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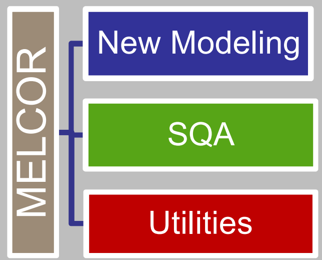



# MELCOR Code Development Status
# MCAP 2016

Presented by Larry Humphries
llhumph@sandia.gov

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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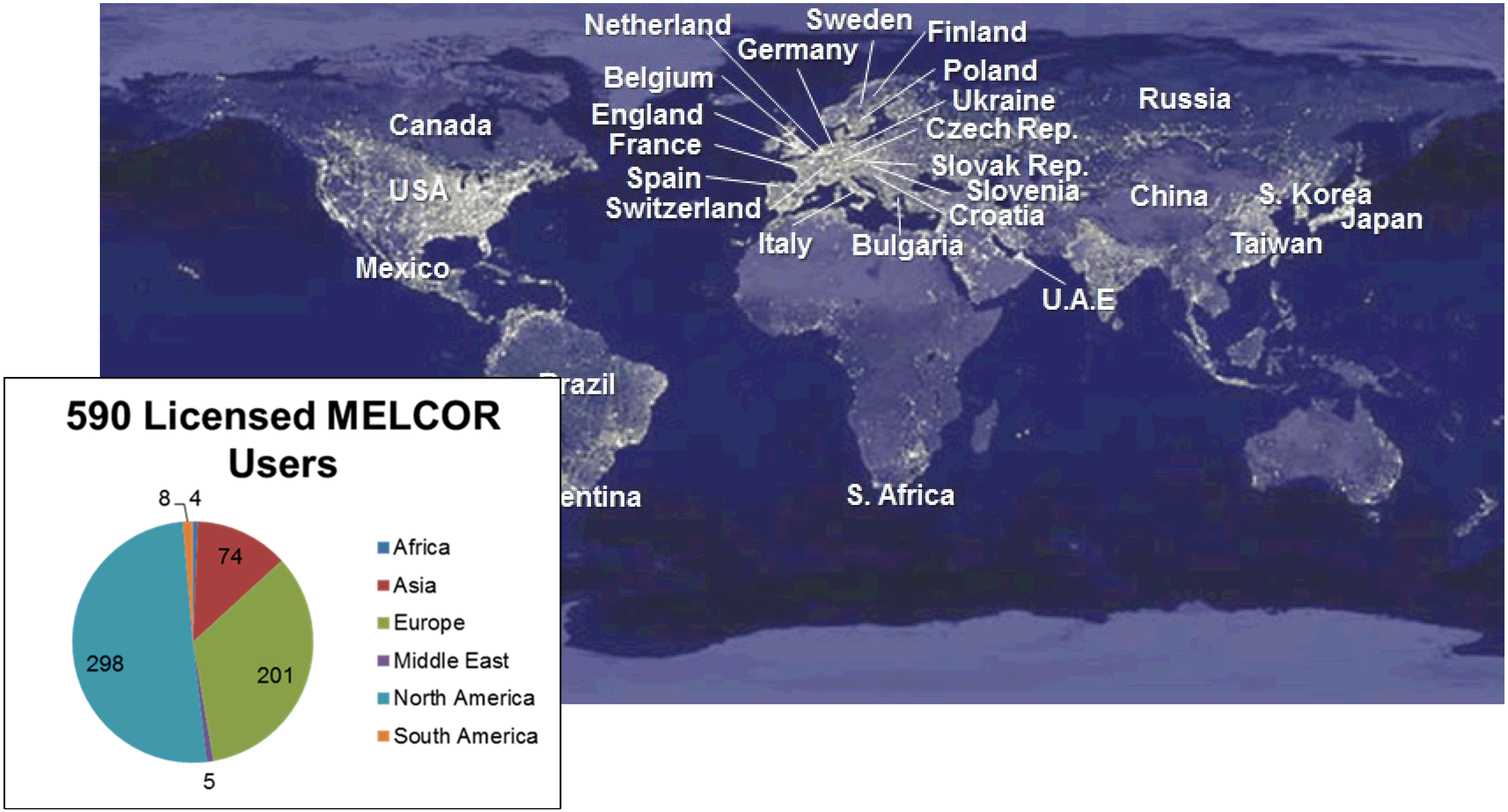
# International Use of MELCOR

Sandia National Laboratories



# MELCOR Workshops & Meetings

- 2015 Asian MELCOR User Group (AMUG)
  - Hosted by CRIEPI (Japan)
  - November 2015
- 2016 European MELCOR User Group (EMUG)
  - Hosted by  Imperial College London & AMEC
  - April 6-7, 2016
- 2016 CSARP/MCAP/MELCOR Workshop
  - September 12, 2016
  - Bethesda, MD
  - Focus will be on CF package & new models
- 2016 Asian MELCOR User Group (AMUG)
  - Hosted by SPICRI & NRSC (Beijing)
  - October 17 – 21, 2016
  - MELCOR/MACCS Workshop

# 2016 MELCOR Workshop Preliminary Agenda

- 1 Workshop Introductions & Overview (15 min) — Humphries
  - *Review of the MELCOR code development and introduction of workshop.*
- 2 MELCOR overview (30 min) — Humphries
  - *Very general overview of MELCOR code and discussion of how data utilities are used.*
- 3 Data & Control Utilities (90 min) — Phillips
  - *Discussion of MELCOR tabular functions, control functions, and EDF utility.*
- 5 Practical CF Modeling (90 min) — Ross
  - *Practical examples of CF modeling in a plant application and the use of SNAP in visualizing control functions.*
- 4 Recent Control Function Enhancements (60 min) — Humphries
  - *Use of vector control functions, vector arguments, and user-defined functions.*
- 6 New MELCOR models -1 (90 min) — Beeny
  - *Use of the new homologous pump model and second lower head (core catcher) with working examples and exercises.*
- 7 New MELCOR Models – 2 (45 min) — Humphries
  - *Working with the radiation enclosure model, multi-rod model , and turbulent deposition & resuspension with working examples and exercises.*
- 8 Workshop Wrap-up (30 min) — Humphries
  - *Workshop Q/A, presentation of certificates, workshop evaluations.*

# MELCOR Documentation

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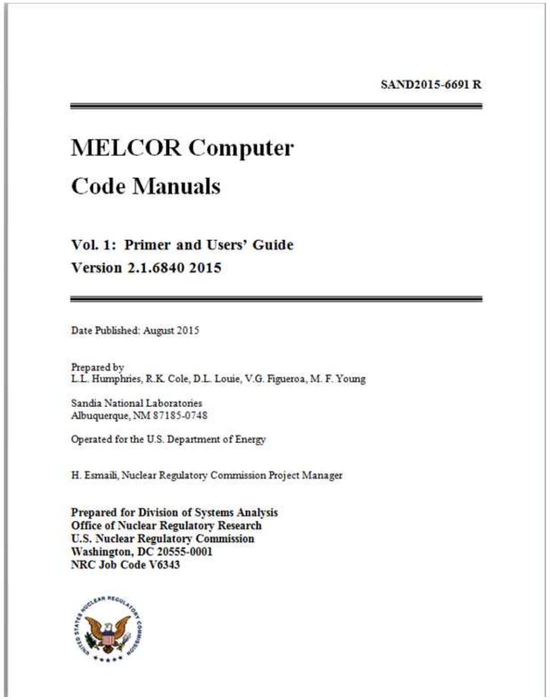


SAND2015-6691 R

MELCOR Computer
Code Manuals

Vol. 1: Primer and Users' Guide
Version 2.1.6840 2015

Date Published: August 2015

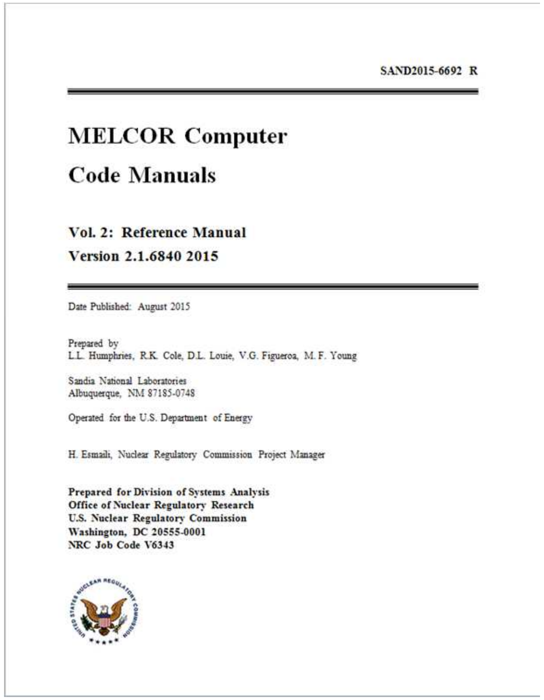
Prepared by
L.L. Humphries, R.K. Cole, D.L. Louie, V.G. Figueroa, M. F. Young

Sandia National Laboratories
Albuquerque, NM 87185-0748

Operated for the U.S. Department of Energy

H. Esmaili, Nuclear Regulatory Commission Project Manager

**Prepared for Division of Systems Analysis**
**Office of Nuclear Regulatory Research**
**U.S. Nuclear Regulatory Commission**
**Washington, DC 20555-0001**
**NRC Job Code V6343**



SAND2015-6692 R

MELCOR Computer
Code Manuals

Vol. 2: Reference Manual
Version 2.1.6840 2015

Date Published: August 2015

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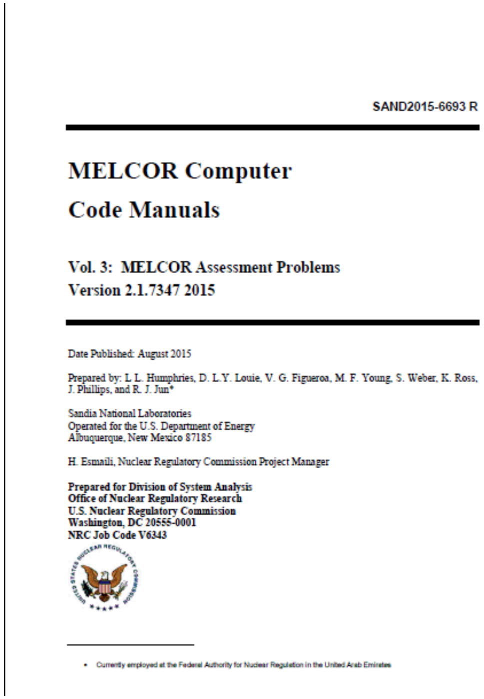

SAND2015-6693 R

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*

Sandia National Laboratories
Operated for the U.S. Department of Energy
Albuquerque, New Mexico 87185

H. Esmaili, Nuclear Regulatory Commission Project Manager

**Prepared for Division of System Analysis**
**Office of Nuclear Regulatory Research**
**U.S. Nuclear Regulatory Commission**
**Washington, DC 20555-0001**
**NRC Job Code V6343**

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

## Volume I: User Guide

R&A Complete
SAND2015-6691 R

## Volume II: Reference Manual

R&A Complete
SAND2015-6692 R

## Volume III: Assessments

R&A Complete
SAND2015-6693 R

# 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

# LACE LA3 Assessment of Turbulent Deposition

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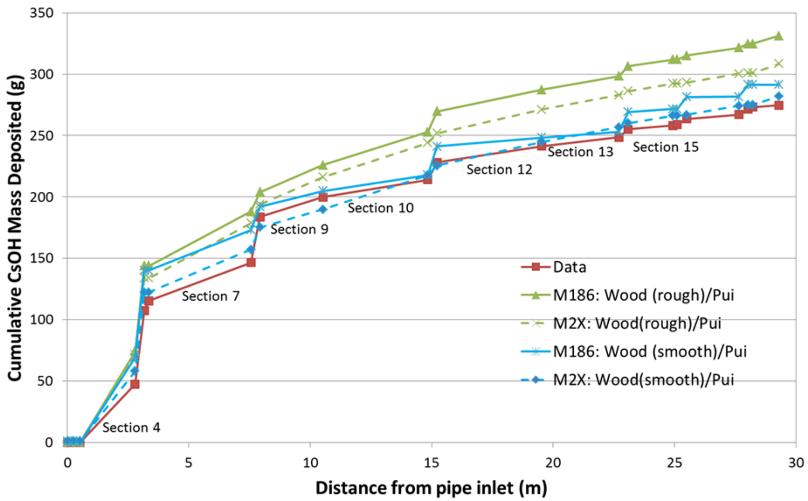
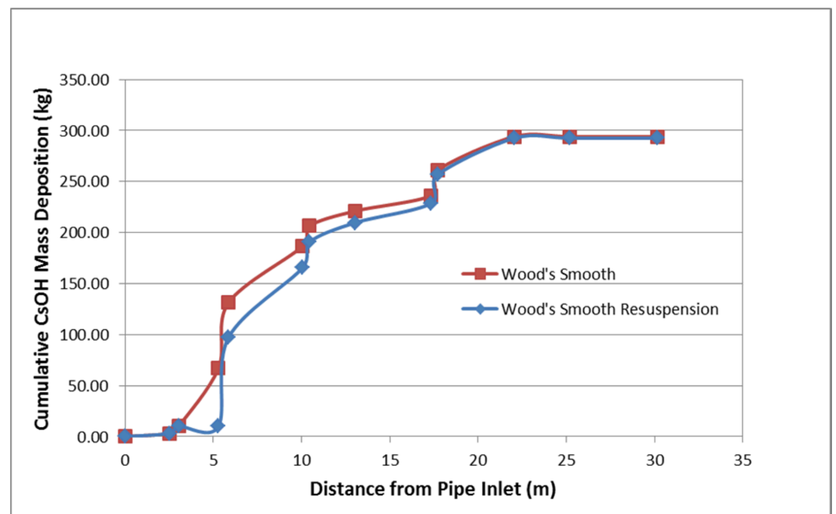
- MELCOR 2.1 assessment of turbulent deposition model shows excellent agreement with test data
  - Minor modeling improvements/corrections were made since the M186 implementation
  - Input for turbulent deposition model was recently improved
    - Workshop exercise
    - Updated in recent manuals
- New turbulent deposition model was assessed against this test
  - Predicted resuspension may be too large at entrance
  - May not correctly account for sticking of aerosols



