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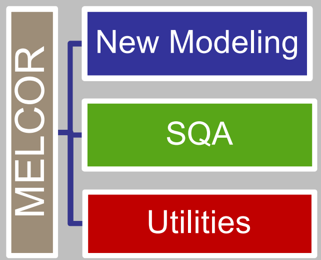

Validation analysis of COR lower plenum and RN package using SNAP

AMUG 2017

Presented by Larry Humphries

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U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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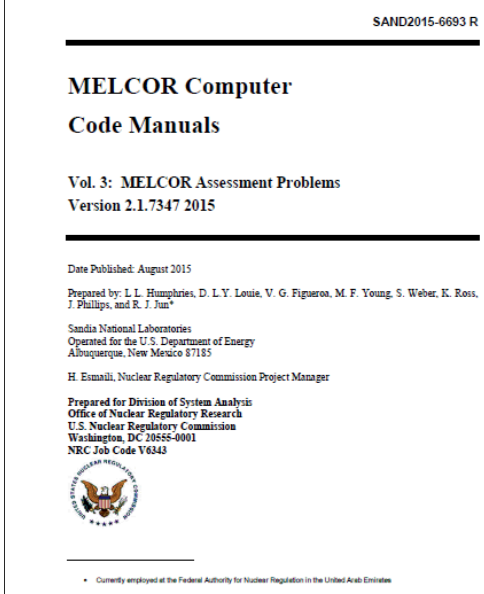
Outline of Presentation

- Overview of MELCOR validation
  - Review of MELCOR validation
  - Use of SNAP in validation
- SNAP review
  - Creating animations from existing plotfiles
  - Animation drawing tools
- Validation of Lower Plenum
  - Important plot variables for validation
  - Visualization within SNAP
- Validation of RN package
  - Important RN plot variables for validation
  - MACCS flow paths
  - Visualization within SNAP
  - Visualization with RNVisual
- SNAP Demonstration

Future MELCOR Manual Updates


SAND2015-6693 R

MELCOR Computer

Code Manuals

Vol. 3: MELCOR Assessment Problems
Version 2.1.7347 2015

Date Published: August 2015

Prepared by: L. L. Humphries, D. L.Y. Louie, V. G. Figueroa, M. F. Young, S. Weber, K. Ross, J. Phillips, and R. J. Jun*

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Washington, DC 20555-0001
NRC Job Code V6343

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Volume III: Assessments

R&A Complete
SAND2015-6693 R

By December 2017
- Demo PWR plant deck
- Demo BWR plant deck
- COR/CVH Nodalization
- Containment DBA
- Numerical Variance
- Steady State Initialization

By December 2018
- FL/CVH Modeling
- Uncertainty Analysis
- Spent Fuel Pool Modeling
- Radionuclide Class Modeling
- MELCOR/MACCS Integration
- Troubleshooting MELCOR runtime issues
- Lower Head Modeling
- Heat Structure Modeling
- Cavity Related Modeling

Volume IV: Modeling Guide

Cases in MELCOR Assessment Report SAND2015-6693 R

- **MELCOR ANALYTIC ASSESSMENT**
  - Saturated Liquid Depressurization
  - Adiabatic Expansion of Hydrogen
  - Transient Heat Flow in a Semi-Infinite Heat Slab
  - Cooling of Heat Structures in a Fluid
  - Radial Heat Conduction in Annular Structures
  - Establishment of Flow
- **MELCOR ASSESSMENTS AGAINST EXPERIMENTS**
  - Analysis of ABCOVE AB5 and AB6 Aerosol Experiments
  - Analysis of ACE Pool Scrubbing Experiments
  - Analysis of AHMED 1993 NaOH Experiments
  - Analysis of the Bethsy 6.9c Experiment (ISP-38)
  - Analysis of Containment System Experiment for Spray –A9 Test
  - Analysis of the Cora 13 (ISP 31) Experiment
  - Analysis of Aerosol Behavior from the Demona-B3 Experiment
  - Analysis of Level Swell from the General Electric Large Vessel Blowdown and Level Swell Experiment – 5801-13
  - Containment Analysis from the JAERI Spray Experiments
  - Analysis of LACE LA-4 Experiment
  - Analysis of LOFT LP-FP-2 Experiment
  - Analysis of Critical Flow from the Marviken CFT-21 and JIT-1 Experiments
  - Analysis of Marviken-V Aerosol Transport Test (ATT-4)
  - Analysis of NTS Hydrogen Burn Combustion Tests
  - Analysis of the Nuclear Power Engineering Corporation (NUPEC) Mixing Tests
  - Analysis of the PHEBUS FPT-1 Experiment
  - Analysis of the PHEBUS FPT-3 Experiment
  - Analysis of the POSEIDON Integral Experiments under Hot Pool Conditions
  - Analysis of STORM Aerosol Mechanical Deposition Tests
  - Melt Coolability and Concrete Interaction Experiments
    - CCI-1, CCI-2, and CCI-3
- **ASSESSMENTS IN NEXT REVISION**
  - LACE LA3 (Turbulent Deposition)
  - TMI-2 Accident
  - STORM (resuspension phase)

ISP-45 Quench06 Experiment

Overview of MELCOR Validation

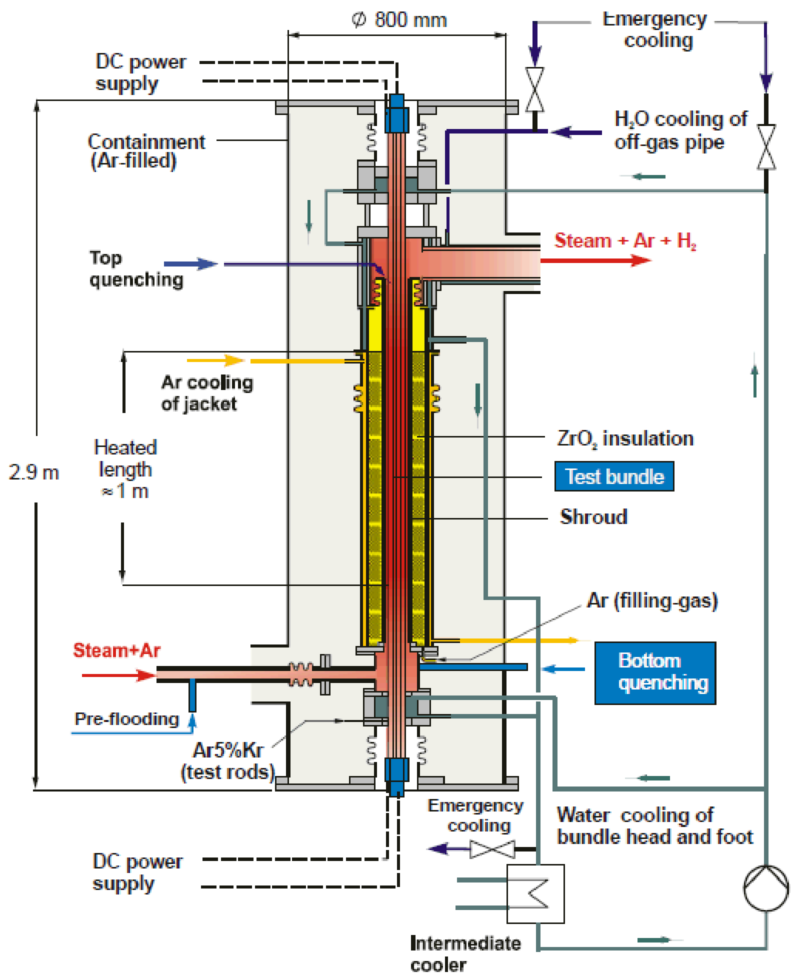
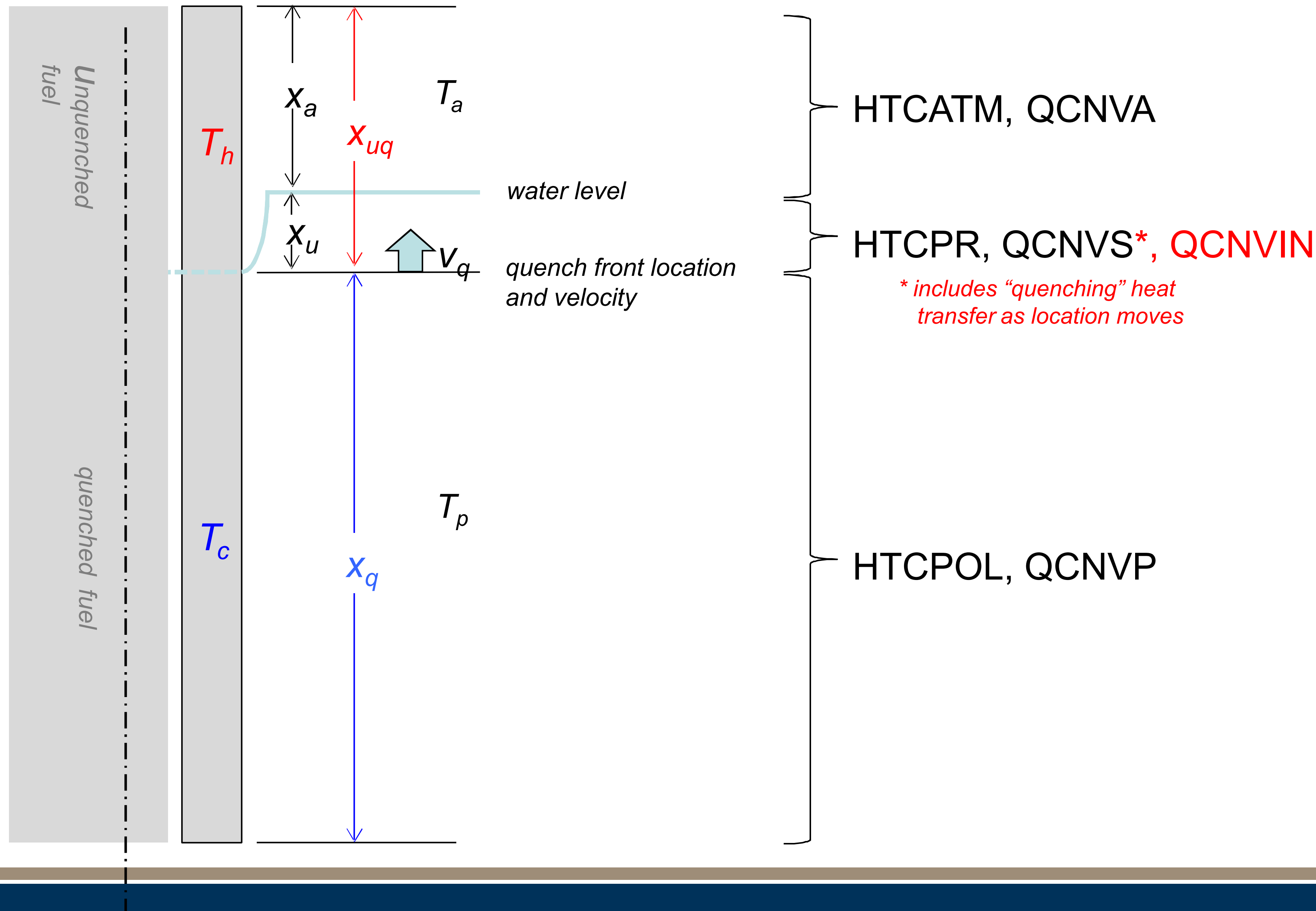


