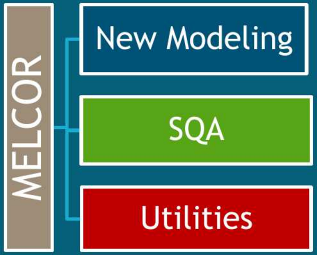
SAND2019-3104PE

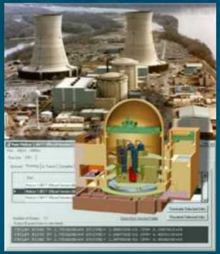
COR Heat Transfer
2019 European MELCOR User Group Workshop

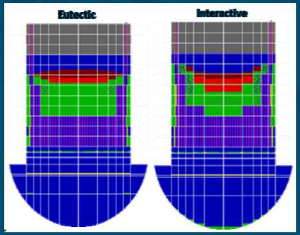

MELCOR

New Modeling

SQA

Utilities





PRESENTED BY

Larry Humphries

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Outline

- COR Cell Overview
- Heat Generation
  - Decay heat
  - Fission power
  - Point kinetics model
- General Heat Transfer
  - Conduction
  - Convection
  - Radiation
- Special Sub-grid models
  - Fuel/Clad gap modeling
  - Multi-rod model
  - Quench model
  - dT/dZ model
- User-defined heat transfer paths

Lower Head heat transfer and modeling deferred to a separate presentation

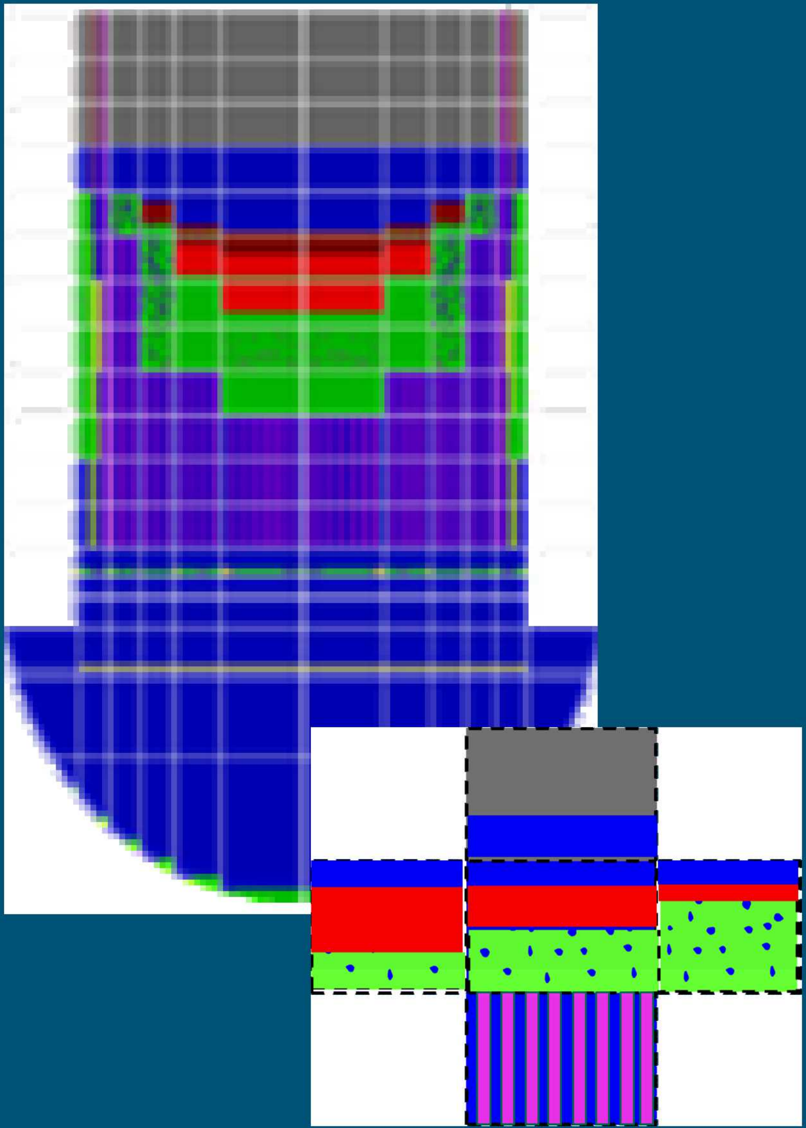
COR Cells and COR Components

COR cells are nodalized regions of volume containing a number of COR components available for a particular reactor type (i.e., FU, CL, SS, NS, CN, PD, MP)

- Each COR component has a single temperature
  - COR components can exchange heat with other Components in the cell, adjacent cells, or with the fluid associated with the COR cell.

A fluid control volume (CVH package) is also associated with the COR cell and exchanges heat with components in the cell

A heat structure (HS package) may also be associated with the COR cell and exchange heat with components in the cell.



Core Package
Fission and Decay Power

Fission power

- Define fission power (COR_TP)
  - Control Function or
  - Use Chexal-Layman correlation
- Distribute over UO_2 (COR_TP)
  - in all cells in core (not lower plenum), or
  - only liquid-covered cells containing intact fuel
- Profile based on radial and axial shapes

Decay power is added to fission power

- If RN package is active, power associated with fission products
- If RN package is not active, distribute total ("whole core") power from Decay Heat (DCH) package

If the RN package is not active, information on the distribution of fission products is not available. In this case, the total decay heat can only be approximately distributed over the UO2 content of the active core components and debris in the cavity. The radial and axial power densities are considered for the UO2 remaining in intact fuel pellets, but because of the absence of tracking information, the average specific power must be assigned to UO2 in all other locations. This average specific decay power (W/kg-UO2) is calculated from the whole core decay power provided by the DCH package as

$$DH(t) = \frac{DH_T(t)}{M_{UO2,cor}(0) + M_{UO2,cav}(0)}$$

Physics and Phenomena

Point kinetics

- Six delayed neutron precursor group point kinetics model

- Allows for a zero-power neutron source

- Allows for reactivity feedback effects:
  - External, user-specified reactivity insertion (+/-)
  - Fuel Doppler feedback
  - Fuel density feedback
  - Graphite density feedback

$$\frac{dn}{dt} = \frac{\rho - \beta}{\Lambda} n + \sum_{i=1}^{6} \lambda_i C_i + S_0$$

$$\frac{dC_i}{dt} = \frac{\beta_i}{\Lambda} n - \lambda_i C_i$$

- User-defined region averages for core temperatures in feedback model

- Nuclear data:
  - LSQ fit to INL neutronics calculations of NGNP for temperature feedback coefficients
  - ^{235}U thermal spectrum reactor for λ_i, β_i, and Λ

Axial Conduction

Like components in adjacent axial cells

Plate supporting structure and all components supported by it

Component and particulate debris in adjacent cells if

- component exists in only one of the two adjacent cells
- physical contact between debris and component is predicted.
  - assumed if the debris resides in the overlying cell where it is presumed to rest on components in the underlying cell

Heat transfer from convecting molten pool components handled separately

$$q_{ij} = K_{eff}\left(T_i - T_j\right)$$

$$K_{eff} = \frac{1}{{}^{1}\!/\!_{K_i} + {}^{1}\!/\!_{K_j}}$$

$$K_i = \frac{k_i A_i}{\Delta x_i}$$

$$A_i = \frac{V_{tot,comp,i}}{\Delta z_i}$$

$$\Delta x_i = \tfrac{1}{2}\Delta z_i$$

Conduction - Other

Radial

- Conduction is calculated between elements of supporting structure (SS) modeling contiguous segments of a plate in radially adjacent core cells.
- Conduction is also calculated between particulate debris in radially adjacent core cells unless the path is blocked by intact canisters

Intracell

- debris and any remaining intact core components.

Intracell

$$A_i = A_j = \frac{V_{tot,PD}}{V_{tot,PD} + V_{free}} A_{intact}$$

$$\Delta x_{PD} = \frac{V_{bed}}{2\, A_{bed}}$$

$$\Delta x_{intact} = \frac{V_{tot,intact}}{2\, A_{intact}}$$

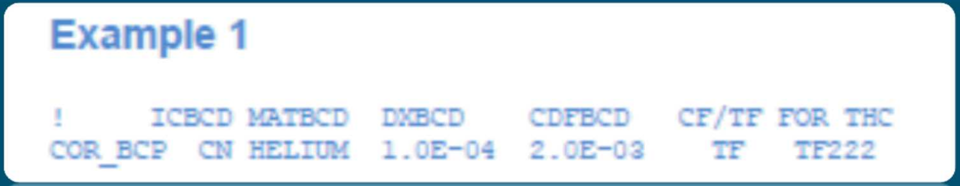
Conduction to Boundary Heat Structures

Optionally, on the COR_BCP record the user can specify conduction from a component in the outermost radial ring to the radial boundary HS

- Contact resistance between component and HS

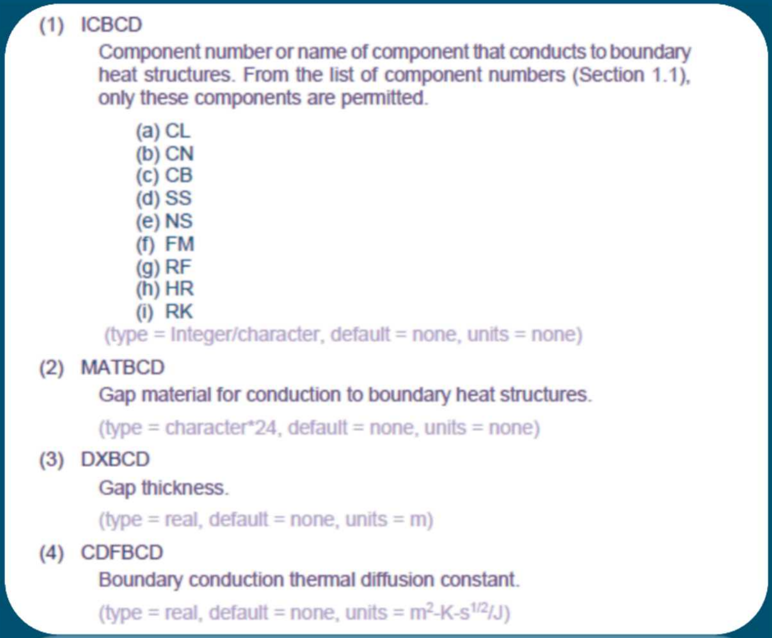
$$q_{C-HS} = \frac{T_C - T_{HS}}{R}$$

- sum of gap and diffusive resistance $R = R_{gap} + R_{dif}$
- Gap resistance $R_{gap} = \Delta r_{gap} / k_{gap}$
- Diffusive resistance $R_{dif} = \sqrt{\frac{\pi \Delta t}{(k \rho c_p)_{HS}}}$



Example 1

```
!      ICBCD MATBCD   DXBCD      CDFBCD    CF/TF FOR THC
COR_BCP  CN HELIUM  1.0E-04   2.0E-03     TF    TF222
```



(1) ICBCD

Component number or name of component that conducts to boundary heat structures. From the list of component numbers (Section 1.1), only these components are permitted.