MELCOR | New Modeling | SQA | Utilities

# MELCOR Debugging Trends

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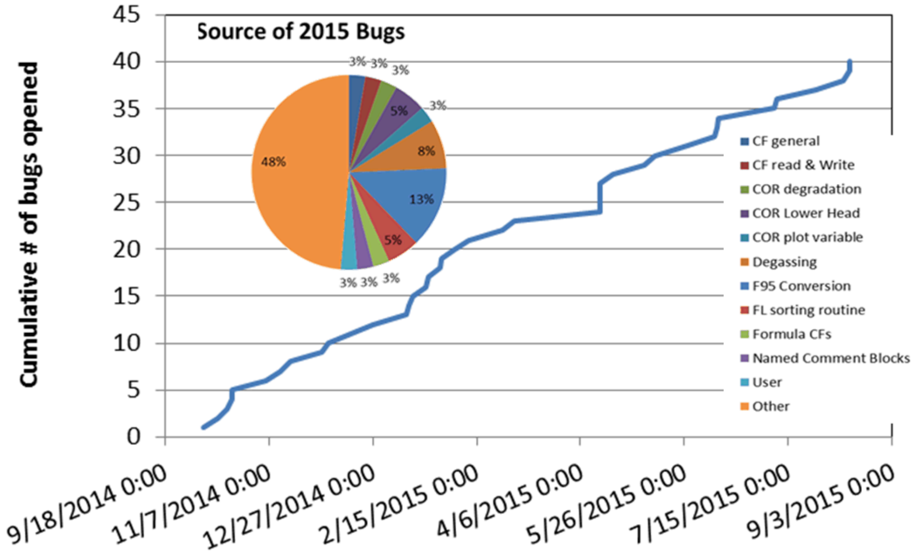
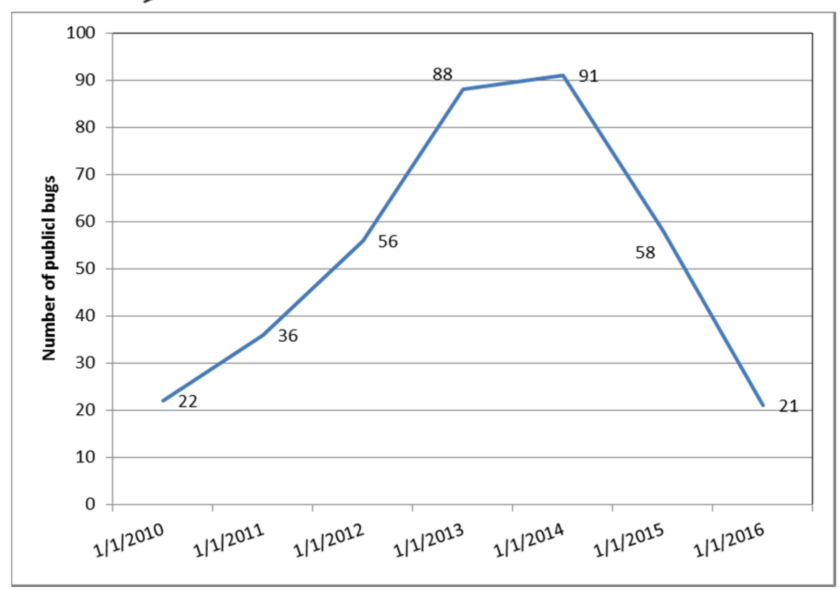
- Statistics
  - Approximately 40 public bugs are reported each year.
    - There are additional private bugs that are resolved.
  - More than 50 bugs were resolved in 2015
    - F95 Conversion 13%, Degassing 8%, etc.
- Important bugs recently resolved
  - Lipinski dryout model not used above the core support plate
    - Occurrence of PD would stop convective heat removal in a COR cell
  - Revised candling model for B4C
    - Metallic zircalloy from canister rubble candled onto intact rods, leading to oxidation and fuel rod failure
  - Improvements to quench model
    - Pool Atmosphere interaction
    - Temporal relaxation of quench velocity

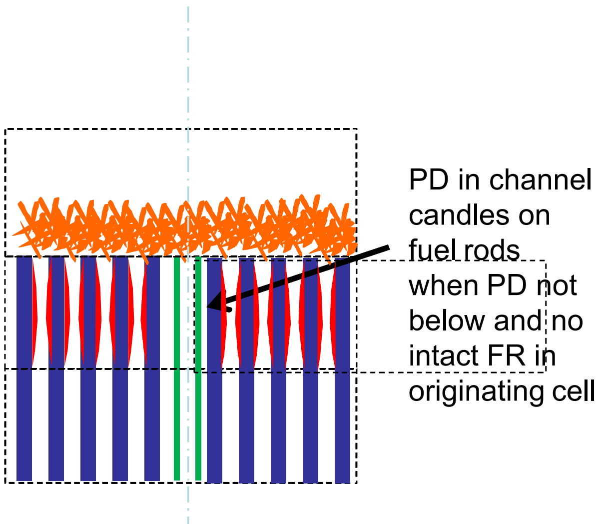


# Revised Candling Model from PD to Cell below with intact Rods

## PD from cell with no intact FR

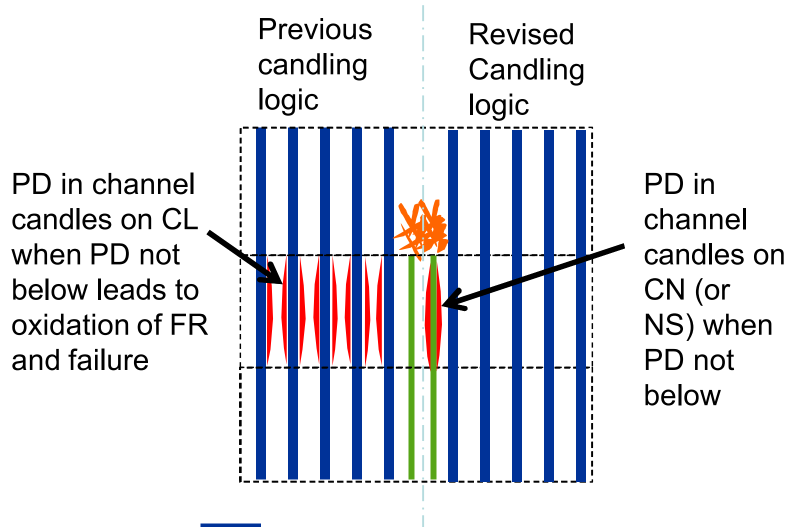
**No Change**




- Fuel Rods (FU+CL)
- Canister (CN+CB)
- Conglomerate (candling)
- Particulate Debris (PD+PB)

## PD from cell with intact FR

**Candles on NS, CN, or CB**




- Fuel Rods (FU+CL)
- Canister (CN+CB)
- Conglomerate (candling)
- Particulate Debris (PD+PB)

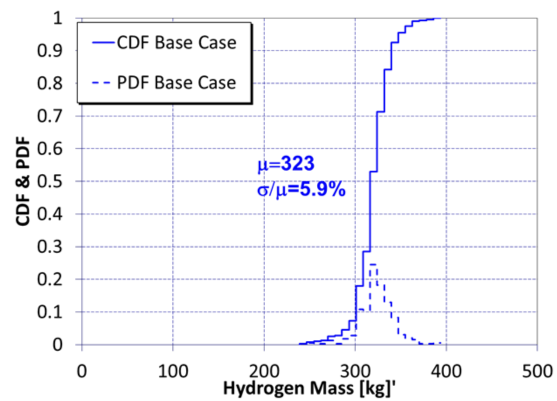
# MELCOR Numerical Variance Analysis

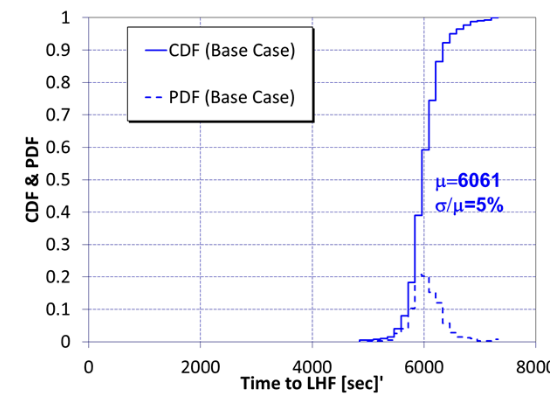


- Characterize MELCOR Numerical Variance
  - Flow path shuffling, time step convergence, etc.
  - Study multiple plant decks/scenarios as variance may be scenario dependent
  - Identify Thresholds
  - Examine matrix conditioning.
  - Add plot variables and CF arguments to enable analysis.
  - Examine relationship between numerical variance and uncertainty trends.
- Reduce Numerical Variance
  - Study parameters in existing models
  - Remove or reduce thresholds.
  - Correct possible modeling errors or inadequacies
  - Goal is not to eliminate variance (impossible) but to reduce it.
    - Code will be more robust as a consequence
- Provide User Guidance
  - Impact of COR nodalization on variance
  - Identify sources of numerical variance due to user effects.
  - Provide guidance for uncertainty analysis studies

