Overview of In-core Degradation Processes

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Phenomena Modeled by MELCOR

- **Main phenomena modeled include**
  - Two-phase hydrodynamics, from RCS (Reactor Coolant System) to environment
  - Heat conduction in solid structures
  - Reactor core heat-up and degradation
  - Ex-vessel behavior of core debris
  - Fission product release and transport
  - Aerosol and vapor physics

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MELCOR Modeling Approach

- **Modeling is as mechanistic as possible, consistent with a reasonable run time**
  - "Reasonable" is up to the user, depends on level of detail
    - Original thought was "a few hours"
    - Some applications now run many days
- **Some parametric models, where appropriate**
- **Uses general, flexible models**
  - Relatively easy to model novel designs
  - Puts greater burden on analyst to develop input deck
- **Allows sensitivity analyses**
  - Many parameters accessible to user from input
    - Properties of materials, coefficients in correlations, numerical controls and tolerances, etc.

MELCOR Packages

- **Major pieces of MELCOR called "Packages"**
  - Each handles a set of closely-related modeling functions
- **Packages (Order of Advancement)**
  - DCH: decay heat data
  - COR: Models the Reactor Core
  - SPR: Containment Sprays
  - BUR: Hydrogen Burn
  - FDI: Fuel Dispersal Interactions
  - CAV: Ex-vessel Molten Core/Concrete Interactions (MCCI)
  - ESF: Engineered Safety Features (PARS, Fan Coolers CND, PCCS)
  - RN: Radionuclides
  - HS: Heat Structures
  - CVH: Thermal Hydraulics

MELCOR COR Modeling Introduction

- **MELCOR COR package models core-specific structures in the core and lower plenum**
  - Fuel assemblies
    - Fuel rods (and grid spacers), BWR canisters
  - Control elements
    - PWR rods, BWR blades
  - Structural elements
    - Core plate
    - BWR control-rod guide tubes
    - Vessel lower head
      - Including penetrations

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MELCOR Core Modeling Phenomenological Models

- **Nuclear heat sources in core**
  - Fission power from models in COR package
  - Decay power from decay heat (DCH) package
- **Thermal response of core**
  - Temperature and stored heat in core structures and debris
  - Conduction and radiation between them
  - Convective and radiative heat transfer to CVH fluids
  - Radiation to boundary structures in HS package
- **Oxidation behavior**
  - Oxidation of Zircaloy and steel by water vapor and/or O_2
  - Oxidation of boron carbide (B_4C) in BWRs
  - Heat generation by oxidation
  - Release of hydrogen (and other gases) to CVH package

MELCOR Core Modeling Phenomenological Models (2)

- Failure of core and lower plenum structures
  - Local failure by loss of integrity
    - Melting, oxidation, materials interactions
  - Local failure of supporting elements under load
  - Failure of other elements by loss of support
- Creation of debris beds
  - Contain material from failed original structures
- Relocation of core materials
  - Downward flow of molten debris, “candling”
  - Downward relocation of solid debris
  - Radial spreading (leveling) of molten and/or solid debris, when appropriate
  - Changes in volume distribution communicated to CVH

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MELCOR Core Modeling Phenomenological Models (3)

- **Response of vessel lower head**
  - Failure of penetrations
  - Gross failure of lower head
- **Ejection of debris to reactor cavity**
  - "Handed off" to cavity models via a utility interface
- **Interface is the Transfer Process (TP) package**
  - Eliminates need for detailed knowledge of other models
  - Simplifies handling of different representations
    - Cavity (CAV) package has different equations of state
  - Deals with data storage, possible fallbacks
  - Material can go directly to CAV, or consider other Fuel Dispersal Interactions first, in the FDI package
  - Return to this later

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MELCOR Core Modeling Basic Approach

- Take boundary conditions from CVH and HS
  - Standard approaches and heat transfer correlations
- Nodalization may be more detailed than hydro
  - Local temperature profiles inferred where necessary
- Build core structures from "components"
  - Limited number of "building blocks"
  - Components have temperature (enthalpy), mass, composition, surface area
- Use lumped mass treatment for each component in each cell
  - Single temperature
  - Multiple materials
    - Distinguish original ("intact") masses from melted/refrozen masses ("conglomerate debris")
- Unified approach for PWR and BWR

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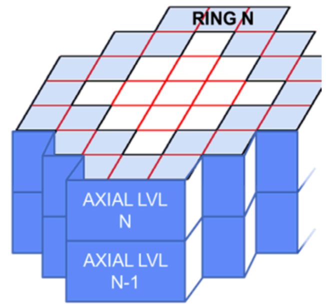
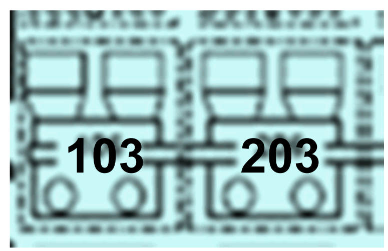
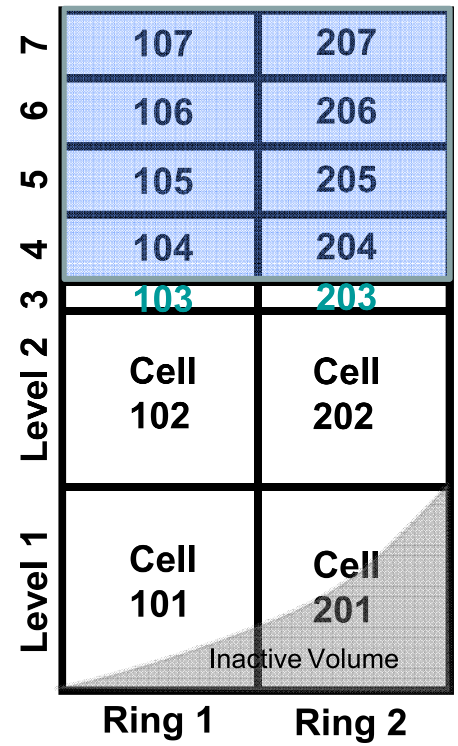
MELCOR Core Modeling
Core Nodalization

