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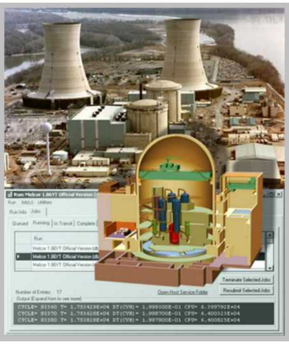

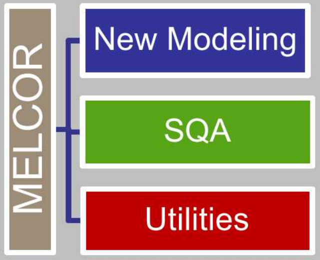
MELCOR

New Modeling

SQA

Utilities

MELCOR Code Development Status

EMUG 2017

Presented by Larry Humphries

llhumph@sandia.gov

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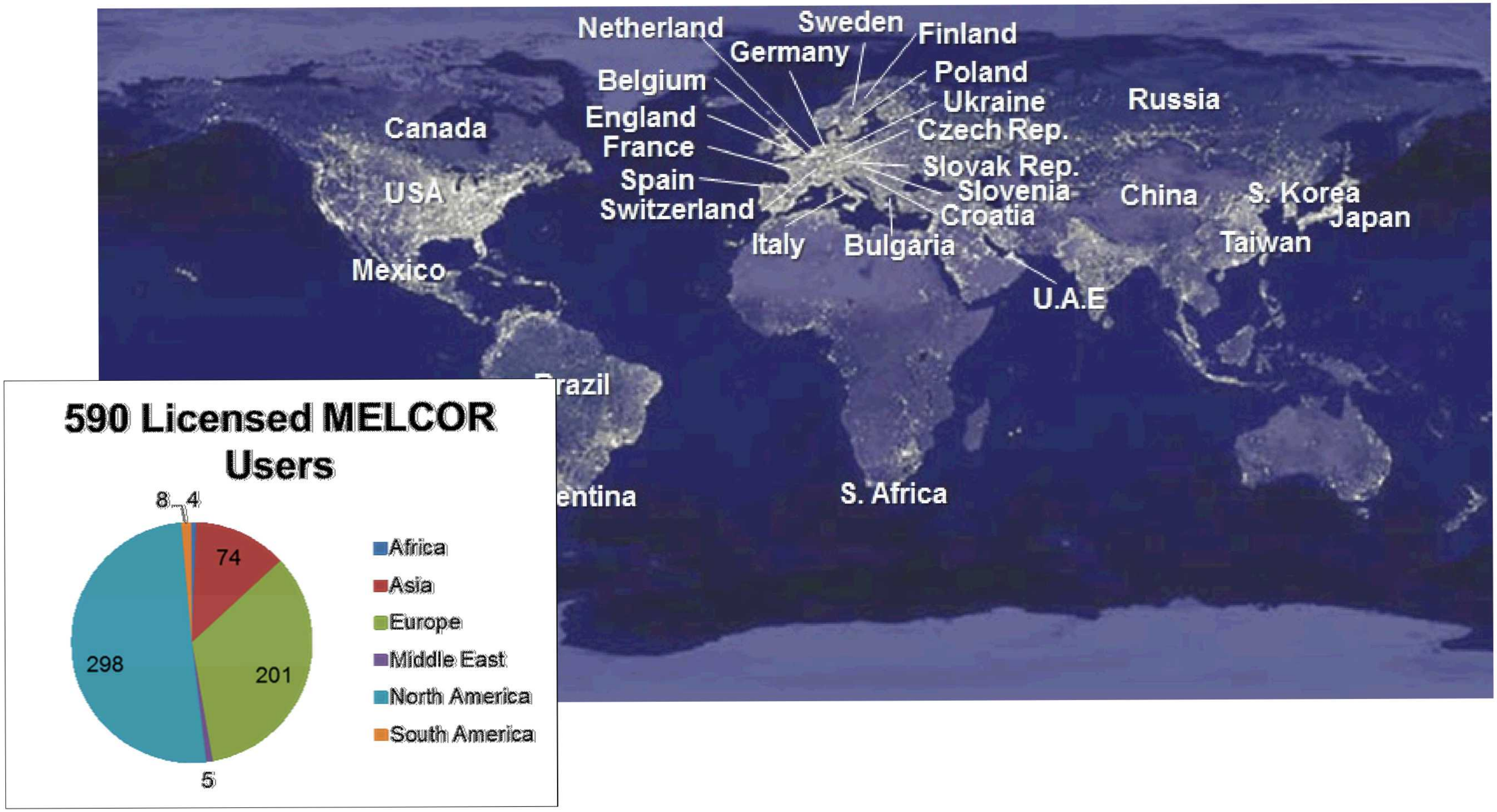
International Use of MELCOR



590 Licensed MELCOR Users

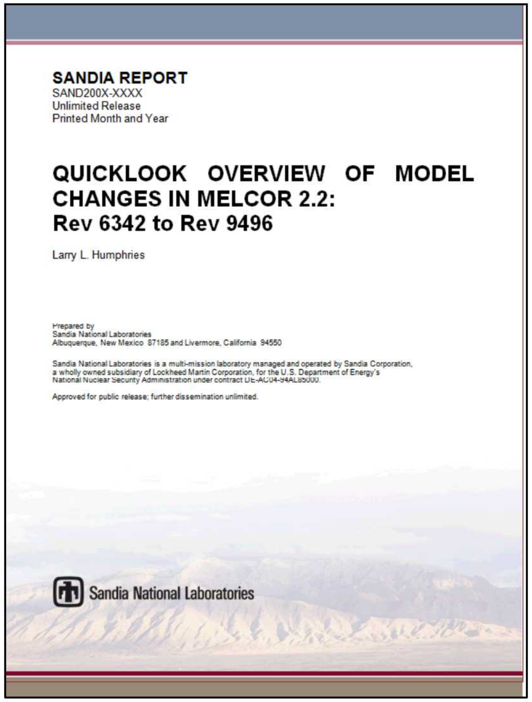
MELCOR Workshops & Meetings

- 2016 Asian MELCOR User Group (AMUG)
  - Hosted by SPICRI & NRSC (Beijing)
  - October 17 – 21, 2016
  - MELCOR/MACCS Workshop
- 2017 European MELCOR User Group (EMUG)
  - Hosted by CIEMAT
  - April 6-7, 2017
- 2017 CSARP/MCAP/MELCOR Workshop
  - September, 2017
  - Bethesda, MD
  - Focus will be on new models
- 2017 Asian MELCOR User Group (AMUG)
  - Hosted by SPICRI & NRSC (S Korea)
  - November 6– 8, 2017 (tentative)
  - MELCOR/MACCS Topics

Historical Review of MELCOR Workshops (Since 2001)

- 2001 – 1 Week Beginner Workshop
  - MELCOR 1.8.5 release
- 2002 – 1 Week Beginner Workshop
  - Focused on MELCOR physics models (Reference Manual)
- 2005 – 1 Week Beginner Workshop
  - MELCOR 1.8.6 release
- 2006 – 1 Week Beginner Workshop
  - MELCOR 2.0 beta release
- 2008 – 1 Week Beginner Workshop
  - Converting between code versions, best practices, 2.1 input
- 2009 – One Day: New or Improved Models
  - CC flow, HTGR, 2.1 Input, Formula CFs, Smart Restart, Accumulators
- 2010 – One Day: RN Package
  - Also highlighted HTGR modeling
- 2011 – 1 Week Beginner Workshop
  - First use of SNAP,
  - Special Topics: SFP, Turbulent deposition, HTGR
- 2012 – One Day: COR Package
- 2013 – One Day: Containment Modeling
- 2014 – 1 Week beginner Workshop
  - Special Topics: SFP and Uncertainty Analysis
- 2016 One Day: Control functions and New Models
- 2017 One Day: New Models

MELCOR 2.2 Code Release



SANDIA REPORT
SAND200X-XXXX
Unlimited Release
Printed Month and Year

QUICKLOOK OVERVIEW OF MODEL CHANGES IN MELCOR 2.2:
Rev 6342 to Rev 9496

Larry L. Humphries

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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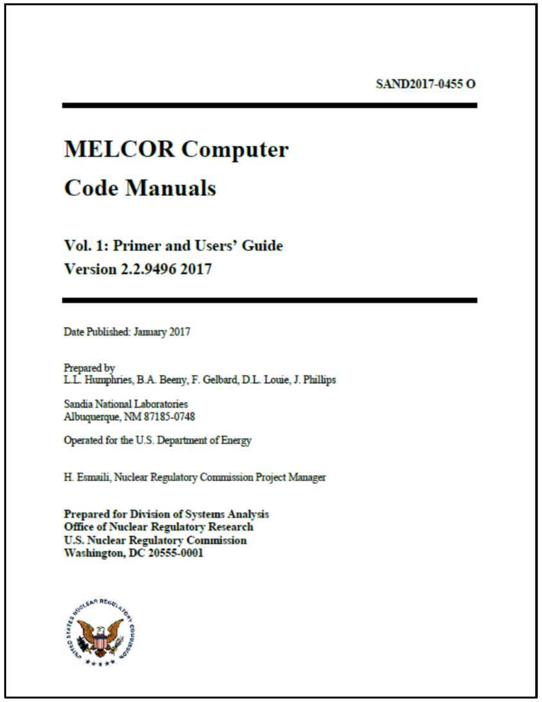
MELCOR 2.2 Quicklook Overview of Model Changes in MELCOR 2.2



SAND2017-0455 O

MELCOR Computer
Code Manuals

Vol. 1: Primer and Users' Guide
Version 2.2.9496 2017

Date Published: January 2017

Prepared by
L.L. Humphries, B.A. Beeny, F. Gelbard, D.L. Louie, J. Phillips

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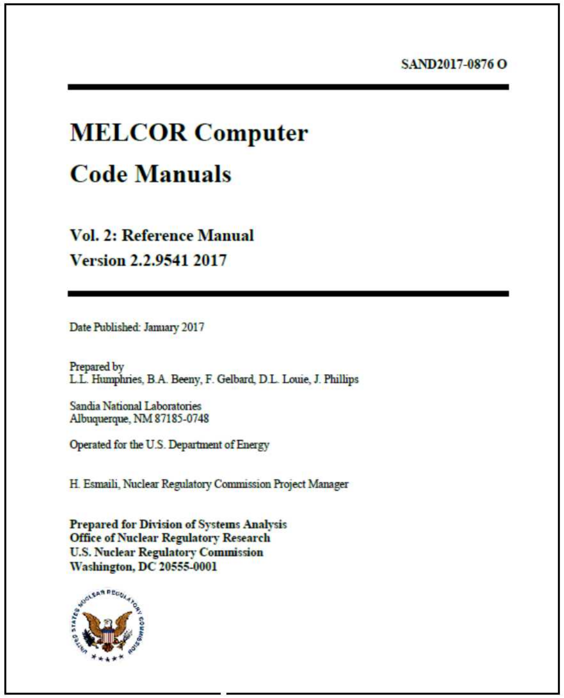
Operated for the U.S. Department of Energy