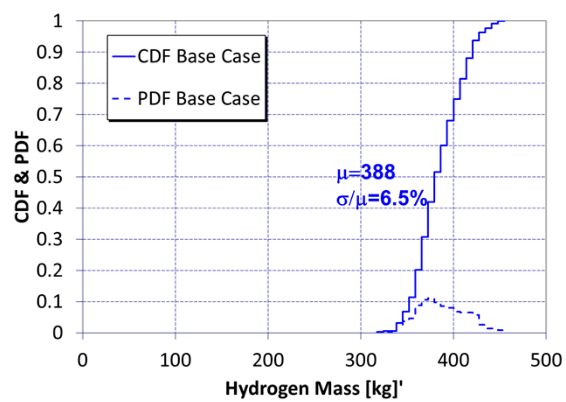
Hydrogen Mass | Time to LHF

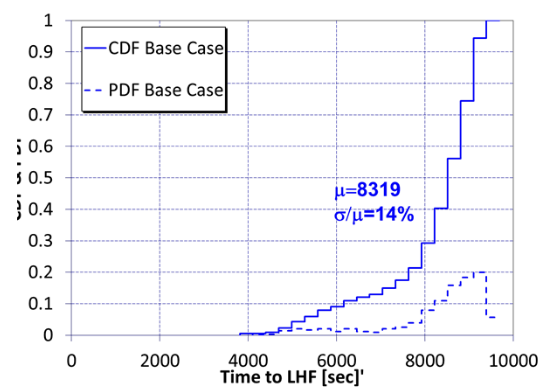
Simple PWR



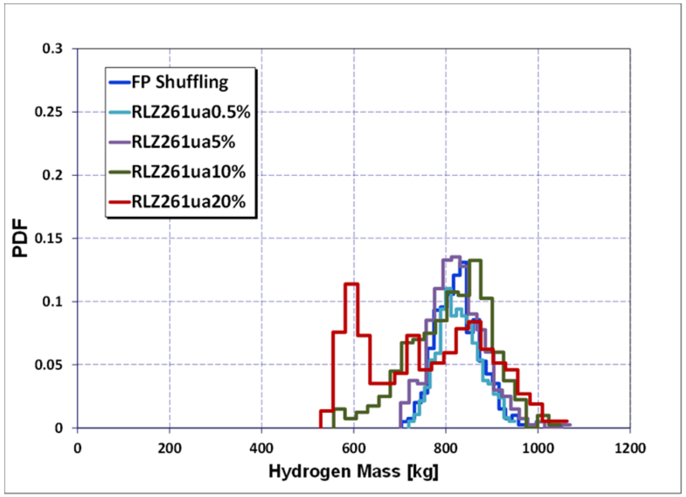

Simple BWR

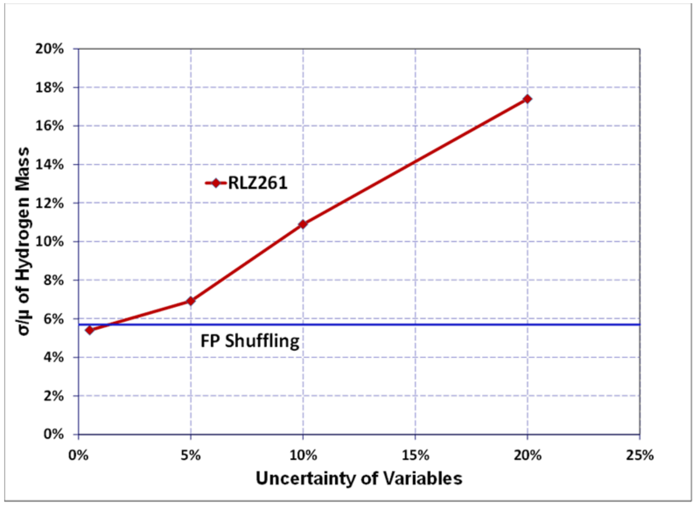


# Uncertainty Variance and Numerical Variance

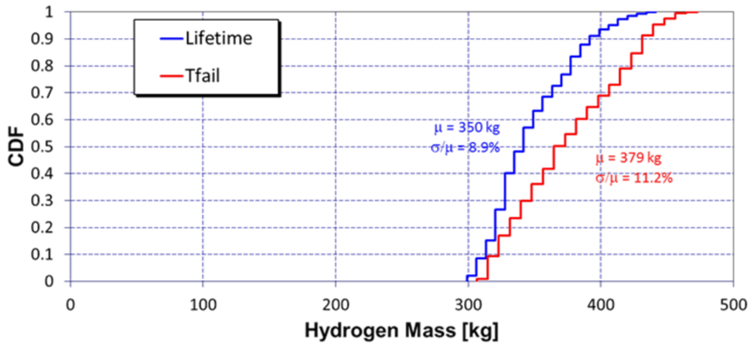
- Comparison of uncertainty variance with inherent numerical variance
  - Uncertainty parameters from FU1 Uncertainty Analysis varied over various sample ranges
  - Numerical variance estimated from flow path shuffling.
- Observations
  - Small perturbation cases show similar variation to numerical variance
  - Larger sampling range shows more statistically significant variance (greater signal to noise ratio) with shift in average to lower hydrogen release (physical trend).

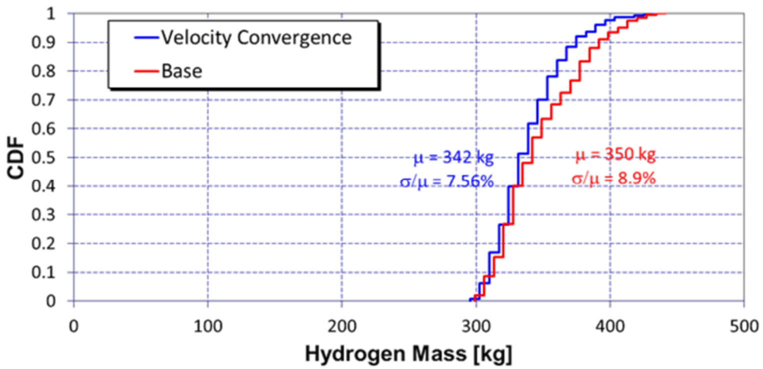


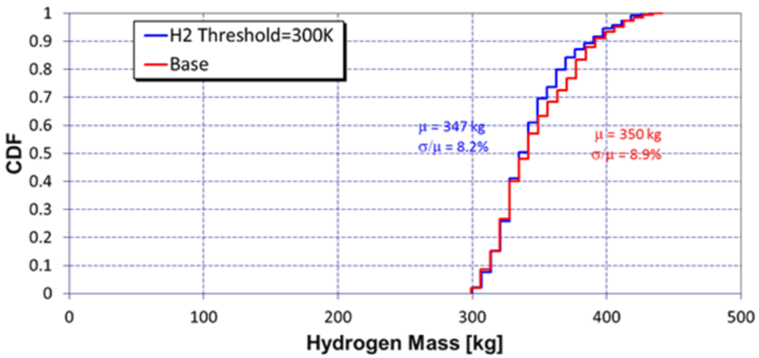



# Numerical Variance Reduction

- Fuel Rod Collapse Model
- Velocity convergence criteria (CVELR)
- Pressure convergence criteria (XXCONV)
- Pressure convergence criteria 2
- Solver and solver convergence
- Hydrogen threshold
  - Change from 1100 K to 300 K
- Threshold mass for oxidation
- Hysteresis refinement
- Core degradation smoothing



# New Model Development Tasks (2014-2015)



- Completed
  - Homologous pump model
  - Multi-HS radiation enclosure model
  - Aerosol re-suspension model
  - Zukauskas heat transfer coefficient (external cross-flow across a tube bundle)
  - Core Catcher (multiple containment vessels)
  - Multiple fuel rod types in a COR cell
  - Generalized Fission Product Release Model
  - New debris cooling models added to CAV package
    - Water-ingression
    - Melt eruption through crust
  - Spreading model implemented into CAV package (almost completed)
  - Miscellaneous models and code improvements
    - COR_HTR extended to heat structures
    - LAG CF
    - MACCS Multi-Ring Release
    - Valve Flow Coefficient
    - MACCS release types
- In Progress
  - Vectorized Control Functions
  - CONTAIN/LMR models for liquid metal reactors
  - CVH/FL Numerics

# Homologous Pump Model

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- Transient Pump operation characterized by
  - Rotational speed
  - Volumetric flow rate
  - Dynamic head
  - Hydraulic torque
- Pump characteristic curves or four quadrant curves
  - Any one of the above quantities can be expressed as a function of any other two
    - Dynamic head and hydraulic torque are expressed as functions of volumetric flow and rotational speed ratios
      - Eight curves for the dynamic head
      - Eight curves for hydraulic torque
  - Empirically developed by manufacturer
  - Similarities to RELAP and TRACE models
- Curve Definitions
  - Built-in pump curves
    - Semi-scale
    - Loft
  - User defined curves
    - Uses tabular function (32 TFs for full coverage)
    - If user does not define all modes, error occurs when pump enters undefined domain
  - Universal correlation
    - Systematic approach for predicting pump performance where data does not exist
    - Fits to several data sets (including LOFT & Semiscale)
    - Only valid in normal operating mode
    - Lahssuny, Jedral. Universal Correlations for Predicting Complete Pump Performance Characteristics. 2004.

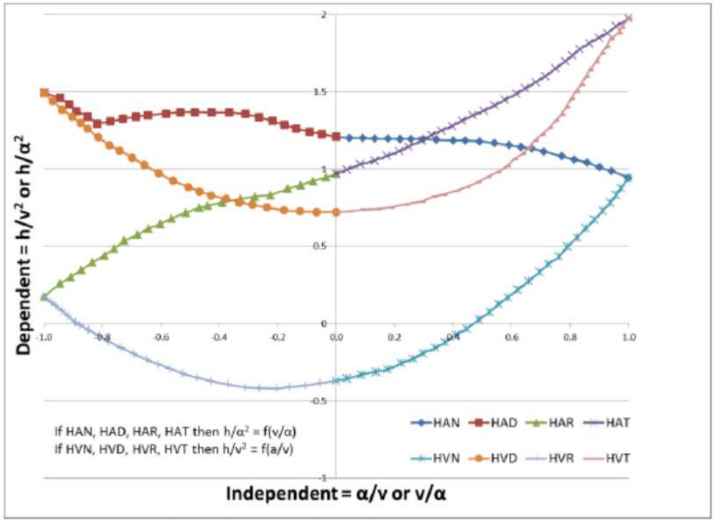


**Figure 1.** Semiscale single-phase head curve

**Table I.** Possible pump operating modes

| Plot Quadrant | Nondim. Speed/Capacity | Mode Identifier |
|---|---|---|
| 1st (Upper Right) | $\alpha >= 0$ and $v >= 0$ | Normal (N) |
| 2nd (Upper Left) | $\alpha > 0$ and $v < 0$ | Dissipation (D) |
| 3rd (Lower Left) | $\alpha <= 0$ and $v <= 0$ | Turbine (T) |
| 4th (Lower Right) | $\alpha < 0$ and $v > 0$ | Reversal (R) |

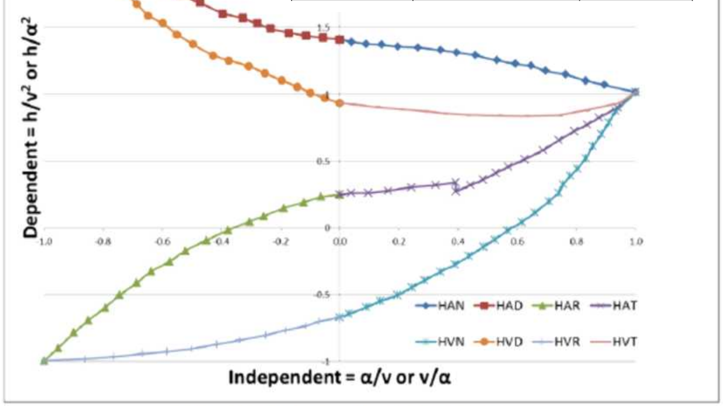


**Figure 4.** LOFT single-phase head curve

$$\alpha = \frac{\omega}{\omega_R} \text{ and } v = \frac{Q}{Q_R}, \text{for rated speed and capacity } \omega_R, Q_R$$

# Homologous Pump Model

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- MELCOR specific implementation
  - Equations cast in polar form which reduces to two closed curves
    - Simplifies programming
      - Independent variable is always positive and bounded
      - Octants are ordered in monotonically increasing fasihion, simplifying interpolation
    - Dynamic head
    - Hydraulic torque
- Data output
  - Single phase and fully-degraded pump head, single-phase and fully-degraded hydraulic torque, dissipation losses
- Data input
  - Flow path associated with pump
  - Rated pump data
    - Impeller speed, volumetric flow rate, head, hydraulic torque, density of pumped fluid, motor torque, ratio of initial speed to impeller speed
  - Single/2-phase homologous pump performance curves
    - Optional built-in data for Semi-scale, LOFT, and "universal correlation"
  - Pump friction torque as a polynomial in pump speed
  - Pump inertia as a polynomial in pump speed
  - Pump speed and motor torque controls
  - Pump trips

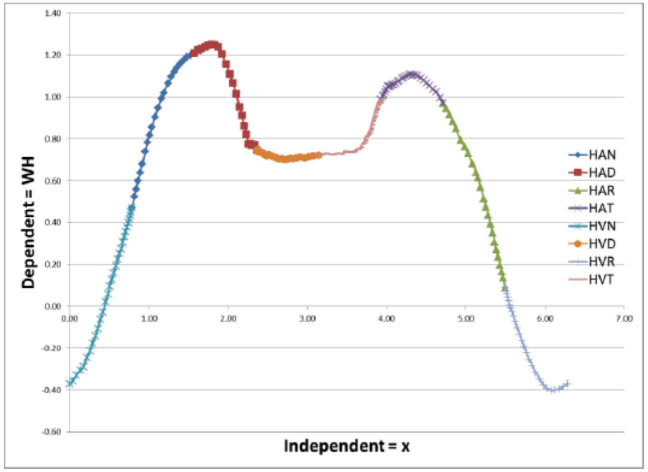


**Figure 6.** Polar homologous single-phase head curve, Semiscale, compare to figure 1

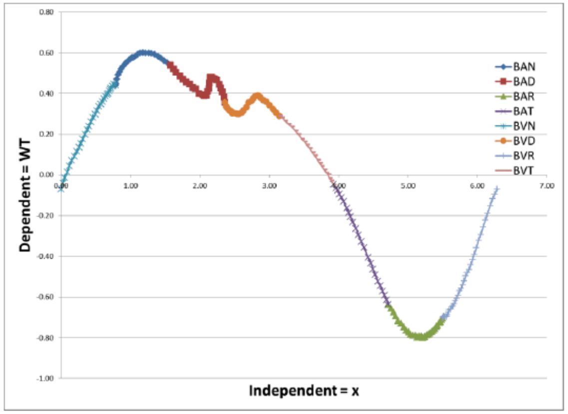


**Figure 7.** Polar homologous single-phase hydraulic torque curve, Semiscale, compare to figure 2

$$\alpha = \frac{\omega}{\omega_R} \text{ and } v = \frac{Q}{Q_R}, \text{for rated speed and capacity } \omega_R, Q_R$$