(a) CL
(b) CN
(c) CB
(d) SS
(e) NS
(f) FM
(g) RF
(h) HR
(i) RK

(type = Integer/character, default = none, units = none)

(2) MATBCD

Gap material for conduction to boundary heat structures.

(type = character*24, default = none, units = none)

(3) DXBCD

Gap thickness.

(type = real, default = none, units = m)

(4) CDFBCD

Boundary conduction thermal diffusion constant.

(type = real, default = none, units = m^2-K-$s^{1/2}$/J)

Convection

Heat transfer rates calculated for each component using heat transfer coefficients

$$q = h_{rlx} \; A_s \; (T_s - T_f)$$

Does not use a critical Reynolds number to determine laminar or turbulent flow regimes

- Maximum of laminar and turbulent Nusselt number is used
- Maximum of forced and free used
- Alleviates some numerical difficulties associated with discontinuities in Nu

Convection – Vertical Surfaces

Single-Phase

- Intact geometry
  - Laminar forced convection
  - Turbulent forced convection
  - Laminar and turbulent free convection
- Particulate debris
  - Forced convection
  - Free convection

Pool Boiling

- HS correlations (default)
- March 2.0 simplified curves (enabled with C1241(5))

March 2.0 Simplified Boiling Curves

$\Delta T < 23.4$ K

$$h = 34.5 \ P^{1/4} \ \Delta T^{1.523}$$

$\Delta T \geq 23.4$ K

$$h = 1.41(10^7) \ P^{1/4} \ \Delta T^{-2.575}$$

Where,
P = pressure
ΔT = surface superheat

Convection – Support Structure Plates

Horizontal plates have horizontal bottom and top surfaces that can be covered or uncovered with a relatively small change in the pool level.

Optional model for horizontal specified on COR_PC record

```
COR_PC 1 !IA IR DZBOT DZTOP CONST/CF HPBOT CONST/CF HTBOT
         1  2  3    0.2     0.2    CONST      100.     CONST    100.
```

DZBOT

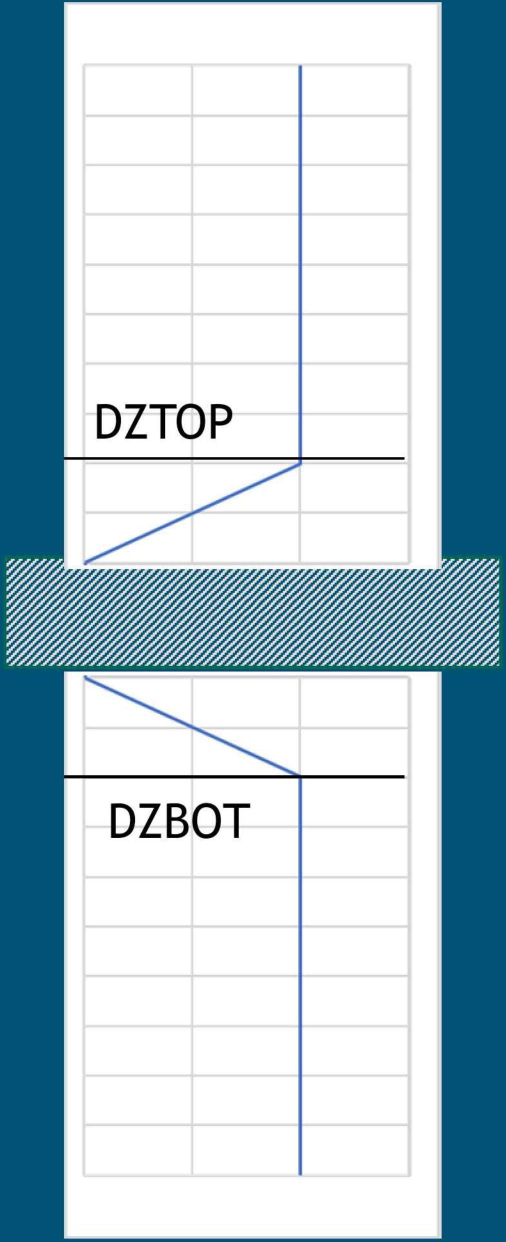
Clearance (relative distance) between bottom of plate and pool surface for no contact.

- Linearly reduced to zero between DZBOT and bottom surface.
- If negative, no heat transfer is considered between the bottom surface and the pool.

DZTOP

Pool depth (relative distance) over top surface of plate for complete coverage.

- Linearly reduced to zero between upper surface and DZTOP.
- If negative, no heat transfer is considered between the top surface and the pool.



Radiation

Radiosity

- Net Heat transfer rate from surface
- Net heat transfer rate between surfaces

Radiation to participating medium (steam)

Emissivity

- Zircaloy
- Other

View Factors

The net heat transfer rate from surface i to surface j

$$q_{ij} = A_i F_{ij} \tau_{ij} \left(J_i - J_j\right)$$

Where:

Fij = geometric view factor from surface i to surface j

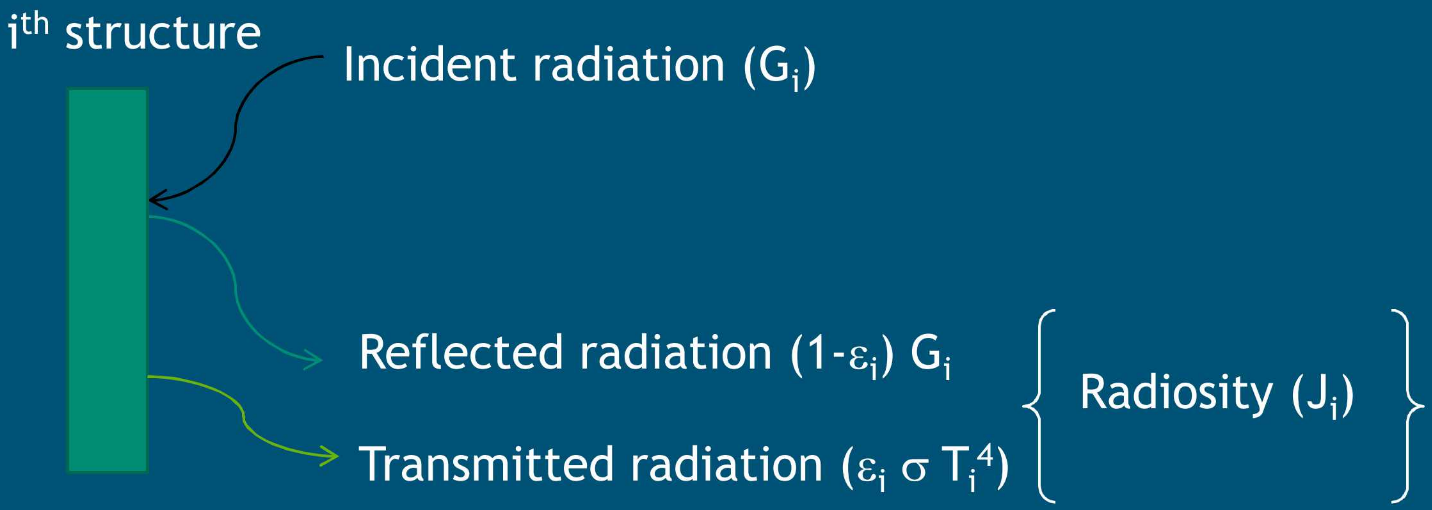
τ_{ij} = geometric mean transmittance between surfaces i and j

$$J_i = (1 - \varepsilon_i) G_i + \varepsilon_i E_{bi}$$

G_i = radiation flux incident on surface i

E_{bi}= blackbody emissive power of surface i σT_i^4

Radiation Heat Transfer



i^{th} structure

Incident radiation (G_i)

Reflected radiation $(1-\varepsilon_i)\ G_i$

Transmitted radiation ($\varepsilon_i\ \sigma\ T_i^4$)

Radiosity (J_i)