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

Volume I: User Guide

R&A Complete
SAND2017-0445 O



SAND2017-0876 O

MELCOR Computer
Code Manuals

Vol. 2: Reference Manual
Version 2.2.9541 2017

Date Published: January 2017

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L.L. Humphries, B.A. Beeny, F. Gelbard, D.L. Louie, J. Phillips

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H. Esmaili, Nuclear Regulatory Commission Project Manager

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Washington, DC 20555-0001

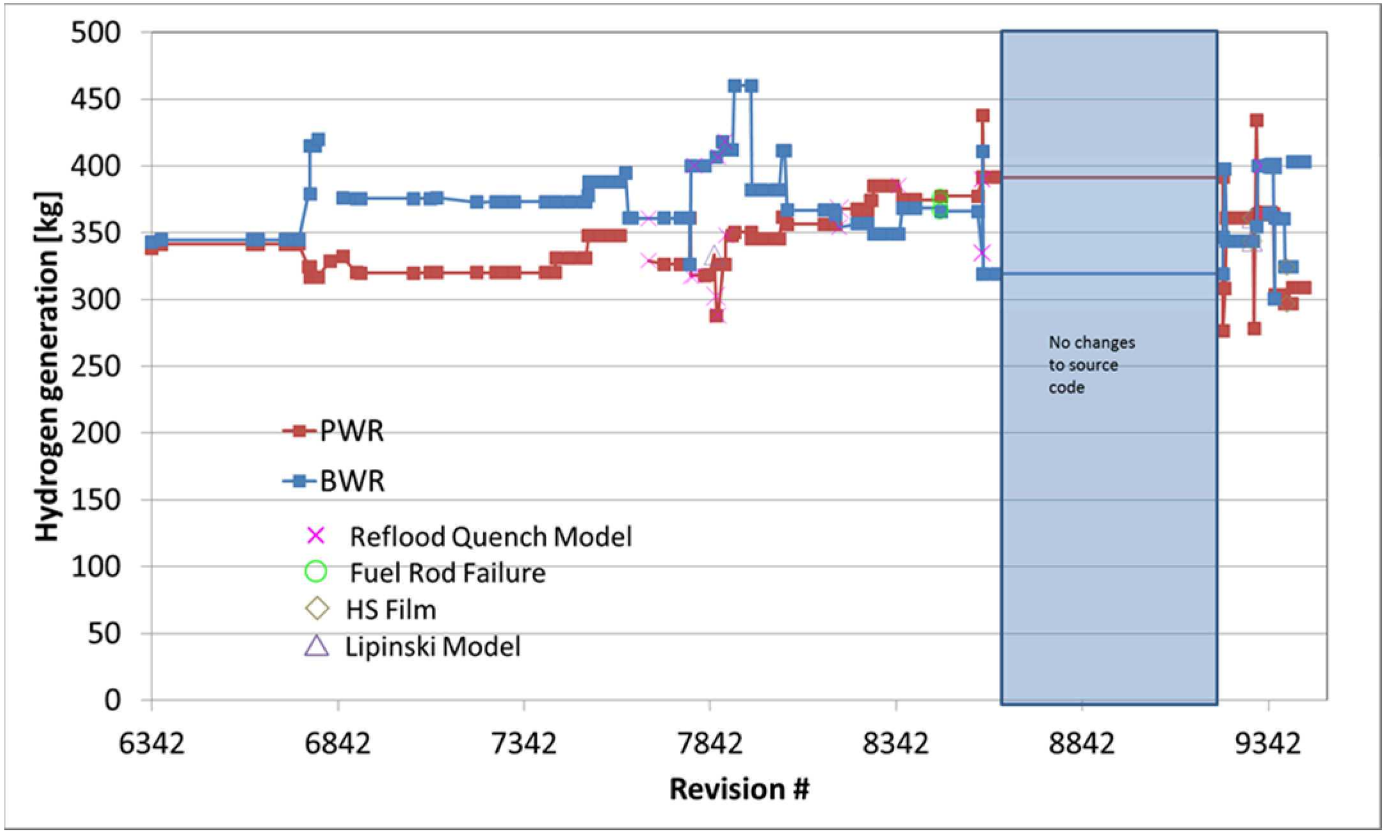
Volume II: Reference Manual

R&A Complete
SAND2017- 0876 O

Significant Code Changes

- New Defaults
  - Fuel Rod Collapse Model
  - Melt Spreading Model
- Code Corrections
  - Mass error with flashing model when hygroscopic model is enabled [r8612]
  - Corrections to reflood quench model [multiple revisions]
  - Lipinski dryout model not used above the core support plate [r7874]
  - Revised candling model for canisters [r7864 but not active until 9387]
  - Decay heat transfer to small fluid volumes [r8274]
  - Correction to fuel rod collapse modeling (temperature failure criteria) [r8574]

Changes in H2 Generation from Oxidation



New Model Development Tasks (2014-2015)

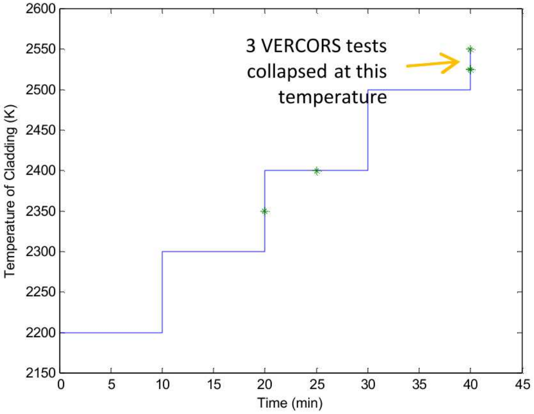
- Completed
    - Fuel Rod Collapse Model
    - Homologous pump model
    - Multi-HS radiation enclosure model
    - Aerosol re-suspension model
    - Zukauskas heat transfer coefficient (external cross-flow across a tube bundle)
    - Core Catcher (multiple containment vessels)
    - Multiple fuel rod 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
    - 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

Fuel Rod Collapse Model

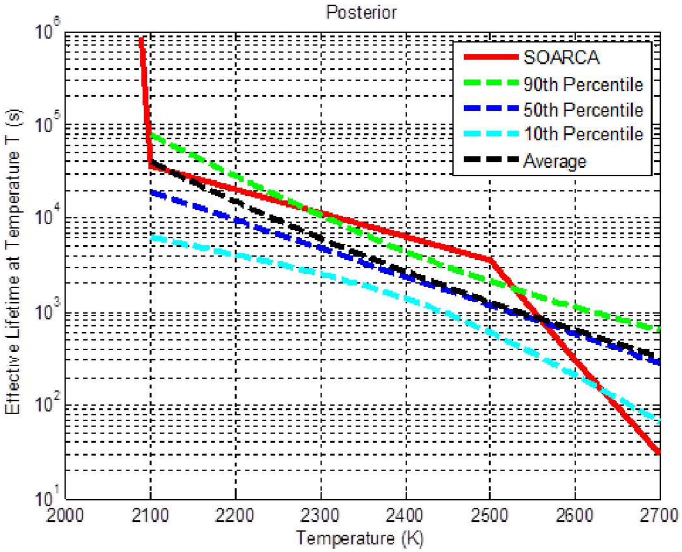
- Time-at-temperature model
  - Available in M186 but not default until now
  - Characteristics had to be provided by user
  - Eliminates temperature threshold effect from failure temperature model
- Updated based on VERCORS experiments and SOARCA models
  - Damage function used in SOARCA analyses

$$\frac{1}{L(T)} = A\,exp(BT)\ , DF(t) = \sum\left(\frac{1}{L(T)} * \Delta t\right)$$

  - Coefficients A & B fit using Bayesian statistical analysis of VERCORS fuel collapse data
    - 6 Data points



Time at Temperature Histories from the VERCORS Experiments . All tests underwent identical temperature ramps, stars indicate fuel collapse times.



“Development of the SharkFin Distribution for Fuel Lifetime Estimates in Severe Accident Codes”, 2016 ANS Winter Meeting**.**
M. R. Denman

Homologous Pump Model

- 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 characterized 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.