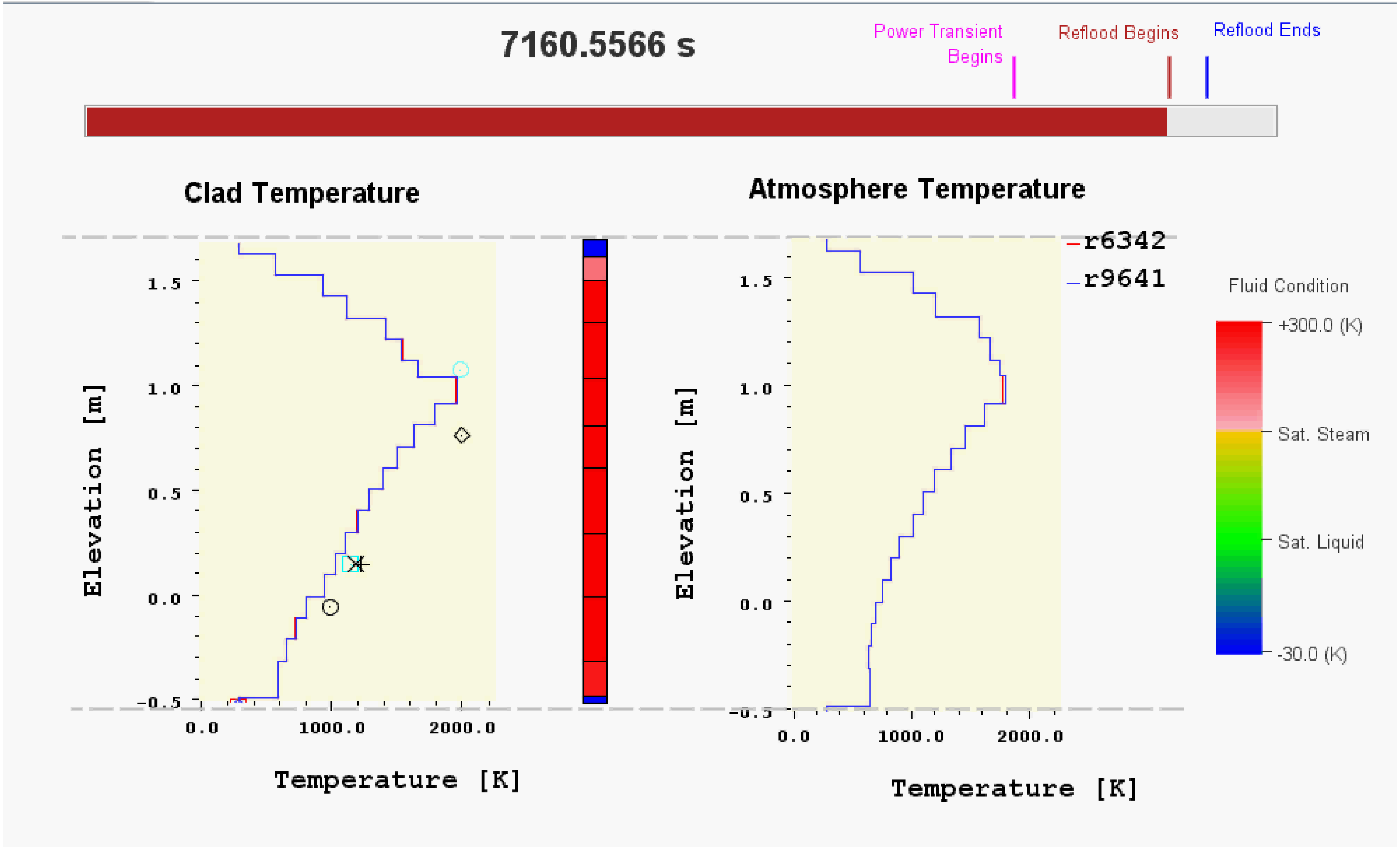
Figure 2.1 Main flow paths in the QUENCH facility.

Time	Event	Phase
0	Start of data acquisition	
30	Heat up to about 1500 K	Pre-oxidation
1965	Pre-oxidation at about 1500 K	
6010	Initiation of power transient	Power transient
6620	Initiation of pull-out of corner rod (B)	
7179	Quench phase initiation	Reflood
	Shut down of steam supply	
	Onset of fast water injection	
	Start of quench water pump	
	Detection of clad failure	
	First temperature drop at TFS 2/1	
7181	Steam mass flow rate zero	Quench
7205	Onset of electric power reduction	
7221	Decay heat level reached	
7430	Onset of final power reduction	
7431	Shut down of quench water injection	Post-reflood
7431	Electric power < 0.5 kW	
7435	Quench water mass flow zero	
11420	End of data acquisition	

