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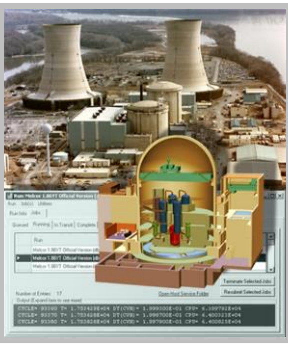

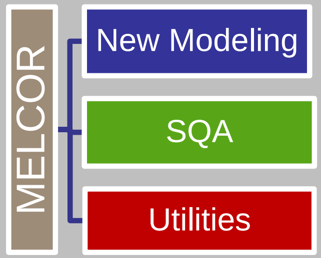

Workshop Introduction
2017 MELCOR OJP

Presented by Larry Humphries

llhumph@sandia.gov

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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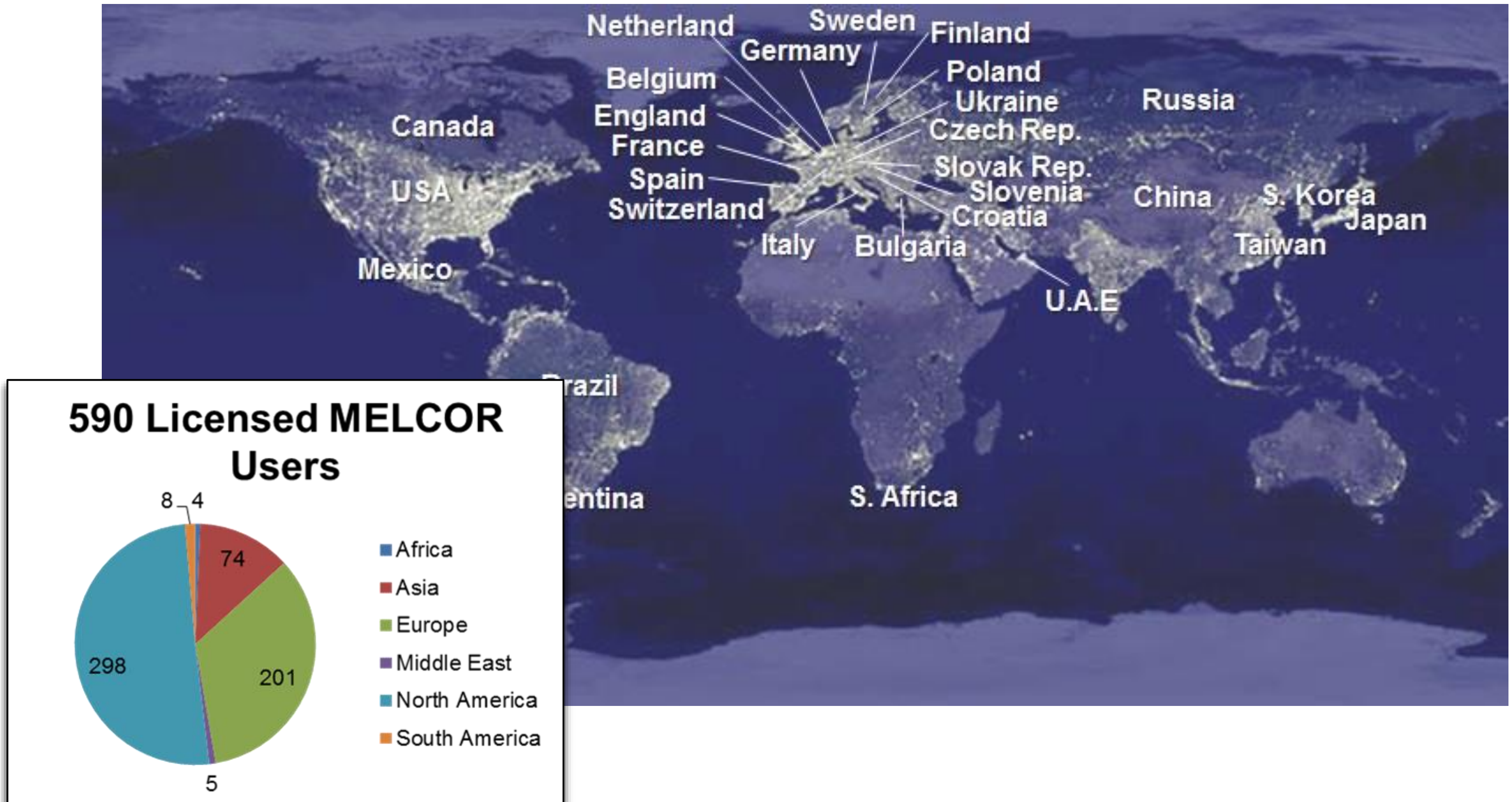
International Use of MELCOR



Upcoming MELCOR Workshops & Meetings

- 2016 European MELCOR User Group (EMUG)
  - Hosted by Imperial College London & AMEC
  - April 6-7, 2016

Monday

Session	Time
Workshop Introduction	8:30 am
MELCOR Overview	9:00 am
Break	10:30 am
Getting Started with MELCOR	11:00 am
Lunch	12:30 pm
Introduction to SNAP	1:30 pm
Break	3:00 pm
Other MELCOR I/O Tools	3:30 pm
Adjourn	5:30 pm

Tuesday

Session	Time
CVH/FL	8:30 am
Break	10:30 am
Data & Control	11:00 am
Lunch	12:30 pm
Containment Models	1:30 pm
Break	3:30 pm
Heat Structures	4:00 pm
Adjourn	5:30 pm

Wednesday

Session	Time
Heat Structures	8:30 am
Vapor & Aerosols	9:30 am
Break	10:30 am
Vapor & Aerosols	11:00 am
Lunch	12:00 pm
COR Package Modeling	1:00 pm
CAV/RN Package	4:00 pm
Adjourn	5:30 pm

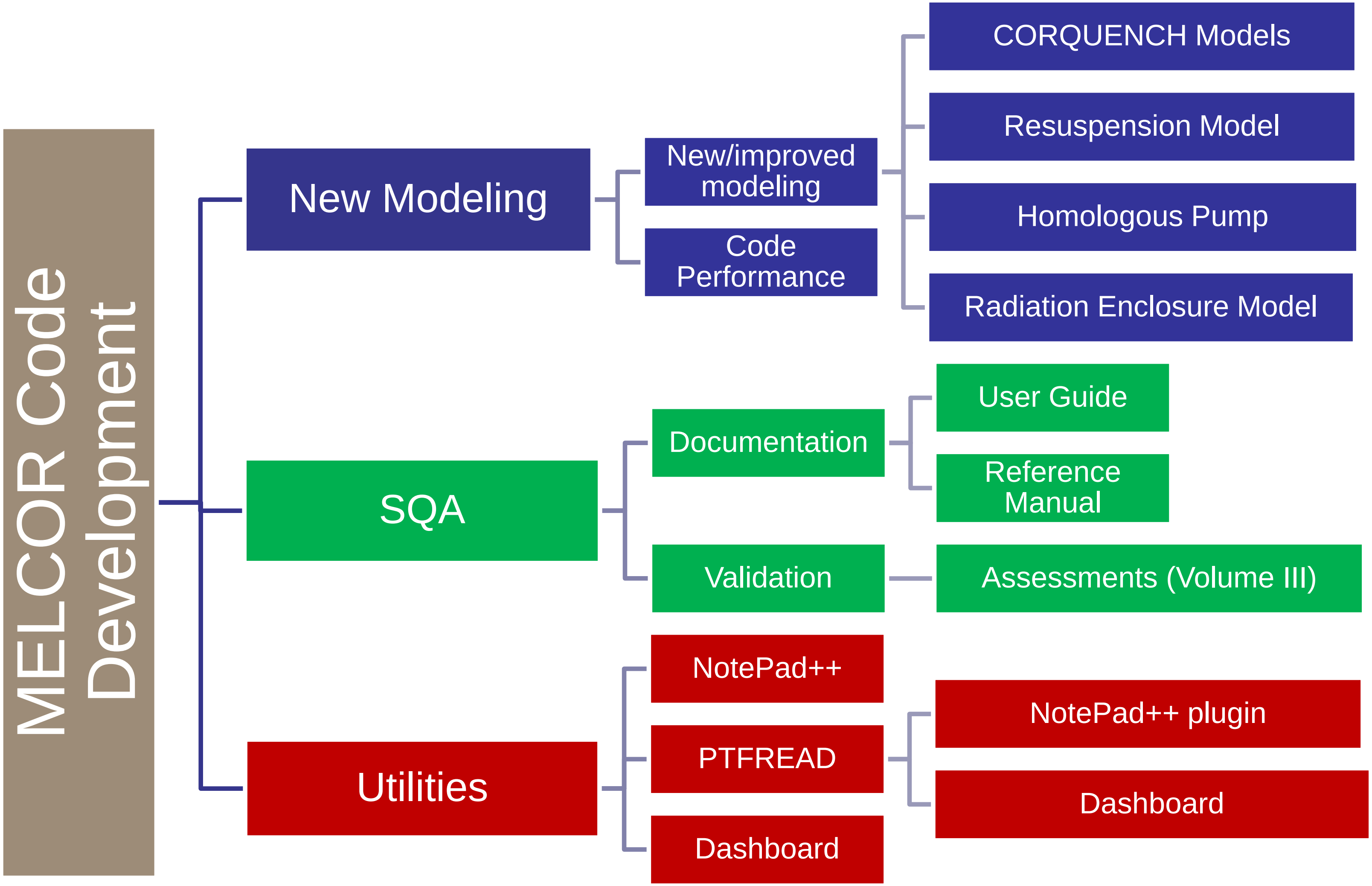
Thursday

Session	Time
Decay Heat Package	8:30 am
Break	10:15 am
Turbulent Deposition Modeling	10:30 am
Lunch	12:00 pm
SRV Modeling and Failure	1:00 pm
Spent Fuel Pool Analysis	2:00 pm
Break	3:30 pm
MELCOR Validation	4:00 pm
Adjourn	5:30 pm

Friday

Session	Time
TI SG Tube Failure	8:30 am
Natural Circulation in Primary	9:30 am
Break	10:30 am
Modeling Filters and Using MACCS Flow Paths	10:45 am
Adjourn	12:00 pm

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

Session 2 - MELCOR Overview

Prepared by
MELCOR Development Team

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Objective of Presentation

- Introduce MELCOR simulation code
  - What is it, and what it does
  - General view of phenomena modeled
- Show top level organization of MELCOR
  - MELGEN and MELCOR executables
  - Organization of modeling as "Packages"
    - Phenomena modeled in various packages
    - Interfaces between packages
    - Illustrate the utility of the Control Function Package in interfacing with MELCOR
- For complete information, see documentation
  - Reference Manuals describe models and algorithms
  - Users' Guides describe user interface

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MELCOR History

- **NRC sponsored simulation code for analysis of accidents in nuclear power plants**
  - **Conceived (in early 1980s) as a PRA (Probabilistic Risk Assessment) Code for LWRs (Light Water Reactors)**
    - **Primary objective: include consistent modeling of "all" relevant phenomena, including coupling of effects**
  - **Application has expanded over the years**
    - **Other accidents, including DBA (Design Basis Accident) and containment response**
    - **Other reactor types, including heavy water reactors and HTGRs (High Temperature Gas Reactors)**
  - **Also used for various non-reactor analyses**
    - **General thermohydraulics model**
    - **Tracking transport of vapors or aerosol**
      - **Come back to this when discuss Radionulide models**

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Phenomena Modeled by MELCOR

- Goal of modeling "all" relevant phenomena is quite ambitious
- Main phenomena modeled include
  - Two-phase hydrodynamics, from RCS (Reactor Coolant System) to environment
  - Heat conduction in solid structures
  - Reactor core heatup and degradation
  - Ex-vessel behavior of core debris
  - Fission product release and transport
  - Aerosol and vapor physics
- Others will be mentioned in presentation
- There is no detailed neutronics model
  - Fission power history can be user-specified
  - Point kinetics model available

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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.

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MELGEN and MELCOR

- **“MELCOR” is actually two executables that perform different parts of the simulation**
- **MELGEN is run first**
  - —Its basic task is to set up the desired calculation
    - ✶ Problem definition, initial and boundary conditions
  - —Has no time-advancement capability
- **MELCOR is run next**
  - —Its basic task is to advance the simulation in time
  - —Reads complete problem description from a file
  - —Has limited ability to modify that description before starting the time advancement
- **Two codes share many subroutines**
  - —I/O, properties, etc.

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MELGEN

- MELGEN execution
  - Basic task is to set up the desired calculation
  - Input focuses on problem definition
    - Reads description of system to be simulated as provided through user input, including:
      - Nodalization to be used
      - Initial and boundary conditions
      - Modeling options
    - Checks input for completeness and consistency
    - Issues diagnostic warnings and/or error messages when appropriate
  - If (and *only* if) input contains no errors
    - Initializes all time-dependent data
    - Writes full text edit with model and state description
    - Writes restart file dump with complete database

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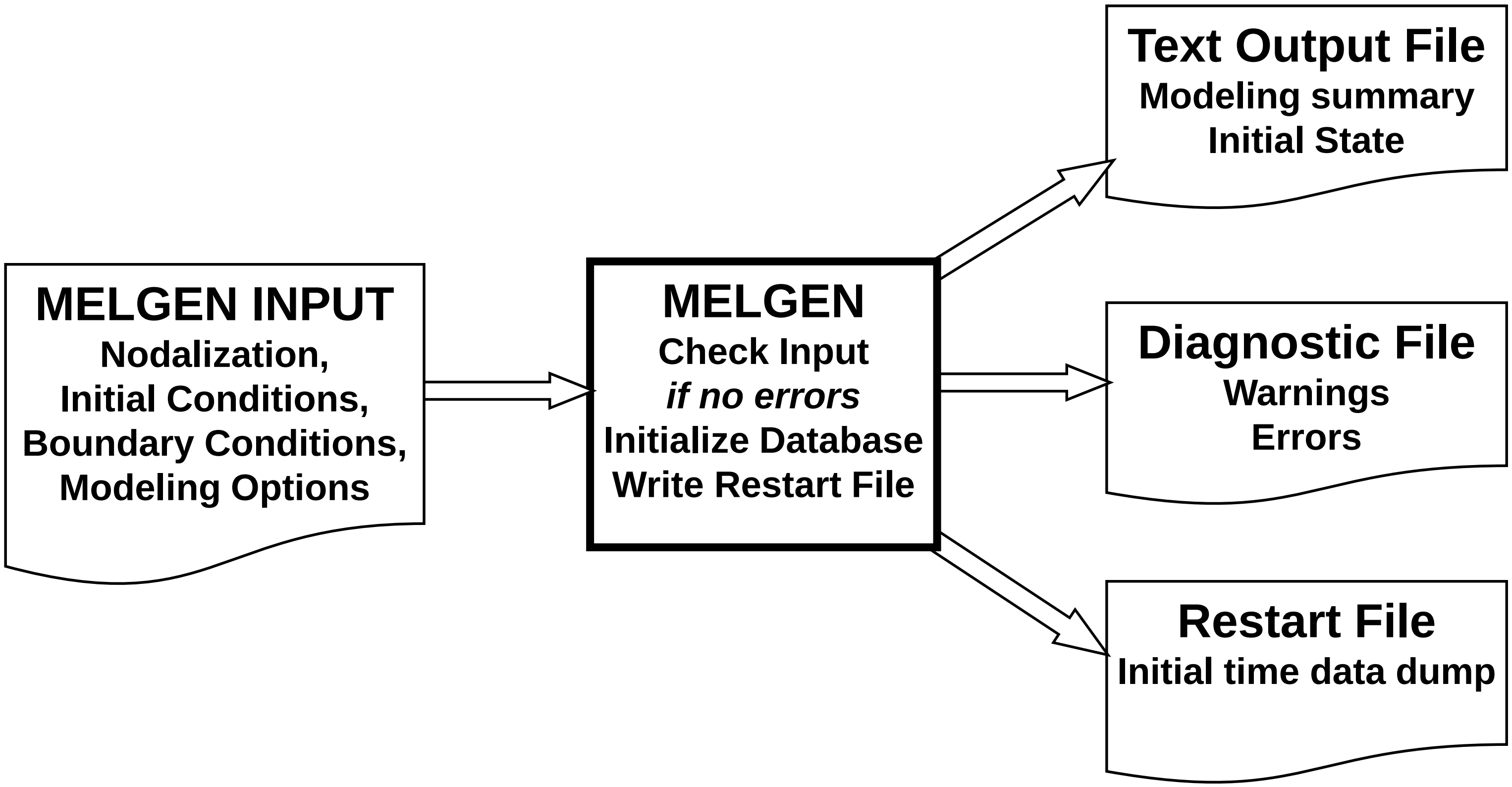
MELGEN Files and Information Flow



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MELCOR

- **MELCOR execution**
  - Basic task is to advance simulation in time
  - Always run in “restart” mode
    - Reads time-independent and initial time-dependent data from a restart file “dump”
      - May be more than one, corresponding to different simulation times
        - First was written by MELGEN
        - Can have later ones written by previous MELCOR execution(s)
    - Advances time-dependent data through time
  - Input focuses on control of advancement
    - Start time, end time, time steps, output frequency
    - Limited capability to modify problem description
      - Useful for sensitivity studies, treatment of branches in event trees
    - Writes text edits, restart, and plot files as requested
      - Any point in the restart file can be used as the initial state for a subsequent MELCOR execution

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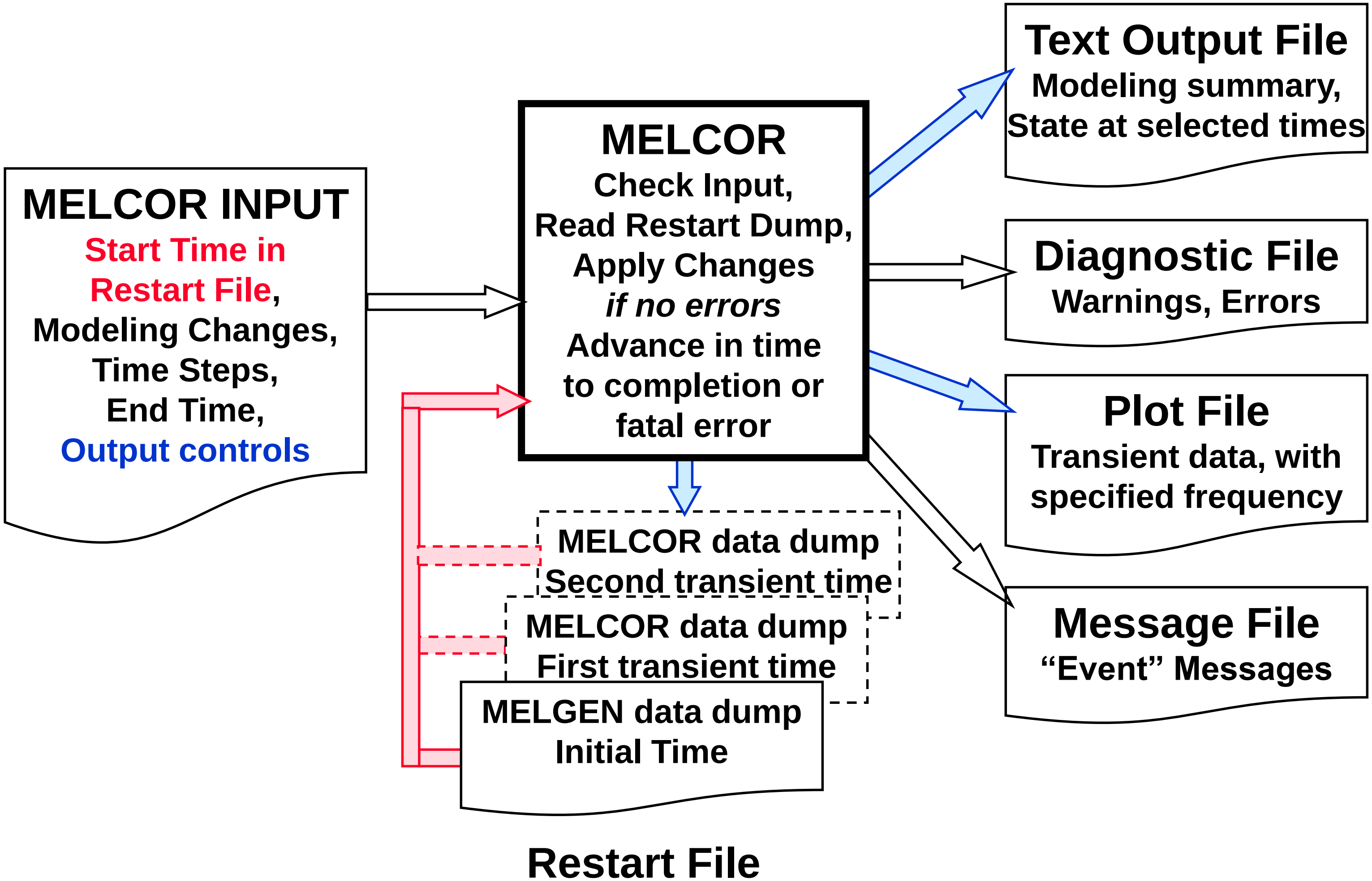
MELCOR Files and Information Flow



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MELCOR Packages

- Major pieces of MELCOR called "Packages"
  - Each handles a set of closely-related modeling functions
  - Do *not* correspond to ancestral codes
- Three general types of packages in MELCOR
  - Basic physical phenomena
    - Hydrodynamics, heat and mass transfer to structures, gas combustion, aerosol and vapor physics, etc.
  - Reactor-specific phenomena
    - Core degradation, ex-vessel phenomena, sprays and other ESFs (Engineered Safety Features)
  - Support data and functions for general use
    - Thermodynamic equations of state, other material properties, decay heat generation data
    - Data-handling utilities, equation solvers

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MELCOR Code Structure

- Code structure reflects basic phenomena more than reactor design
  - Same general control-volume/flow-path hydrodynamics used in reactor cooling system and containment
  - There is NO single package that deals with the vessel and all its contents or with a steam generator
- Time advancement for each package is largely independent
  - Reduces need for simultaneous solutions of many equations
    - Solution strategy for each can be appropriately chosen
  - Possible through carefully designed package interfaces
    - Restricted information exchange between packages
    - Use of partially-implicit “predictor/corrector-like” methods to deal with stiffness of equations

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MELCOR Top-Level Control (1)

- Executive level coordinates other modules
  - Manages input, output, time step definition, etc.
    - Each package has its own i/o routines, called in turn
    - Time step chosen subject to various constraints
      - Executive input defines maximum and minimum timesteps
      - Any package can request a limit on timestep for next advancement
      - Executive considers all requests and reconciles with bounds
        - Calculation will be terminated if no acceptable timestep
  - Controls time advancement of each package's data, in turn
    - Package coupling numerically explicit
      - Each package uses start-of-step data from other packages (with a very few exceptions, where end-of-step data are used)
      - Pass changes (e.g. heat and mass transfers) to other packages
      - Order of advancement chosen to facilitate this

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MELCOR Top-Level Control (2)

- Executive deals with advancement problems
  - Any package can force a "fallback"
    - Problems in advancement of package itself
      - Convergence problem or other failure of solution algorithm
      - Change in properties too large (excesive rate of change)
    - Problems with end-of-step data from *another* package
      - Change too large (e.g. advection far overshoots ignition limit for combustion)
    - Requests repeat of advancement attempt with a reduced timestep
  - Executive provides graceful termination with final text edit and restart dump if advancement fails
    - Timestep less than minimum
    - Error in any package where reduced step wouldn't help
    - "Logic Error", meaning occurrence of a situation that the code developer considered impossible

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More about MELCOR Packages

- **Packages conventionally referred to by 2- or 3-letter names, mnemonic of functions, e.g.**
  - CVH (Control Volume Hydrodynamics) and FL (FLow path) treat the control volume and flow path portions of the hydrodynamic modeling
  - EOS (Equations of State) provides thermodynamic state equations
  - HS (Heat Structures) treats conduction in, heat and mass transfer to/from structures such as walls, floors, pipes
  - COR (CORe) treats reactor core response and degradation phenomena
  - DCH (DeCay Heat) generates decay power history
  - MP (Material Properties) provides various properties
  - TF (Tabular Function) is a general table utility
- **In general, no duplication of function**
  - No in-line materials properties; (should) use MP package
  - All input data tables (should be) processed and stored by TF package

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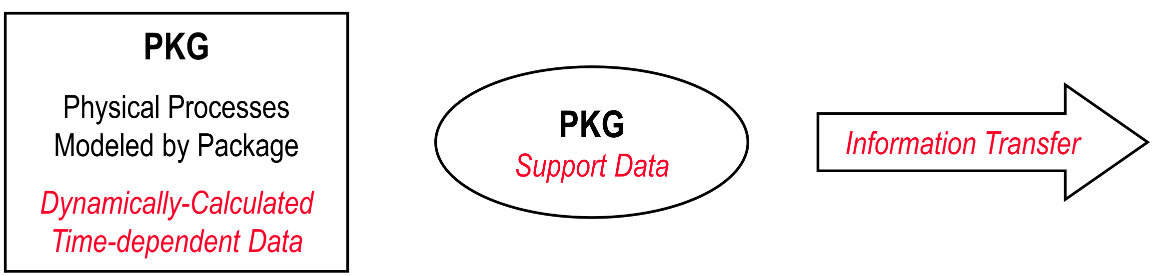
Basic Thermal Hydraulic Packages

- **Next several slides describe modeling in a few of the major packages in MELCOR**
  - **Ignore Radionuclide package and details of possible relocation of decay heat sources for now**
- **Will be followed by a data flow chart showing:**
  - **Dynamic data associated with each package**
  - **Information flow to/from other packages**
  - **Rectangles for packages that model physical phenomena,**
  - **Ovals for packages that provide support data**
  - **Arrows for information transfer between packages**



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Phenomena Modeled by MELCOR, Packages Involved (1)

- Hydrodynamics involves several packages
  - CVH and FL packages treat control volume and flow path aspects (inventories and advective transport, respectively)
  - EOS package provides Equations Of State (for closure)
  - Interfaces to almost everything else in MELCOR
    - Provides boundary conditions to other packages
    - "Sees" most other packages only as sources and sinks of mass, energy, and volume available to fluids
      - Zircaloy oxidation in core is a sink of H_2O with source of H_2 and/or sink of O_2
      - Movement of core debris changes volume available to fluids in CVH
    - Changes in core geometry can change flow resistance
      - Not default, requires optional user input to relate nodalizations
  - Most other packages are advanced first, with sources accumulated for inclusion in Hydro solution
    - Will show order later

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Phenomena Modeled by MELCOR, Packages Involved (2)

- **Heat Structures, HS Package**
  - Treats heat transfer to and within non-core structures
    - Walls, floors, ceilings, pipes, etc.
    - Ice condensers
    - Most of reactor vessel, PWR core support barrel, BWR core shroud, upper internals in PWR and BWR
  - Also treats mass transfer and water films on surfaces
    - Condensation and evaporation, drainage to other structure surfaces and/or volume pools
  - Some structures can decompose or melt
    - Degassing of concrete walls and floors, melting of ice in ice condensers, steel in some reactor internals
  - Gets boundary conditions from, transfers mass and energy to/from CVH
  - Receives energy from COR, can transfer mass to COR

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Phenomena Modeled by MELCOR, Packages Involved (3)

- Core Response, COR Package
  - Calculates heatup, degradation, oxidation, relocation of materials in core structures
    - Fuel, BWR canisters, PWR shroud and formers
    - Control elements
    - Supporting structures like plates and columns
  - Handles debris until it leaves the vessel
    - "Passed off" to FDI or CAV (described later)
  - Also calculates response of vessel lower head
  - Gets boundary conditions from CVH
  - Displaces fluid in, transfers mass and energy to/from CVH
  - BWR core baffle, PWR core support barrel, all upper internals are modeled as heat structures
    - Radiates to these heat structures
    - Receives mass from them if they melt (optional)

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A Few Important Support Packages

- Equations of State, EOS Package
  - Implements a mixed-material equation of state for hydrodynamic materials (water and gases)
    - Water properties from H2O package
    - NonCondensible Gas properties from NCG Package
  - H2O and NCG properties are also available separately
- Materials Properties, MP Package
  - Provides thermal EOS for non-hydrodynamic materials
  - Provides thermophysical properties for all materials
    - Thermal conductivity, viscosity, diffusivity, etc
    - Mixture rules used where appropriate
- Decay Heat, DCH Package
  - Can provide whole-core decay heat and/or distribution of that heat among fission products (discuss later)

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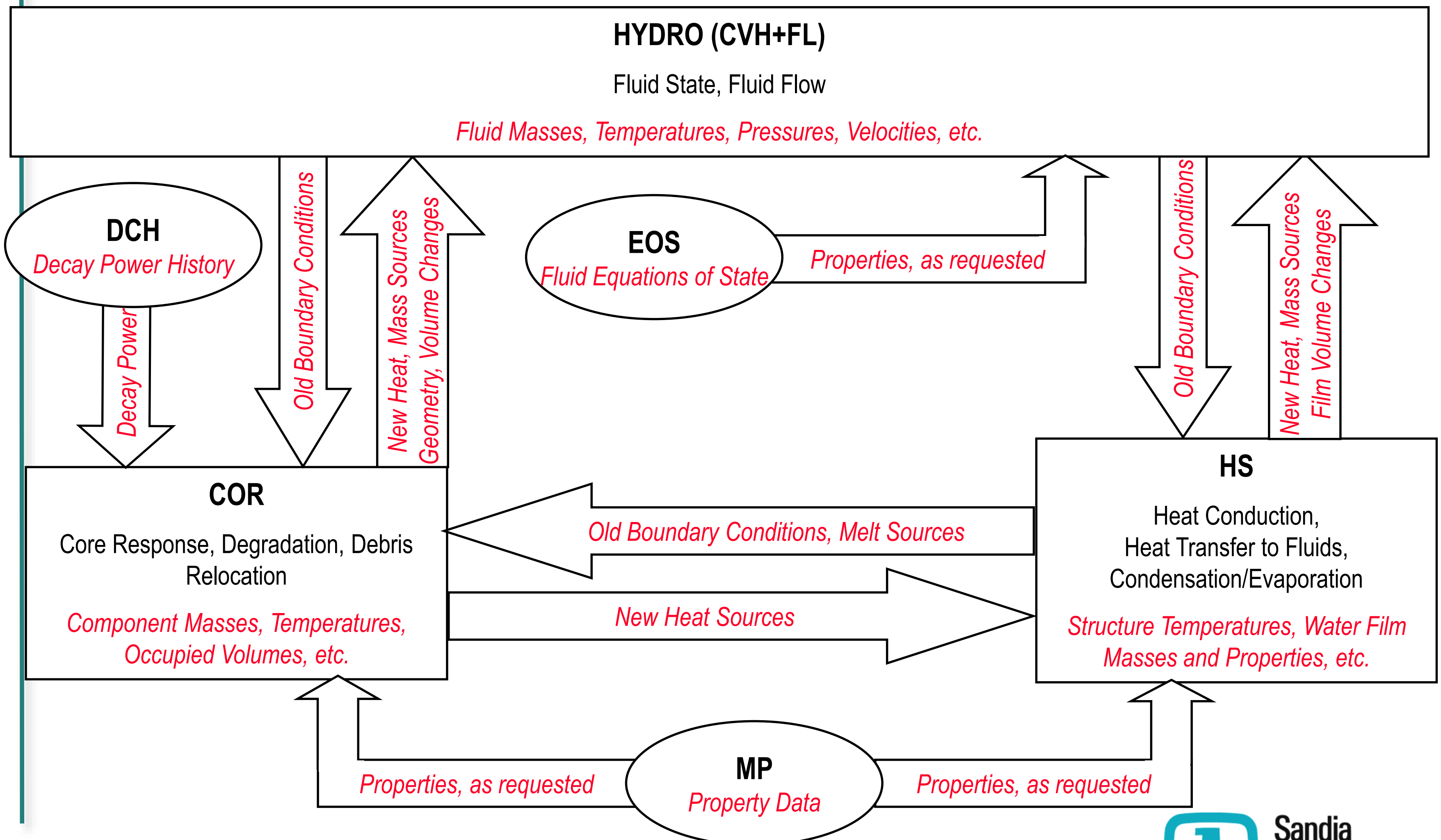
Data and Data Flow for CVH, FL, HS, COR



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Phenomena Closely Tied to Hydro (1)

- **BUR handles combustion (BURn) of H_2, CO**
  - Permitted in any volume
  - Deflagration only (no detonations)
  - Includes modeling of igniters
- **Various containment models, some grouped as ESFs (Engineered Safety Features)**
  - SPR models containment SPRays
  - PAR models Passive Autocatalytic Recombiners
  - FCL models Fan CooLers
  - CND models an Isolation CoNDenser System (ICS) and/or Passive Containment Cooling System (PCCS)

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Phenomena Closely Tied to Hydro (2)

- Modeling in BUR, SPR, PAR, FCL, and CND
  - All get boundary conditions from CVH
    - Pressure, temperature, saturation state, concentrations of noncondensible gases, etc.
  - All have relatively simple internal modeling, appropriate to phenomena treated
  - All transfer mass and/or energy to/from CVH
    - Chemical reactions "look like" sink of reactants, source of products to CVH
      - Equations of state for hydro fluids have thermochemical reference points, like JANAF tables
        - Heats of reaction implicit in reference points

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Example, PAR (1)

- **Simple model**
  - —Combustion rate proportional to hydrogen through-flow through empirical efficiency
  - —Steady-state total volumetric flow related to hydrogen concentration by empirical correlation
  - —Actual flow relaxes towards steady flow with empirical time constant
- **Only dynamic variable is total volumetric flow through recombiner unit**
  - —New value easily calculated from old value, current hydrogen concentration, and time constant
- **Given total flow, calculate**
  - —Hydrogen flow from atmosphere composition
  - —Reaction rate, H_2 and O_2 sinks, H_2O source from efficiency

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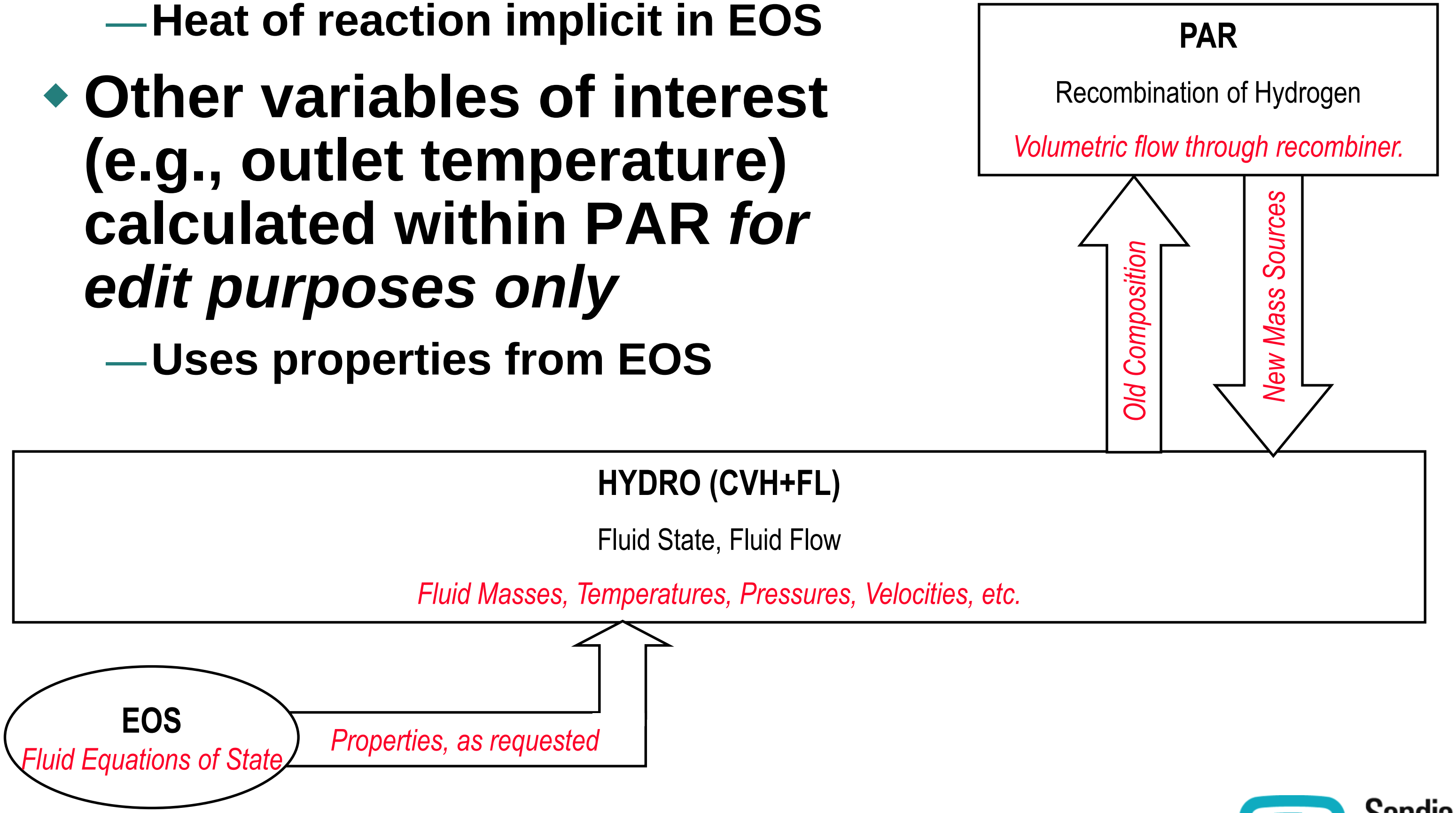
Example, PAR (2)

- **Only mass sources to CVH**
  - **Heat of reaction implicit in EOS**
- **Other variables of interest (e.g., outlet temperature) calculated within PAR *for edit purposes only***
  - **Uses properties from EOS**



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Ex-Vessel Debris Phenomena (1)

- If reactor vessel fails, debris can be ejected
  - Ends up on floor
  - Can interact with gases and/or water pools on the way
- CAV (CAVity) Package models behavior of "core on the floor"
  - Essentially CORCON Mod 3
    - Concrete ablation
      - Release of interstitial and hydrated water
      - Decomposition of hydroxides and carbonates
      - Addition of oxides to debris
    - Oxidation of metal in debris by released H_2O and CO_2
  - Mass sources, heat transfer to CVH fluids
    - Heat transfer from debris surface
    - Reduced gases, primarily H_2 and CO

Ex-Vessel Debris Phenomena (2)

- FDI (Fuel Dispersion Interactions) Package models interactions between vessel and floor
  - Use is optional, depends on user input
  - Low pressure melt ejection (LPME) option
    - Debris falls under gravity
    - Break up of debris in water pool
    - Heat transfer to water pool in CVH
  - High pressure melt ejection (HPME) option
    - More violent expulsion of debris
    - Heat transfer to CVH fluids
    - Oxidation of debris
    - Deposition of some debris on structure surfaces

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Ex-Vessel Debris Phenomena (3)

- TP (Transfer Process) Package handles bookkeeping for transfers between packages
  - Just a clean interface used for flexibility
    - ✶ "Insulates" each package from unneeded details
      - Whether transfer is COR → CAV or COR → FDI → CAV
      - Structure of database in the various packages
    - ✶ Motivated by code developer concerns
      - Greatly simplifies code structure
      - Need for user input sometimes seen as an annoyance
  - Provides temporary storage for information about parcels of debris leaving COR or FDI (or any other) package
    - ✶ Stored in standard format
    - ✶ Source doesn't need to know where they are going
  - Allows these parcels to be picked up by FDI or CAV (…)
    - ✶ Recipient doesn't need to know where they came from

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MELCOR Radionuclide Modeling (1)

- Need for consistent modeling of radionuclides a major reason for development of MELCOR
  - Radionuclides present in fission products in reactor fuel
    - They are source of decay heat that drives accidents
      - Heat sources move debris when intact core structure is lost
    - They can be released from fuel and/or debris
      - Can be widely transported as vapors or aerosols after release
      - Decay heat sources move with them
        - Can appear in Hydro fluids, on filters or on HS surfaces
      - Release from reactor cooling system has serious consequences
- Basic assumptions
  - Materials are “traces”
    - Mass, volume, and heat capacity are negligible
    - Hosted in or on other materials or structures

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MELCOR Radionuclide Modeling (2)

- RN is divided into two parts
  - RN1 models mainly within-volume processes, calculated before hydrodynamic advancement
    - Releases, interactions, …
  - RN2 models mainly between-volume processes, calculated during or after hydrodynamic advancement
    - Advection with fluids, removal by filters
- RN in MELCOR can also be used for tracking "trace" materials in non-reactor situations
  - Transport of radiological releases, toxins, and biohazards in buildings, building complexes
  - "Leak-path factor analysis" (Google it)
  - Wikipedia: "[MELCOR] is sometimes, though incorrectly, said to be an acronym of Methods for Estimation of Leakages and Consequences of Releases"

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Radionuclide *Class* Concept

- **There are too many distinct radionuclides to track each separately**
  - **Grouped as *Classes***
    - **A typical class contains all isotopes of one or more elements considered to be "similar enough" physically and chemically that they can be treated alike:**
      - **Noble gases (Xe, Kr), Alkali Metals (Cs, Rb), Alkaline Earths (Ba, Sr), etc.**
      - **Often referred to by name of characteristic element (Xe, Cs, Ba, …)**
    - **Can also have composite classes like CsI, Cs_2MoO_4**
    - **Additional classes represent inert materials that interact with these**
      - **Boron from control poison**
      - **Oxides from molten core/concrete interactions (MCCI)**
      - **Water**

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Unreleased RN Inventories, Release Rates

- RN package follows unreleased inventories associated with COR and CAV packages
  - Classes associated with fission products reside in fuel and/or debris
    - Release rate is function of temperature, etc.
    - Various empirical correlations in COR
    - VANESA model for ex-vessel debris
  - During normal operation of LWR, some fission products accumulate in fuel/cladding gap
    - User defined inventory, released when cladding fails
- RN transfers released masses to fluids
  - Can define initial inventories in fluids
  - Can also define tabular (and other) sources

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Post-Release RN Inventories

- **Defined by location**
  - CVH pools, CVH atmospheres
  - HS surfaces
- **Defined by total and radioactive mass**
  - Some phenomena depend on total mass
    - Include any non-radioactive sources that can dilute fission products
    - Includes OH is CsOH and O_4 in Cs_2MoO_4
  - Decay heat can be associated with radioactive mass through DCH (DeCay Heat) package
- **Defined by vapor vs. aerosol state**
  - Aerosols have a size distribution
    - Several classes typically combined into a single aerosol *component* in calculating that distribution

Post-Release RN Modeling

- Agglomeration, deposition of aerosols on surfaces
  - MAEROS model
- Condensation/evaporation of vapors to/from walls and aerosols
  - TRAP-MELT model
- Chemisorption on HS surfaces
- Advection between volumes with Hydro flows
- Washing from HS surfaces by film drainage

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RN and DCH

- MELCOR *tries* to distinguish RN and DCH in code structure and user interface
  - RN provides general modeling of trace vapors, aerosols
    - Handles actual inventories, wherever they may be
  - DCH provides information on associated decay heat
    - Specific decay heat (W/kg) associated with classes
- Packages still entangled
  - Both use “class” structure, which must be consistent
  - Total radioactive inventories in RN should be consistent with actual core
    - From generic “typical” PWR or BWR or specific ORIGEN calculation
- Changes from MELCOR 1.8.6 to 2.1 to clarify
  - Not entirely successful

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Water Aerosols

- **Water aerosols are "special"**
  - Water vapor, water in volume pools, water in films on structure surfaces is not part of RN inventory
  - Water aerosols (droplets in the atmosphere, "fog") interact with other aerosols and deposit on surfaces
    - Must be treated by RN, reconciled with water elsewhere
    - Two options
      - Original, non-hygroscopic model
        - Water aerosol is "pure", with same properties as other water
        - CVH "owns" liquid water in atmosphere, included in Hydro
        - RN simply infers size distribution, calculates deposition
      - Hygroscopic model
        - Water aerosol has modified vapor pressure
        - RN "owns" liquid water in atmosphere, not included in Hydro
        - RN calculates condensation/evaporation, deposition
        - Source/sink of vapor, deposition on pool, structure surfaces

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Order of Advancement

- Advance packages that evaluate sources or relocations before those that use them
  - DCH: First to update time-dependent decay heat data
  - COR: Before CVH and HS that will receive heat/mass
  - LHC: After COR which may receive debris, before CVH
  - SPR: Before CVH that will receive heat/mass
  - BUR: Before CVH that will receive mass changes
  - FDI: After COR to receive debris, before CAV and CVH
  - CAV: After COR and FDI to receive debris, before CVH
  - ESF: Before CVH
  - RN1: After COR and CAV to receive releases
  - HS: After COR to receive sources, before CVH
  - CVH: After COR, CAV, and HS to receive sources
  - RN2: After CVH to use fluid relocations
  - CF: After all physics packages

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Control Functions, the "Crown Jewel"

- Control Functions, CF Package
  - Heart of MELCOR power and flexibility
  - Comes close to letting user write code as part of input
- Allows user input to define functions of MELCOR-calculated time-dependent variables
  - Values can be REAL or LOGICAL, are part of time-dependent database with all other time-dependent data
    - Calculated from definition using *current* conditions
    - Relatively easy, *very* flexible way to model complex systems
  - Older versions used own "language", difficult to read
  - MELCOR 2.X adds ability to write function as a FORMULA, that looks much like fortran
  - Many (not all) variables are available as arguments
  - Recent version permits vector CFs and CF arguments

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Control Function Use

- Can be used to generate custom output
  - Values can be printed, plotted
  - Change in value of logical can produce event message
- Function values can be used in calculations
  - Input to many packages allows reference to the value of a control function rather using than a fixed constant
    - Sources, sinks, other boundary conditions
      - Allow dependence on current state
        - Drain liquid currently present in volume with correct enthalpy
    - Valves, pipe failures, containment failures
      - Complex control logic
      - Larson-Miller cumulative damage strain model
    - Can provide simple modeling of systems (injection, cooling, etc.) when no internal model provided
      - Define mass/energy sources and sinks with appropriate logic
      - PAR could have been done entirely with CFs

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New Model Development Tasks (2014-2015)

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

New Defaults in M2.2

- **Fuel Rod Collapse Model**
  - MELCOR has long had a time-at-temperature model for determining the collapse of fuel rods but it has not been the default behavior and the time-at-temperature characteristics had to be provided by the user. By default, rods will collapse based on a temperature failure criteria. Such a criteria leads to a threshold effect that leads to numerical variance in calculations since failure of a ring of rods, a catastrophic degradation event, is highly sensitive to the maximum clad temperature that is calculated. Default parameters for the time-at-temperature model are based on work by Denman. The time-at-temperature characteristics are based on experimental observations from the VERCORS experiments together with SOARCA models as derived from Phebus experience.
- **Water Ingression Model**
  - A new water ingression model (see below) was added in revision 7108 and replaces the practice of modifying conductivity conduction multipliers and boiling heat transfer. Now, boiling and conduction multipliers have been reset to 1.0 and the ingression model is exercised. Because of this change, it is important that the user examine any changes to the conductivity/boiling modifiers on the CAV_U record. Often these modifiers were adjusted to capture the effect of water ingression. This is now done by model and these multipliers should be reset by default. If they have been modified, a warning message will be issued if the water ingression model is active.
- **Melt Spreading in Cavity**
  - A new melt spread model for debris in the cavity has been added and is now the default. Previously, debris would immediately spread across the floor unless a control function was provided to specify a user-defined spreading rate.