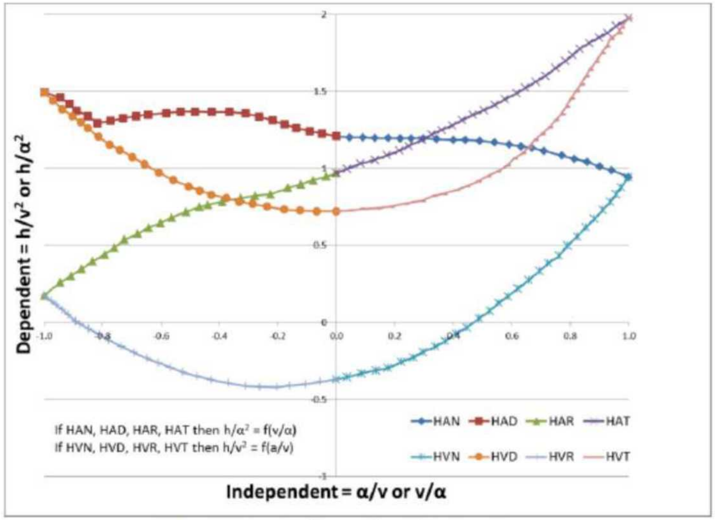


Figure 1. Semiscale single-phase head curve

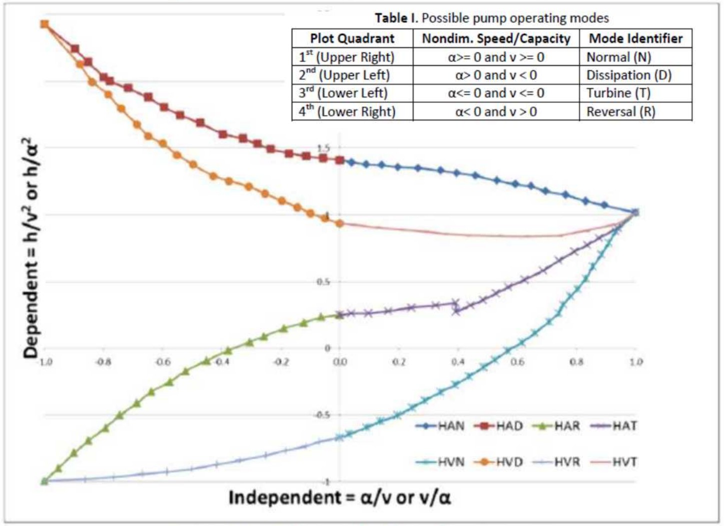


Table I. Possible pump operating modes

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

Figure 4. LOFT single-phase head curve

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

Multi HS Radiation Enclosure Model

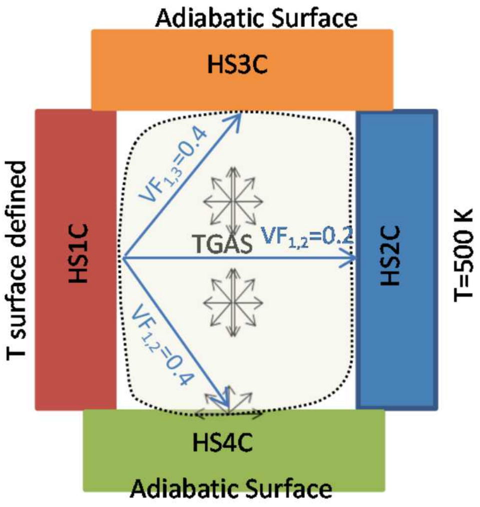
- Previous HS radiation model
  - Radiation defined only for surface pairs
  - Radiation to gas performed independently for each surface
    - Does not account for transmissivity of gas
- New enclosure model
  - Multiple enclosure networks, each with multiple heat structures defined by the user.
    - 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

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

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

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



```
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
```

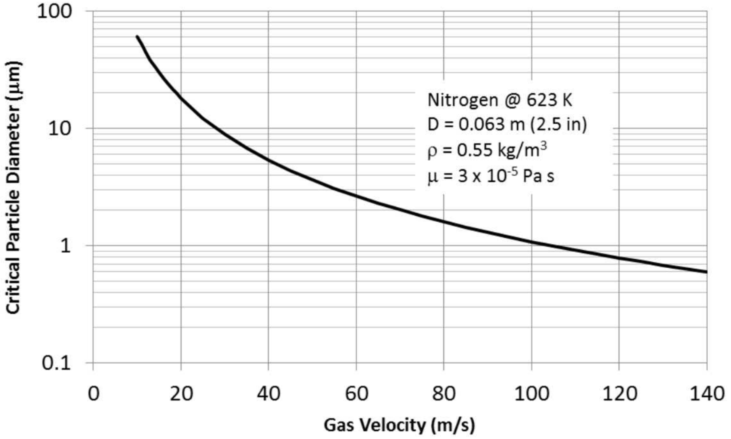
Re-suspension Model

- 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

$$D_{crit} = \frac{4\times10^{-5}}{\pi\tau_{wall}} \text{ (m)}, \qquad \tau_{wall} = \frac{f\rho v^2}{2} \text{ (N/m}^2\text{)} \qquad f = \frac{0.0791}{Re^{0.25}}$$

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

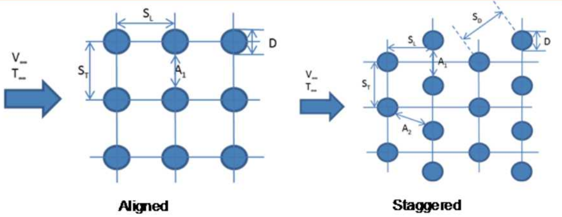
Zukauskas Heat Transfer Coefficient

- 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:

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



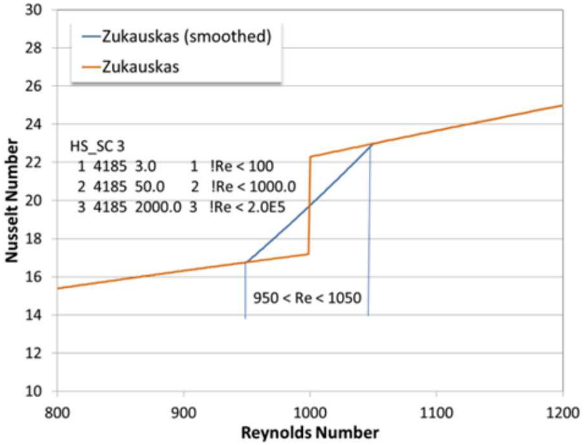
Staggered:

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

else

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

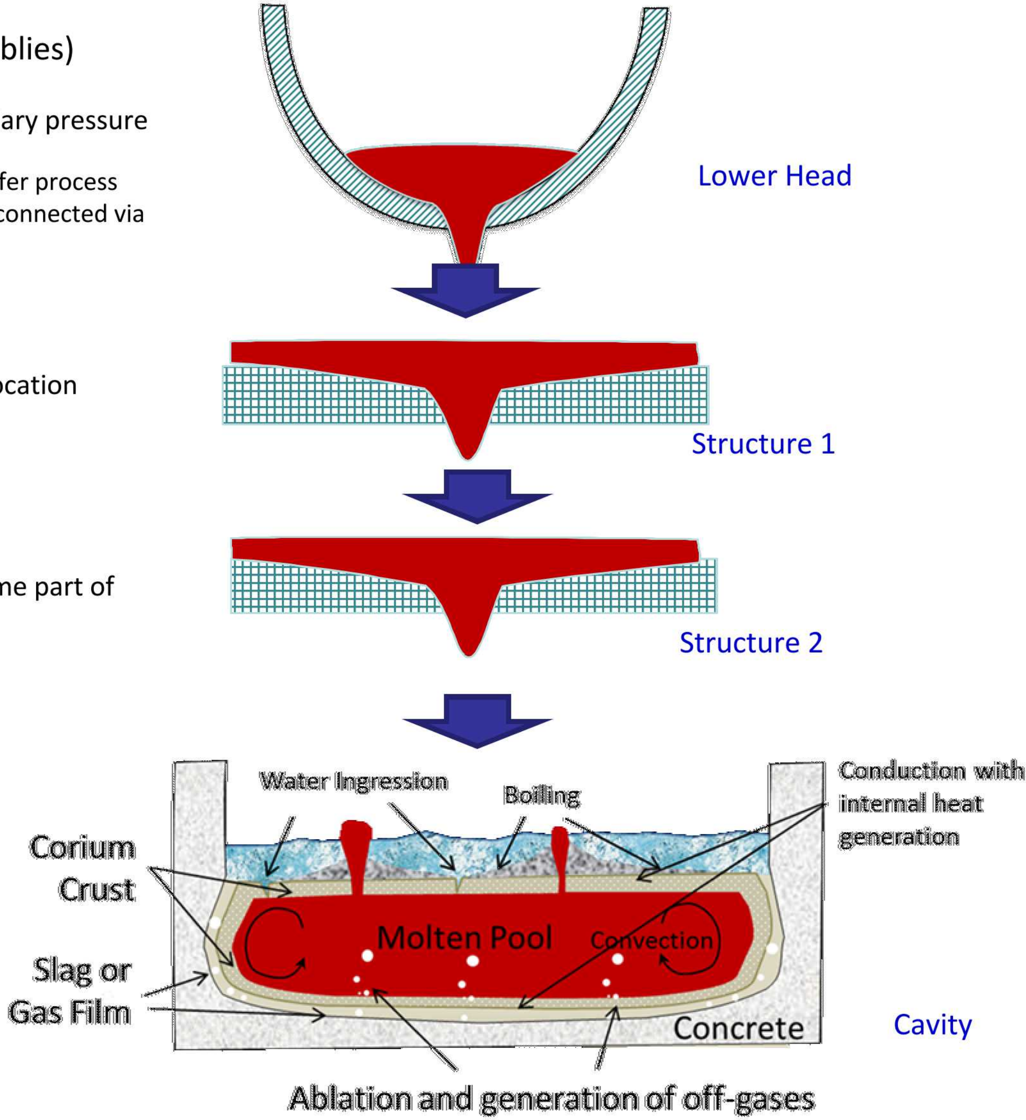
	$Re_{D,max}$	Condition	C	m	n
Aligned	10 < $Re_{D,max}$<100		0.8	0.4	0.36
	100 < $Re_{D,max}$<1000	Pr<10	0.51	0.5	0.37
		Pr > 10	0.51	0.5	0.36
	1000 <$Re_{D,max}$<=2 x 10^5		0.27	0.63	0.36
	2x10^5 <$Re_{D,max}$<=2 x 10^6		0.021	0.84	0.36
Staggered	10 < $Re_{D,max}$<100		0.9	0.4	0.36
	100 < $Re_{D,max}$<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



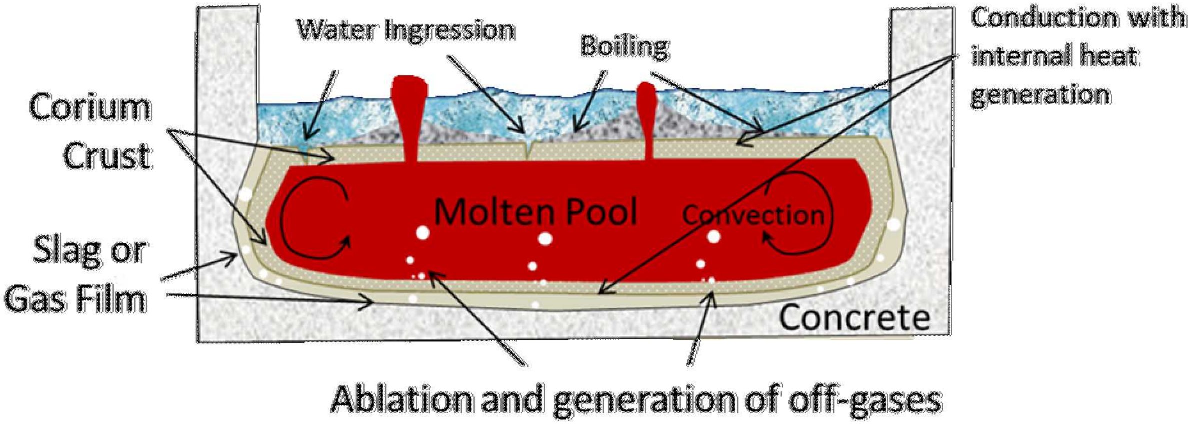
```
HS_SC 3
 1 4185 3.0     1 !Re < 100
 2 4185 50.0    2 !Re < 1000.0
 3 4185 2000.0 3 !Re < 2.0E5
```