# Multi HS Radiation Enclosure Model

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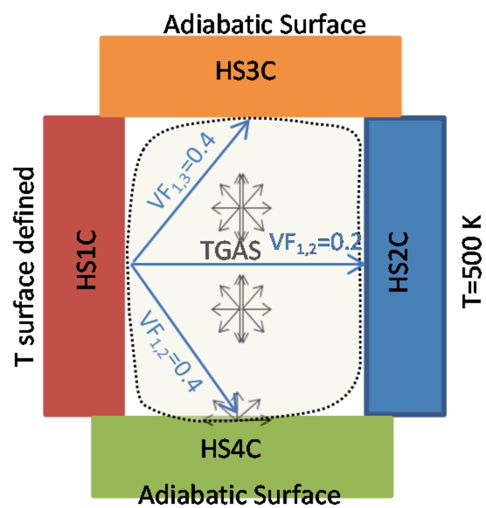
- Previous HS radiation model
  - Radiation defined only for surface pairs
  - Radiation to gas performed independently for each surface
    - Does not account for transmissivity of gas
- New enclosure model
  - Multiple enclosure networks, each with multiple heat structures defined by the user.
    - Memory dynamically allocated
  - User defines all surfaces exchanging radiant heat
    - Matrix of view factors connecting surfaces
  - Participating gas
    - Transmissivity accounts for reduction in radiation between surfaces
    - Only 1 CV associated with all surfaces
    - User supplies beam length (similar to COR package)

$\tau_{j,i}$ is the transmissivity through gas

$$J_i = (1-\varepsilon_i)\cdot\sum_j^N\left[F_{ij}\cdot\tau_{j,i}\cdot J_j\right] + \varepsilon_i\cdot\sigma\cdot T_i^4 + \rho_i\varepsilon_m E_{bm}$$

$$G_i = \sum_j^N\left[A_j\cdot F_{j,i}\cdot\tau_{j,i}\cdot J_j\right]/A_i + \varepsilon_m E_{bm}$$

$$q_i = A_i\left(J_i - G_i\right)$$




```
HS_RAD 4  NET3 !EM   BeamL    VF
 1 HS1C  LEFT   EM1  0.5     0.0  0.2  0.4  0.4
 2 HS2C  LEFT   EM2  0.5     0.2  0.0  0.3  0.5
 3 HS3C  LEFT    -   0.5     0.4  0.3  0.2  0.1
 5 HS4C  LEFT    -   0.5     0.4  0.5  0.1  0.0

TF_ID TEMP   1.0    0.0  !T Surface Defined
TF_TAB 4
    1 0.0       500.0
    2 500.0     1500.0
    3 1000.0    1500.0
    4 30000.0   1500.0
```

# Multi HS Radiation Enclosure 3HS Example

- Identical HS definition
  - HS1 and HS1A
    - TBC(t)=500+t*2 t<500
    - TBC(t)=1500-(t-500)*2  t>500
  - HS2 and HS2B adiabatic BC
  - HS3 and HS3B adiabatic BC
  - Emissivity = 0.1 = EM1
- Surface-Surface radiation pairs

  HS_RD  3 !( n

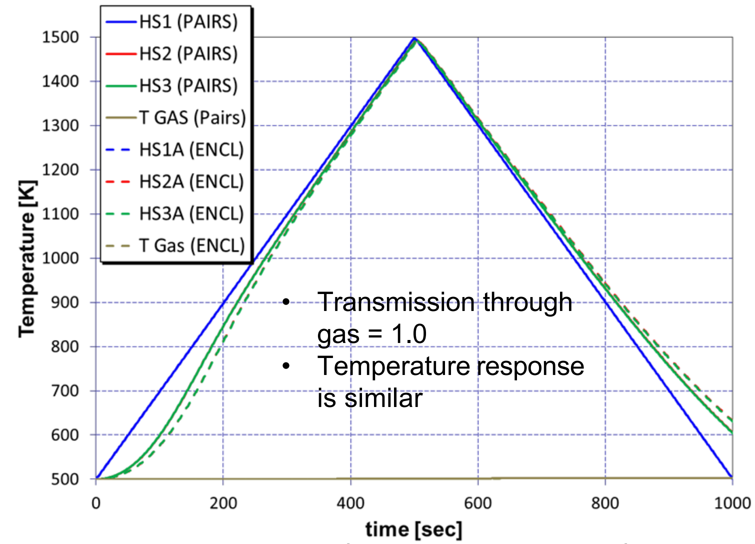
  1 'HS1'  LEFT 'HS2'  LEFT  0.4  EM1  EM1
  2 'HS1'  LEFT 'HS3'  LEFT  0.5  EM1  EM1
  3 'HS2'  LEFT 'HS3'  LEFT  0.5  EM1  EM1

  Radiation to gas

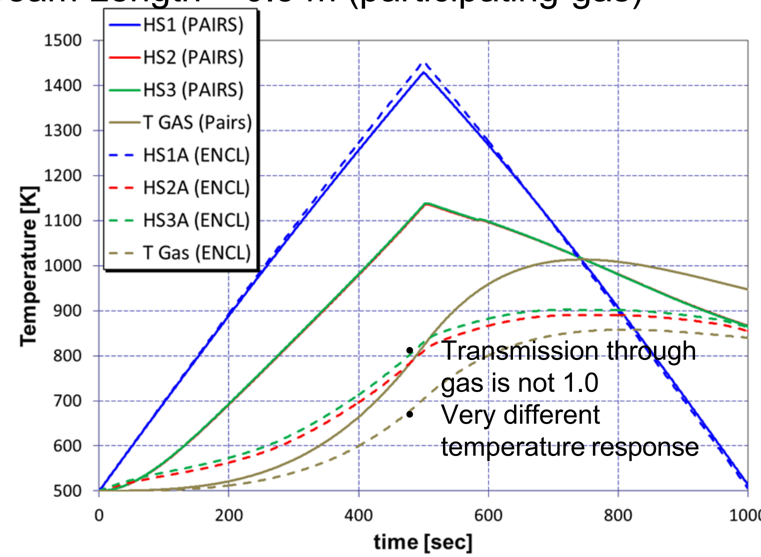
  HS_LBR  0.1  Gray-Gas-A  0.5
  No accounting for transmission through gas
- Enclosure Model
  - View factors and beam length

    HS_RAD  3  NET2 !EM  BeamL  VF
    1 HS1A  LEFT  EM1  0.5  0.1  0.4  0.5
    2 HS2A  LEFT  EM1  0.5  0.4  0.1  0.5
    3 HS3A  LEFT  EM1  0.5  0.5  0.5  0.0

Beam Length = 0.0 (no participating gas)




Beam Length = 0.5 m (participating gas)



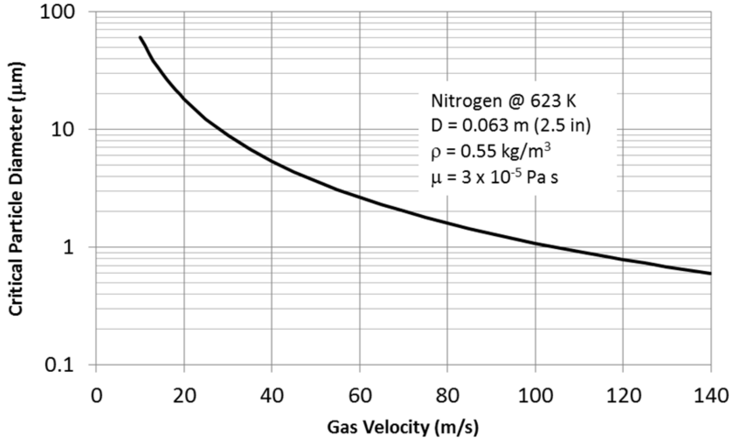
# Re-suspension Model

- Deposited material can be re-suspended
  - All sections for which the lower section boundary particle diameter is greater than a critical diameter
  - Critical diameter is calculated from gas flow conditions

$$D_{crit} = \frac{4 \times 10^{-5}}{\pi \tau_{wall}} \text{ (m)}, \qquad \tau_{wall} = \frac{f \rho v^2}{2} \text{ (N/m}^2\text{)} \qquad f = \frac{0.0791}{Re^{0.25}}$$

Wall shear stress

  - Uses CV velocity
  - Critical diameter can be specified by user
    - Control function
    - Constant value
- By default, surfaces do not re-suspend
- Wet surfaces cannot re-suspend.
  - Pools and surfaces with condensed water
- Relaxation time for resuspension
- Reference
  - "Liftoff Model for MELCOR," Mike Young
  - SAND2015-6119
- Validation against Tests
  - STORM tests (SR11 and SR12)
  - Validation against LACE tests




**Examples**

**To fully activate resuspension, specify a value of FractResuspend as 1.0, and let MELCOR determine the critical diameter:**

HS_LBAR 1. ! Left surface

HS_RBAR 1. ! Right surface

# Zukauskas Heat Transfer Coefficient

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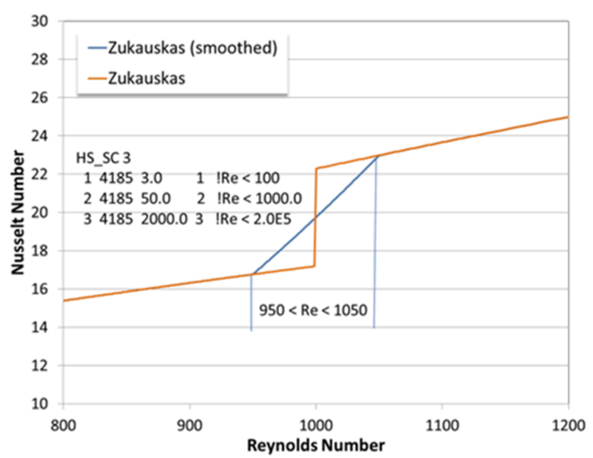
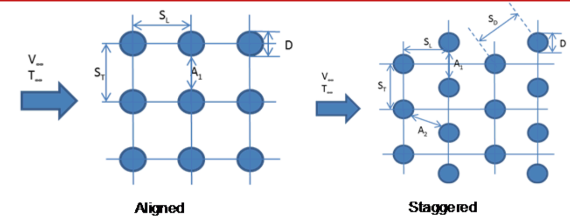
- Heat transfer for external cross-flow across a tube bundle
  - Aligned or staggered
- Implemented as option for HS boundary condition (HS_LB & HS_RB IBCL=2 or ZUKAUSKAS).
- Correction factor $C_2(N_L)$ can be specified or determined from number of rows
- Option to smooth at discontinuities




$$Nu_D = C_2(N_L) C Re_{D,max}^m Pr^n \left(\frac{Pr}{Pr_s}\right)^{0.25}$$

Aligned:

$$V_{max} = \frac{S_T}{S_T - D} V$$




Staggered:

$$if\ S_D = \left[S_L^2 + \left(\frac{S_T}{2}\right)^2\right]^{1/2} < \frac{S_T + D}{2} \qquad V_{max} = \frac{S_T}{2(S_D - D)} V$$