- **Core and lower plenum divided axially and radially into cells**
  - **Number and size of cells defined by user input**
  - **Axial *levels* numbered from bottom up**
  - **Radial *rings* numbered from center out**
- **Contents determine function**
  - **Core plate is just another level (3)**
  - **A ring in fueled region represents a group of assemblies**





Core Support Plate & Elephant's Foot



MELCOR Core Modeling
Channel and Bypass

- **Same representation used for PWR and BWR**
  - In a BWR, MELCOR calls the region outside the canisters (channel boxes) in the core region the "bypass"
  - In a PWR, MELCOR calls the region outside the core shroud the "bypass"
  - Everything else is called the "channel"
    - In a BWR, "channel" includes the interior of canisters and the lower plenum
- **Input specifies the CVH volume representing channel and bypass for each core cell**
  - No distinction in the lower plenum
  - Common to interface several cells to a single CVH volume

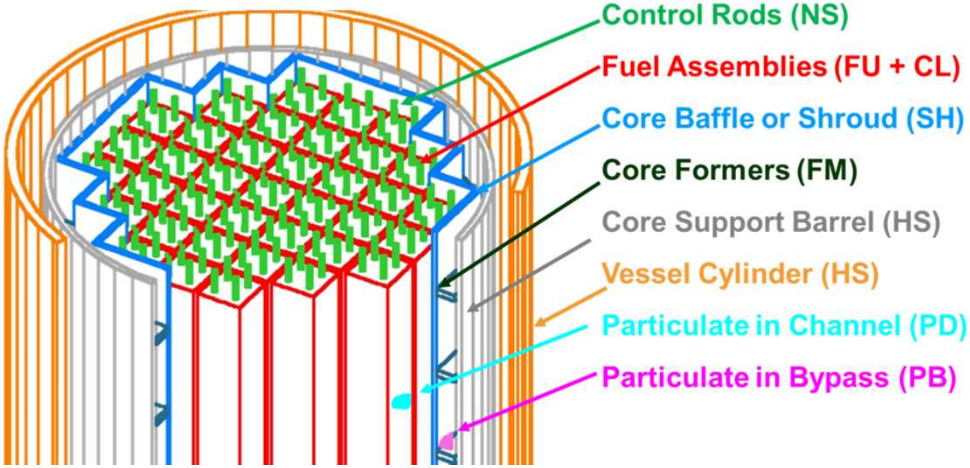
MELCOR Core Modeling
Core Components

- **Each core cell may contain one or more of a set of permitted core components (or none)**

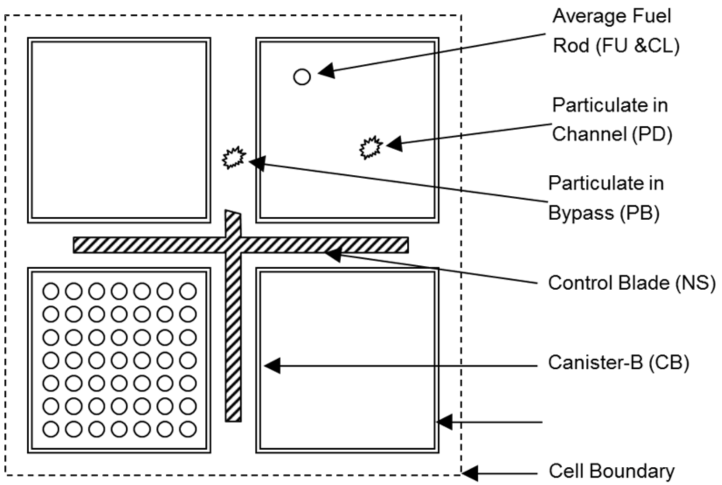
1	FU	intact fuel component
2	CL	intact cladding component
3	CN	intact canister component (portion not adjacent to control blade
4	CB	intact canister component (portion adjacent to control blade)
4	SH	Intact PWR core shroud (baffle)
5	FM	Intact PWR core formers
6	PD	particulate debris component (portion in the channel for a BWR)
7	SS	supporting structure component
8	NS	nonsupporting structure component
9	PB	particulate debris component in the bypass (for a BWR)
10	MP1	Oxide or mixed molten pool component (portion in channel for a BWR)
11	MB1	Oxide or mixed molten pool component in bypass (for a BWR)
12	MP2	Metallic molten pool component (portion in channel (for a BWR)
13	MB2	Metallic molten pool component in bypass (for a BWR)