Where,

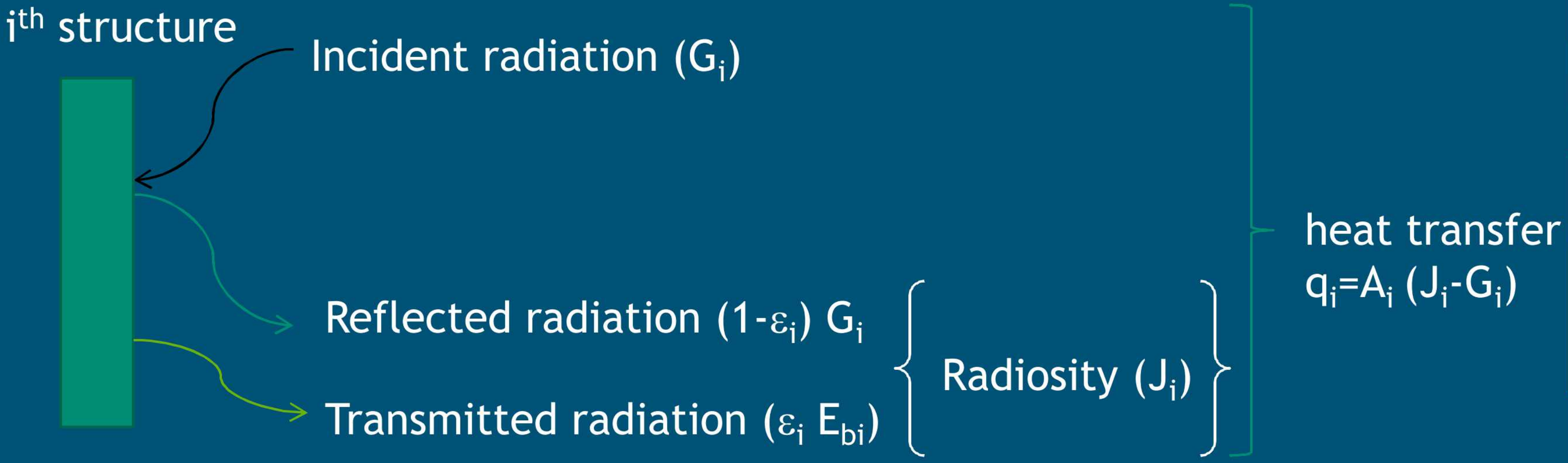
ε = emissivity

σ =Stefan-Boltzmann constant

T = surface temperature

Let E_{bi} = blackbody emissive power ($\sigma\ T^4$)

Radiation Heat Transfer



i^{th} structure

Incident radiation (G_i)

Reflected radiation ($(1-\varepsilon_i)\ G_i$)

Transmitted radiation ($\varepsilon_i\ E_{bi}$)

Radiosity (J_i)

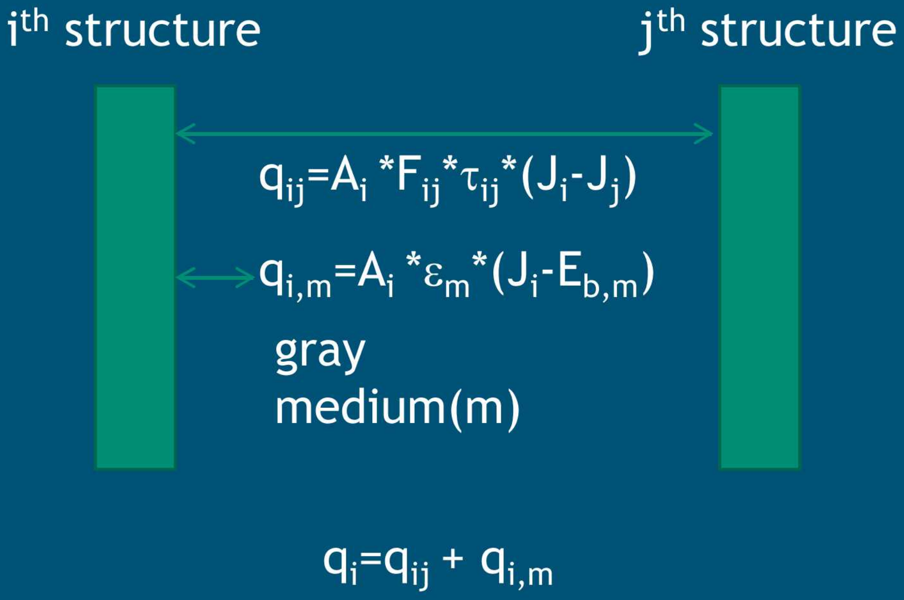
heat transfer

$q_i=A_i\ (J_i-G_i)$

$q_i=A_i * \varepsilon_i / (1-\varepsilon_i) * (E_{bi}-J_i)$

Radiation Heat Transfer

- **Steam Emissivity**
  - Determined from assumed core geometry to giving the mean beam length between components
  - Optical depth versus steam temperature lookup table to determine emissivity
    - Optical depth = partial pressure * mean beam length



i^{th} structure

j^{th} structure

$q_{ij}=A_i *F_{ij}*\tau_{ij}*(J_i-J_j)$

$q_{i,m}=A_i *\varepsilon_m*(J_i-E_{b,m})$

gray medium(m)

$q_i=q_{ij} + q_{i,m}$

MELCOR Inter-cell Exchange Factors

MELCOR has a very simple model for calculating the radiant heat exchange between COR cells. It does this in an approximate way by defining the product of view factor and surface area for radiation across a cell boundary as:

$$\begin{aligned} A_1 F_{12} = A_2 F_{21} \equiv AF &= \min\left(A_1, A_2, A_{cell,x}\right) F_{cell,x} \\ &= A_{cell,x} F_{cell,x} \min\left(A_1 / A_{cell,x}, A_2 / A_{cell,x}, 1\right) \end{aligned}$$

- where $F_{cell,x}$ is the effective inter-cell view factor input by the user and x may be r (radial) or a (axial), A_1 is the surface area of the component in cell 1, A_2 is the surface of the component in cell 2, and F_{12} is the actual view factor between components in cells 1 and 2.
- In effect, $F_{cell,x}$ is the view factor for a pseudo component at the boundary, having the inter-cell surface area ($A_{cell,x}$) and radiating at the cell average temperature.
- It is not the direct view factor between components.

Radiation View Factors

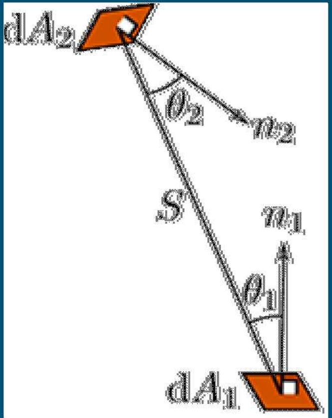
Complicated geometric calculation
  - May change with core degradation

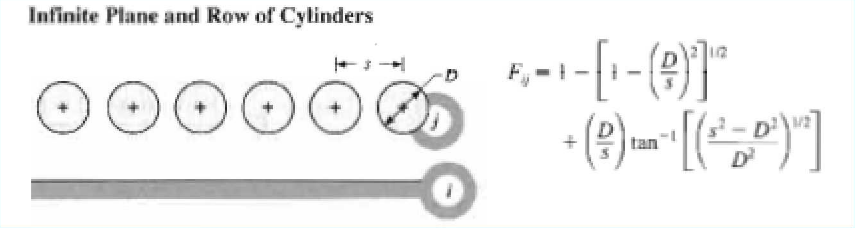
Calculated by many CFD codes
  - FLUENT, STARCD

Monte Carlo calculation
  - Version of MELCOR used to calculate view factors for rod bundle geometries

Engineering Compilation of view factors
  - Howell, J.R., "Radiation Heat Transfer Configuration Factors"
    - http://www.thermalradiation.net/indexCat.html
  - J. R. Howell, R. Siegel and M. P. Menguc, "Thermal Radiation Heat Transfer", 5th edition, Taylor and Francis/CRC, New York (2010).
  - Modest, M., "Radiative Heat Transfer," Elsevier, 2013

$$F_{1-2} = \frac{1}{A_1}\int_{A_1}\int_{A_2}\frac{\cos(\theta_1)\cos(\theta_2)}{\pi S^2}dA_1 dA_2$$




Infinite Plane and Row of Cylinders

$$F_{ij} = 1 - \left[1 - \left(\frac{D}{s}\right)^2\right]^{1/2} + \left(\frac{D}{s}\right)\tan^{-1}\left[\left(\frac{s^2 - D^2}{D^2}\right)^{1/2}\right]$$

Incropera & Dewitt

Radiation Exchange Factors

View factor	Default Value	Notes
FCNCL	0.25	View factor for radiation heat transfer from the canister wall to the fuel rod cladding surfaces. (This view factor is applicable to BWRs only).
FSSCN	0.25	Radiative exchange factor for radiation from NS (e.g., control blades) to the adjacent canister walls or to fuel rods and debris if canister is not present. Redefined in the spent fuel pool model as a view factor for radiation heat transfer from cladding surfaces to the rack surfaces (if applicable) within a ring.
FCELR	0.1	View factor for radiation heat transfer radially outward from the cell/node boundary to the adjacent cell/node boundary.
FCELA	0.1	View factor for radiation heat transfer axially upward from the cell/node boundary to the next adjacent cell/node boundary.
FLPUP	0.25	View factor for radiation from the liquid pool to the core components.