else

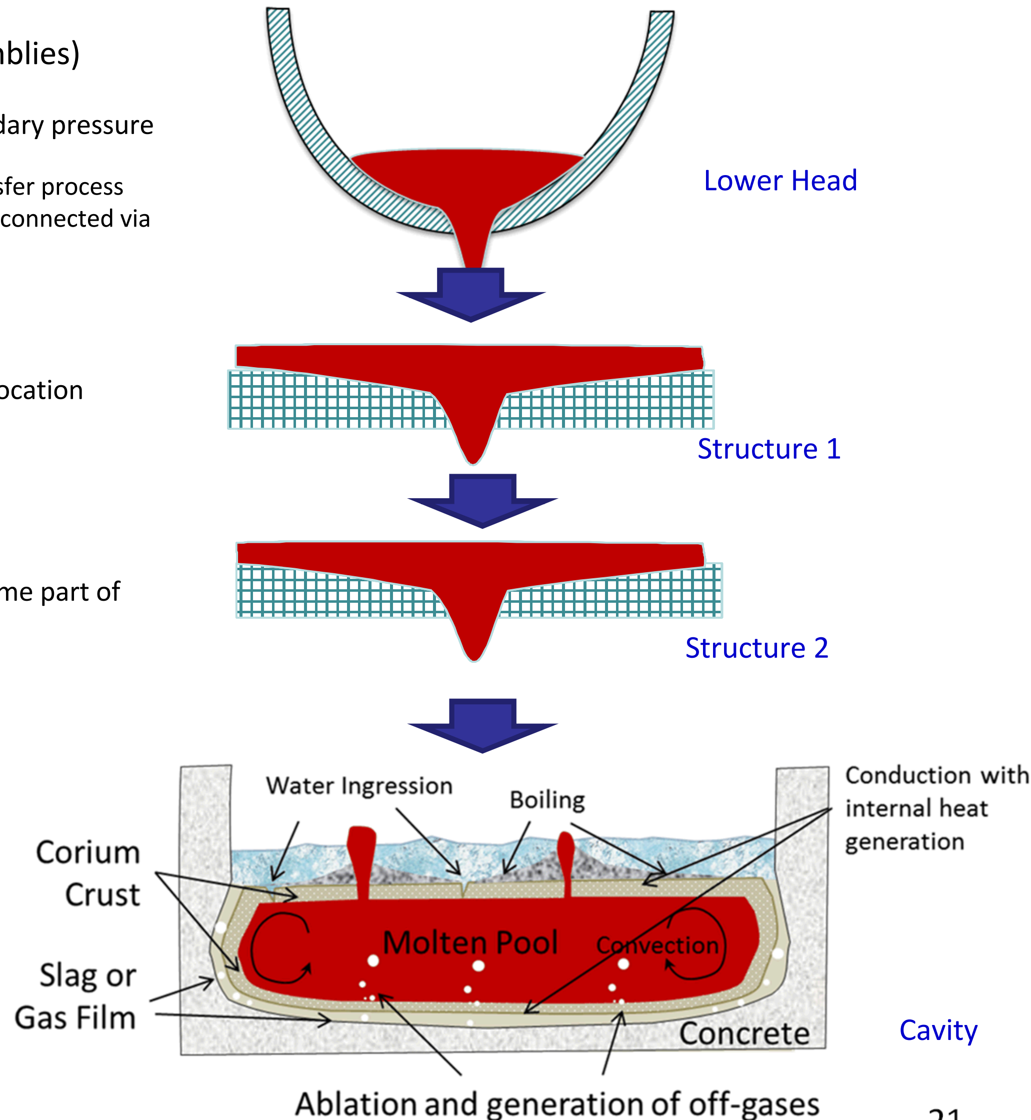
$$V_{max} = \frac{S_T}{S_T - D} V$$

| | $Re_{D,max}$ | Condition | C | m | n |
|---|---|---|---|---|---|
| Aligned | 10 < $Re_{D,max}$<100 | | 0.8 | 0.4 | 0.36 |
| | 100 < $Re_{D,max}$<1000 | Pr<10 | 0.51 | 0.5 | 0.37 |
| | | Pr > 10 | 0.51 | 0.5 | 0.36 |
| | 1000 <$Re_{D,max}$<=2 x $10^5$ | | 0.27 | 0.63 | 0.36 |
| | $2x10^5$ <$Re_{D,max}$<=2 x $10^6$ | | 0.021 | 0.84 | 0.36 |
| Staggered | 10 < $Re_{D,max}$<100 | | 0.9 | 0.4 | 0.36 |
| | 100 < $Re_{D,max}$<1000 | Pr<10 | 0.51 | 0.5 | 0.37 |
| | | Pr > 10 | 0.51 | 0.5 | 0.36 |
| | 1000 <$Re_{D,max}$<=2 x $10^5$ | $S_T/S_L$ < 2 | $0.35(S_T/S_L)^{1/5}$ | 0.6 | 0.36 |
| | | $S_T/S_L$ > 2 | 0.4 | 0.6 | 0.36 |
| | $2x10^5$ <$Re_{D,max}$<=2 x $10^6$ | | 0.022 | 0.84 | 0.36 |

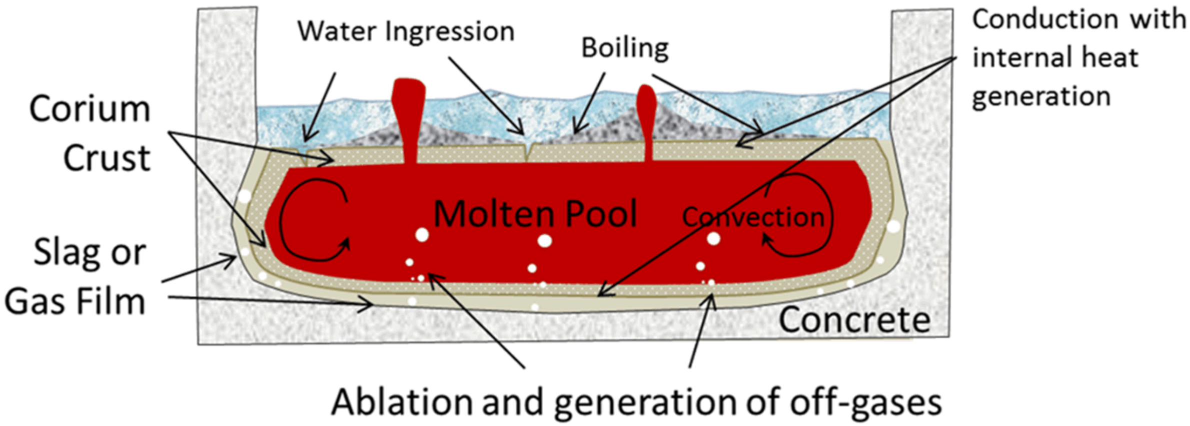
# Core Catcher / Ex-Vessel Structure Model



- 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
    - Allows insulation or other non-structural material
  - 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
  - Special features (like penetrations) modeled
- Multiple failure criteria
    - Failure by melt-through
    - Failure by control function
    - Secondary Pressure Vessel
      - Larson-Miller Creep
      - Yield Stress
- Work completed in September 2015



# 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

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- 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

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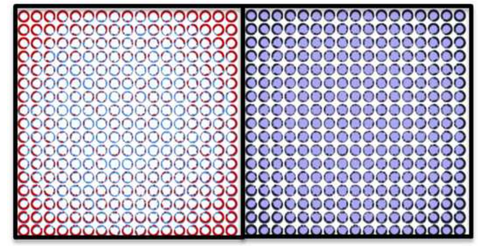
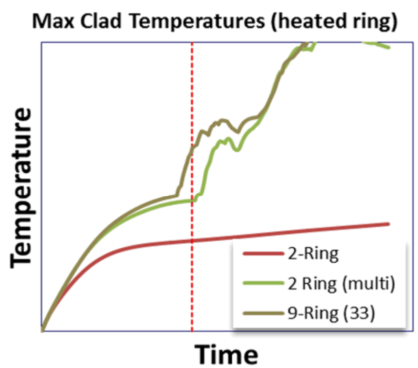
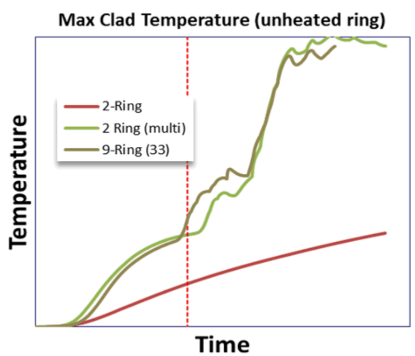
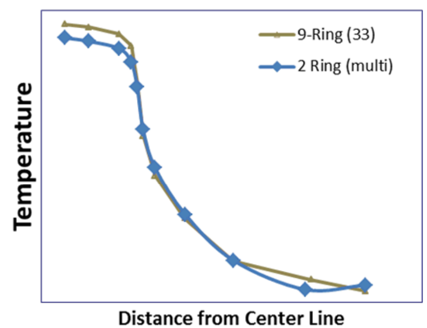
- Motivation
  - It is desirable to model an entire assembly within a single MELCOR ring
- Challenge
  - When hot assembly reaches ignition, heat transfer to cold assembly is problematic

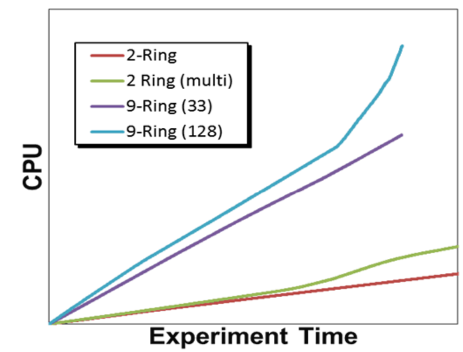


Hot Assembly Cold Assembly




- 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
- Fuel rod degradation modeling is nearly complete

# Generalized Fission Product Release Model

- A cumulative burst fission product release fraction is described by the following equation:

$$FB_{j,i} = a\_burst_j\left(c_0 + c_1 * T_i + c_2 * T_i^2 + c_3 * T_i^3\right)$$

Where

$T_i$ is the fuel temperature that existed during the time interval $Dt_i$

$c_0$, $c_1$, $c_2$, $c_3$ are constant coefficients provided in user input

$a_j$ is a constant class dependent coefficient provided in user input.

- A cumulative diffusive fission product release fraction is described by the following equation:

$$FD_{j,i} = b\_diff_j\left(FD_{j,i-1} + \left(1 - FB_{j,i-1} - FD_{j,i-1}\right) \cdot \left[1 - e^{-kd_{j,i} \cdot \Delta t_i}\right]\right)$$

Where

$FD_{j,i}$ is the cumulative fraction of diffusive fission product released up to time $t_i$

$B\_diff_j$ is a constant class dependent coefficient provided in user input

$FD_{j,i-1}$ is the cumulative fraction of diffusive fission product released up to time $t_{i-1}$

$FB_i$ is the cumulative fraction of burst fission product released up to time $t_i$

$\left[1 - e^{-kd_{j,i} \cdot \Delta t_i}\right]$ is the fractional release due to diffusion during the time interval $Dt_i$

$kd_{j,i}$ is the release rate coefficient for fission product class j calculated using the temperature, Ti, that existed during the time interval $Dt_i$

$$kd_{j,i} = A_j e^{-B_j/(RT_i)}$$

Where $A_j$ and $B_j$ are class dependent coefficients provided in user input.

- The total cumulative fission product release fraction at time $t_i$ for fission product j is determined by:

$$F_{j,i} = d\_total_j \cdot \left(FB_{j,i} + FD_{j,i}\right)$$

- The cumulative release fraction cannot exceed the amount of fission product available

$$FB_{j,i} = FB_{j,i-1} \; and \; FD_{j,i} = FD_{j,i-1} when \; FD_{j,i} \geq 1.0$$

- The derivative of the cumulative burst release with respect to time cannot be less than zero; if the temperature decreases, the cumulative burst release remains constant.

$$FB_{j,i} = FB_{j,i-1} \; when \; T_{i-} \geq T_{B-max} \; or \; T_{melting}$$

- The cumulative burst release reaches its maximum when the fuel temperature reaches $T_{B\text{-}max}$ or $T_{melting}$ whichever is lower

$$FB_{j,i} = FB_{j,i} \; when \; T_i \geq T_{B-max} \; or T_{melting}$$

# DOE Models: CONTAIN/LMR Models for

- 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
  - Implementation of CONTAIN/LMR models into CONTAIN2
- Phase 3 – Implementation and Validation of:
  - Implementation of CONTAIN/LMR models into CONTAIN2
  - Sodium spray fires (ongoing)
  - Upper cell chemistry (ongoing)
  - Sodium pool chemistry (ongoing)
- Phase 4 – Implementation and Validation of:
  - Condensation of sodium
  - Sodium pool fire models
  - Debris bed/concrete cavity interactions.

# Extensions to the CF Package (September 2016)



- Constant CF Argument
- Vectorized CF arguments
- Ranges
- Vector Control Functions
- Analytic Control Functions

# Constant CF Argument (September 2016)



- In the past, MELCOR had no specific way of identifying a constant control function argument. For example, the constant pi would be referenced as follows:

  1 EXEC-TIME 0.00 3.1415

- This was always confusing to new users and requires careful reading to know for sure that the argument is truly a constant or a function of the execution time. A new CF argument can be used to identify this constant value

  1 CF-CONST 3.1415

# Control Function Ranges

- The range is an object that is defined once in the database and then can be referenced by other control function arguments. The range specifies an ordered list of objects such a control volumes, COR cells, materials, or components
- A range can be referenced by control functions and control function arguments. The hashtag (#) that precedes range specified for the volume in the CF argument indicates a range of control volumes rather than a single volume.