Denman, et al., "Fukushima Daiichi Unit 1 Uncertainty Analysis – Exploration of Core Melt Progression Uncertain Parameters – Volume II", SAND2015-6612 (2015)

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Getting Started with:

MELGEN/MELCOR
&
EXEC Package

Larry Humphries

Sandia National Laboratories

Objective of Presentation

- Running MELCOR
- Become familiar with the Input File Structure
  - Structure
  - Records
- Become familiar with the Output files available
- Overview of Executive (EXEC) Package
  - Overall execution control of MELGEN and MELCOR
- Simple example and look at some output
  - Without going too deep into Components
  - Launch Pad
- Advance Input File Processing Features

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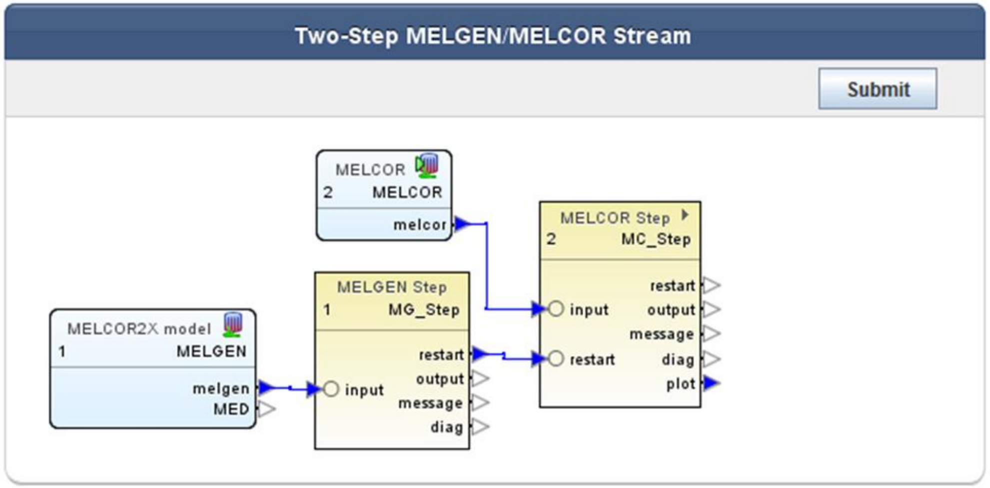
Options for Running MELCOR

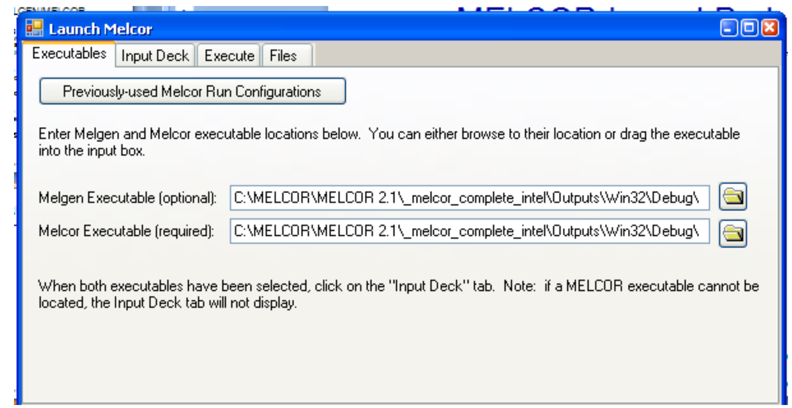
Running MELCOR

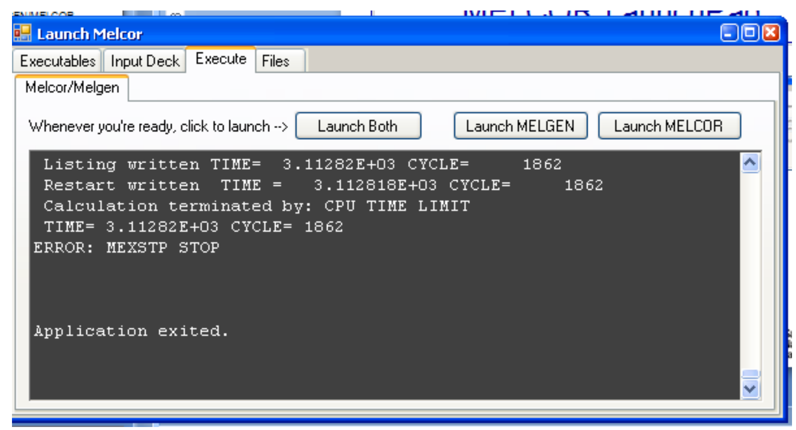
- Double-click executable
  - Copy of executables usually kept with each input file set
  - Often leads to proliferation of executables
- Batch file
  - Requires creation of bat file for each input
  - Can redirect to executable from another path
- Launchpad
  - Simple to run and point to executables and input decks
  - Remembers previously run executables and input decks
  - Complete console output captured to text file.
  - Links to output files
- SNAP
  - Difficult to configure
  - Once set up, easy to rerun
  - Link to output files.
  - Powerful post-processing tools



LAUNCH PAD

- Executables can be selected from multiple methods
  - Directly typed or pasted
  - Navigation through file manager
  - ‘Drag and Drop’
  - Selected from recent history
- Input files can be selected in a similar manner
- Remembers previous executable/input file configurations
- Execution of MELGEN MELCOR
- MELGEN/MELCOR input/output files can be edited from hyperlinks
- Complete console output captured to text file





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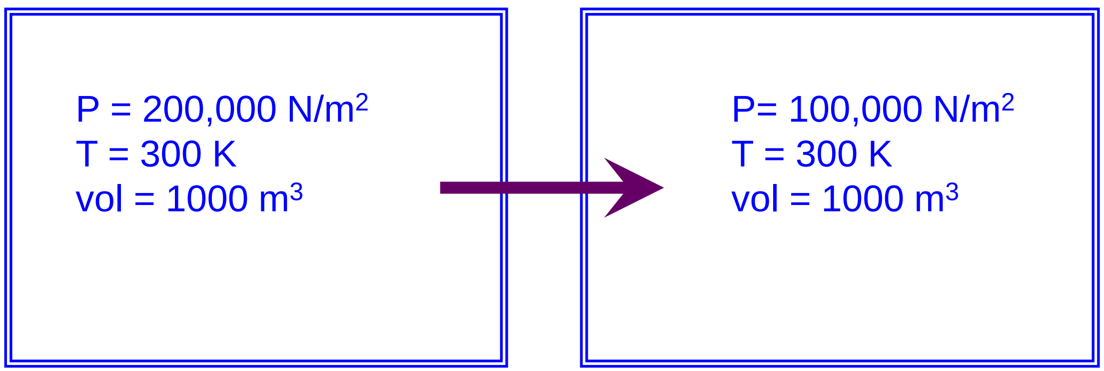
Interactive Control

- MELCOR can be interrupted by certain messages typed at the terminal
  - STATUS! or ! for one-line status message
  - STOP!, QUIT!, END!, or EXIT! to terminate job
  - OFF! to turn off interactive input
  - **HELLO!** For interactive menu
- Commands are case-insensitive
- Any character string not on this list will produce a brief list of recognized commands

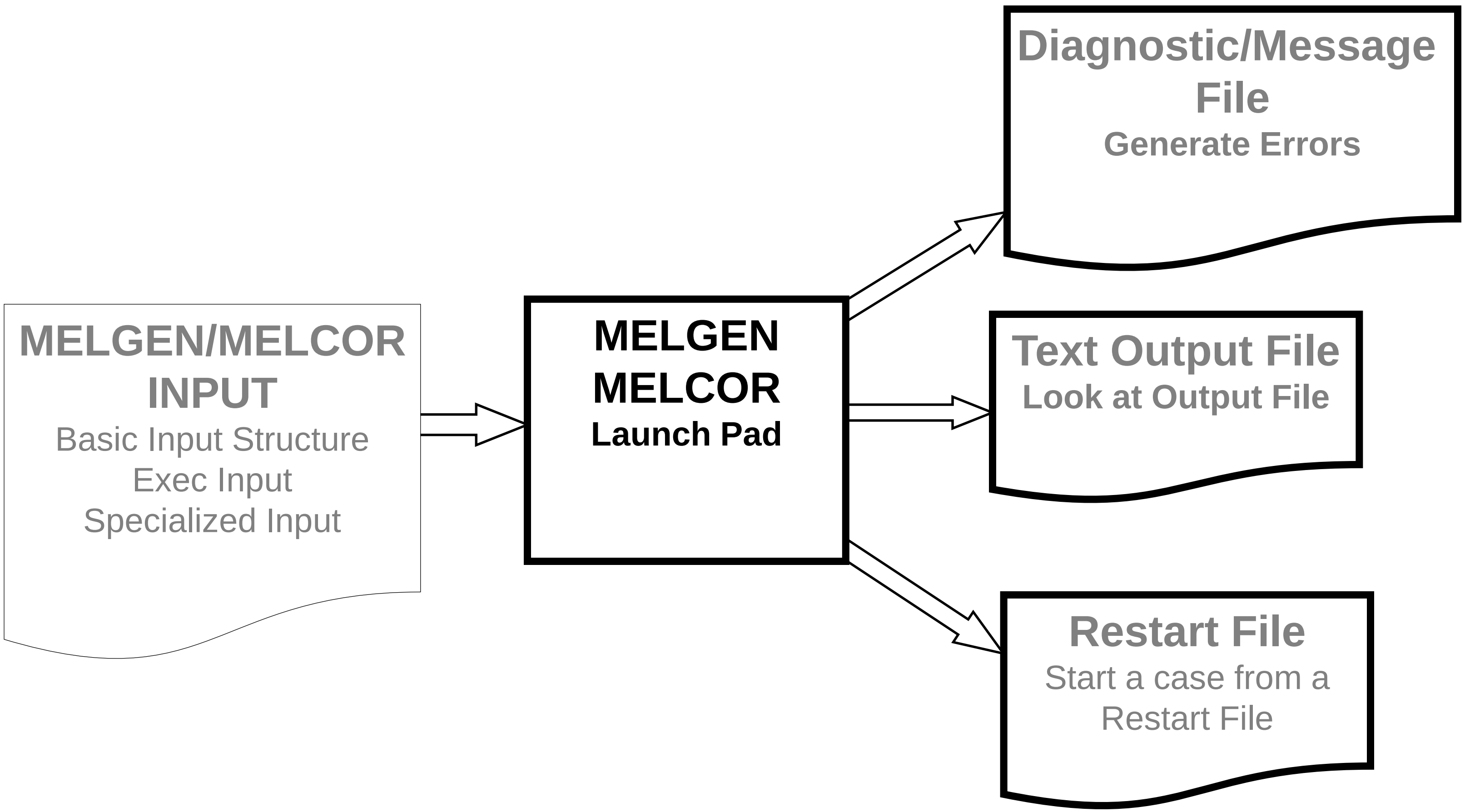
Simple test problem Hydrogen1.inp

- Given two volumes pressurized with Hydrogen
- The pressure in one volume is higher than the pressure in the other volume
- Open the two volumes to each other at time zero



Hydrogen Depressurization

Simple Example



Input Files

- MELGEN (User Input File)
  - Time independent data (e.g., Geometry)
  - Initial conditions (e.g., pressures, temperatures, flows, etc.)
  - Writes initial Restart dump
- MELCOR (User Input File)
  - Time-step, problem duration, frequency of various outputs for post-processing
  - Relies on the Restart File for current conditions.
    - Initial or some intermediary restart file

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Input File Structure (1)

```
! GLOBAL DATA
DEFAULTDIRECTORY   ..\GS_exercise
………..

Program MELGEN
EXEC_INPUT
EXEC_TITLE 'hydrogen'
………..

NCG_INPUT
NCG_ID H2
………..

CVH_INPUT
CV_ID 'high-pressure'
………..
CV_ID 'low-pressure'
………..

FL_INPUT
FL_ID 'high-to-low'
………..
END Program MELGEN

Program MELCOR
EXEC_INPUT
EXEC_TITLE 'hydrogen'
………..
END Program MELCOR
```

object level

package level

program level

- MELGEN/MELCOR each has its own **Program** block
- Data blocks for each package start with the special record **XYZ_INPUT**
- Objects inside each package start with the special record **XYZ_ID**
- Each object **data record** contains an identifier record and free-format fields
  - Fields are to the right of the record identifier
- Order is not important as long as this structure is maintained

Input File Constructs 2.x

Working with Input

```
MEG_OUTPUTFILE  DEMOGn.OUT
MEG_DIAGFILE  DEMOGn.DIA……..
MEL_RESTARTFILE  DEMOn.RST
MEL_OUTPUTFILE   DEMOn.OUT

Program MELGEN
!  This is a comment
CVH_INPUT
CV_ID       'containment'           601
CV_PTD           PVOL 1.0E5
CV_AAD           TATM          300.0
CV_NCG             2            RHUM           0.5
!                  n          namgas          mass
                   1            'N2'           0.8
                   2            'O2'           0.2
FL_INPUT
FL_ID    COR-OUT   115
FL_FT    'UPPER PLENUM _1' 'UPPER PLENUM _2' 10.0  10.0
FL_GEO        7.0    4.0   1.0
FL_JLT       10.0   11.0
FL_USL        6.0    6.0
FL_SEG      1 !n    sarea  slen shyd
            1    7.0    2.0   0.01
…
INCLUDE rpv.gen
(((
!Skip all records within delimeters
)))

END Program MELGEN

Program MELCOR
*          TIME      DTMAX    DTMIN    DTEDT    DTPLT    DTRST
TIME1        0.0       1.0    0.001    1000.0    2.0     200.0
……….
END Program MELCOR
```

- 2 or 3-character Package Identifier
- Object Number is optional though recommended for CV, FL, HS, CF, etc.
- Input files for each program specified before program records with other global data
- INCLUDE record used to read input from other files
- Program record used to distinguish MELGEN and MELCOR input
- Comments start with !
- Comment block specified with ((( )))
- Input ends with “END Program” record

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Input File Constructs 1.8.6

```
*eor* melgen
*
OUTPUTFILE    DEMOGn.OUT
DIAGFILE      DEMOGn.DIA
*
*  This is a comment

CV30000   CONTAINMENT  2    2    7    * NON-EQL, VERTICAL,
*                                     * MISCELLANEOUS TYPES
CV300A1   PVOL 1.0E5   ZPOL -24.0   TATM 300.0   RHUM 0.5
CV300A3   MLFR.4  .8       MLFR.5  .2    * 0.8 N2, 0.2 O2

*                    VOLUMES      JUNCT.ELEV
*                    FM    TO     FM     TO
FL11500  COR-OUT     110   150    10.0   10.0
FL11501   7.0  4.0   1.0                * A, L, FRACT OPEN
FL1150T  10.0 11.8
FL11503  6.0   6.0                      * FORM LOSS
FL115S0   7.0  2.0   0.01               * A, L. HYD.DIAM.
r*i*f rpv.gen
*eor* skip
* Records here are skipped
*eor melgen
. * End of input

*eor* melcor
RESTARTFILE   DEMOn.RST
OUTPUTFILE    DEMOn.OUT
*         TIME      DTMAX    DTMIN    DTEDT    DTPLT    DTRST
TIME1        0.0      1.0    0.001    1000.0    2.0     200.0
………..
. * End of input
```

- 2 or 3-character Package Identifier
- Object Number embedded in record identifier (RID)
  - Unique RID for each object
  - No need for block header records
  - Records can be ordered randomly
- Input files for each program specified anywhere among program records
- R*I*F record used to read input from other files
- *eor* record used to distinguish MELGEN and MELCOR input
- Comments start with *
- Comment block specified with *eor* skip … *eor* melgen
- Input ends with a ".".

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Input – Character Case and Whitespace

Working with Input

- Delimiters are blanks (·) or tab characters (→). Multiple delimiters have the same effect as one delimiter

```
XYZ_ABC···············4.4··········5.5············6.6
XYZ_ABC    →    4.4 →    5.5 →    6.6
```

- Lower case characters are automatically converted to upper case except for character strings enclosed by single quotes

```
XYZ_ABC george  1.e7
XYZ_ABC GEORGE  1.E7
XYZ_ABC "George"10000000.
```

- Use single quotes if there are internal blanks in a character strings

```
XYZ_ABC BIG-BOY
XYZ_ABC 'BIG BOY'
```


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Comments in Input

- All characters to the right of an exclamation mark (!) are interpreted as comments
- An entire part of the input deck enclosed in triple parenthesis— (((and))) —placed as the leftmost nonblank characters is regarded as a comment and ignored when processing the input deck.

```
NCG_INPUT          ! ********************
………..
NCG_ID H2
(((                ! Start comment block
NCG_ID N2
NCG_ID CO2
)))                ! End comment block
………..
```


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Tabular Input

- Much of MELCOR 2.X input specified as table input
  - All sensitivity coefficients, valves, pumps, Volume Altitude Tables, HS nodes, COR masses, COR areas, COR temperatures, etc.
- A third field on the COR_SC card will allow multiple tables
  - Necessary for Allowreplace

```
COR_INPUT
 . . .
COR_SC    2  Table1
               1   1020        60.0        1
               2   1504        0.1E-04     1
 . . .
COR_SC    1  Table 2
               1   1600        1.0         1

 . . .
```

- Currently implemented for all SC tables, valve tables, pool scrubbing tables, Time-specified flow path tables, Intermediate Heat Exchangers tables, and Mechanical Model tables

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GLOBAL DATA Input

Working with Input

```
!GLOBAL DATA RECORDS
DEFAULTDIRECTORY    ..\GS_exercise
!
MEG_DIAGF          HYDRODECG.DIA
MEG_OUTPUTF        HYDRODECG.OUT
MEG_RESTARTF       HYDRODEC.RST
!
MEL_DIAGF          HYDRODEC.DIA
MEL_OUTPUTF        HYDRODEC.OUT
MEL_HTML           HYDRODEC.HTM
MEL_RESTARTF       HYDRODEC.RST   CYCLE   -1
!MEL_RESTARTF      HYDRODEC.RST   TIME   600.0
!MEL_RFMOD         'HYDRODEC_CON.rst' 3 5-15 -1
!MESSAGEF          'IMPORTANT_EVENTS.MSG'
!
!ALLOWREPLACE
EXTDIAGF           HYDRODEC_EXTD.TXT
PLOTF              HYDRODEC.PTF
PRINTCURRENTSC        HYDRODEC_MY_SC.TXT
!PRINTDEFAULTSC       HYDRODEC_DEFLT_SC.TXT
!STATUSF           STATUS.TXT
!STOPF             STOP.TXT
……..
```

- ❑ Default directory for all MELGEN & MELCOR output
- ❑ Restarts the calculation based
  - On Cycle <integer>
    - If -1, the last restart dump is used
  - On Time <seconds>
    - First time step greater than or equal to the input time
- ❑ Copies restart dumps 3, 5 to 15, and the last to file HYDRODEC_CON.rst
- ❑ Duplicate records are by default fatal errors. Allow replacement records. Only the last record is retained.
- ❑ Print My SC or Default SC to file
- ❑ In batch execution, presence of file will cause generation of 'MELMAIL' file
- ❑ In batch execution, presence of file will stop job

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Referencing Objects

- MELCOR recognizes object numbers as well as character names
- All objects can be referenced by numbers or names
  - i.e., CF_ID, CV_ID, FL_ID, HS_ID, etc.
- Permits mixed number and character references

```
CF_ID 'OVERPRESS'      400  ADD   !(
CF_ID 'OPEN FILTER'    501  T-O-F  !(
CF_SAI    1.0    0.0    0.0 ! CFSCAL CFADCN CFVALR (INITIAL VALUE)
CF_MSC   -1.0E+9   0.2500000000E+05
CF_ARG    1 ! NARG CHARG            ARSCAL           ARADCN
                  1   CF-VALU(400)   1.0      0.0
```

Is functionally equivalent to

```
CF_ID 'OVERPRESS'      400  ADD   !(
CF_ID 'OPEN FILTER'    501  T-O-F  !(
CF_SAI    1.0    0.0    0.0 ! CFSCAL CFADCN CFVALR (INITIAL VALUE)
CF_MSC   -1.0E+9   0.2500000000E+05
CF_ARG    1 ! NARG CHARG            ARSCAL           ARADCN
                  1   CF-VALU('OVERPRESS')   1.0      0.0
```

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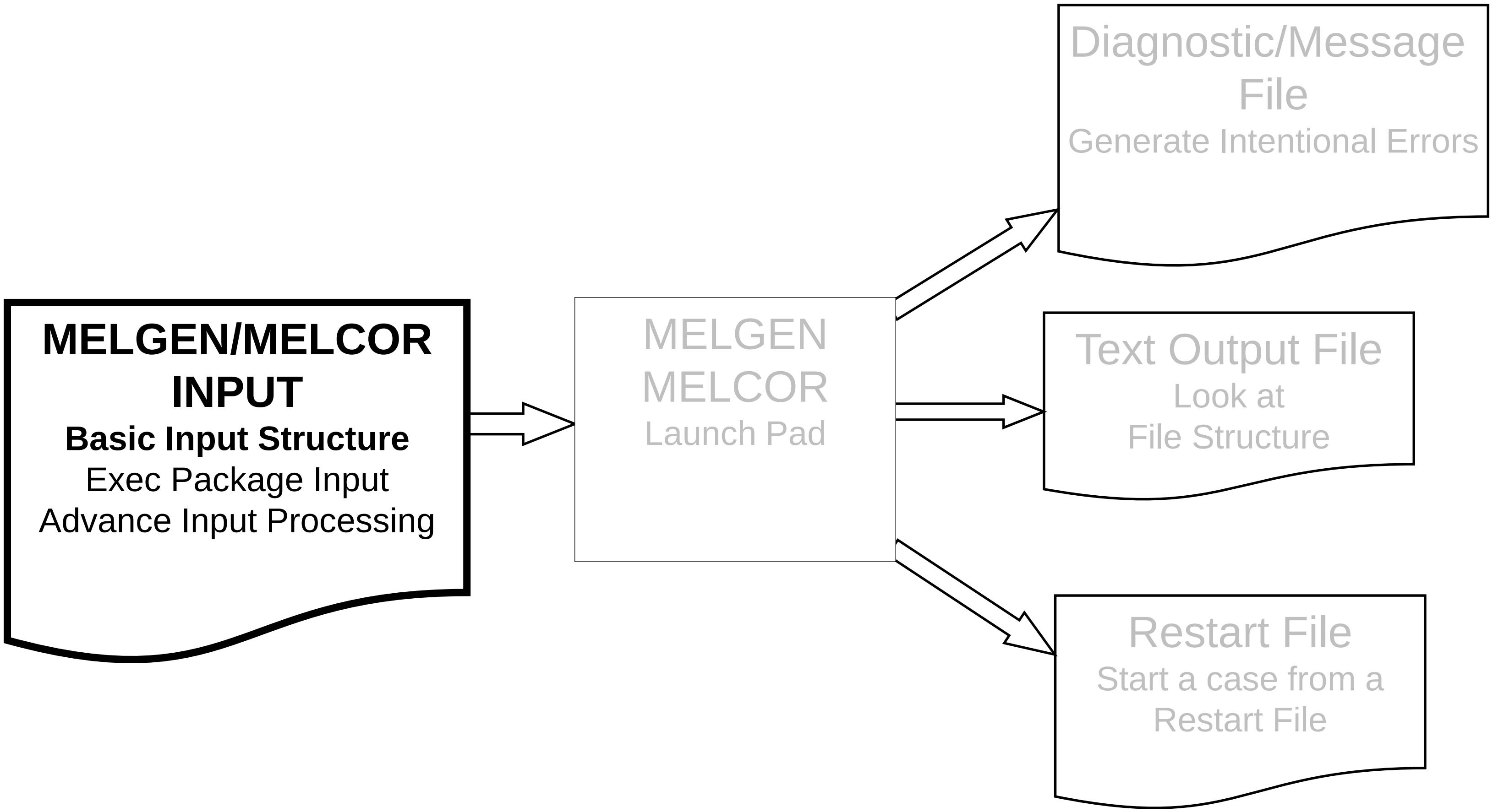
Basic Input File Structure



Output Files

- MELGEN contains a full listing of all processed data, including the initial conditions
- MELCOR contains time independent data and initial conditions, and subsequent snapshots of time-dependent data
  - Output written at time intervals determined by the user
- MELCOR writes data to the binary plot file
  - Output written at time intervals determined by the user

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Diagnostic/Message Files

- Both files should be closely examined after every run
- Diagnostic File
  - Contains error messages or other information that may indicate a problem with the initial conditions specified in MELGEN or with the MELCOR calculation
  - Examine for indications of problems in the results
- Message File
  - Contains information concerning the timing of important events such as combustion of gases, failure of the lower head, etc.
  - Provides a summary of the events in the calculation without having to look through the entire output file
  - Also contains information about the Restart File
- Output from these files is also included in the Output File

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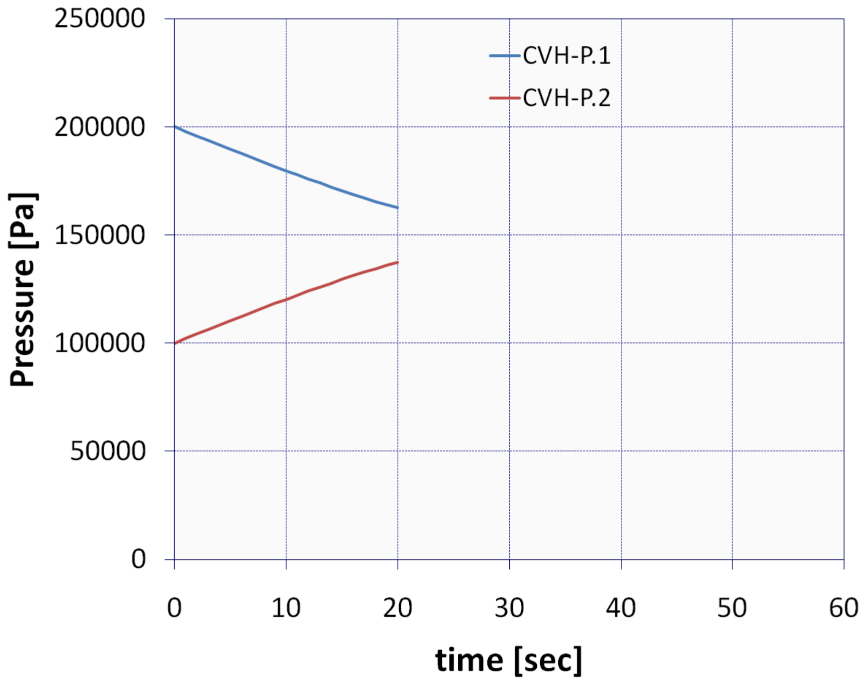
MELCOR Binary Plotfile

- Named by user in global input, e.g.,

  PLOTFILE 'Bethsy_v2.ptf'

  - Default name is MELPTF.PTF
- Multiple post-processors available
  - PTFREAD, SNAP, HISPLT, etc.
  - Topic of another session
- File processed by MACCS code



Generated in EXCEL using Hydrogen.PTF and the PTFREAD Tool

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Restart Files

- Let's start run from Restart File
  - Binary File
  - All information required to restart the calculation is contained in each dump.
  - A restart file dump is always generated
    - Calculation terminates gracefully
    - When terminated by a MELCOR-detected error from which it cannot recover
  - User may specify which dump in the restart file to use when starting the calculation

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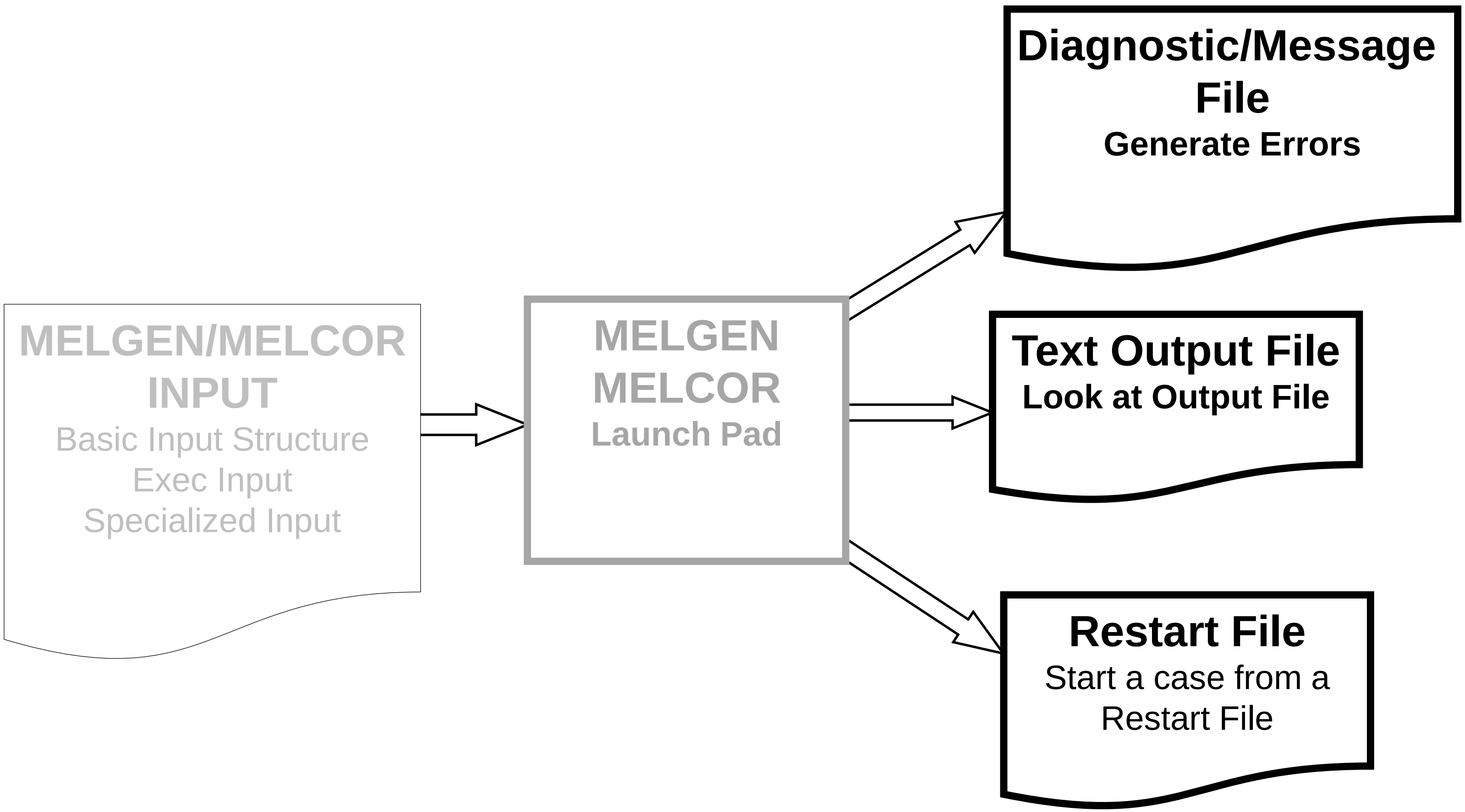
Simple Example

MELCOR Output Files



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EXEC Package

- Responsible for overall execution control of MELGEN and MELCOR calculations
- Coordinates various processing tasks for other MELCOR packages, including
  - File handling
  - Input and output processing
  - System time-step selection
  - Time advancement
  - Calculation termination
  - Sensitivity coefficient modification
- Responsible for processing global data

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EXEC Records

- Global (Environmental) Data records
  - Must appear at the start of the input deck (i.e., before the MELGEN and MELCOR record blocks)
  - Allow the user to rename default MELGEN and MELCOR output files
  - Control calculation restart
  - Batch execution control
  - Advance File Processing
- MELGEN EXEC records
- MELCOR EXEC records

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MELGEN EXEC Input


```
! MELGEN EXEC INPUT
EXEC_INPUT
EXEC_TITLE   'hydrogen'
!
!
!
!
EXEC_PLOT        2 ! Plot Variable
                 1   COR-VOL-FLU(7,1)
                 2   COR-VOL-FLU(8,1)
```

- ❑ Required (EXEC_INPUT)

- ❑ Required
- ❑ MELGEN title must have same number of characters as MELCOR title
- ❑ Must be in single quotes if it contains blanks or lower-case character are significant

- ❑ Optional
- ❑ Makes CF-only variables available as plot variables

- Other optional MELGEN EXEC inputs (see Users' Guide for details)
  - EXEC_DTTIME – initial timestep (default = 1.0 s)
  - EXEC_JOBID – job identifier
  - EXEC_RUNONLY – run only with a specified code version
  - EXEC_TSTART – initial start time (default = 0.0 s)
  - EXEC_UNDEF – redefine initialization of real database and scratch storage

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MELCOR EXEC Input

```
! MELCOR EXEC INPUT
EXEC_INPUT
EXEC_TITLE   'hydrogen'
!
!
EXEC_CPULIM   5000
EXEC_CPULEFT 100
!
!
!
!
!
!
!
!
EXEC_TIME   2   ! N    TIME    DTMAX   DTMIN   DTEDT   DTPLT   DTRST     DCRST
                  1    0.0      1.0     0.1     25.0    0.01    0.1       1.e+10
!
EXEC_TEND   100.0
!
```

EXEC_INPUT:
- ❑ Required

EXEC_TITLE:
- ❑ Required
- ❑ MELCOR & MELCOR title must have same number of characters
- ❑ Must be in single quotes if it contains blanks or lower-case character are significant
- ❑ Type = character*110

EXEC_CPULIM:
- ❑ Required
- ❑ Maximum number of CPU seconds allowed for execution

EXEC_CPULEFT:
- ❑ Required
- ❑ Calculation will halt if CPU seconds remaining after a cycle is less than this value

EXEC_TIME:
- ❑ Required

EXEC_TEND:
- ❑ Optional
- ❑ Default = 5.4321E20 s

Advanced File Processing

- Advanced Features are optional
  - Not necessary for a new MELCOR user
  - Adds flexibility for more advanced users
- Features include
  - Advanced Input Processing
    - CommentBlock
    - Variable Input
  - Constructs for multiple files
    - Allows user to scatter input among multiple files
    - Include Files & Include Blocks

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Named Comment Blocks (1)

- This feature was added to allow the user to include blocks of input records that can be ‘activated’ or skipped by a variety of input methods.
- User can encapsulate multiple versions of a test case within a single input deck.
  - Sensitivity calculations
  - Variations for a standard plant deck
- Analogous to the *EOR* capability for MELCOR 1.8.6
  - More flexible and powerful to use

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Named Comment Blocks (2)

- MELCOR comment blocks were added as part of the code conversion project. In MELCOR 2.1, a block of input can be commented out by enclosing that block of input within a set of triple parenthesis.

```
(((
These input records are ignored
)))
```

- Named comment blocks are either ignored or processed depending on user input.
  - The example to the right demonstrates the input instructing MELGEN to read a block of records required for a SBO calculation.
    - Only the SBO comment block is read and the LBLOCA block is ignored.
    - Alternatively, if the second field on the CommentBlock record were LBLOCA, the LBLOCA records would be read.
  - The CommentBlock record can also contain more than one field so that multiple comment blocks can be read, i.e.,
    CommentBlock SBO LBLOCA.

```
CommentBlock  SBO
...
PROGRAM MELGEN
...
(((SBO  !Additional comments placed here
...These input records are not ignored
)))
...
(((LBLOCA   !This is a large break LOCA scenario
...These input records are ignored
)))
```


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Named Comment Blocks (3)

- There can be multiple comment blocks with the same name
  - Three comment blocks are given the name 'SBO' at right.
  - useful if you have many test case options with variations in multiple locations in the input deck
- Furthermore, the named comment block construct allows multiple names or pseudonyms for a comment block.
  - This would allow some commonalities between a subset of your multiple test options.
- Named Comment blocks can also be nested
  - Comment block 'Nested' can only be processed when both 'LBLOCA' and 'Nested' fields are present on the CommentBlock record.

```
CommentBlock  SBO
...
PROGRAM MELGEN
...
(((SBO  !Additional comments placed here
...These input records are not ignored
)))
...
(((LBLOCA   !This is a large break LOCA scenario
...These input records are ignored
(((Nested  !This is an example of a nested block
)))
)))
(((SBO
...These input records are not ignored
)))
(((SBO+LBLOCA
...These input records are not ignored for either SBO
or LBLOCA cases
)))
```

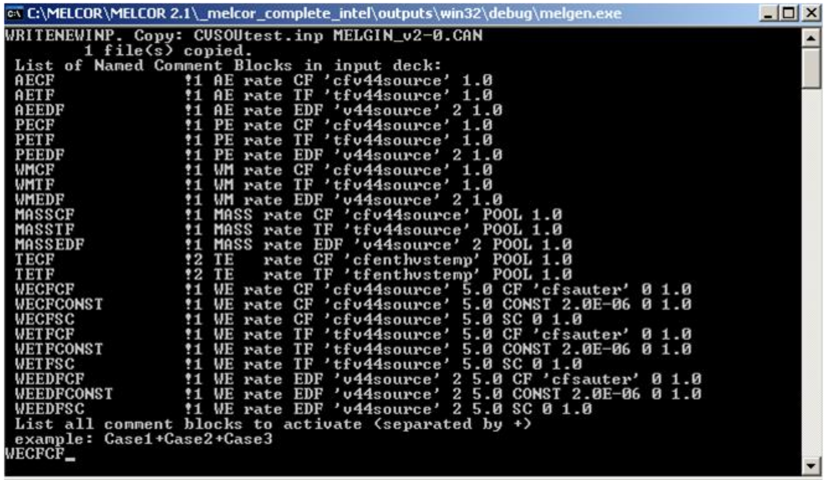
Named Comment Blocks (4)

- Comment Blocks can be 'activated' through the following input:
  - CommentBlock Record

    CommentBlock case1 case2 case3
  - Command line arguments

    melgen i=inputfile c=case1+case2+case3
- – Interactive Method
  - **Comments are echoed with comment block names**
  - **Multiple blocks can be specified by delimiting names with '+'**
- **DefaultNamedCommentBlock record**
  - **Placed in the global variable section**
  - **When present, if the user does not select any comment blocks, those listed on the DefaultNamedCommentBlock record are used**

```
DefaultNamedCommentBlock 2HSNODE+BIGDT
```



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Variable Input Fields (1)

- This feature allows the user to insert variable input fields into records which can then be updated through user input at the time of execution.
- This can be useful for testing ranges of input fields, managing variant assessment calculations, and could be used to aid interfacing MELCOR to other applications.
- Users can provide variable values through a variety of methods.

Variable Input Fields (2)

- Input fields are tagged so that MELCOR will preprocess the input file, replacing the tagged variables with a value specified by the user.
- These tagged variables can occur multiple places in the input deck and all instances are replaced by the same value.
- The tagged placeholder on an input record includes the variable name and the default value enclosed in a set of triple curly parenthesis, {{{}}}, i.e.,

```
FL_SEG 1    !        SAREA            SLEN             SHYD          SRGH      LAMFLG    SLAM/CFNAME
            1    {{{SAREA=1.0}}}  {{{SLEN=0.2}}}  0.24000E-01   0.5E-04   CONST     0.00
```

- In this example, two variables, SAREA and SLEN, are specified on the flow segment record. Default values are 1.0 and 0.2 respectively are provided.

Variable Input Fields (3)

- Input Values for the Variable fields can be provided as follows:
  - Variable Input File
    - A file can be specified in the global specifications, containing values for all or some of the variables found in the input deck.

```
DefineVariablesFile    Variables.dat  !Values read from Variables.dat file
```

    - ed interactively to provide values.
    - If this file is missing, the user will be asked to interactively provide values

```
{{{Var1=1.0}}}        !Additional comment
{{{Var2='Wetwell'}}}  !Additional comment
{{{Var3=3}}}          !Additional comment
```

  - VariableValue record
    - Values are provided on the VariableValue record located in the global variable section of the input.
    - Any data type can be provided but must be consistent with the requirements of the associated input record to avoid MELGEN errors.
    - The supplied value effectively replaces the {{{var=nnn}}} variable field.
  - Interactive Method
    - A list of all variables is provided and the user is queried for the required value.
    - If the user does not specify a value, then the default value will be used unless it was specified by any of the previous methods.

```
VariableValue   {{{Var1=1.00}}} {{{Var2='Wetwell'}}}  {{{Var3=3}}} !These 3 variables are evaluated
```

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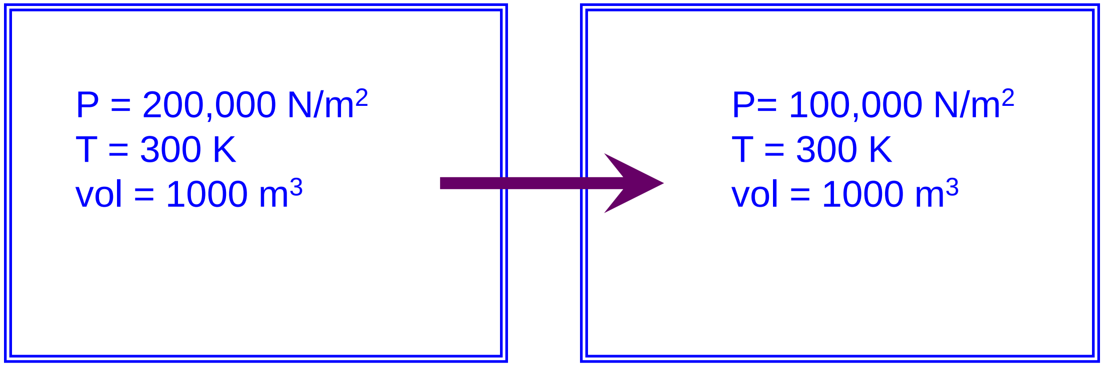
Simple Test problem Hydrogen 2.inp

- Same as Hydrogen1.inp except:
  1. Ending time is a variable input
  2. Volume of low pressure volume determined by named comment block
     - Use ‘V2000’ for 2000 m3
     - Otherwise the volume is 1000 m3
  3. Output is redirected to another folder
     1. DEFAULTDIRECTORY ..\case2



Hydrogen Depressurization

Subdividing Decks (1)

- The INCLUDE directive includes the contents of one input file in another
  - Simple case

```
! filename: hydrogen.inp
DEFAULTDIRECTORY    ..\case1
!
MEG_DIAGF           HYDRODECG.DIA
MEG_OUTPUTF         HYDRODECG.OUT
...

INCLUDE hydrogen.gen
INCLUDE hydrogen.cor
```

```
! filename: hydrogen.gen
Program MELGEN
 . . .
END Program MELGEN
```

```
! filename: hydrogen.cor
Program MELCOR
 . . .
END Program MELCOR
```

- hydrogen.gen and hydrogen.cor can each contain INCLUDE directives

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Subdividing Decks (2)

- Many users split MELGEN input for large problems into several files
  - Makes it easier to find specific input; allows reuse of pieces for differing scenarios or similar plants

```
! filename: hydrogen.inp
Program MELGEN
EXEC_INPUT
EXEC_TITLE  'hydrogen'
 . . .
INCLUDE high-pressure.gen
INCLUDE low-pressure.gen
INCLUDE high-to-low.gen
. . .
END Program MELGEN
```

```
! filename: high-pressure.gen
 . . .
```

```
! filename: low-pressure.gen
 . . .
```

```
! filename: high-to-low.gen
 . . .
```

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Subdividing Decks (3)

- MELGEN input for a given package can also be split up
  - Parts may be in more than one file, and/or in more than one place in a file
    - Package specification is required in each case

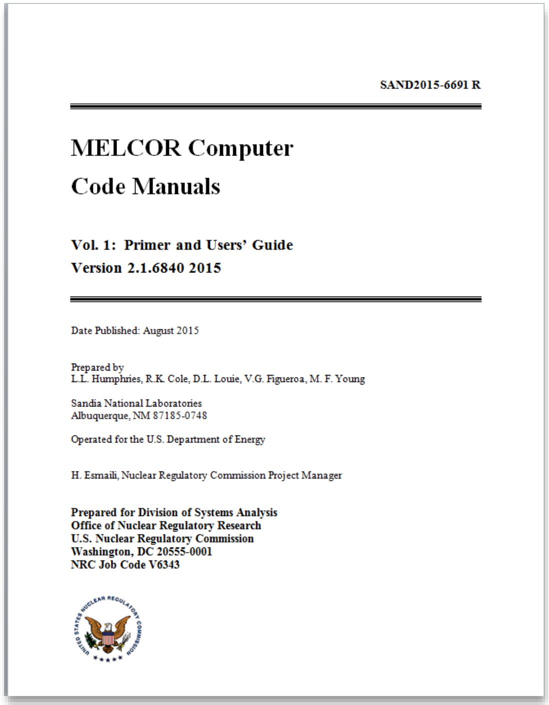
```
! filename: high-pressure.gen
 . . .
CVH_INPUT
CV_ID 'high-pressure'
 . . .
```

```
! filename: high-to-low.gen
 . . .
FL_INPUT
CV_ID ‘high-to-low'
 . . .
```

- <u>All input for any one object (CV_ID, FL_ID, etc.) must be grouped together</u>

MELCOR Documentation

MELCOR Manuals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Version 2.1.6840 2015

Date Published: August 2015

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

Sandia National Laboratories
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Operated for the U.S. Department of Energy

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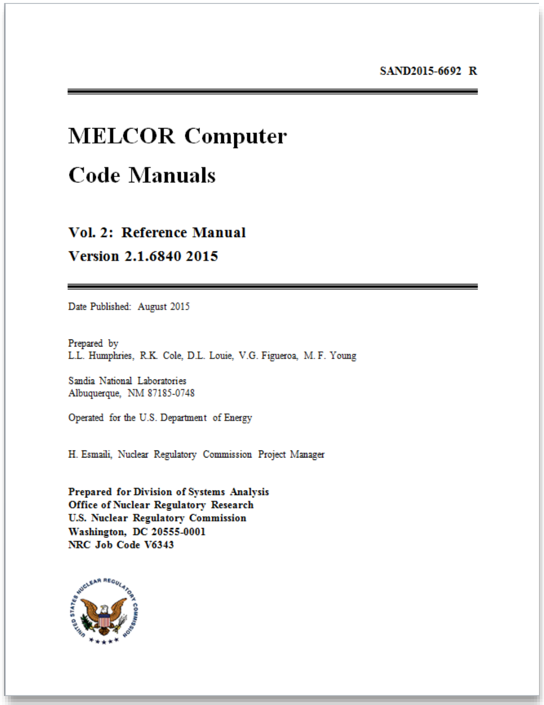
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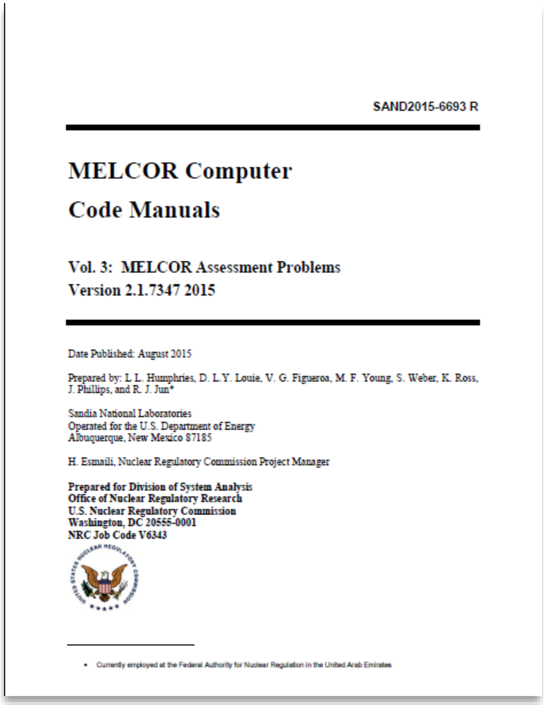
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- Currently employed at the Federal Authority for Nuclear Regulation in the United Arab Emirates

Volume I: User Guide

R&A Complete
SAND2015-6691 R
Preparation of final PDF

Volume II: Reference Manual

R&A Complete
SAND2015-6692 R
Preparation of final PDF

Volume III: Assessments

R&A Complete
SAND2015-6693 R
Preparation of final PDF

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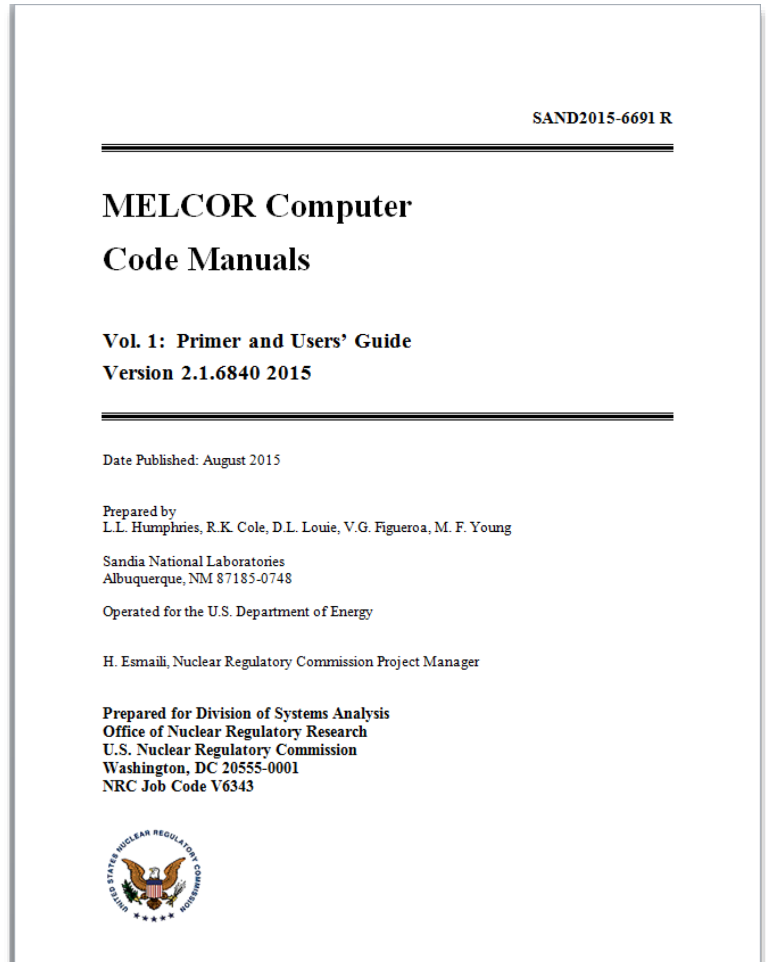
Volume I: User Guide

MELCOR Manuals

- Organized by Package
  - PDF has thumbnails
- Brief Package description
  - Detailed physical model description in Reference Manual
- Description of each Input Record
  - Record Identifiers
  - Fields defined
  - Optional or default
  - Default values
  - Units
- Description of each sensitivity coefficient
  - Sensitivity coefficients are certain modeling parameters exposed to user for modification
    - Coefficients in correlations
    - Tolerances
  - Equations & correlations
  - Defaults
  - Units
- Description of each plot variable
  - Calculated variables available in the binary plot file
  - Units
  - Dimensions defined
- Description of each control function argument
  - Variables exposed to users that can be used for controlling problem execution
    - Open & close valves
    - Sourcing in mass
    - Can be used by other control functions
  - Units defined
  - Dimensions defined



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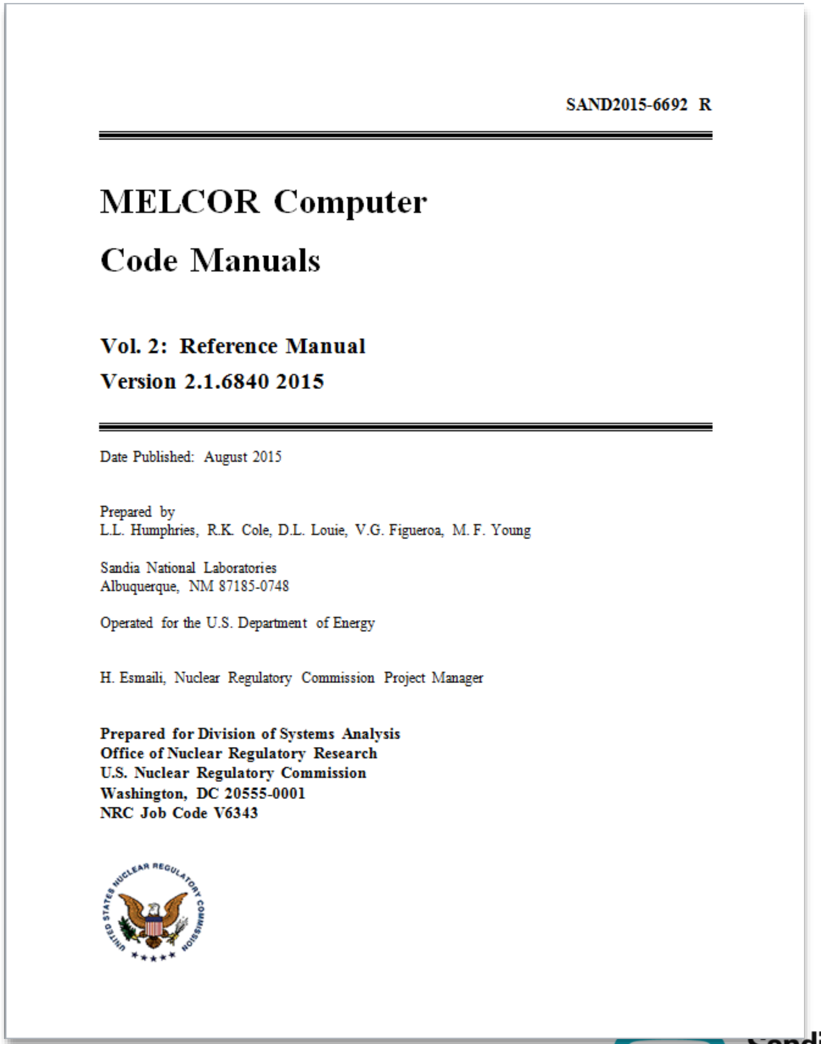
Volume II: Reference Manual

MELCOR Manuals

- Package Introduction
  - Brief overview description of package
- Detailed Models
  - References to UG for input and Sensitivity coefficients
- Discussion & Development Plans
- Published August 2015



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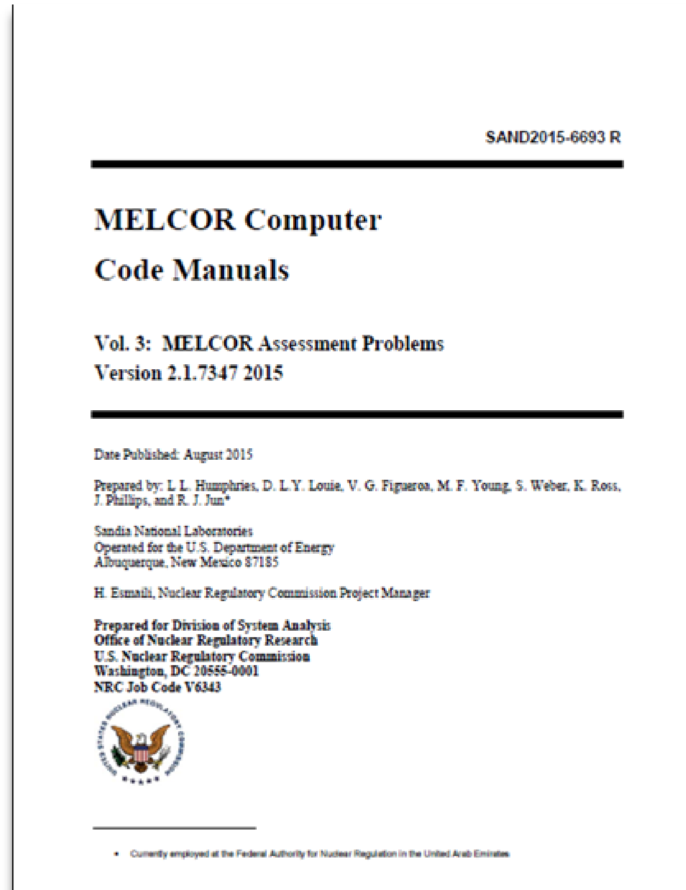
Volume III: Assessment Report

- Last assessment report was published for MELCOR 1.8.5
  - Validation for both M1.8.6 & M2.1 in current report.
- More thorough report
  - More validation tests
  - More synthesis of assessments
- Status
  - Published August2015



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SNAP Overview

Presented by
MELCOR Development Team

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Objective of Presentation

- Introduce SNAP
  - A breakdown of the Model Editor Graphical User Interface (GUI)
  - Discuss the various tools (Job Status, Configuration Tool)
  - General discussion of functionality regarding MELCOR
- Demonstrate user input workflow
  - MELGEN and MELCOR
    - General "Packages" are maintained
    - General User Guide information is accessible
- Demonstrate job submittal
- SNAP is a very feature rich suite
  - Therefore we'll focus on using it solely to create MELCOR input and perform calculations

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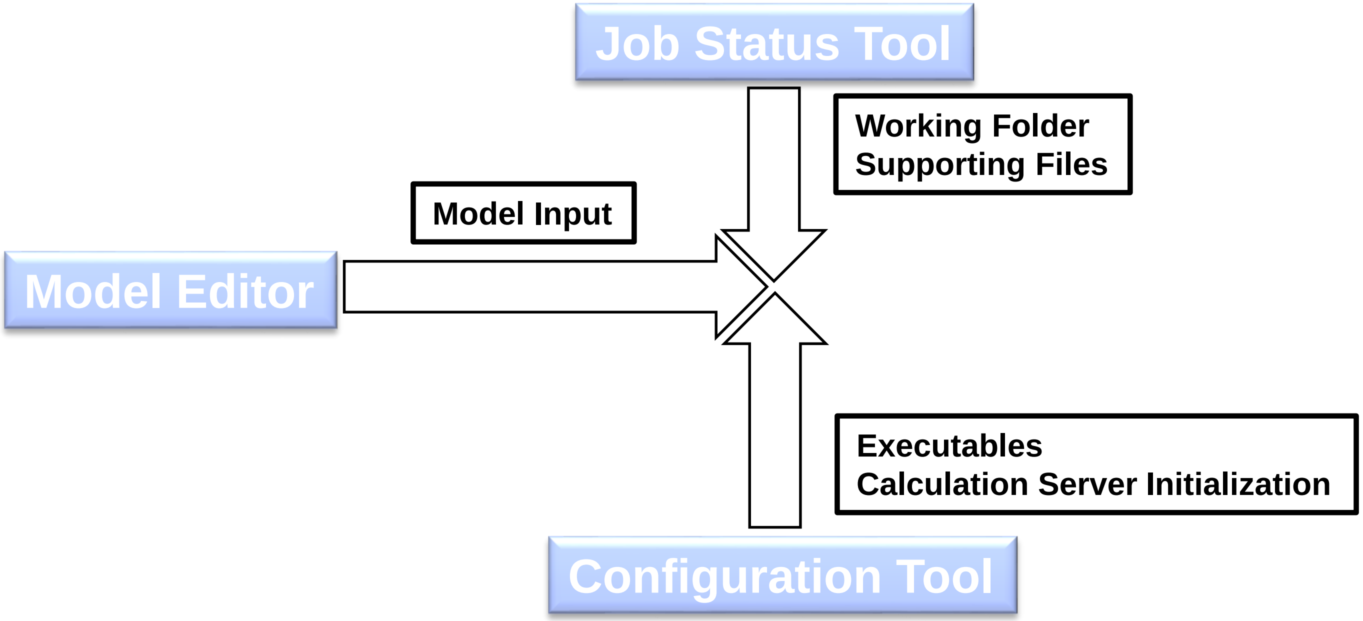
Simplistic Idea on Information Flow for Job Submittal

- From a simple user's understanding of information flow



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SNAP Model Editor

- **Model Editor**
  - Unique plug-ins handle specific model details for a given code (MELCOR, RELAP, etc.)
  - Stores both MELGEN and/or MELCOR user input
  - Can convert older MELGEN/MELCOR 1.86 input to 2.x
  - Submits input processed by executables (i.e. job submittals)
  - Can create an Animation Model for post processing output
- **Model Editor Advanced**
  - User Defined Numerics
  - Engineering Template
  - Automated Validation Framework
  - And more….