MELCOR Core Phenomenon Radiative Heat Trans. Modeling

Radiative exchange based on superposition of "important" surface pairs, participating medium

- Based on very simple model and a few input view factors
  (does *not* use net enclosure model)
- Particulate debris competes for view in some cases
- Reciprocity considered, bounds imposed

Caveats

- View factors for average surfaces in cell (not peripheral)
- Should include effects of geometry, temperature profiles
  - Reduce axial view factors, appropriate value depends on cell height

When Single COR Component Temperature isn't Sufficient

There are times when a single component temperature is not sufficient

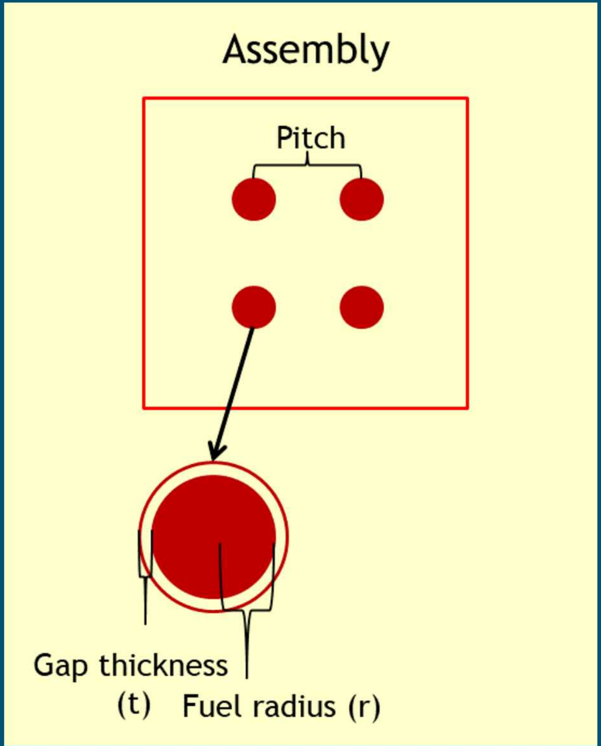
- Fuel surface temperature for gap resistance to clad
- Moving axial temperature profile from quenching near water level
- Propagation of ignition through fuel bundle (SFP)

Since hydrodynamic fluids are evaluated by the CVH package and multiple core cells can be assigned to a single control volume, an estimate of the temperature distribution in the control volume must be made.

dT/dz model

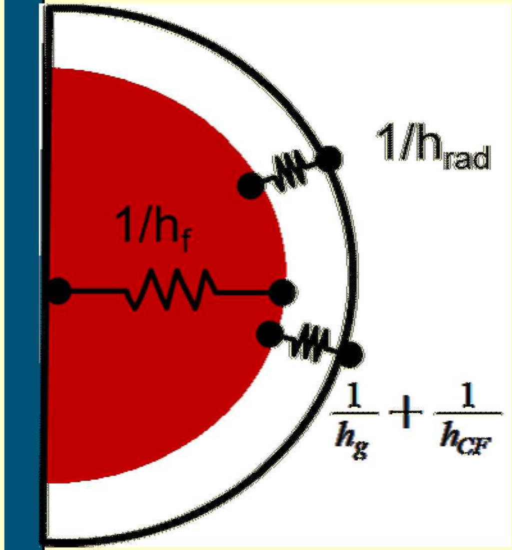
Fuel Cladding Gap Heat Transfer

Geometric Description



User provided input

Model



$$\frac{1}{h_{gap}} = \frac{1}{h_f} + \frac{1}{\frac{1}{\frac{1}{h_g} + \frac{1}{h_{CF}}} + h_{rad}}$$

Where:

$$h_f = 4\ k_f\ /\ r_f$$

$$h_g = k_g\ /\ \Delta r_g$$

$$h_{rad} = \frac{4\ \sigma\ T_a^3}{\frac{1}{\varepsilon_f} + \frac{1}{\varepsilon_c} - 1}$$

h_f based on assumed parabolic temperature distribution for the fuel temperature

Assumption: Parabolic Temperature Profile in Fuel

What’s needed: h_f

$$\dot{q}" = h_f(\bar{T} - T(R))$$

Problem: T(R) at surface is unknown

Assume Fuel Temperature Profile

$$T(r) = T(0) + [T(R) - T(0)]\left(\frac{r}{R}\right)^2$$

Parabolic profile appropriate for LWR application

Assumes Uniform Heat Generation

$$\dot{Q}(r) = -2\pi r L k \frac{dT}{dr} \propto \pi r^2 L$$

the total radial heat flow at any radius, r, is proportional to the volume within that radius

Calculate the Average Temperature

$$\begin{aligned}\bar{T} &= T(0) + \frac{1}{\pi R^2}[T(R) - T(0)]\int_0^R \left(\frac{r}{R}\right)^2 2\pi r\,dr \\ &= T(0) + \tfrac{1}{2}[T(R) - T(0)] = \tfrac{1}{2}[T(R) + T(0)]\end{aligned}$$

Single (average) Temperature model in MELCOR

Solve for T(0)

$$T(0) = 2\bar{T} - T(R)$$

Substitute this back into parabolic profile

Solve for heat flux to radial surface

$$\dot{q}'' = -k\frac{dT}{dr}\bigg|_R = 4k\frac{\bar{T} - T(R)}{R}$$

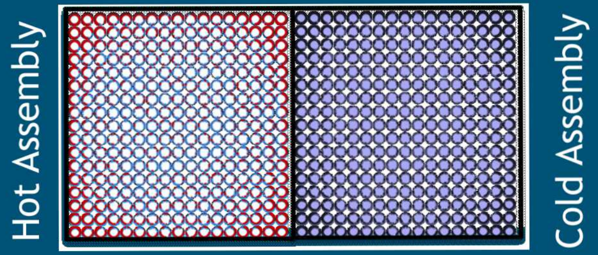
This heat flux matches convection and radiation from this surface

Solve for h_{gap}

$$h_f = \frac{rk}{R}$$

h_f is used in calculating h_{gap}

Multi-Rod Model



Challenge
When hot assembly reaches ignition, heat transfer to cold assembly is problematic

Motivation

- It is desirable to model an entire spent fuel pool assembly within a single MELCOR ring. Radiative heat transfer is an important heat transfer mechanism
- However, a single ring may contain a large number of fuel rods. Radiation to adjacent rings uses the bulk ring temperature and an effective 'radiation exchange factor' to capture both the geometric view factor and the temperature effect
- The multi-rod model, a sub-grid model, allows this

Advantages over many COR cell approach

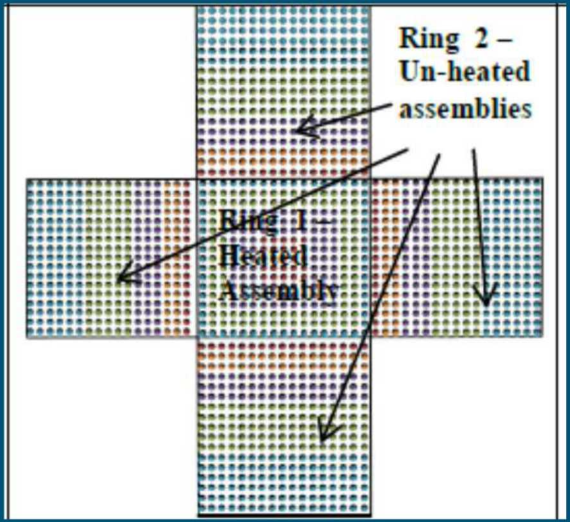
- CPU time is greatly reduced for multi-rod model
- Simplified input requirements

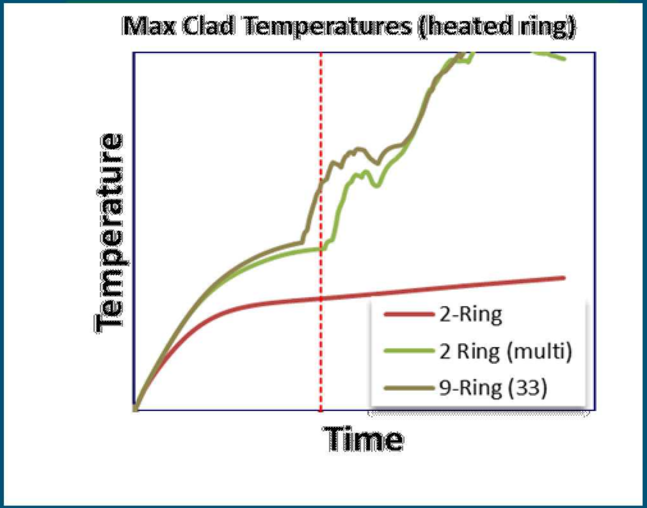
Modeling assumptions

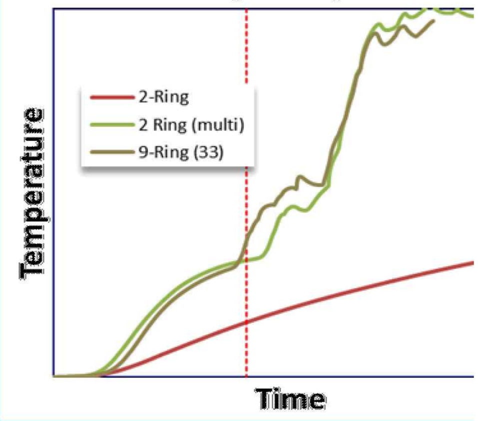
- Same CVH boundary condition taken for each component (rod type).
  - Local dtdz temperature
- Rods of all rod types in a cell fail simultaneously
  - First rod type to satisfy failure criteria
- Candling, oxidation, convective heat loss, and radiation calculated separately for each rod type
- Static, user defined view factors only

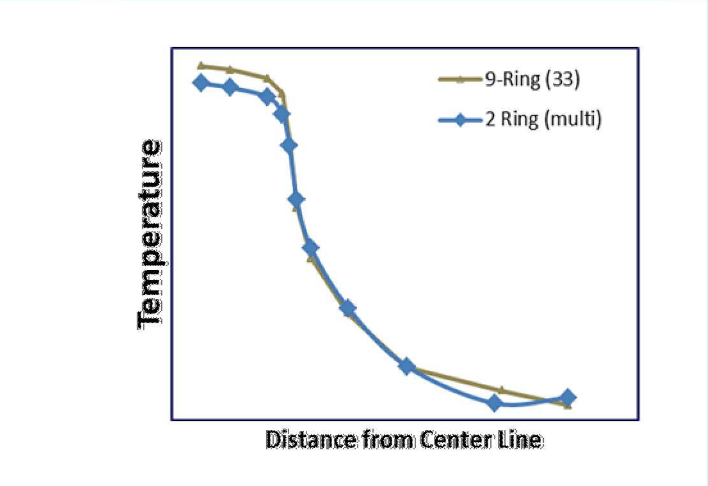
Multi-Rod Model Validation

- 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.