**Define a Range:**

```
           name      type       ndim  Number
CF_RANGE  CVRANGE  CVOLUMES     2      30
CONSTRUCT  2
 1 CVTYPE='PRIMARY'
 2 DC
REMOVE  1
 1  LowerPlenum
```

Reference that Range:

```
CF_ID      'CVMass2'  1010  ADD
CF_SAI 1.0 0.00
CFVALR (INITIAL VALUE)
CF_ARG 1
 1   CVH-MASS(#CVRANGE,POOL)      1.0
0.0
```

# Ranges

- Ranges can be specified by enumeration and/or keywords.
- Enumeration 1

  CF_RANGE  RANGE1  CELLS 15
  CONSTRUCT  4
  1 1  2  8 1
  2 1  3
  3 2  1
  4 2  3
- Enumeration 2

  CF_RANGE  RANGE1  CELLS 15
  CONSTRUCT  2
  1  6-10  1-2
  2  11-13  3
- Keywords

  CF_RANGE  CVRANGE  CVOLUMES 30
  CONSTRUCT  2
  1 DC160  UP+UH150
  2 CVTYPE='CVTYPE01'

| Range Type | Keywords |
|---|---|
| **CVRANGE** | 'ALL' CVTYPE=, BYPASS, CHANNEL |
| **CORCELLS** | 'ALL' 'LP' 'UC' 'RING1' 'ELEV5' 5-7 1-2 |
| **HSRANGE** | 'ALL' 'COR' 'CVTYPE=' |
| **CLASS** | ALL |
| **CORCOMPONENTS** | 'ALL' 'COR' 'BYP' |
| **MATERIALS** | Oxides, Metals |

# Vectorized CF Arguments

- Traditionally, MELCOR recognizes scalar control function arguments that can be used as parameters in evaluating the control function. For example, the masses in several control volumes can be summed by including an itemized list of each control volume.
- The user can now specify a vectorized control function argument that can be recognized by modified control functions (such as the the 'ADD' control function type) which can greatly reduce the number of arguments required by the control function
- Vectorized control functions can be added to the plotfile using ranges

```
CF_ID      'CVMass' 1010ADD
CF_ARG 1
 1   CVH-MASS('CORE',POOL)      1.0    0.0
 2   CVH-MASS('BYPASS',POOL) 1.0    0.0
 3   CVH-MASS('LP',POOL)         1.0    0.0
 4   CVH-MASS('UP+UH',POOL)   1.0    0.0
 5   CVH-MASS('DC',POOL            1.0    0.0
```

```
CF_ID      'CVMass2'  1010  ADD
CF_ARG 1
 1   CVH-MASS(#CVRANGE,POOL)    1.0    0.0
```

# Vector Control Functions

- Control functions can now return a vector of values. The dimension of the vector must be specified on the CF_VF record

  CF_VF 5

  The field on this record indicates that the function returns a vector with 5 elements.

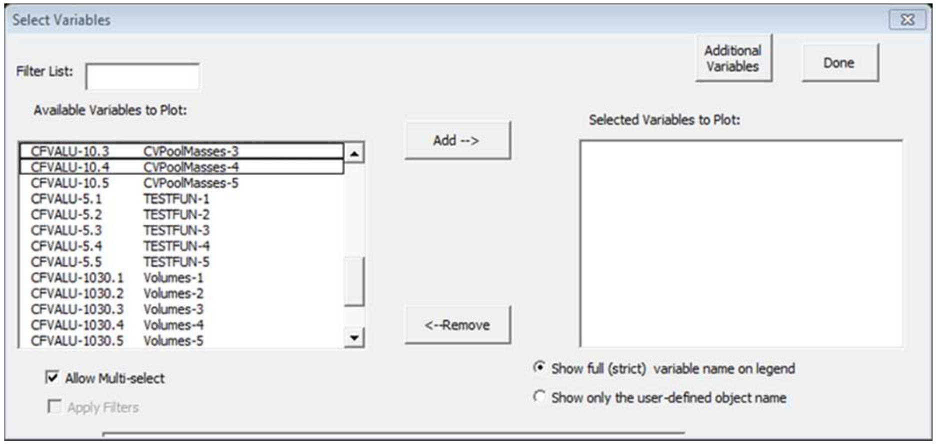
  CV_VF #CVVOLUMES

  The dimension is taken implicitly from the dimension of the #CVVOLUMES range

- If the user would like to reference a particular element from the vector results (e.g., the 4th element of the vector function 'TESTFUN'), that reference is made as follows:

```
CF_ID        'OXIDE-FR71'        71        EQUALS
CF_ARG 1
 1 CF-VALU('TESTFUN')[4]   1.0   0.0
```

- Elements of a vector CF can be referenced from plotting routines like PTFREAD



# Analytic Functions

- Rather than passing a fixed number of arrays through an argument list to the analytical function, a new user defined type called tUDFArguments was added to contain all arguments (real arrays, integer arrays, real values, etc.) This data structure contains information regarding the total number of arguments, the dimension of each argument, a text descripton of each argument, and the range over which each argument may be defined (cell numbers, CVnames, etc.). This information may be useful to the user in debugging the dll.

| | |
|---|---|
| UDFarguments | {...} |
| UDFarguments%NARGS | 2 |
| UDFarguments%ARGUMENTS | {...} |
| UDFarguments%ARGUMENTS(1) | {...} |
| UDFarguments%ARGUMENTS(2) | {...} |
| UDFarguments%ARGUMENTS(2)%KIND | 2 |
| UDFarguments%ARGUMENTS(2)%NDIM | 0 |
| UDFarguments%ARGUMENTS(2)%INTARRAY | Undefined pointer/array |
| UDFarguments%ARGUMENTS(2)%REALSCALAR | 0.000000000000000D+000 |
| UDFarguments%ARGUMENTS(2)%REALARRAY | {...} |
| UDFarguments%ARGUMENTS(2)%REALARRAY(1) | 11423.2178468055 |
| UDFarguments%ARGUMENTS(2)%REALARRAY(2) | 174.333207580820 |
| UDFarguments%ARGUMENTS(2)%REALARRAY(3) | 11329.6978079948 |
| UDFarguments%ARGUMENTS(2)%REALARRAY(4) | 3611.48073217145 |
| UDFarguments%ARGUMENTS(2)%REALARRAY(5) | 16817.0733501201 |
| UDFarguments%ARGUMENTS(2)%DESCRIPTION | 'CVH-MASS ' |
| UDFarguments%ARGUMENTS(2)%ELEMENT | {...} |
| UDFarguments%ARGUMENTS(2)%ELEMENT(1) | 'DC160 ' |
| UDFarguments%ARGUMENTS(2)%ELEMENT(2) | 'UP+UH150 ' |
| UDFarguments%ARGUMENTS(2)%ELEMENT(3) | 'CORE110 ' |
| UDFarguments%ARGUMENTS(2)%ELEMENT(4) | 'BYPASS111 ' |
| UDFarguments%ARGUMENTS(2)%ELEMENT(5) | 'LP120 ' |

# Application: Plotting summation of variable over a region

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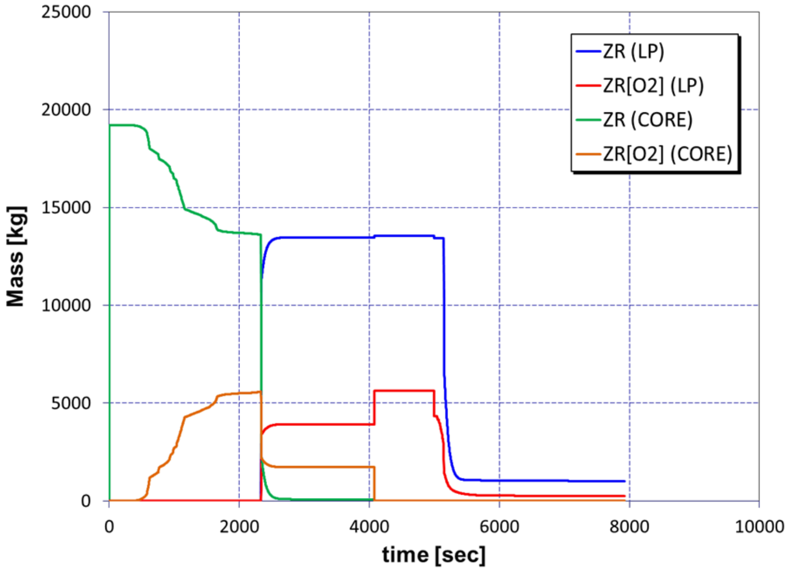
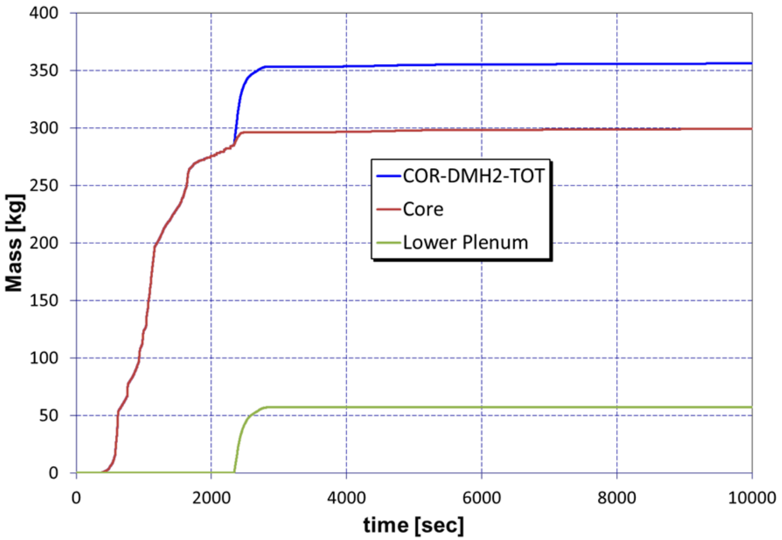
## Zr/ZrO2 Mass in Lower Plenum




```
CF_RANGE  L_PLEN  CELLS 2  12
CONSTRUCT  1   ADD
   1 LP


CF_ID  'ZRO2_LP' 302 ADD
CF_SAI  1.0  0.0  0.0
CF_ARG 1
  1   COR-CELLMASS(# L_PLEN (1),# L_PLEN(2 ),'ZR[O2]')  1.0  0.0
```

## H2 Mass generated in Lower Plenum




```
CF_ID  'H2_LP' 305 ADD
CF_SAI  1.0  0.0  0.0
CF_ARG 11
  1   COR-H2(#LOWERPLEN(1),#LOWERPLEN(2),'CL')  1.0  0.0
  2   COR-H2(#LOWERPLEN(1),#LOWERPLEN(2),'SH')  1.0  0.0
  3   COR-H2(#LOWERPLEN(1),#LOWERPLEN(2),'NS')  1.0  0.0
  4   COR-H2(#LOWERPLEN(1),#LOWERPLEN(2),'SS')  1.0  0.0
  5   COR-H2(#LOWERPLEN(1),#LOWERPLEN(2),'FM')  1.0  0.0
  6   COR-H2(#LOWERPLEN(1),#LOWERPLEN(2),'PD')  1.0  0.0
  7   COR-H2(#LOWERPLEN(1),#LOWERPLEN(2),'PB')  1.0  0.0.
...
```