Illustrative picture for COR convective heat transfer

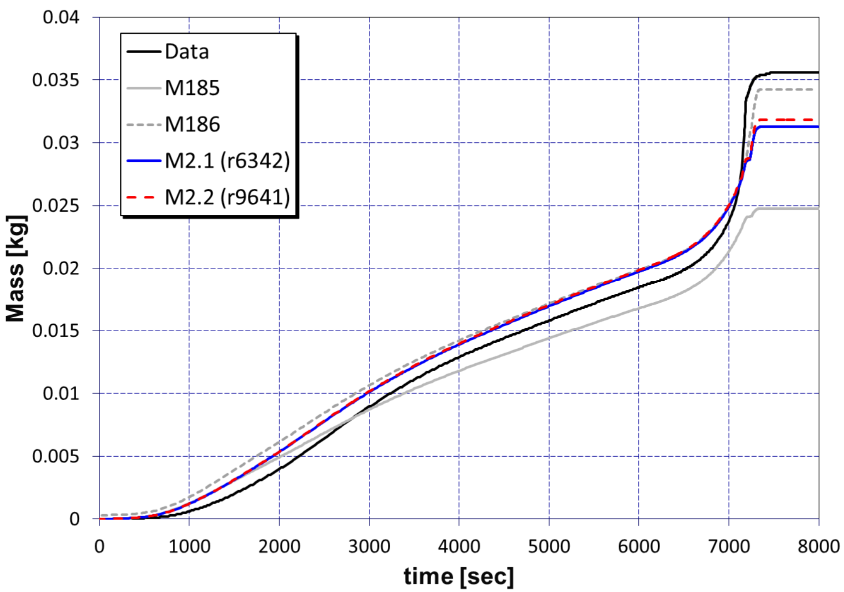


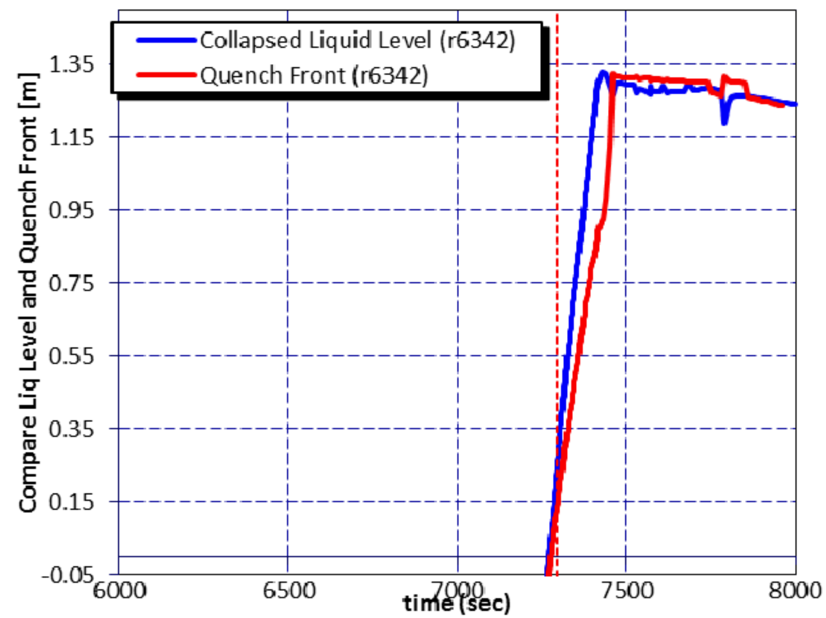
ISP-45 (Quench-06 experiment) MELCOR Simulation



ISP-45 (Quench-06 experiment) MELCOR Simulation

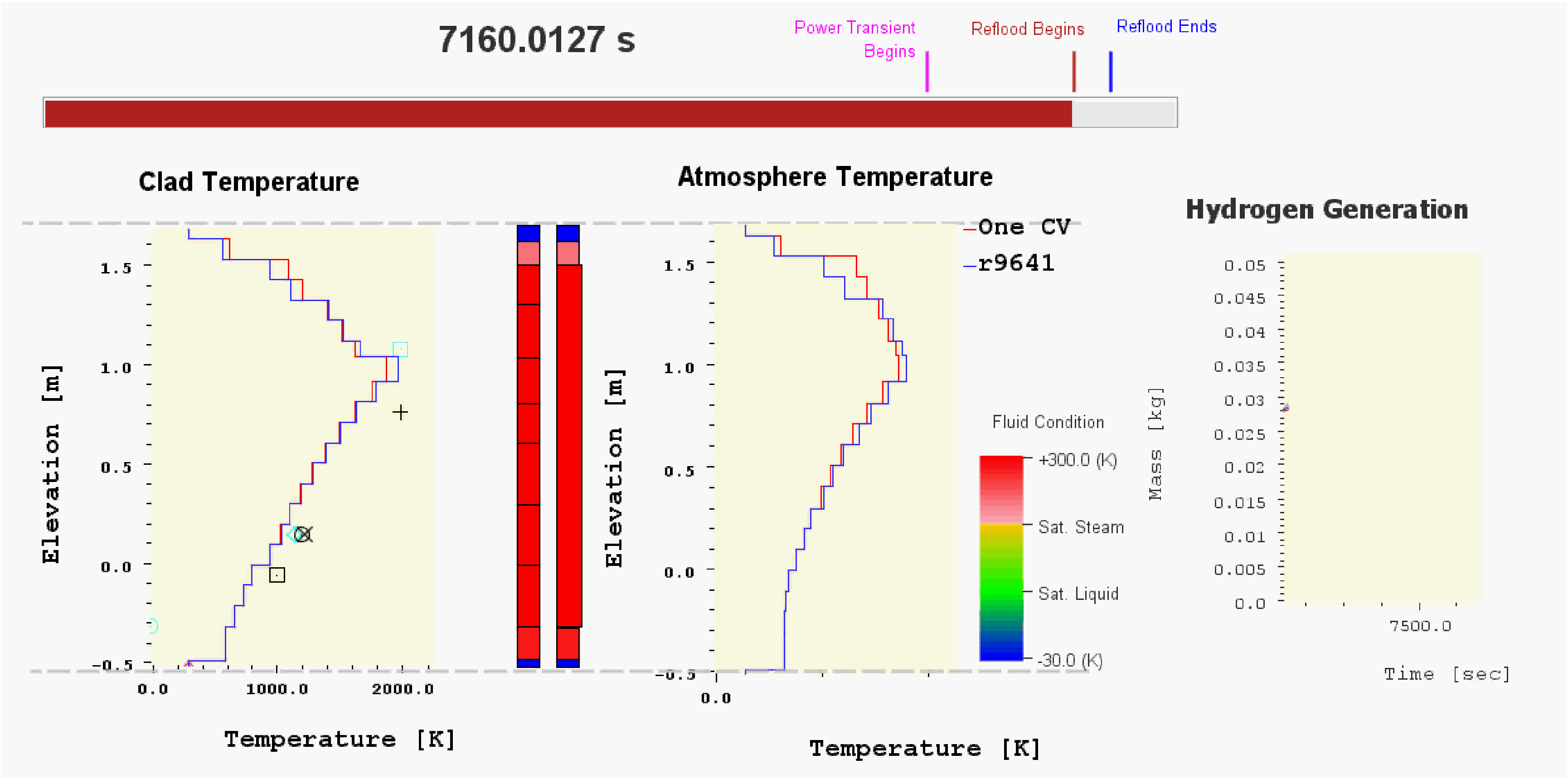
- Quench model effects oxidation
  - Changes component temperatures
  - Oxidation of submerged components
  - Little change in total oxidation since last release (r6342)





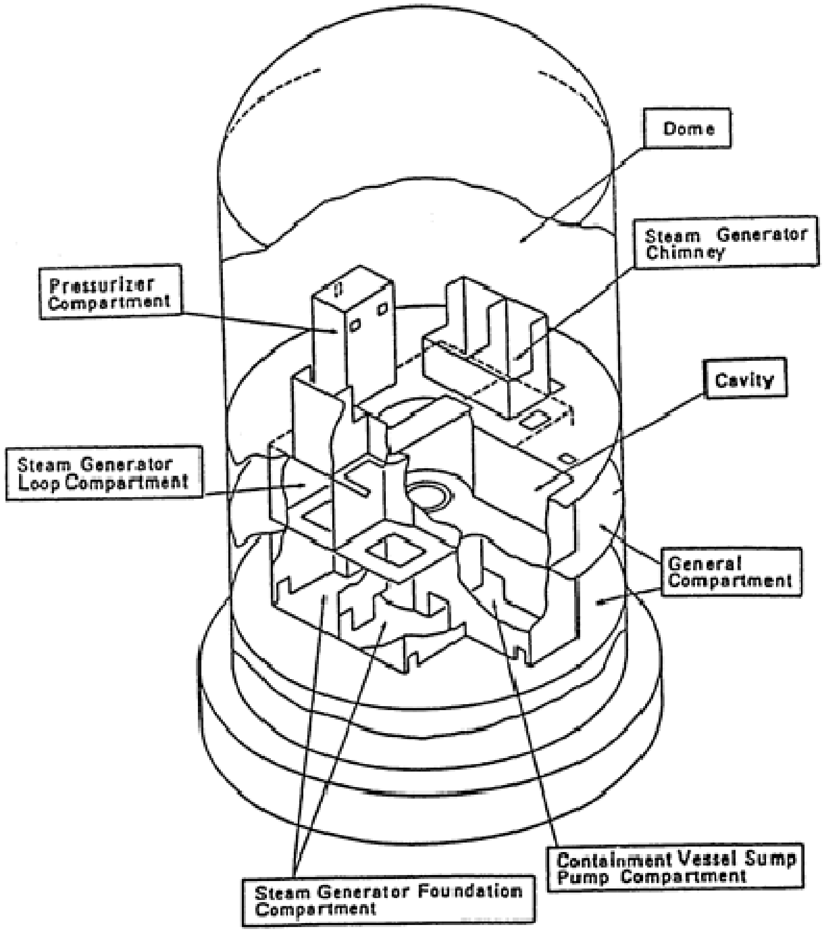
Overview of MELCOR Validation

Nodalization – Compare Single CV to CV stack (Preliminary Results)



