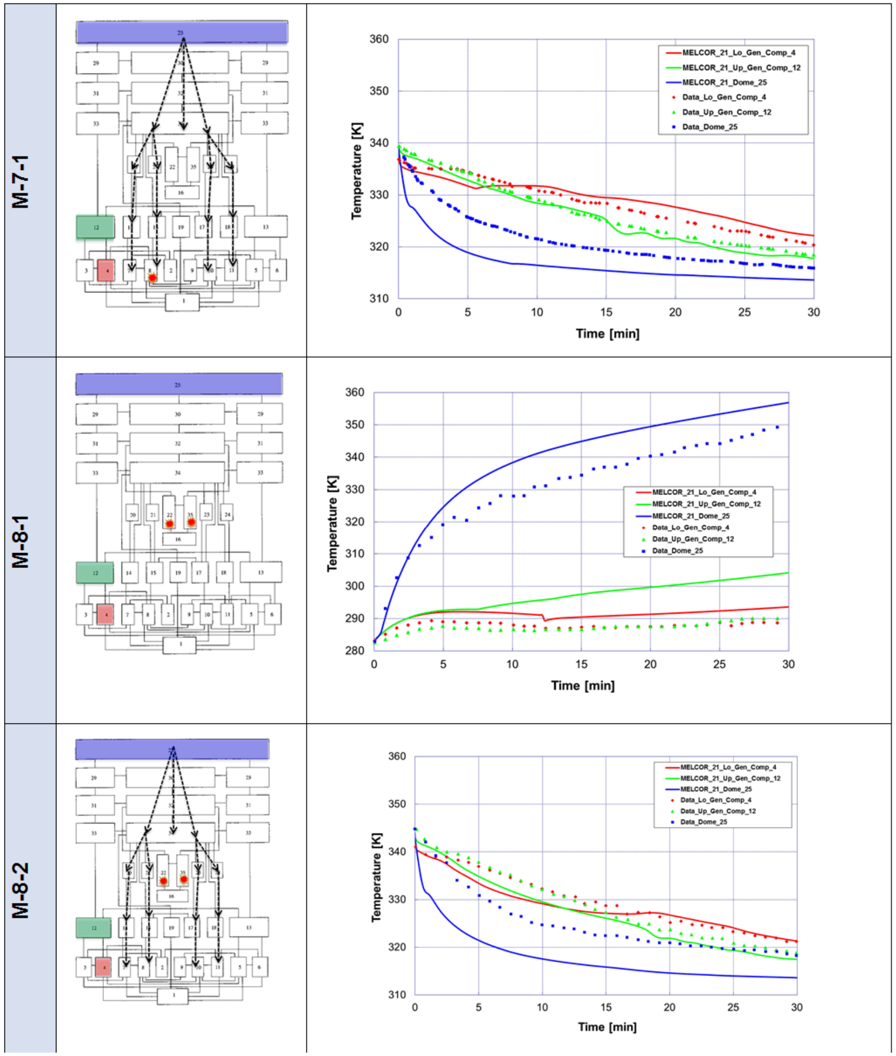
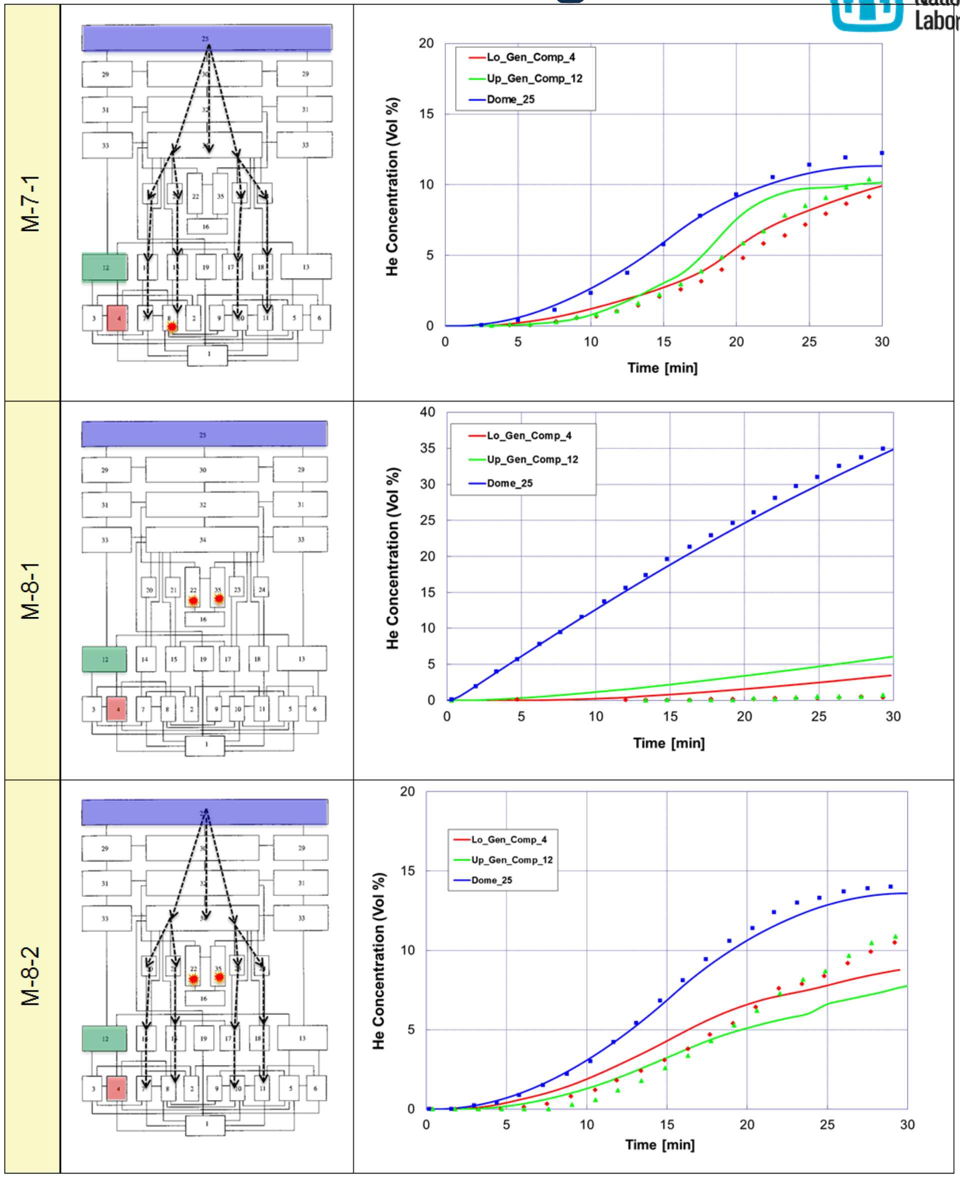
- Calculated temperature in dome is less than measured data for spray tests
  - Cooling from spray is overpredicted slightly by MELCOR
- Calculated temperature in dome is greater than data without sprays.
  - Stratification may be slightly overpredicted.