MELCOR CORE Representation
COR Components

PWR Core



BWR Assembly



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Conglomerate On Components

- Each component has an intact mass field
  - User typically defines intact masses only (before onset of core degradation)
  - User also defines surface areas of intact components
  - Intact material has never melted (though it may have resulted from failure of intact component, i.e., intact particulate debris)
- Each component has a conglomerate mass field
  - Material has melted but may have refrozen on surfaces
    - Can be molten in molten pool component
  - Can fill interstitials in particulate debris
  - Different Composition
    - Can have materials that are not available in the intact field
  - Intact and conglomerate mass in thermal equilibrium (same temperature)
  - Affects surface area exposed to fluid convection, oxidation, radiation, and further refreezing
  - Affects thermal conductivity of particulate debris

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Special Components Created During Core Degradation

Particulate Debris (PD, PB)

- Formed when an intact component fails or when molten pool freezes
- Has both intact & conglomerate fields
  - Unique composition but same temperature
- “Intact” mass
  - Porosity assumed from user input & conglomerate mass
  - Has never melted
- Conglomerate mass
  - Fills interstitials first
    - Affects effective thermal conductivity, heat surfaces for oxidation and radiation, and fluid flow
  - Excess assumed above

Molten Pool (MP1, MP2, MB1, MB2)

- Formed when other components melt
  - molten material blocked during candling
  - Melting PD
- All mass resides in the conglomerate field.
- Freezing MP is moved to the PD component and equilibrated
- Can form contiguous molten pool
  - Special routines for convection and freezing (Stefan model)
- Non-contiguous cells
  - Does not participate in convecting molten pool calculation (more later)
  - Heat transfer similar to PD

MELCOR Core Modeling
Input for Cell Contents

- **User input defines the components initially present in each core cell**
  - **Masses of materials in each component**
    - **Can contain one or more of a list of 7 materials defined in the material properties package**
      - **Restricted list for most components**
      - **PD, MP, and conglomerate can contain any of them,**
      - **User can redefine materials**
  - **Initial temperature of each component**
  - **Surface areas of components**
    - **Except debris and molten pool which are Internally calculated from surface/volume ratio**
  - **Hydraulic diameters**
  - **PD porosity**

COR name	MP name
UO2	'URANIUM DIOXIDE'
ZR	'ZIRCALOY'
ZRO2	'ZIRCONIUM DIOXIDE'
SS	'STAINLESS STEEL'
SSOX	'STAINLESS STEEL OXIDE'
CRP (control rod poison)	'BORON CARBIDE' for BWR *or* 'SILVER INDIUM CADMIUM' for PWR
INC (Inconel)	'STAINLESS STEEL'

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Heat Transfer
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

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

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

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

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

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

Heat Transfer
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

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

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

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

Heat Transfer
Convection

- **Heat transfer rates calculated for each component using heat transfer coefficients**
  - **Uses Local cell temperature predicted from dT/dz model**

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

- **Partially implicit solution**
- **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**

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Oxidation Models - General

- **Objects that can oxidize**
  - COR components
    - Metals include Zr, SS, and B4C
  - Debris in CAV package
- **Objects that cannot oxidize**
  - Heat structures
- **Oxidation behavior for COR components**
  - Oxidation of Zircaloy and steel by water vapor and/or O_2
  - Oxidation of boron carbide (B_4C) in BWRs
  - Heat generation by oxidation
  - Release of hydrogen (and other gases) to CVH package

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Oxidation Reactions

- **Specific models for each oxidizing material**
- **Reaction Kinetics**
- **Zircaloy**
  - **Reactions**
  - **Kinetics**
- **Steel**
  - **Reactions**
  - **Kinetics**
- **Boron Carbide**
  - **Reactions**

Solid-state diffusion of oxygen through an oxide layer to unoxidized metal is represented by the parabolic rate equation:

$$\frac{d\,(W^2)}{dt} = K(T)$$

This is integrated over a timestep:

$$(W^{n+1})^2 = (W^n)^2 + K(T^n)\,\Delta t$$

Urbanic Heidrich evaluation of rate constant, K

For very low oxidant concentrations, gaseous diffusion may limit the reaction rate.

$$\frac{dW}{dt} = \frac{MW\;k_c\;P_{ox}}{n\;R\;T_f}$$

The gaseous diffusion oxidation rate is used if it is less than the rate calculated from the parabolic rate equation.

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Oxidation
Additional Considerations

- Refrozen conglomerate (candled) material blocks intact surface (including PD) from oxidation
- Surface areas must be defined consistently with component mass since they are used in calculating thickness.
- Two-sided components residing in channel with a surface in contact with bypass can oxidize
  – Volume expansion accommodated through borrowing virtual volume from bypass
- Zirconium emissivity is calculated as a function of oxide thickness
- Oxidation calculated for submerged surfaces
  – Gas film between unquenched surfaces and pool
  – Currently suppressed by default because of uncertainty in quenching?
- Debris surface area is partitioned between Zr, SS, and other materials
  – Surface area for Zr oxidation from volume fraction of Zr + ZrO_2
    - Modeled as layers with ZrO_2 outer layer
  – Surface area for SS oxidation from volume fraction of SS + SSOX
    - Modeled as layers with SSOX outer layer