# Miscellaneous New Models: COR_HTR extended to HS

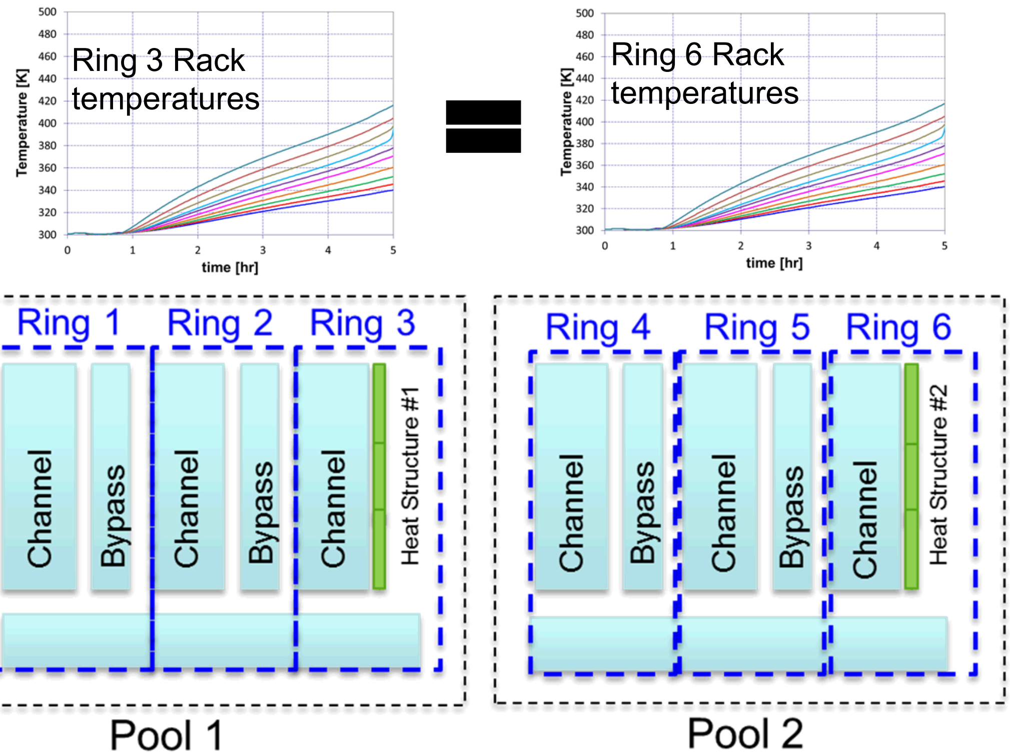
- This feature has been extended to allow specification of a heat transfer path from a COR component to a heat structure. The heat transfer path must be defined 'From' a valid COR component and the heat structure must not have a user specified boundary condition (i.e., IBCL = 0,20,30,80, or 90). Furthermore, 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
```

# COR_HTR extended to HS (Application)

- Two connected spent fuel pools
- Rods near boundary radiate to concrete wall.
- Modification enables heat transfer to heat structures other than boundary heat structures
- Pool 1 & 2 Rack (and HS) temperatures are equivalent.




## Caveats

- Emissivity of boundary HS can be specified by user for SFP reactor types
  - HS_LBR record
  - A value of 0.9999 is assumed for boundary heat structures for all other reactor types
- Input is required to connect the HS surface to the COR cell
  - HS_LBF record
  - Otherwise DTDZ model will not use the structure for calculating local TSVC

# 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

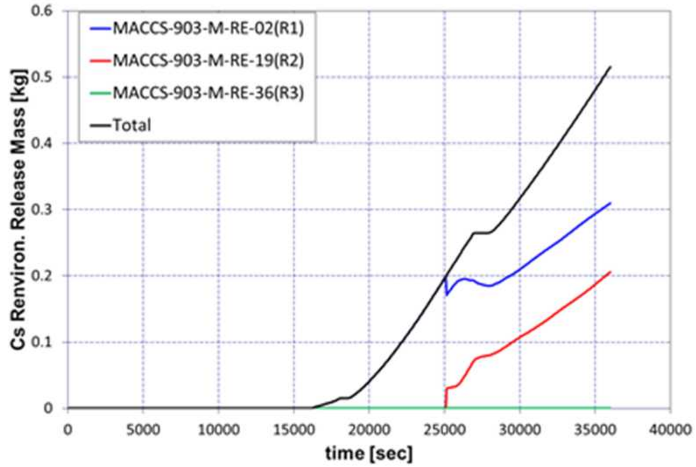
# Miscellaneous New/Improved Models: MACCS Flow Path Types

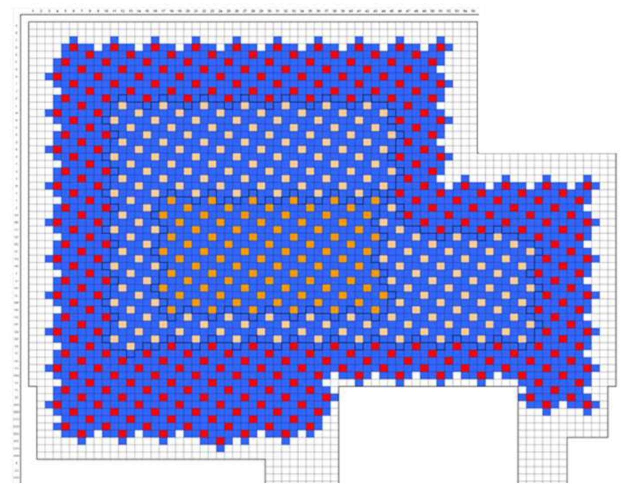
- Origin of MACCS FP Model
  - Flow paths designated to be used in tracking advection of RadioNuclides
  - Originally intended to track airborne release to atmosphere
    - Did not track RNs in Pool that are transported through FP
    - Did not track RNs trapped in filters associated with FP
    - Did not track RNs that are removed through pool scrubbing
- MACCS FP can also be used for calculating mass conservation of RNs between CVs or in calculating DFs
  - Need to include RNs advected with pool, RNs trapped in filters, and RNs removed through pool scrubbing to obtain total inventory transported from a CV.
  - MACCS FP can be designated as a DF type on field 6 of the FL_MACCS record.