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

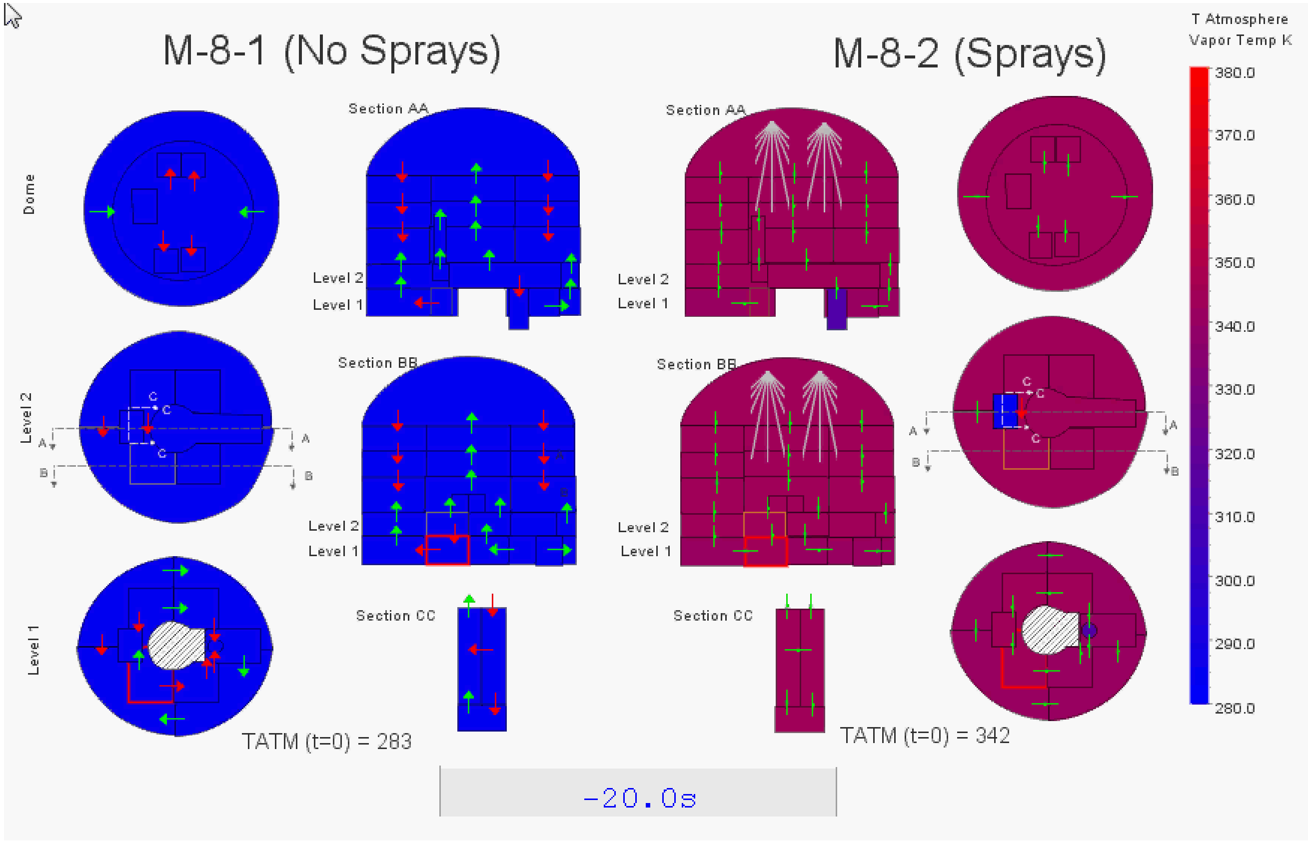
- Validation objectives
  - Pressure response;
  - Temperature distribution and
  - Hydrogen mixing
  - Spray modeling
  - Film Tracking Model
- ¼ Scale Containment
  - 10.8 m OD domed cylinder,
  - 17.4 m high
  - 25 interconnected compartme
- Sprays
  - M-8-1   No Sprays
  - M-7-1 and M-8-2   Sprays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