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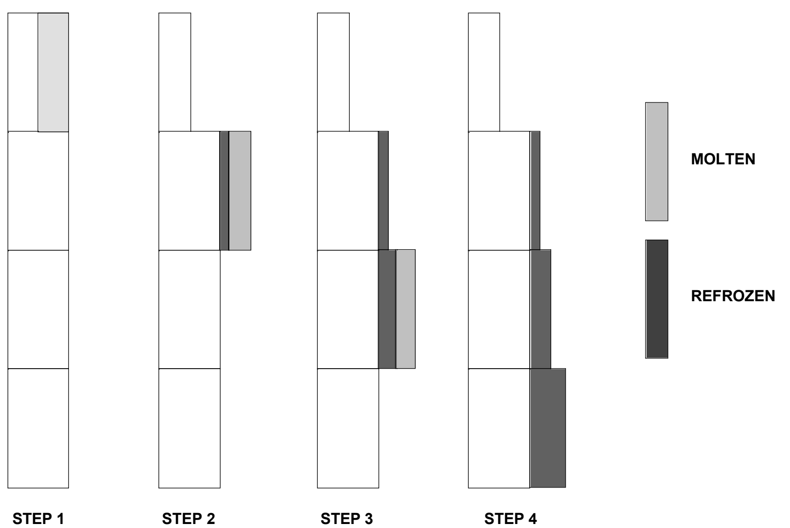
COR Degradation Models

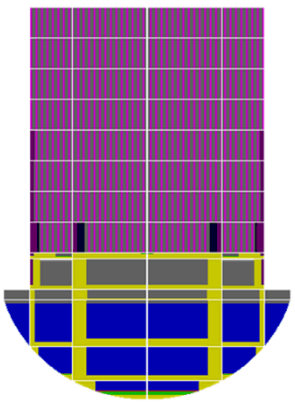
- **Ballooning Model**
  - There is no comprehensive model for clad ballooning in the code though MELCOR provides limited capabilities for simulating the effects.
    - Gap release model
      - Gap release at user temperature (1173 K default)
- **Candling**
  - Thermal-hydraulic based
    - (does not account for viscosity or surface tension)
    - Does not have a separate field (temperature)
  - Simple holdup model for melt inside an oxide shell
  - Formation of blockages from refrozen material
- **Formation of Particulate debris**
  - Failure temperature / component thickness / CF / support structures
  - Clad optional time at temperature modeling (best practice)
  - Downward relocation of (axial and radial) by gravitational settling
    - not modeled mechanistically but through a logical sequence of processes through consideration of volume, porosity, and support constraints.
    - Time constants associated with leveling
    - Fall velocity that limits axial debris relocation rates
  - Support structure modeling for COR components leads to failure of supported intact components when support structure is lost
- **Molten Pool Modeling**
  - Forms when downward candling molten material reaches a blockage and still has superheat
    - Settling similar to particulate debris but particulate debris displaces molten pool
    - Time constants associated with leveling
    - Fall velocity that limits axial debris relocation rates

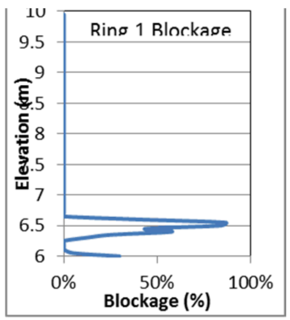
Downward Relocation of Molten Material

- Candling - Downward flow of molten core materials
  - Subsequent refreezing (creation of ‘conglomerate’)
  - Blockage (creation of molten pool)
  - Solid material transport of secondary materials
    - Thin oxide shells or dissolution of UO2 by molten Zr
- Semi-mechanistic
  - Based on fundamental heat transfer principles
  - Assumptions
    - Steady generation and flow of molten material
      - Does not solve a momentum equation for velocity
      - All material generated in a time step reaches its final destination in that step
        - » There is no separate field for conglomerate and must equilibrate with a component
      - relatively independent of time step history
    - Molten material is held up behind oxide shell or retained behind blockage.
      - For breakaway melt, assumption of steady generation no longer valid
    - Freezes on originating component or alternate component



Sub-Grid Model Prediction of Blockages





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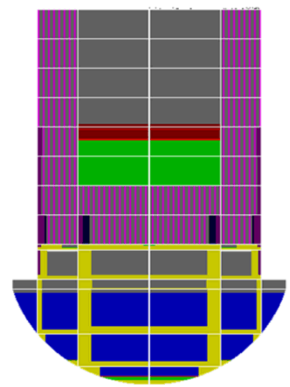
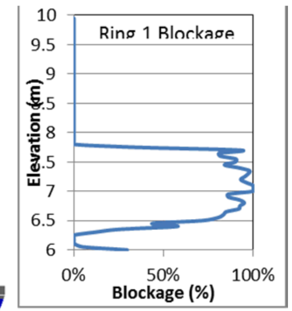
Candling of low melting point metals to lower fuel rods





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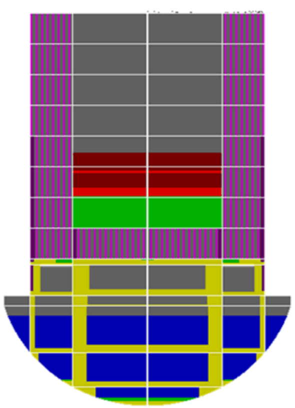
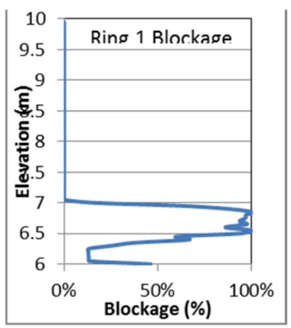
Formation of PD and conglomerate filling interstitials