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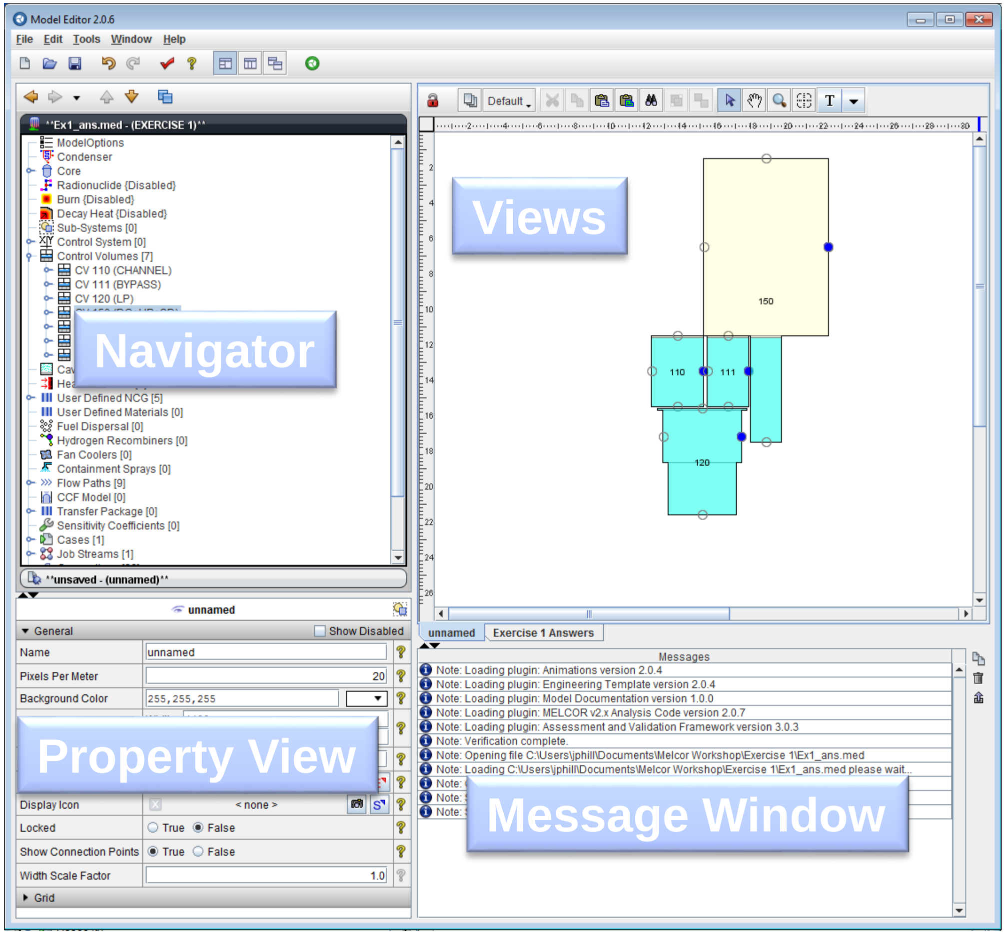
Model Editor Interface



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Navigator View

- Nodal based tree for each package
  - Blue node can be clicked to expand the tree
  - Select the MELCOR component to view its properties in the Property view (Components can be selected in either the Navigator or the View port.)
  - Packages with different names
    - Model/Options == EXEC package
    - Control Systems == CF/EDF/TF packages
  - Internal Controls
    - Cases – Where the MELCOR input is treated
    - Job Streams – Identifies MELCOR input files and executables using an information flow map
    - Connections – list component dependencies
    - Numerics – user defined substitutions to input
    - Views – List of views available in the View port

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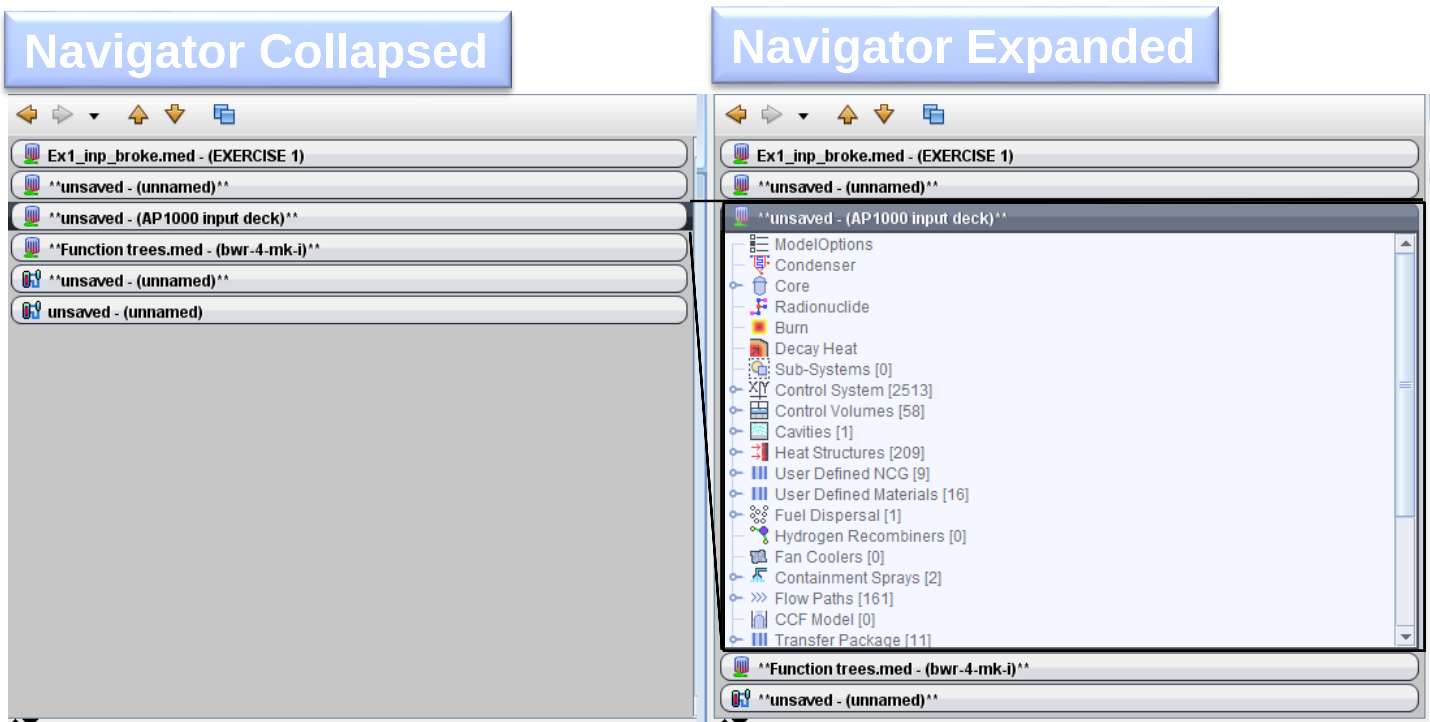
Sub-Systems

- Sub-Systems allows user input to be grouped logically into system sets
  - Components can be added to a sub-system from the currently available component
  - Exporting a text files will maintain sub-systems in independent files (a typical practice for MELCOR file organization where components are stored in unique files)
    - Example
      - RHR components may include
        - Pumps, reservoir water sources, heat exchangers, etc.
        - Their associated flow paths, controls volumes, controlling logic are often kept primarily in one input file for book-keeping purposes

Navigator View

- Multiple models can be open in one SNAP instance
  - Accordion Display



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Properties and Message View

- Properties View
  - Where all user input is accepted
    - Both MELCOR and/or SNAP components
  - Editable fields
  - Drop down menu
  - Editable window pop-ups
  - Selectable elements
  - Model notes
  - User guidance
- Message
  - Where error messages associated with SNAP are placed.
  - MELCOR error messages are still written to the MELCOR files
    - Message file, diagnostic file, output file, etc.

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View Port

- New Views are created in the Navigator tree
  - Right click View, select new to create a new view component
- View components have several internal drawing methods for various components
  - Components can be placed in the view by right clicking on the component in the navigator tree and selecting add to view
  - Control Volumes utilize the CV_VAT information (Volume and Altitude Table) when determining the depiction
  - Flow paths utilize Connections (see Navigator tree) to determine which Control Volumes to connect. Location of the connecting line is taken from the FL_FT record versus the CV_VAT input
  - Core, Control Functions, Database Variables, etc.

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Drawing in the View Port

- Drawing is very straight forward. Experiment to learn
  - Tools available
    - Layers
      - Drawn components are assigned to a given layer
      - Layers can be made visible or invisible making editing easier
    - Docking
      - View can be detached from the view port and moved about the desktop
        - Right click the view in the Navigator>Undock View
    - Standard copy/cut/past/zoom/pan controls
      - CNT+C / CNT+X / CNT+P / CNT+MouseWheel / MouseWheel(Shift+MouseWheel)
    - Grouping components, found in tool bar
    - Lasso select (left click hold and drag)

(Continued)

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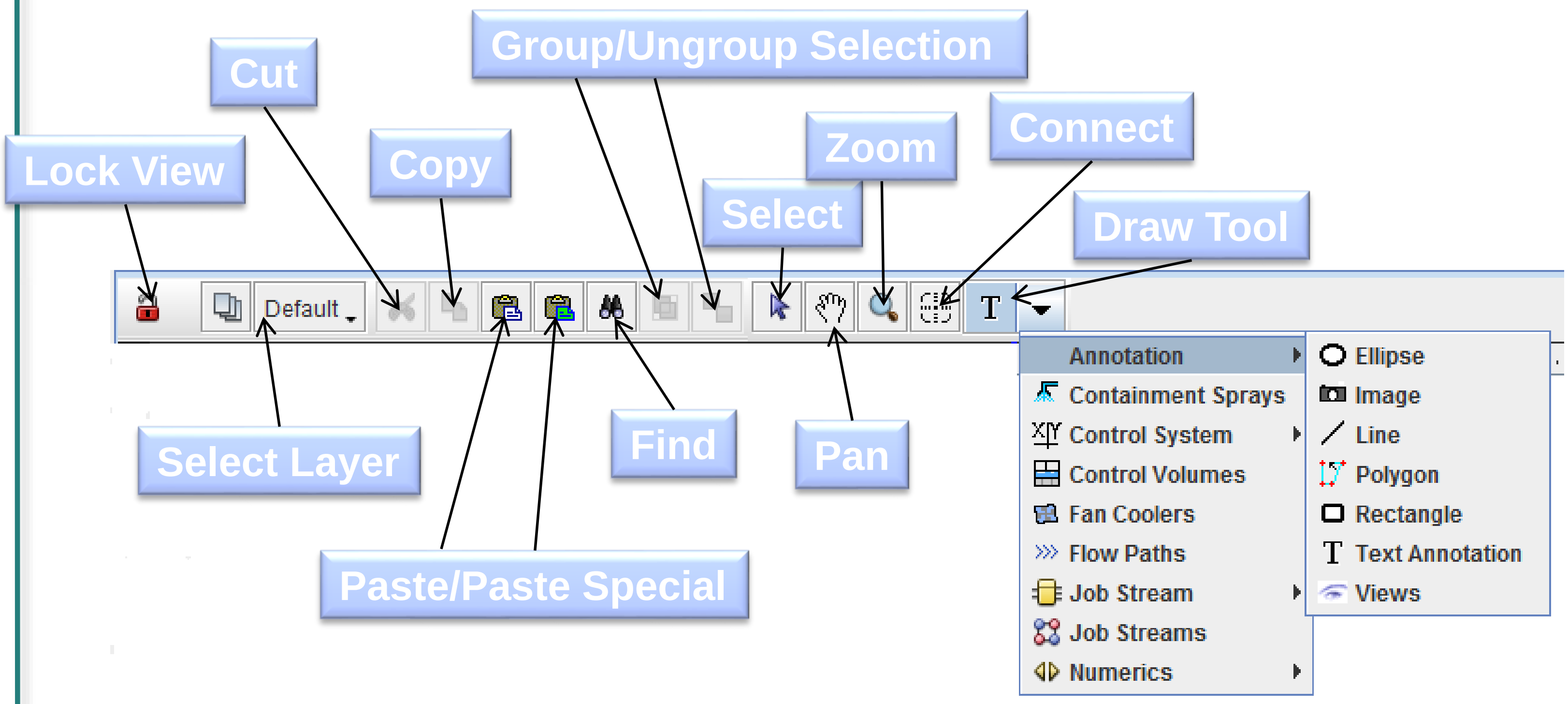
Drawing in the View Port

- Tools available (continued)
  - Connection Tool
    - Components (Control Volumes, Flow Paths, and a few others can be initiated in the view port, likewise connections can be created between such components with the connection tool)
  - Drawing Tools
    - Annotate
      - Add text, lines, shapes, etc.
    - MELCOR components
      - Sprays, Control Volumes, Flow Paths, etc.
    - Job Stream information flow maps
- Toolbar

View Port Toolbar



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View Port Notes

- Interactive elements can only be selected from the View Port if the view is locked
  - This is to prevent accidental interactions while editing the view components
- If the screen is locked you cannot edit any of the components
- Individual layers can be locked to prevent editing certain components
- Connections can only be made in the View Port for the following
  - Flowpaths to Control Volumes, Sprays to Control Volumes, and Fan Coolers to Control Volumes

Example: Import MELGEN File

- Importing a pre-existing MELCOR model
  - File > Import > MELGEN 2X
    - Make sure the Code Version is correct
    - Select the root file
      - Note R*I*F or INCLUDE files are read with regard to their hosting file not the main root file. (MELCOR performs these functions with regard to the root file only.)
        - Hosting file is the file with the R*I*F or INCLUDE file location
        - Root file has the main MELGEN or MELCOR block
        - Include block names have caused issues in the past. If nothing imports try adjusting the block names to remedy issue. Remove quotes, spaces, etc.
    - Name options can be specified by the user
      - Preserve existing component names as reasonable (16 character limit and repeated names will have an _# appended to the end of the name)
      - Generate with number
        - With package prefix i.e. CV###
        - Without prefix i.e. #####

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Example: Import MELCOR File

- Within the Navigator Tree
  - Add a Case if none exists (right click case select new)
    - This will create a MELCOR Case
  - Right Click the newly created MELCOR Case and select Import Case
  - Navigate to file location
    - If error Messages are overwhelming
      - The “Code Version” didn’t match the file type
        - 1.86 vs 2.x mismatch

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Example: Importing MELGEN/MELCOR Input

- **Performed during workshop**

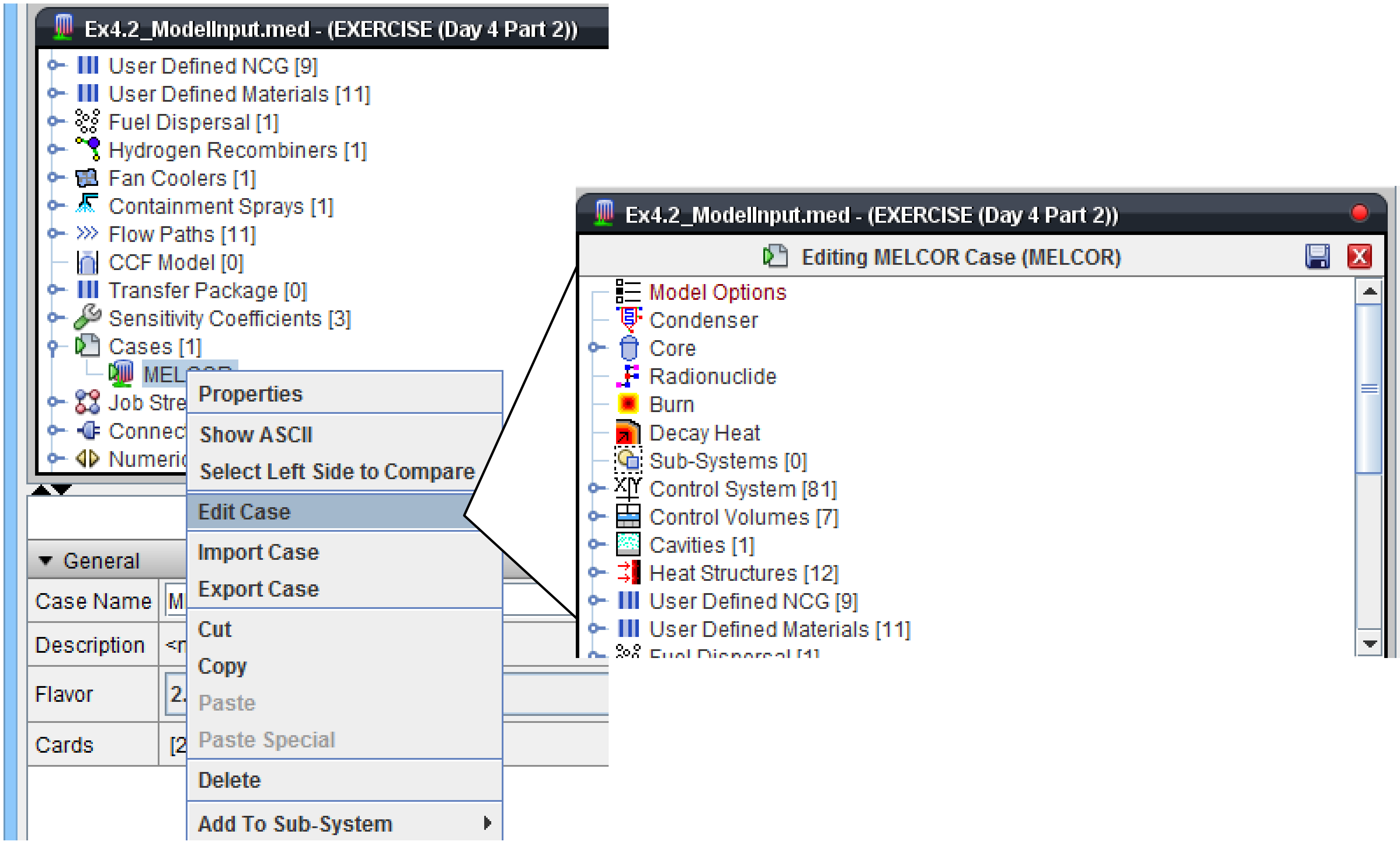
Notes on Importing

- Review the Message View for import errors
  - May require some corrections
  - Once again if the error messages are overwhelming
    - 1.86 vs 2.x mismatch likely occurred
- Import the MELCOR case BEFORE changing the "Code Flavor" i.e. from 1.86 to 2.x or reverse
  - SNAP is anticipating like versions

MELCOR Navigator Tree

- MELCOR input is stored under Cases in the MELGEN navigator tree
- To see the MELCOR input right click on one of the MELCOR inputs under Cases and select Edit Case
- A new MELCOR Navigator Tree will be created
- Similar to the MELGEN Navigator Tree, under Model/Option you can convert the code flavor or makes changes to the MELCOR input.
- NOTE: Code Flavor found in the MELGEN Navigator Tree under Cases->MELCOR, DOES NOT DO ANYTHING. See for your self by changing the value.

MELCOR Navigator Tree



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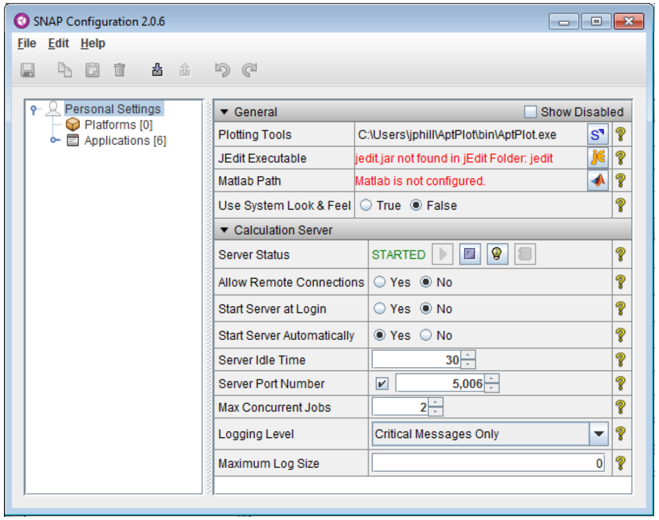
Configuration Tool

- General Use
  - Lets SNAP know where the executables are located
    - MELGEN/MELCOR
    - APT Plot (Not necessary but useful for Post Processing)
  - Initiates the Calculation Server
    - Calculation Server is where the calculations are performed
    - By default your current machine is assumed to be the calculation server
      - Therefore if your machine is the one to perform the calculations you will not need to adjust this setting



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Configuration Tool Setup

- **Personal Setting**
  - APT Plot location can be specified
    - As well as other tools if so desired
  - Server Status
    - Click the play button, there are several other user actions that can start the Server.
- **Applications**
  - Right click Applications > New > MELGEN > location of MELGEN
  - MELCOR (same as MELGEN)
  - Specify the Server
    - If your machine will perform the calculations no further work is necessary

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Example: Setting Up the Configuration Tool

- **Performed during the workshop**

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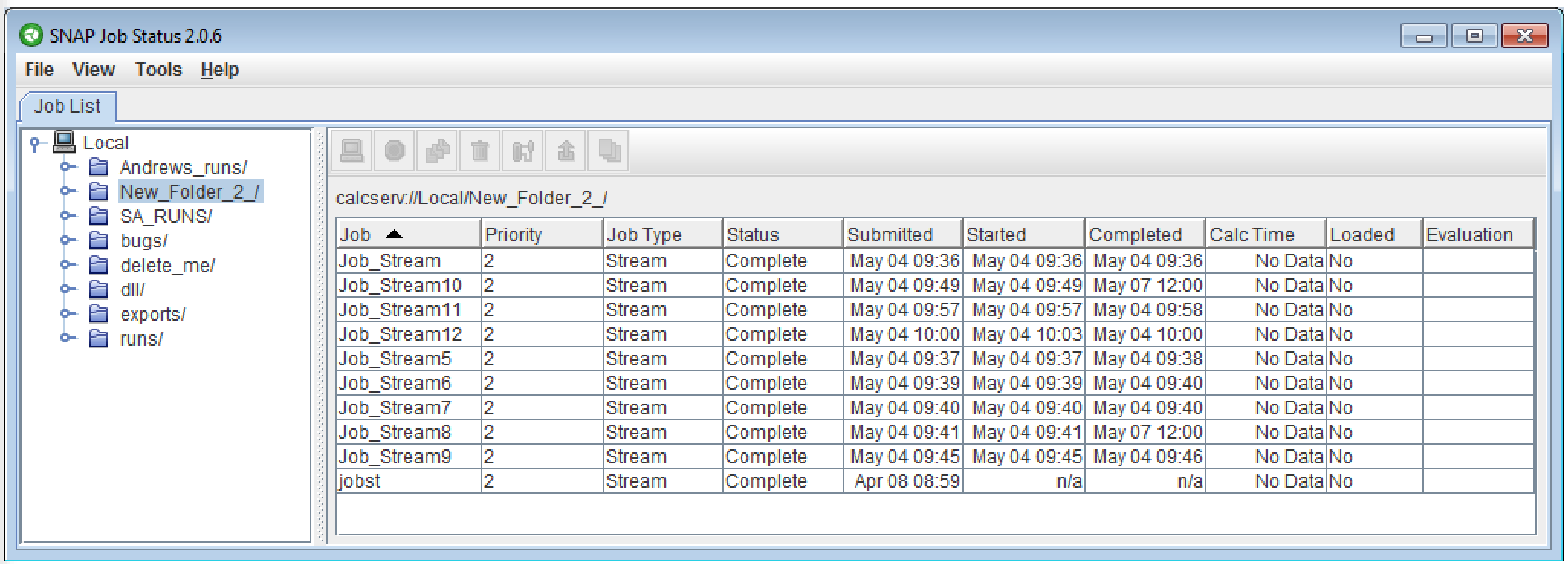
Job Status Tool

- **Job Status Tool**
  - —**Keeps track of prior performed jobs**
  - —**Only displays the folder list and jobs when the Calculation Server has been started**



Job	Priority	Job Type	Status	Submitted	Started	Completed	Calc Time	Loaded	Evaluation
Job_Stream	2	Stream	Complete	May 04 09:36	May 04 09:36	May 04 09:36	No Data	No	
Job_Stream10	2	Stream	Complete	May 04 09:49	May 04 09:49	May 07 12:00	No Data	No	
Job_Stream11	2	Stream	Complete	May 04 09:57	May 04 09:57	May 04 09:58	No Data	No	
Job_Stream12	2	Stream	Complete	May 04 10:00	May 04 10:03	May 04 10:00	No Data	No	
Job_Stream5	2	Stream	Complete	May 04 09:37	May 04 09:37	May 04 09:38	No Data	No	
Job_Stream6	2	Stream	Complete	May 04 09:39	May 04 09:39	May 04 09:40	No Data	No	
Job_Stream7	2	Stream	Complete	May 04 09:40	May 04 09:40	May 04 09:40	No Data	No	
Job_Stream8	2	Stream	Complete	May 04 09:41	May 04 09:41	May 07 12:00	No Data	No	
Job_Stream9	2	Stream	Complete	May 04 09:45	May 04 09:45	May 04 09:46	No Data	No	
jobst	2	Stream	Complete	Apr 08 08:59	n/a	n/a	No Data	No	

Job Status Tool Setup

- User will need to create a working folder
  - Right click Local > Mount Root Folder
  - Specify the working folder
- Job Streams can be submitted to any mounted root folder
  - The files submitted and produced by MELGEN and MELCOR will be located in \Root Folder\Job Stream Name
- From an existing Job
  - Files associated with the run can be viewed with the Job Status Tool
  - Data can be plotted with APT Plot from the Job Status Tool
  - Jobs viewable from the Job Status Tool will be available for post processing with an Animation Model from the Model Editor

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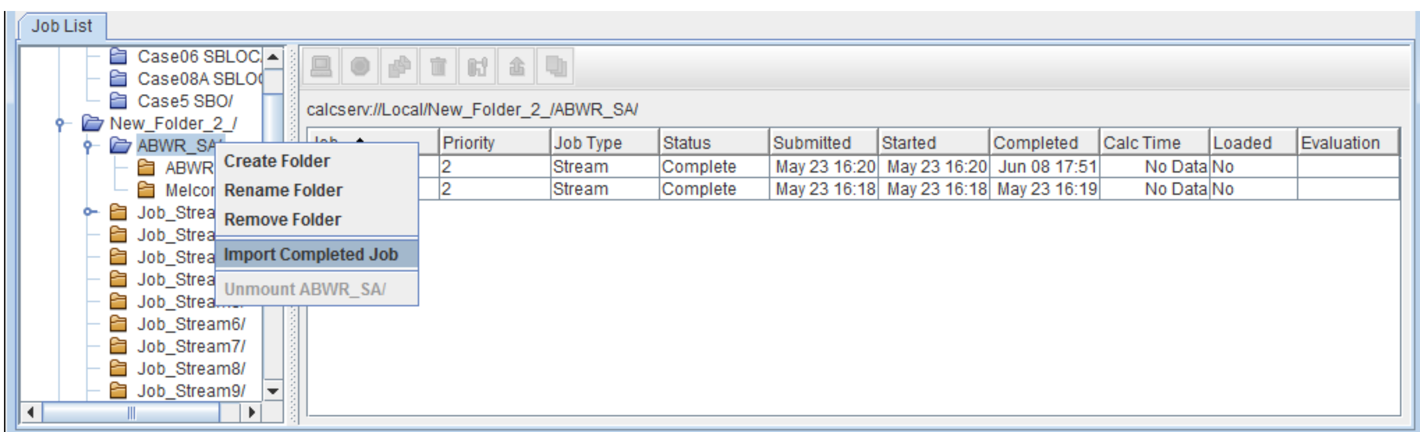
Importing a Standalone Job with the Job Status Tool

- The Job must reside in a folder within the working directory of a mounted Root Folder
- Navigate down to the folder where the Job files reside
- Right click the folder>Import Completed Job
- Select the applicable application
- Click Next then input a Job Name if desired
- Click Next then select the location of all desired files



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Example: Mounting a Root Folder and Importing a Completed Job Plotfile

- Performed during the workshop

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Creating a Job Stream

- **Job Stream**
  - Created within the Model Editor
  - Performs MELGEN and/or MELCOR runs
    - Can be either or both
  - Submits the input files to the MELGEN/MELCOR executables and specifies the folder where the results will be placed
  - Produces a new Job within the Job Status Tool
  - Can specify the post processing tool to generate a set of plots
  - Has several default Job Streams which can be selected to simplify the setup process

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Setting Up a Job Stream

- Checklist before setting up a Job Stream
  - —MELGEN/MELCOR executables setup in the Configuration Tool
  - —Calculation Server started
  - —Root Folder present in the Job Status Tool where the resulting files will be located
- Set-up
  - —In the Navigator right click Job Streams>New
  - —Select Basic Stream
  - —Select calculation type (Two-Step)
  - —A new View will be created containing an information flow diagram
    - The MELGEN input and MELCOR input will be present
    - A MELGEN and MELCOR executable will be selected from the Configuration Tool automatically

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Job Stream

- Independent files can be specified in the Job Stream
  - Restart Files, ASCII Input Files, etc.
- Sensitivity cases can be performed
  - If a Numeric has been included in the model it can be used to perform various like calculation where the Numeric value is varied
    - Create a new numeric by expanding Numeric tree and right clicking desired Numeric type
    - Create a Numeric Job Stream and edit the Parametric Properties
    - Edit the Parametric Tasks

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Example: Continuation of Import Example with Job Stream Creation

- **Performed during the workshop**

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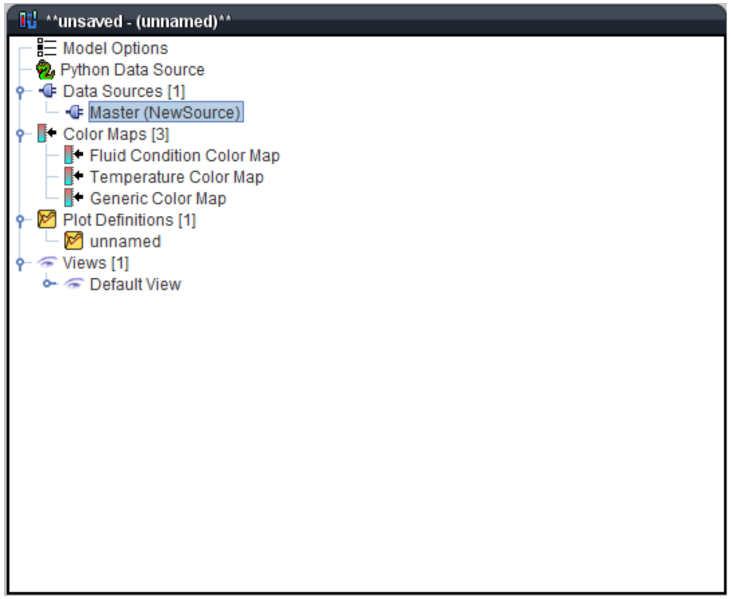
Post Processing with SNAP

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



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Creating a Basic Animation Model

- **Attaching a plotfile**
  - Two Steps
    - Click on Master in the Data Source Tree in the Navigator and set the Source Run URL in the Properties to a completed Job
    - Click the Data Connector Icon
- **Create a Color Map**
  - Three steps
    - Right Click Color Maps in the Navigator>New
    - Right Click the new Generic Color Map>Add To View
    - Adjust some Properties
      - Set Color Map Type to Generic
      - Specify Dynamic as True
      - Set Channel Name Pattern to MELCOR "CVH-P_%V"
        - Review the MELCOR User's Guide to see all the available plot channels
        - %V is a place holder for the components Control Volume number (see notes for a detailed description on its use)

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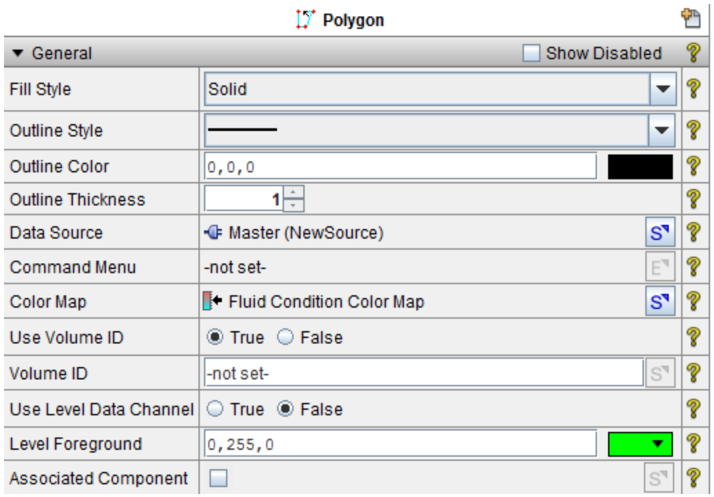
Creating a Basic Animation Element

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



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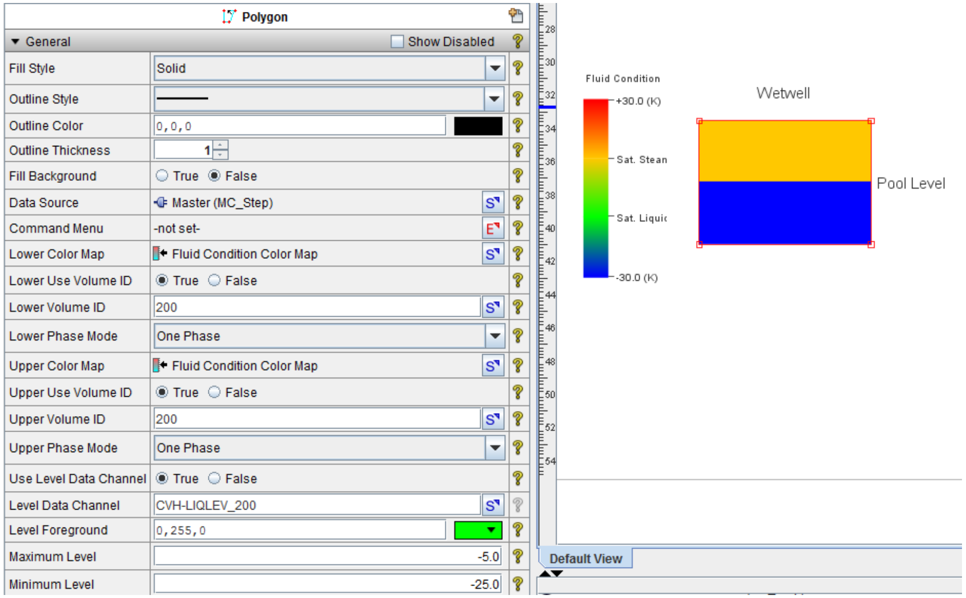
CVH-FL Example Problem: Drawing the Wetwell

- **Set the following**
  - —Color Maps
  - —Liquid Level Data Channel
  - —Volume IDs
  - —Max and Min Levels
  - —Upper Phase Mode to One Phase



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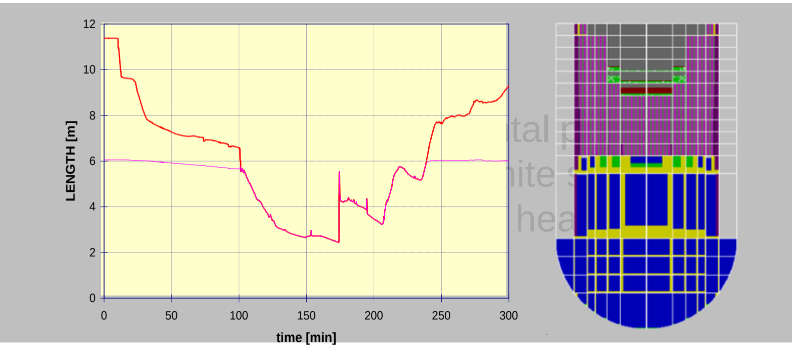
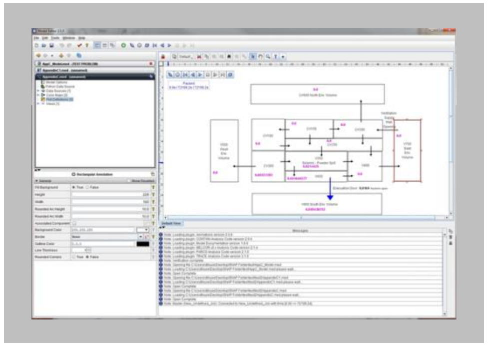
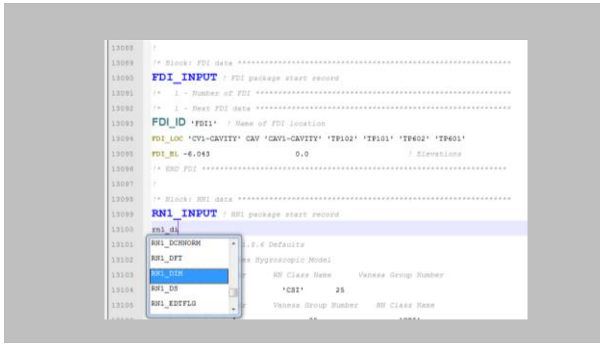






MELCOR Tools

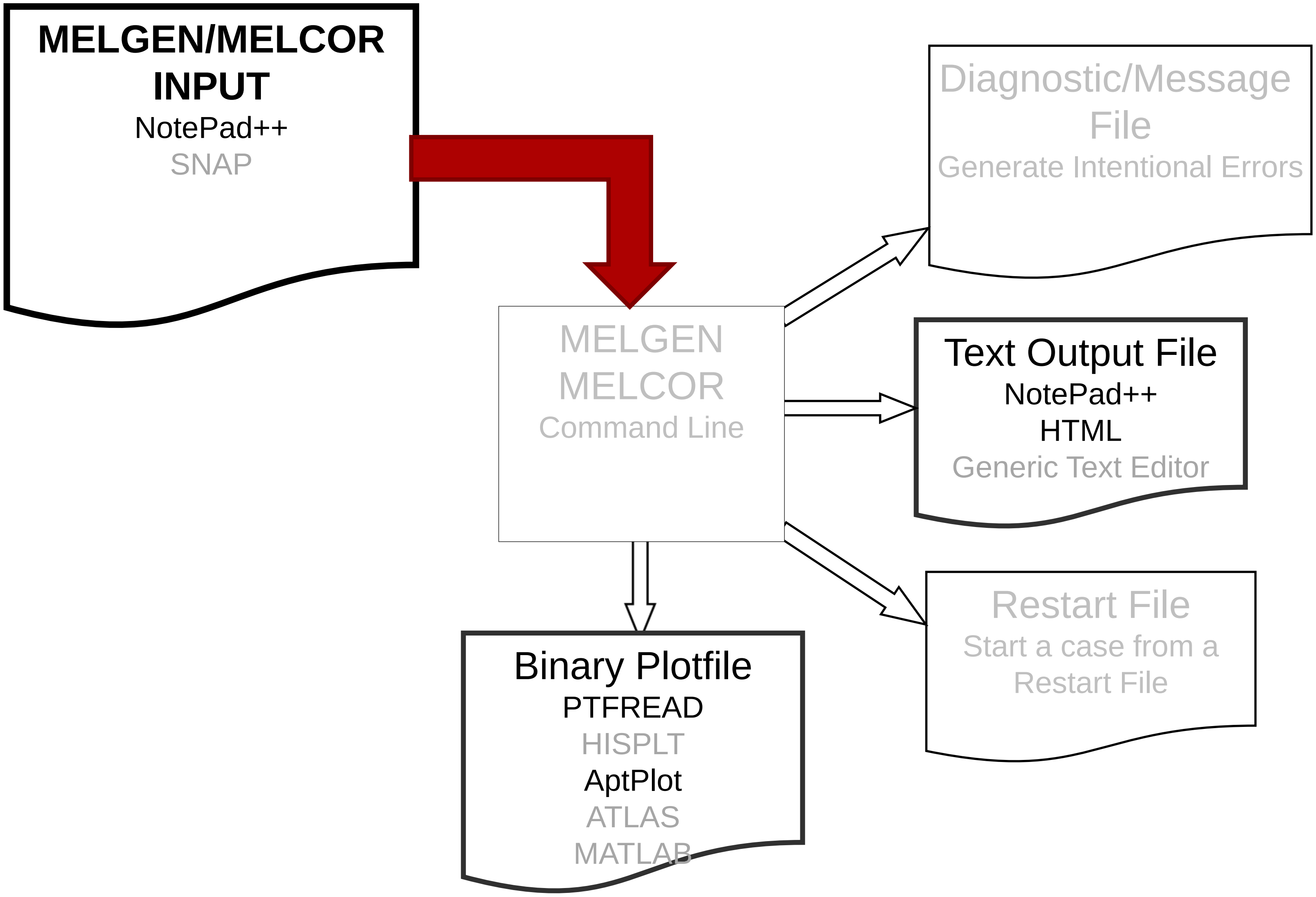
Presented by Larry L. Humphries

llhumph@sandia.gov

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

MELCOR I/O Tools



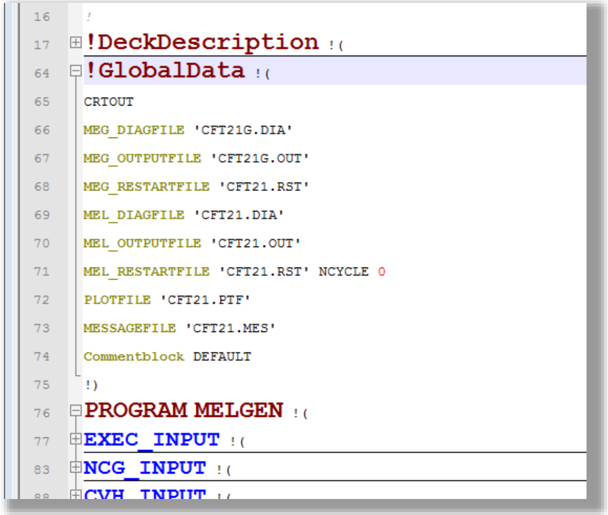
Notepad++ Plugin for MELCOR 2.1

- Recognition of MELCOR record identifiers
  - Auto-completion of record identifiers
  - Can be updated by user
- Style applied to various levels of MELCOR records
  - Comments in Gray
  - Package Input identifiers blue
  - Objects green
  - Properties are gold

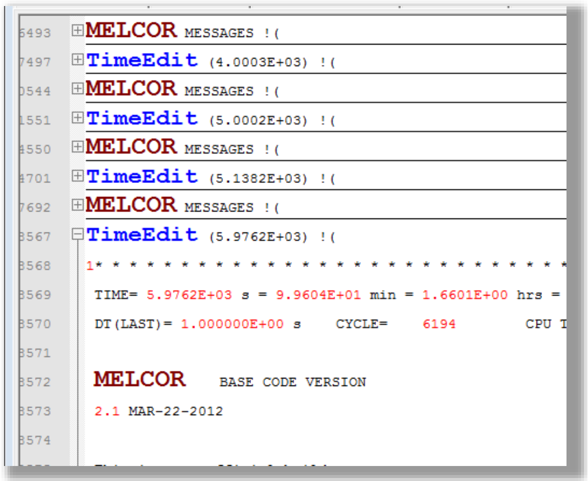
Notepad++ MELCOR 2.1 Collapsible I/O

- Expandable/Collapsible Input Decks
  - Input decks are easier to navigate
    - View outline or details
  - !(and !) are used to mark open and close of collapsible region
    - MELCOR Interprets as comments
  - Nested regions permitted
- MELCOR output file is also Collapsible
  - Keyword NotePad++ ON in Global variables generates outline marks
  - Information for each time dump is in outline form

Input



Output



NotePad++ MELCOR Plugin

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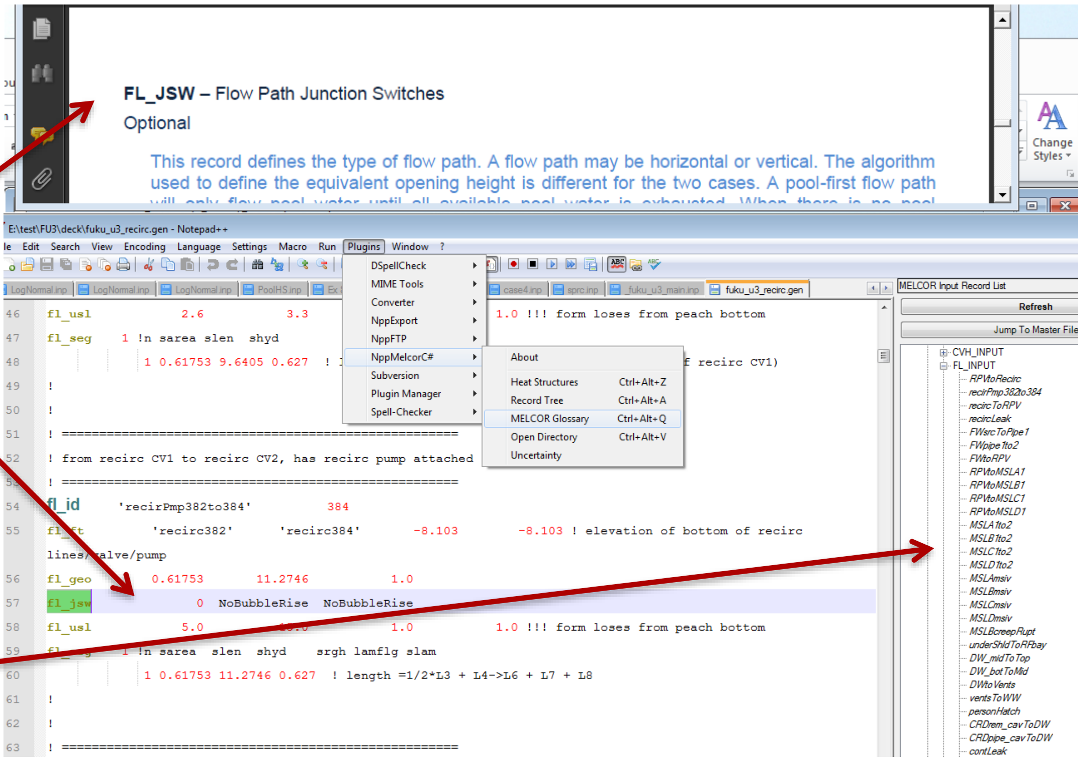
Input Tools: NotePad++

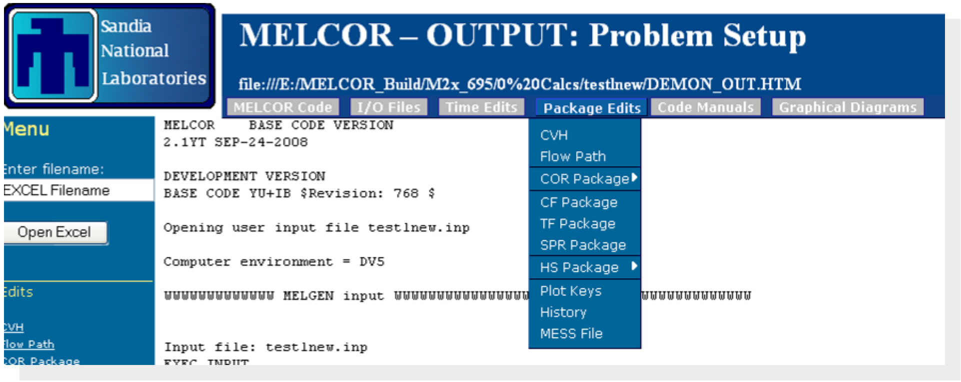
- MELCOR Plugin for NotePad++
  - Currently under development
- MELCOR Glossary
  - User guide information available to text editor
  - Context intelligence
- Navigation sidebar
  - Object recognition
  - Double-click to jump to object definition
  - Support for distributed files
    - Master file and ‘included’ files
    - Objects read from all included files

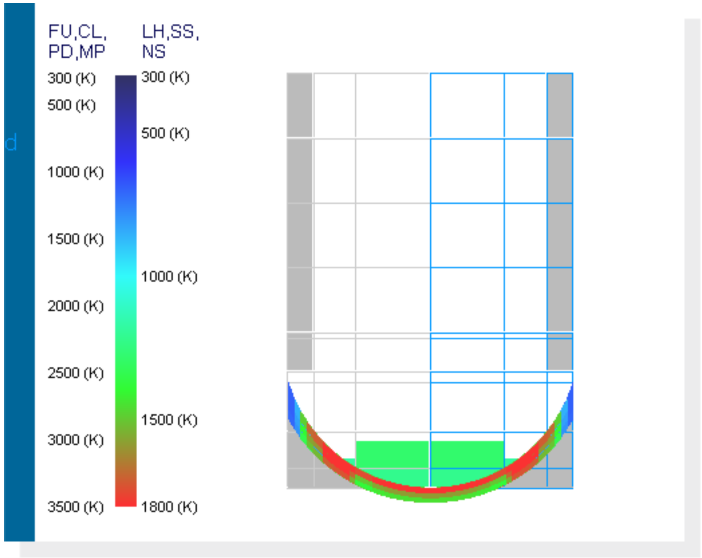


MELCOR Output

Output Tools: HTML Files

- HTML Time Edits
  - Specified with global input
    - MEL_HTMLFILE 'DEMON_Out.htm'
  - File for each time edit
  - Links to other time edits
  - Links to package edits/tables





Plot file structure

- The job title, with identification of the code version and the date and time of the run;
- A "key" to the plot variables available in each time record;
  - A list of plot keys is printed in the MELGEN output
- A list of "special" time-independent variables and their values; and
  - axial elevations, ring radii, CVH associated with each cell, HS names, RN class names, FP names, FP connections, etc.
  - **New**: MELCOR-VERSION(0) indicates the revision number of the code
    - i.e. 2.1.5254
  - **New**: MELCOR-SCRAM_TIME(0): Taken from the DCH_SHT record (default is at time=0.0 sec)
- A series of records containing problem time and all plotable variables at that time.