Color indicates CV

He Concentrations for vert. distribution of general region

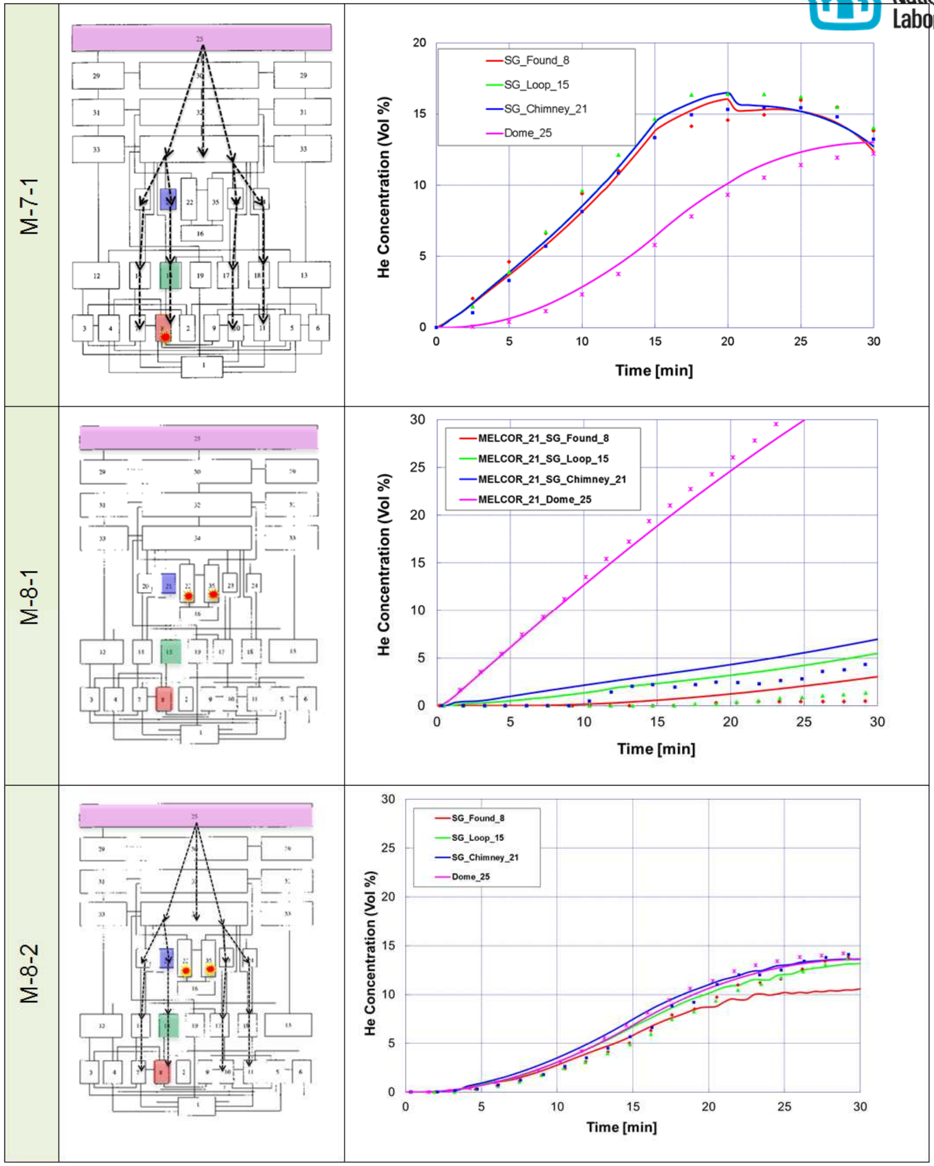
- Without sprays
  - MELCOR significantly overpredicts concentration in lower general compartments
- With sprays
  - He concentration well-predicted for all compartments



Color indicates CV

He Concentrations for vertical distribution of SG loop D

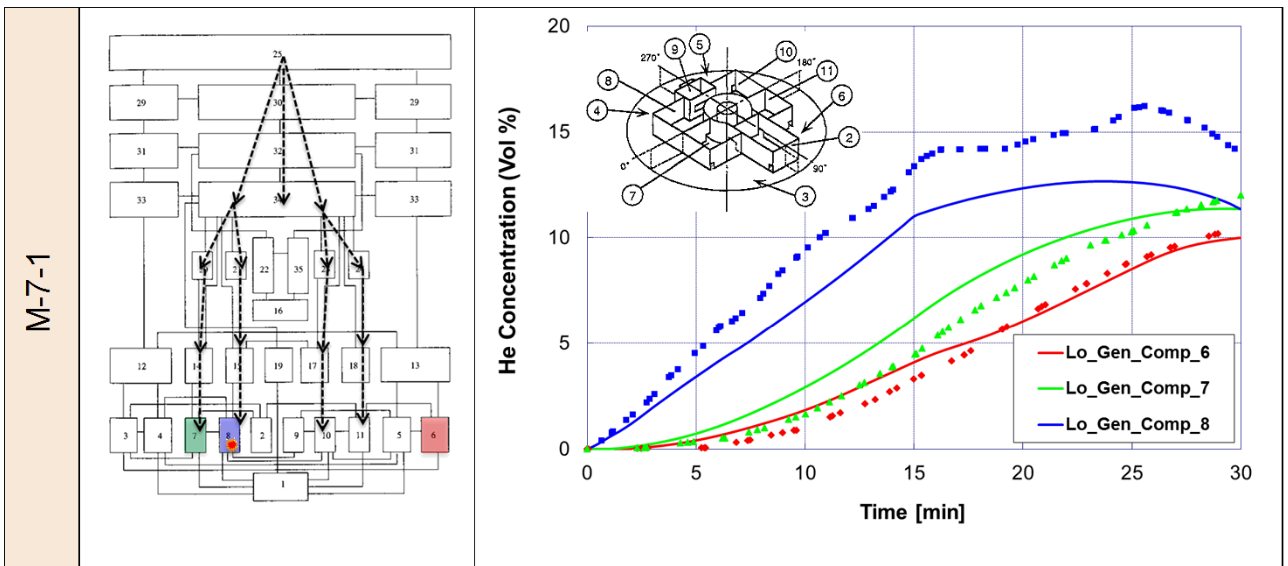
- Concentration in dome is well-predicted for all cases
- M-7-1 shows underprediction of He in mid-level compartments for source in lower level
- Slight under-prediction of concentration for lower compartments in M-8-2 otherwise, well predicted