Specification of multi-rod types

User specifies a fraction of fuel rods in each ring of a particular type

```
COR_ROD2  2 !  One record for every ring with multi-rods
          1 0.1    0.3   0.35   0.00  0.25
          2 0.05  0.1   0.2     0.30   -
```

- Table contains a record for each ring with multi-rod types
- The number of multi-rod types is determined from the number of fields on the COR_ROD2 table records
  - The number of rod types is the number of fields specified (five for this example)
  - The sum of the fractions must be 1.0
    - Any single entry can be replaced with '-' and will be calculated from the others
- Each ring must contain an entry for each rod-type but is not required to have all rod types (specify a fraction of zero)
  - View factors must be specified correctly to account for 'missing' rod types (don't radiate to a missing rod)

User specifies cell properties (mass, surface areas, etc) generally for all rods in a cell and not individually for each rod type

- MELCOR uses the fraction to calculate masses and surface areas for individual rod types
- All other cell properties are identical for all rod types (Initial Temperature, hydraulic diameter, CVH volume)

Similar input is used in specifying multiple control rod types

```
COR_CR2   2 !( n  ri
          1 0.1    0.3   0.35   0.00  0.25
          2 0.05  0.1   0.2     0.30   -
```

Specification of multi-rod types

Specification of view factors

View factors are not specified for control rods. For PWR and PWR_SFP it is assumed that the control rods see nothing but fuel rods.

A table of view factors connecting rod types, COR_ROD_VF, is required for each ring

COR_ROD_VF 5 1 !(

1	0.0	VF_{1-2}	0.0	0.0	0.0	0.0
2	0.0	0.0	VF_{2-3}	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	VF_{3-5}	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	$VF_{5-ring2}$

- View factors to non-existent fuel rod types must be avoided
- View factors to next ring (rack for SFP, fuel rods for PWR (or shroud if it exist)) given for column 6.
  - Takes the place of FCELR

Reflood Quench Model

MELCOR computes a quench velocity, distinct from pool water level

- The quench velocity correlation implemented is that of Dua and Tien[1]

$$Pe = \left[\bar{B}(1+0.4\bar{B}) \right]^{1/2}$$

  - Where
    - Pe is the dimensionless quench velocity or Peclet number
    - $\bar{B}$ is a dimensionless Biot number
- May be thought of as an interpolation between a result based on one-dimensional conduction in thin surfaces (small Bi), and one based on two-dimensional conduction in thick surfaces (large Bi).

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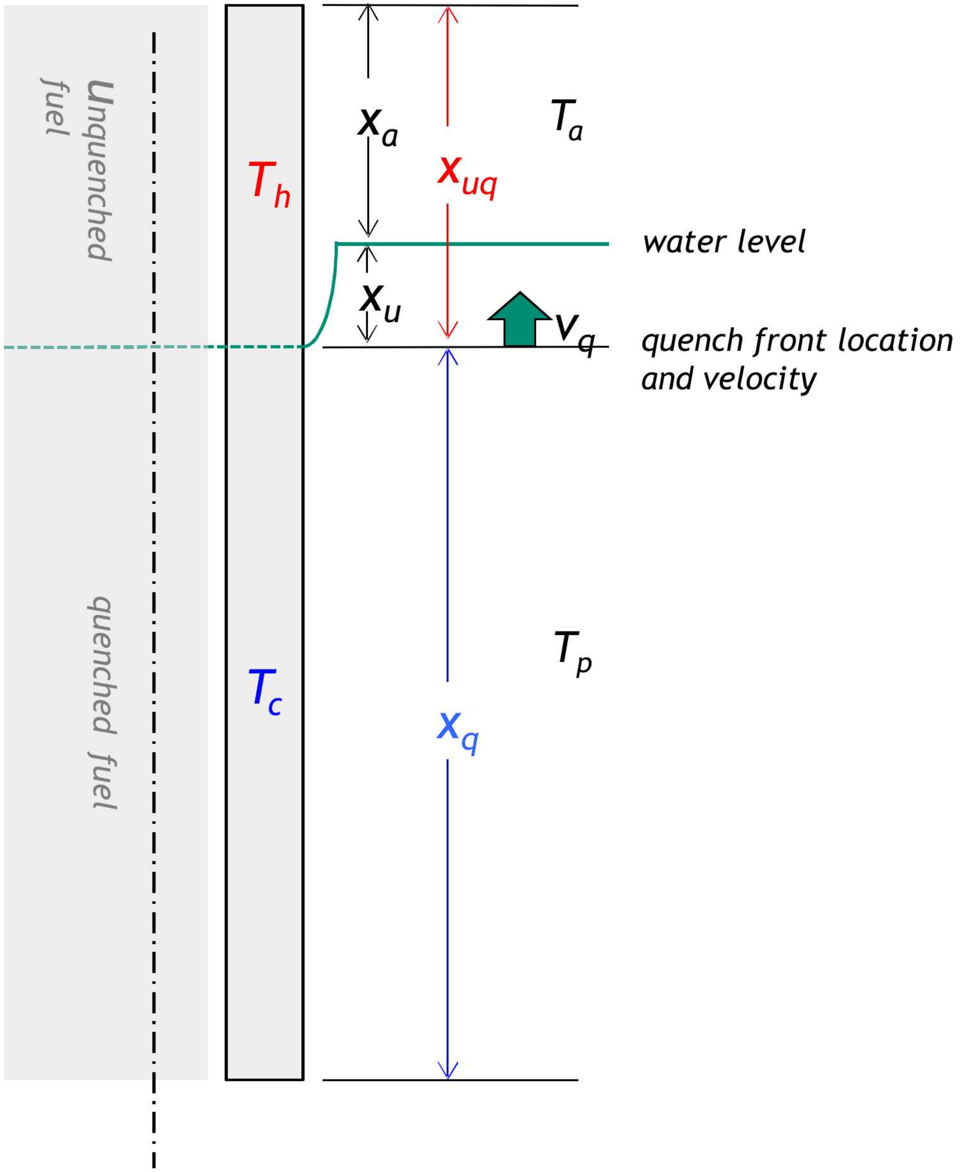
[1] *S. S. Dua and C. L. Tien, Intl. J. Heat and Mass Transfer 20, pp.174-176 (1977).*

Illustrative picture for COR convective heat transfer



HTCATM, QCNVA

HTCPR, QCNVS*, QCNVIN

** includes "quenching" heat transfer as location moves*

HTCPOL, QCNVP

Problematic Assumptions in Original Model Implementation

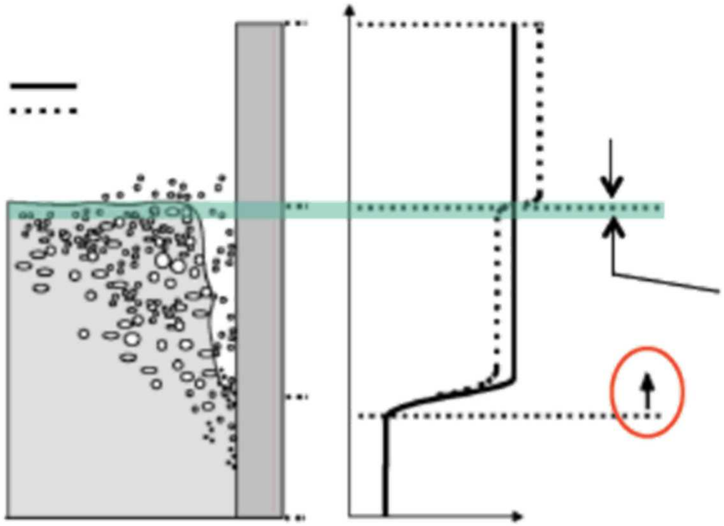
1. All of the thermal energy associated with the change in temperature across the quench front is transferred into a direct vaporization of liquid water into steam.
2. The thermal capacitance of the COR components relative to that of the surrounding coolant is typically quite large.
3. Because the quench velocity model is based on "steady" (i.e. non time-varying") conditions, when conditions change, no matter how quickly, the computed quench velocity will also change instantaneously.

Revised Quench Front Velocity

This revision prevents the code from producing unphysical pressure oscillations by enabling the quench front velocity to

(1) Have its rate-of-change temporally relaxed, and

(2) be smoothly driven to zero within a small user-specified distance of the pool level (C1260(5), DXQNCH).



Example specification of DXQNCH:

```
COR_SC  1 ! n nnnn   value  index
           1  1260   0.02    5
```

DXQNCH: fractional width of quench vel. Reduction zone near pool level (default is 0.02)

Temporal relaxation is not applied to receding quench fronts

The reduction in velocity near the surface is computed using a simple cubic polynomial-based multiplier that drives the value to zero.

ISP-45 Quench06 Experiment

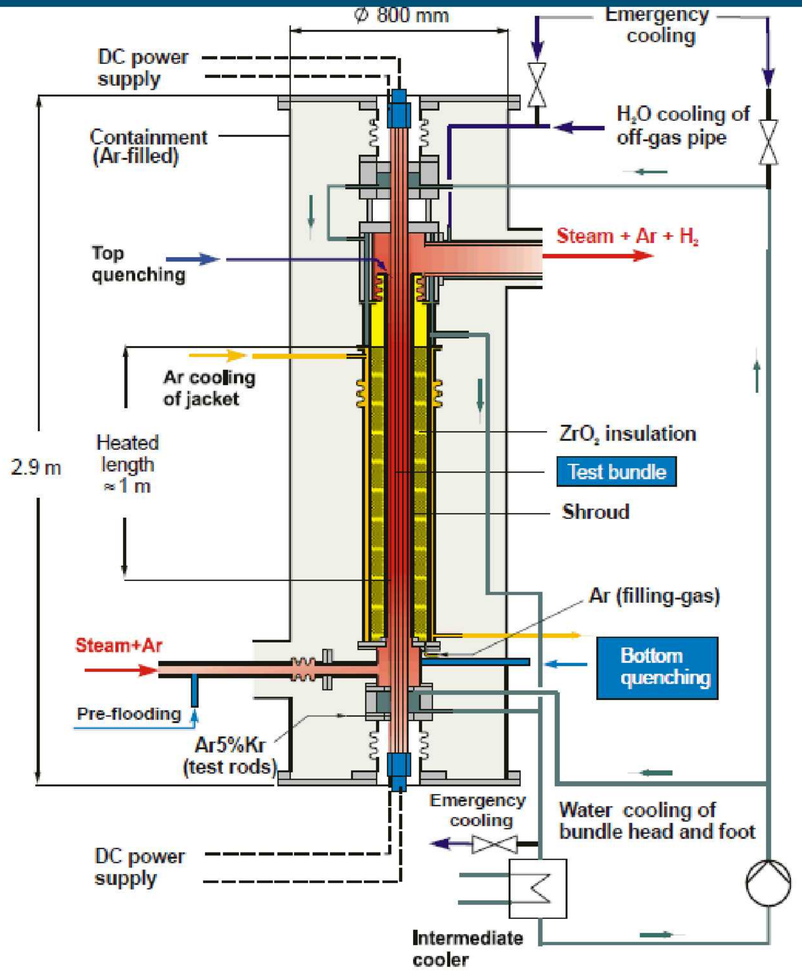


Figure 2.1 Main flow paths in the QUENCH facility.