Plot Variables

- PLOT VARIABLES – CCC.n (character name followed by an index
  - Character name
    - The first characters are typically the name of the package that owns the data
  - Index
    - If the specified variable ends in a decimal point and a number, the number is taken as in index. Within MELCOR, a plot variable is treated as having at most one index; other decimal-delimited numbers are considered to be part of the name.
- Examples
  - CVH-P.150
    - denotes the pressure in CVH control volume 150.
  - CVH-MASS.3.150
    - denotes the density of material 3 (water vapor) in control volume 150. In this case, the '3' is considered to be part of the name and not an index.

Useful MELCOR Input

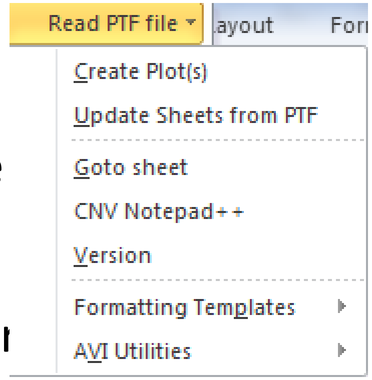
- EXEC_PLOT – Control function argument to be plotted
  - xxx is any three-character alphanumeric string, used for sequencing only
  - These records may be used to add elements of the MELCOR database that are available as control function arguments to the plot file on restarts.
- EXEC_PLOTCF – Special plot control function
  - This record specifies the number of a LOGICAL valued control function that will generate a plot dump if its value is .TRUE. If the control function is .FALSE., then a plot dump will still be generated if some other mechanism (e.g., time, physics package request) requests it.
- EXEC_FORCEPLOT – Control of extra plot information following timestep cuts
  - If there is a large timestep drop between consecutive cycles, MELCOR will generate plot dumps in addition to those defined by the TIMEk records described in this document.

Loading EXCEL Addin

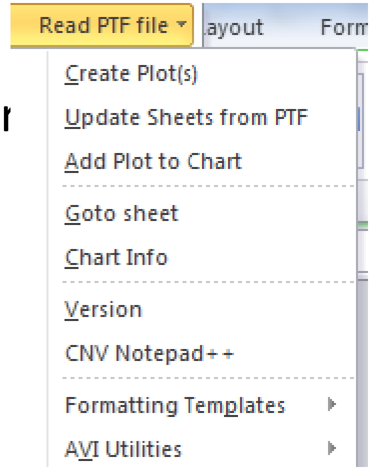
- Place the add-in in the user profile:
  - C:\Documents and Settings\Userprofile\Application Data\Microsoft\Addins\ (Windows XP)
  - The AddIn Path is a registry key value that indicates the search path for AddIns.
- This may require that you change the folder options so that hidden files and folders are visible.
- When PTFREAD.xla is located in this folder then it can be loaded from the add-in manager (Tools|Add-Ins). In this way the add-in is easily found in future sessions, it can be loaded automatically when EXCEL is started, and there are options for activating and deactivating the add-in at will.
- The alternate method is to open the add-in as you would any other EXCEL file (File|Open).

Creating EXCEL Plots From Binary Plot Files

- Create Plot
  - Creates a new EXCEL chart from a binary plot file
- Add Plot
  - Adds a new plot (series) to an existing EXCEL char read from a binary plot file

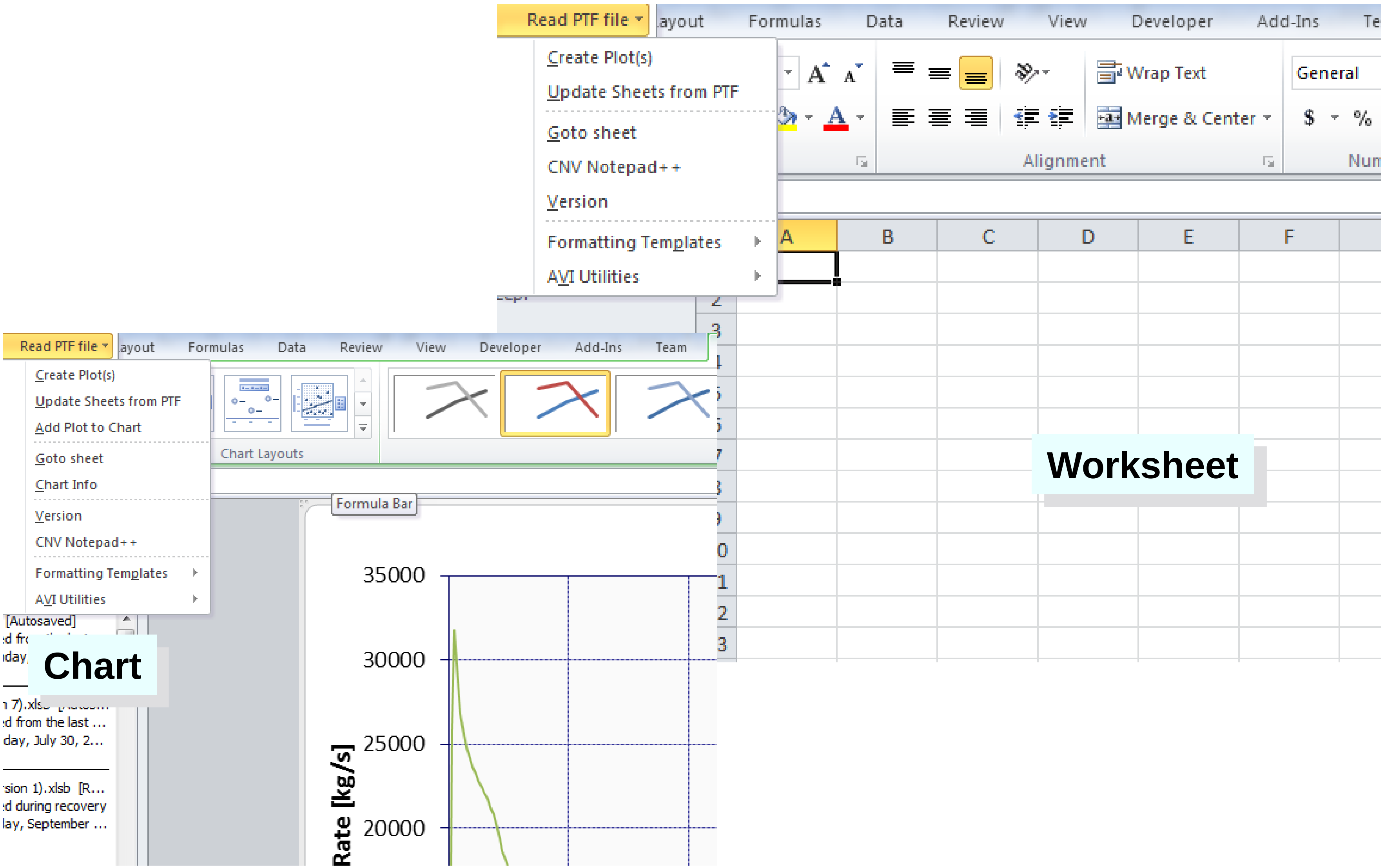


- Update Plot
  - Reads the binary plot file and updates selected wor associated charts
  - Only available when active sheet is a chart



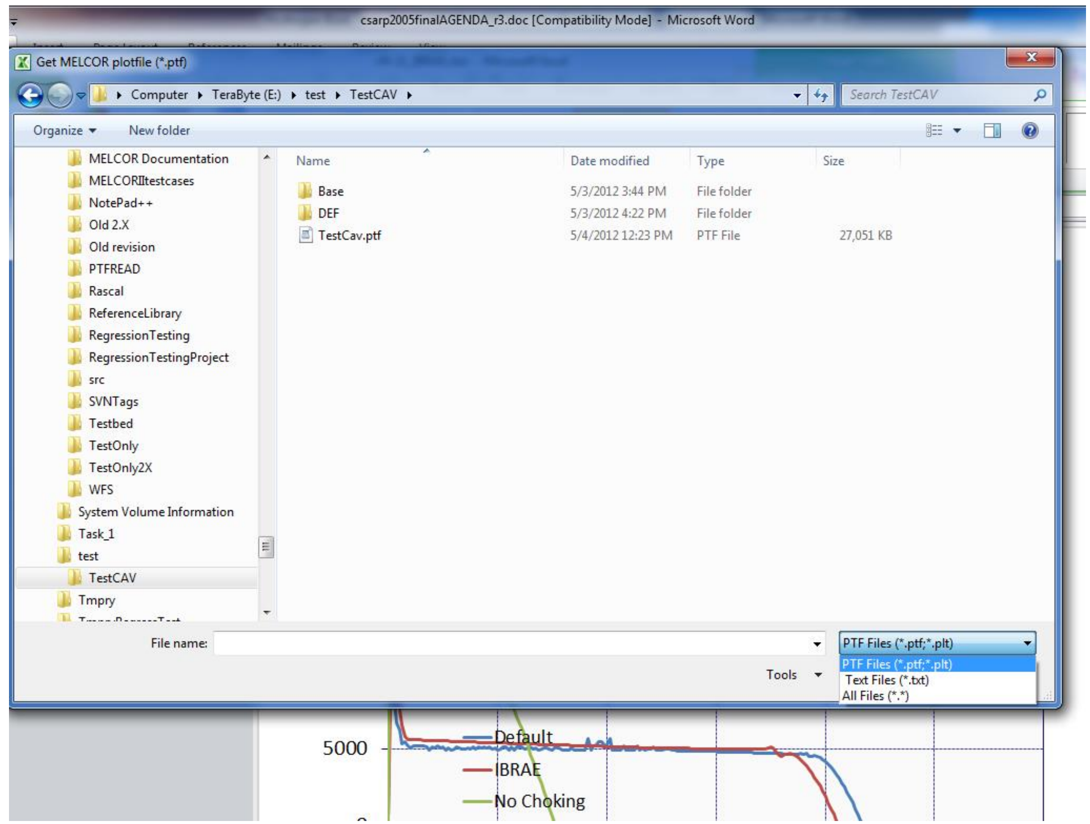
Drop-down Menu Varies Depending on Active Sheet

Plot File Tools: PTFREAD

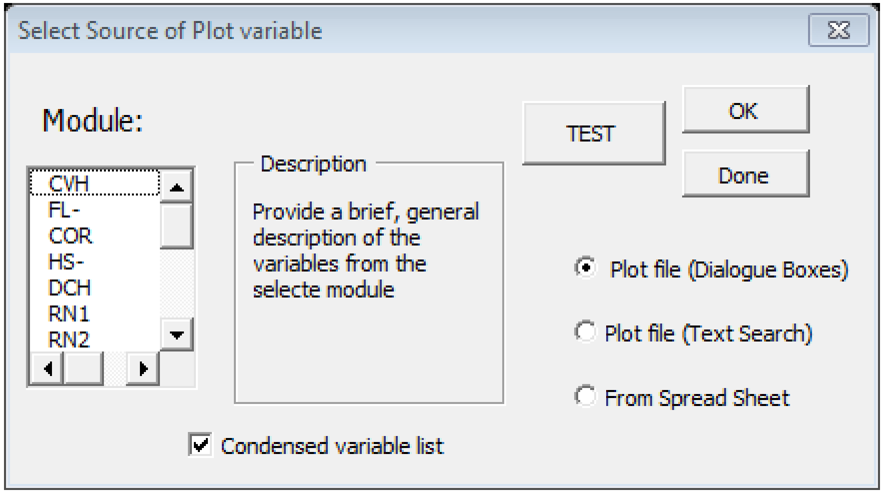


Select MELCOR Plot File

- Plot file selected from point-and-click window
- File type filter looks for *.ptf files, though all files are available
- Searches directory from last plot created



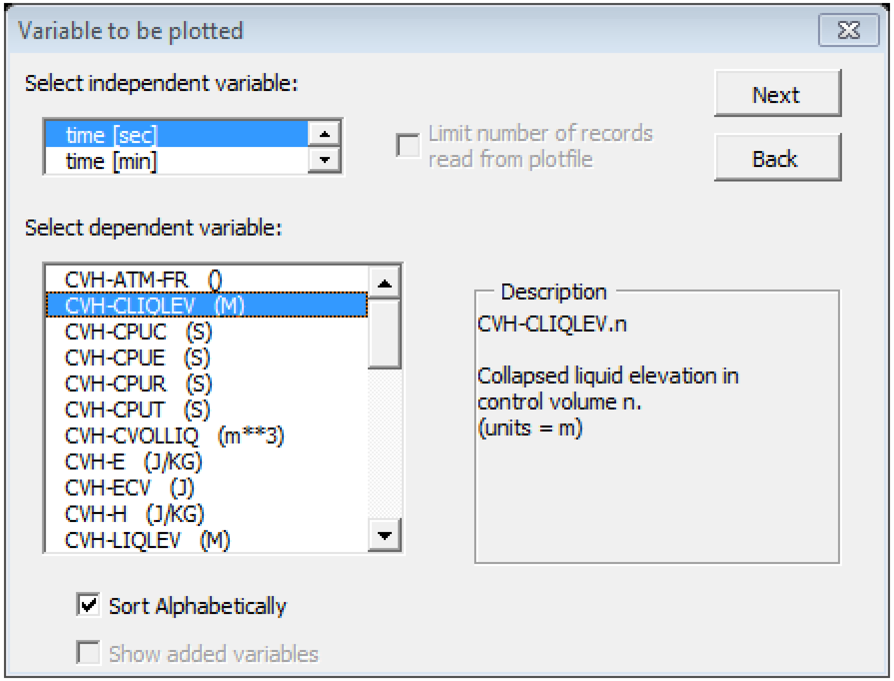
Select the MELCOR package (Level 1)



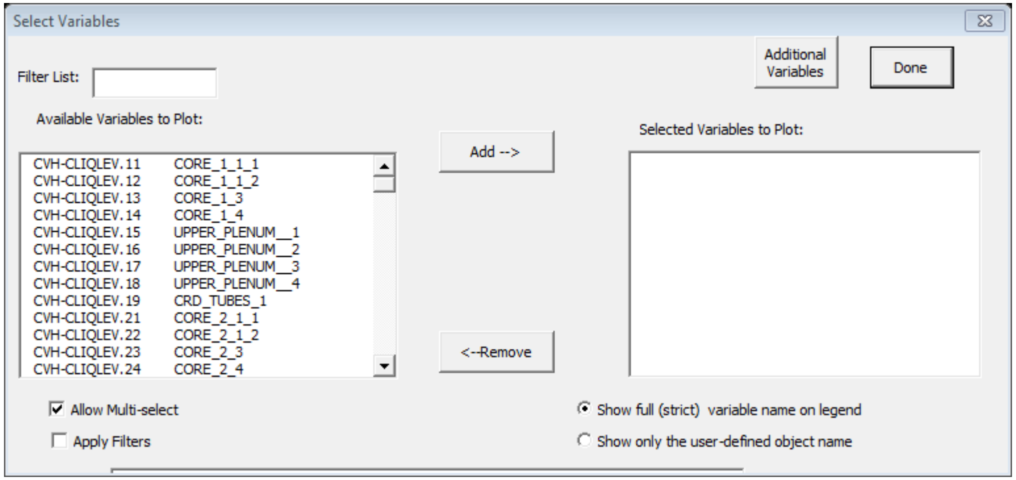
- Select set of standard plot variables associated with a particular MELCOR package
- Additional calculated variables available
- Select Dialogue box for description of variables associated with particular package provided
- Select Text search for faster access to plot variables (without dialogue help)

Select Variables Associated with Previously Selected Package (Level 2)

- Select independent variable (will remind you if you forget)
- Select dependent variable from list of available variables for MELCOR package
- Description of variable is provided
- Default units for dependent variable also provided
- Control Function variables added to plot file can be plotted if available by checking 'show added variables'



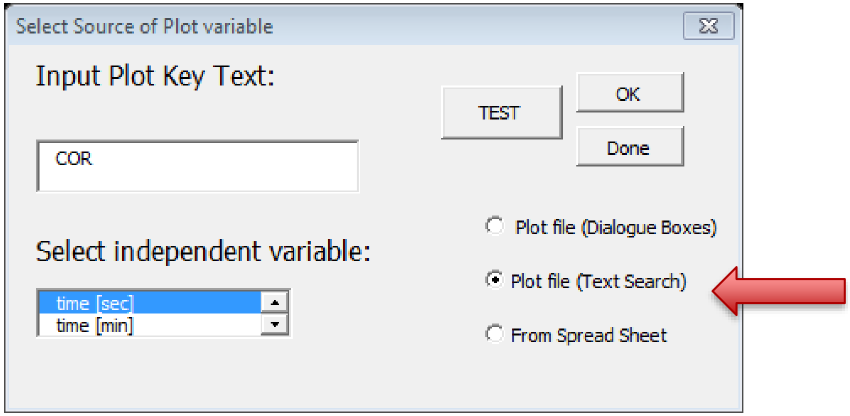
Construct Plot Variables List (Level 3)



- Add variables from the 'Available Variables' list to the 'Selected Variables' list
- Can remove variables from the 'Selected Variables' list
- Can add additional variables not in current list, i.e., other flow variables or even variables from other packages. (Level 1)
- Descriptive information provided if available, i.e., control volumes connecting flow path, name of control volume name of flow path, name of radionuclide class, name of material, name of heat structure, etc.
- Allows multi-selection of variables
- Do not mix variables with dissimilar units at this time

Optional Method for Constructing Plot

- Enter text search string on level 3 input.
- Recognizes '*' as wildcard
- Recognize '!' to indicate position at end of variable name.
- Useful in plotting all temperatures at a single elevation or all temperatures in a cell



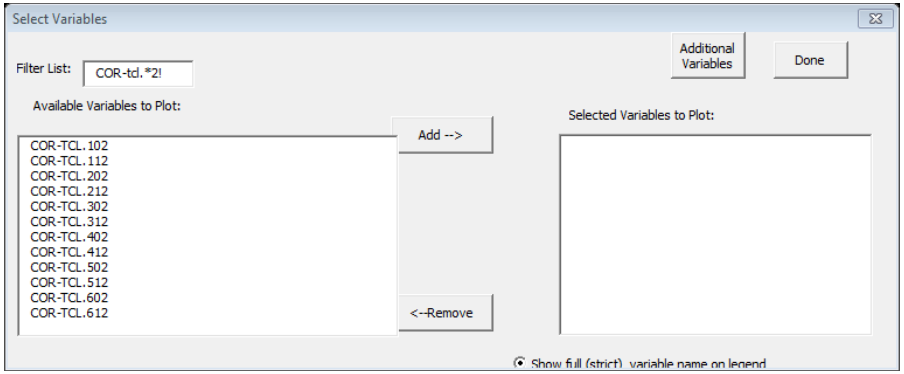
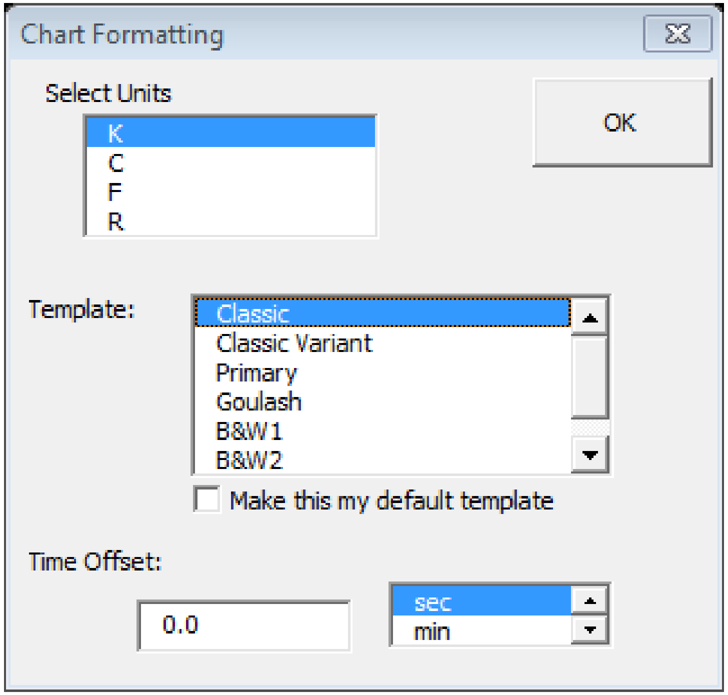


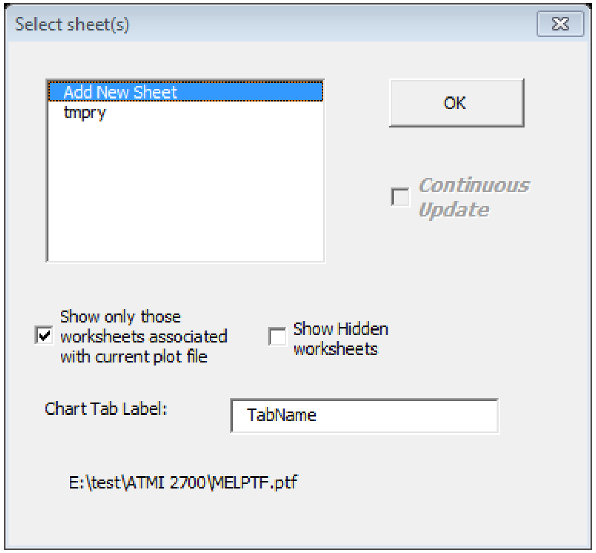
Chart Formatting

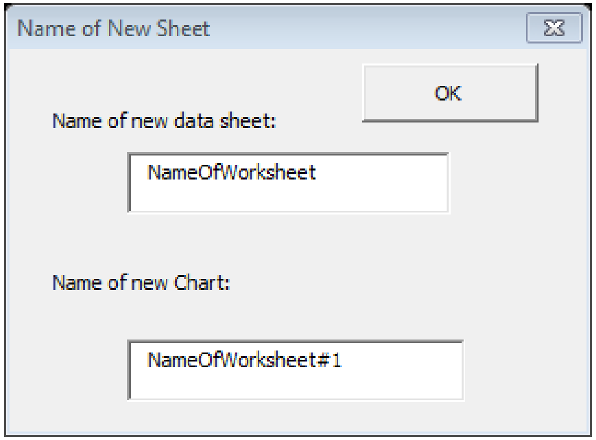
- Select Name of Template
- Default units on plotfile converted before storing to spreadsheet
  - Kg (kg, gm, lb, MT)
  - K (K, C, R, F)
  - Pa (Pa, MPa, psi, atm, bar)
  - KG/m^3 (kg/m^3, gm/cm^3, lb/ft^3)
  - m (m, cm, ft, in)
  - m^3 (m^3, gal)
  - J (J,KJ, MJ,)
  - W (W, KW, MW)
  - kg/s (kg/s, kg/min, kg/hr, gm/s, gm/min, gm/hr, lb/s, lb/min, lb/hr)
  - m/s (m/s, cm/s, ft/s, in/s, m/min, cm/min, ft/s, in/min, m/hr,) cm/hr, ft/hr, in/hr
- Time offset for all plots in a spreadsheet
  - i.e., 10 minute offset means that 600 seconds subtracted from time array on spreadsheet



Plotfile Data Added to EXCEL Worksheet

- Plot variables are added to existing worksheet or new worksheet created
- Sheet named ‘tmpry’ is a temporary worksheet that is destroyed each time a new chart is created
- User can hide worksheets and variables can be added to hidden worksheets





Structure of Time/ Value Worksheet

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	A	B	C	D	E	F	G	H	I	J	K
1	time (sec)	time (min	time (hr)	ncycle	COR-TCL.102	COR-TCL.112	CC				-TCL
2											
3	0	2			K	K	K				
4	-200	-3.33333	-0.05556	0	0	555					
5	-199.8	-3.33	-0.0555	2	0	567.0768					
6	-199.461	-3.32435	-0.05541	6	0	593.6505					
7	-199.204	-3.32007	-0.05533	12	0	614.5259					
8	-194.995	-3.24991	-0.05417	251	0	623.2606					
9	-190	-3.16666	-0.05278	629	0	621.9626	0	621.8493	0	621.7194	
10	-184.995	-3.08326	-0.05139	1071	0	622.0959	0	621.96	0	621.8006	
11	-179.99	-2.99984	-0.05	1510	0	621.5833	0	621.4476	0	621.2964	
12	-174.998	-2.91664	-0.04861	2132	0	621.9352	0	621.7955	0	621.6341	

E:\test\ATMI 2700\MELPTF.ptf
Processed: 3:23:31 PM 11/7/2012

COR-TCL.n
Temperature of Zircaloy cladding in cell n.
(units = K)

- First four columns (yellow) on a time/value worksheet contain time information
- Variables added to an existing worksheet are placed in first available column to right of existing columns
- First row contains variable name
- Third row contains unit
- Second row available for user information
- Comment in header row provides plotfile/ process time information
- Time offset (seconds) in row 1 of column A

Comparison of Variables from Two Calculations

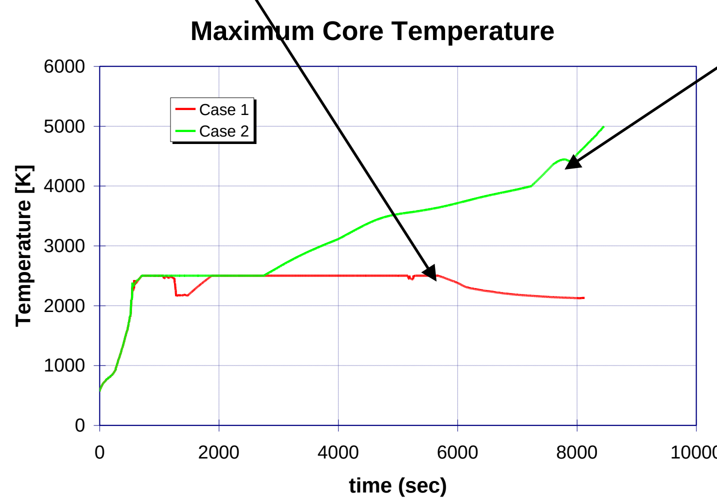
Plot File Tools: PTFREAD

	A	B	C	D	E	F
1	time (sec)	time (min)	time (hr)	ncycle	Max. Temp.	
2						
3	0	2			K	
4	0	0	0	0	565	
5	2	0.033333	0.000556	2	583.0339	
6	4	0.066667	0.001111	4	594.1201	
7	6	0.1	0.001667	6	600.3292	
8	8	0.133333	0.002222	8	603.6857	
9	10	0.166667	0.002778	10	605.6039	
10	12	0.2	0.003333	12	606.5465	
11	14	0.233333	0.003889	14	609.6237	
12	16	0.266667	0.004444	16	615.7722	
13	18	0.3	0.005	18	621.6302	
14	20	0.333333	0.005556	20	627.2025	

CVH0 / HS / COR / aaaa / **Case 1** / Case 2 / Case 1#1

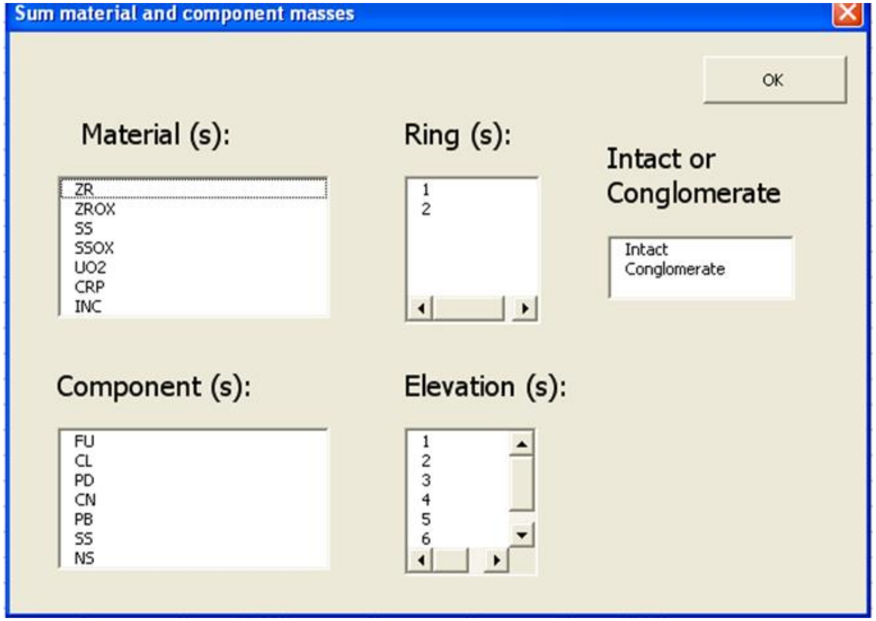
	A	B	C	D	E	F
1	time (sec)	time (min)	time (hr)	ncycle	Max. Temp.	
2						
3	0				K	
4	0	0	0	0	565	
5	2	0.033333	0.000556	2	583.0339	
6	4	0.066667	0.001111	4	594.1201	
7	6	0.1	0.001667	6	600.3292	
8	8	0.133333	0.002222	8	603.6857	
9	10	0.166667	0.002778	10	605.6039	
10	12	0.2	0.003333	12	606.5465	
11	14	0.233333	0.003889	14	609.6237	
12	16	0.266667	0.004444	16	615.7722	
13	18	0.3	0.005	18	621.6302	
14	20	0.333333	0.005556	20	627.2025	

CVH0 / HS / COR / aaaa / Case 1 / **Case 2** / Case 1#1 / tmp



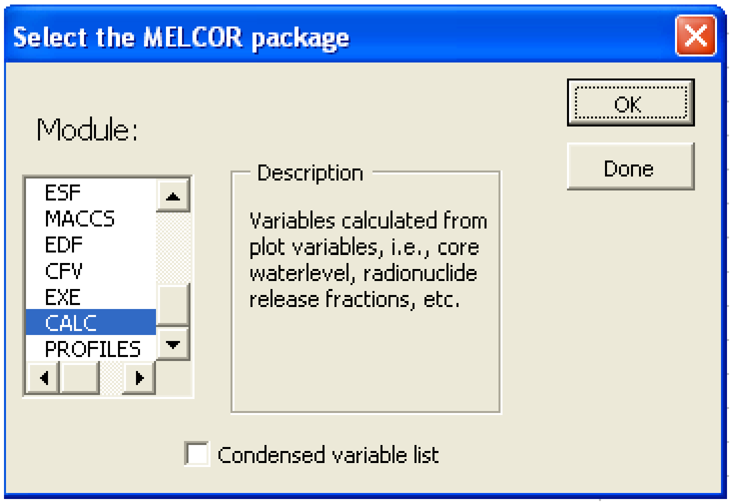
Calculated Variables

- Core water level
  - Swollen or collapsed water level
  - no more stair-stepped plots
- Fission product release
  - release to particular CVHTYPE or Total release
  - Done with user functions in HISPLT
- Maximum core temperatures
  - clad, particulate, fuel, or total
- Local maximum temperature
- Masses (by component, by rings, by levels, by material, by intact/conglomerate

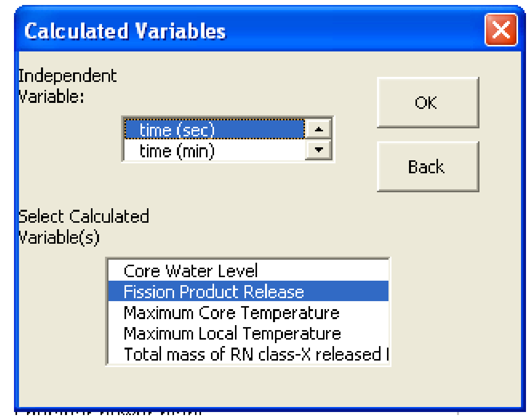


Fission Product Release Fractions (1)

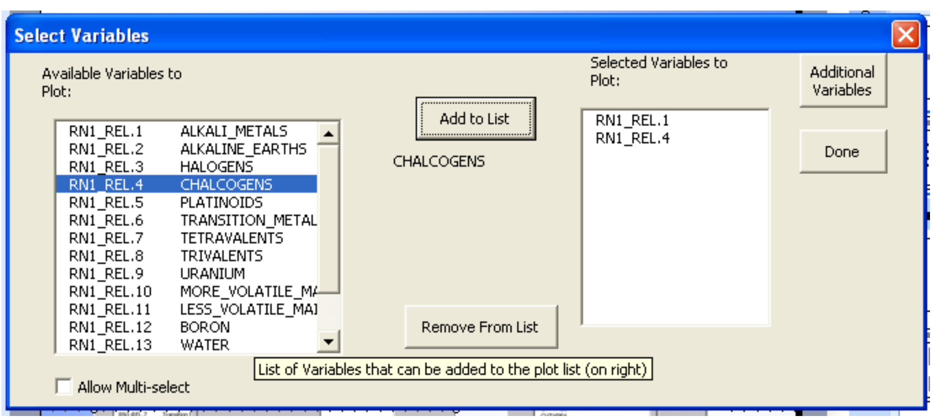
1) Select Calculated Variables



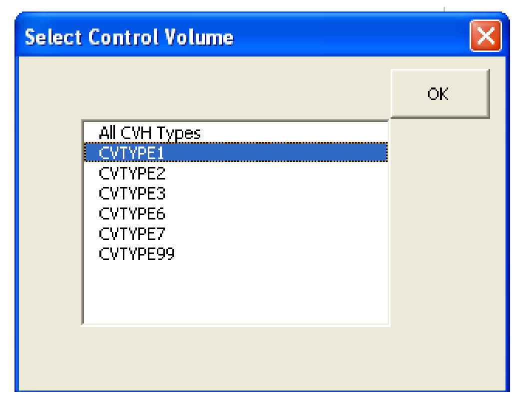
2) Select Fission Product Release



3) Select RN Classes

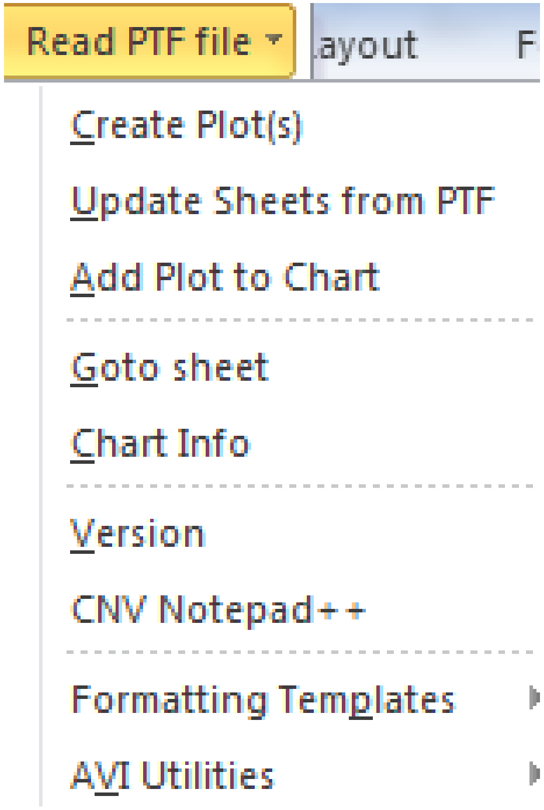


4) Select Control Volume Types



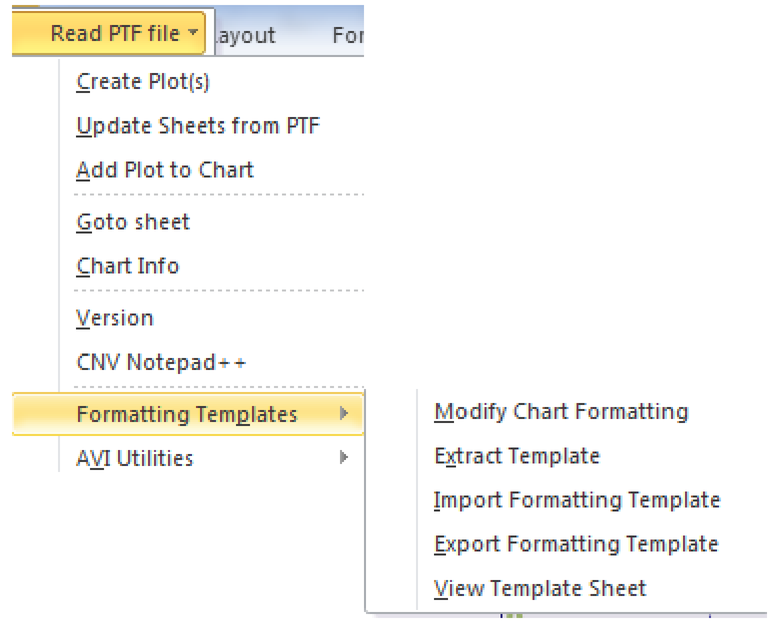
Useful Utilities

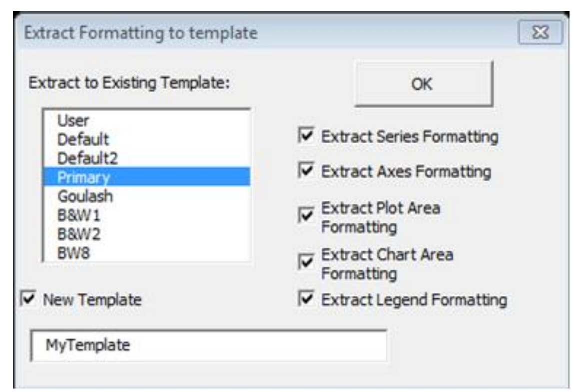
- Chart Info
  - Tools for obtaining information on location and pedigree of data plotted
- Goto sheet
  - Tool for navigating through large number of EXCEL sheets
- CNV Notepad++
  - Reads an input deck and formats it so that Notepad++ is able to outline package/object input
- Formatting Templates
  - Users can create custom templates that PTFREAD uses in generating charts. User can modify a chart through the EXCEL interface and then extract formatting to a template



Managing Formats

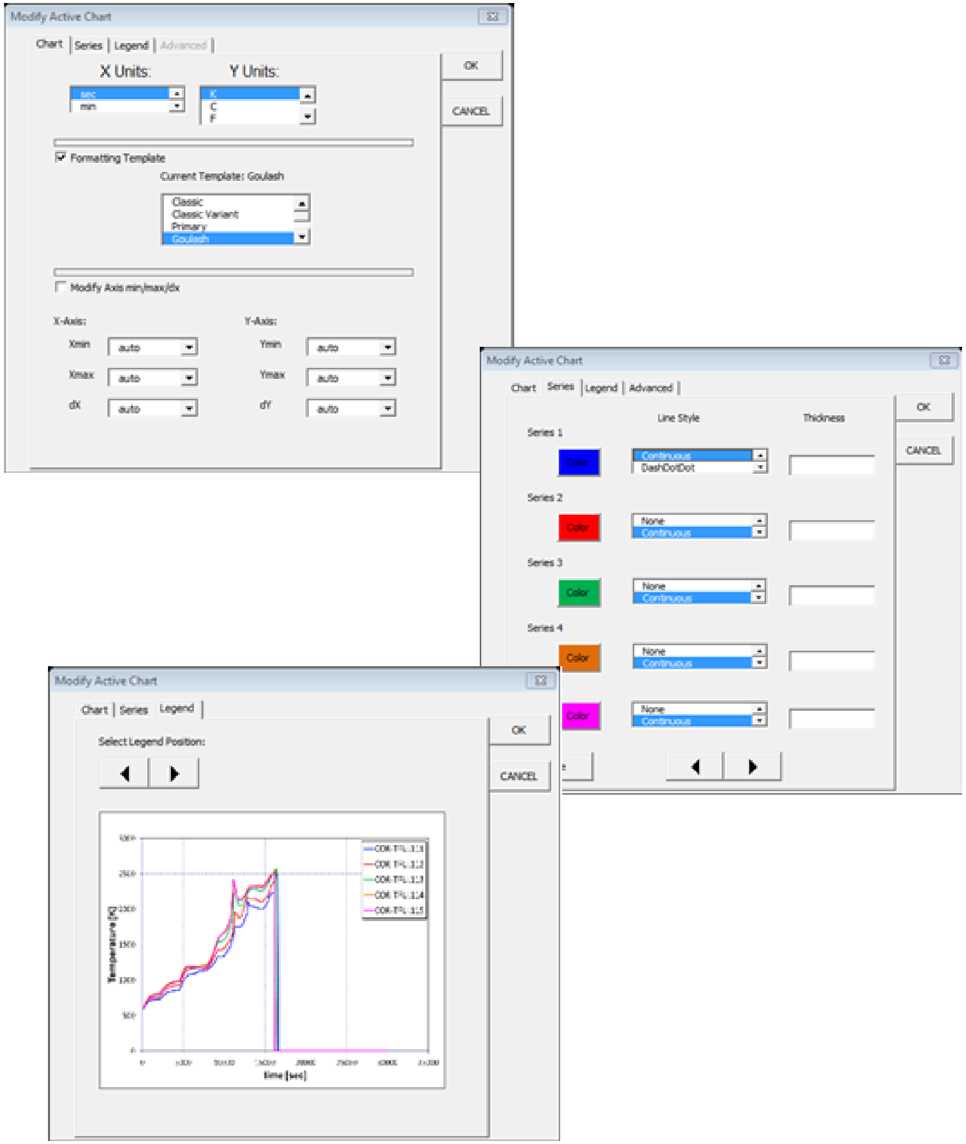
- Modify Chart Formatting
  - Make changes to the active chart and optionally to apply a template to the plot. Some formatting changes can be made to the template at this time
- Extract Template
  - Read the formatting from the activechart and apply this formatting to a saved format template
- Export Formatting Template
  - Write the formatting information from a formatting template to a file
- Import Formatting Template
  - Read the formatting information from a text file an save as a formatting template.





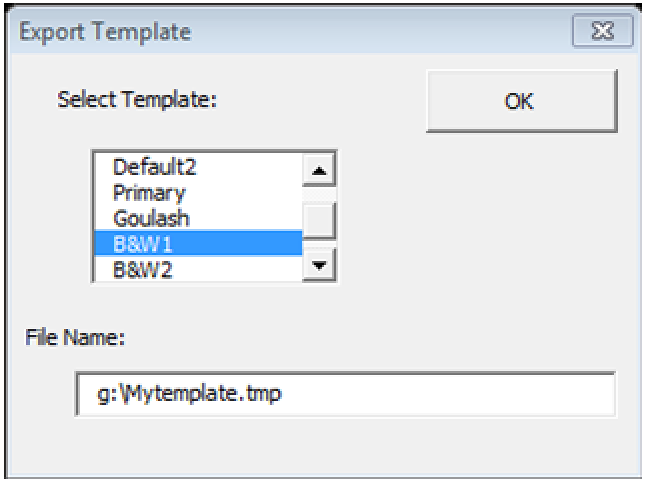
Modify Chart Formatting

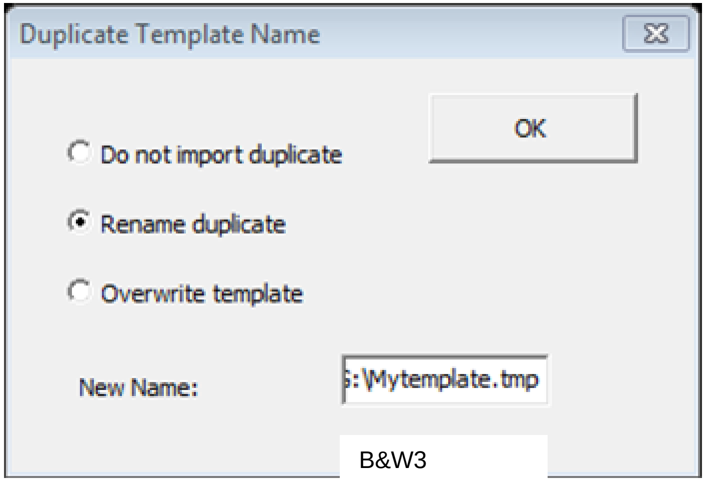
- ‘Chart’ Tab
  - Make changes to chart units, select alternate formatting template, and mofify axis min/max
- ‘Series Tab’
  - Make changes to formatting for plot series , i.a., line color, line style, and line thickness
- ‘Legend’ Tab
  - Make changes to the legend. Currently only placement of legend is changed here
- ‘Advanced’ Tab
  - Currently not active



Export/Import Templates

- Export Template:
  - User supplies name and location of text file
  - User selects internal Formatting Template
- Import Template:
  - User must resolve situation with duplicate template names





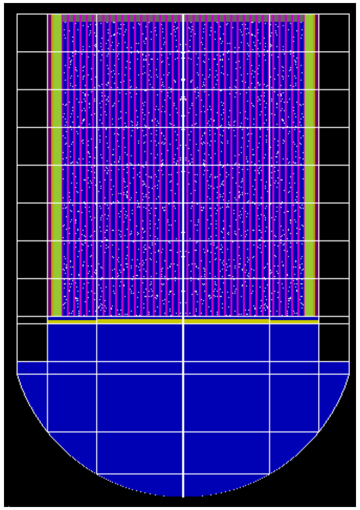
PTFREAD
Node Initialization Table

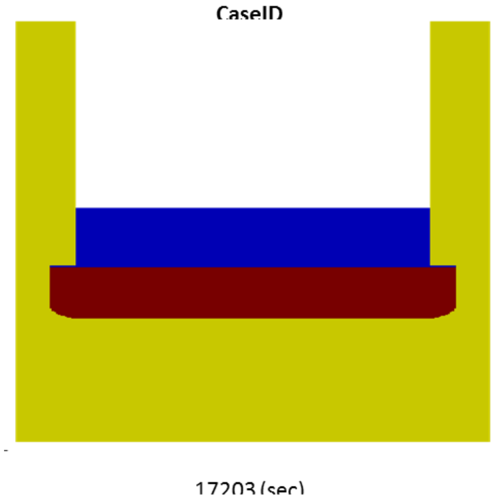
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1														
2		hsn	name	nodes	mult	left CVH	right CVH	left area	right area	geometry	hslaxl	hsraxl	bottom altitude	orientation
3	1	10001	PRIMARY	5	1	160	300	105.0549	115.5603	CYLINDRI(	7.6	7.6	5.4	Vertical
4	2	10002	DRYWELL	5	1	200	300	500	500	RECTANG	20	20	-6	Horizontal
5	3	11003	CSB_LEV	5	1	120	160	5.654867	5.811946	CYLINDRI(	0.5	0.5	5.4	Vertical
6	4	11004	CSB_LEV	5	1	120	160	1.130973	1.162389	CYLINDRI(	0.1	0.1	5.9	Vertical
7	5	11005	CSB_LEV	5	1	111	160	11.30973	11.62389	CYLINDRI(	1	1	6	Vertical
8	6	11006	CSB_LEV	5	1	111	160	11.30973	11.62389	CYLINDRI(	1	1	7	Vertical
9	7	11007	CSB_LEV	5	1	111	160	11.30973	11.62389	CYLINDRI(	1	1	8	Vertical
10	8	11008	CSB_LEV	5	1	111	160	11.30973	11.62389	CYLINDRI(	1	1	9	Vertical
11	9	15001	SHROUD_	5	1	150	150	12	12	RECTANG	4	4	10.1	Horizontal
12	10	15002	SHROUD_	5	1	150	150	12	12	RECTANG	4	4	10.1	Horizontal
13	11	15003	SHROUD_	5	1	150	150	12	12	RECTANG	4	4	10.1	Horizontal
14	12	20001	WETWELL	5	1	0	200	0	500	RECTANG	0	20	-27	Horizontal

Geometry | HS Input | COR Input | FL Input | CVH Input | Sheet2 | Sheet3

PTFREAD Visualization of Results

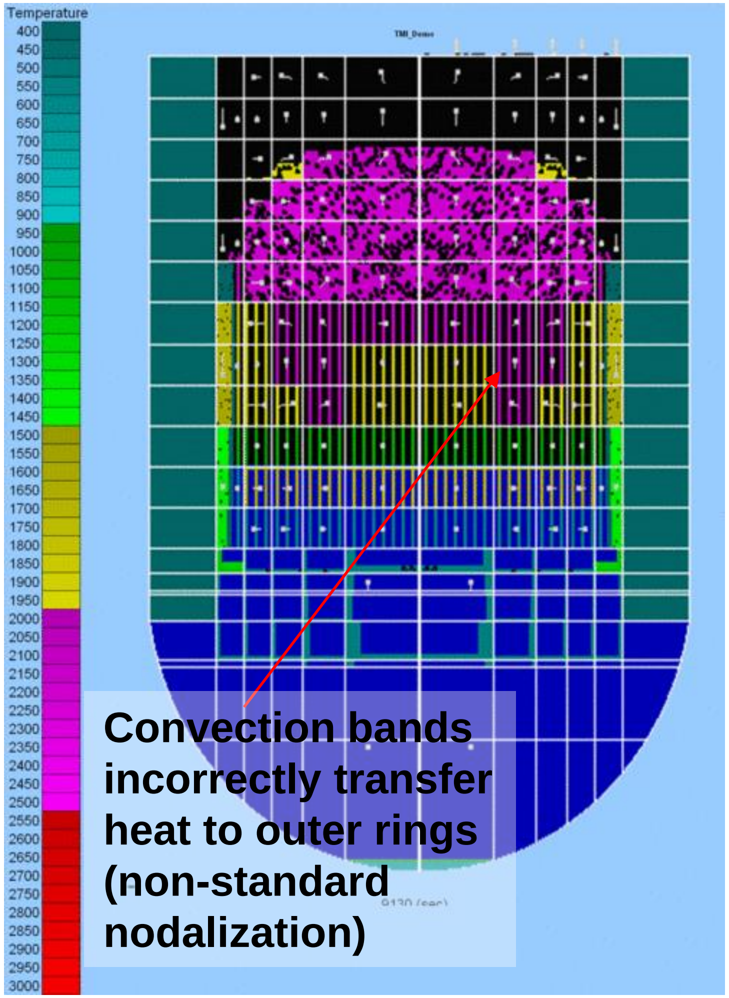
- Several variants available
  - COR package
    - Components: Fuel rods, support structures, Heat structures
    - Temperatures
    - Porosity of debris
    - Bubbles in flow
    - Flow vectors
  - CAV package
    - Geometry of CAV package
    - Ablation shapes
    - Layers
    - Bubbles from gases and steam





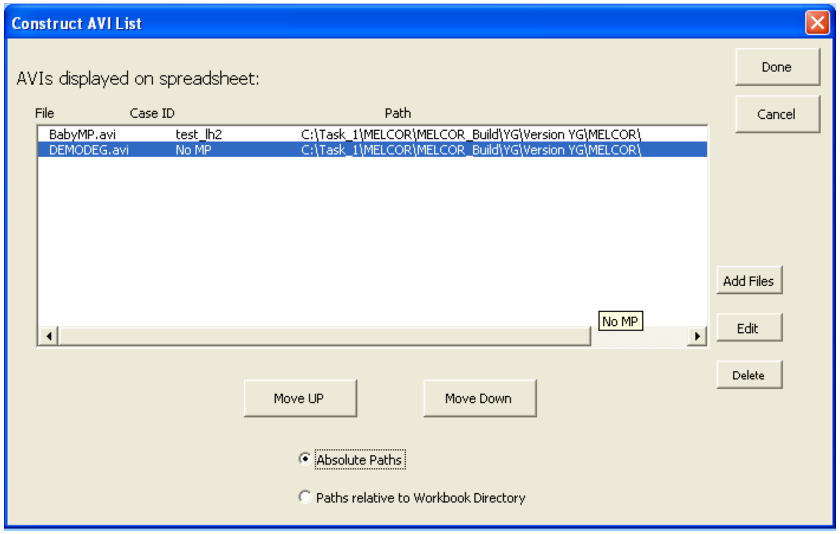
PTFREAD AVI Capabilities

- Option to indicate temperature of component by color
- Flow velocities
  - If horizontal flow paths exist
    - Vertical component
      - linear interpolation of the vertical flow velocity at the flow path junction height horizontal velocity
    - Horizontal component
      - taken from the horizontal flow path.
    - Vector is positioned at the radial center of the CV & the horizontal flow path junction height.
  - If a horizontal flow path does not exist
    - The vertical velocity component in a control volume is calculated as the average of all inlet and outlet vertical flow velocities and a vector is drawn at the center of the control volume.