Color indicates CV

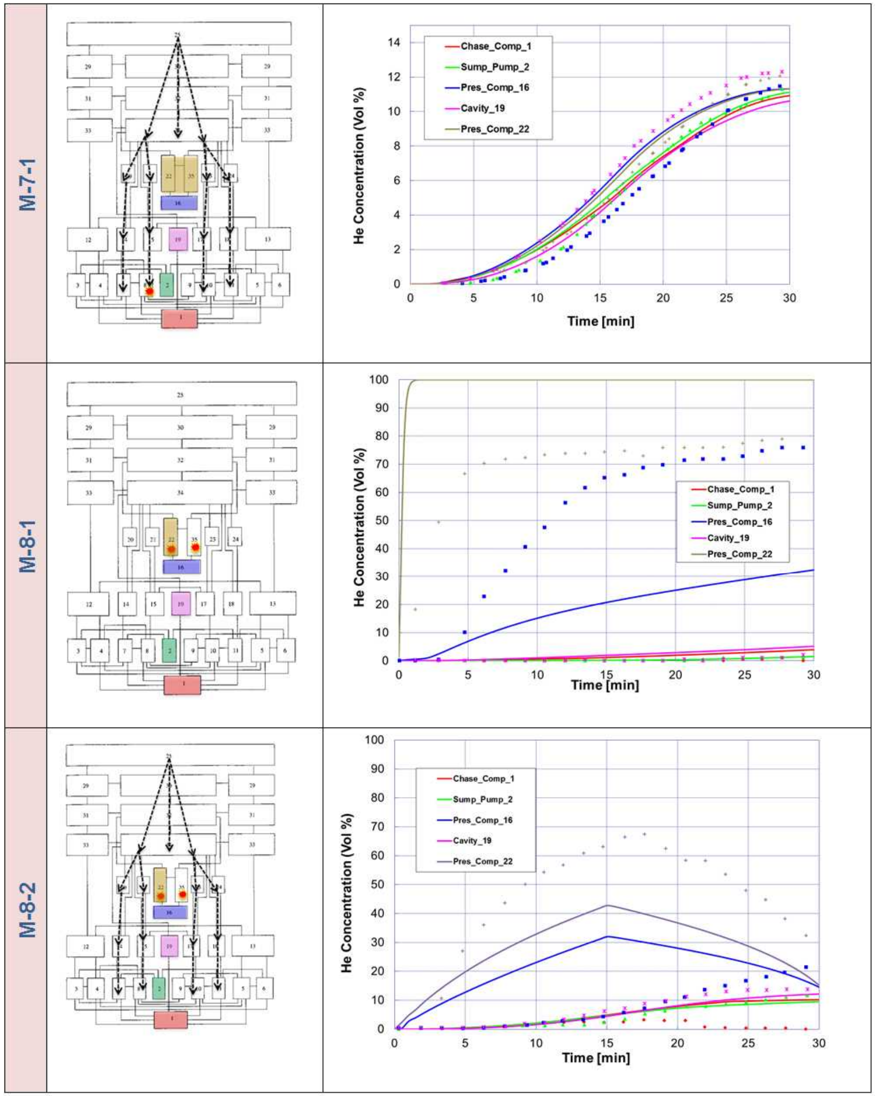
He Concentrations for 1st floor horizontal distribution

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



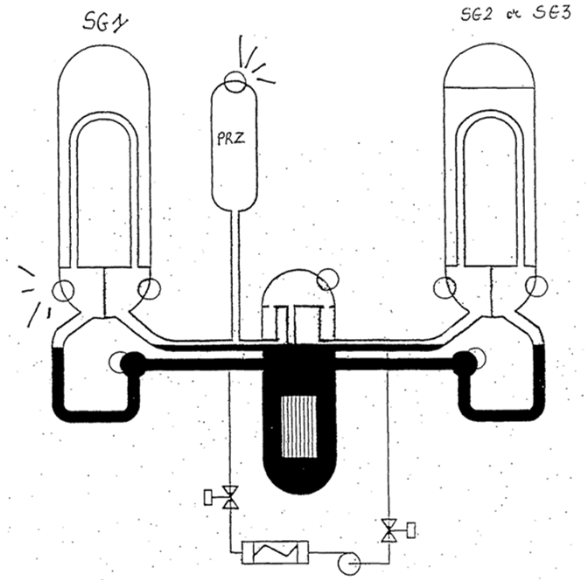
He concentrations for vertical distribution center/pressurizer region