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



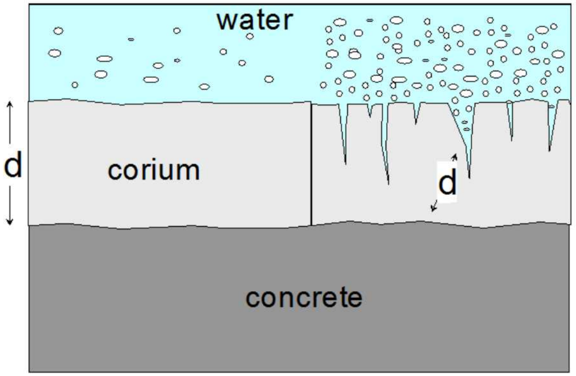
New Modeling for Top-Quenched Debris in Cavity



- 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

Pre 2015 MELCOR Best Practice

- Water ingression will increase the contact surface area between water and the corium
- Decrease the conduction path length through the corium, both of which will enhance the heat transfer through the crust



$$Q = -A \cdot k\frac{dT}{dz} \sim -\frac{\boldsymbol{A}}{\boldsymbol{d}}k\Delta T \sim -\frac{A}{d}\boldsymbol{k}\Delta T$$

- MELCOR best practice attempted to account for this effect by applying a thermal conductivity multiplier
  - Based on benchmarking against MACE tests
- MELCOR model development is focusing on improvements in the CAV package to capture water ingression and melt eruptions
  - New porous layer for debris relocating above crust
  - New porous crust layer
  - Dense crust layer

CORCON/CORQUENCH Model

Enhanced Conductivity (2010)

```
CAV_U   9
   …
  5 BOILING   value  10.0
  6 COND.OX    mult 5.0
  7 COND.MET   mult 5.0
  8 HTRINT  multip 1.0
  9 HTRSIDE multip 1.0
```

Modified Enhanced Conductivity (2012)

```
CAV_U   10
   …
  5 BOILING   value  10.0
  6 COND.OX    mult 1.0
  7 COND.MET   mult 1.0
  8 HTRINT  multip 5.0
  9 HTRSIDE STAND
  10 COND.CRUST   3.0
```

Water Ingression (2015)

```
CAV_U   10
   …
  5 BOILING    VALUE 10.0
  6 COND.OX    MULT 1.0
  7 COND.MET   MULT 1.0
  8 COND.CRUST 1.0
  9 WATINGR    ON
  10 ERUPT  ON
```

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

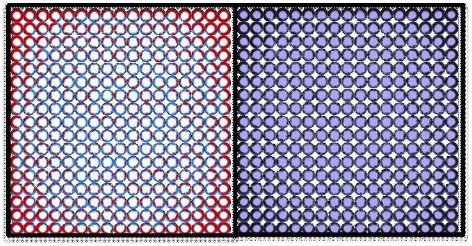
1 or 'TF'
Use data from tabular function.
-1 or 'CF'
Use data from control function.
2 or 'CHANNELEDF',
Use data from channel of external data file NameCF_TF_EDF.
0 or 'MODEL',
This option allows the code to internally calculate the debris radius as a function of time. However, this option requires the initial debris radius (RADTINI).

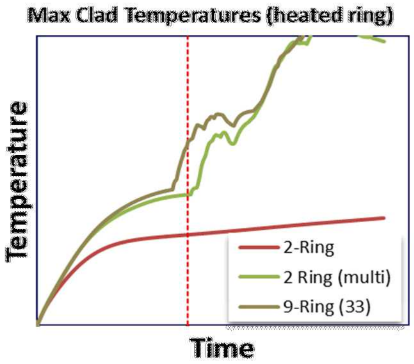
If SOURCE = 0, the following record is required:

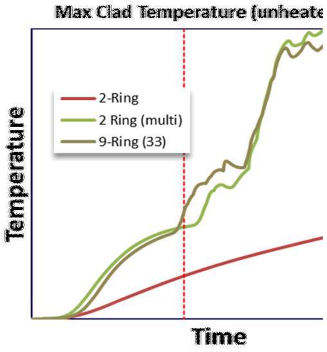
(2) RADTINI - Initial time-dependent debris radius for the internal model

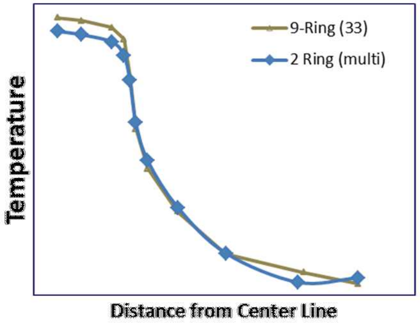
Multi-Rod Model

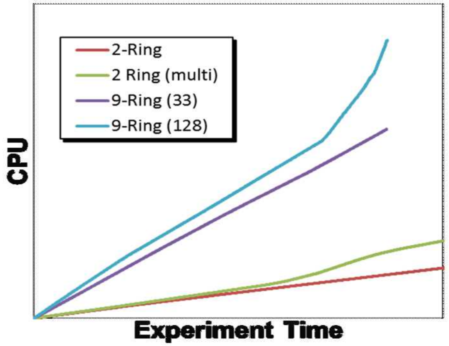
- Motivation
  - It is desirable to model an entire assembly within a single MELCOR ring
- Challenge
  - When hot assembly reaches ignition, heat transfer to cold assembly is problematic











- 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
- Recently extended to PWR reactor type in addition to PWR-SFP

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

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

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)

- Ranges
  - User defined construct that generates an ordered list of objects to be used by vectorized CFs
- Vectorized CF arguments
  - Control Function arguments can now be specified as a vector of values by specifying and index with a range
- Vector Control Functions
  - Certain control functions now permit vector operations such as add, multiply, divide, equals, L-GT, L-GE, etc.
- Package input support of vector CFs
  - Some input records have been modified to allow vector fields in place of scalar fields
- Analytic Control Functions
  - Ultimate flexibility allowing users to pass vectors to a user specified FORTRAN function.

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.

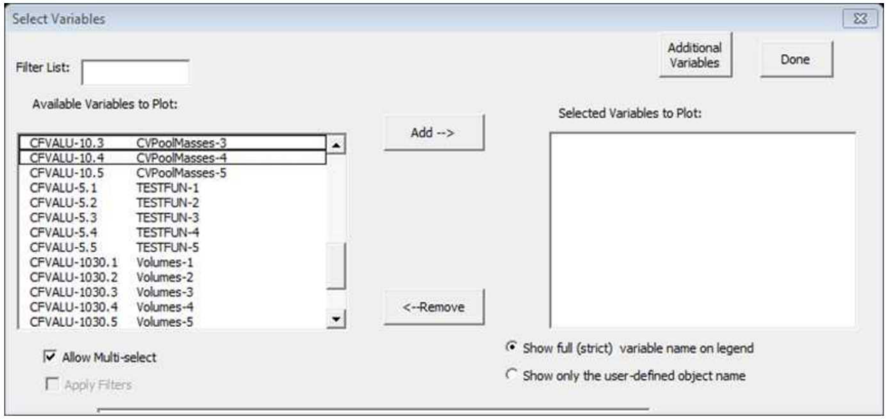
```
CV_VF #CVVOLUMES
```

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
```

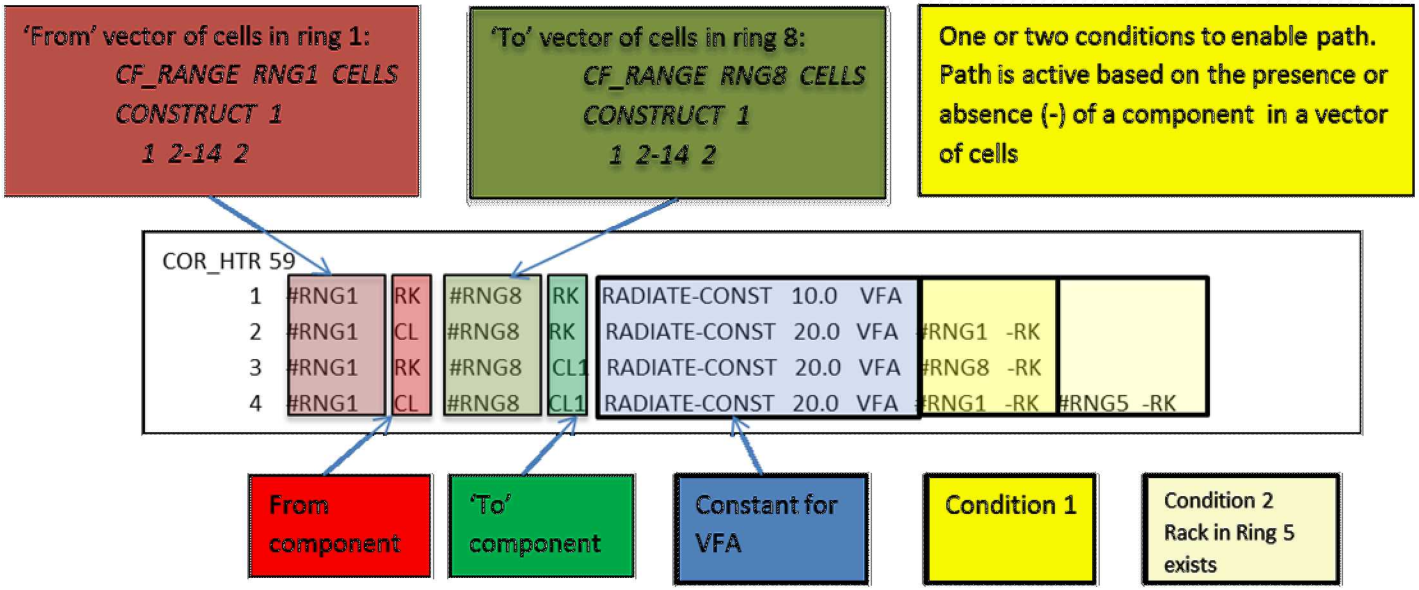
- Elements of a vector CF can be referenced from plotting routines like PTFREAD



CFVALU-10.3	CVPoolMasses-3
CFVALU-10.4	CVPoolMasses-4
CFVALU-10.5	CVPoolMasses-5
CFVALU-5.1	TESTFUN-1
CFVALU-5.2	TESTFUN-2
CFVALU-5.3	TESTFUN-3
CFVALU-5.4	TESTFUN-4
CFVALU-5.5	TESTFUN-5
CFVALU-1030.1	Volumes-1
CFVALU-1030.2	Volumes-2
CFVALU-1030.3	Volumes-3
CFVALU-1030.4	Volumes-4
CFVALU-1030.5	Volumes-5

☑ Allow Multi-select
☐ Apply Filters
● Show full (strict) variable name on legend
○ Show only the user-defined object name

Vectorized COR_HTR Input



'From' vector of cells in ring 1:

```
CF_RANGE  RNG1  CELLS
CONSTRUCT  1
  1  2-14  2
```

'To' vector of cells in ring 8:

```
CF_RANGE  RNG8  CELLS
CONSTRUCT  1
  1  2-14  2
```

One or two conditions to enable path. Path is active based on the presence or absence (-) of a component in a vector of cells

```
COR_HTR 59
     1  #RNG1  RK  #RNG8  RK   RADIATE-CONST  10.0  VFA
     2  #RNG1  CL  #RNG8  RK   RADIATE-CONST  20.0  VFA  #RNG1  -RK
     3  #RNG1  RK  #RNG8  CL1  RADIATE-CONST  20.0  VFA  #RNG8  -RK
     4  #RNG1  CL  #RNG8  CL1  RADIATE-CONST  20.0  VFA  #RNG1  -RK  #RNG5  -RK
```

From component

'To' component

Constant for VFA

Condition 1

Condition 2 Rack in Ring 5 exists

- Reduces number of input records significantly.
  - Otherwise input is required cell by cell.
  - Unnecessary CF logic required to determine existence of components.
  - Difficult to read (QA)
    - Input for a cell is scattered among COR_HTR records and multiple CF records
  - One example reduced number of records from over 7000 records to under 100

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

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

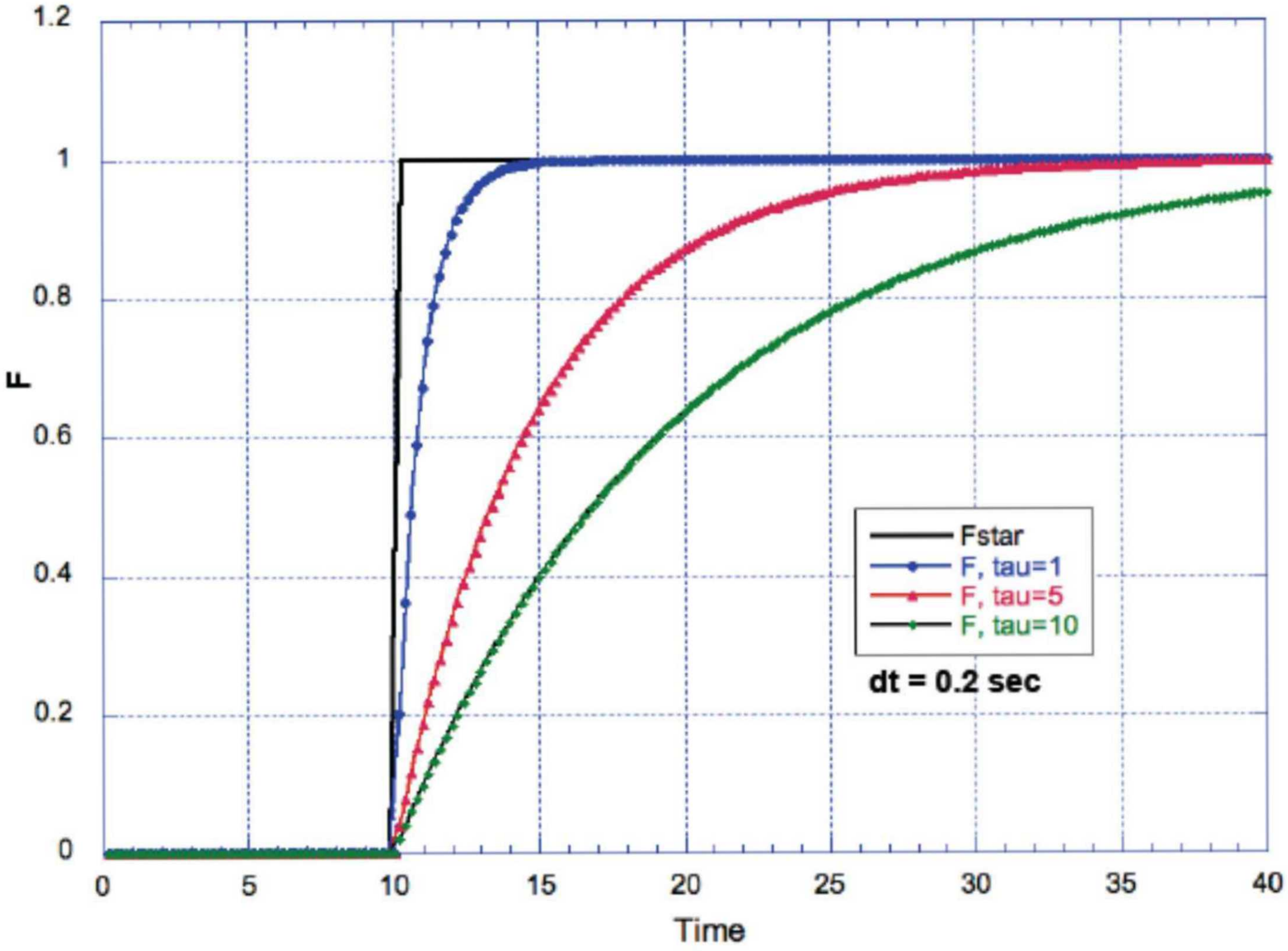
$f^{n+1} = value\ of\ f\ at\ time\ step\ n + 1$

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

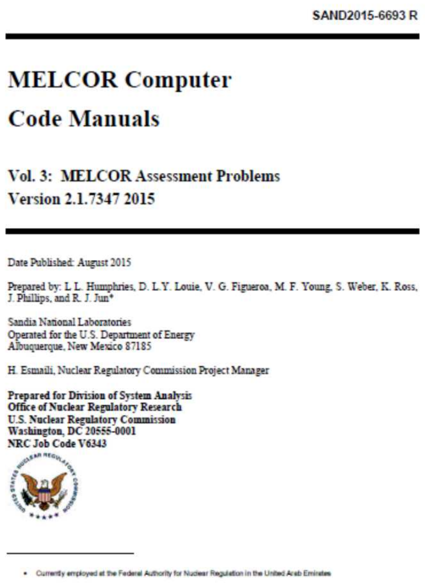