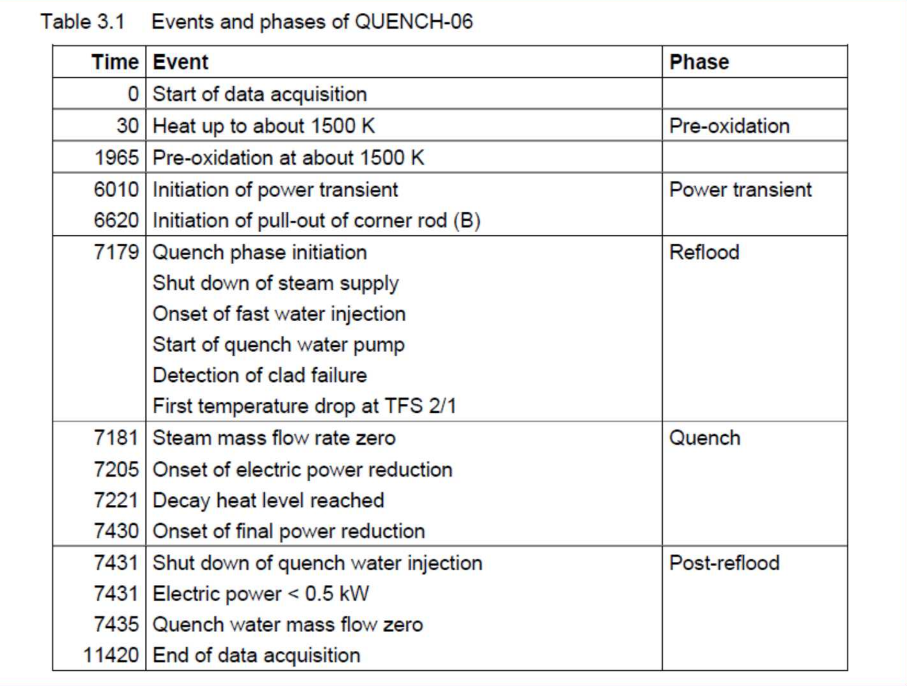
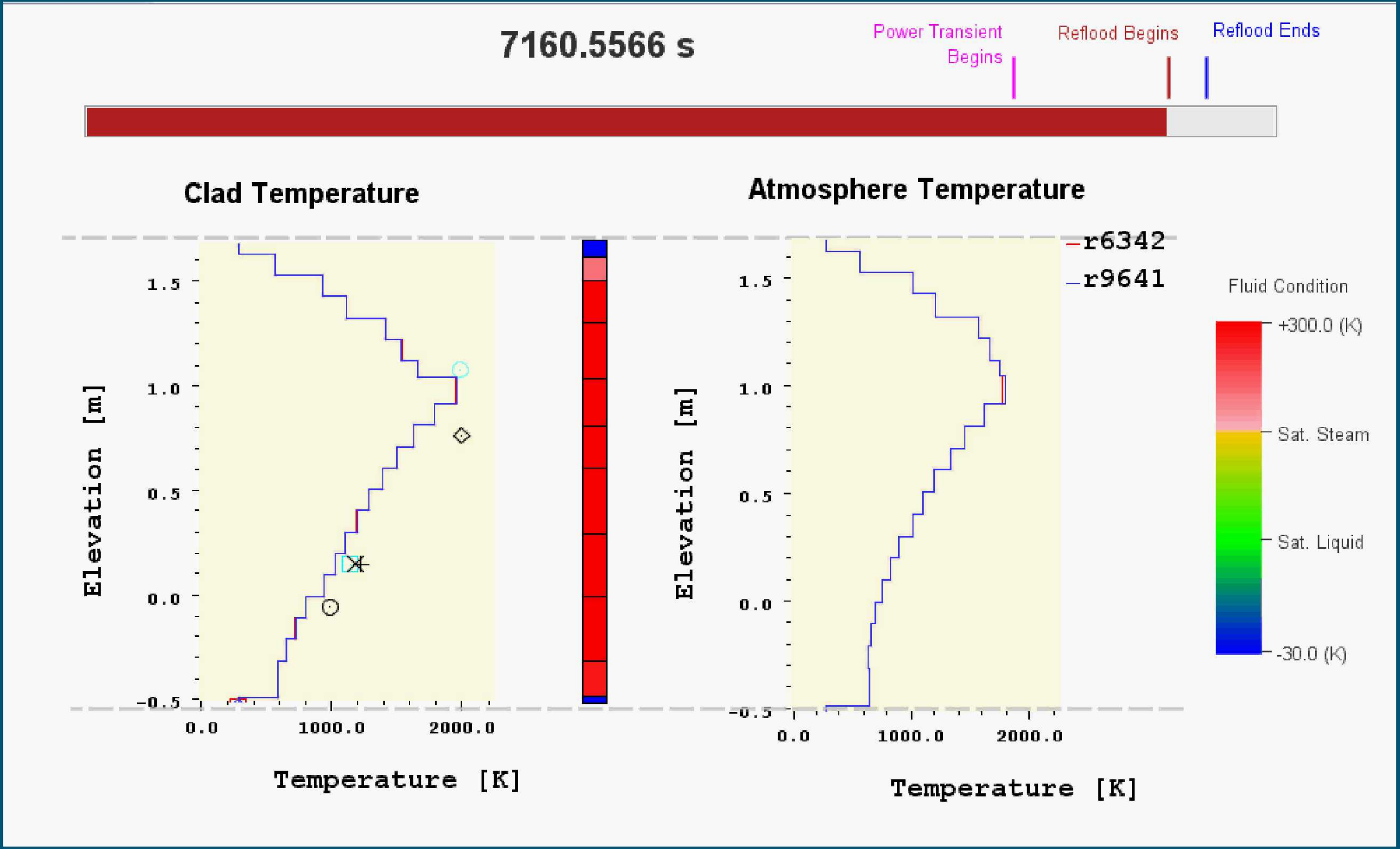


Table 3.1 Events and phases of QUENCH-06

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	

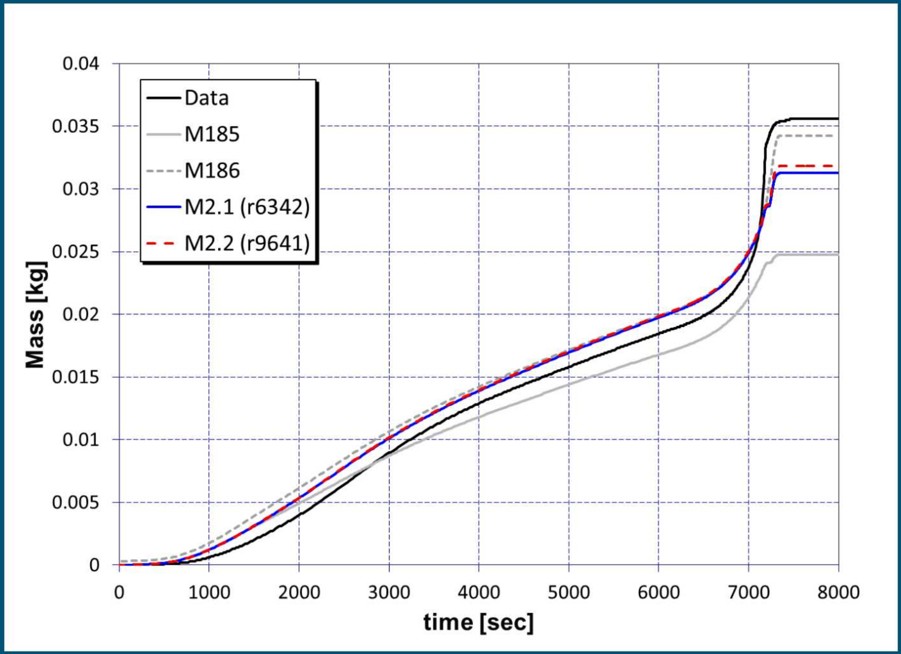
ISP-45 (Quench-06 experiment) MELCOR Simulation