- 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

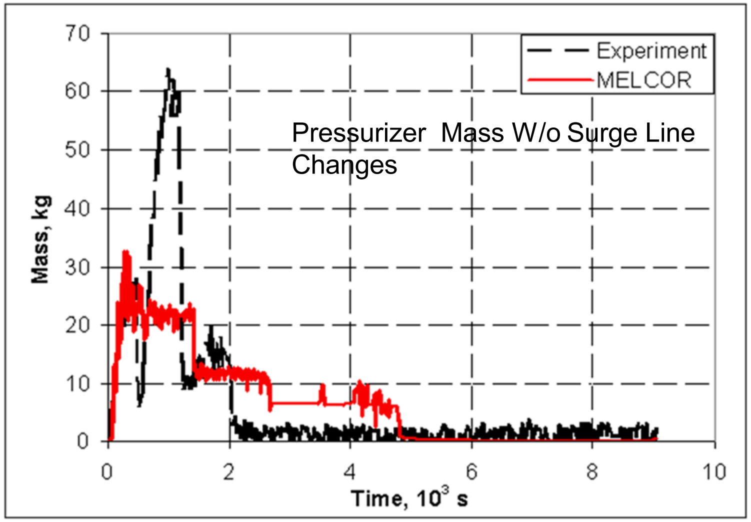


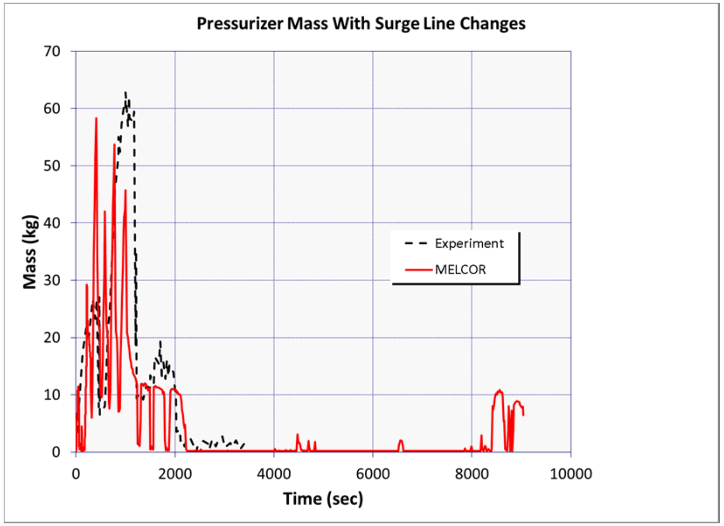
Color indicates CV

Findings: Proper Modeling of Surge Line (Bethsy)

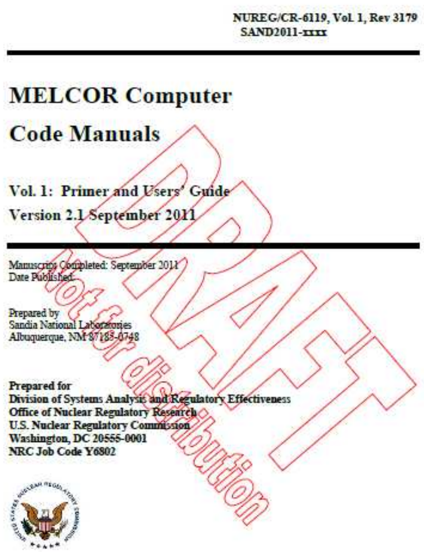


- Key surge line modeling aspects:
  - Pressurizer surge line FL junction heights (from and to) need to extend the full height of connected control volumes with the exception of the junction from the hot leg for which height should be defaulted
  - Pressurizer surge line FL momentum exchange lengths need to reflect full elevation differences between connected points
  - The pressurizer needs to be represented by more than one control volume
- Important model-wide modeling aspects:
  - Flow path momentum exchange lengths need to meaningfully couple the phases (water and steam) throughout
  - Flow path (FL) junction heights need to allow meaningful carry-under of steam and carryover of water throughout
  - Stopped RCP flow resistance needs to be accounted for





MELCOR Documentation



NUREG/CR-6119, Vol. 1, Rev 3179
SAND2011-xxxx

MELCOR Computer Code Manuals

Vol. 1: Primer and Users' Guide
Version 2.1 September 2011

Manuscript Completed: September 2011
Date Published:

Prepared by
Sandia National Laboratories
Albuquerque, NM 87185-0748

Prepared for
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code Y6802

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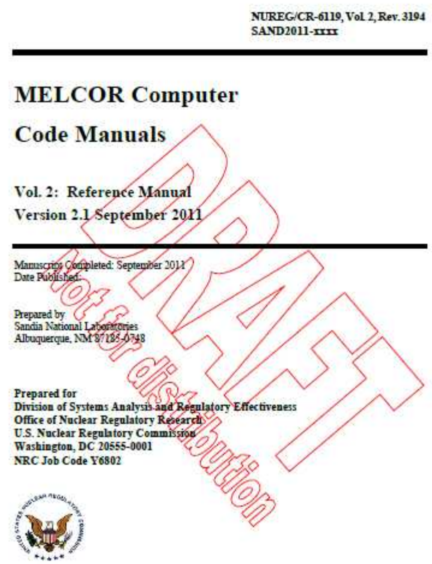

NUREG/CR-6119, Vol 2, Rev. 3194
SAND2011-xxxx

MELCOR Computer Code Manuals

Vol. 2: Reference Manual
Version 2.1 September 2011

Manuscript Completed: September 2011
Date Published:

Prepared by
Sandia National Laboratories
Albuquerque, NM 87185-0748

Prepared for
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code Y6802

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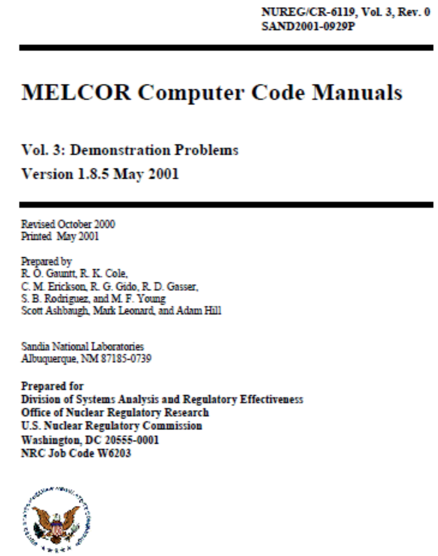

NUREG/CR-6119, Vol. 3, Rev. 0
SAND2001-0929P

MELCOR Computer Code Manuals

Vol. 3: Demonstration Problems
Version 1.8.5 May 2001

Revised October 2000
Printed May 2001

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Prepared for
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code W6203