PTFREAD
Add/Edit AVI

[Add Files](#)
[Edit Files](#)
[Delete](#)
[Move Up/Down](#)
[Absolute Paths](#)
[Paths Relative to Workbook](#)
[Case ID](#)

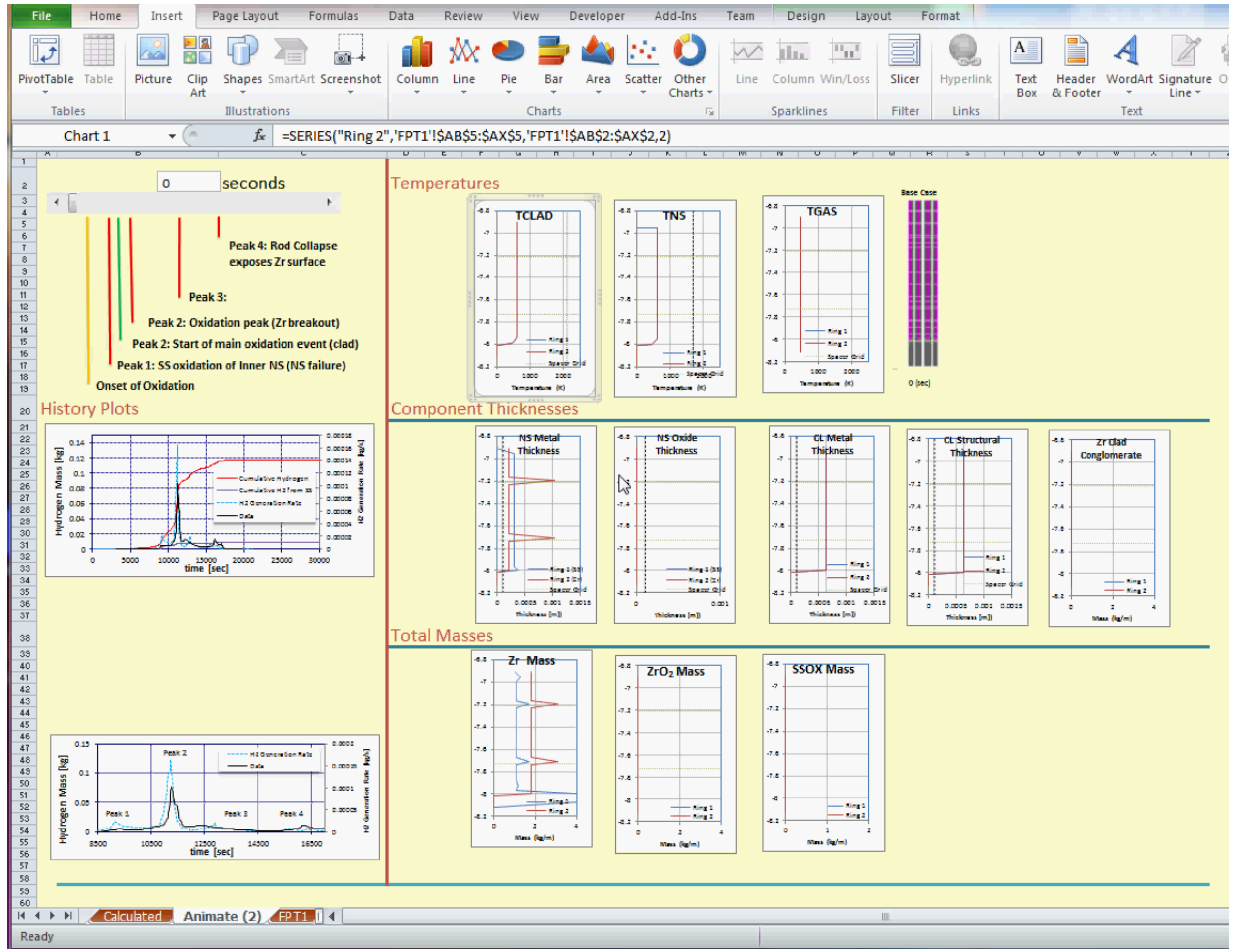


Delete

Delete selected AVI object from active spreadsheet.

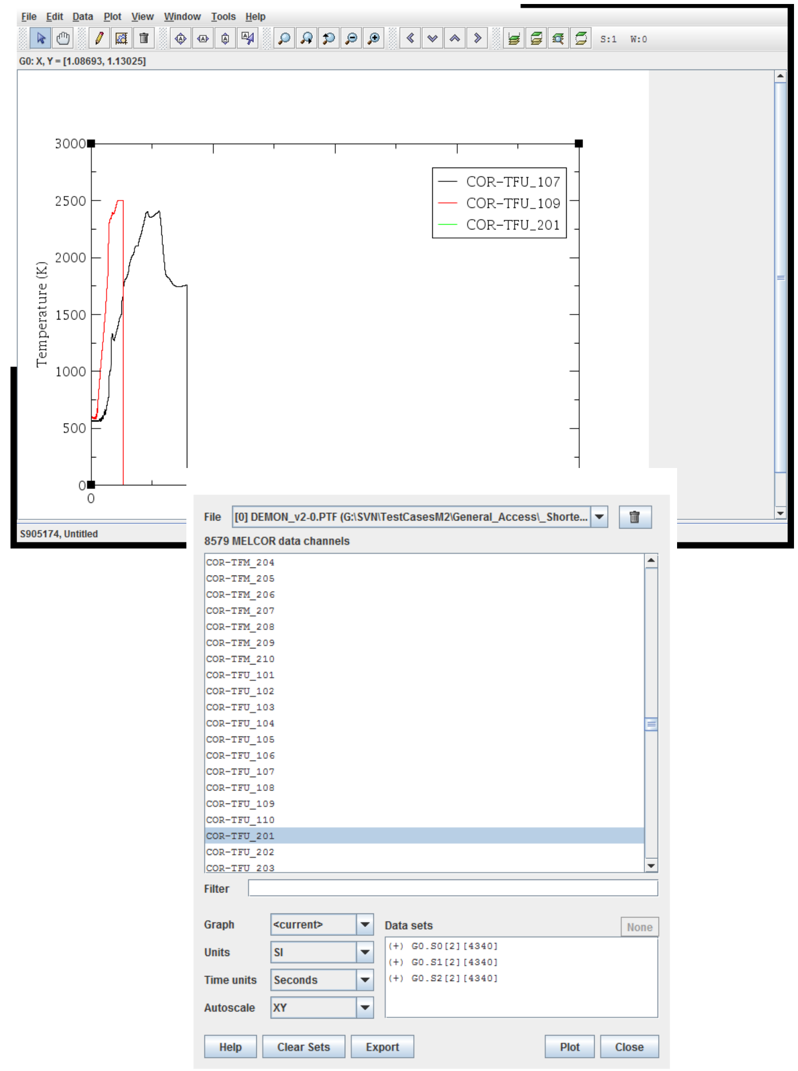
PTFREAD-Animated Charts

- Animation of multiple plots and BMPs on a single worksheet
  - History plots
  - Profile plots
  - COR degradation images
  - CAV images
- Comparison of multiple MELCOR runs
- Simple to generate
  - Copy and paste to AVI page



AptPlot – Available with SNAP

- Plotting routine for generating plots for various NRC analytical packages
  - RELAP5, MELCOR, TRACE, FRAPCON, COBRA, PARCS, CONTAIN
- Runs on various platforms
  - Windows, Unix
- Several chart formats available
  - XY graph, XY chart, Polar graph, Pie charts
  - Limited control over formatting of plots
- Some data manipulation available
  - A bit clumsy
- Used mostly by Unix users when PTFREAD is unavailable
  - Windows integration is a bit clumsy
    - Unable to copy and paste to/from clipboard
    - Quality of plots is poor



READPTF FORTRAN Utility

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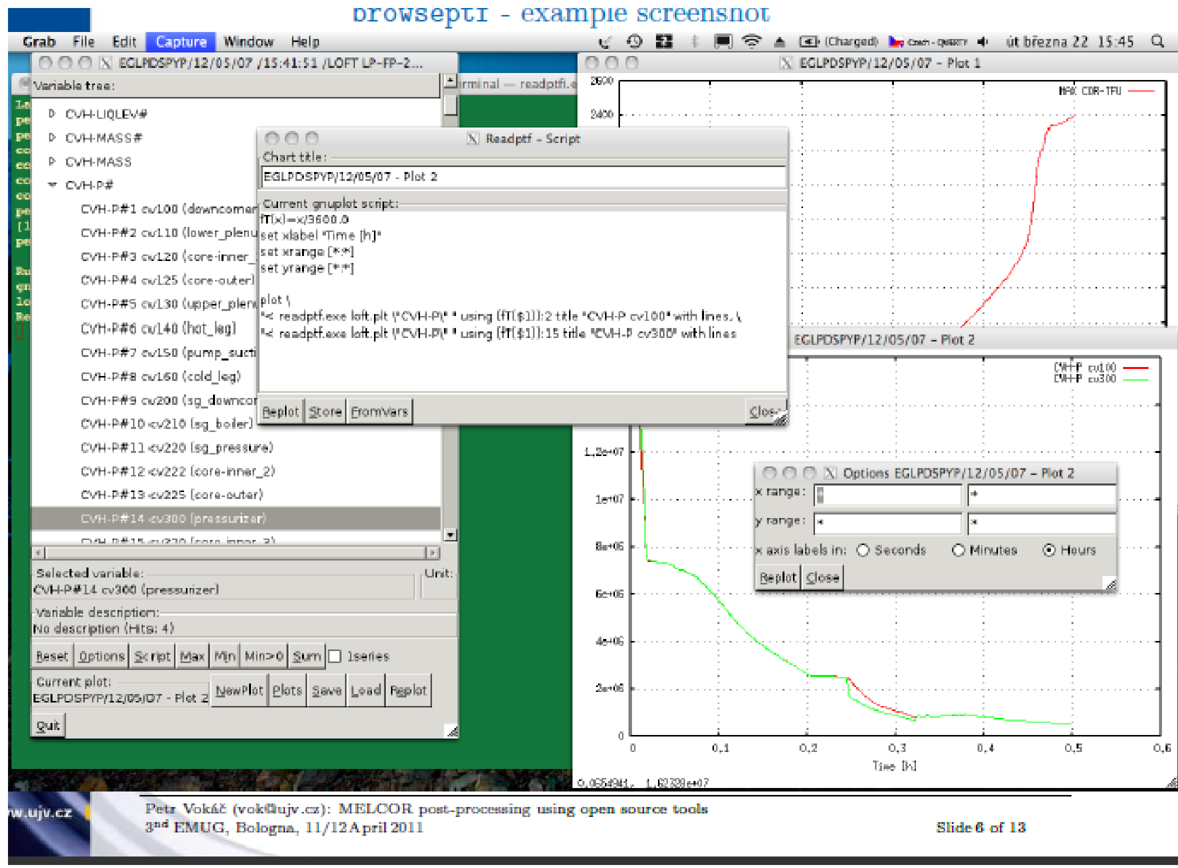
- Developed by Petr Vokac, NRI Rez
- Runs on Linux machines
- Command line utility



HISPLT – plotting package

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- Powerful for its day but not generally used today
  - SAND91-1767
  - Used for very large plotfiles >2GB which EXCEL was unable to handle
- Uses a Free-form input processing language
- Does not produce publication quality plots directly

Summary

- Tools are available for working with input
  - NotePad++, SNAP, etc.
- Many tools are available for post-processing results
  - PTFREAD, SNAP, APTplot, ReadPTF, HISPLT
  - Available on various platforms
  - Some are easier to work with than others
  - Recommend using PTFREAD or SNAP

MELCOR Hydrodynamics

Prepared by
MELCOR Development Team

MELCOR Hydrodynamics Overview of Presentation

- **Limited discussion of formulations**
  - In-depth descriptions on models are found in the Reference Manual
- **Concentrate on user input**
  - Essential aspects first
    - Show simplest options, but note existence of others
  - Will add more features as the workshop progresses
    - Must defer things involving other packages until later
  - Illustrate with specific examples of MELGEN input
- **Start development of a complete plant model**
  - Present description of problem for Exercise 1
  - All example input will be drawn from this problem

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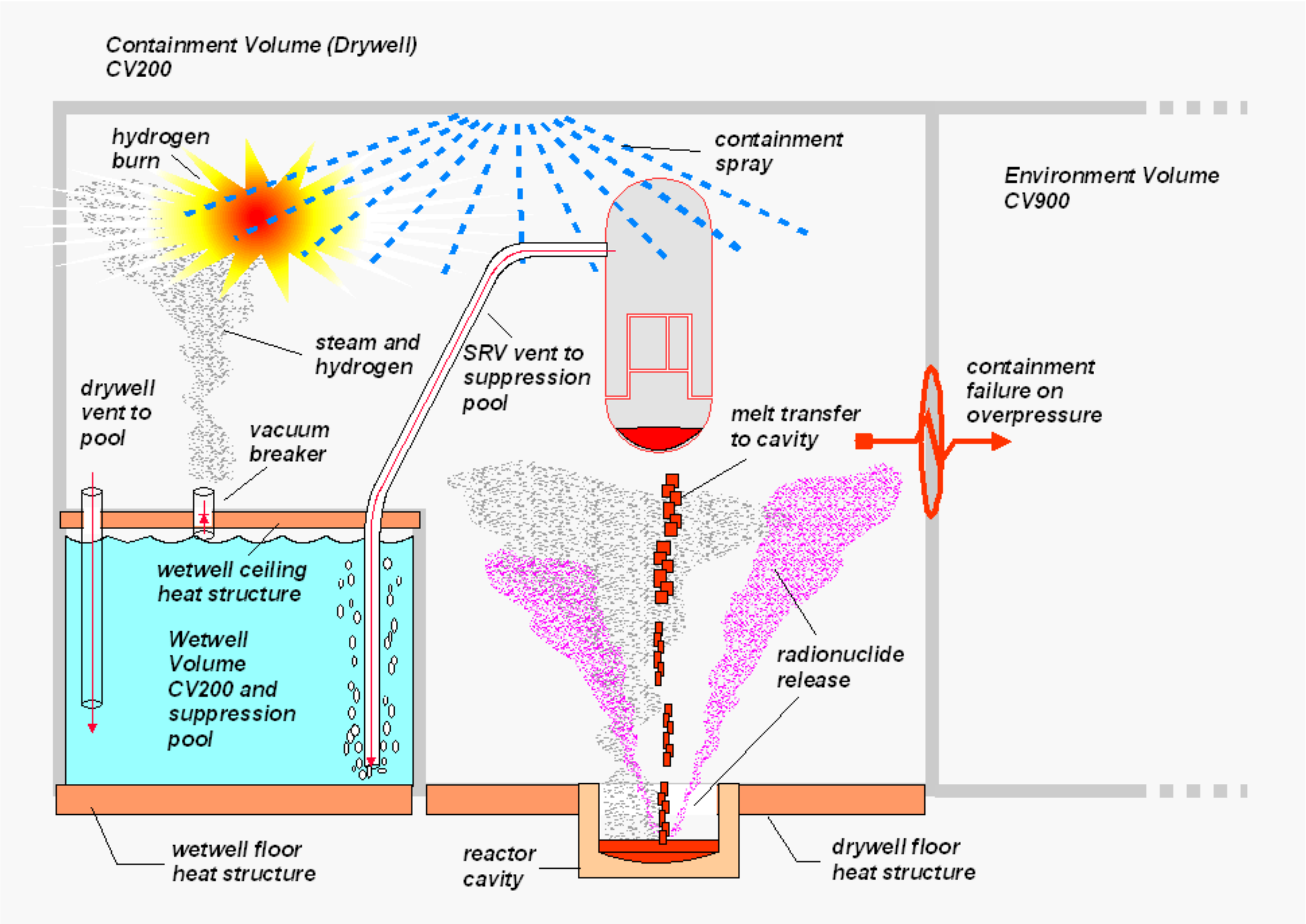
MELCOR Tutorial
Schematic of Test Problem



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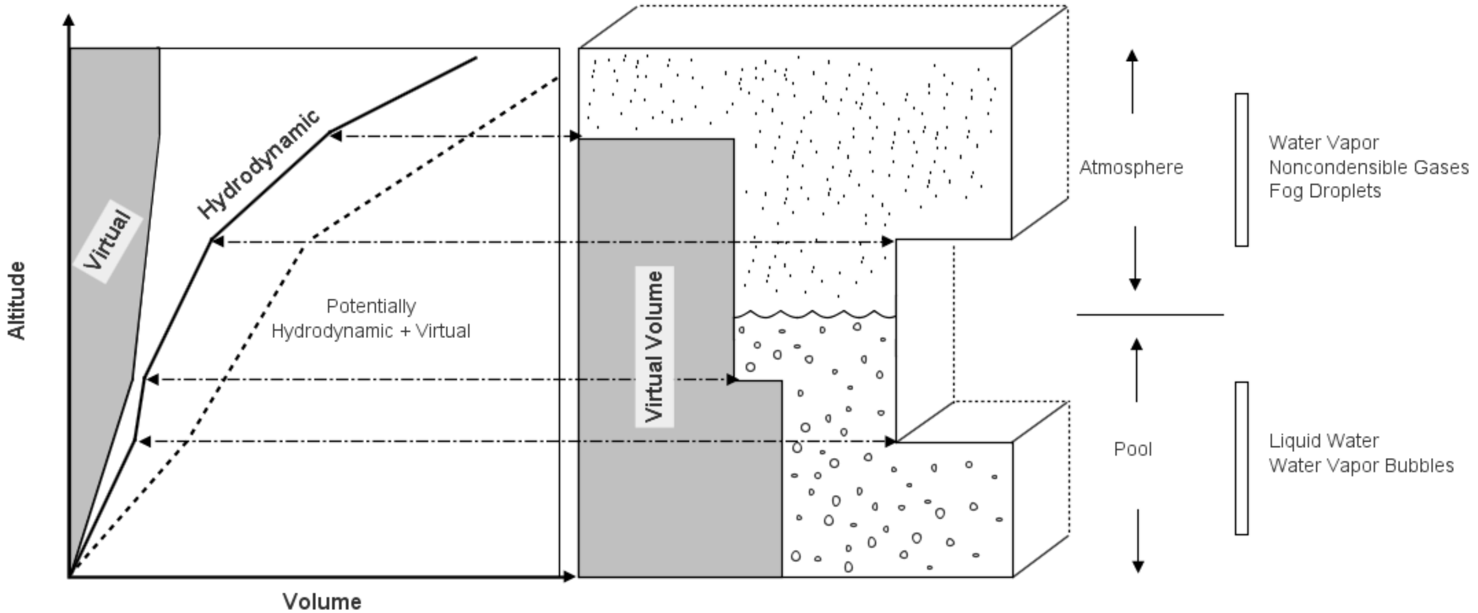
MELCOR Hydrodynamics Control Volume Basics

- **Control volume**
  - An arbitrary region of space filled with hydrodynamic material and associated energy (Water and NCGs)



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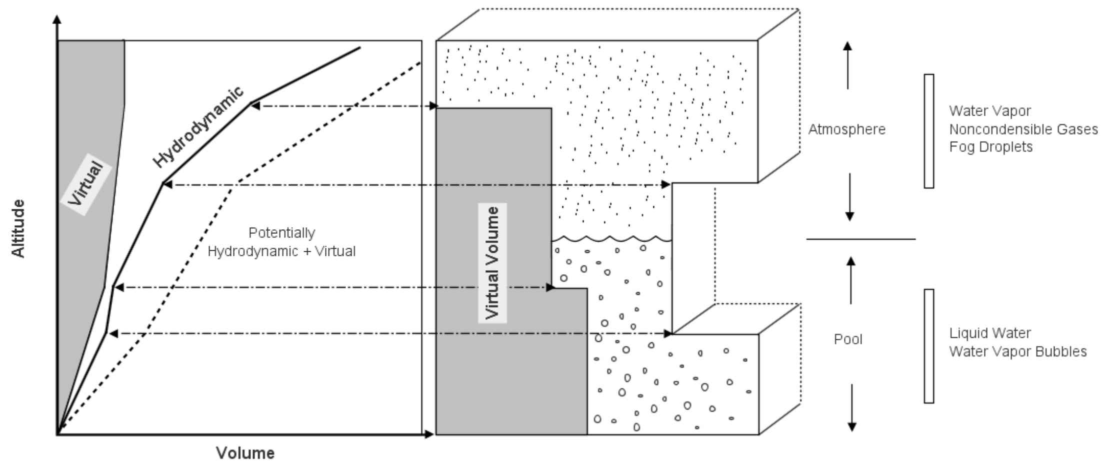
MELCOR Hydrodynamics Control Volume Basics

- Control volume partitioned into two fields
  - Fields are called "pool" and "atmosphere"
    - Stratification under gravity
  - Each in complete internal thermodynamic equilibrium
  - Limited disequilibrium between fields
    - Equal pressures, unequal temperatures
    - User input can force complete equilibrium



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MELCOR Hydrodynamics Pool and Atmosphere

- Pool can contain vapor bubbles, but no noncondensible gases
  - Liquid in equilibrium with bubbles
- Atmosphere can contain liquid droplets, called “fog”
  - Droplets in equilibrium with water vapor
- Pressure equilibrium between fields
  - Pressure defined at interface (or top or bottom of volume)
  - Stratification assumed in calculating static head terms for flow between volumes
- Coupling between fields
  - Mass exchange from condensation or evaporation
  - Momentum exchange driven by relative velocity

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MELCOR Hydrodynamics Materials

- **Water**
  - Full two-phase formulation from Helmholtz function
    - Based on Keenan and Keyes, agrees with steam tables
  - Data are thermodynamically consistent (Maxwell relations)
    - Derivatives are accurate, etc.
- **Noncondensible gases**
  - Pressure from ideal gas law
  - Thermal equation of state from analytic fit to $C_v(T)$
    - Built in properties library for 14 gases (H_2, N_2, O_2, etc.)
      - Default properties can be modified from input
    - Provision for 10 user-defined gases
      - All properties from user input

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MELCOR Hydrodynamics CVH Package Input

- Defines all volumes and their initial contents
- Required input for each volume
  - User-defined name and RN “type” flag
  - Volume geometry and flow direction
  - Initial contents, thermodynamic state, and EOS option
- Optional input for each volume
  - Volume number (treat it as though it was required)
  - Flow area, used to convert through-flow to velocity
    - Used in heat transfer correlations only
    - Default is volume/height, appropriate for vertical flow
  - Initial volume-averaged velocities for pool, atmosphere
  - Mass and/or energy sources/sinks
  - Additional model flags

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MELCOR Hydrodynamics CVH Input Records

- Following examples are from a simplified plant deck
  - Boiling water reactor (BWR)
  - Correspond to no known reactor
  - At best, data intended to be "not unreasonable"
- Next slide shows CVH nodalization of vessel
  - Nodalization in core package may be different
  - Channel and bypass modeled as separate volumes
  - So-called "volume/altitude table" describes shape
    - In effect, represent single volume as stacked sections
  - Quite simple compared to current practice

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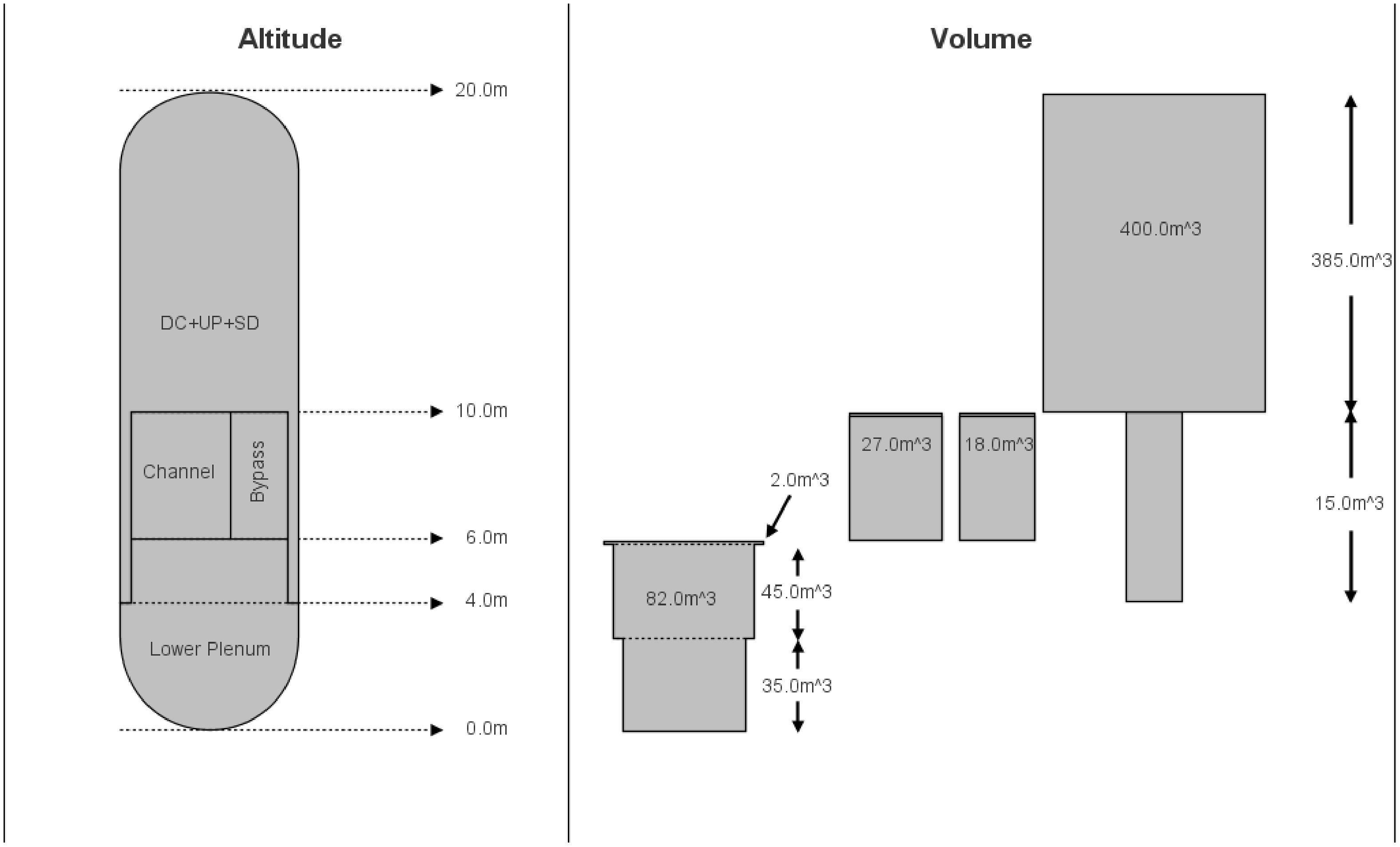
MELCOR Hydrodynamics Volume Geometry



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MELCOR Hydrodynamics Example Geometry Input

- **Native MELCOR 2.x input for the lower plenum volume see User's Guide for details**

```
Record Identifier
!          Comment with Input field identifier
                 User Input
---------------------------------------------------------
!                  cvname        icvnum
CV_ID                'LP'           120
!                 icvtyp
CV_TYP           'CTYP-1‘
!             icvthr          ipfsw    ......
CV_THR       NONEQUIL            FOG          ACTIVE
CV_ARE           NOCF           12.5
CV_PAS       SEPARATE     POOLANDATM     SATURATED     SATURATED
CV_PTD           PVOL          7.0E6
CV_BND           ZPOL            6.0
CV_VAT      4 !n           cvz         cvvol
               1           0.0           0.0
               2          2.95          35.0
               3           5.9          80.0
               4           6.0          82.0
```


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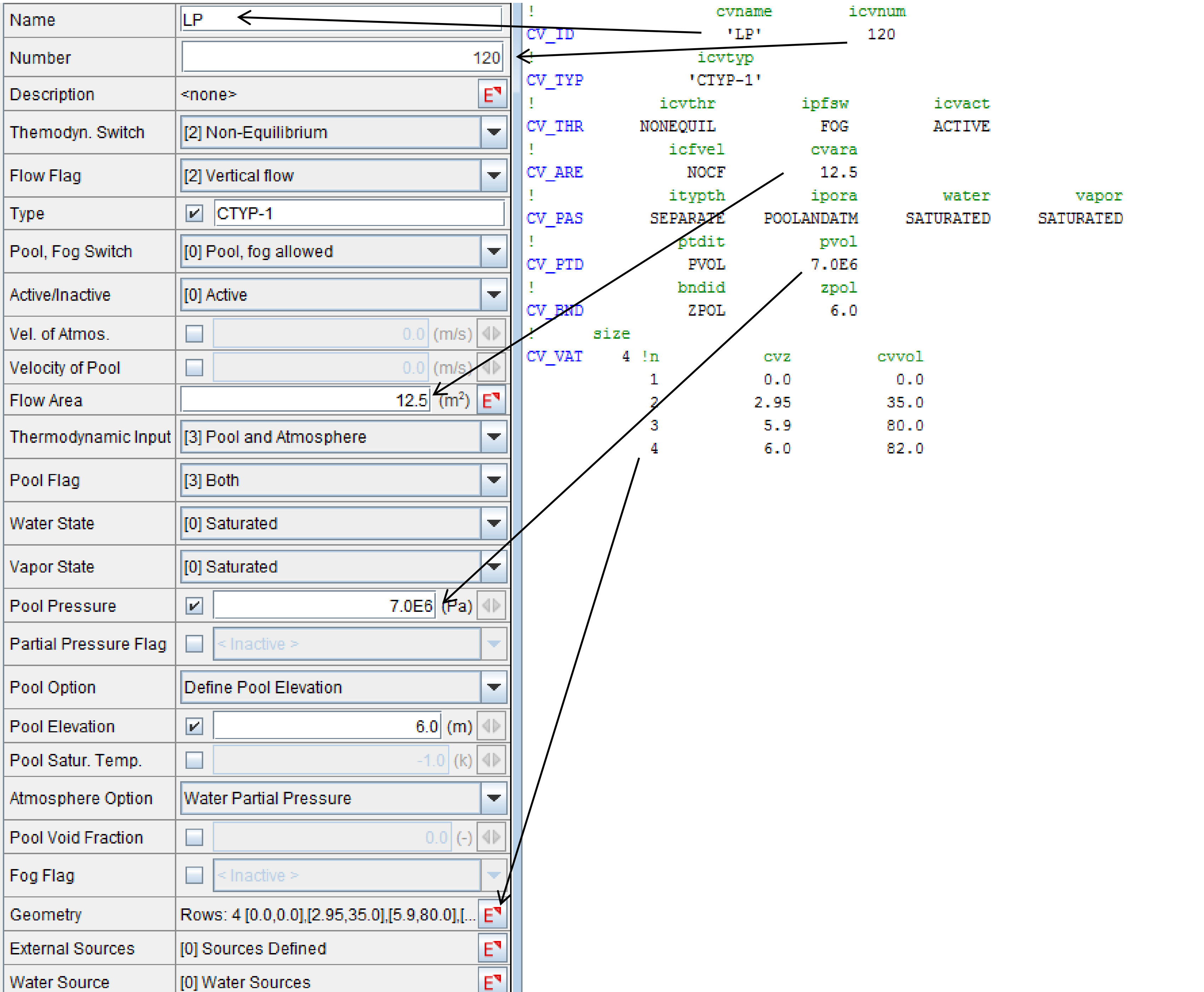
Name LP
Number 120
Description <none>
Themodyn. Switch [2] Non-Equilibrium
Flow Flag [2] Vertical flow
Type CTYP-1
Pool, Fog Switch [0] Pool, fog allowed
Active/Inactive [0] Active
Vel. of Atmos. 0.0 (m/s)
Velocity of Pool 0.0 (m/s)
Flow Area 12.5 (m2)
Thermodynamic Input [3] Pool and Atmosphere
Pool Flag [3] Both
Water State [0] Saturated
Vapor State [0] Saturated
Pool Pressure 7.0E6 (Pa)
Partial Pressure Flag < Inactive >
Pool Option Define Pool Elevation
Pool Elevation 6.0 (m)
Pool Satur. Temp. -1.0 (k)
Atmosphere Option Water Partial Pressure
Pool Void Fraction 0.0 (-)
Fog Flag < Inactive >
Geometry Rows: 4 [0.0,0.0],[2.95,35.0],[5.9,80.0],[...
External Sources [0] Sources Defined
Water Source [0] Water Sources
! cvname icvnum
CV_ID 'LP' 120
! icvtyp
CV_TYP 'CTYP-1'
! icvthr ipfsw icvact
CV_THR NONEQUIL FOG ACTIVE
! icfvel cvara
CV_ARE NOCF 12.5
! itypth ipora water vapor
CV_PAS SEPARATE POOLANDATM SATURATED SATURATED
! ptdit pvol
CV_PTD PVOL 7.0E6
! bndid zpol
CV_BND ZPOL 6.0
! size
CV_VAT 4 !n cvz cvvol
1 0.0 0.0
2 2.95 35.0
3 5.9 80.0
4 6.0 82.0

Session I

MELCOR Hydrodynamics Volume Contents

- Many options, many ways to define a given state
  - General rules
    - State must be completely specified, *not* over specified
    - If only P or T specified, water assumed to be saturated
  - One straightforward approach presented here
    - Will comment on some obvious alternatives
- Materials are numbered
  - Material 1 is water in pool (including bubbles)
  - Materials 2 and 3 are fog and water vapor in atmosphere
  - Material n>3 is a noncondensible gas in atmosphere
    - MELGEN input defines which gas is number 4, 5, etc.

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MELCOR Hydrodynamics Volume Contents (2)

- **Always use separate pool/atmosphere input**
  - **This is default; other options retained for *very* old decks**
- **All units are SI (kg, m, K, Pa)**
- **All elevations are absolute**
  - **Same reference point for input to *all* packages**
  - **Common practice is to specify the bottom of the Lower Plenum at 0.0**
- **Specify the volume pressure, PVOL**
  - **Recall that it is defined at the pool/atmosphere interface (or top of pool, or bottom of atmosphere)**
    - **Static head (ρ g Δz) terms may be important**
    - **May also be important in interpreting MELCOR output**

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MELCOR Hydrodynamics Generic Specifications

- Specify a Name and Control Volume Number
- Thermodynamic Switch (equilibrium vs non-equilibrium; always use non)
- Set Pool/Fog Allowance Switch (constant throughout problem time)
- Set Pool Flag to the initial Control Volume Fields. (Only Atm., Only Pool, or Both)
- Specify water state for each field (Subcooled, Saturated, or Superheated)

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MELCOR Hydrodynamics Input for Atmosphere

- **Atmosphere input (no input if there is no atmosphere, i.e., no space above the pool)**
  - **If atmosphere contains no noncondensible gases**
    - **If saturated, specify the fog mass**
      - **Can omit for fog mass of zero**
    - **If superheated, specify the atmosphere temperature**
  - **If atmosphere contains noncondensible gases, specify its temperature**
    - **If saturated, specify fog mass (if any)**
      - **Can omit for fog mass of zero**
    - **If superheated, specify partial pressure of water, PH2O**
      - **Alternatives: relative humidity or dew point**
    - **For either saturated or superheated, specify mole fractions of noncondensible gases**
      - **Only needed for gases present in volume, fractions must sum to 1.0**

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MELCOR Hydrodynamics Input for Pool

- Pool input (no input if there is no pool, set Pool Flag accordingly)
  - Specify the elevation of pool surface
    - Alternatives: pool volume or mass
  - Note that following two choices are mutually exclusive
    - If subcooled, specify temperature
      - Must be less than T_{sat}(Control Volume Pressure)
    - If saturated, specify void fraction
      - Can omit for void fraction of zero

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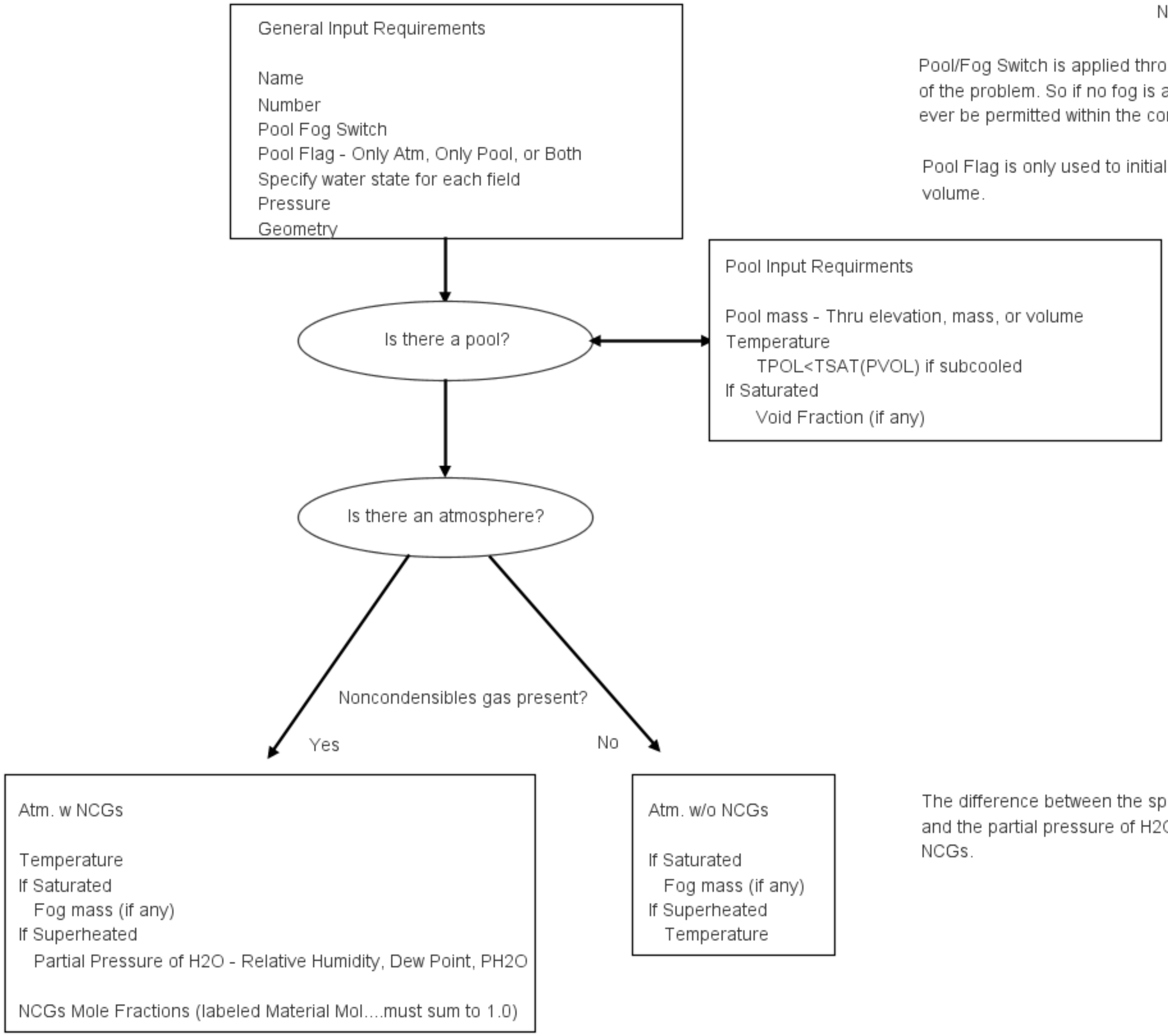
Control Volume Checklist



Notes

Pool/Fog Switch is applied throughout the run-time of the problem. So if no fog is allowed, none will ever be permitted within the control volume. (same for pool)

Pool Flag is only used to initialize the contents of the control volume.

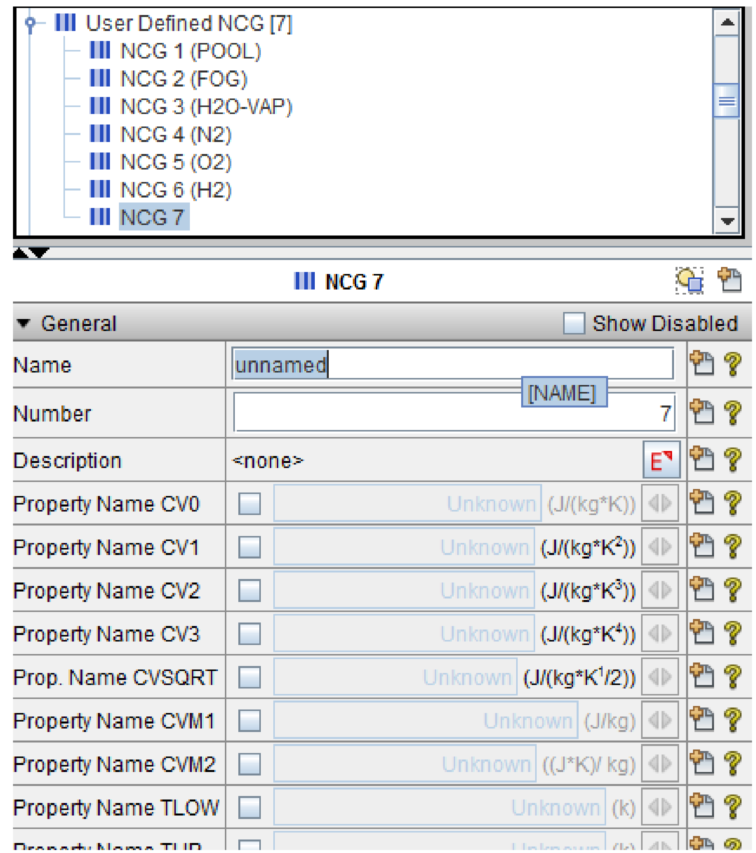
The difference between the specified control volume preesure and the partial pressure of H2O is the total pressure of the NCGs.