$f^* = unrelaxed\ value\ of\ f\ at\ time\ step\ n + 1$

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

Example plot for different temporal relaxation time-scales



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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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

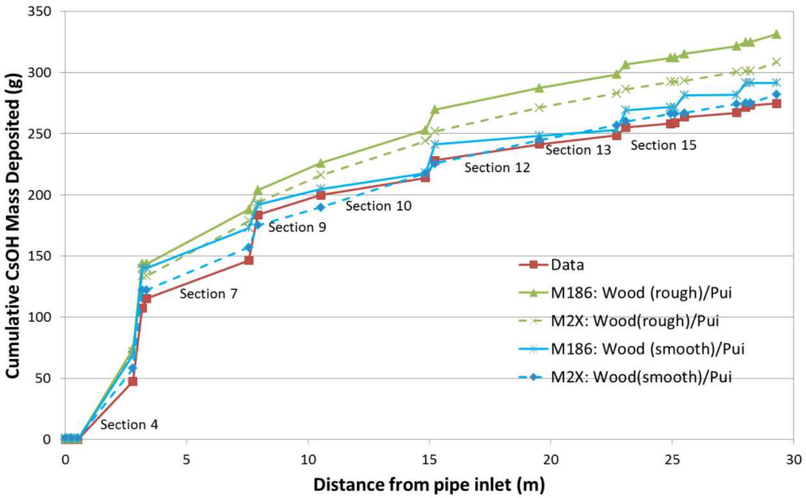
Volume IV: Modeling Guide

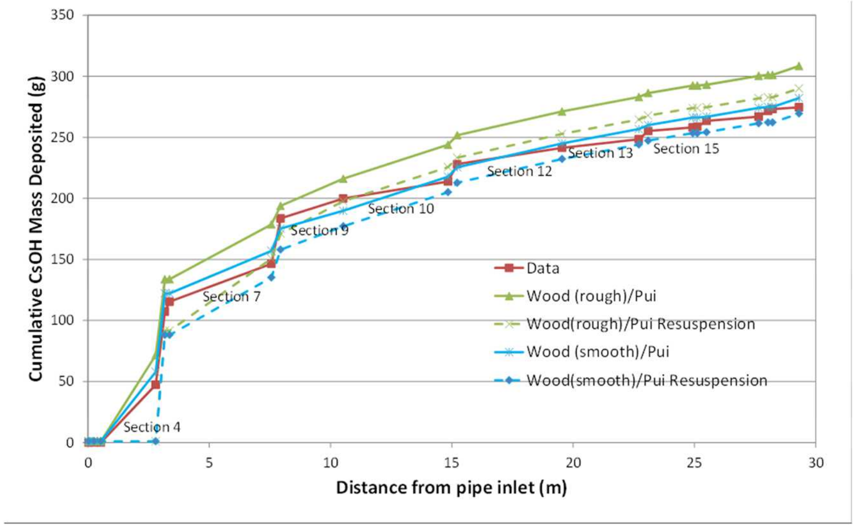
Cases in MELCOR Assessment Report - SAND2015-6693 R

- **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

LACE LA3 Assessment of Turbulent Deposition

- 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 resuspension model was also assessed against this test
  - Predicted resuspension may be too large at entrance
  - May not correctly account for sticking of aerosols

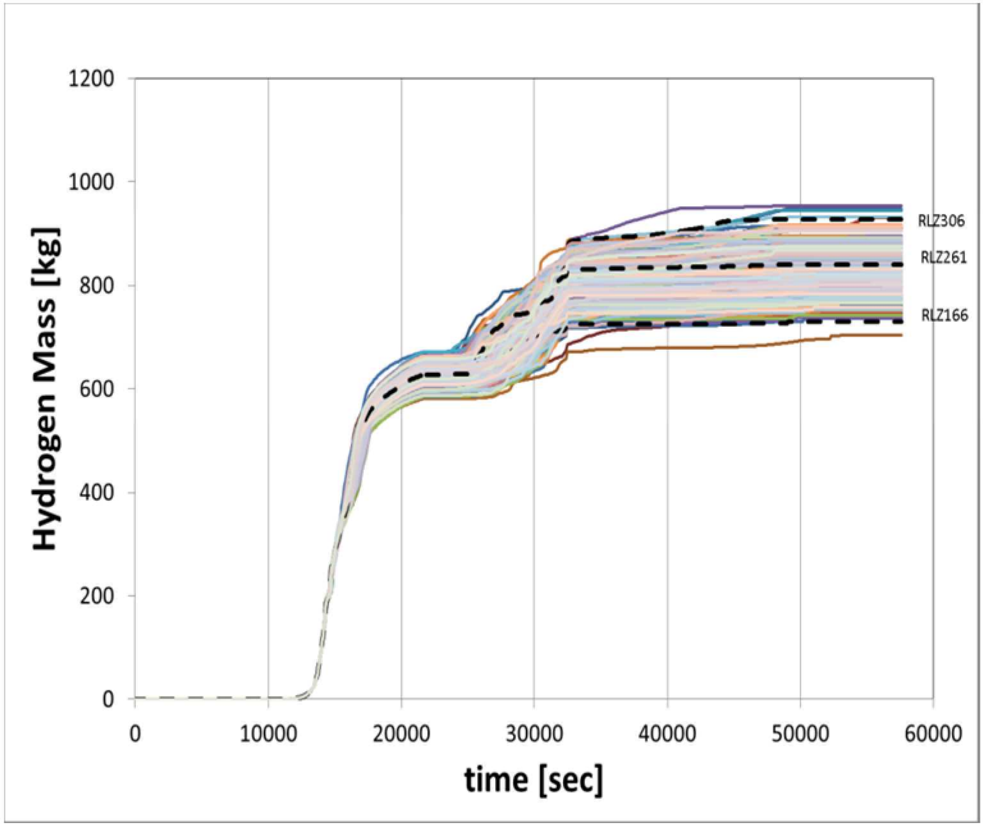




Numerical Variance

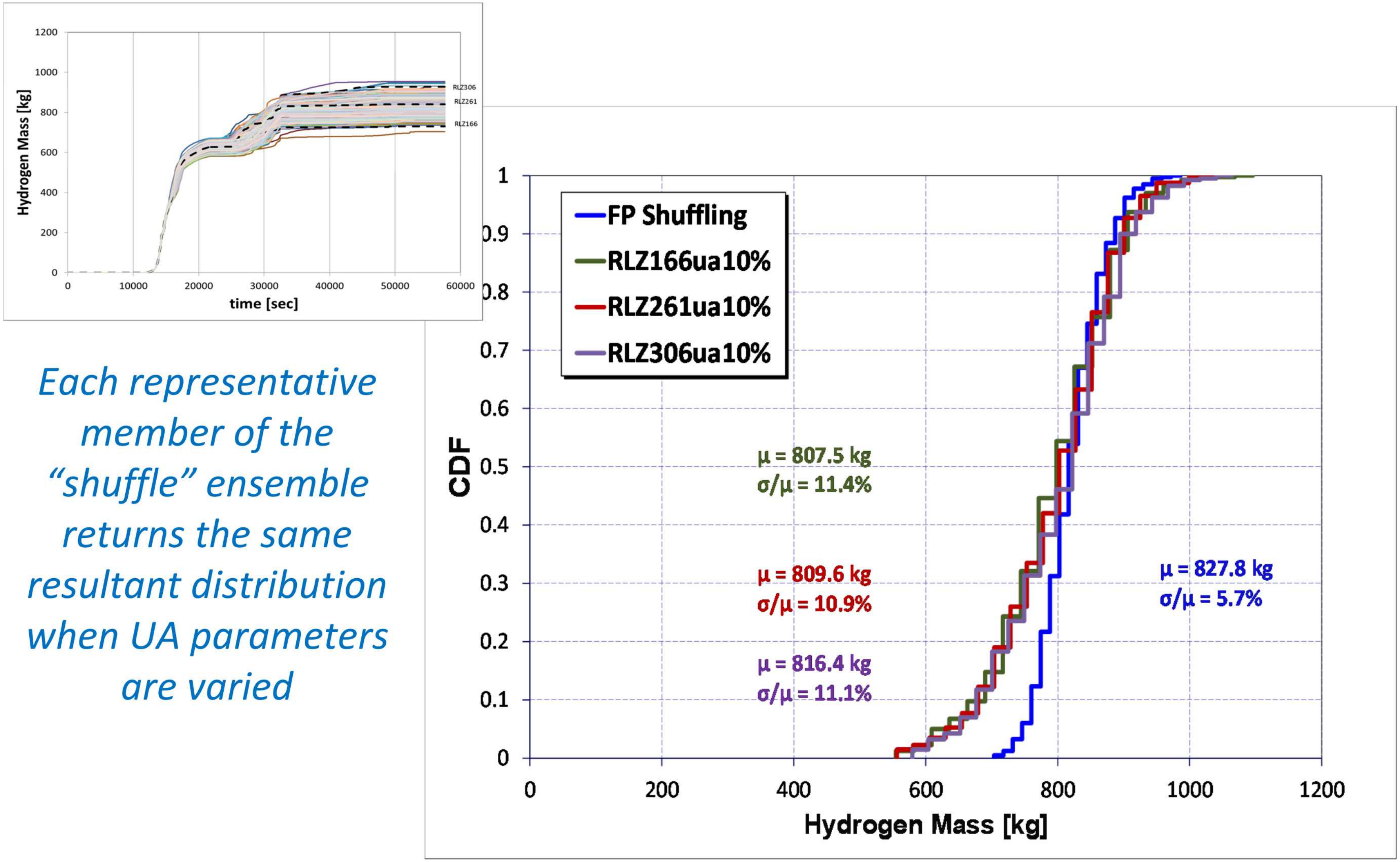
- Characterization of Numerical Variance
  - Background code variance
    - Sources of variance
    - Amplifiers
  - Effect of COR Nodalization on Numerical Variance
    - COR cell nodalization
    - CVH nodalization
  - Assess the sensitivity of the variance to COR degradation models
  - Time step variations & time step convergence
  - Application to UA variations