Volume I: User Guide

NRC Currently Reviewing

Volume II: Reference Manual

NRC Currently Reviewing

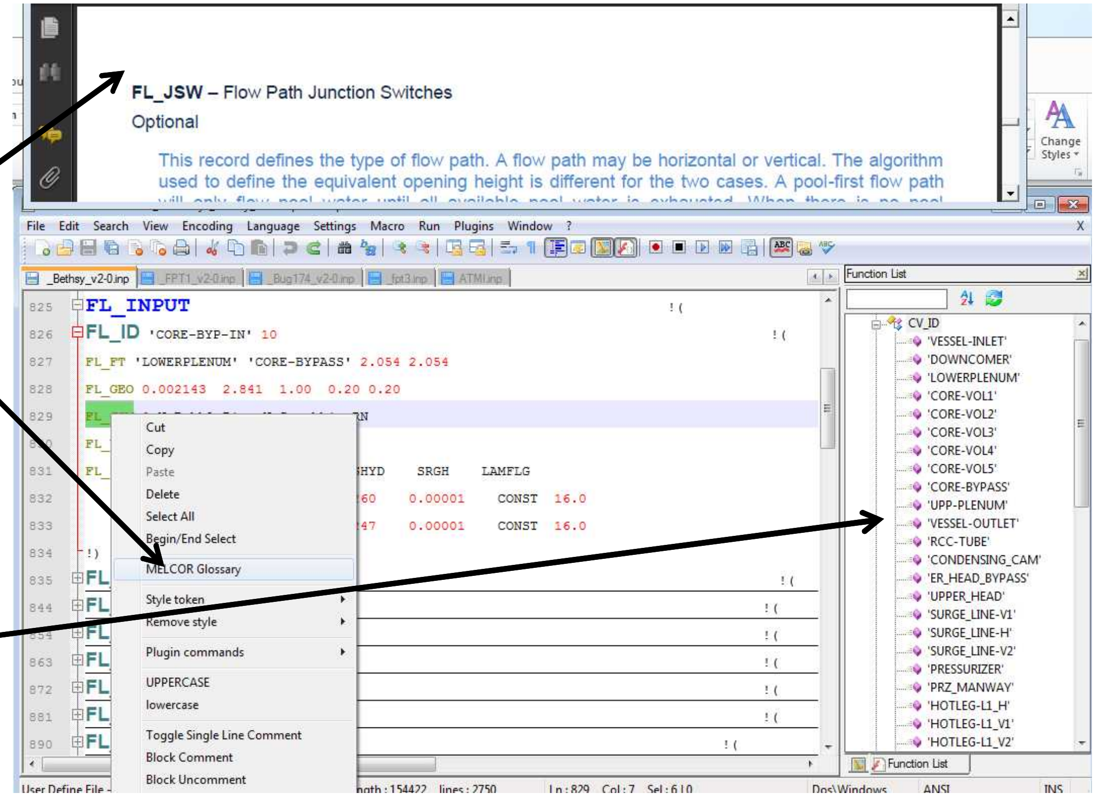
Volume III: Assessments

Submitted for NRC Review March 2015

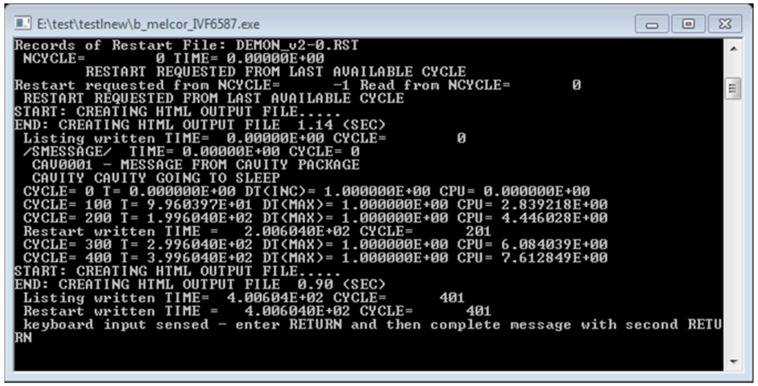
NotePad++ MELCOR Plugin

Sandia National Laboratories

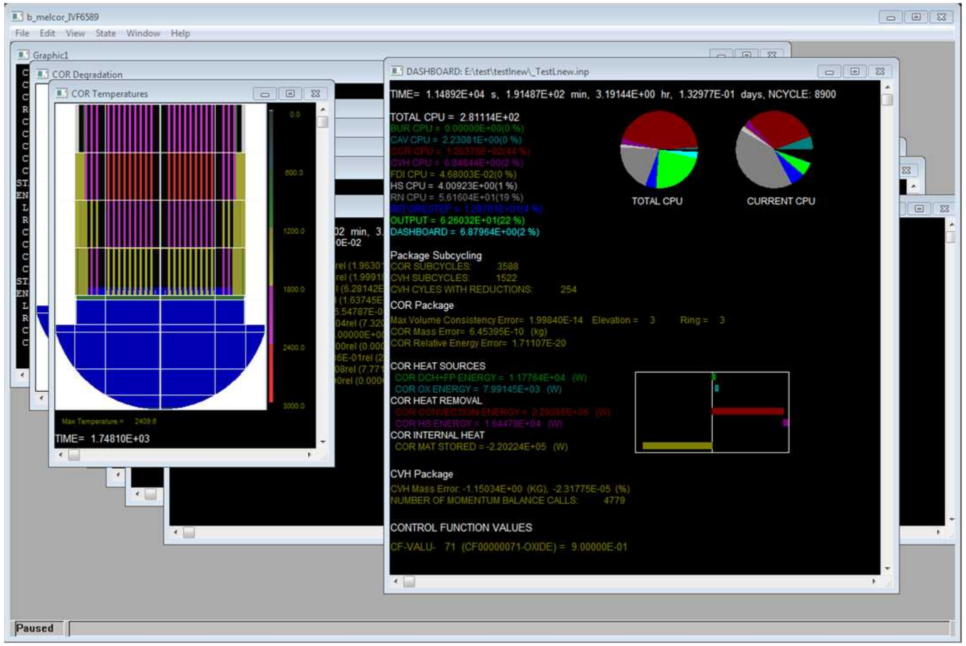
- MELCOR Plugin for NotePad++
  - Currently under development
  - Installer <u>greatly</u> simplifies setup
- MELCOR Glossary
  - User guide information available to text editor
  - Context intelligence
- Navigation sidebar
  - Object recognition
  - Double-click to jump to object definition