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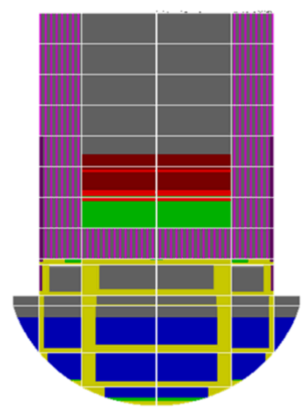
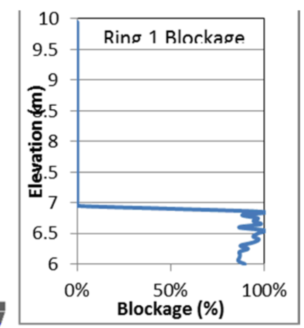
PD slumping and maintaining blockages





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Melting of PD ‘crust’ and freezing on lower fuel rods

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MELCOR Core Modeling
Supporting Structures

- **Supporting structure can support itself, other components (including particulate debris)**
  - **Load and stress calculations depend on basic model from engineering handbook equations**
  - **Failure by creep rupture, yielding, or buckling**
  - **Failure by melting**
- **In a BWR, two support structures are of particular interest**
  - 'PLATEB' models the core support plate
    - Supports itself and debris but not assemblies
    - Does not fail when support plate in neighboring rings fail
    - Remains in place after failing but melts
  - 'COLUMN' models the CRGTs
    - Supports the assemblies and canisters
    - Failure in any cell leads to failure of all contiguous COLUMN elements higher
- Other support structures available

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Mechanical Failure of Components (Formation of Particulate Debris)

- Particulate debris
  - channel and bypass
  - Debris Behavior
  - Debris Porosity and Surface Area
  - Debris Exclusion :
- Formation from failed fuel rods:
  - Failure of oxidized rods
  - Failure of unoxidized fuel rods
    - Inert environment or candling of all ZrO2
    - Metal thickness < DRCLMN
  - Or failure by control function
    - Possible failure based on a cumulative damage function)
- From Failure of BWR fuel canisters (channel box)
  - Metal thickness < DRCLMN or
  - Temperature > canister oxide melt point
  - Or failure by control function

◆ **Channel and Bypass**

— Debris from failed NS modeling BWR control blade becomes particulate in bypass (PB)

— So does failed SS in a cell with a separate bypass

— All others become particulate in the "channel" (PD)

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Gravitational Settling of PD and MP components

- Gravitational Settling occurs at constant velocity (VFALL) for both particulate debris and molten pool
  - PD displaces MP
- Each ring is calculated separately, starting at the center (radial spreading occurs later)
  - Calculation proceeds from the bottom up
    - Determine how far source mass can move in time step
      - Limited by available space and support
    - Moves mass from source to that level and above
    - Moves up to next source cell
  - Distinction between channel and bypass
    - PD stays in channel & PB stays in bypass
  - Relocation to elevation where channel box has failed,
    - PD & PB are mixed
  - Relocation from an elevation where channel box has failed to one where it hasn't
    - PD & PB split based on available cross-sectional area

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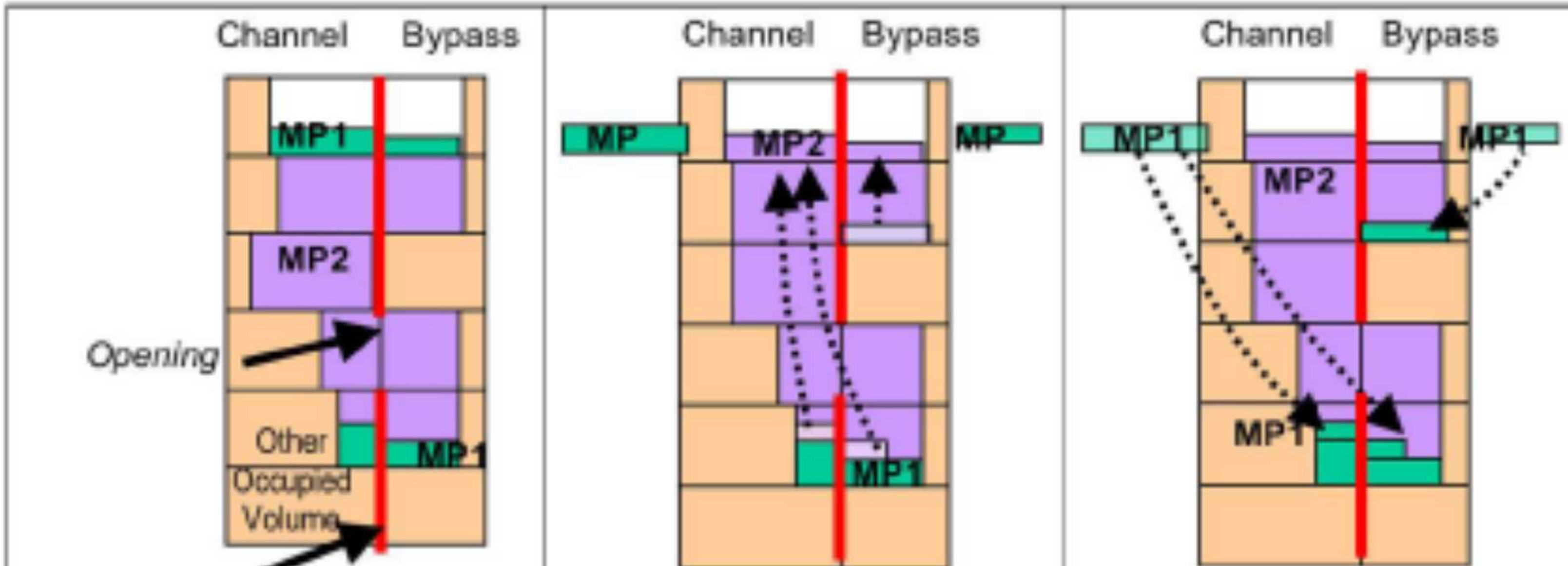
Displacement of Molten Pool by PD during Gravitational Settling