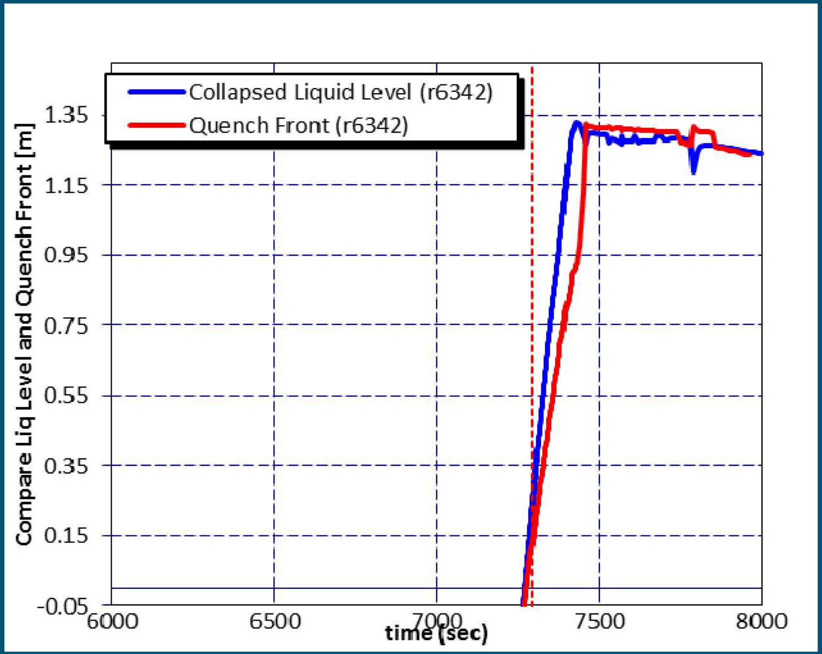


ISP-45 (Quench-06 experiment) MELCOR Simulation

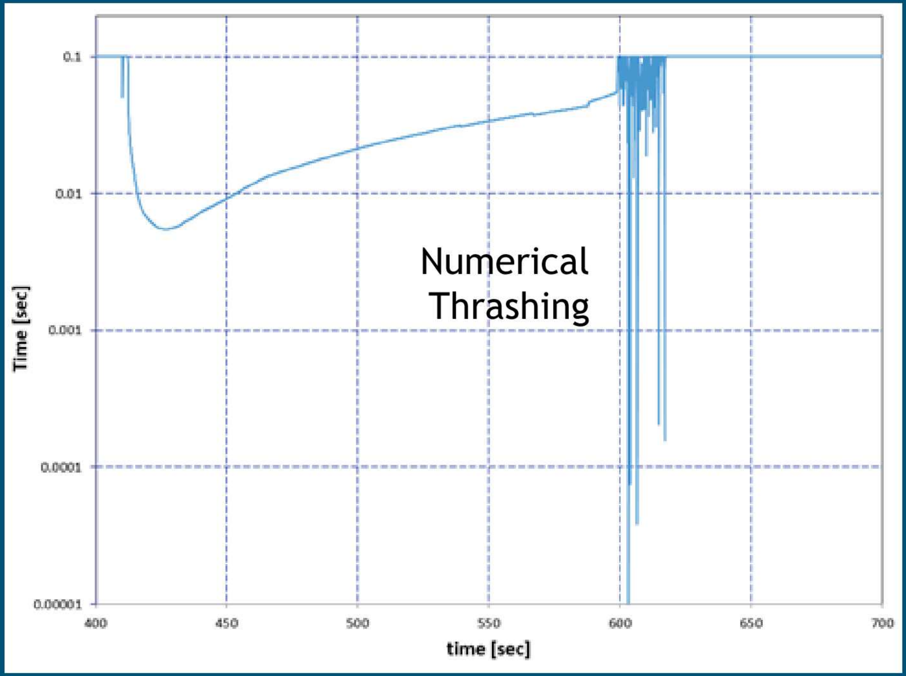
Quench model effects oxidation

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



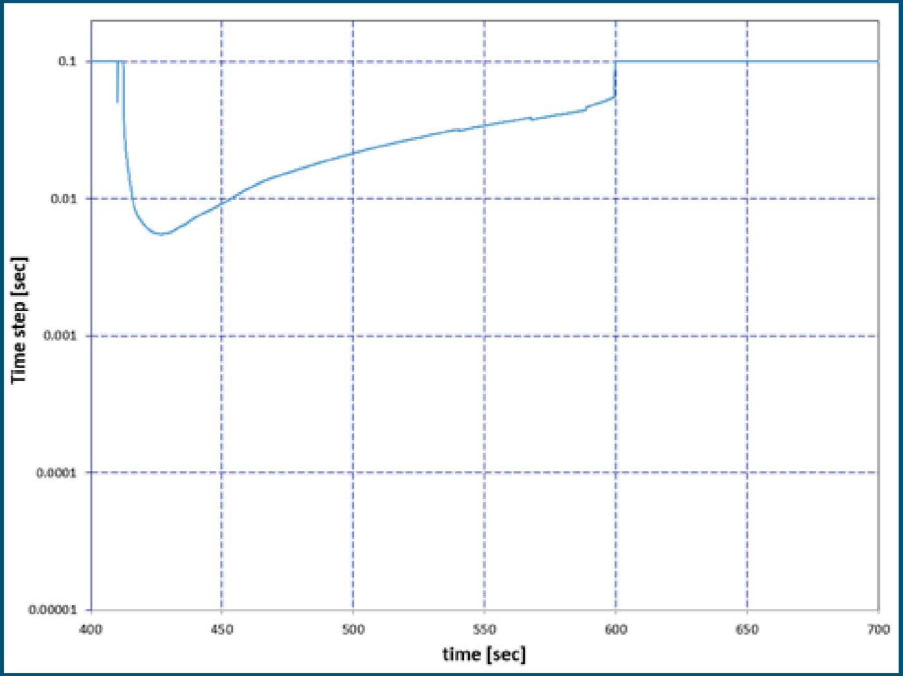


Time-step size vs. simulation time



Numerical Thrashing

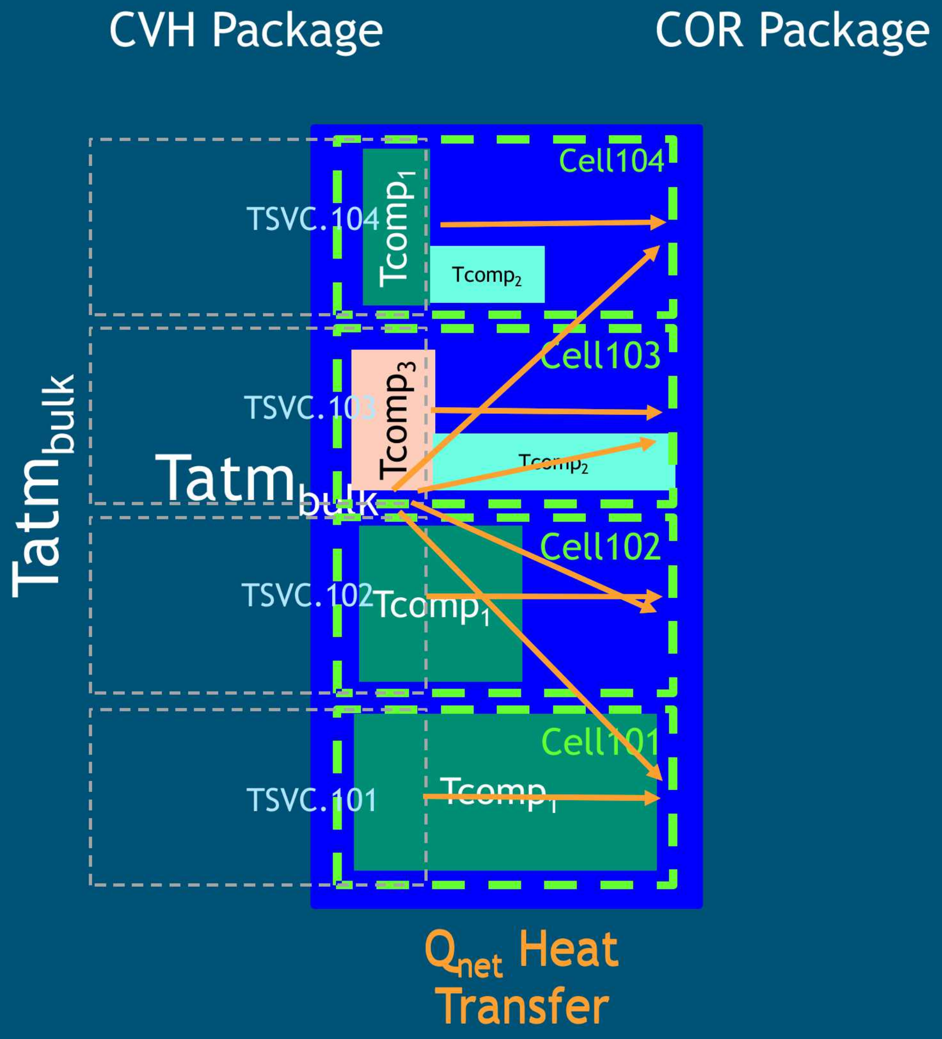
Modeling changes inactive



Modeling changes active

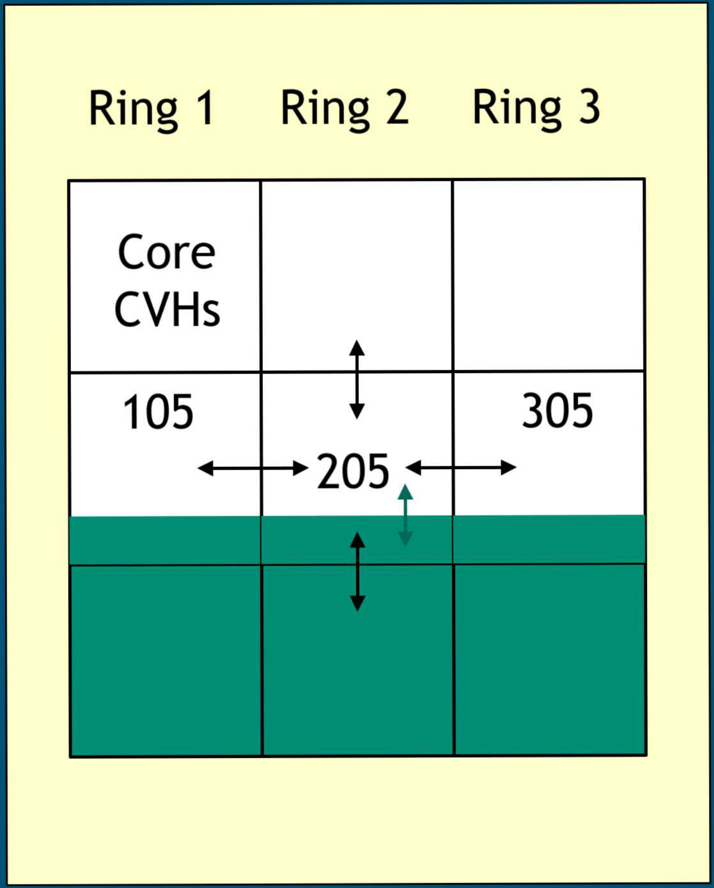
dT/dz Model

- Multiple COR cells may be associated with a single CVH control volume
- A single temperature is calculated for a CVH control volume
  - For calculating heat transfer, local vapor temperatures should be used
    - The dTdz model is a sub-grid model for predicting local vapor temperatures
    - These vapor temperatures are only used in calculating heat transfer to COR components (and HS) and are not state temperatures.
- A simple energy balance is performed to evaluate the atmospheric temperatures of the upper cells