MELCOR Hydrodynamics Special Note for NCGs

- **If noncondesible gases are in atmosphere they must be initialized**

```
NCG_INPUT   ! Order dictates number assigned
NCG_ID     N2    ! N2 is material number 4
NCG_ID     O2    ! O2 is material number 5
```

- **The water states occupy the first 3 material numbers (1=Pool,2=Fog,3=Vapor)**



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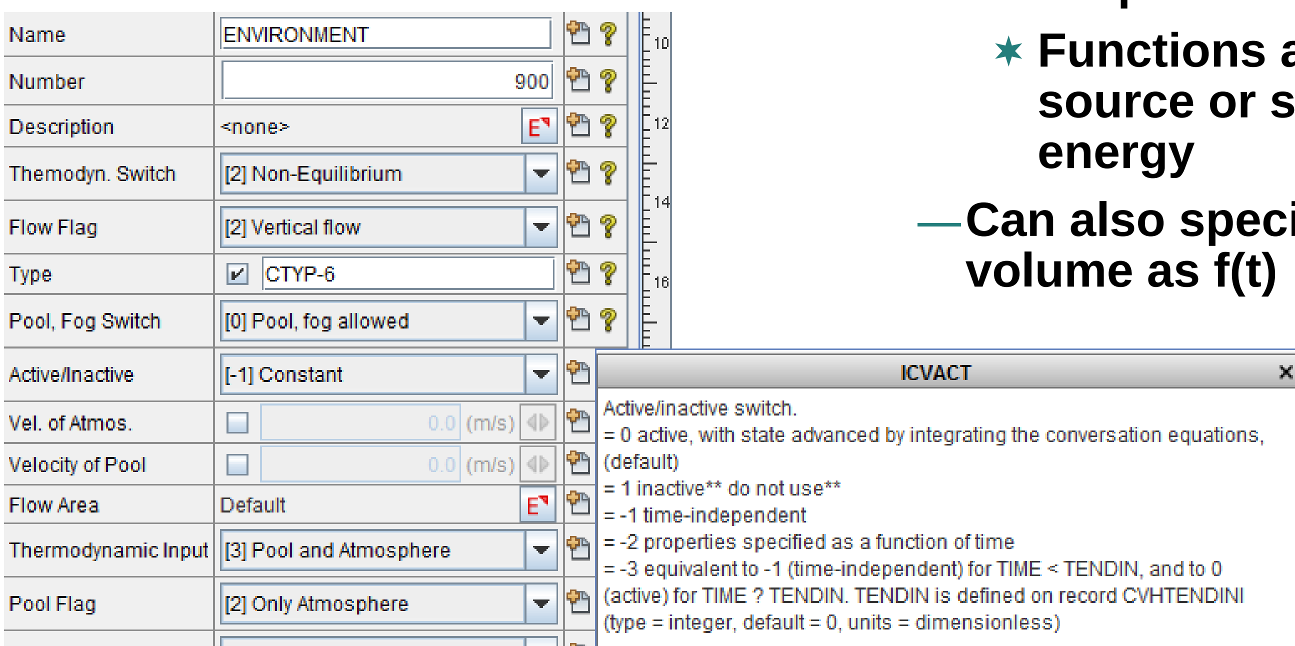
MELCOR Hydrodynamics Boundary Volumes

```
!                cvname           icvnum
CV_ID        'ENVIRONMENT'            900
!             icvthr     ipfsw        icvact
CV_THR       NONEQUIL      FOG    TIME-INDEP
```



- **Volumes to impose boundary conditions**
  - **Simplest is time-independent volume**
    - **Properties never change**
    - **Functions as an infinite source or sink of mass, energy**
  - **Can also specify state of a volume as f(t)**

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MELCOR Hydrodynamics Notes on Volume Input

- **Combine small volumes in a TRAC or RELAP nodalization into one MELCOR control volume**
  - **Small volumes limit timestep and increase run time**
  - **Can represent detailed shape using volume/altitude table**
- **Can split one large volume to form an approximate finite-difference grid**
- **Volume occupied by structures in other packages may become available to fluids**
  - **Volumes defined by the other packages, not CVH input; e.g., for core, CVH input is *fluid* volume only**
- **Properties in MELGEN edit may differ slightly from input values**
  - **Results from change in independent variables (to M, E)**

MELCOR Hydrodynamics Direct Sourcing

- Mass and/or energy can be sourced to control volumes
  - Hydrodynamic material
  - Corresponding energy (Temperature)
  - Independent energy
- Can be sourced to Atmosphere or Pool
- User may implement external data files, control functions or tabular functions
  - Specifying rate or integral source
- Water has unique Flashing Model if WM and WE are specified as the source types
  - Different from pool, fog, and water vapor

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MELCOR Hydrodynamics Flashing Model

- **Associated input**
  - Elevation (determine whether entering atm. or pool)
  - Sauter mean diameter (const., control function, sensitivity coefficient)
  - Fog distribution
    - Use the Rosin-Rammler distribution
    - Allow RN (RN must be active) to apply new fog as condensation to the existing aerosols distribution
- **RN active**
  - Rosin-Rammler (RR) populates RN defined aerosol section using section diameter
- **RN Inactive**
  - Total fog mass = liquid mass entering * (1-vapor fraction) * (1 - RR for (d>dmax))

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MELCOR Hydrodynamics Rosin-Rammler Equation

$$\frac{M(d > d_P)}{M_{Total}} = \exp\left\{ -\left[\Gamma\left(\frac{k-1}{k}\right)\right]^{-k} \left(\frac{d_p}{\overline{d}_S}\right)^k \right\}$$

Γ – Gamma function

d_p – droplet diameter

d_s – Sauter mean diameter (65.0E-6) SC4500(3)

k – constant (5.32) SC4500(5)

M – Liquid mass (fog and eventually pool)

All Fog with d > Dmax are sourced to the pool

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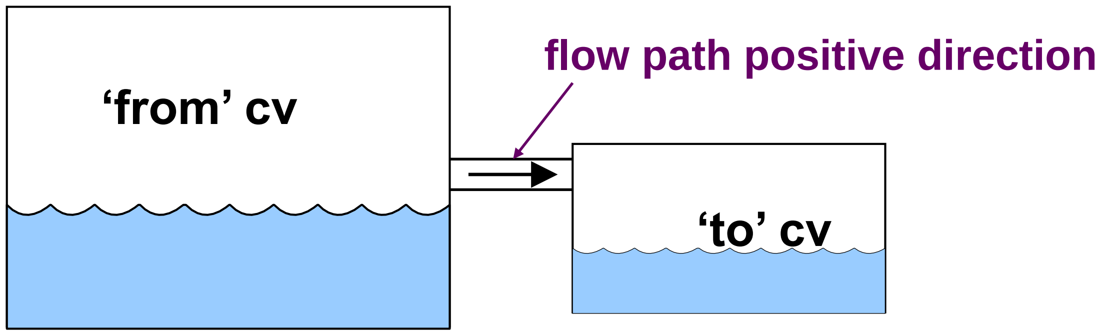
End of CVH Presentation

BREAK

MELCOR Hydrodynamics Flow Paths



- **Each flow path connects two control volumes**
- **One volume is referred to as the ‘from’ volume and the other as the ‘to’ volume thus defining positive flow**
- **Flow paths advect hydrodynamic material between Control Volumes**

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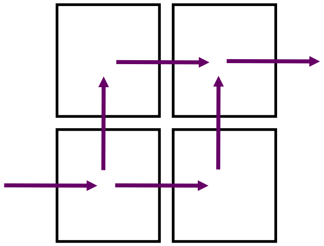
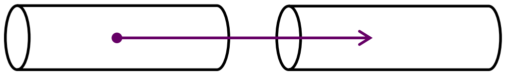
MELCOR Hydrodynamics Flow Paths



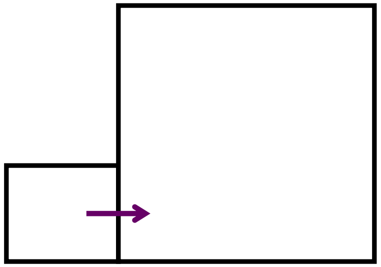
- Any number of flow paths may be connected to a volume
- Properties correspond roughly to “cell boundary” variables in finite-difference CFD formulations
- Internal variables for CV are mass and energy
- Internal variable for FL is velocity

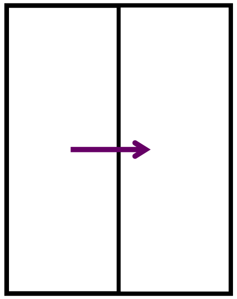
MELCOR Hydrodynamics Flow Paths

- A flow path can represent either of two things
  - A pipe-like connection in a "tank-and-tube" model



  - An open area between two volumes
    - A doorway or similar opening
    - A cell boundary when a large room is subdivided





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MELCOR Hydrodynamics Formulation

- Two fluid (six equation) hydrodynamics
- Control-volume/flow-path formulation
  - Provides maximum flexibility
  - Convenient for coarse nodalization, arbitrary connections
  - Can construct 1- 2- or 3-dimensional finite difference grids
    - Responsibility placed on user
- Omit v^2 terms (kinetic energy, momentum flux)
  - Only important for large Mach Numbers
- Same formulation used for all volumes (primary, secondary, and containment)
  - Consistent treatment, no problems after depressurization
  - Simultaneous solution of flow equations

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MELCOR Hydrodynamics Formulation

- **Conservation Equations see Ref. Manual**

Mass:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho v) = \Gamma$$

Momentum:

$$\alpha_{j,\varphi}\rho_{j,\varphi}L_j \frac{\partial v_{j,\varphi}}{\partial t} = \alpha_{j,\varphi}(P_i - P_k) + \alpha_{j,\varphi}(\rho g \Delta z)_{j,\varphi} + \alpha_{j,\varphi}\Delta P_j$$
$$- \frac{1}{2}K^{*}_{j,\varphi}\alpha_{j,\varphi}\rho_{j,\varphi}\left|v_{j,\varphi}\right|v_{j,\varphi} - \alpha_{j,\varphi}\alpha_{j,-\varphi}f_{2,j}L_{2,j}\left(v_{j,\varphi} - v_{j,-\varphi}\right)$$
$$+ \alpha_{j,\varphi}\rho_{j,\varphi}v_{j,\varphi}(\Delta v)_{j,\varphi}$$

Energy:

$$\frac{\partial E_{i,\varphi}}{\partial t} = \sum_j \sigma_{ij}\alpha_{j,\varphi}\left(\sum_m \rho^d_{j,m}h^d_{j,m}\right)v_{j,\varphi}F_jA_j + \dot{H}_{i,\varphi}$$

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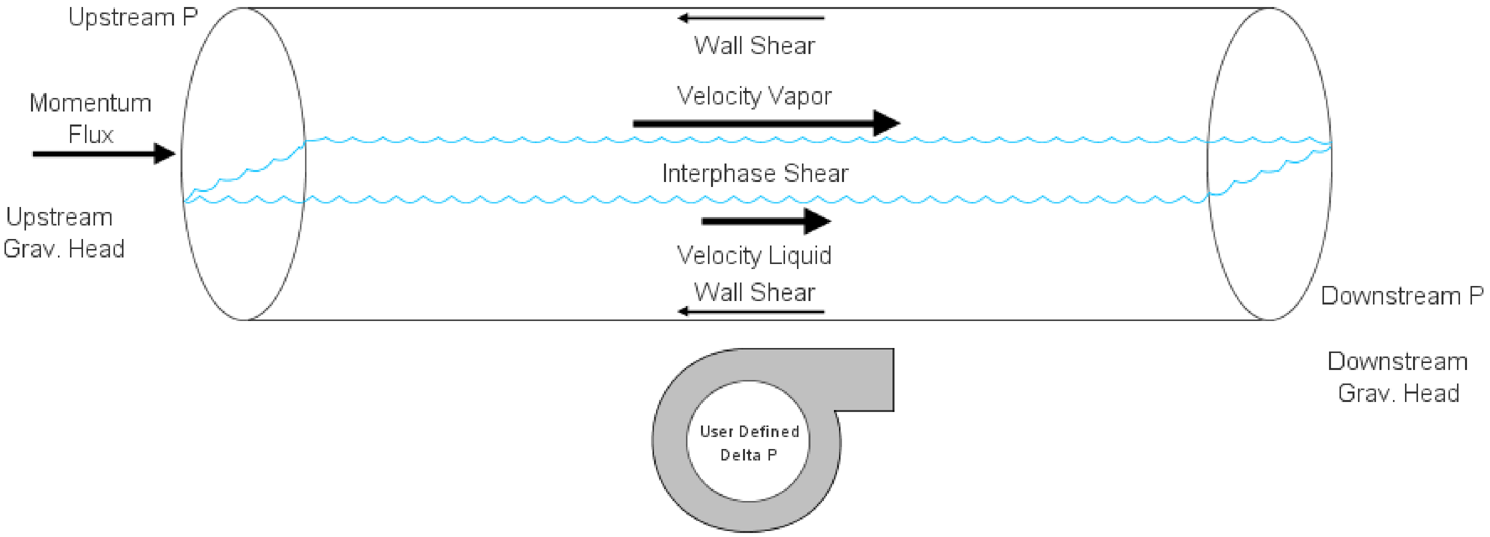
MELCOR Hydrodynamics Momentum



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MELCOR Hydrodynamics Formulation

- **The ordinary differential equations are converted to linearized-implicit finite difference equations**

<u>Conservation of mass:</u>

$$M_{i,m}^{n} = M_{i,m}^{o} + \sum_{j} \sigma_{ij} \alpha_{j,\varphi}^{n} \rho_{j,m}^{d} v_{j,\varphi}^{n} F_j A_j \Delta t + \delta M_{i,m}$$

<u>Conservation of energy:</u>

$$E_{i,\varphi}^{n} = E_{i,\varphi}^{o} + \sum_{j} \sigma_{ij} \alpha_{j,\varphi}^{n} \left(\sum_{m} \rho_{j,m}^{d} h_{j,m}^{d} \right) v_{j,\varphi}^{n} F_j A_j \Delta t + \delta H_{i,\varphi}$$

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MELCOR Hydrodynamics Formulation

Linearized form of the velocity equation:

$$v_{j,\varphi}^{n} = v_{j,\varphi}^{o+} + \frac{\Delta t}{\rho_{j,\varphi} L_j}\left(P_i^{\tilde{n}} + \Delta P_j - P_k^{\tilde{n}} + (\rho\, g \Delta z)_{j,\varphi}^{\tilde{n}} + v_{j,\varphi}^{o}(\rho\, \Delta v)_{j,\varphi}^{o}\right)$$

$$- \frac{K_{j,\varphi}^{*}\Delta t}{2L_j}\left(\left|v_{j,\varphi}^{n-} + v'_{j,\varphi}\right| v_{j,\varphi}^{n} - \left|v'_{j,\varphi}\right| v_{j,\varphi}^{n-}\right) - \frac{\alpha_{j,-\varphi} f_{2,j} L_{2,j} \Delta t}{\rho_{j,\varphi} L_j}\left(v_{j,\varphi}^{n} - v_{j,-\varphi}^{n}\right)$$

Use control-volume/flow path formulation to solve the finite difference equations

MELCOR Hydrodynamics FL Input

- Required input for each flow path
  - User-defined name
  - User volumes names connected, and nominal elevations of connections
  - Nominal area, fraction open
    - Flow path velocity defined as volumetric flow/open area
    - This velocity is used only with form loss and choking
  - Inertial length, used with nominal area
    - This length is *not* used for wall friction
  - Wall friction data
    - Describes pipe and/or halves of connected volumes
    - Frictional loss added to form loss

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MELCOR Hydrodynamics FL Input (2)

- Optional input for each flow path
  - Form loss coefficients
    - Can be different for forward and reverse flow
    - Default is 1.0
  - Range of elevations “seen” in each control volume
    - Determines if outflow is pool, atmosphere, or both
    - There is a default, but it is most applicable to pipes
  - Discharge coefficients for choked flow
  - Initial velocities of pool and atmosphere
  - Other flow models
    - Imposed velocity (used for boundary conditions)
    - Varying area (valve)
    - Momentum source (pump)

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MELCOR Hydrodynamics FL Input (3)

- Further optional input for each flow path
  - Flow path "type", input as a single integer
    - Defines horizontal or vertical
    - Can specify one-way flow (ideal check valve)
    - Can define preferential flow of pool or atmosphere
      - Use not recommended, retained for old decks
  - Bubble behavior
    - Atmosphere flow entering volume below pool surface may interact with flow
      - Thermal equilibration, condensation, or evaporation
      - Controlled by an "efficiency" as in old versions of SPARC
      - Input also controls decontamination calculations (SPARC 90)
      - Model is off by default

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MELCOR Hydrodynamics FL Input (4)

- **Still *more* optional input for each flow path**
  - **Momentum exchange length**
    - **Defines length over which interfacial force acts**
    - **Controls coupling between pool and atmosphere**
      - **Default provides strong coupling for horizontal flow paths**
      - **Default reproduces Wallis flooding curve for vertical flow paths**
  - **Momentum flux**
    - **Provides limited ability to include effects of v $\partial v/\partial x$**
  - **Blockage**
    - **Uses areas and flow resistances defined by COR**
    - **Provides coupling to changing core geometry**
      - **Open path on failure of BWR canister**
      - **Account for different resistance of debris bed compared to intact geometry**

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MELCOR Hydrodynamics Junction Geometry

- Junction of flow path to control volume limits range of elevations *from* which fluid can flow
  - Need not span entire height of volume
- Pool and atmosphere can share a flow path
  - Split corresponds to fractions of junction area occupied
    - Considers junction to donor volume for concurrent flow
    - Interpolation used for countercurrent flow
      - Form motivated by flooding curve
  - Pool can be trapped below bottom of opening
  - Atmosphere can be trapped above top of opening

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MELCOR Hydrodynamics
Junction Opening Size and Location

- Define limits for outflow in all cases
- Impose limits on entrainment in vertical paths
- Default opening based on flow path area
  - Appropriate for tank-and-tube limit
  - Centered on nominal elevation, if possible
  - Height is diameter of equivalent circle for horizontal flow
  - Height is radius of equivalent circle for vertical flow
  - Truncated (if necessary) to lie within volume
- Can directly specify top and bottom elevations
  - Define precise heights for trapping of pool or atmosphere
  - More appropriate for large openings

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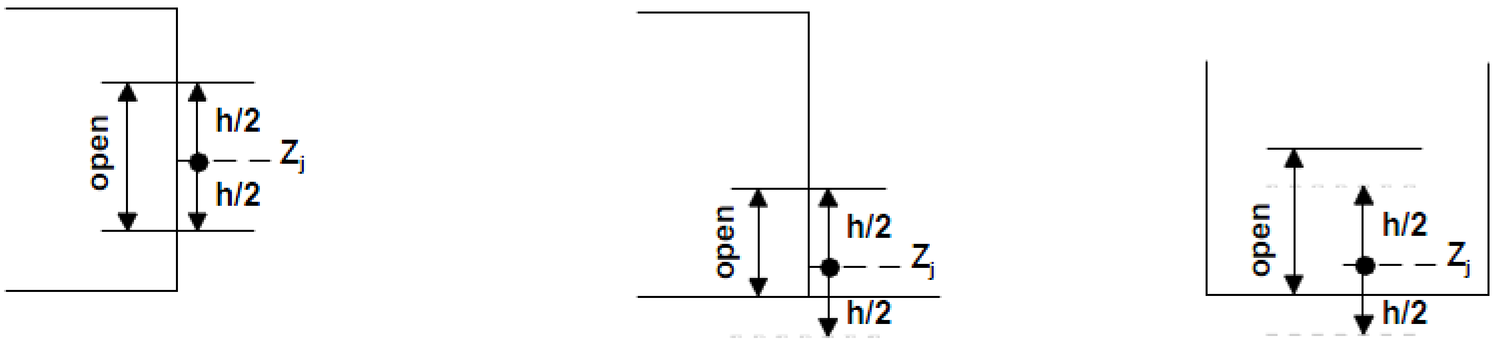
MELCOR Hydrodynamics Unspecified Junction Height

- From Ref. Manual



(a)

Normal junction

(b)

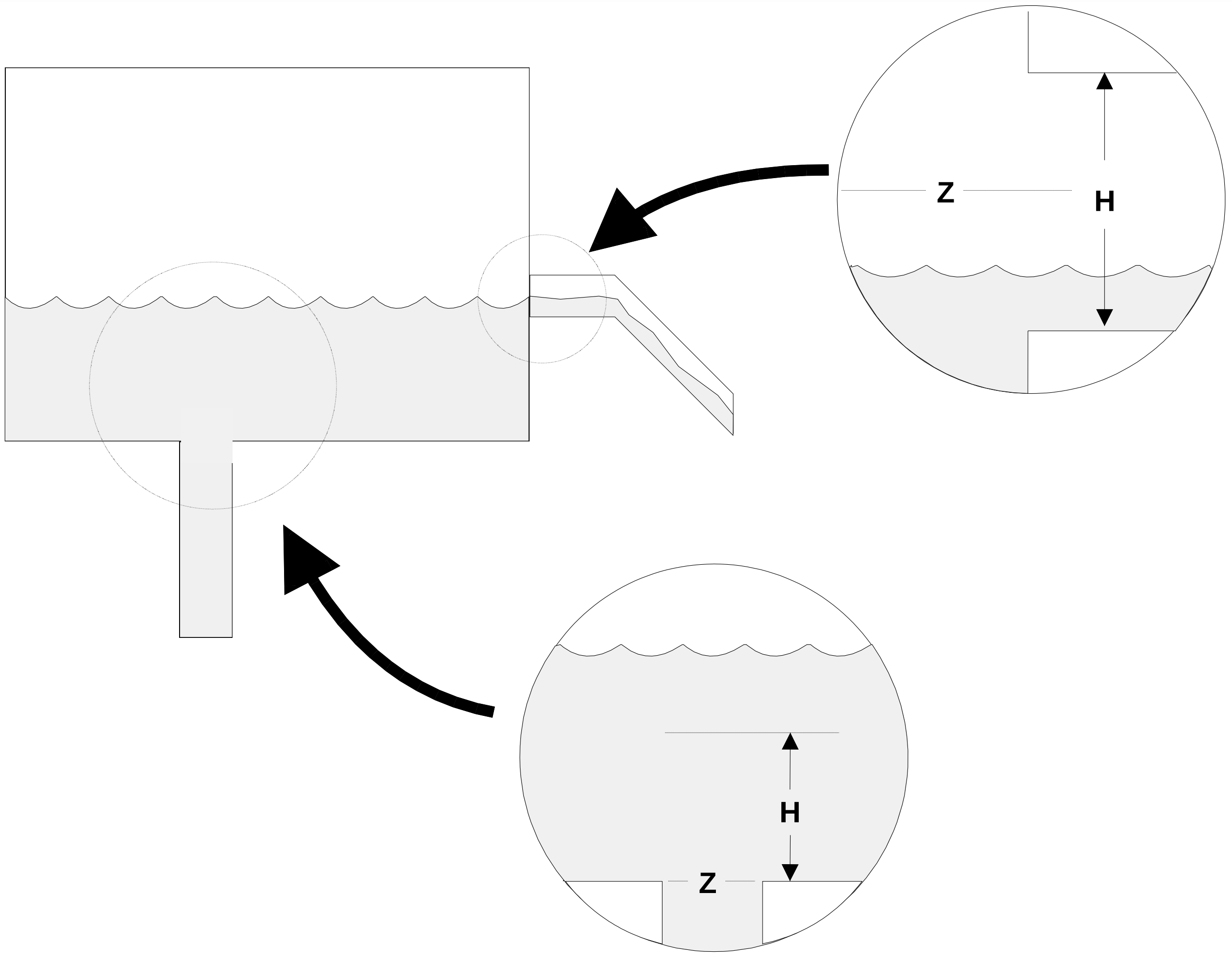
Truncation for a horizontal path, opening height reduced

(c)

Truncation for a vertical path, opening height preserved (if possible)

Figure 3-1 Junction geometry

MELCOR Hydrodynamics Tank-and-Tube Junction



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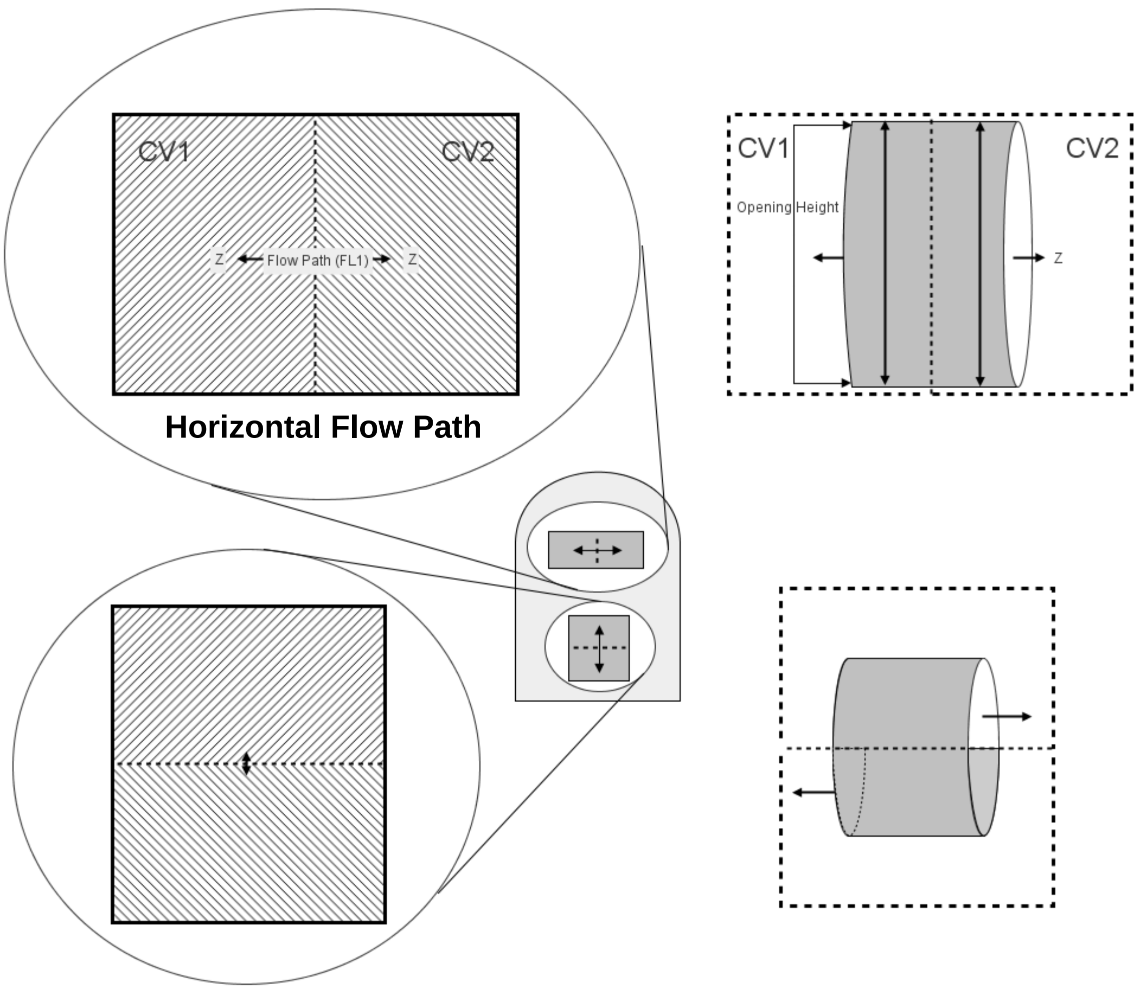
MELCOR Hydrodynamics Finite-Difference Junction



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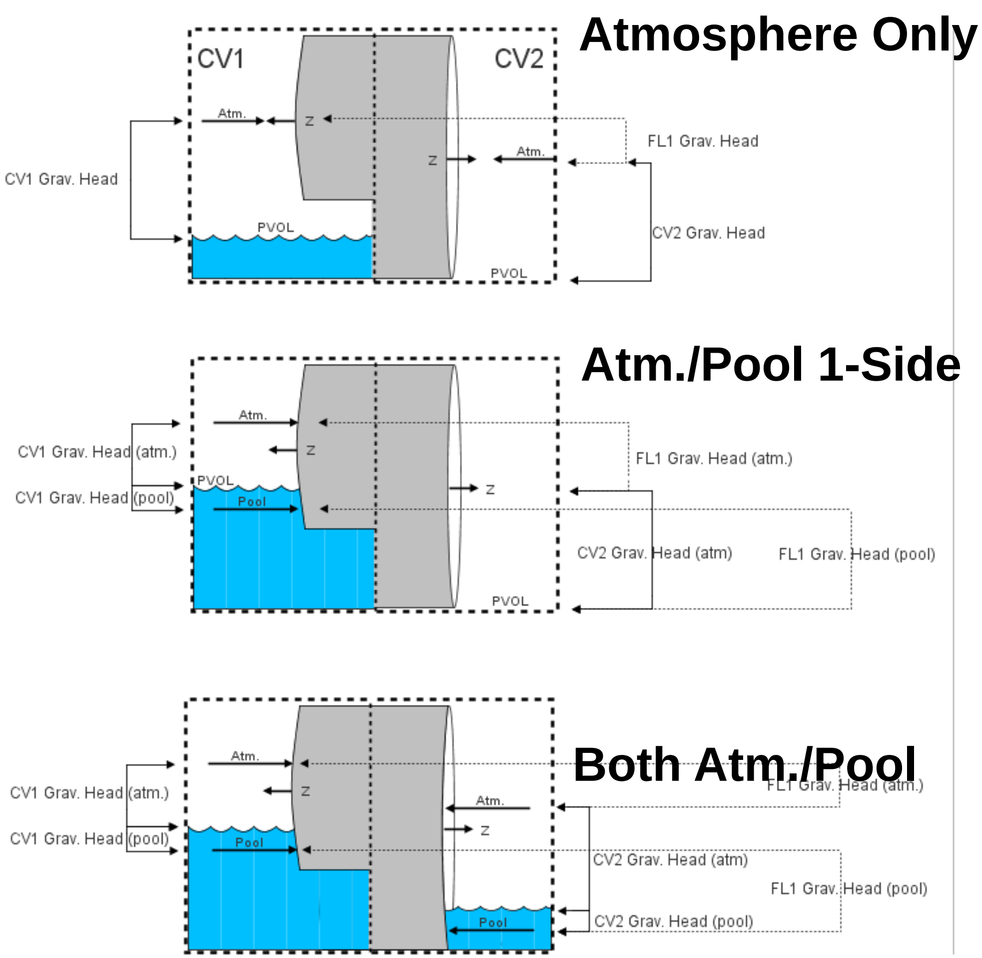
MELCOR Hydrodynamics
Gravitation Head Components



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MELCOR Hydrodynamics Flow Path Resistance

- Two contributors to flow resistance
  - Form loss, using K coefficient and velocity in open area
  - Wall losses, for one or more flow path “segments”
    - Segments connected in series, losses summed
- Flow path segment properties
  - Each has area, length, hydraulic diameter, and roughness
    - There is default for roughness
    - There is optional provision to vary laminar coefficient (can be used to model pressure drops through filters)
  - Resistance of each segment calculated as $2\ f\ L\ /\ D_h$ using Colebrook-White equation
    - Uses velocity from volumetric flow and segment area
    - In essence, assume incompressible flow within path

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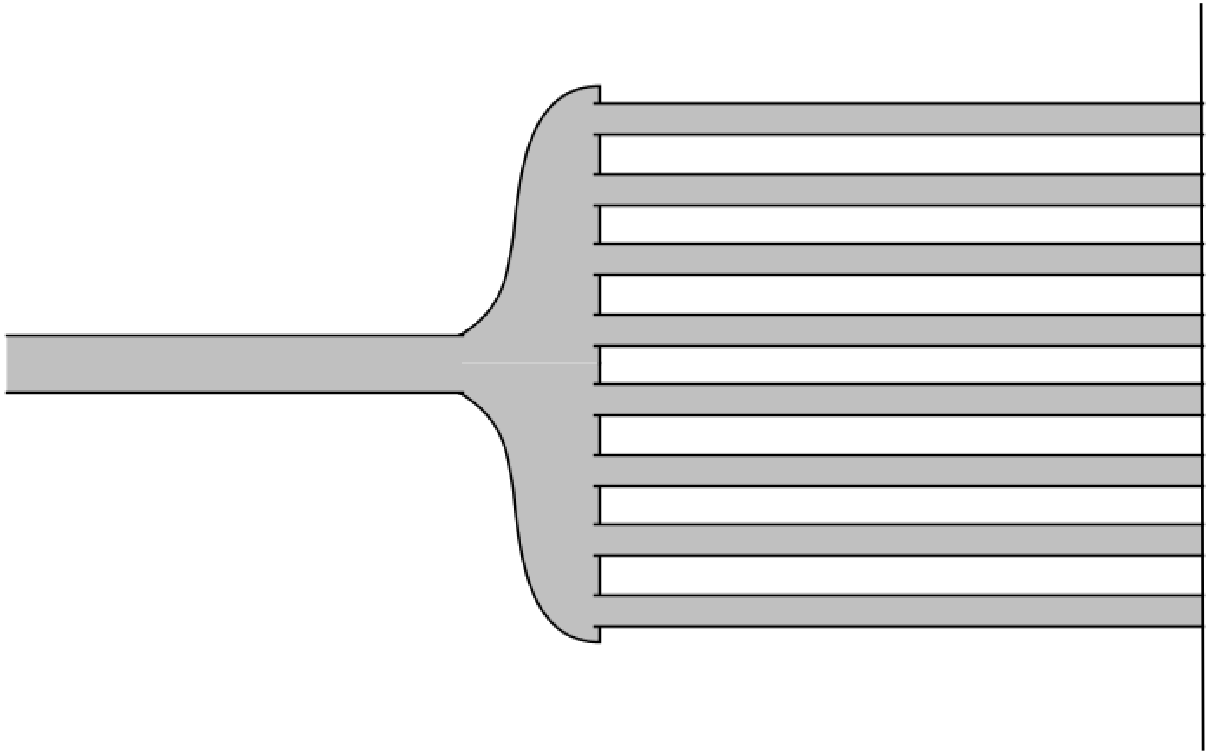
Creating a Flow Path Input

Here is my complicated geometry and I want to capture it in a single flow path



Tube Center-Line

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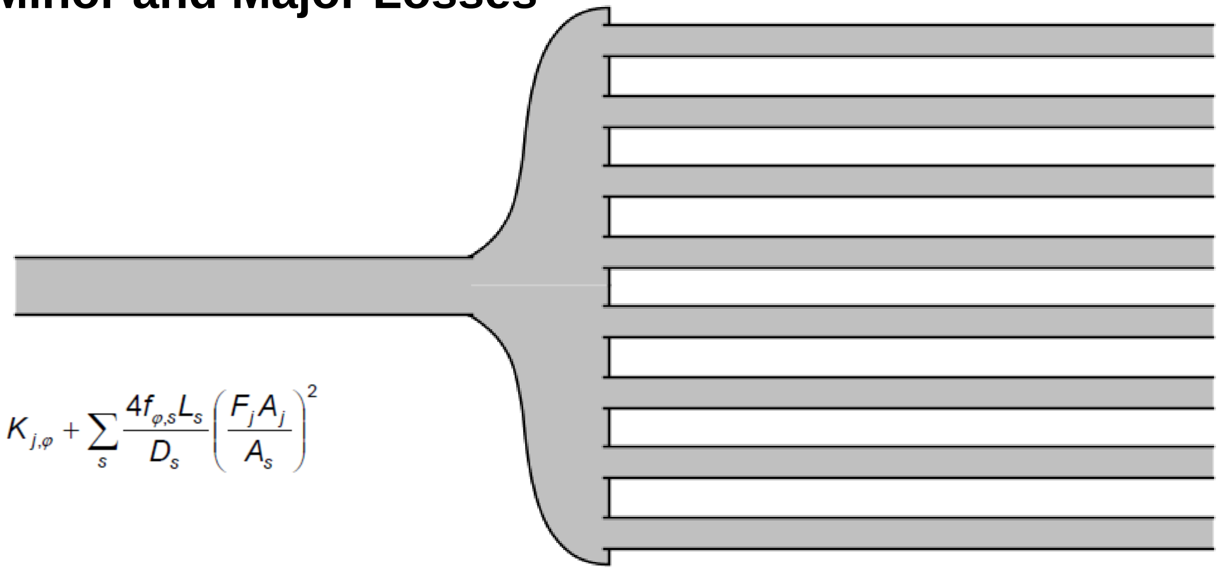
Creating Flow Path Input

- Divide the problem into segments
  - Segments used to calculate pressure drop
    - Minor and Major Losses

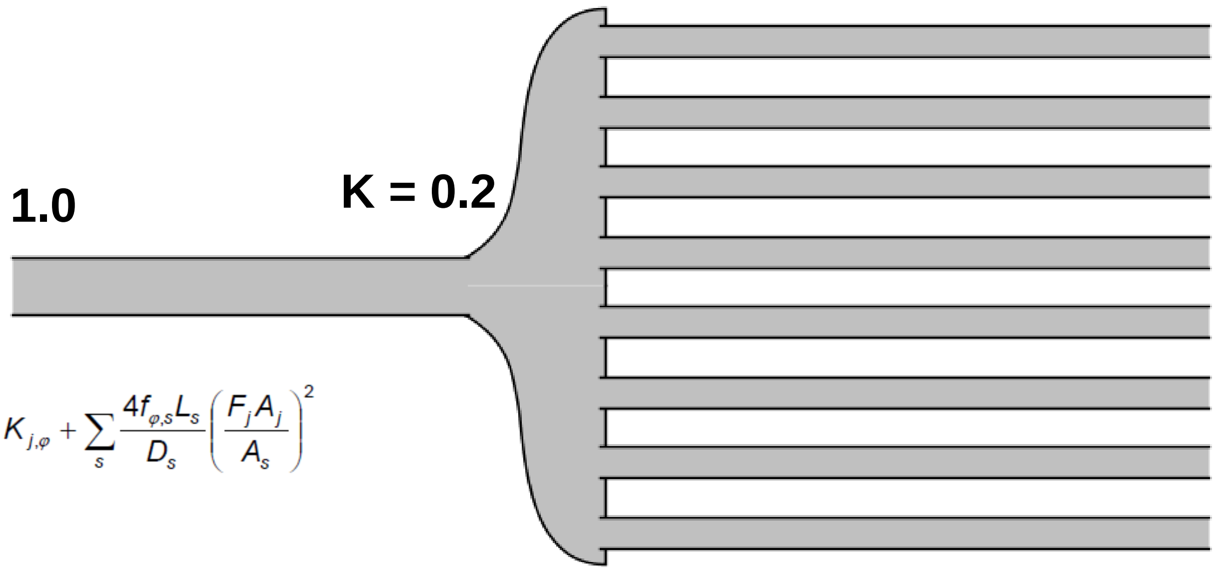


$$K^*_{j,\varphi} = K_{j,\varphi} + \sum_s \frac{4f_{\varphi,s}L_s}{D_s}\left(\frac{F_jA_j}{A_s}\right)^2$$

$$\Delta P^f_{j,\varphi} = \frac{1}{2}K^*_{j,\varphi}\rho_{j,\varphi}\left|v_{j,\varphi}\right|v_{j,\varphi}$$

Creating a Flow Path Input

Summing form losses to create the single Flow path form loss



$$K^*_{j,\varphi} = K_{j,\varphi} + \sum_s \frac{4 f_{\varphi,s} L_s}{D_s} \left(\frac{F_j A_j}{A_s} \right)^2$$

$$\Delta P^f_{j,\varphi} = \frac{1}{2} K^*_{j,\varphi} \rho_{j,\varphi} \left| v_{j,\varphi} \right| v_{j,\varphi}$$

K_n = K * (A_j/A_s)2**
User Specified K = ΣK_n

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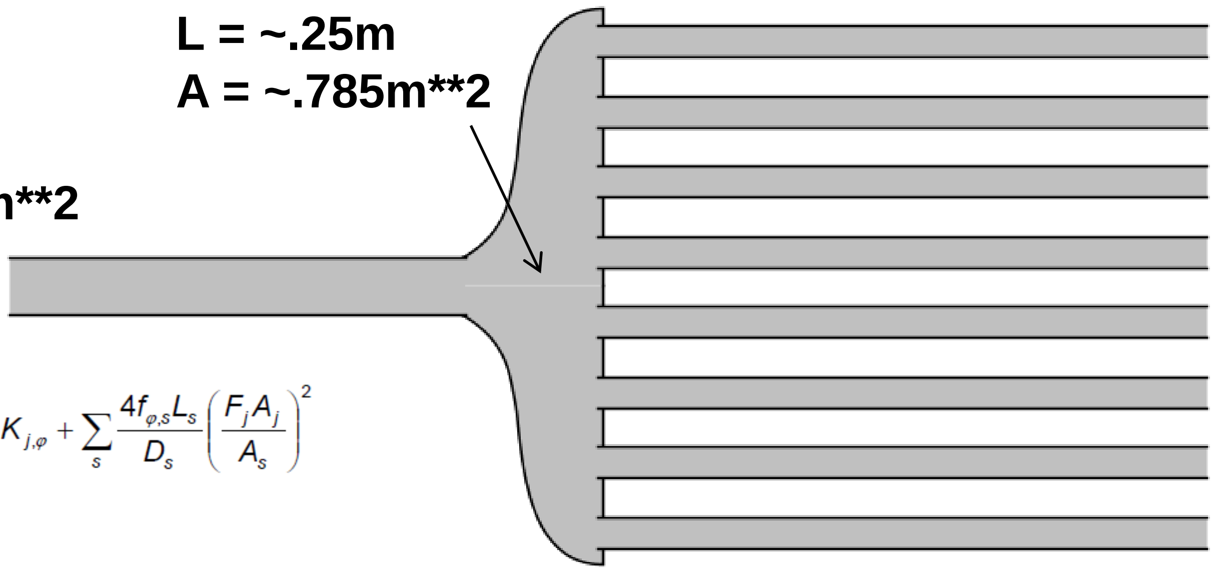
Creating a Flow Path Input

Separating into segments for frictional losses

L = 1.5m
A = 0.68m2 (total area)**

L = ~.25m
A = ~.785m2**

L = 1.0m
A = 0.05m2**



$$K^*_{j,\varphi} = K_{j,\varphi} + \sum_s \frac{4 f_{\varphi,s} L_s}{D_s}\left(\frac{F_j A_j}{A_s}\right)^2$$

$$\Delta P^f_{j,\varphi} = \frac{1}{2} K^*_{j,\varphi}\rho_{j,\varphi}\left|v_{j,\varphi}\right|v_{j,\varphi}$$

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Creating a Flow Path Input

$$\frac{1}{\sqrt{f}} = 3.48 - 4.0\log_{10}\left[\frac{2.0\,e}{D} + \frac{9.35}{\mathrm{Re}\sqrt{f}}\right]$$

Reynolds number is defined for each segment as

$$\mathrm{Re}_s = \frac{\left(\alpha\,\rho_A|V_A| + (1-\alpha)\rho_P|V_P|D_s\right.}{\mu_m}\left(\frac{F_j A_j}{A_s}\right)$$

- A_j/A_s is correcting the flow path velocity for the segment
- Velocity in each tube is V_j*A_j/TotalAreaOfTubes
  (Q_1=Q_2 => V_jA_j = V_sA_s)
- A_s should therefore be the Total Area of the Tubes so the correct velocity is used for the Re calc.
- D_s (the hydraulic diameter) should be for a single tube
  The tubes of the HX are parallel to one another

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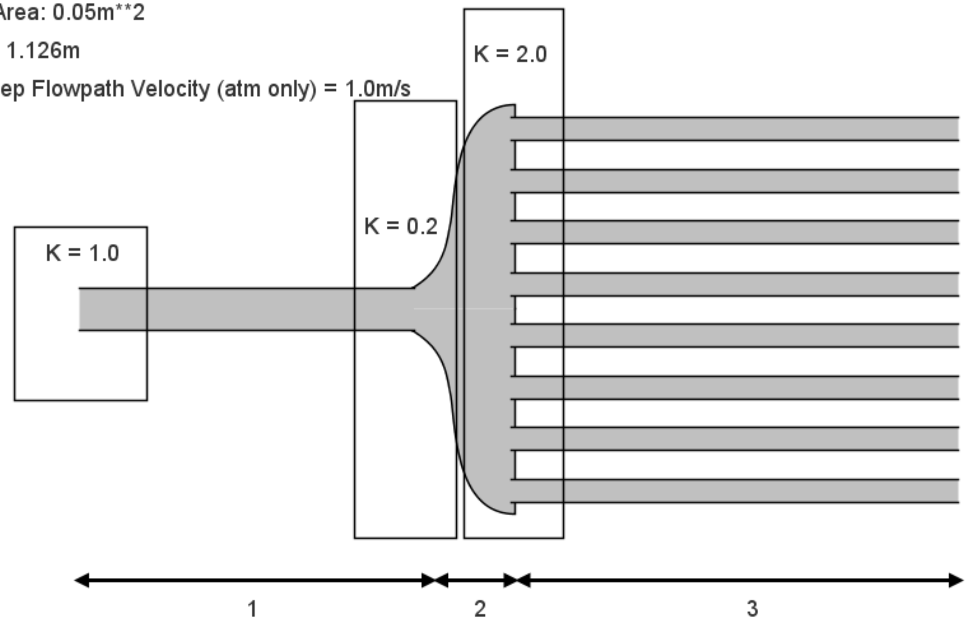
Flow Path Segments

Nominal Flow Area: 0.05m**2

Inertial Length: 1.126m

Current Timestep Flowpath Velocity (atm only) = 1.0m/s



	1	2	3
Segment Area	.05m**2	~.785m**2	.68m**2 (total flow area)
Segment Length	1m	~.25m	1.5m
Segment Hydraulic Diam.	.25m	1.0m	.01m (one tube hydraulic diameter)

Segment Velocity = Vflowpath*(Nom.Area/Seg.Area)

Segment Velocity (Vs)	1.0m/s	0.064m/s	0.074m/s

Minor Losses use of the flow path velocity (based on its nominal area)

K(minor) = K1 * (Nom. A / Seg. 1 A)^2 + K2 * (Nom. A / Seg. 1 A)^2 + K3 (NA/S3A)^2 + K4*(NA/S3A)^2

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MELCOR Hydrodynamics Flow Blockage Model

- Flow blockage model allows easy connection between flow paths and state of core
  - Connection is not automatic, requires user input
  - Design is more general, but only available links are to core
- Opening of flow path when BWR canister fails
- Change in flow area and resistance when convert from intact fuel geometry to debris
  - Pressure drop uses Ergun equation for porous medium
  - Flow resistance increases as porosity decreases
    - If ignored, unchanged velocity and reduced fluid volume reduce timestep to near zero (Courant)
    - When included, increased resistance dominates reduced fluid volume as volume fills with debris

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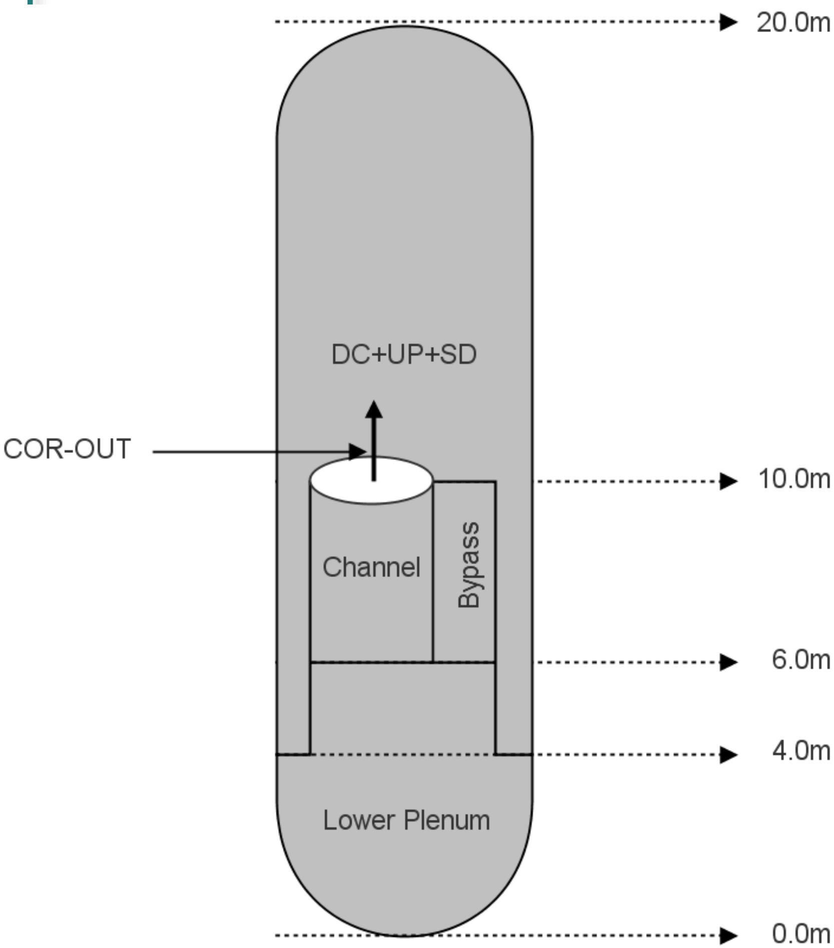
MELCOR Hydrodynamics Flow Path Geometry

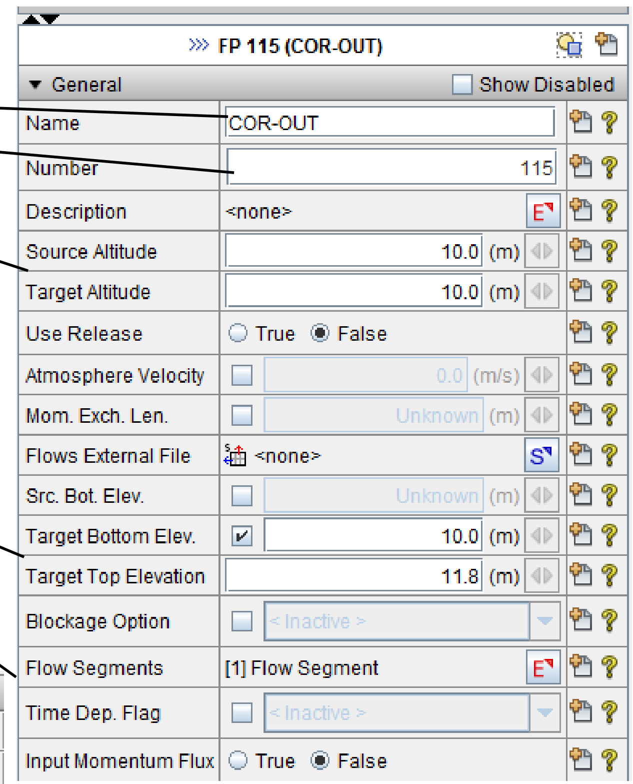


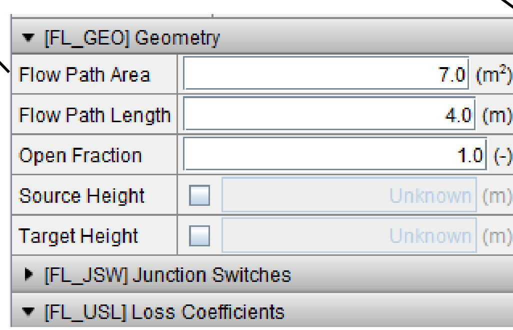
Core to Upper Plenum

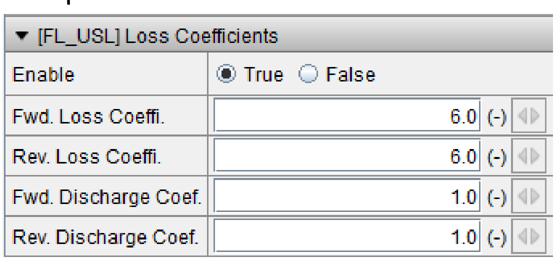
- From Channel to DC+UP+SD
- Both junctions at 10.0 m
- Area 7.0 m^2, fully open
- Inertial length 4.0 m
- Junction openings
  - Below exit plane in Channel
  - Above exit plane in DC+UP+SD
- Loss coeff. 6.0 both ways
- One segment
  - Area 7.0 m^2, length 4.0 m
  - Hydraulic diam 0.01 m

MELCOR Hydrodynamics Example Flow Path Input

```
!
!           fpname          ifpnum
FL_ID       'COR-OUT'          115
!            kcvfm           kcvto             zfm            zto
FL_FT       'CHANNEL'    'DC+UP+SD'           10.0           10.0
!            flara           fllen           flopo
FL_GEO         7.0             4.0             1.0
!           fricfo          fricro          cdchkf         cdchkr
FL_USL         6.0             6.0             1.0            1.0
!            zbjto           ztjto
FL_JLT        10.0            11.8
!       size
FL_SEG     1 !n sarea slen shyd srgh lamflg slam
             1   7.0  2.0 0.01
```







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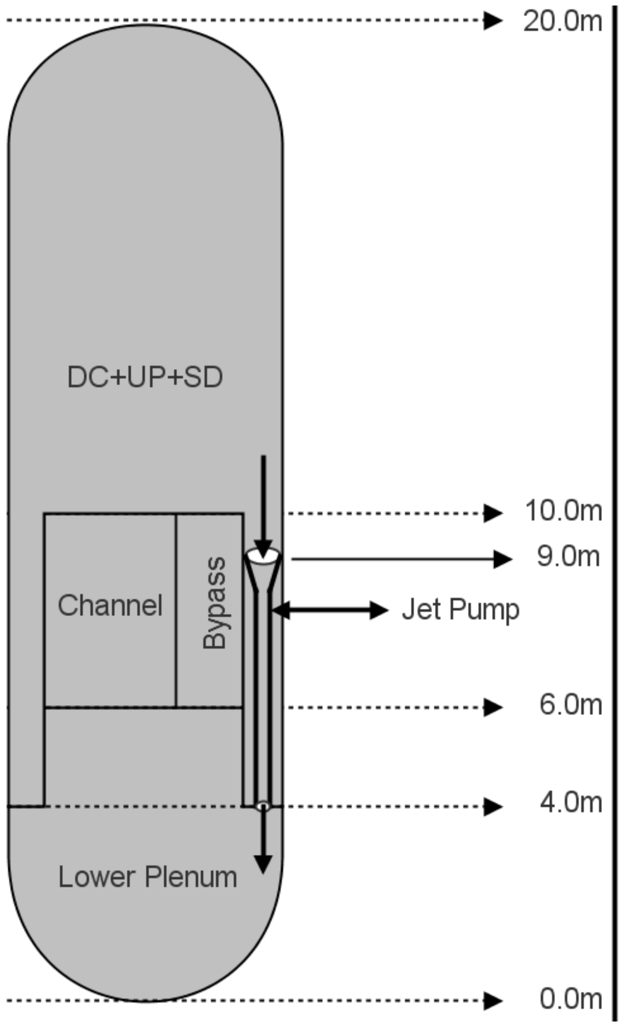
MELCOR Hydrodynamics Flow Path Geometry (2)



- **Jet Pump**
  - From DC to LP
  - Upper junction at 9.0 m
  - Lower junction at 4.0 m
  - Area 0.3 m^2, fully open
  - Inertial length 5.0 m
  - Junction openings
    - Accept default in DC+UP+SD
    - Below exit plane in LP
  - Accept default loss coeff.
  - One segment
    - Area 0.3 m^2, length 5.0 m
    - Hydraulic diam 0.25 m

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MELCOR Hydrodynamics Example Flow Path Input (2)

```
!
!              fpname        ifpnum
FL_ID       'JET-PUMP'          151
!               kcvfm         kcvto            zfm          zto
FL_FT       'DC+UP+SD'         'LP'            9.0          4.0
!               flara         fllen          flopo
FL_GEO            0.3           5.0            1.0
!              zbjfm         ztjfm
FL_JLF           9.0           9.3
!              zbjto         ztjto
FL_JLT           3.7           4.0
!      size
FL_SEG    1 !n sarea slen shyd srgh lamflg slam
            1   0.3  5.0 0.25
```


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MELCOR Hydrodynamics Other Flow Path Input

- Input fragment for thermodynamics of bubble interactions (SPARC model)

```
FL_ID            'SRV'            199
FL_FT       'DC+UP+SD'      'WETWELL'            15.0          -24.0
FL_...
*         Flow path “type” (vertical)
*         |            Leaves SPARC off in from volume
*         |            |             Activates SPARC in to volume
*         v            v                       v
!       kflgfl        ibubf                  ibubt
FL_JSW        0 NoBubbleRise AerosolIodineScrubbing
```

- Ideal check valve requires no control logic
  - Add 10 or 20 to flow path type for forward or reverse flow

```
FL_ID    'VAC BREAK'  230
FL_...
*          Flow path “type” (vertical, forward flow only)
*          vv                (use 20 for reverse flow only)
FL_JSW     10            * Ideal check valve
```

MELCOR Hydrodynamics New Flow Path Input

- **FL_CCF (Counter Current Flow Model)**
  - Permits coupling two flow paths to capture counter-flow forces
- **FL_IHX (Intermediate Heat Exchanger Model)**
  - Simulates parallel or counter flow heat exchanger for two flow paths
- **FL_MCH (Mechanical Model)**
  - Allows temperature and pressure boosting to be adjusted to simulate turbines/compressors

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End of FL Presentation

BREAK

Backups

The following is provided should any future users not have access to these files, but not to SNAP.