Split between channel & bypass determined by flow areas

Overall: Configuration at start of the time step	Step 1: Movement of MP2 upward into vacated MP1 volume	Step 2: Movement of MP1 downward into vacated MP2 volume

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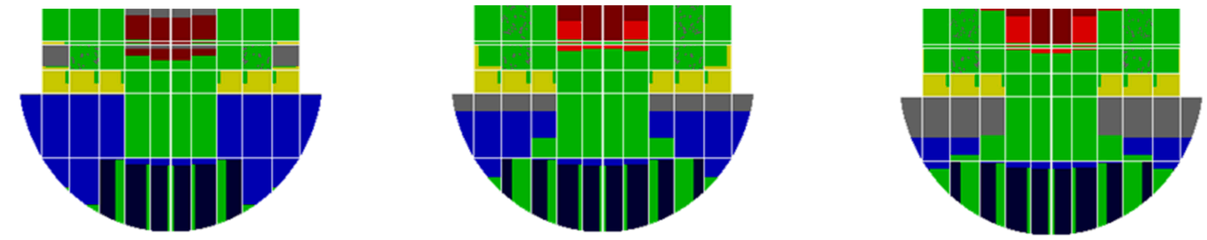
Radial Spreading of Debris & Molten Pool

- **Radial Spread is through gravitational settling**
  - Applies to both particulate debris and molten pools
    - Equalizing debris heights and pool heights for neighboring rings
    - Time constant for spread
      - Molten pool & PD have separate time constants
    - Displacement during radial spread
      - Particulate debris can displace molten pool
      - Oxide molten pool displaces metallic molten pool
    - Must take into account the volume vs elevation relation for cells adjacent to lower head



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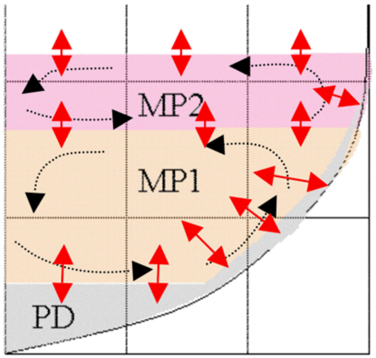
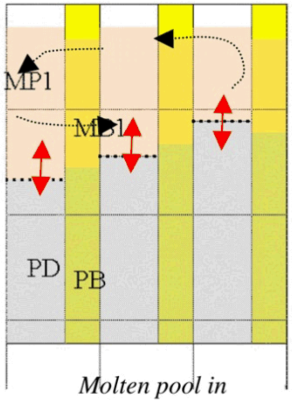
MELCOR Core Phenomenon
Stratified Molten Pool Model

- **Treat molten pools, both in core and lower head**
  - Can contain oxidic and metallic materials
  - May be immiscible, and separate by density
  - Same approach in core and lower head
    - Requires distinguishing pool in channel from that in bypass
- **Stratified melt pool - Additional material relocation models**
  - Downward and radial flow of molten pools
  - Sinking of particulate debris in molten pool
    - Particulate displaces pool
  - Stratification of molten pools by density
    - Denser pool displace less dense
      - Currently oxide pool is assumed denser
  - Partitioning of fission products between metallic and oxidic phases
    - Can affect heat generation and natural convection in core molten debris.



Molten pools in lower plenum



Molten pool in upper core

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Molten Pool Convective Heat Transfer

Energy Balance on MP1:

$$MC_{P,MP1}\frac{T^{n}_{MP1}-T^{o}_{MP1}}{\Delta t} = \dot{Q}_{MP1,decay}$$

$$-\sum_{s\in seg} h_{MP1\to s}A_s\left(T^{n}_{MP1}-T_s\right) - h_{MP1\to MP2}A_{1,2}\left(T^{n}_{MP1}-T^{n}_{MP2}\right)$$

$$-\left\langle h_{MP1-fluid}\,A_f\left(T_{MP1}-T_{fluid}\right) - \sigma\varepsilon_{eff}A_{up}\left(T^{4}_{MP1}-T^{4}_{ambient}\right)\right\rangle$$