    - Discriminating parameter variance from background variance
      - Signal to noise ratio
- Reduction of Numerical Variance
  - Reduction of tolerances
  - Hysteresis effects (Relief Valves)
  - Others

Identical Input Definition but Input Record Ordering is Randomized



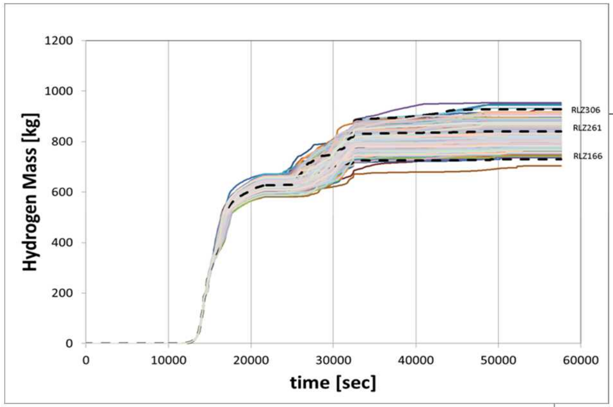
- Each realization is essentially equivalent descriptions of problem
- Order of input definition randomly varied
- Representative extremes examined separately by Monte Carlo sampling over state of knowledge uncertain parameters
- Do different but equivalent flow path descriptions produce different distributions in UA ?

Representative Extremes of "shuffle" used as seed for 10% UA variations



Each representative member of the "shuffle" ensemble returns the same resultant distribution when UA parameters are varied

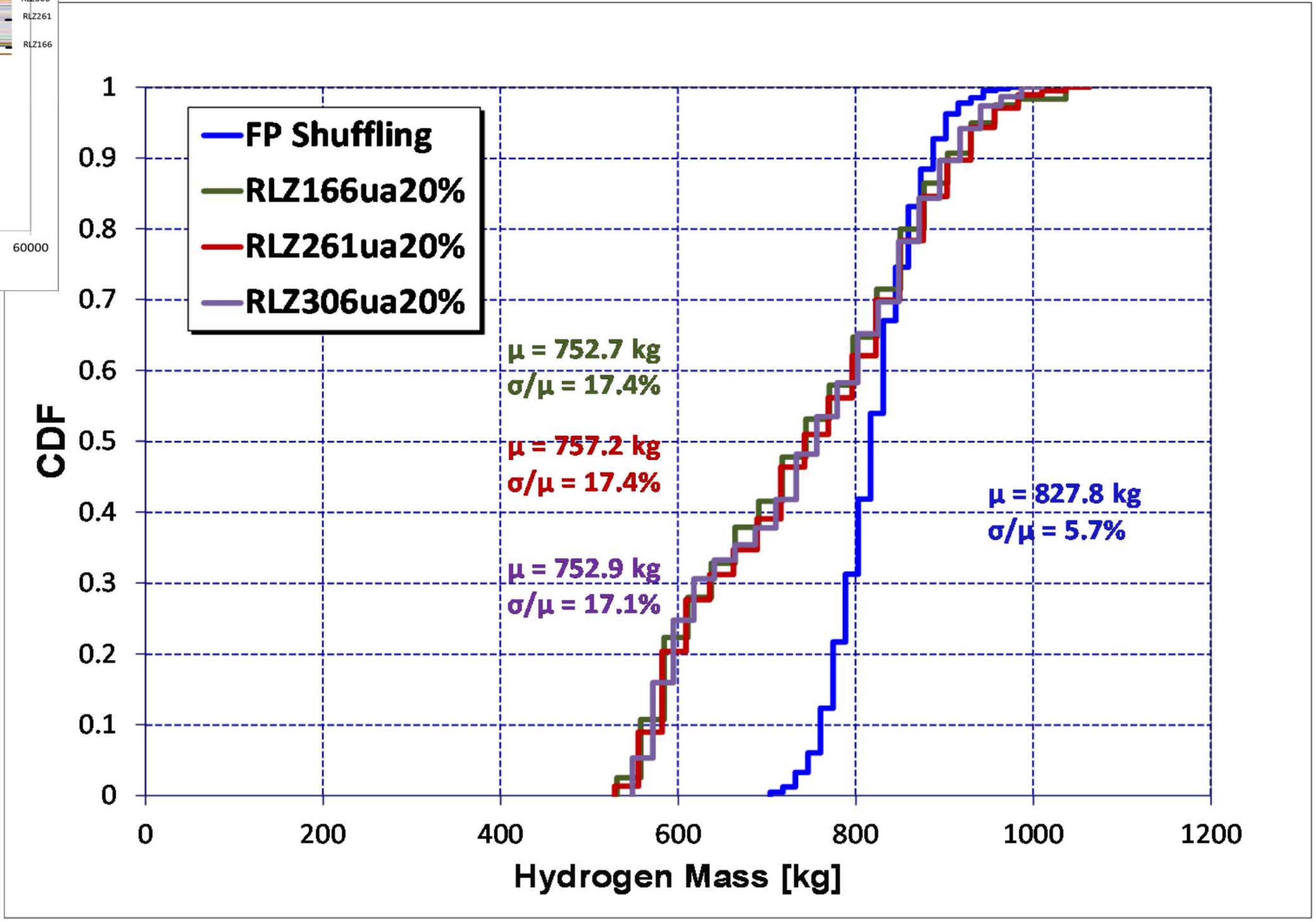
Representative members of “shuffle” used as seed for 20% UA variations



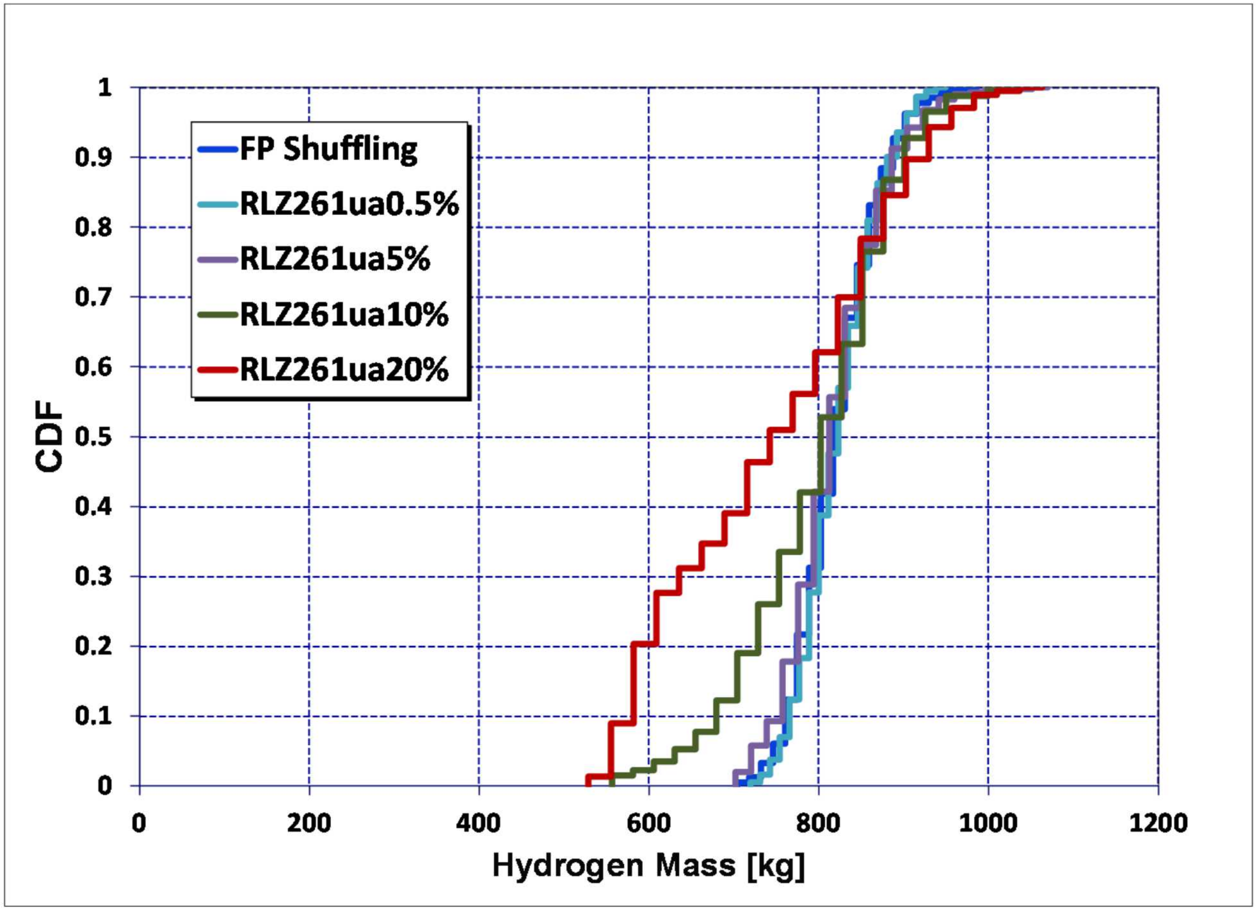
Same result for 20% UA Variation

Note: that mean is shifting down,

Upper H2 limited by core degradation



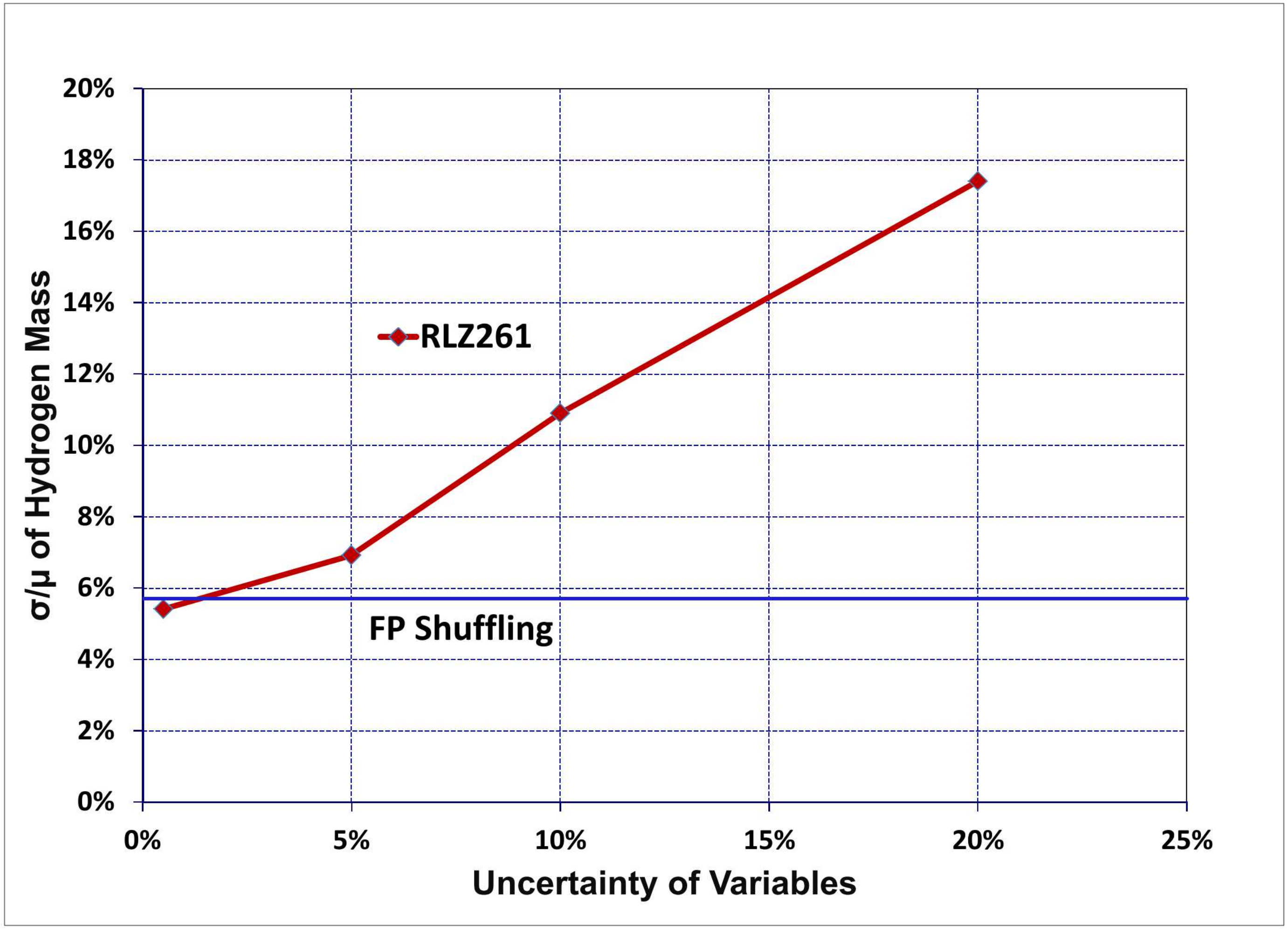
UA Variation Explored to Characterize Signal to Noise Ratio



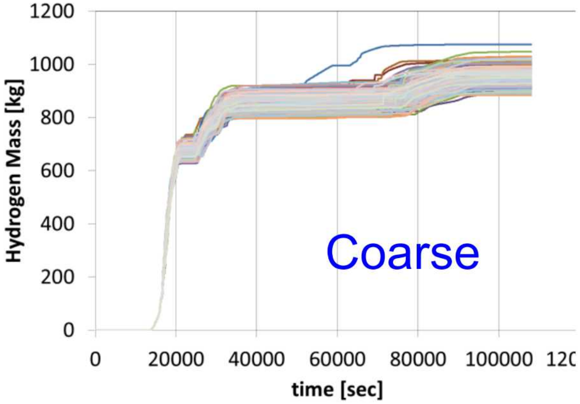
0.5% and 5% UA variations nearly same as background numerical noise