dT/dz Inlet Temperature

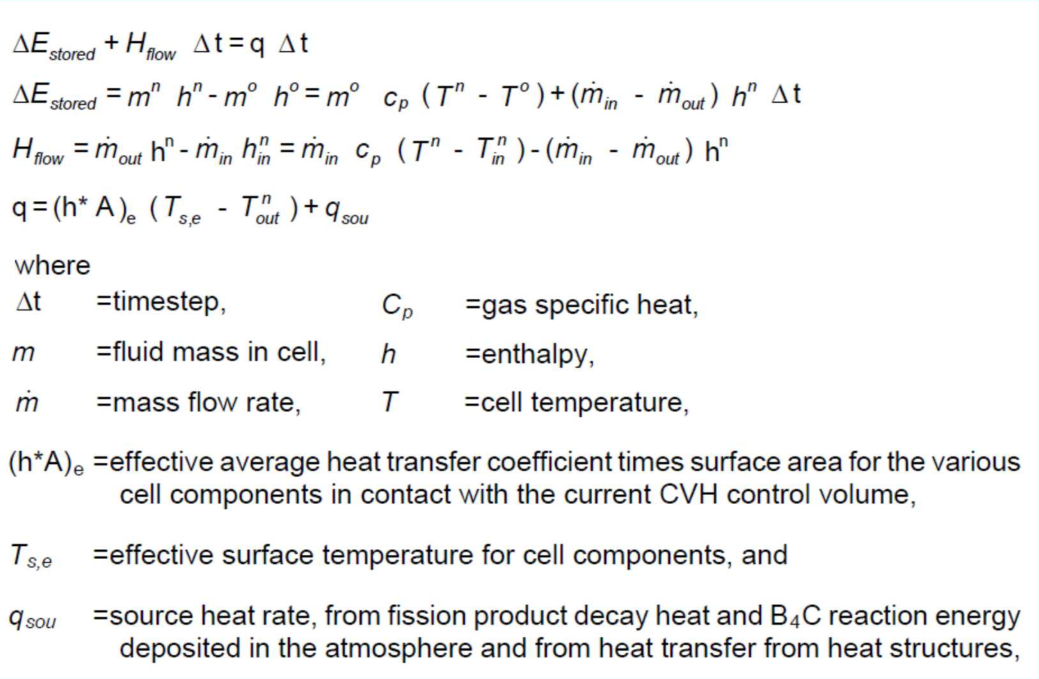
- Temperature of in-flowing vapors are heat-capacity-weighted to find the average inlet temperature
  - Boiling within the core cell is treated as an in-flow of vapor at Tsat
- The top core flows determine dT/dz gradient direction (upward or downward flow through the core)



dT/dz Mass and Energy Balance

The atmosphere temperature (Cell 208) was determined from the weighted Tvap in-flow as T^n_{in}.

Following is used to determine T^n (out-flow temp), which is the new T^n_{in} for the next cell (209)



$$\Delta E_{stored} + H_{flow} \ \Delta t = q \ \Delta t$$

$$\Delta E_{stored} = m^n \ h^n - m^o \ h^o = m^o \ c_p \ (T^n - T^o) + (\dot{m}_{in} - \dot{m}_{out}) \ h^n \ \Delta t$$

$$H_{flow} = \dot{m}_{out} \mathrm{h}^n - \dot{m}_{in} \ h^n_{in} = \dot{m}_{in} \ c_p \ (T^n - T^n_{in}) - (\dot{m}_{in} - \dot{m}_{out}) \ \mathrm{h}^n$$

$$q = (\mathrm{h}^* \mathrm{A})_e \ (T_{s,e} - T^n_{out}) + q_{sou}$$

where

Δt =timestep, C_p =gas specific heat,

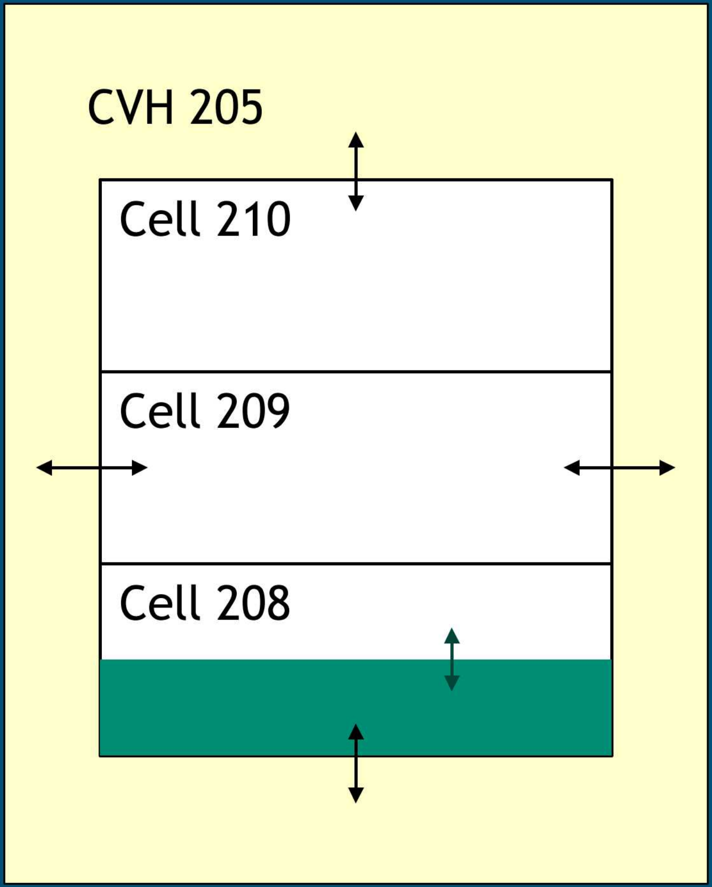
m =fluid mass in cell, h =enthalpy,

$\dot{m}$ =mass flow rate, T =cell temperature,

$(h^*A)_e$ =effective average heat transfer coefficient times surface area for the various cell components in contact with the current CVH control volume,

$T_{s,e}$ =effective surface temperature for cell components, and

q_{sou} =source heat rate, from fission product decay heat and B_4C reaction energy deposited in the atmosphere and from heat transfer from heat structures,



User Defined Arbitrary Heat Transfer Paths

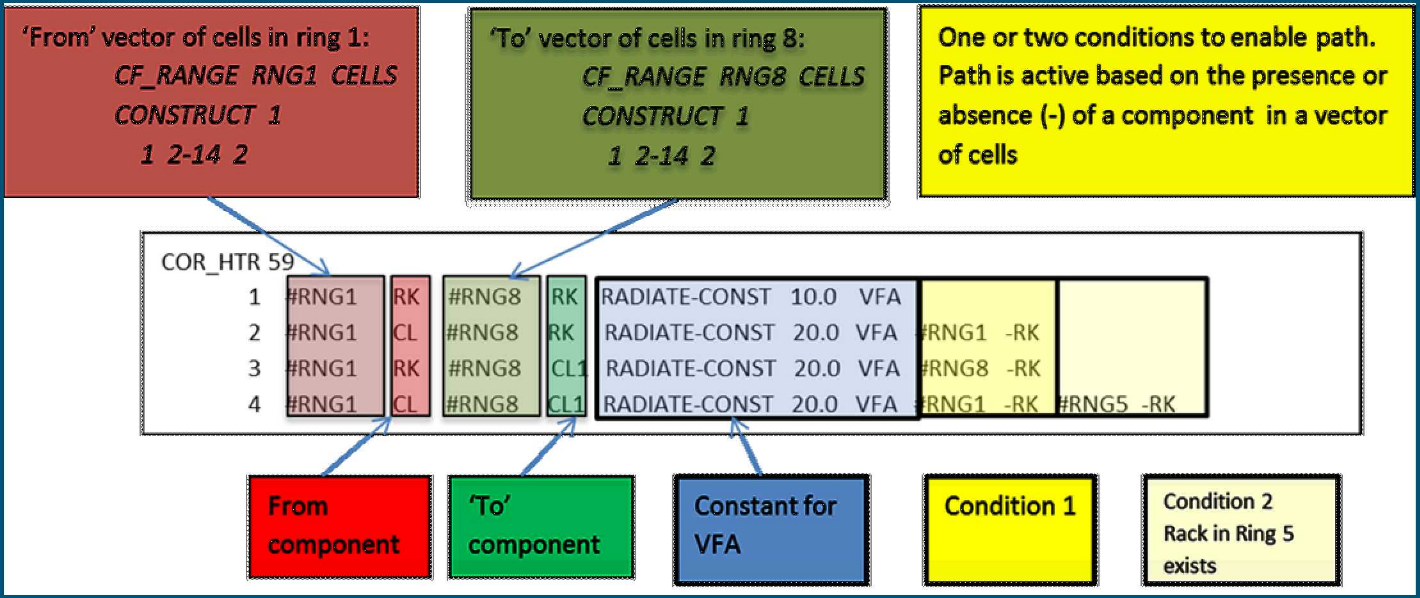
COR_HTR

- Allows the user to define arbitrary heat transfer paths
  - Radiation
  - Conduction

- Constant or Control Function
  - Total conductance or product of the view factor and area

- User can specify heat transfer from any core component at any cell location to another core component at any cell location or to a heat structure surface
  - Rack to rack radiation conduction
  - Former conduction
  - Unique degradation based radiative heat transfer

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
```

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

Questions