Energy Balance on MP2:

$$MC_{P,MP2}\frac{dT^{n}_{MP2}}{\Delta t} = \dot{Q}_{MP2,decay}$$

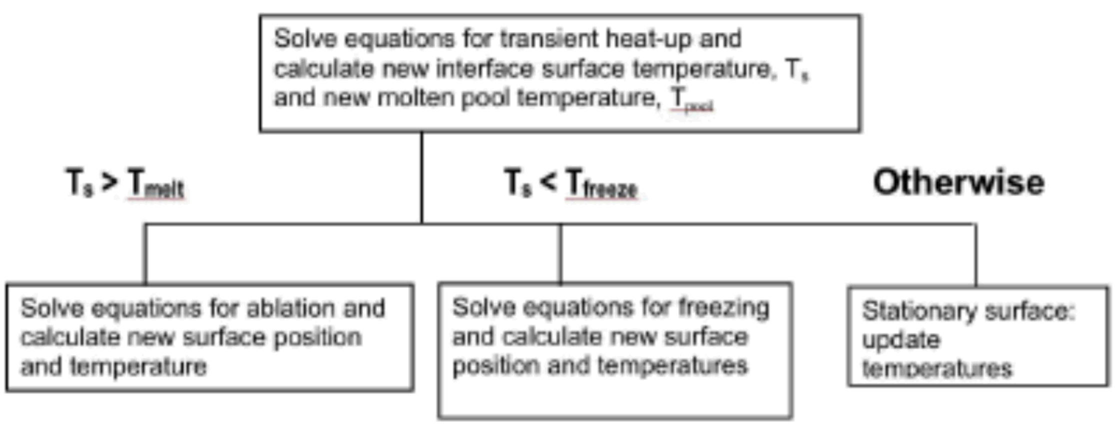
$$-\sum_{s\in seg} h_{MPs\to s}A_s\left(T^{n}_{MP2}-T_s\right) + h_{MP1\to MP2}A_{1,2}\left(T^{n}_{MP1}-T^{n}_{MP2}\right)$$

$$-h_{MP2-fluid}\,A_f\left(T^{n}_{MP2}-T_{fluid}\right) - \sigma\varepsilon_{eff}A_{up}\left(T^{4}_{MP2}-T^{4}_{ambient}\right)$$

- Heat Transfer coefficients from empirical Rayleigh coefficients obtained for steady state conditions correlating Ra number with internal heat generation rate
- Correlations adapted to transient conditions based on the average of the decay heat and the boundary heat losses

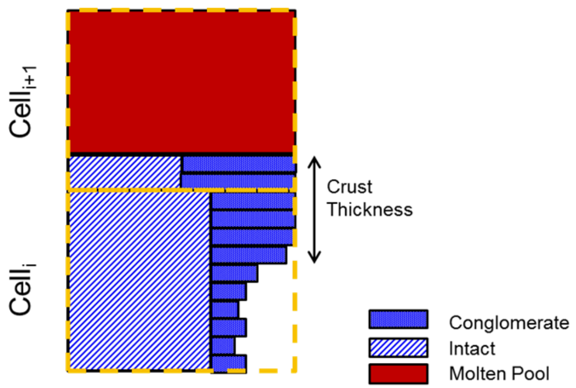
Integral Solution to Stefan Problem

- **Convective molten pool supported by solid substrate**
  - May be PD, lower head, or core support plate
  - Thermal properties vary greatly between phases
  - Temperature gradient in substrate may be highly nonlinear within the dimension of a COR cell
  - Position of the interface may move (Stefan Problem)
- **Integral model for transient calculation**
  - Does not require many nodes
  - Assumes a shape for the temperature profile (quadratic) in the substrate
  - Integration of the conduction equations over the spatial domain
  - Impose convective boundary condition at interface



MELCOR Crust

- **There is no separate component to model crust**
  - Crust is represented as PD component
  - No distinct temperature for crust
  - Crust thickness is inferred from sub-grid model
- **Blockage associated with 'crust' obstructs downward relocation of molten pool**
- **Radial Crust**
  - Crust calculated for cells adjacent to lower head
    - intact PD is always available to spreading routine
    - Fraction of conglomerate associated with crust is frozen to lower head
  - No radial crust modeled for molten pool in upper core
    - Time constant for radial spreading of molten pool component into fuel rod region is 10 times longer than elsewhere



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MELCOR Modeling Experience in Reflood Conditions

Interface of COR Package with Other Packages

- CVH Package
  - Materials in COR can relocate, displacing CVH Volume
    - Changes in displaced volume are tracked separately by CVH and COR
    - Initial COR/CVH fluid volumes defined independently
    - MELCOR checks for consistency
  - Core components “see” local temperature CVH temperature
    - Several COR cells can be associated with a single CVH volume
    - MELCOR’s predictor, dT/dz model
      - Uses inlet temperature, assumes steady gas flow, accounts for cross-flow
- FL Package
  - Blockages in COR can obstruct flow (next slide)
- HS Package
  - MELCOR allows addition of debris from melting steel heat structures.
    - Melting steel is added as particulate debris in the outer radial ring at the appropriate elevation
  - Heat structures“see” local temperature inferred by dT/dz model
    - Calculation includes effects of radial boundary heat structures in the outer ring of the core

MELCOR Core Phenomenon
Core Fluid Flow Blockage Modeling

- **Destruction of original structures, formation of debris will alter flow resistances in core**
  - Debris bed resistance different from rod bundle resistance
    - Ergun equation is used for debris bed
      - New core blockage enhancement factor (multiplier on porosity for resistance calculation)
      - As a core cell becomes completely filled, flow resistance will approach infinity
    - Initial (intact) resistance used until then
      - Small area correction for possible conglomerate debris or changes in clad expansion from oxidation
  - Failure of BWR canisters or PWR shroud opens path between channel and bypass volumes
- **Model connects open area and resistance in a flow path to state of core in specified cells**
  - Flow can be axial or radial
  - For BWR, can restrict to channel or bypass region only
    - Can open path on failure of BWR channel box

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MELCOR Lower Plenum Processes

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MELCOR Core Phenomenon
Falling Debris Quench Model, Sequence of Events