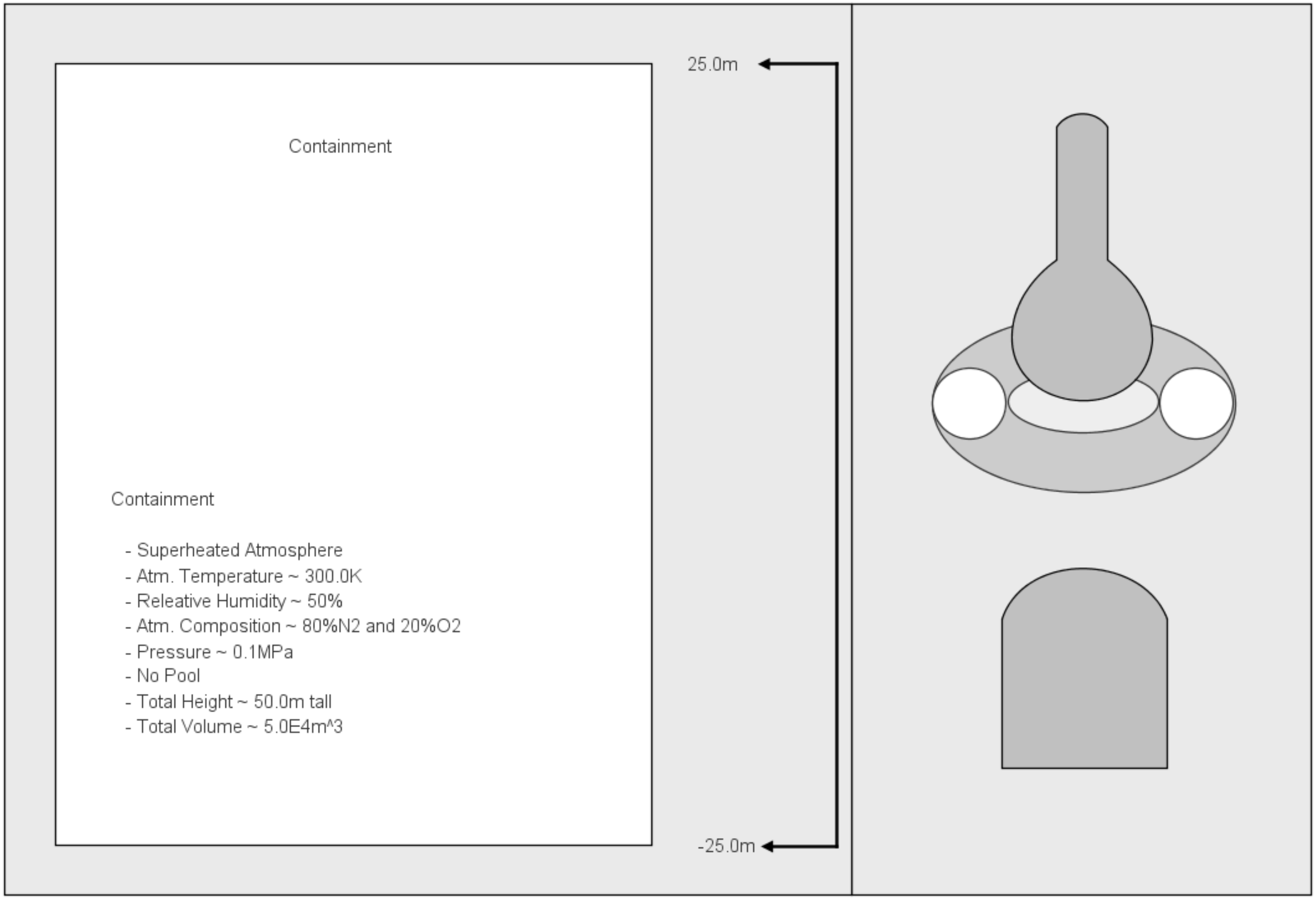
All images presented are screen captures from the SNAP and contain the information needed to create the models during the workshop.

Backups

Wetwell

- Atmosphere Temperature ~ 310.0K
- Pool Temperature ~ 320.0K
- Relative Humidity ~ 90%
- Atm. Composition 80% N2 and 20% O2
- Pressure ~ 1.0E5Pa
- Bottom of Wetwell -25.0m (base of lower plenum is our reference point 0.0)
- Pool ~ 10m above bottom of Wetwell
- Total Height ~ 20m tall
- Total Volume ~ 8000.0m^3

Backups



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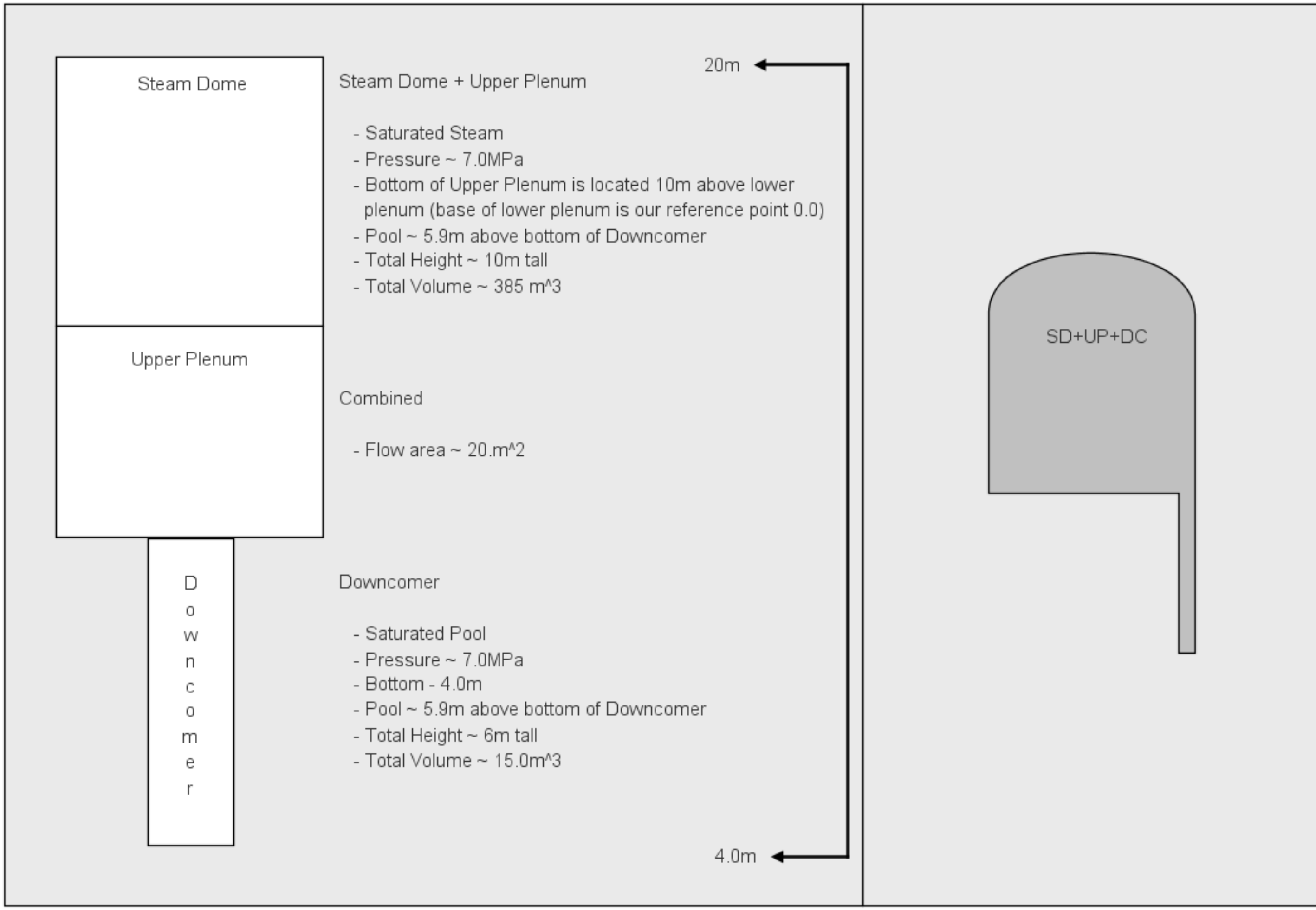
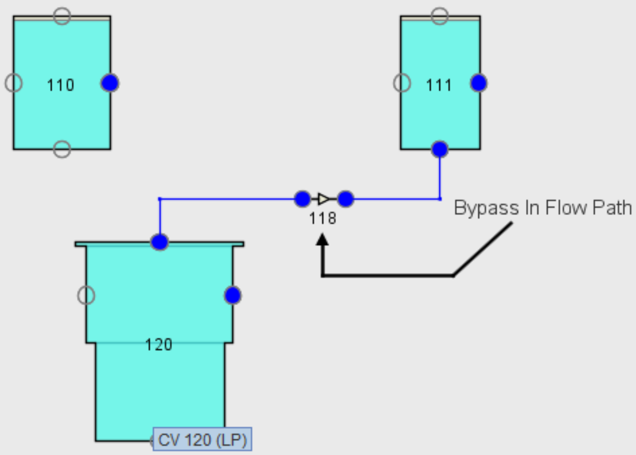
Backups

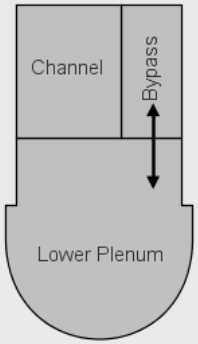

Steam Dome
Upper Plenum
D o w n c o m e r
Steam Dome + Upper Plenum
- Saturated Steam
- Pressure ~ 7.0MPa
- Bottom of Upper Plenum is located 10m above lower plenum (base of lower plenum is our reference point 0.0)
- Pool ~ 5.9m above bottom of Downcomer
- Total Height ~ 10m tall
- Total Volume ~ 385 m^3
Combined
- Flow area ~ 20.m^2
Downcomer
- Saturated Pool
- Pressure ~ 7.0MPa
- Bottom - 4.0m
- Pool ~ 5.9m above bottom of Downcomer
- Total Height ~ 6m tall
- Total Volume ~ 15.0m^3
20m
4.0m
SD+UP+DC

Backups

Bypass In Flow Path

- From top of Lower Plenum
- To bottom of Bypass
- Flow Through Area - 3.0m^2
- From/To Form Loss Coefficients - 6.0
- Inertial Length - 4.0m (aka flow path length)
- Friction Length - 2.0m (aka segment length)
- Hydraulic Diameter - 0.01m
- Default junction opening heights





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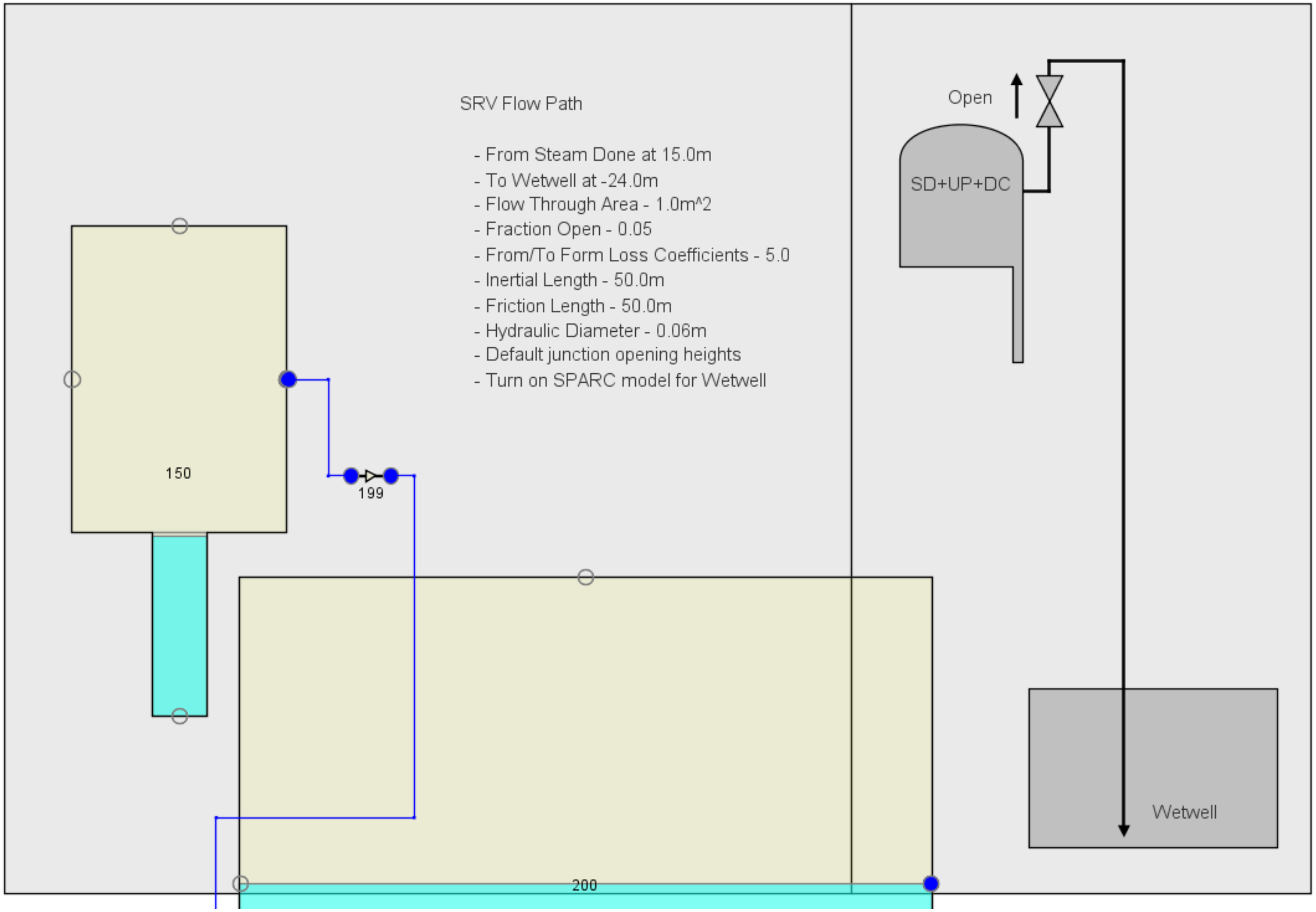
Backups

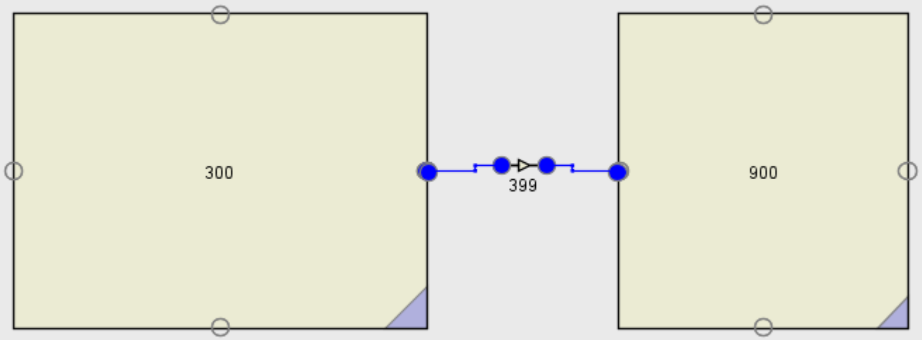


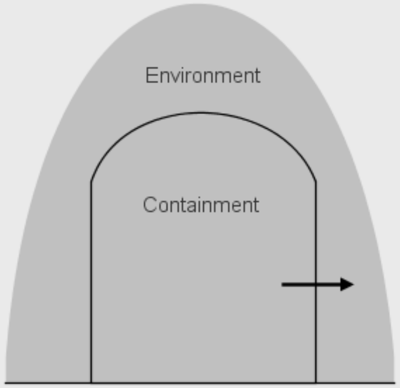
SRV Flow Path
- From Steam Done at 15.0m
- To Wetwell at -24.0m
- Flow Through Area - 1.0m^2
- Fraction Open - 0.05
- From/To Form Loss Coefficients - 5.0
- Inertial Length - 50.0m
- Friction Length - 50.0m
- Hydraulic Diameter - 0.06m
- Default junction opening heights
- Turn on SPARC model for Wetwell
150
199
200
Open
SD+UP+DC
Wetwell

Backups

Cont Fail Flow Path

- From Containment at 0.0m
- To Environemnt at 0.0m
- Flow Through Area - 1.0m^2
- Fraction Open - 0.0 (closed for now)
- From/To Form Loss Coefficients - Default
- Inertial Length - 0.5m
- Friction Length - 0.5m
- Hydraulic Diameter -1.0m
- Default junction opening heights





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Session 3 - MELCOR Data and Control Utilities

Prepared by
MELCOR Development Team

MELCOR Data and Control Presentation Overview

- MELCOR provides data utility packages for performing commonly required functions
  - Handling of data (e.g., tabular input or output)
  - Evaluation of functions for variables and/or control logic
  - Materials properties
- This presentation covers MELCOR data and control packages
  - Tabular Functions (TF) Package: General interface to tabular data
  - External Data Files (EDF) Package: General interface to data files as input or output
  - Control Functions (CF) Package: General interface to control logic and user-defined functions

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Tabular Functions (TF) Package

MELCOR Tabular Functions (TF) Package Overview

- **Tabular Function (TF) utility provides unified treatment**
  - Define 1-dimensional tables of data pairs for arbitrary independent and dependent variables
  - Specify extrapolation conditions at the boundary
  - Value between the specified data pairs generated by linear interpolation
- **Several MELCOR packages use tabular data**
  - Mass and/or energy sources for hydrodynamics (CVH), heat structures (HS), or aerosol/vapor fields (RN1)
  - Imposed time-dependent flow velocities in hydrodynamics (FL)
  - Definition of time-specified volume conditions (CVH)
  - Materials properties (MP)
  - Whole-core decay power (DCH)
  - Definition of control functions (CF)

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MELCOR Tabular Functions (TF) User Input

- **REQUIRED for each tabular function**
  - User-defined tabular function name
  - Number of data pairs (x,y) to define y=f(x)
  - Multiplicative scale factor
- **Optional for each tabular function**
  - Additive constant (default = 0)
  - Boundary condition for evaluation of x outside the range
    - Default is to extend the table with constant boundary value
    - Can also linearly extrapolate or treat as an error
    - Upper and lower limits independently specified
- **Calling package specifies tabular function type (e.g., velocity vs. time) and tabular function name**
- **Value returned:**
  - TF_n = Scale x $Table_n(x)$ + Additive Const.

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MELCOR Tabular Functions (TF)
TF Input: Data Pairs

- **Function defined by (x,y) data pairs**
  - **Can be as few as one pair for constant value**
- **Discontinuous (step) functions allowed, with the same x value in two (or more) pairs**
- **Generally, data pairs are entered in order of non-decreasing x**
  - **If there are no discontinuities, pairs can be input in any order and will be internally sorted**

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MELCOR Tabular Functions (TF) Example TF Input

- **Input block for energy source in CVH volume**

```
CV_ID CV456
!    CV_SOU table for source data
!     |         Energy to pool or atmosphere or mass of material
!     |         |   Rate or integral
!     |         |   |    Source of data (function of time)
!     |         |   |    |  TF name
!     v         vv  vvvv vv vvvv
CV_SOU 1 ! N  SourceInfo
           1  PE  RATE TF 'Core Power' ...
TF_INPUT
! TF_ID - tabular function definition
!  |  Name          Multiplier
!  |  |             |       Additive const. (optional)
!vvvv vvvvvvvvvvv   vvvvv   vvv
TF_ID 'Core Power'  70.E6   0.0 ! Multiplier is desired power
TF_TAB   1 ! NTFPAR   X    Y
                1    0.0  1.0 ! Constant value of 1.0
! (Value Returned = 70.E6 x 1.0 + 0.0 = 70.E6)
```


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MELCOR Tabular Functions (TF)
Example TF Input (2)

- **Input block for forced jet pump velocity**

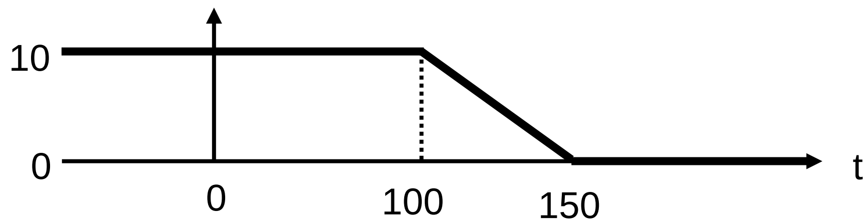
```
! FL_VTM for time dependent velocity
!     |   Number of time dependent flowpaths
!     |   |          Flowpath name
!     |   |          |          Type: TF or CF
!     |   |          |          |       TF or CF name
!vvvvv    v          vvvvvv     vvvvvv  vvvv
FL_VTM    1 !NFLT    FLNAME     NTFLAG  NFUN
              1   FlowPath151     TF    'Jet-V' ! Velocity from
                                                ! TF 'Jet-V'
TF_INPUT
! TF_ID - tabular function definition
!   |  Name
!   |  |          Multiplier for table data
!vvvv vvvvvvv    vvvv
TF_ID 'Jet-V'    10.0 ! Multiplier is rated flow velocity
! Three points in table
         v
TF_TAB   3 ! NTFPAR   X       Y
                 1    0.0     1.0
                 2    100.0   1.0
                 3    150.0   0.0
```

MELCOR Tabular Functions (TF) Example TF Input (3)

- **Input block for forced jet pump velocity**

```
TF_INPUT
! TF_ID – tabular function definition
!   |   Name
!   |   |          Multiplier for table data
!vvvv vvvvvvv    vvvv
TF_ID ‘Jet-V’    10.0 ! Multiplier is rated flow velocity
! Three points in table
         v
TF_TAB    3 ! NTFPAR    X       Y
                1     0.0     1.0
                2     100.0   1.0
                3     150.0   0.0
```

- **Default extrapolation option is to extend the table with constant value at lower and upper boundaries**



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External Data Files (EDF) Package

MELCOR External Data Files (EDF) Overview

- **A general means of communication (read or write) with external data files containing time history data**
  - —Facilitate input of data (e.g., source definition and/or boundary condition) too large for TF
  - —Output data histories for use with another code or special purpose plot program
- **External Data File (EDF) utility provides unified treatment**
  - —Defines file types, data format, and time control of data read and write
  - —Handles connection, opening, positioning, input or output, and closing of named file
  - —Any package can request interpolation to any time within current time step in any READ file

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MELCOR External Data Files (EDF) File Types and Structures

- Three types of external data files
  - READ: data read in for use by MELCOR packages
  - WRITE: user-selected data written to specified file
  - PUSH: collection of data written at request of another MELCOR package
- Each file contains values of time and one or more dependent variables, referred to as "data channels"
- Each record in the file contains a value of time and the value(s) of the dependent variable(s) at that time

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MELCOR External Data File (EDF) Input

- Required input for each external data file
  - User-defined name or ID (EDF_ID)
  - Direction and mode of data transfer (READ, WRITE, PUSH)
  - Name of file on computer system

- Required input for WRITE and PUSH data files
  - Control information for time interval between records (start time and time increment)

- Required input for WRITE data files only
  - List of dependent variables to be written, chosen from available control function arguments

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MELCOR External Data File (EDF) Input (2)

- Optional input for each external data file
  - External data file format (default is unformatted)
  - Format specification uses FORTRAN syntax
  - Time offset between data and MELCOR calculation
    - Intended to handle data with different time reference
    - Useful for experimental data or in interfacing with another simulation code
    - tFile = tMELCOR + tOffset

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MELCOR External Data Files
Example Input using EDF - WRITE

- **Input fragment to write to an external data file containing user-selected variables of interest for post-processing**

```
EDF_INPUT
!  User identification
!    |    Name
!    |    |              Direction and mode of transfer
!vvvvv  vvvv           vvvv
EDF_ID  SPECIAL-DATA  WRITE 'specdat.dat' ! Name of file on system
EDF_CHN   3     ! Number of data channels (3) to be written
          1  CVH-P(DRYWELL)         ! pressure
          2  CVH-TLIQ(SP)           ! Pool temperature
          3  CF-VALU(FEEDWTR_FLOW) ! control function, feedwtr_flow
! EDF_DTW for write increment control
!     |           Starting at time TWEDF
!     |           |      Write a record every DTWEDF seconds
!vvvvvv           vvvvv  vvvvvv
EDF_DTW   2 !NT   TWEDF  DTWEDF
             1     500.0   1.0
             2     1000.0  10.0
! Note dependent variables (data channels) must be 'control function'
! arguments
```

MELCOR External Data Files Example Input using EDF - READ

- Input fragment for steam source read from an unformatted file

```
CV_ID CV123
!  Integral steam mass and enthalpy from EDF 7 (British units)
CV_SOU 2 !N, SourceInfo
   1 MASS INTEGRAL EDF EDF7 1  H2O-VAP 0.4535924 ! pound to kg
   2 AE   INTEGRAL EDF EDF7 2  1055.06           ! BTU to J
...
EDF_INPUT
!  User identification
!    |    Name
!    |    |      Direction and mode of transfer
!vvvvv  vvvv  vvvv
EDF_ID  EDF7  READ '../data/steam.dat' ! Name of file on system
EDF_CHN   2     ! Number of data channels
EDF_TIM 7200.0 ! t=0 in MELCOR is 7200s on file
```

- Each record in file '../data/steam.dat' contains values of ($t, \int^t \dot{M} dt', \int^t \dot{H} dt'$) in British units.

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MELCOR External Data Files
Example Input using EDF (2) - PUSH

- **Write mass/energy through a flowpath, as calculated in one MELCOR run, to a file**

```
FL_ID   FL123
! FL_EDF for flowpath connection to EDF
!       File name (must be a PUSH file)
FL_EDF ‘Flow in 123’
...
EDF_INPUT
!  File must have NUMMAT+2 channels to record (as integrals)
!  all material flows and pool and atmosphere enthalpy flows
!  User identification
!   |   Name
!   |   |            Direction and mode of transfer
!vvvvv  vvvvvvvvvvvv vvvv
EDF_ID ‘Flow in 123’ PUSH ‘flow_123.dat’ ! Name of file on
                                         ! system
EDF_CHN   11    ! Number of data channels (9 materials)
! EDF_DTW for write increment control
!     |            Starting at time TWEDF
!     |            |      Write a record every DTWEDF seconds
!vvvvvv            vvvvv  vvvvvv
EDF_DTW   2 !NT    TWEDF  DTWEDF
             1      0.0    1.0
             2      100.0  10.0
! Note use of unformatted file to get full machine precision
```


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MELCOR External Data Files
Example Input using EDF (3) – PUSH/READ

- **“Play back” mass/energy through a flowpath from one MELCOR run as source in another**

```
CV_ID CV456
!  Sources of all masses and enthalpies from a single EDF file.
!  Assumed to be integrals, as written in previous example
!  The order is MASS POOL, MASS FOG,. . .,ENERGY P, ENERGY A
CV_SOU 1 !N, SourceInfo
          1  FILE EDF123
...
EDF_INPUT
!  Same file and format as  in previous example, but now
!  connected as ‘READ’
EDF_ID  EDF123  READ ‘flow_123.dat’ ! Name of file on system
EDF_CHN   11
```


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Control Functions (CF) Package

MELCOR Control Functions (CF) Overview

- "Control Functions" are simply user-defined functions of MELCOR-calculated variables
  - May be LOGICAL- or REAL-valued
  - All functions are evaluated at the start of every time step
  - All control-function-based models are numerically explicit
- Many uses, not just control
  - Define valve behavior, failure conditions, scram criteria
  - Define internally-calculated sources and boundary conditions
- Many variables in MELCOR database are available as arguments for control functions
  - Any CF variable can be written to an external data file
  - Any CF variable can be added to the plot file

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MELCOR Control Functions
Control Function Arguments

- Many variables in MELCOR time-dependent database are available as function arguments
  - Not all variables, due to coding required to access them
  - Most are REAL-valued, but a few are LOGICAL
  - Listed, by package, in the various User's Guides
- Most packages use names of form xyz-name
  - "xyz" identifies the package and "name" the variable
  - e.g.) COR-MUO2-TOT is total UO2 mass in COR package
- Simple names for those defined by Executive Package
  - EXEC-TIME is problem time
  - EXEC-DT is (system) time step
  - EXEC-CPU is (total) computer time

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MELCOR Control Functions
Control Function Arguments (2)

- Many control function arguments are essentially elements of arrays
  - Index is user-defined name of volume, flowpath, etc.
  - Index is added to name in a parenthesis
    - CVH-P(Drywell) is pressure in ‘Drywell’ volume
    - CVH-LIQLEV(DC) is liquid level in ‘DC’ volume
  - Arrays may have more than one index
    - FL-MFLOW(vent,all) is total mass flow in flowpath ‘vent’
    - EDF(out-10, 2) is data channel 2 in EDF ‘out-10’
    - RN1-VMG(Drywell, I2, TOT) is total vapor mass of I2 class in the atmosphere of control volume ‘Drywell’

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MELCOR Control Functions Direct Use of CF Arguments

- **Any CF argument can be written to an external data file (EDF package)**

```
EDF_INPUT
EDF_ID 'Misc Data' WRITE 'Misc.dat' ! File name on system
EDF_CHN   3 !N New Name Value
             1 CVH-P(CV150)           ! Pressure in volume CV150
             2 FL-MFLOW(FL199,ALL)    ! Mass flow in path FL199
             3 COR-CellTemp(2,4,CL)   ! Cladding temperature in
                                      ! cell IA = 2, IR = 4
! EDF_DTW for write increment control
!     |            Starting at time TWEDF
!     |            |      Write a record every DTWEDF seconds
!vvvvvv            vvvvv  vvvvvv
EDF_DTW  1 !NT     TWEDF  DTWEDF
           1       1000.  10.       ! Output frequency
EDF_FMT  4E12.5 ! Format: time + 3 variables
```


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MELCOR Control Functions Direct Use of CF Arguments (2)

- **Any CF argument can be added to the plot file (EXEC_PLOT)**
  - **Add any number in MELGEN input: written for entire run**
  - **Add any number on MELCOR restart: included in the plot file for the duration of current execution**

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MELCOR Control Functions Composite Functions

- Values of control functions are available for use as arguments of other control functions
  - Can construct composite functions such as $\sin\left(\sqrt{\sum M_I}\right)$
- Functions are evaluated in the numerical order of the CF number (no longer based on order read)
  - A function should ordinarily use only previously-defined functions as arguments
  - There are exceptions, where the value from the previous time step is desired
    - Evaluating out of order will use the previous time step value

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MELCOR Control Functions CF Input: Required

- Required input for each control function
  - User-defined name
  - Function type (Add, EXP, SIN, L-AND, L-OR, etc.)
    - Type determines whether value is REAL or LOGICAL
  - Number of arguments
  - List of arguments
- Required input for REAL-valued control function
  - Multiplicative scale factor

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MELCOR Control Functions CF Input: Optional

- **Optional Input for each control function**
  - Initial value (real, true or false)
    - Only needed if value will be needed early
- **Optional Input for REAL control function**
  - Additive constant for function (default = 0.0)
    - Evaluated as $CF_n = scale*f_n[\overline{X}(t)] + add$
  - Upper and lower bounds
    - Results bounded within limits
- **Optional Input for LOGICAL control function**
  - Message to be output when function switches state
    - Report user-defined ‘events’ in the output files
  - Logical function classification as ‘LATCH’ or ‘ONE-SHOT’
  - If initially FALSE, ‘ONE-SHOT’ can be TRUE for one step only; if initially TRUE, ‘LATCH’ can only be .FALSE. once

MELCOR Control Functions Built-in Functional Forms

- Most FORTRAN and simple math functions
  - Arithmetic, trigonometric, hyperbolic, and LOGICAL
- Tabular function (using table in TF package)
- IF-THEN-ELSE structures
- Numerical integrals and derivatives
  - Includes a proportional-integral-differential (PID) controller
- Hysteresis function
  - References TF package to defined loading/unloading curves
- A variety of “trips”
  - Trips are REAL-valued; value returned is time since trips
  - Simplifies logic involving delays
  - Usable as timer or ramp-generator

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MELCOR Control Functions Built-in Functional Forms (2)

- Larson-Miller creep rupture Control Function (LM-CREEP)
  - Evaluates cumulative damage based on the Larson-Miller creep rupture failure model and gives time to rupture in seconds
- Pipe stress control function (PIPE-STR)
  - Evaluates maximum stress in a thick-walled cylindrical pipe under internal pressure
- User-Defined function (FORMULA)
  - Allows definition of a complicated function on a single record instead of series of records
- Lag function
  - Evaluated as a scaled change in the function value by scaling the change in the argument (Time Lag) as well providing a multiplication scale for the argument.

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Step in Evaluating MELCOR Control Function

- **Demonstrate the order of operations MELCOR uses to evaluate the following control function**

```
...
CF_INPUT
!  User identification
!  |   Name
!  |   |       Type of function (add argument)
!vvvv  vvvvvv  vvvvvv
CF_ID  'CF12'  ADD
!      Multiplier for function
!      |   Added constant
CF_SAI 0.0 70.E6
!       Bounds used
!       |      LowerBound
!       vvvv   vvv   UpperBound
CF_UBL  BOTH   2.0   7.0
CF_ARG     1 ! NARG CHARG      ARSCAL   ARADCN(optional)
                1   EXEC-TIME  1.0      0.0
                2   CF-CONST   1.0
```


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Step in Evaluating MELCOR Control Function

1ST Step

- Evaluate the individual arguments
  - Arg(n) = Package_Arg_Value(n) * ARSCAL + ARADCN

```
...
CF_INPUT
!  User identification
!  |    Name
!  |    |       Type of function (add argument)
!vvvv  vvvvvv  vvvvvv
CF_ID  'CF12'  ADD
!      Multiplier for function CFSCAL
!      |     Added constant CFADCN
CF_SAI 1.0   0.0                    2.0 ! Initial value
!           LowerBound
!           vvv   UpperBound
CF_UBL Both 2.0   7.0
CF_ARG    2 ! NARG CHARG      ARSCAL   ARADCN(optional)
               1   EXEC-TIME  1.0      0.0
               2   CF-CONST   1.0
```


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Step in Evaluating MELCOR Control Function

2nd Step

- **Perform function on the scaled argument(s)**
  - **For this case: Func_Arg = Arg(1) + Arg(2)**

```
...
CF_INPUT
!  User identification
!  |   Name
!  |   |       Type of function (add arguments)
!vvvv  vvvvvv  vvvvvv
CF_ID  'CF12'  ADD      ! Func_Arg = Arg(1) + Arg(2)
!      Multiplier for function CFSCAL
!      |     Added constant CFADCN
CF_SAI 1.0   0.0                     2.0 ! Initial value
!           LowerBound
!           vvv   UpperBound
CF_UBL Both 2.0   7.0
CF_ARG     2 ! NARG CHARG       ARSCAL   ARADCN(optional)
               1  EXEC-TIME  1.0      0.0 ! Arg(1) = Problem_Time*1.0+0.0
               2  CF-CONST   1.0          ! Arg(2) = 1.0
```


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Step in Evaluating MELCOR Control Function

3rd Step

- **Apply function scalar and additive values**
  - InterFunc = Func_Arg * CFSCAL + CFADCN

```
...
CF_INPUT
!  User identification
!  |   Name
!  |   |       Type of function (add argument)
!vvvv  vvvvvv  vvvvvv
CF_ID  'CF12'  ADD
!      Multiplier for function CFSCAL
!      |     Added constant CFADCN   InterFunc=Func_Arg*CFSCAL+CFADCN
CF_SAI 1.0   0.0                     2.0 ! Initial value
!            LowerBound
!            vvv   UpperBound
CF_UBL Both 2.0   7.0
CF_ARG    2 ! NARG CHARG      ARSCAL   ARADCN(optional)
                1  EXEC-TIME  1.0      0.0
                2  CF-CONST   1.0
```


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Step in Evaluating MELCOR Control Function

4th Step

- **Impose upper and lower boundaries**
  - **Func = max(LowerBound,min(InterFunc,UpperBound))**

```
...
CF_INPUT
!  User identification
!  |   Name
!  |   |       Type of function (add argument)
!vvvv  vvvvvv  vvvvvv
CF_ID  'CF12'  ADD
!      Multiplier for function CFSCAL
!      |     Added constant CFADCN
CF_SAI 1.0   0.0                     2.0 ! Initial value
!           LowerBound
!           vvv   UpperBound
CF_UBL Both 2.0   7.0
CF_ARG    2 ! NARG CHARG      ARSCAL   ARADCN(optional)
                1  EXEC-TIME  1.0      0.0
                2  CF-CONST   1.0
```


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MELCOR Control Functions Simple Examples

- **Simple examples first to demonstrate CF format and usage**
  - **More examples and complete list of built in function types given in CF package user's guide**
  - **There are often several ways to build a function**

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MELCOR Control Functions Example Input Using CF

- **Input block for energy source in core**
  - **(same as TF example input shown earlier, but uses CF)**

```
CV_ID CV110
!  Results equivalent to TF example earlier, but use CF
!                        vvvvvvv
CV_SOU 1 ! N  SourceInfo
           1  PE  RATE CF CF12
...
CF_INPUT
!  User identification
!  |   Name     ID Number
!  |   |        |        Type of function (equal to argument)
!vvvv  vvvvvv   vvv      vvvvvv
CF_ID  'CF12'   001       EQUALS
!      Multiplier for function
!      |   Added constant
CF_SAI 0.0 70.E6
CF_ARG    1 ! NARG CHARG      ARSCAL  ARADCN(optional)
                1  EXEC-TIME  0.0
! Must specify one argument
! Value of ‘CF12’ = 0.0 x [(EXEC-TIME x 0.0) + 0.0] + 70.E6 = 70.E6
```

MELCOR Control Functions Example Input Using CF (2)

Alternate ways of expressing a constant

Constant using CF multiplier

```
CF_ID 'Core Power' 001 EQUALS
!      Multiplier for function
CF_SAI 70.E6 ! Add 0.0 (default)
! CF_ARG for specification of arguments
! |             Name of argument
! |             |        Multiplier for argument
! |             |        |       Constant added to argument
!vvvvv          vvvvv    vvvvv   vvvvvv
CF_ARG 1 ! NARG CHARG    ARSCAL  ARADCN
             1  EXEC-TIME   0.0    1.0 ! Could use any argument
! Value returned = 70.E6 x [(EXEC-TIME x 0.0) + 1.0] + 0.0 = 70.E6
```

Constant using argument multiplier

```
CF_ID 'Core Power' 001 EQUALS
!      Multiplier for function
CF_SAI 1.0   ! Add 0.0 (default)
!                                Constant added to argument
!                                vvvvvv
CF_ARG 1 ! NARG CHARG    ARSCAL  ARADCN
             1  EXEC-TIME  0.0     70.E6
! Value returned = 1.0 x [(EXEC-TIME x 0.0) + 70.E6] + 0.0 = 70.E6
```

MELCOR 2.2

```
CF_ID 'Core Power' 001 EQUALS
!      Multiplier for function
!      vvv
CF_SAI 1.0   ! Add 0.0 (default)
!                                Constant added to argument
!                                vvvvvv
CF_ARG 1 ! NARG CHARG    ARSCAL  ARADCN
             1 CF-CONST 70.E6
```


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MELCOR Control Functions Example Input Using CF (3)

- **Example CF Input: Containment failure with message**

```
! LOGICAL function, .true. if arg1 > arg2
CF_ID 'Failure' 100 L-GT
CF_LIV FALSE ! Initial value is .false.
CF_CLS LATCH ! Once .true., stays .true.
!         Flag: writes to all files at completion of step
!         |   Message to be written when function changes value
!         v        vvvvvvvvvvvvvvvvvvvv
CF_MSG FULL-OUTPUT 'Containment Failed'
CF_ARG 2  !  Argument      Scale  Add
          1  CVH-P('CV300') 1.0   0.0  !Pressure in volume CV300
          2  CVH-P('CV900') 1.0   1.E5 !Pressure in volume CV900 + 1.E5
! CF becomes true if CV300 pressure exceeds CV900 by 1 bar
```

MELCOR Control Functions Example Input Using CF (4)

- **Example CF Input: Opening a valve in a flowpath**

```
! FL_VLV for valve
! |               Valve name
! |               |          Flowpath name
! |               |          |                CF that gives open fraction
!vvvvv            vvvvvvv    vvvvvv           vvvvvv
FL_VLV  1 !    NV VLVNAME    FLNAME   KEYTRIP NVFONF
           1   ‘Valve1’     ‘FL399’   NoTRIP  ‘Hole’ ! Open fraction
                                                     ! from CF ’Hole’
...
CF_INPUT
! REAL function, equivalent to IF-THEN-ELSE
                   vvvvvvvv
CF_ID   'Hole‘ 101 L-A-IFTE
CF_SAI  1.0
!              Argument        Scale   Add
CF_ARG  3 ! NARG CHARG        ARSCAL  ARADCN
            1 CF-VALU(‘Failure’) 0.0   0.0 ! LOGICAL, true after failure
            2 EXEC-TIME          0.0   1.0 ! Hole = 1.0 if arg 1 true
            3 EXEC-TIME          0.0   0.0 ! Hole = 0.0 if arg 1 false
```


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MELCOR Control Functions Example Input Using CF (5)

- **Generate restart and plot at time of failure**

```
EXEC_INPUT
EXEC_RESTARTCF ‘E+R Flag’ ! (MELCOR input) restart dump if CF
                          ! ‘E+R Flag’ is .true.
EXEC_PLOTCF    ‘E+R Flag’ ! (MELCOR input) plot dump if CF
                          ! ‘E+R Flag’ is .true.
...
CF_INPUT
! Edit for *start* of step on which CF becomes true
! LOGICAL function, set equal to argument
!                      vvvvvvvv
CF_ID ‘E+R Flag’  105  L-EQUALS
CF_LIV FALSE     ! Initial value is .false.
CF_CLS ONE-SHOT ! Can be .true. only once
CF_ARG 1 ! NARG CHARG     ARSCAL ARADCN
       1 CF-VALU(‘Failure’)   0.      0. ! Becomes true on
                                          ! ‘Failure’
```


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MELCOR Control Functions Example Input Using CF (6)

- **Calculate maximum pressure in volume 200**

```
! REAL function, 2 or more arguments
!                          vvv
CF_ID   ‘Peak P.200’  110  MAX
CF_SAI  1.0  0.0  0.0 ! Initialize to zero
!                  Argument         Scale     Add
CF_ARG 2 ! NARG      CHARG         ARSCAL    ARADCN
            1      CVH-P(‘CV200’)    1.0       0.0 ! *CURRENT*
                                         ! pressure in volume CV200
            2 CF-VALU(‘Peak P.200’)  1.0       0.0 ! *PREVIOUS*
                                         ! value of maximum
```


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MELCOR Control Functions Example Input Using CF (7)

- **Built in function 'PIPE-STR' expressed with 'FORMULA' in a single control function**

```
! Maximum stress in a thick-walled pipe under internal pressure
! given as, PIPE-STR(t)=[(Ro^2+Ri^2)*Pi-2Ro^2Po]/(Ro^2-Ri^2)
!
CF_ID   'Stress'  120  FORMULA
CF_SAI  1.0  0.0
CF_FORMULA 5 ((Ro^two+Ri^two)*Pi-two*Ro^two*Po)/(Ro^two-Ri^two)
           1  Pi   CVH-P(CV500) ! Inner pressure
           2  Po   CVH-P(CV8)   ! Outer pressure
           3  Ri   0.37         ! Inner radius (constant value)
           4  Ro   0.45         ! Outer radius (constant value)
           5  two 2.0           ! (constant value)
```


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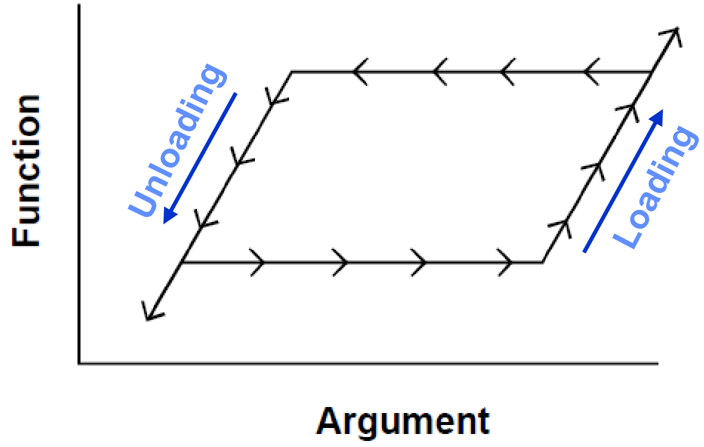
MELCOR Control Functions Hysteresis Function

- Can be used to model the type of hysteresis behavior exhibited by components such as relief valves
- Defined by "loading" and "unloading" curve with a dead band in between
  - Loading curve is used when argument is increasing
  - Unloading curve is used when argument is decreasing



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MELCOR Control Functions
Relief Valve Example Using Hysteresis Function

- **Input block for SRV in flowpath ‘SRV’**

```
!     Normal (untripped) valve, open fraction from CF 'SRV Open Fr'
FL_VLV   1 !NV VLVNAME FLNAME   KEYTRIP   NVFONF        NVFONR NVTRIP
            1  Valve1  SRV      NoTRIP   'SRV Open Fr'
...
CF_INPUT
! REAL function of a single argument
CF_ID 'SRV Open Fr‘ 300 HYST
CF_SAI    0.2    0.0    0.0 ! Initialize to zero
! HYST requires four miscellaneous numbers; the first and the third
! identify either TF or CF; the second and the fourth define the
function name that defines the loading and unloading curve.
CF_MSC  TF    'SRV Load'   TF  'SRV Unload'
CF_ARG    1 ! NARG CHARG                  ARSCAL  ARADCN
                1 CVH-P('DC+UP+SD')   1.0     0.0 ! Pressure in CV
                                                  ! 'DC+UP+SD'
```


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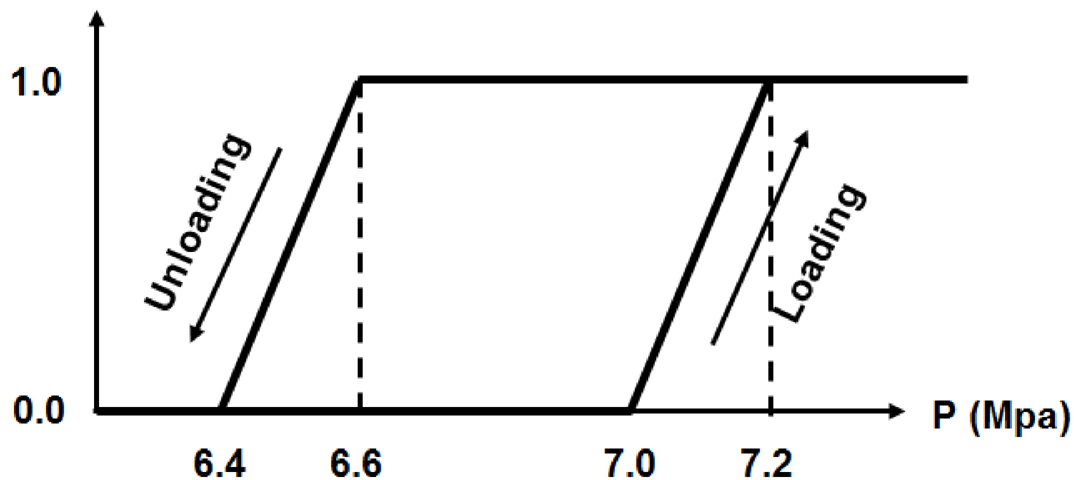
MELCOR Control Functions
Relief Valve Example Using Hysteresis Function (2)

- **Input block for loading curves (TF) referenced in SRV example**

```
TF_ID 'SRV Load'    1.0
TF_TAB    2 ! 2 points, using constant extrapolation
               1      7.0E6      0.0     !Open frac. 0.0 at and below 7.0 MPa
               2      7.2E6      1.0     !Open frac. 1.0 at and above 7.2 MPa
TF_ID 'SRV Unload'    1.0
TF_TAB    2 ! 2 points, using constant extrapolation
               1      6.4E6      0.0     !Open frac. 0.0 at and below 6.4 Mpa
               2      6.6E6      1.0     !Open frac. 1.0 at and below 6.6 Mpa
```



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MELCOR Control Functions
Trips

- The “TRIPS” in MELCOR are REAL-valued
  - In essence, returned value is time elapsed since switched on
  - Useful for imposing delays (as timers)
    - Start a timer on change of a LOGICAL argument
    - Start or reset a timer when a REAL argument crosses an upper or lower “set-point”
  - Value can be positive or negative of elapsed time
    - Referred to as “on-forward” and “on-reverse”

- Consider following simple case

MELCOR Control Functions
Example Input Using Trips

- **Revisit previous example, containment failure, but open hole over 2 seconds**

```
FL_VLV   1 !   NV VLVNAME     FLNAME    KEYTRIP NVFONF
         1     'Valve1'       'FL300'   NoTRIP  'Hole'
!                  REAL function, absolute value = time since trip
!                  vvvv
CF_ID     'Hole'   TRIP
CF_SAI     0.5     0.0    0.0    ! Scale so that value is 1.0 at 2s
                                 ! Initially off
CF_ARG     1
      1  CF-VALU(Failure)        ! Logical, true after failure
! Value of TRIP is positive time after false -> true
!                OR negative time after true -> false
! This makes 'LATCH' in CF 'Failure' essential
!
! Bound value to [0,1]; 3 (or 'BOTH') to impose lower and upper bounds
CF_ULB    3   0.0  1.0    ! Lower and upper bounds
                          ! Note – bounds are applied after scaling
```


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MELCOR Control Functions Example Input Using Trips (2)

- **Can also include failure criterion directly in TRIP function**

```
FL_VLV   1 !   NV VLVNAME     FLNAME    KEYTRIP NVFONF
         1     'Valve1'       'FL300'   NoTRIP  'Hole'
!                  REAL function, see below for value
!                  vvvv
CF_ID     'Hole'   T-O-F        ! 'Trip-off-forward'
CF_SAI     0.5     0.0    0.0   ! Scale so that value is 1.0 at 2s
!        Lower  &  Upper set points
CF_MSC    -1.0     2.E5         ! 2 REALS Required for T-O-F type;
CF_ARG   1  ! Pressure in volume CV300
         1  CVH-P(CV300)  1.0   0.0
! Value is always off (value = 0.) below lower set-point
!           always on  (value = elapsed time since turned on) above
!                        upper set point;
!           [-1.0 , 2.E5] is dead band
!
! Bound value to [0,1]; 3 (or 'BOTH') to impose lower and upper bounds
CF_ULB    3   0.0  1.0    ! Lower and upper bounds
                          ! Note – bounds are applied after scaling
! Easy to impose a delay, say 10 sec
! CF_SAI    0.5     -5.0    0.0
```


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MELCOR Control Functions Input Changes on Restart

- Change any CF and TF parameters from the restart
  - Allow addition of new CFs and TFs
  - Easy to run variations of a failure criterion
  - Run multiple scenarios that branch late in a sequence
    - Define input to include several failure paths
    - Run alternate sequences by restarting from a point before failure, changing break sizes, leak paths, or bounds/limits to allow a different path
    - No need to re-run a long pre-failure calculation
- Continue calculation from last restart dump
  - Need to set 'MEL_RESTARTFILE' record in environmental data appropriately
    - e.g., MEL_RESTARTFILE 'RUN1.RST' NCYCLE -1

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MELCOR Control Functions
Input Changes During a MELCOR Run(2)

- Change actual value of control function thru READ (for REAL-valued) and L-READ (for LOGICAL-valued) option during a MELCOR run
  - Requires a new file containing name of CF and new value
    - New value type must match type of CF (REAL or LOGICAL)
    - New file name specified on “EXEC_CFEXFILE” record
  - Can be used to simply turn-on or –off a valve without stopping and restarting a calculation

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Recent extensions to the CF Package

- **Miscellaneous Changes**
  - **Constant CF Argument**
  - **CF argument units**
  - **Optional print of control functions**
- **Ranges**
- **Vectorized CF arguments**
- **Vector Control Functions**
- **Analytic Control Functions**