```
FL_MACCS    2 !NFL  MACCSnam     MACCSn  MCCSFP        DIRFL    DF or MACCS
              1     Leakage      110   FlowPath190     FROM          DF
```

# 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



# Temporal Relaxation of the "Rate-of-Change"



- Introduction
  - Many physical processes in MELCOR are modeled by correlation based relationships developed from steady-state experiments. These models do not represent the time it takes for these processes to respond if conditions change. As a result, temporal "rate-of-change" aspects of MELCOR simulations are not expected to be highly accurate and numerical instabilities can be magnified when sudden changes occur.
  - Temporal relaxation is a simple way to introduce a user-imposed time-scale based model that limits how quickly processes being modeled can change in time. Note that "steady-state" values are not changed, only the temporal rate-of change.

- Fundamental Equation
  - $f^{n+1} = \omega f^* + (1-\omega) f^n$

*Where*

$\omega = min[1.0, dt/\tau_{rel}]$

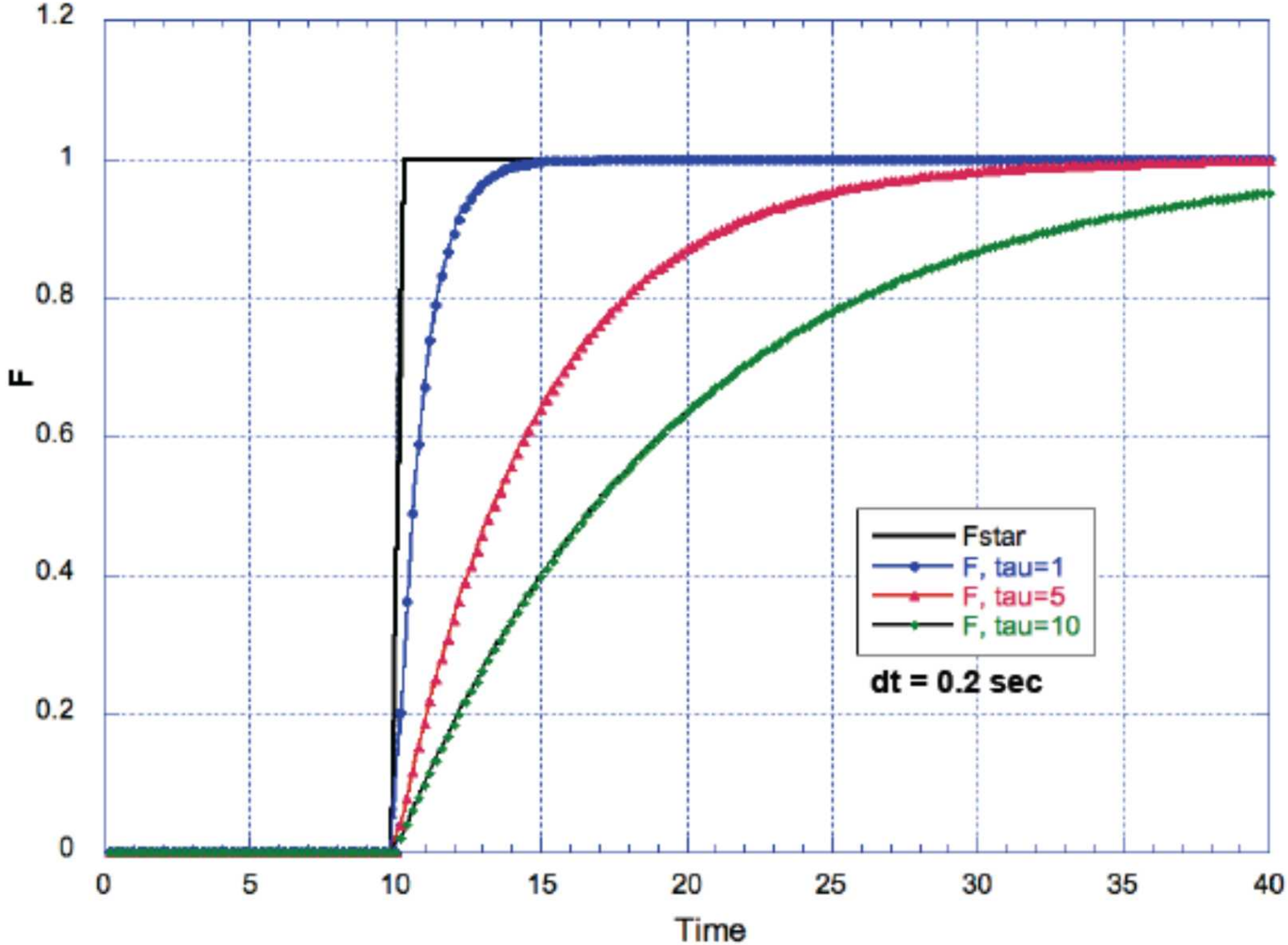
$f^{n+1} = value\ of\ f\ at\ time\ step\ n+1$

$f^n = relaxed\ value\ of\ f\ at\ time\ step\ n$

$f^* = unrelaxed\ value\ of\ f\ at\ time\ step\ n+1$

$\tau_{rel} = temporal\ relaxation\ time\ scale$

# Example plot for different temporal relaxation time-scales



# New HS Plot Variables (Non-dimensional variables)



| New Control Function | Description |
|---|---|
| HS-RE-POOL(NameHS, Sn) | Reynolds number for pool at boundary Sn surface of heat structure NameHS. |
| HS-RE-ATM(NameHS, Sn) | Reynolds number for atmosphere at boundary Sn surface of heat structure NameHS. |
| HS-PR-POOL(NameHS, Sn) | Prandtl number for pool at boundary Sn surface of heat structure NameHS. |
| HS-PR-ATM(NameHS, Sn) | Prandtl number for atmosphere at boundary Sn surface of heat structure NameHS. |
| HS-PRS-POOL(NameHS, Sn) | Wall Prandtl number for pool at boundary Sn surface of heat structure NameHS. |
| HS-PRS-ATM(NameHS, Sn) | Wall Prandtl number for atmosphere at boundary Sn surface of heat structure NameHS. |
| HS-NU-POOL(NameHS, Sn) | Nusselt number for pool at boundary Sn surface of heat structure NameHS. |
| HS-NU-ATM(NameHS, Sn) | Nusselt number for atmosphere at boundary Sn surface of heat structure NameHS. |

# New HS Plot Variables (Energy terms)

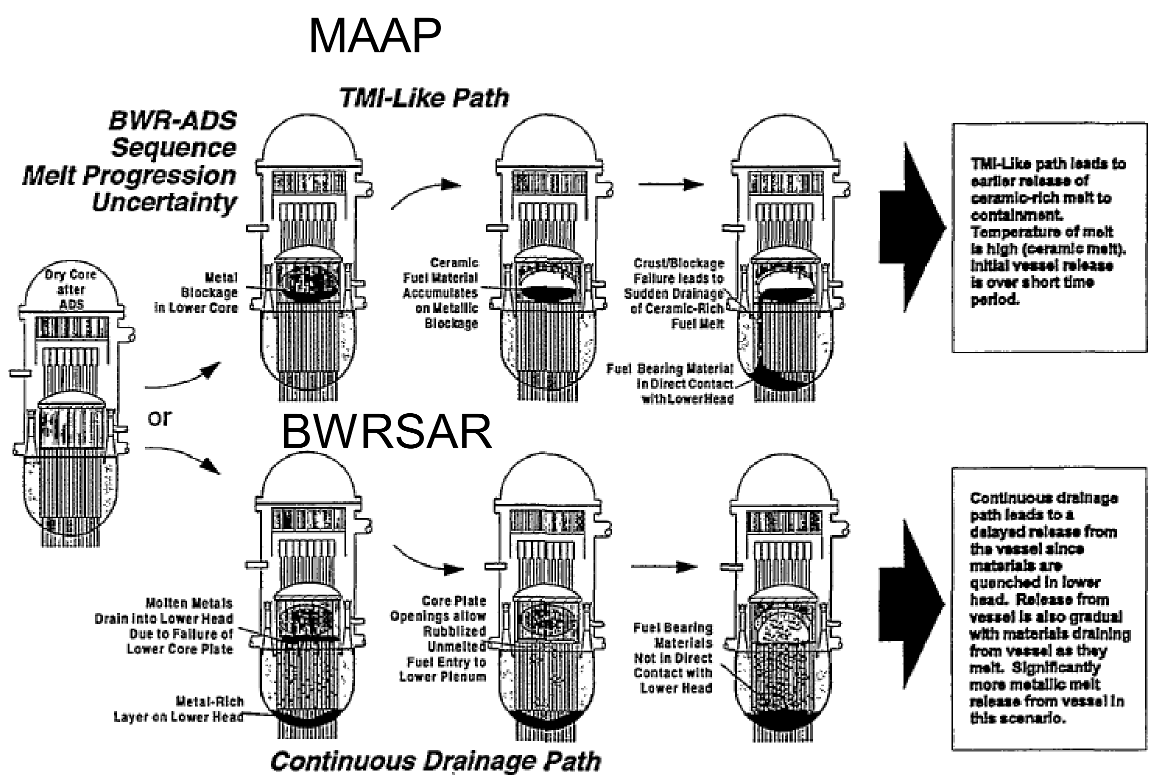
| New Control Function | Description |
|---|---|
| HS-Q-ATMS(NameHS, Sn, TYPE*) | Heat transfer to atmosphere at boundary Sn surface of heat structure NameHS from all modes of heat transfer. |
| HS-Q-POOL(NameHS, Sn, TYPE*) | Heat transfer to pool at boundary Sn surface of heat structure NameHS from all modes of heat transfer. |
| HS-Q-DECAY(NameHS, Sn, TYPE*) | Heat transfer to boundary Sn surface of heat structure NameHS from decay heat associated with radionuclides deposited on the surface. |
| HS-Q-BCFIX (NameHS, Sn, TYPE*) | Heat transfer to boundary Sn surface of heat structure NameHS to accommodate fixed temperature boundary condition. |
| HS-Q-RAD (NameHS, Sn, TYPE*) | Radiation heat transfer to boundary Sn surface of heat structure NameHS. |
| HS-Q-RADG (NameEncl,TYPE*) | Radiation heat transfer to intermediate gas in control volume associated with the enclosure NameEncl. |
| HS-Q-TOTAL (NameHS, Sn, TYPE*) | Total heat transfer at boundary Sn surface of heat structure NameHS from all modes of heat transfer. |

*TYPE indicates whether the value returned is a heat flux, heat rate, or cumulative (integral) heat

| | |
|---|---|
| TYPE = 'FLUX' | heat flux (W/m^2), |
| TYPE='RATE' | heat rate (W) |
| TYPE='INT' | integral heat transfer (J) |

# NRC/DOE MELCOR-MAAP-ASTEC Crosswalk Post-Fukushima Cooperation with EPRI/IRSN

- MAAP code is very TMI-centric
  - Core-wide blockage
  - Less hydrogen
  - Large melt mass
- MELCOR not as biased towards TMI-2
  - Blockage determined by conditions
  - More hydrogen
  - Often partly molten fuel slumping



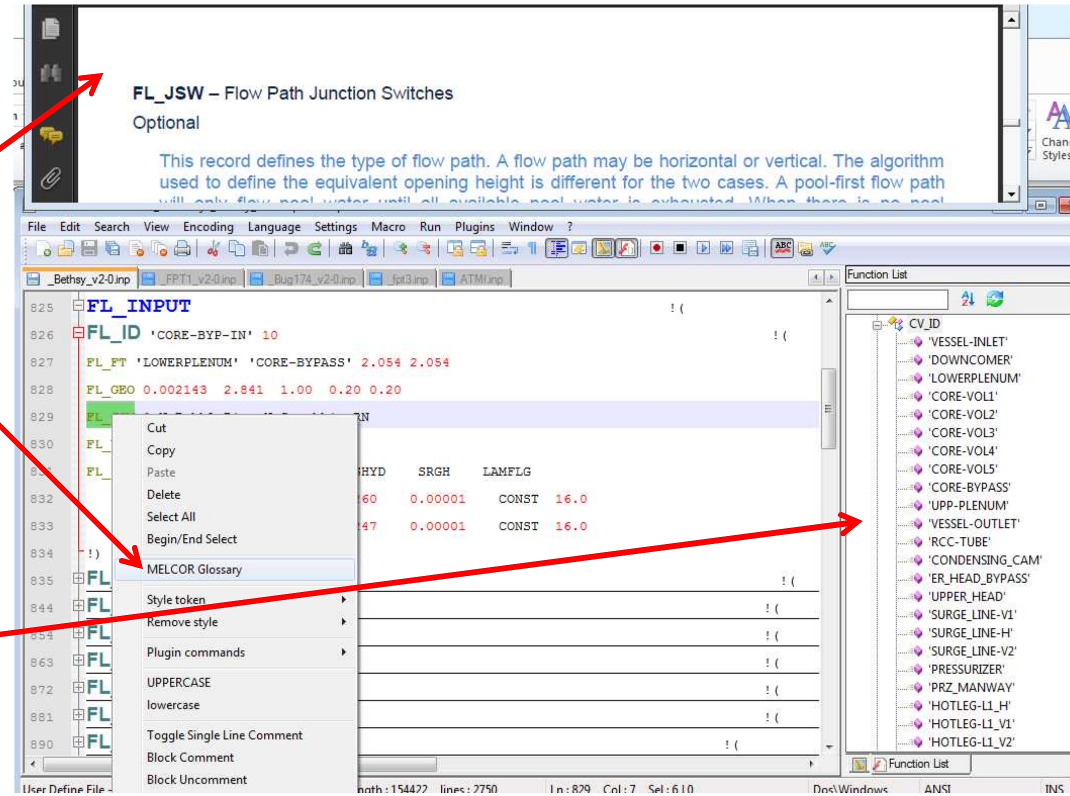

**Final Results of the XR2-1 BWR Metallic Melt Relocation Experiment**
Manuscript Completed: April 1997
Date Published: August 1997

NUREG/CR-6527
SAND97-1039
Prepared by
R. O. Gauntt, SNL
L. L. Humphries, SAIC

# NotePad++ MELCOR Plugin

Sandia National Laboratories

- MELCOR Plugin for NotePad++
  - Continued development
- MELCOR Glossary
  - User guide information available to text editor
  - Context intelligence
- Navigation sidebar
  - Object recognition
  - Double-click to jump to object definition
  - Recently updated to recognize objects defined in multiple files
    - User opens 'master' file
    - Hyperlinks to objects defined in subordinate files



# MELCOR Dashboard

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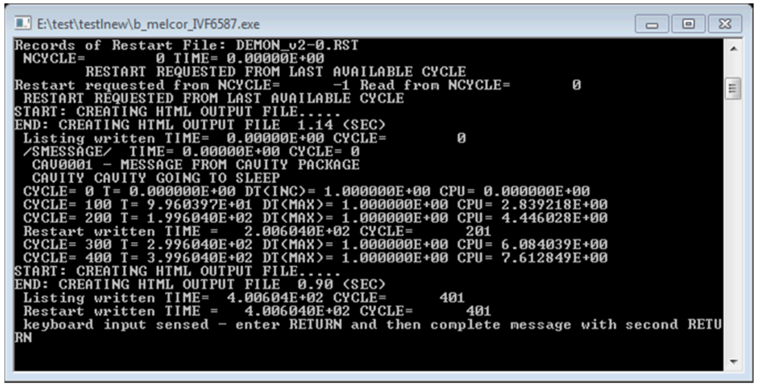
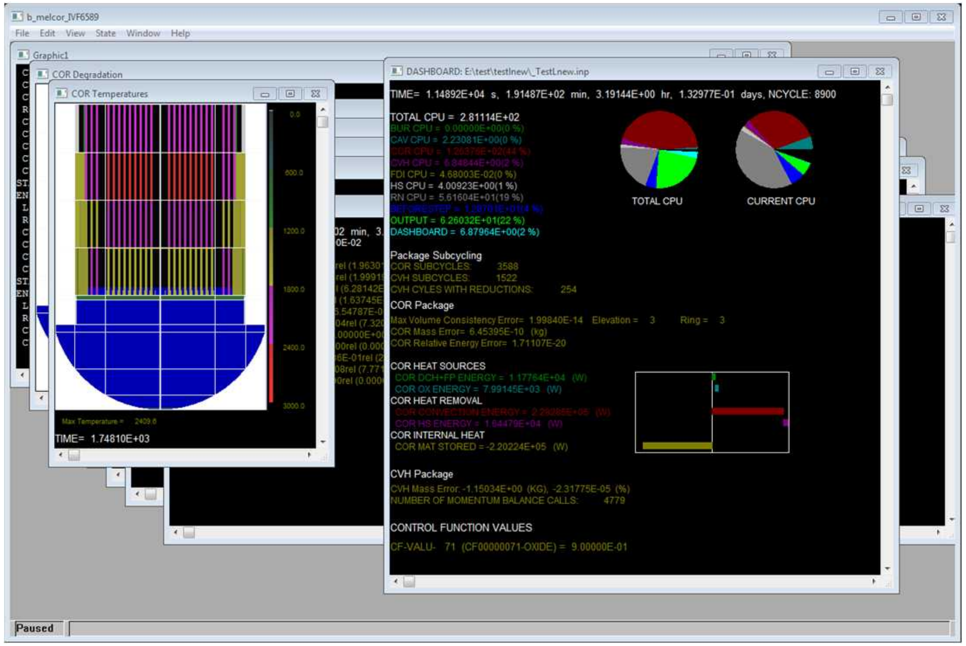
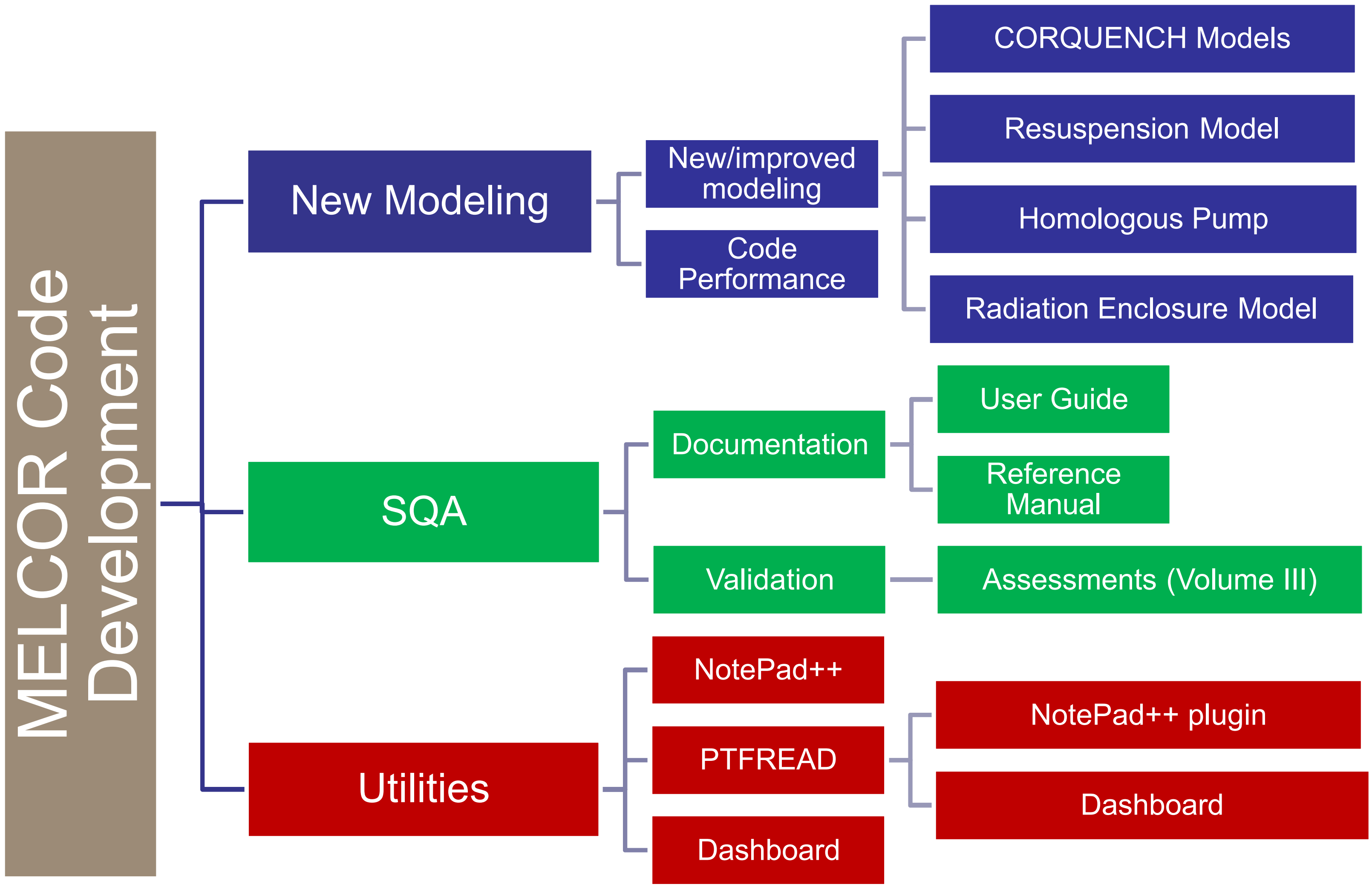



Console Application




QuickWin Application

# Questions?


MELCOR Code Development
New Modeling
New/improved modeling
Code Performance
CORQUENCH Models
Resuspension Model
Homologous Pump
Radiation Enclosure Model
SQA
Documentation
Validation
User Guide
Reference Manual
Assessments (Volume III)
Utilities
NotePad++
PTFREAD
Dashboard
NotePad++ plugin
Dashboard