Temperature Distributions

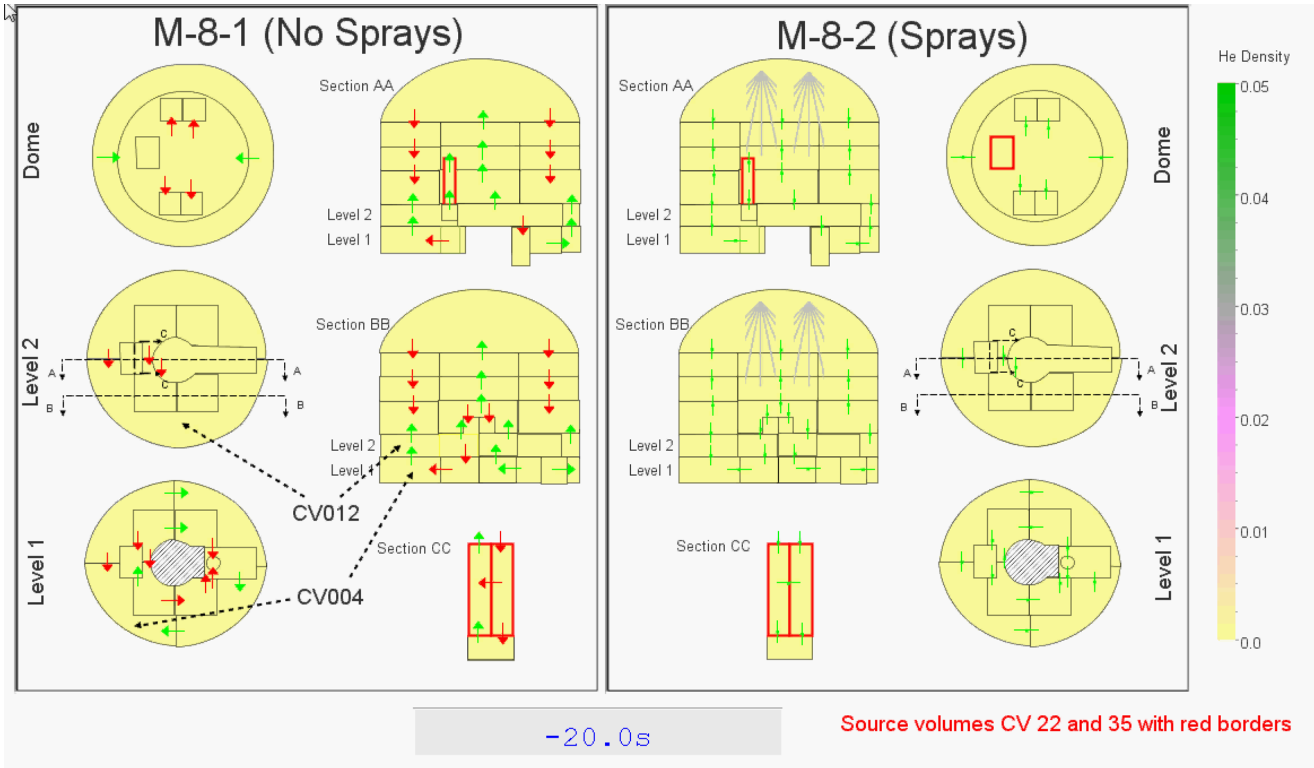
Overview of MELCOR Validation

- 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

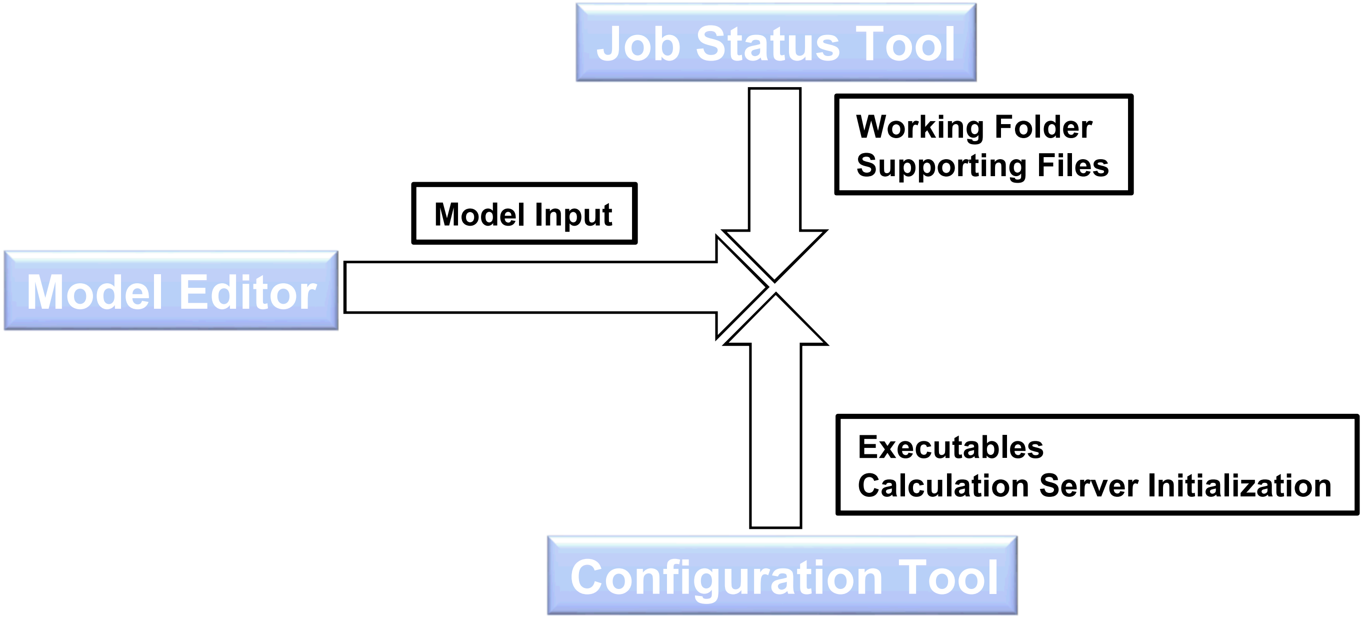
- Similarly, stratification of helium in the upper dome is much more significant for M-8-1 than M-8-2
- Stratification by floor in outer, lower compartments



Simplistic Idea on Information Flow for Job Submittal

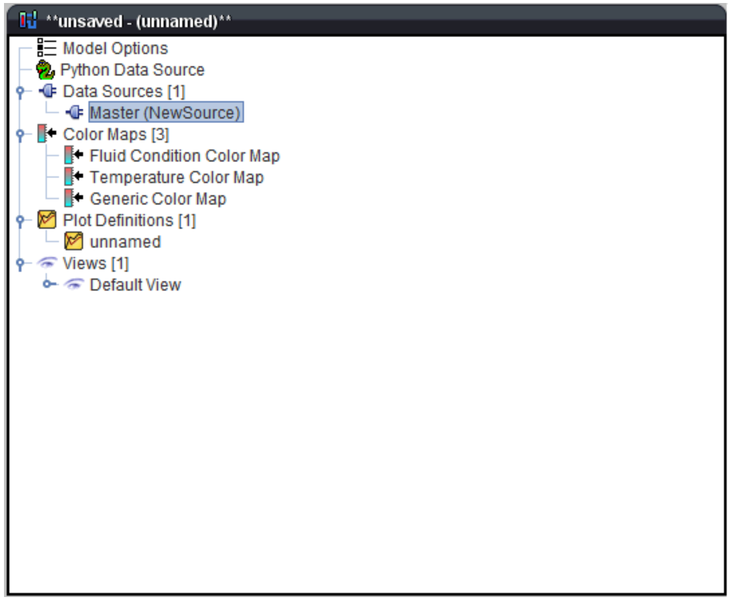
Review of SNAP Animations

- From a simple user's understanding of information flow



Post Processing with SNAP

- Animation Model is a separate model from the MELCOR model
  - File>New select Animation model



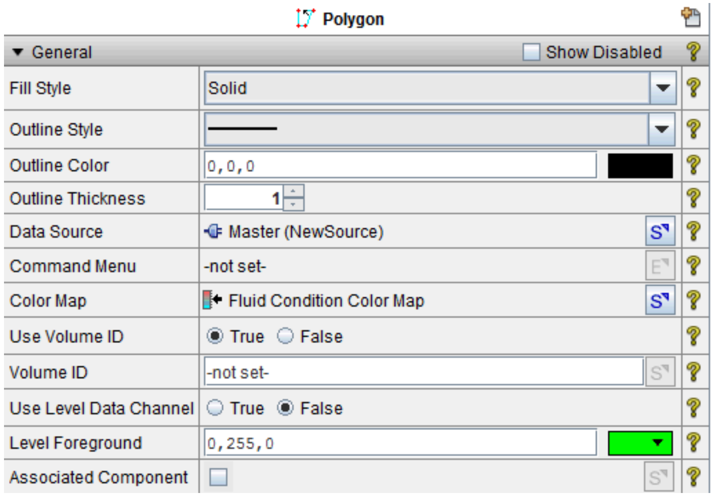
Creating a Basic Animation Model

- Attaching a plotfile
  - Two Steps
    - Click on Master in the Data Source Tree in the Navigator and set the Source Run URL in the Properties to a completed Job
    - Click the Data Connector Icon
- Create a Color Map

  - Three steps
    - Right Click Color Maps in the Navigator>New
    - Right Click the new Generic Color Map>Add To View
    - Adjust some Properties
      - Set Color Map Type to Generic
      - Specify Dynamic as True
      - Set Channel Name Pattern to MELCOR “CVH-P_%V”
        - » Review the MELCOR User’s Guide to see all the available plot channels
        - » %V is a place holder for the components Control Volume number (see notes for a detailed description on its use)