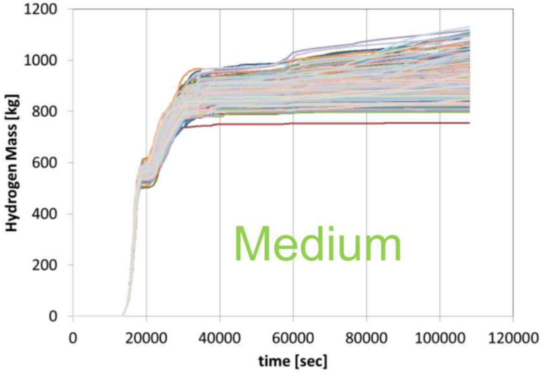
10% and higher variation clearly distinguishable from background noise

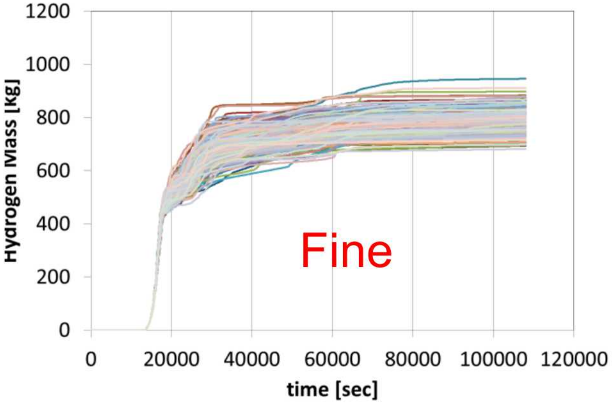
Signal to Noise versus % Variation for Hydrogen



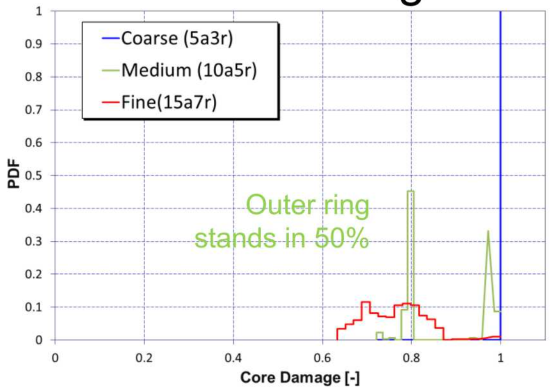
Numerical Variance from Nodalization (Flow Path Shuffling)



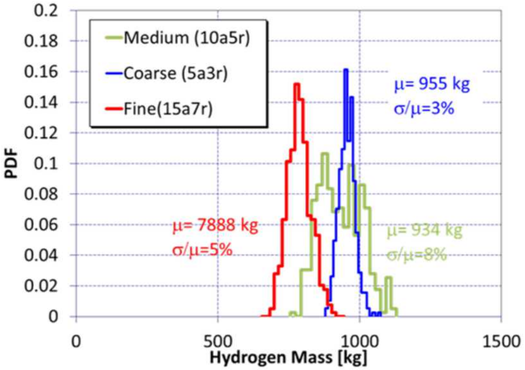




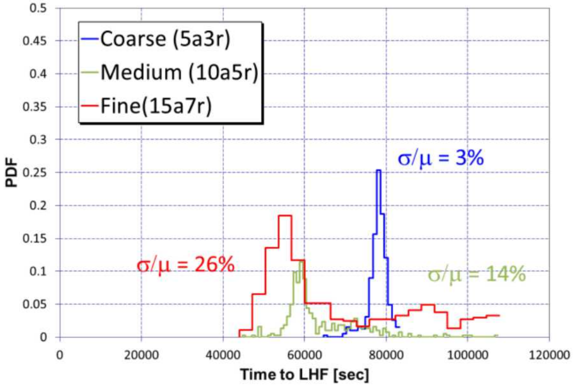
Core Damage



Hydrogen Mass



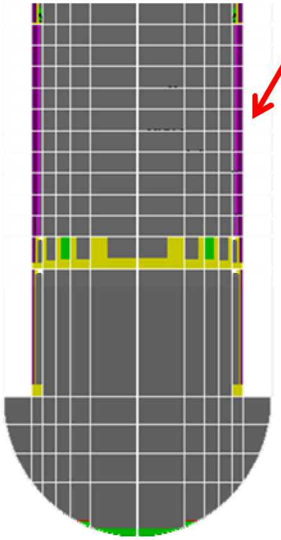
Time to LHF

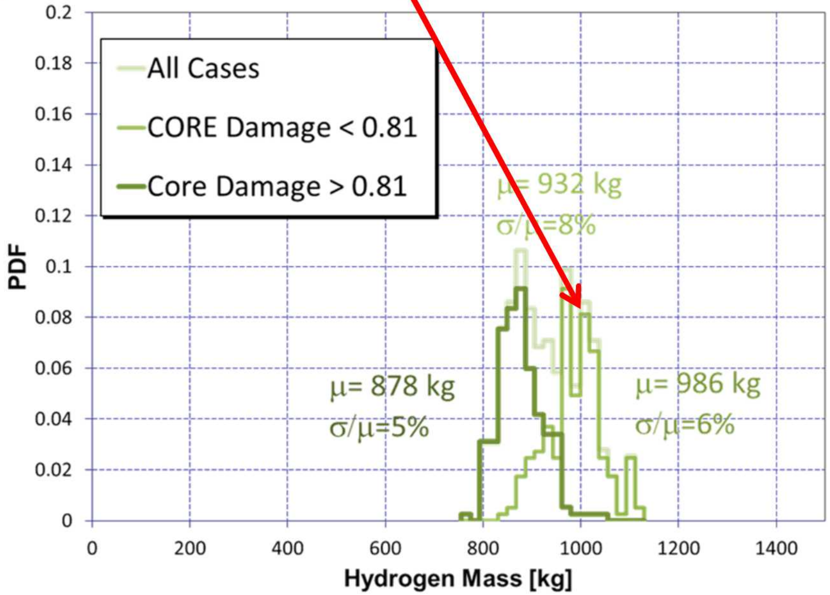


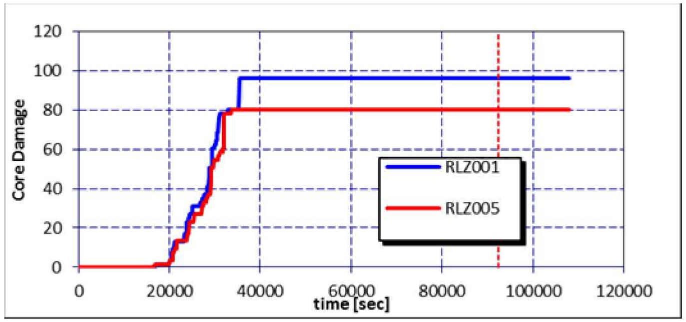
Hydrogen variance in medium nodalization Case

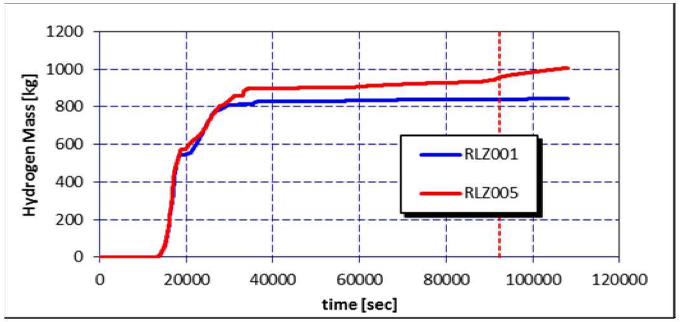
- Hydrogen variance strongly dependent on failure of outer ring.
  - Hydrogen distribution and core damage are highly correlated.
- Cases where outer rod survives results in more overall hydrogen generation in core after vessel failure and more variance

Fuel Rods in Outer Ring

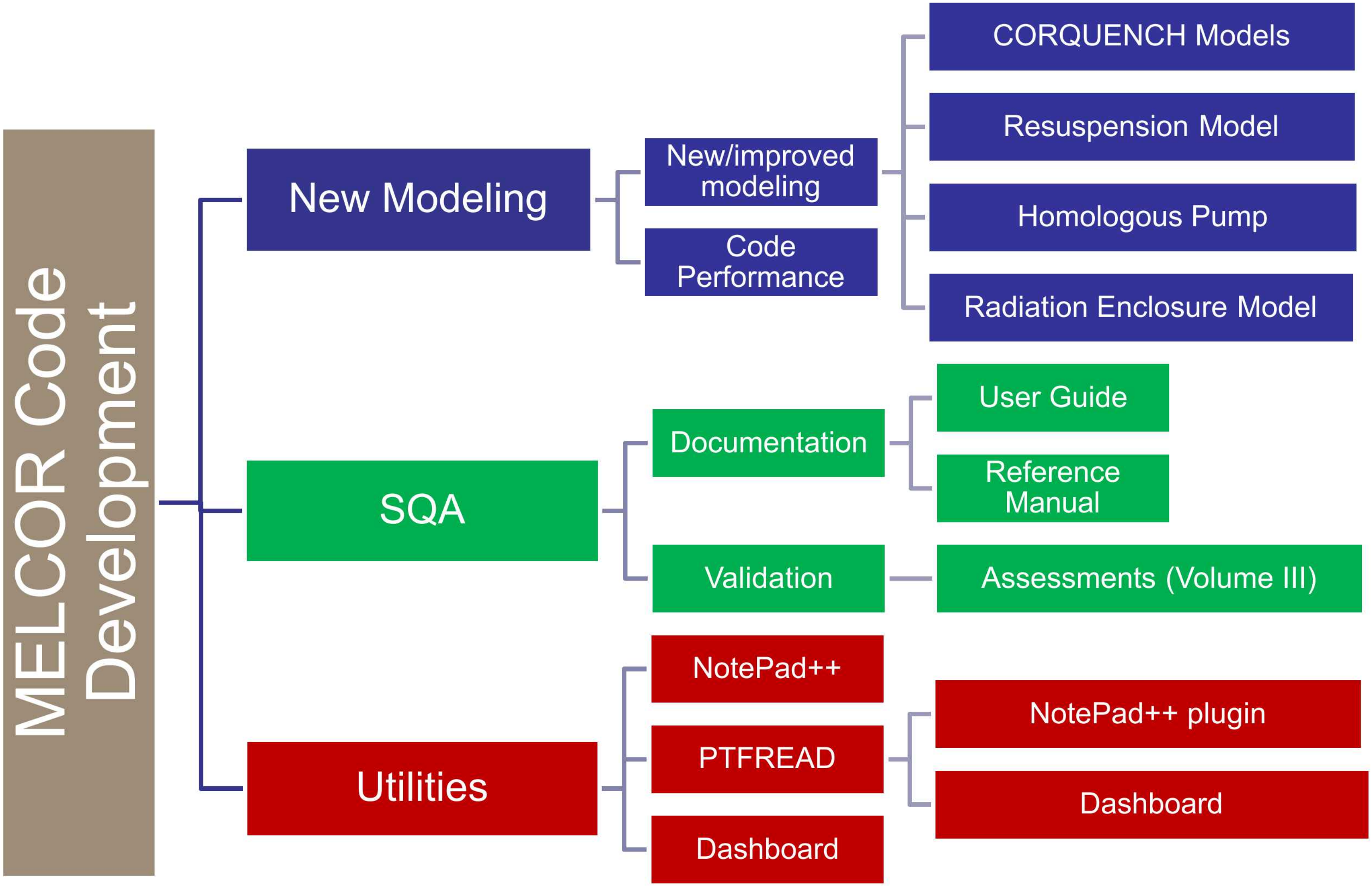








Questions?



MELCOR Code Development

New Modeling

New/improved modeling

Code Performance

CORQUENCH Models

Resuspension Model

Homologous Pump

Radiation Enclosure Model

SQA

Documentation

User Guide

Reference Manual

Validation

Assessments (Volume III)

Utilities

NotePad++

PTFREAD

Dashboard

NotePad++ plugin

Dashboard