- **Core Support Failure**
  - Debris falls into lower plenum
  - Falls with user defined velocity, VFALL
  - Candling, spreading, and dissolution deactivated
- **Debris reaches pool**
  - Surface area inferred from DHYPD
  - Constant heat transfer coefficient (HTC) from input
- **Leading edge of debris reaches lower head**
  - Decay factor applied to HTC
    - Spreading time constant
    - Significant continued relocation delays decay
  - Candling, spreading, and dissolution activated
- **Stationary Debris bed**
  - Decay factor < 0.01
  - Limited by dryout (Lipinski zero- dimensional model)
    - Currently disabled in best practices

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Lower Head Failure Criteria

- **Creep-rupture failure of a lower head ring occurs**

$$t_R = 10^{\left(\frac{P_{LM}}{T} - C\right)}$$

$$P_{LM} = \min\left[a_1 \log_{10}(\sigma_e) + b_1, a_2 \log_{10}(\sigma_e) + b_2\right]$$

Temperature dependent failure

- – **Failure Temperature, TPFAIL, set on COR_LHF card**

- **Overpressure from the falling-debris quench model**
  - – **Default failure criterion is 20 MPa**
    - **Redefine on record COR_LP, but not greater than P_{crit}**
  - – **Temperature of inner node exceeds defined failure, TFAIL**
    - **Input on record COR_LHF (default 1273.15 K)**
    - **Penetration failure**

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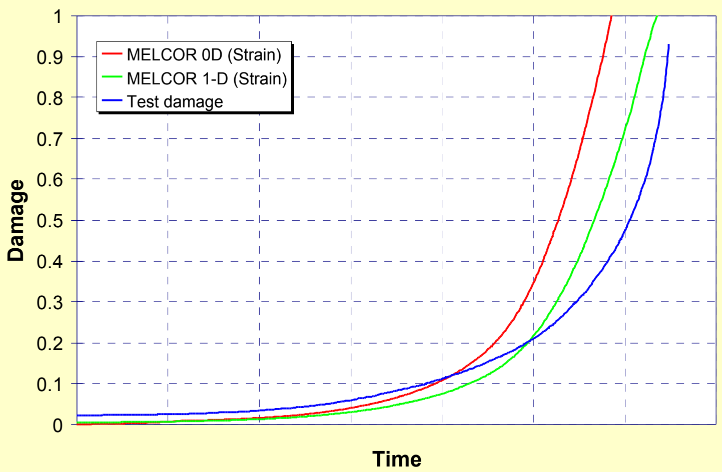
MELCOR Lower Head Failure Models

- **Failure based on Robinson's Rule, i.e., lifetime rule from Larson-Miller parameter**
- **Two models are available in MELCOR:**
  - **Zero-Dimensional Model**
    - **Default Model**
  - **One-Dimensional Model**
    - **Selected by setting sensitivity coefficient SC1600(1) = 1**
    - **Recommended Model**
  - **Part of thickness can be non-load-bearing (e.g., insulation)**
    - **NINSLH (from record COR00000) outer meshes, with default 0, will be excluded from the calculation**



Assessment of models with LHF and OLHF test results

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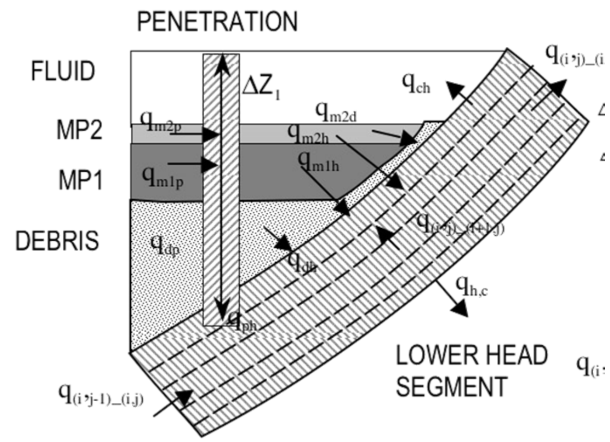
MELCOR Core Modeling
Modeling of Lower Head Penetrations (2)

- **Each "penetration" represents the aggregate of all like penetrations in a single segment**
  - **Can have up to three distinct types in a single segment**
    - **Allows for instrumentation tubes, control rod guide tubes, and drain plugs**
  - **Can have a maximum of 19 distinct penetrations**
- **Failure defined by failure temperature or LOGICAL control function**
  - **Initial hole size, discharge coefficient for debris defined**
    - **Discharge rate calculated from Bernoulli equation**
  - **Ejection of debris may be delayed, During debris ejection, ablation increases hole size (Pilch and Tarbell)**
    - **Ablated material is *not* added to debris**



Curved Lower Head

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MELCOR Core Modeling
Vessel Failure Consequences (2)

- **Failure of penetration or lower head provides path for debris to reach cavity**
  - Threshold imposed to avoid problems in CAV package
  - No ejection until 5000 kg debris in lowest core cell (or molten material fills more than 10% of its volume)
- **Ejected debris is "handed off" to Transfer Process (TP) package**
  - Input must specify number of appropriate transfer process

```
! COR_TP defines transfer process to receive debris
!        NTPCOR is name of 'IN' transfer process or NO
COR_TP   NTPCOR
```

  - NTPCOR=0 is allowed, even though it is not an acceptable transfer process number
    - Calculation will be terminated if ejection is predicted
    - MELGEN will issue a warning to this effect