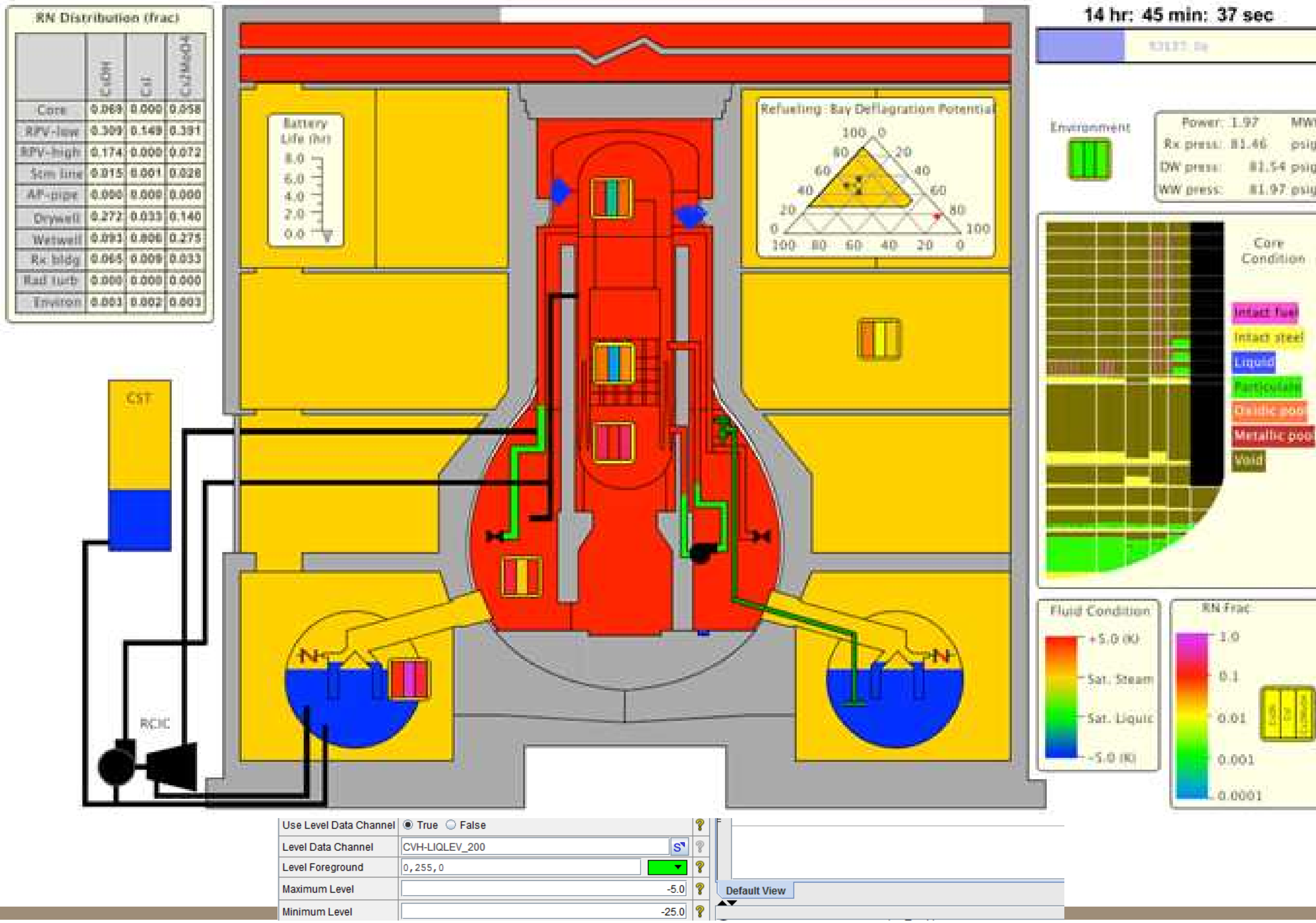
Creating a Basic Animation Element

- Creating a Polygon
  - Select Polygon from the Annotation section of the View Port Toolbar (review earlier slides if you can’t remember what the Toolbar looks like)
  - Start clicking in the View port and the drawing logic will become clear (left click to set a point, right click to remove the last point)
  - If you click on top of an old point it will close the polygon and the instance will be complete.



CVH-FL Example Problem: Drawing the Wetwell

Review of SNAP Animations



COR Plot Variables for Validation of Lower Plenum

Validation of Lower Plenum

- Molten Pool Variables

Masses COR-M-<P>-<MP>	Mass of the convecting oxide molten pool <MP=MP1> or the metallic molten pool <MP=MP2> in the active COR <P=UP> or in the lower plenum<P=LP>. (units = kg, default = ON, KEYWORD=COR-MP-MASS)
Temperatures COR-T-<MP>-<P>	Temperature of the convecting oxide molten pool <MP=MP1> or the metallic molten pool <MP=MP2> in the active COR <POOL=UP> or in the lower plenum<POOL=LP>. (units = K, default = ON, KEYWORD=COR-MP-T)
Volumes COR-V-<MP>-<P>	Volume of the convecting oxide molten pool <MP=MP1> or the metallic molten pool <MP=MP2> in the active COR <POOL=UP> or in the lower plenum<POOL=LP>. (units = m^3, default = ON, KEYWORD=COR-MP-V)
Rayleligh Number COR-RA1-<MP>-<P>	Rayleigh of the convecting oxide molten pool <MP=MP1> or the metallic molten pool <MP=MP2> in the active COR <POOL=UP> or in the lower plenum<POOL=LP>. (units = -, default = ON, KEYWORD=COR-MP-RA)

COR Plot Variables for Validation of Lower Plenum

- Energy Balance Molten Pools

COR-RAD-<MP>-<P>	Radiation power from upper surface of pool where <MPX> can be MP1 (oxide) or MP2 (metallic) and <P> can be in the active core <COR> or in the lower plenum <LP> (units = w, default = OFF, KEYWORD=COR-MP-RAD)
COR-CONV-<MPX>-<P>	Convective heat removal rate from pool where <MPX> can be MP1 (oxide) or MP2 (metallic) and <P> can be in the active core <COR> or in the lower plenum <LP> (units = w, default = OFF, KEYWORD=COR-MP-CONV)
COR-QINT-<MPX>-<P>	Convective heat transfer at interface between stratified molten pools where <MPX> can be MP1 (oxide) or MP2 (metallic) and <P> can be in the active core <COR> or in the lower plenum <LP> (units = w, default = OFF, KEYWORD=COR-MP-QINT)
COR-QDCH-<MPX>-<P>	Decay heat power generated in pool where <MPX> can be MP1 (oxide) or MP2 (metallic) and <P> can be in the active core <COR> or in the lower plenum <LP> (units = w, default = OFF, KEYWORD=COR-MP-DCH)

COR Plot Variables for Validation of Lower Plenum

Validation of Lower Plenum

- Energy Balance Outer Surface

COR-HTCLH(IS) (CF only)	Heat transfer coefficient from segment IS of lower head to water pool. (units = W/m^2K)
COR-HTCLH-AVE	Average heat transfer coefficient from lower head to water pool. (units = W/m^2K, Default=ON, Keyword=COR-HTCLH-AVE)
COR-QFLXLH(IS)	Exterior heat flux from segment IS of lower head to water pool. (units = W/m^2, Default=ON, Keyword=COR-QFLXLH)
COR-QFLXLH0(IS) Recently added	Interior heat flux to segment IS of lower. (units = W/m^2, Default=ON, Keyword=COR-QFLXLH)
COR-QFLXLH-AVE	Average heat flux from lower head to water pool. (units = W/m^2, Default=ON, Keyword=COR-QFLXLH-AVE)
COR-QTOTLH(IS)	Cumulative heat transferred from segment IS of lower head to water pool. (units = J, Default=ON, Keyword=COR-QTOTLH)
COR-QTOTLH-TOT	COR-QTOTLH-TOT Total cumulative heat transferred from lower head to water pool. (units = J, Default=ON, Keyword=COR-QTOTLH-TOT)

COR Plot Variables for Validation of Lower Plenum

- Newly Added

COR-CHF(IS)	Critical Heat Flux from segment IS of outer lower head to water pool. (units = W/m^2K, Default=ON, Keyword=COR-QLH)
COR-QLH-OUT	Cumulative energy transfer from outer surface (units = J, Default=ON, Keyword=COR-QLH)
COR-QLH-IN	Cumulative total energy transfer to inner surface (units = J, Default=ON, Keyword=COR-QLH)
COR-QLH-ENTH	Cumulative enthalpy change of Lower Head (units = J, Default=ON, Keyword=COR-QLH)

COR Plot Variables for Validation of Lower Plenum

Validation of Lower Plenum

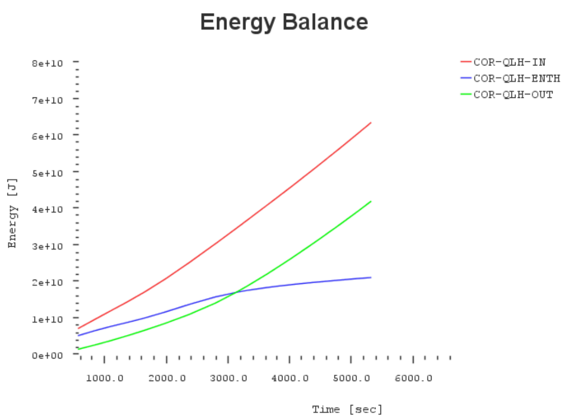
- Newly Added Dimensionless numbers

COR-**RE**-POOL-cmp.n COR-PR-POOL-cmp.n, etc.	Re, Pr, Gr, Ra # for pool of surface cmp in cell n. (units = none, Default=OFF, Keyword=COR-RE-POOL, COR-PR-POOL, COR-GR-POOL)
COR-RE-FILM-cmp.n	Re, Pr, Gr, Ra # for film of surface cmp in cell n. (units = none, Default=OFF, Keyword=COR-RE-FILM, COR-PR-FILM, COR-GR-FILM)
COR-RE-ATM-cmp.n	Re, Pr, Gr, Ra # for atm of surface cmp in cell n. (units = none, Default=OFF, Keyword=COR-RE-ATMS, COR-PR-ATMS, COR-GR-ATMS)
COR-NU(N)FRAC-POOLQ-cmp.n	Nusselt no. including (or excluding) area fractions for quenched pool of surface cmp in cell n (units = none, Default=OFF)
COR-NU(N)FRAC-POOLU-cmp.n	Nusselt no. including (or excluding) area fractions for unquenched pool of surface cmp in cell n (units = none, Default=OFF)
COR-NU(N)FRAC-ATM-cmp.n	Nusselt no. including (or excluding) area fractions for atm of surface cmp in cell n (units = none, Default=OFF)