MELCOR Dashboard

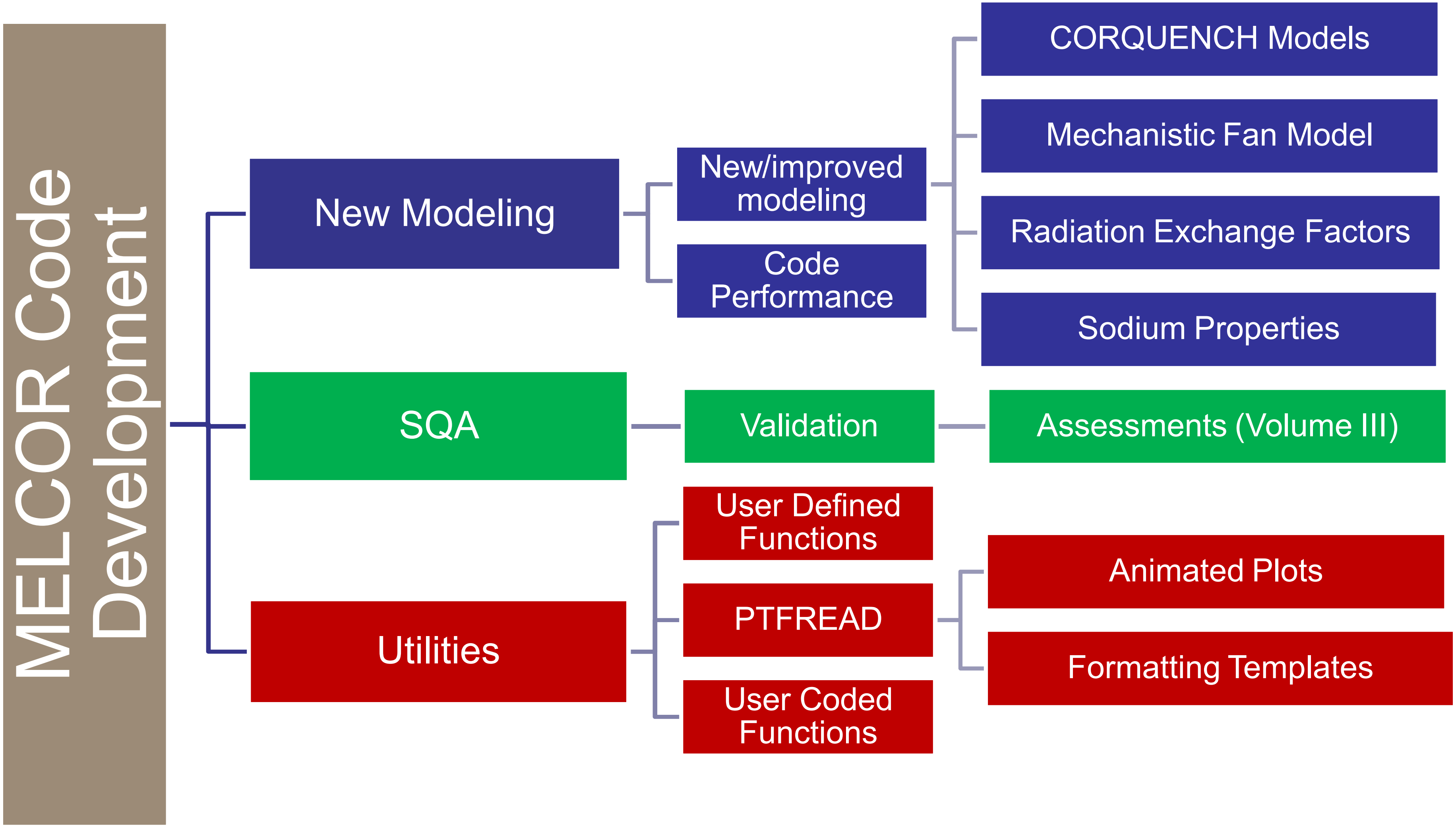


Console Application



QuickWin Application

Questions?



MELCOR Code Development
New Modeling
New/improved modeling
Code Performance
CORQUENCH Models
Mechanistic Fan Model
Radiation Exchange Factors
Sodium Properties
SQA
Validation
Assessments (Volume III)
Utilities
User Defined Functions
PTFREAD
User Coded Functions
Animated Plots
Formatting Templates