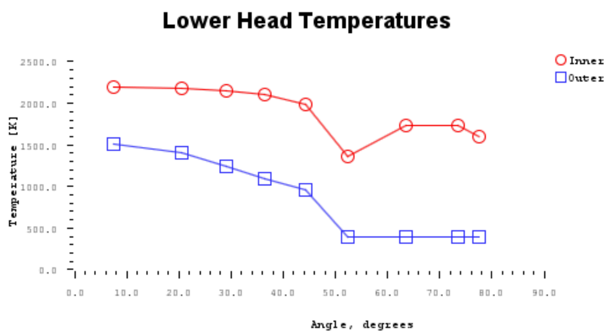
Useful COR Visualization Tools with SNAP

Validation of Lower Plenum

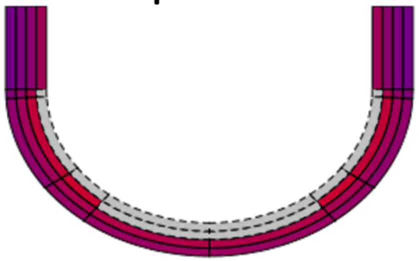
- Trend Plots



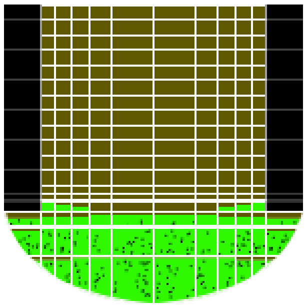
- Profile Plots



- Lower Head Component



- Core Degradation Component



MACCS Flow Paths

- Masses of radioactive masses transported through flow paths are available as plot variables and/or control function arguments for paths that have been designated as MACCS release paths.
  - Data about fluid and radionuclide transport through the path will be preserved in the database and written to the plot file. Masses are also available as control function arguments.
- Originally implemented for interface to MACCS to track RN release to environment
  - However, used regularly to track RN transport throughout the system

```
FL_MACCS     2 !NFL  MACCSnam     MACCSn  MCCSFP         DIRFL
               1     Leakage      110    FlowPath190     FROM
               2      Break       120    FlowPath700     TO
```

Plot Variables for Validation of RN Package

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- Mass Balance

MACCS-nn-M-RE-cc.ii	Released radioactive mass for RN class cc in size group (section) ii, associated with release path index nn. Vapor is in size group 0. Here, "cc" is the two-digit class number. (units = kg)
RN1-TYCLAIR-x-y.ty	Airborne mass of class x in all volumes of type ty, including aerosols and vapors. The parameter y specifies either total mass (y=1) or just the radioactive mass (y=2). (units = kg)
RN1-TYCLT-x-2.ty	Radioactive mass of class index x in all control volumes of type index ty, including mass deposited on heat structures associated with the control volumes. (units = kg)
RN1-AMG (NameCV,NameCLS,w,y) RN1-VMG (NameCV,NameCLS,w,y)	Aerosol (or vapor) mass of section w (if aerosol), class name NameCLS, in the atmosphere of control volume name NameCV not including aerosols deposited on heat structures. The parameter y specifies total mass (y='TOT') or radioactive mass only (y='RAD'). (units = kg.)

Plot Variables for Validation of RN Package

- Deposition Control Functions

RN1-AML(NameCV,NameCLS,y)	Aerosol mass of class name NameCLS, in the pool of control volume name NameCV not including aerosols deposited on heat structures. The parameter y specifies total mass (y='TOT') or radioactive mass only (y='RAD'). (units = kg)
RN1-VML(NameCV, NameCLS,y)	Vapor mass of class name NameCLS, in the pool of control volume name NameCV not including vapor deposited on heat structures. The parameter y specifies either total mass (y='TOT') or radioactive mass only (y='RAD'). (units = kg)
RN1-ADEP(NameHS,s,NameCLS,y)	Aerosol mass of class NameCLS, deposited on side s (s='LHS' or s='RHS') of heat structure name NameHS. The parameter y specifies total mass (y='TOT') or radioactive mass only (y='RAD'). (units = kg)

Plot Variables for Validation of RN Package

- Deposition Control Functions

RN1-DEPHS(NameHS,s,*NameCLS*,p) CF only	Total aerosol mass of class NameCLS deposited on side s (s='LHS' or s='RHS') of heat structure HS NameHS from deposition physics model p. This is the total mass deposited from each mechanism and does includes mass that may be later resuspended.The deposition models that are tracked are as follows: p = 'DIFF', Diffusion deposition p = 'THERM', Thermophoresis p = 'GRAV', Gravitational settling p = 'TURB', Turbulent deposition in straight sections p = 'BEND', Deposition in pipe bends p = 'VENT', Deposition in venturi transitions p = 'CONT', Deposition in contraction transitions (units = kg)
RN1-TOTRES	Total radionuclide mass that has been resuspended. (units = kg)

Visualization Tool

- Stacked bar chart provides new data view
- A tool for users to create such a display
  - Capability added for this workshop to construct them
  - Optional MELCOR input, output file(s)
    - Too much special-use data to add to plot file
    - Optional root for file names in `Global Data`

```
RN1VISUALFILE 'Bug608' ! Default is 'RN1VISDATA'
```

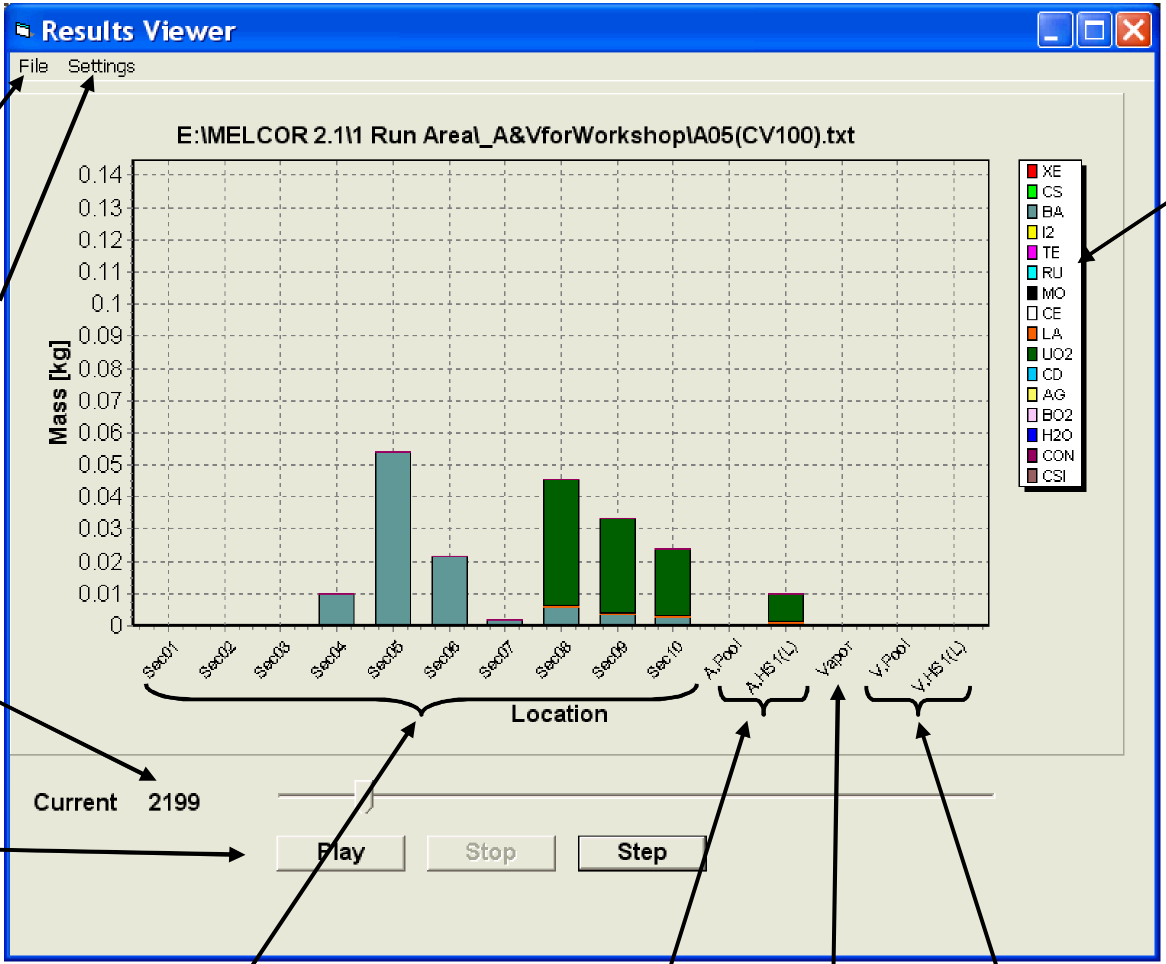
    - List of volumes for which data desired in `RN1_Input`

```
RN1_VISUAL  2 ! List of Volume names
             1   'Init Ba' ! -> Bug608(Init Ba).txt
             2   'Init Cs' ! -> Bug608(Init Cs).txt
```

  - Prototype implemented in Excel
    - Easy to generate snapshots using native Excel functionality
    - Unsatisfactory for animation
  - Visual Basic application, “Results Viewer” developed by Sigma Software (Katherine McFadden)

Results Viewer

Validation of RN Package



Open (File Navigation) Exit

Limits (Auto|Manual)

Color Key, RN Classes

Current Time

Playback Controls

Aerosol Sections

Deposited Aerosols

Vapors

Deposited Vapors

Two-Material Agglomeration Calculations

- Ran two versions of a 2 material case
  - Initial 0.1 kg of Ba aerosol, d_p=0.880μm
  - Initial 0.1 kg of UO2 aerosol, d_p=10.57μm
  - ρ =1000kg/m^3, 10^{-10} m^2 surface
- Case 1: default component assignments
  - Both Ba and UO2 assigned to component 1
- Case 2: custom component assignments
  - Ba assigned to component 1, UO2 to component 4

Visualization of Results, Cases 1 and 2

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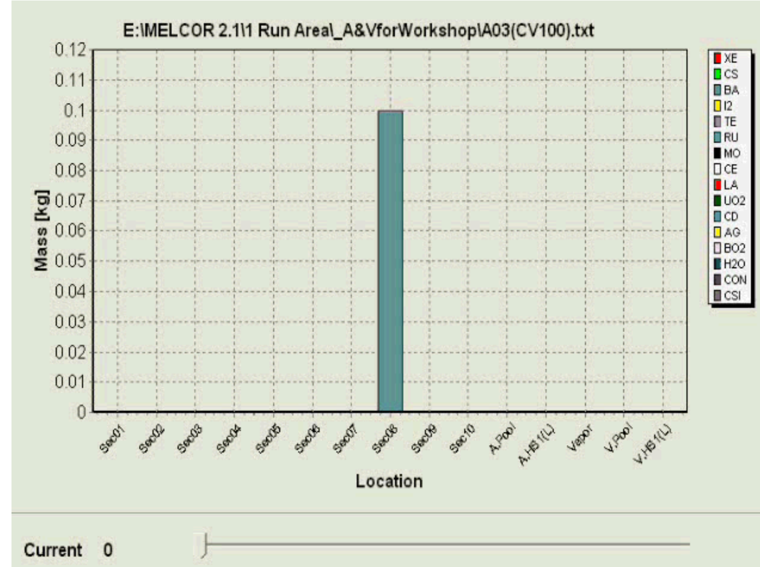
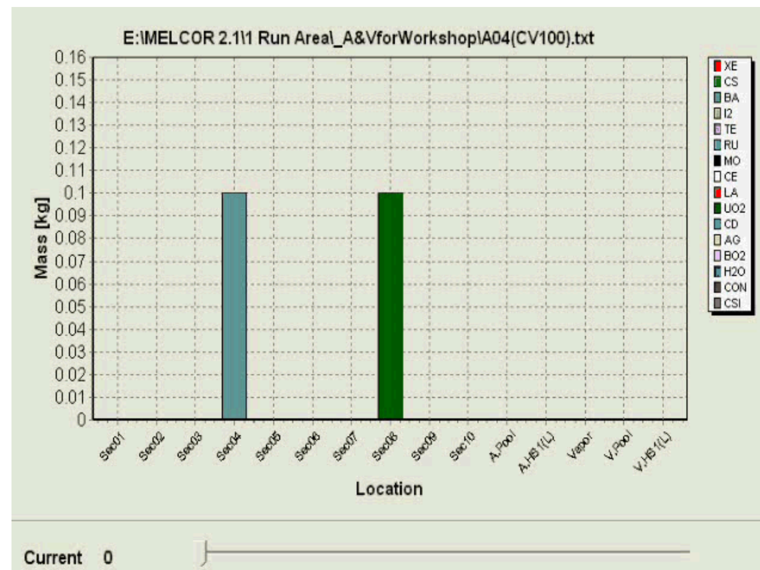
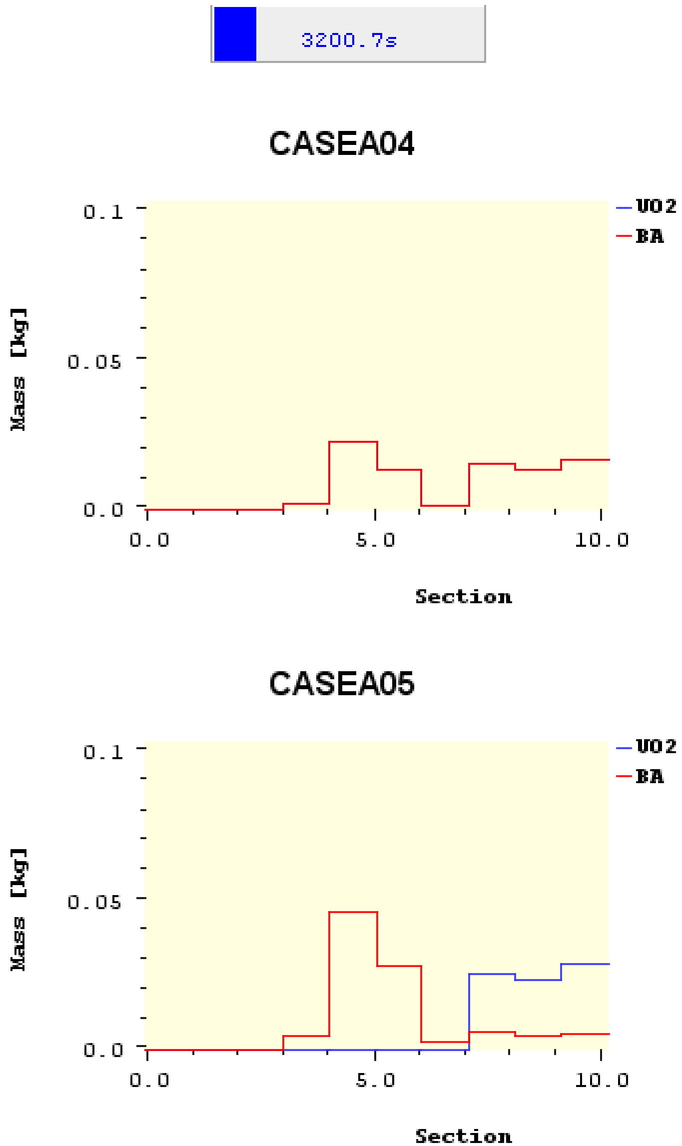
- Case 1 (same component)
  - MAEROS does not maintain distinction
    - Aerosol distribution "homogenized" on first advancement
      - Puts half UO2 mass into smaller section, half Ba mass into larger one
- Case 2 (distinct component)
  - MAEROS maintains distinction
    - Agglomeration of small and large aerosols slowly moves some Ba mass into larger sections





Similar Animations Generated in SNAP

- By default, information by section is not provided to user through the binary plot file
  - Memory requirements can be high
  - Code modification to allow data to be plotted for limited set of the problem space.
- Demonstration will show creating plots is somewhat laborious but manageable
  - Data could be imported to SNAP previously as a python source but was even more difficult to do.



Similar Animations Can Now be Generated in SNAP

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- Option enabled by previous MELGEN input for the RN visualization tool

  RN1_VISUAL 1 SNAP

  1 CV100

  - Output is now redirected to binary plotfile
- New plot variables added to plotfile for just those CVs specified on RN1_VISUAL

RN1-VIS-A-CV-CL.IS	Mass airborne aerosol class CL in control volume CV in section IS. (units = kg)
RN1-VIS-AP-CV.CL	Mass of aerosol class CL deposited on pool surface in control volume CV in section IS. (units = kg)
RN1-VIS-V-CV.CL	Mass of airborne vapor class CL in control volume. (units = kg)
RN1-VIS-V,Pool-CV.CL	Mass of vapor class CL removed by pool control volume CV. (units = kg)
RN1-VIS-HS,A-CV-IS	Mass of aerosol class CL deposited on HS, IHS, associated with control volume CV. (units = kg)
RN1-VIS-HS,V-CV-IS	Mass of vapor class CL deposited on HS, IHS, associated with control volume CV. (units = kg)

SNAP DEMONSTRATION