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

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

CF_RANGE  CVRANGE2  CVOLUMES  40
CONSTRUCT  1
           1 CVTYPE='CVTYPE01'
```


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End of Data and Control

MELCOR Containment Models

Prepared by
MELCOR Development Team

MELCOR Containment Models Overview of Presentation

- Present several containment-related models that have general applicability
  - Gas combustion models in the BUR package
  - Passive Autocatalytic Recombiner model, PAR
    - Part of Engineered Safety Features (ESF) Package
  - Fan cooler model, FCL (also part of ESF)
  - Spray models in the SPR package
    - Thermodynamics only at this point
- Show simple example input
  - More flexibility is available, as described in code manuals
- Provide information necessary to add these models to evolving input deck

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MELCOR Gas Combustion Models Description

- **Calculates burning of H_2 and CO**
  - **Does not treat burning of structures**
  - **Uses LeChatelier's formula for mixtures**
  - **Deflagration only, but can warn of possible detonation**
- **Models based on HECTR**
  - **Parametric representation (*not* detailed kinetics)**
  - **Criteria for ignition and inerting based on mole fractions**
    - **Different criteria with igniters on and off**
  - **Correlations for combustion velocity and completeness**
    - **Assumes duration is characteristic_dimension/velocity**
    - **Constant rate over duration of burn (with checks)**
  - **Criteria for propagation between connected volumes**
    - **Different for upward, horizontal, or downward**

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MELCOR H2 Model Ignition and Propagation

LeChatelier's formula

$$X_{H2} + X_{CO}\left(L_{H2,ign} / L_{CO,ign}\right) \geq L_{H2,ign} \quad \text{Ignition criteria}$$

$$X_{H2} + X_{CO}\left(L_{H2,prp} / L_{CO,prp}\right) \geq L_{H2,prp} \quad \text{Propagation criteria}$$

$$X_{SC} = X_{H2O} + X_{CO2} \quad \text{Diluent}$$

MELCOR Default Ignition and Propagation Limits

Limits			Minimum O_2	Maximum Diluent
	Igniters	No Igniters		
Ignition	**0.07**	**0.10**	**≥ 0.05**	**< 0.55**
Upward Propagation	**0.041**		**≥ 0.05**	**< 0.55**
Horizontal Propagation	**0.06**		**≥ 0.05**	**< 0.55**
Downward Propagation	**0.09**		**≥ 0.05**	**< 0.55**

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MELCOR Gas Combustion Models Example Input

- **Required input**

```
! BUR identifies input for this model
BUR_INPUT   0      ! 0 activates, 1 inactivates (default)
```

- **Commonly-used optional input**
  - Define igniters or prohibit burning in a volume

```
! The following records modify built-in defaults for a volume
!   |   Number of inputs in the following table
!   |   | Control volume number
!   |   | |        IGNITR: 1 for active, 0 for none (default)
!   |   | |        |       86 for burning prohibited
!   |   | |        |       -1 or CF for REAL type CF
!   |   | |        |  Volume dimension (default from volume size)
!   V   v |        |  |
BUR_BRT N vvvvvv   v  v
        1 "CVnam"  1  10.0  * + optional burn delay parameter and
!                            optional alternate dimension and
!                            delay for use during high pressure
!                            melt ejection
```


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MELCOR Gas Combustion Models
Other Optional Input

- **Occasionally used optional input**

```
! Control generation of extra plot points
! (Default is extra plot point at start and end of each burn_
BUR_PLT  . . .  ! MELGEN input (see code manual)
!
! Modify default time step at burn initiation
! (Default is 0.2 s. Internal controls may reduce further)
! (Needed only if default leads to a fatal error)
BUR_TIM  . . .  ! MELCOR input (see code manual)
```

- **Input primarily for specialists**

```
! The following records modify built-in defaults
BUR_IGN/01 . . .  ! Ignition limits
BUR_DET    . . .  ! Detonation warning parameters
BUR_COM    . . .  ! Completeness and propagation parameters
!
BUR_CC     . . .  ! Modify combustion completeness, by volume
BUR_FS     . . .  ! Modify flame speed, by volume
```


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MELCOR Hydrogen Recombiner Model Description

- PAR is a sub-package in ESF Package
  - Simple parametric model of a passive autocatalytic recombiner for hydrogen removal
  - Calculates gas flow through recombiner
    - Flow rate from Fischer model
      - Coefficients can be changed through input
    - Option to define flow rate using a control function
      - Allows ultimate flexibility
  - Calculates catalytic recombination of H_2 and O_2
    - Efficiency constant or from control function
    - Startup and shutdown based on mole fractions
      - User-specified limits for H_2 and O_2
    - Associated heat generation delivered to atmosphere
  - Allow multiple units, different types

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MELCOR Hydrogen Recombiner Model Description (2)

Fischer equations for a single step function in hydrogen concentration:

$$R_H = \eta \; \rho_H \, Q \; f(t)$$

$$f(t) = \left[1 - e^{-\left[\frac{t-t_0}{\tau}\right]}\right]$$

- R_H = hydrogen reaction rate (kg/sec)
- ρ_h = hydrogen density of entering gas (kg/m3)
- η = hydrogen reaction efficiency (~0.85)
- Q = total gas-phase volumetric flow rate through the unit (m3/sec)
- τ = characteristic heat-up time (~1800 sec)
- t_0 = time of PAR initiation (s)
- t = time after PAR initiation (s)
- $f(t)$ = relaxation time function during initial PAR heat-up

The flow rate can be supplied by the user through a CF or it can be calculated:

$$Q = a\, C_H^b$$

- C_H = hydrogen concentration (mole fraction)
- a = constant that depends on PAR unit design parameters (~0.67 kg/sec)
- b = exponent that depends on PAR unit design parameters (~0.307)

Transient effects from multiple step changes in hydrogen concentration:

$$Q_{new} = Q_{ss}\left[1 - e^{-\Delta t/\tau}\right] + Q_{old} e^{-\Delta t/\tau}$$

Gas temperature change is calculated:

$$\sum_{i=1}^{N} w_{i,in} h_{i,in} = \sum_{i=1}^{N} w_{i,out} h_{i,out}$$

Reaction rates of species:

$$\frac{dm(H_2)}{dt} = -R_H, \text{kg/s} \qquad \frac{dm(H_2O)}{dt} = -\frac{M_{O_2}}{2M_{H_2}} * R_H, \ \text{kg/s}$$

$$\frac{dm(O_2)}{dt} = -\frac{M_{O_2}}{2M_{H_2}} * R_H, \text{kg/s} \qquad \frac{dH}{dt} = \sum_{i=1}^{N} w_{i,in} h_{i,in} - \sum_{i=1}^{N} w_{i,out} h_{i,out}, \text{kg/s}$$

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MELCOR Hydrogen Recombiner Model Example Input

```
! PAR identifies input for this model
!
!        Name of PAR
!        vvvv
PAR_ID   PAR1
! PAR interface and control data (required)
!        Name of associated control volume
!        |     Volumetric flow: CF # or 0 for Fischer model
!        |     |  |  Efficiency: CF # or 0 for constant EPAR
!        vvvv  v  v
PAR_ICI  DryW  0  0
! PAR Fischer model parameters (optional)
!
!        APAR  BPAR   Recombiner efficiency
!        |     |      |     Flow relaxation time
!        |     |      |     |       Operation delay time
!        |     |      |     |       |    Number of units
!        vvvv  vvvvv  vvvv  vvvvvv  vvv  vvvv
PAR_PRM  0.67  0.307  0.85  1800.0  0.0  10.0
```


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MELCOR Hydrogen Recombiner Model Example Input (2)

```
! PAR combustion limit data (optional)
!        Limiting H2 mole fractions
!           Startup Shutdown
!        |         |         Limiting O2 mole fractions
!        |         |         Startup  Shutdown
!        vvvvv     vvvvv     vvvvv    vvvvv
PAR_CLD  0.020     0.005     0.030    0.005
```


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MELCOR Fan Cooler Model Description

- FCL is a sub-package in ESF Package
- Based on MARCH 2.0 model, with extensions
  - Empirical relation for total effective heat transfer coefficient from Oconee FSAR
  - Rated operating condition used to infer
    - Temperature change of gas and coolant
    - Effective area for heat transfer
  - Total heat transfer interpreted as sum of sensible heat and condensation
    - Based on average of inlet and outlet temperatures
    - Correlation coefficients accessible as SC array 9001

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MELCOR Fan Cooler Model Description (2)

- **Heat/mass transfer calculated at actual operating conditions**
  - **Cooler can be turned on or off**
  - **User can specify off-rated flows, coolant temperature**
  - **Gas inlet temperature and composition taken from CVH**
  - **Outlet volume can be different than inlet volume**
    - **FCL defines sinks and sources to CVH**

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MELCOR Fan Cooler Model Example Input

```
! FCL identifies input for this model
!     User identification
!      Name
!      vvv
FCL_ID FC1
! FCL interface and control data. (required)
!
!         |    Numbers of associated control volumes
!         Inlet Outlet (defaults to Inlet)
!         |     |     Name of LOGICAL CF that activates
!         |     |     or omitted for always on (default)
!         |     |     |
!         vvv   vvv   vvv
FCL_ICI   300   300   CFName
```


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MELCOR Fan Cooler Model Example Input (2)

```
! FCL rated flows and temperatures (required)
!        Rated VOLUMETRIC gas flow (m**3/s)
!        |      Rated secondary coolant MASS flow (kg/s)
!        |      |       Rated temperatures (K)
!        |      |       Secondary coolant inlet
!        |      |       |       Primary gas inlet
!        vvvv   vvvvv   vvvvv   vvvvv
FCL_RFT  10.0   19.57   293.0   323.0
! FCL additional rated conditions (required)
!        Cooler capacity (W) at rated conditions
!        |         Steam mole fract. (-), rated conditions
!        vvvvvvvv  vvv
FCL_ARC  81.83E03  0.0
!
! FCL off-rated operation (optional)
!        Actual VOLUMETRIC gas flow (m**3/s)
!        |      Actual secondary coolant MASS flow (kg/s)
!        |      |       Actual coolant inlet temperature
!        vvvv   vvvvv   vvvvv
FCL_AFT  10.0   19.57   293.0
```

MELCOR Containment Spray Model Description

- SPR package models interactions between falling droplets and volume atmospheres
  - Heat and mass transfer
  - Aerosol removal
- Sprays can be injected in any volume
  - Specify source elevation, water temperature and flow rate
  - Specify droplet size
    - Distribution allowed, but not recommended for aerosol removal calculations
  - Sprays can be on or off
  - More than one spray train is permitted

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MELCOR Containment Spray Model Description (2)

- Source of spray water can be the following:
  - An external source
  - Taken from the pool of some control volume
    - May specify elevation range and action on dryout
  - From "rain" of water condensed on heat structures
    - Will return to this later
- Droplets reaching bottom of volume
  - Can be carried over to another control volume
  - Can be deposited into the pool in that volume
  - Can be deposited into a designated "sump" volume
  - User input determines fractional disposition
    - Default is to deposit all into local pool
- Droplets *cannot* be deposited on surfaces

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MELCOR Containment Spray Model Description (3)

- User specifies initial droplet temperature and flow rate
  - Can be controlled by a Control Function
- User turns sprays on and off with a CF
- User can specify droplet size distribution
  - Determines terminal velocity

MELCOR Containment Spray Model Example Input

```
! SPR_ID identifies input for spray sources
!       Name
!       |       Control volume receiving spray
!       |       |  Elevation of spray head (m)
!       |       |  (default: top of volume)
!       |       |  |   CF to specify control function defines ‘ON’
!       |       |  |   (always on if NO)
!       |       |  |   |   Name of ON control function
!       |       |  |   |   |
!       |       |  |   |   |
!       |       |  |   |   |
!       |       |  |   |   |
!       |       |  |   |   |
!       vvvvvv  vv vvv vv  vvvvvv
SPR_ID ‘Spray1’ CV 25. CF  SPR-ON
! SPR Spray reservoir data input
!       Dryout Flag (0 to inactivate when reservoir empties)
!       |           (1 to stop calculation when res. empties)
!       | Name of reservoir control volume
!       | |       Pool dryout elevation
!       | |       |     Pool elevation to resume spray post dryout
!       v v       vvvv  vvvv
SPR_SRD 0 Wetwell -24.8 -24.6
```

MELCOR Containment Spray Model Example Input (2)

```
! SPR droplet temperature and flow rate conditions
!        Input switch for droplet temperature (K) (TP for
!        transfer process, Const for constant, or CF for Control Function
!        |  Depending on switch CFName, TPName, or constant temp
!        |  |        Input switch for flow rate when on (m**3/s)
!        |  |        |   Following fields are optional
!        |  |        |     Control function number for temperature
!        |  |        |     (If >0 overrides first field)
!        vv vvvvvvvv vvvvv vvvv
SPR_DTFR CF SPR-Temp Const 0.04
! SPR drop size distribution
!       Total number of table rows/Index number
!       |   Drop diameter (m)
!       |   |       Relative frequency of various drop sizes
!       v   |
SPR_DSD 1  vvvvvv  vvv
        1  5.0E-4  1.0    * All drops start at 0.5 mm
```


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MELCOR Containment Spray Model
Spray Junction Model

- **User can override default disposition of droplets reaching bottom of control volume**
- **Specify fractions that are**
  - **Deposited into local pool (default)**
  - **Carried over to other volumes**
  - **Transported directly to a designated sump volume**

MELCOR Containment Spray Model
Spray Junction Model Input

- **Input records associated with the model**
  - Won't be using in this workshop

```
! SPR junction
!       Total number of table rows/Index number
!       | From control volume name
!       | |    To control volume name
!       v |    |    Droplet fraction reaching bottom transported
SPR_JUN N vvv  vvv  vvv
        1 CV1  CV2  1.0
        . .    .     .
        . .    .     .
        N .    .     .
! SPR sump
!        defines sump volume
SPR_SUMP CVName
!      Total number of table rows/Index number
SPR_CV 1 ! Control volume name through which droplets may fall
           into sump
       1   CVName
```


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End Containment Models

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Backups

The following is provided should any future users not have access to these files, but not to SNAP.

All images presented are screen captures from the SNAP and contain the information needed to create the models during the workshop.

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Exercise 3

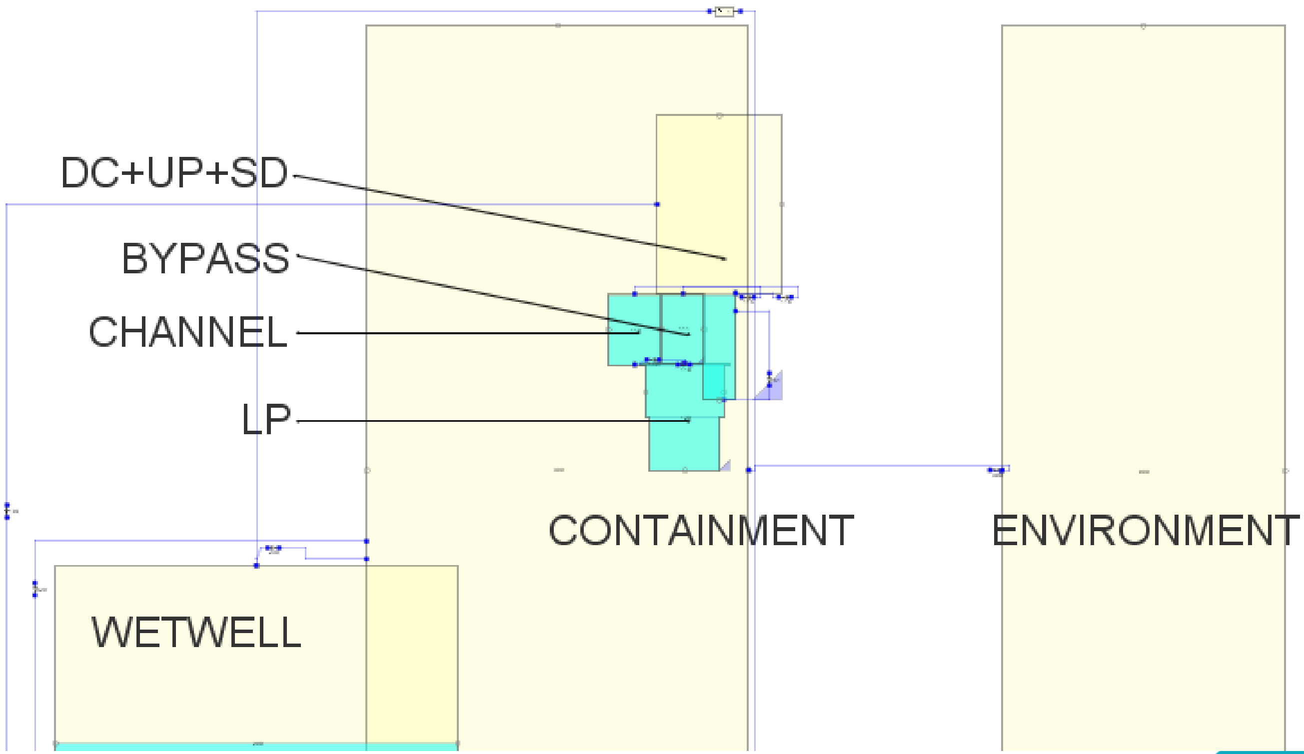
Tasks

1. Activate the Burn Package.
   - o Submit Job
   - o Observe the Deflagration View in the PostProcessing file

2. Activate the Containment spray.
   - o Adjust the CF310 "Sprays are ON" to activate the sprays when Containment pressure is greater than 0.12MPa.
   - o Submit Job

3. Create 10 PAR units within the containment volume.
   - o See Par View Tab for details
   - o Submit Job

4. Add a Fan Cooler
   - o See Fan View Tab for details
   - o Submit Job



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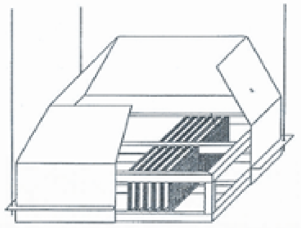
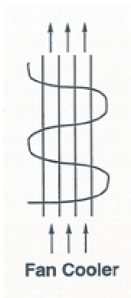
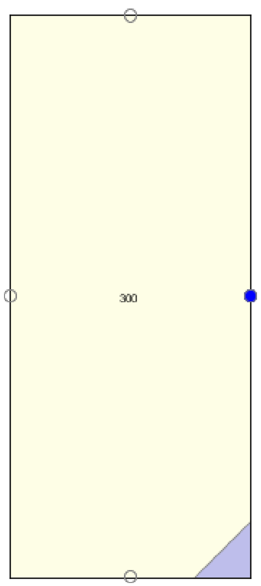


Passive Autocataliytic Recombiner (PAR)

- o Name the PAR units PAR1
- o Create 10 PAR units (Note you'll only need 1 PAR with 10 units)
- o Placed in Containment
- o Reduce relaxation time to 1000.0 seconds





o Name the FC unit FC1
o Connect the inlet and outlet to the Containment
o Specify the Control Function to turn FC1 on

o Set the Following Conditions

Volumetric Gas Flow	10.0m**3/s
Coolant Mass Flow	19.57 kg/s
Coolant Inlet Temp.	293.0 K
Gas Inlet Temp.	323.0 K
Capacity	81.83e03
Steam Mole Fraction	0.0

o Adjust the FCL Actuation CF to start when vapor temperature in containment > 323.0 K

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Heat Structures

Presented by:
Larry Humphries

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Overview of Presentation

- Present characteristics of MELCOR Heat Structures (HS) package
- Discuss use of Material Properties (MP) package to provide properties
- Example input will be presented based on the heat structure modeled in the depressurization problem

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Introduction

- MELCOR heat structures used to model thermal response of solid objects
- Used for everything except parts of core
  - Vessels, pipes, steam generator tubes
  - Walls, floors, other containment structures
  - Ice condensers
  - Core shroud and upper internals
    - Not fuel rods, BWR canisters, control elements,
    - Not core plate or BWR control rod guide tubes
- Ability to decompose or melt
  - Degassing of hot concrete, with gases to CVH
  - Melting of ice condensers, with water to CVH
  - Melting of core shroud, with steel debris to COR package

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Heat Structure Definition

- **A heat structure is a solid structure which is represented by one-dimensional heat conduction with specified boundary conditions at each of its two boundary surfaces**

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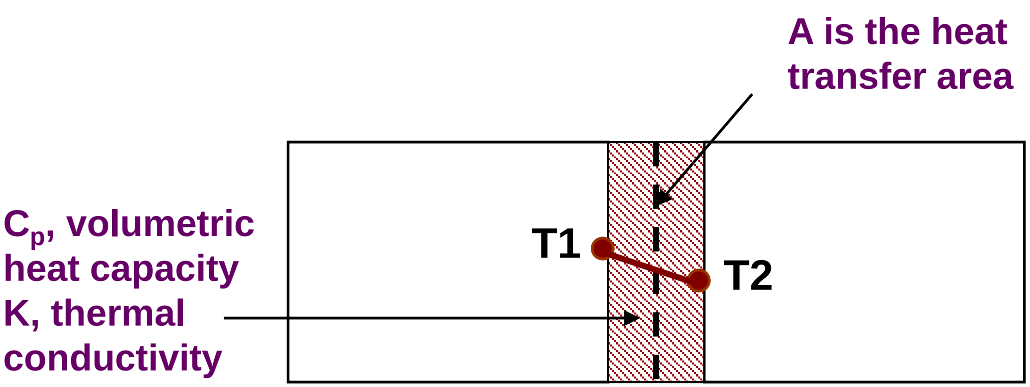
Basic Approach

- One dimensional conduction solution
  - Rectangular, cylindrical, or spherical geometry
  - User-defined nodalization allowing multiple materials

$$C_p \frac{\partial T}{\partial t} = \frac{1}{A} \frac{\partial}{\partial x} \left(KA \frac{\partial T}{\partial x} \right) + U$$

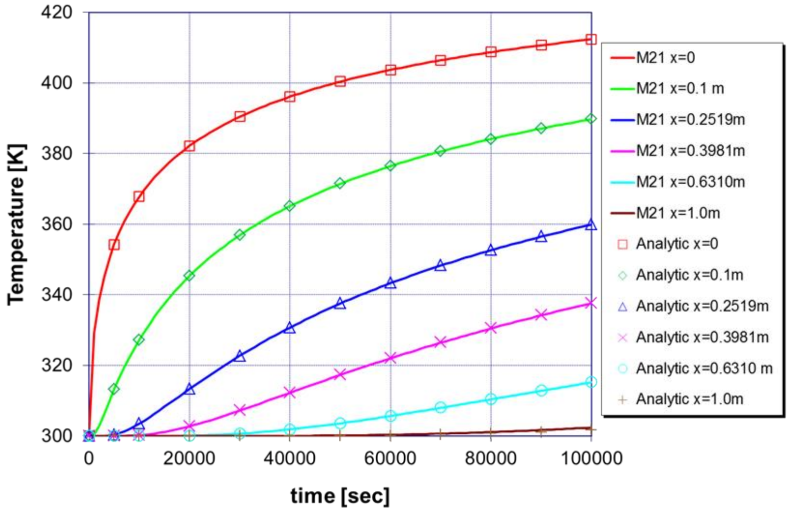


Finite Difference

- Finite-difference equations are used to advance the temperature distribution of a heat structure in time during MELCOR execution or to obtain its steady-state temperature distribution during MELGEN execution if specified by user input
- The finite-difference approximation is a tridiagonal system of N equations for a heat structure with N temperature nodes
- The procedure is iterative because the coefficients are functions of temperature and must be updated between iterations
- Uses an implicit numerical method

Validation Against Analytic Solutions

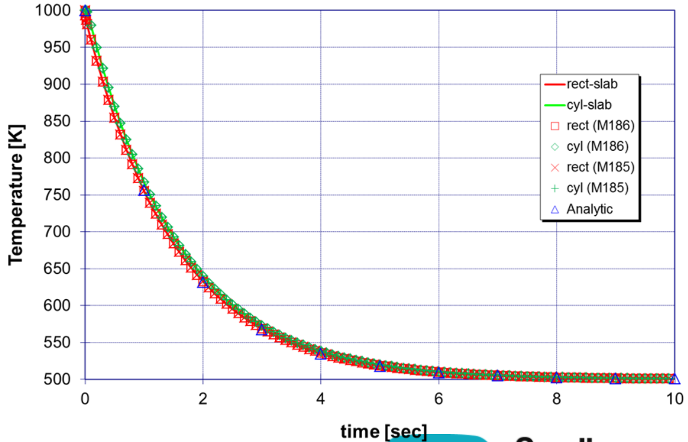
- **Transient Heat Flow in a Semi-Infinite Heat Slab**



$$\frac{T - T_i}{T_o - T_i} = 1 - erf\left[\frac{x}{2\sqrt{\alpha t}}\right] - \exp\left[\frac{hx}{k} + \frac{h^2 \alpha t}{k^2}\right]\left[1 - erf\left(\frac{x}{2\sqrt{\alpha t}} + \frac{h\sqrt{\alpha t}}{k}\right)\right]$$

- **Cooling of Heat Structures in a Fluid**
  - lumped-heat-capacity structure which is immersed in a fluid

$$T = T_f + (T_i - T_f)\left[\exp\left(\frac{-hAt}{\alpha V}\right)\right]$$



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Modeling Capabilities

- One dimensional conduction solution
  - Rectangular, cylindrical, or spherical geometry
  - User-defined nodalization may be non-uniform
- Flexible boundary conditions, two sides
  - Usually interfaced to volume conditions in CVH
    - Heat and mass transfer at surfaces returned to CVH
    - Can include radiation to optically active gas
  - Other boundary conditions available
    - Symmetry (adiabatic), specified temperature, or specified heat flux
  - Allows surface-to-surface radiation

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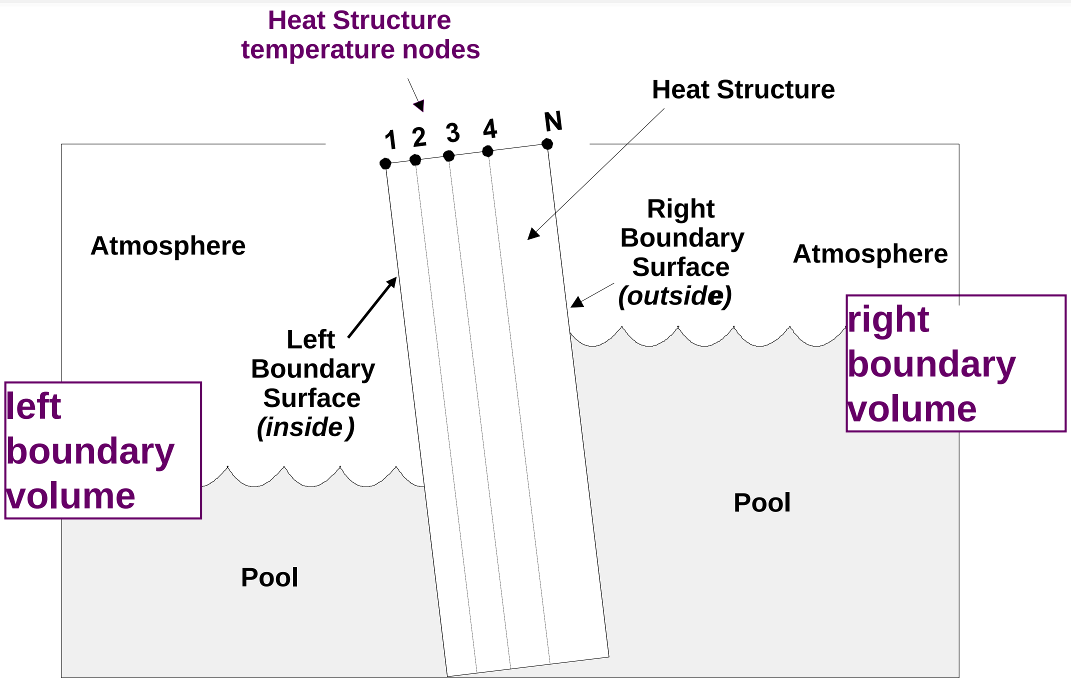
Schematic of HS



- Heat structure is inclined
- Partially immersed
- May have rectangular, cylindrical, spherical or hemispherical geometry

- HS nodalized with N temperature nodes
- Node 1 is at the left boundary surface (or inside), must define it
- Node N is at the right (outside), many options to define rest of nodes
- Region between two nodes is called mesh interval (N-1 meshes)

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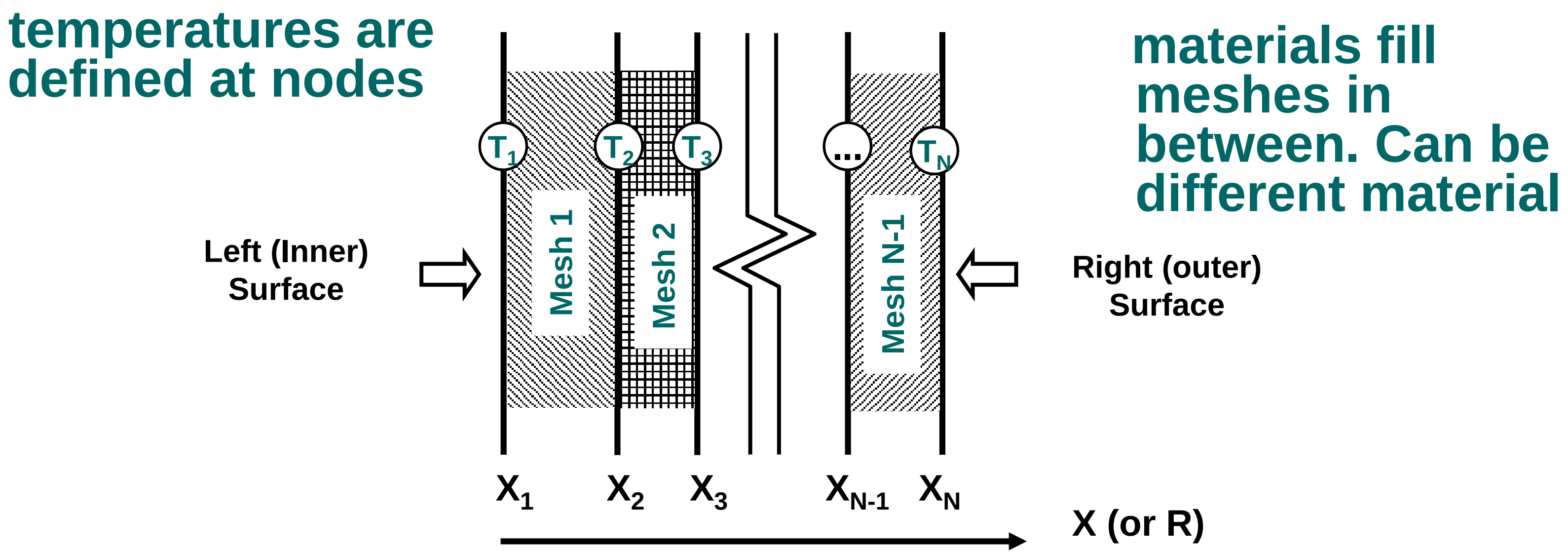
Nodalization



$$\Delta X_{surf} \geq L_D = \sqrt{4\,k\,\Delta t_{max} / C_p}$$

- There are N temperature nodes (points)
- There are N-1 material meshes
- Must define position of first node
- Define positions for other nodes (different options)

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Materials and Temperature Initialization

- Define material for each mesh. Each can be a different material
- Data from Material Properties package
- Built-in data can be modified by user input
- New materials and properties can be defined
- If steady-state initialization calculation is chosen, then there is no need to define initial temperature for the nodes
- If steady-state initialization is not performed, then the initial temperature distribution is required

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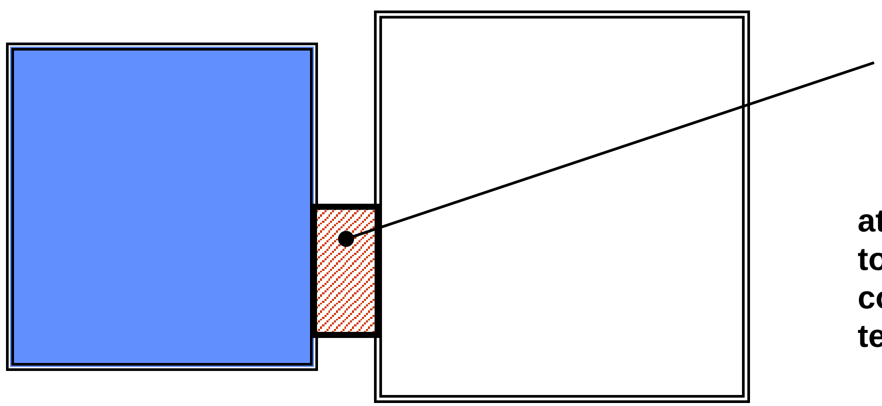
Depressurization Example

- Discuss specific input records
- The following Melgen input examples are from the depressurization problem

HS_SS is the name of heat structure added to thermally equilibrate the two volumes



at time t=0 open the two volumes to each other. The system will come into pressure and temperature equilibrium

Volume 1:
100 m^3 of water, at
P = 8000 KPa, and
T = 568 K

Volume 2:
4000 m^3 of steam, at
P = 10 KPa, and
T = 568 K

Required Input

- General input
  - Name, HS_ID
  - Geometry type, temperature initialization option HS_GD
  - Elevation and Orientation, HS_EOD
  - Internal Power Source Data, HS_SRC
  - Node data, HS_ND
  - Boundary Conditions:
    - HS_LB, HS_LBP, HS_LBS, for left boundary
    - HS_RB, HS_RBP, HS_RBS, for right boundary

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Geometric Input

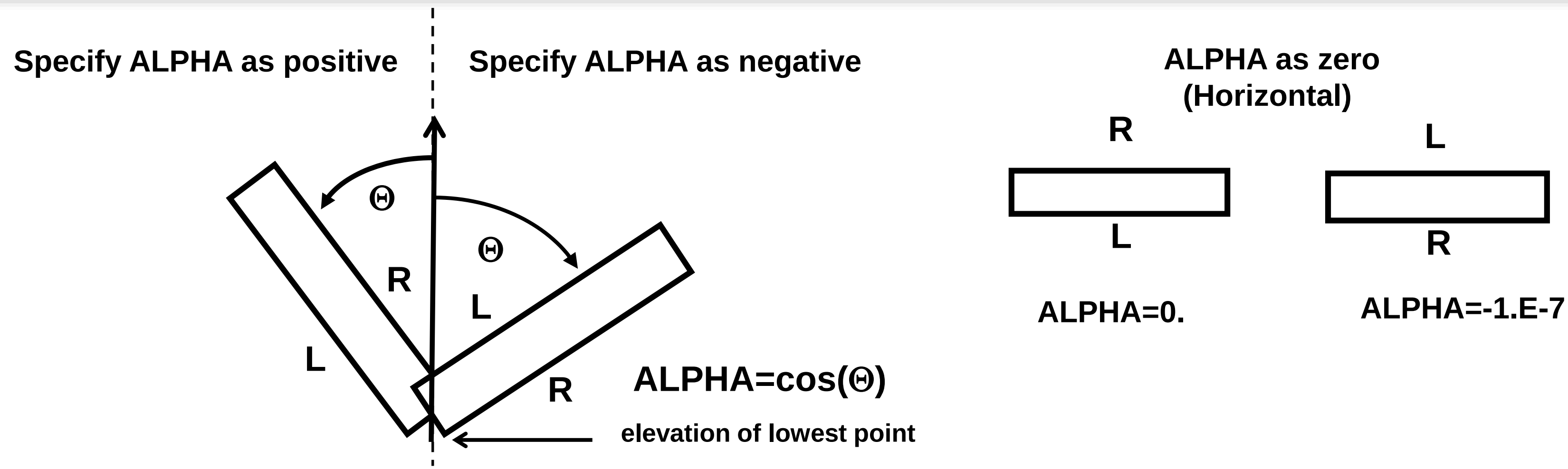
- A heat structure can have one of the following shapes: rectangular (or 1), cylindrical (2), spherical (3), or hemispherical geometry (4 and 5)
- Steady state initialization flag

```
HS_INPUT

HS_ID    'HS-SS'

HS_GD    RECTANGULAR    NO
```

general HS data, required → HS_GD

NO means steady-state initialization calculation is not performed and the initial temperature distribution is input on HS_ND record

Elevation and Orientation



- **Define HSALT as elevation of lowest point on the structure**
- **Define ALPHA the cosine of the angle between surface and vertical**
  - **Also defines which side is "up" for rectangular**
  - **Unused for spherical and hemispherical**
- **Two surfaces, called "left" and "right" for rectangular geometry, "inner" and "outer" for other geometries**

elevation and orientation data, required → | HS_EOD | 1.0 | 1.0 |

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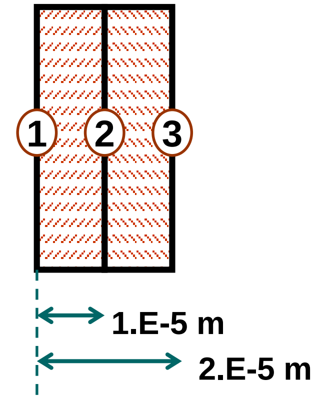
Nodalization and Temperature Initialization



node data, required → **HS_ND** 3

1	1	0.0	568.	stainless-steel
2	2	1.E-05	568.	stainless-steel
3	3	2.E-05	568.	

node number

location of temperature node

because steady-state initialization calculation is not performed, the initial temperature distribution is required

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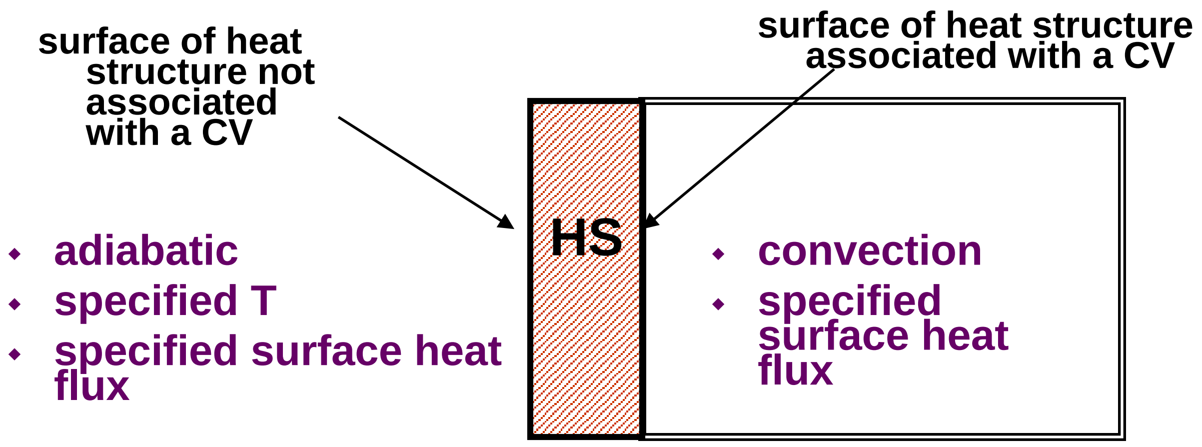
Boundary Conditions



- **The boundary conditions for a boundary surface of a heat structure can be one of the following:**
  - symmetry (adiabatic)
  - specified surface temperature
  - specified surface heat flux
  - Convective
- **Three types of boundary conditions**

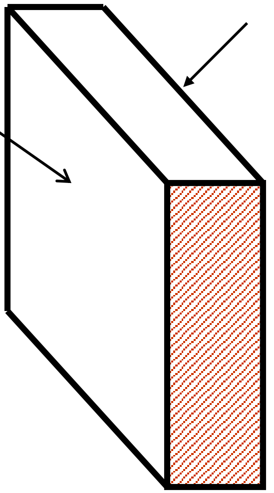
Boundary Conditions (B.C.), Overview

- Sides independent, can "see" different volumes
- Boundary condition "type" and associated control volume (if any) defined on HS_LB (HS_RB)

IBCL and IBCR

HS_LB	COEFTIMETF	TF2	CV1	YES
HS_RB	COEFTIMETF	TF2	CV2	YES

Mass Transfer



COEFTIMETF: convective boundary condition is applied with heat transfer coefficients given as a function of time by Tabular Function

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B.C. First Type

- Boundary conditions not involving a volume
  - Adiabatic (symmetry): IBCL (or IBCR) = 0 or Symmetry
  - Specified (prescribed) surface temperature
    - As tabular function of time: IBCL (or IBCR) = 20 or TempTimeTF
    - As value of a control function: IBCL (or IBCR) = 80 or TempCF

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B.C. Second Group

- Convective boundary conditions to a volume
  - Calculated from internal correlations: IBCL (or IBCR) = 1 or CalcCoefHS
  - Correlations plus surface power source (in Watts)
    - Tabulated function of time: IBCL (or IBCR) = 10 or SourTimeTF
    - Value of a control function: IBCL (or IBCR) = 70 or SourCF
  - User-specified heat transfer coefficients
    - Tabulated function of time: IBCL (or IBCR) = 40 or CoefTimeTF
    - Tabulated function of surface temperature: IBCL (or IBCR) = 50 or CoefTempTF
    - Value of a control function: IBCL (or IBCR) = 60 or CoefCF

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Standard Correlations for Heat Transfer Correlations

- **Atmosphere**
  - Forced Convection
    - Laminar
    - Turbulent $Nu = C\,\mathrm{Re}^m\,\mathrm{Pr}^n + D$
    - Mixed
  - Free Convection
    - Laminar
    - Turbulent $Nu = C\,Ra^m + D$
    - Mixed
- **Pool**
  - Forced Convection
    - Laminar
    - Turbulent $Nu = C\,\mathrm{Re}^m\,\mathrm{Pr}^n + D$
    - Mixed
  - Free Convection
    - Laminar
    - Turbulent $Nu = C\,Ra^m + D$
    - Mixed
- **Nucleate Boiling**
  - Zuber
- **Film Boiling**
  - Modified Bromley

Constants for HS Package Heat Transfer Correlations: Atmosphere

Region	Type of Flow			Geometry	(1)	(2)	(3)	(4)	Ref	SC Array
ATMOSPHERE										
				Rectangular	0.046	1/3	0	-	[1]	C4101
			Laminar	Cylindrical	0.046	1/3	0	-	[1]	C4102
		Internal		Spherical	0.228	0.226	0	-	[1]	C4103
				Rectangular	0.046	1/3	0	-	[1]	C4104
			Turbulent	Cylindrical	0.046	1/3	0	-	[1]	C4105
	Natural Convection			Spherical	0.228	0.226	0	-	[1]	C4106
				Rectangular	0.59	0.25	0	-	[1]	C4107
			Laminar	Cylindrical	0.59	0.25	0	-	[1]	C4108
		External		Spherical	0.43	0.25	2.0	-	[1]	C4109
				Rectangular	0.10	1/3	0	-	[1]	C4110
			Turbulent	Cylindrical	0.10	1/3	0	-	[1]	C4111
	Atmosphere			Spherical	0.43	0.25	2.0	-	[1]	C4112
				Rectangular	8.235	0	0	0	[1]	C4113
			Laminar	Cylindrical	48/11	0	0	0	[1]	C4114
		Internal		Spherical	48/11	0	0	0	[1]	C4115
				Rectangular	0.023	0.8	1/3	0	[]	C4116
			Turbulent	Cylindrical	0.023	0.8	1/3	0	[2]	C4117
	Forced Convection			Spherical	0.023	0.8	1/3	0	[2]	C4118
				Rectangular	0.664	0.5	1/3	0	[2]	C4119
			Laminar	Cylindrical	0.664	0.5	1/3	0	[2]	C4120
		External		Spherical	0.60	0.5	1/3	2.0	[2]	C4121
				Rectangular	0.037	0.8	1/3	0	[2]	C4122
			Turbulent	Cylindrical	0.037	0.8	1/3	0	[2]	C4123
				Spherical	0.60	0.5	1/3	2.0	[2]	C4124

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B.C. Third Group

- Specified surface heat flux
  - As tabular function of time: IBCL (or IBCR) = 30 or FluxTimeTF
  - As value of a control function: IBCL (or IBCR) = 90 or FluxCF
- Can have associated CV or not. For associated volume, heat flux goes to fluid

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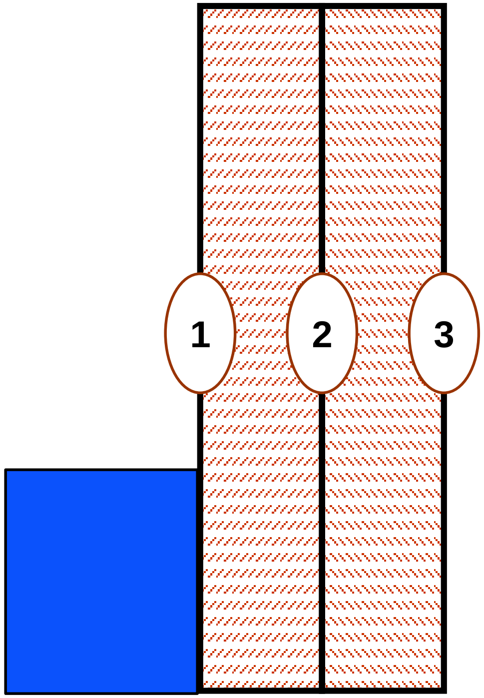
Critical Pool Fraction Concept

- **Only one surface temperature for structure, imposed by one-dimensional modeling**
- **Part or all of a surface will be submerged in pool of associated volume**
  - **Surface temperature will approach pool because of large heat transfer coefficient**
  - **This is often *not* what you want, particularly in containment**
- **Partition heat transfer between pool and atmosphere**
- **Can specify minimum fraction exposed to pool or atmosphere**



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Critical Pool Fraction Definition

- Two variables on HS_LBP (or HS_RBP) records
  - CPFPL (or CPFPR) is value of pool fraction *below* which heat transfer to pool is ignored
  - CPFAL (or CPFAR) is value of pool fraction *above* which heat transfer to atmosphere is ignored
- Setting them equal avoids simultaneous heat transfer, possible unphysical heat flow
- The fraction is the area fraction and includes effects of inclination and curvature

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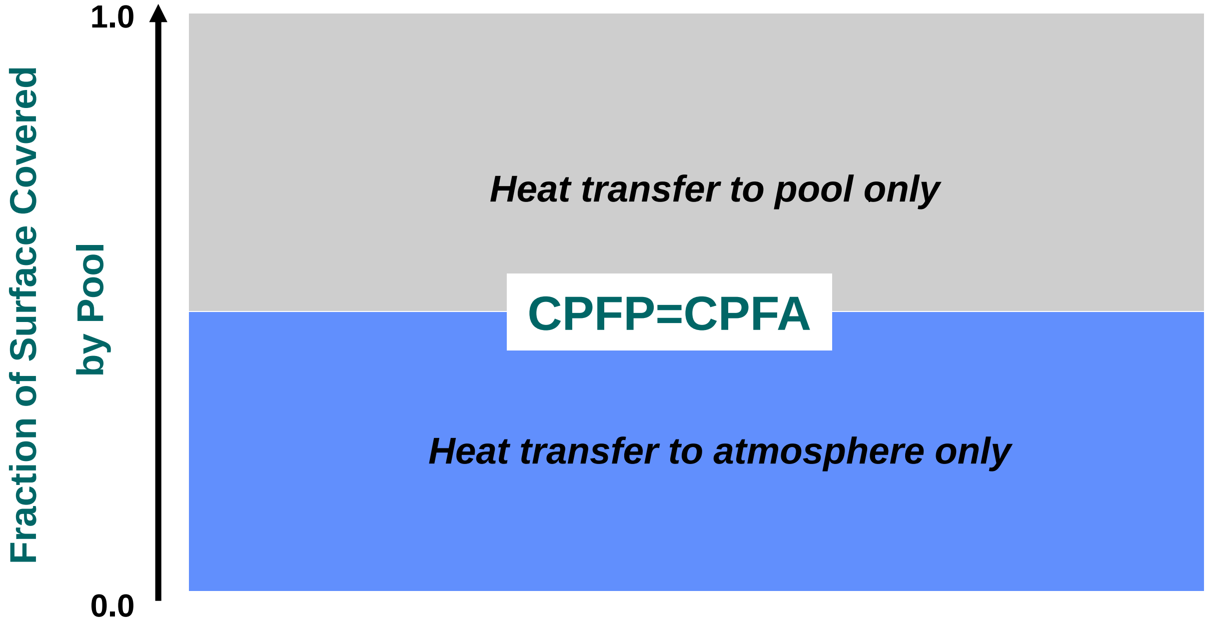
Critical Pool Fraction Interpretation

CPFP is value of critical pool fraction *below* which heat transfer to pool is ignored
CPFA is value of critical pool fraction *above* which heat transfer to atmosphere is ignored



If CPFP=CPFA, then heat transfer will occur to either the pool or atmosphere (but not both at the same time) depending upon the value of the pool fraction

Critical Pool Fraction

- If pool and atmosphere temperatures are similar and
- Heat transfer to both phases expected to be significant
- Simultaneous communication with both phases
  - Set CPFPL = 0 and CPFAL = 1
- Often used for steam generator heat structures
  - Also commonly used for horizontal floors and ceilings

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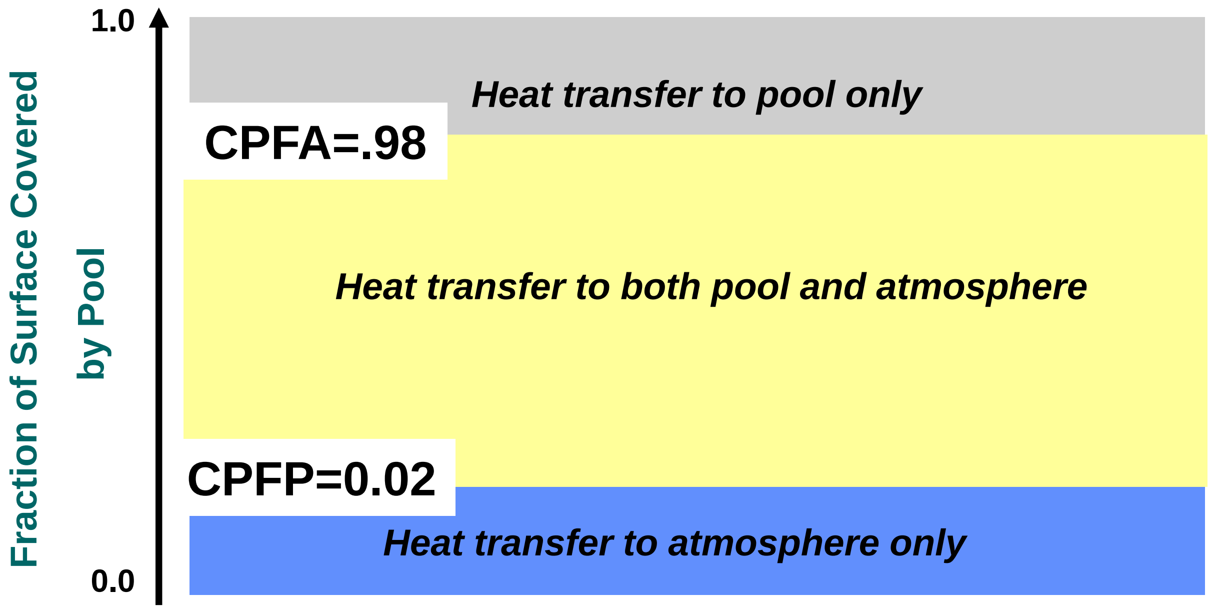
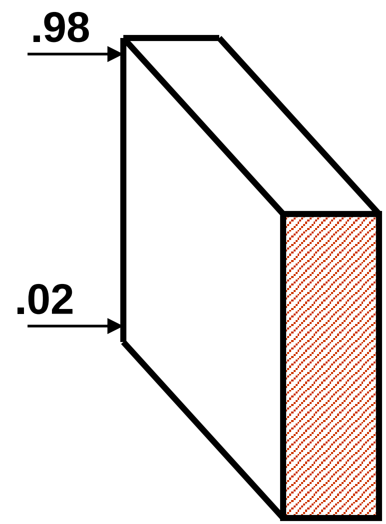
Critical pool fraction

Specify if the flow is internal or external

HS_LBP	EXT	0.02	0.98
HS_RBP	EXT	0.02	0.98



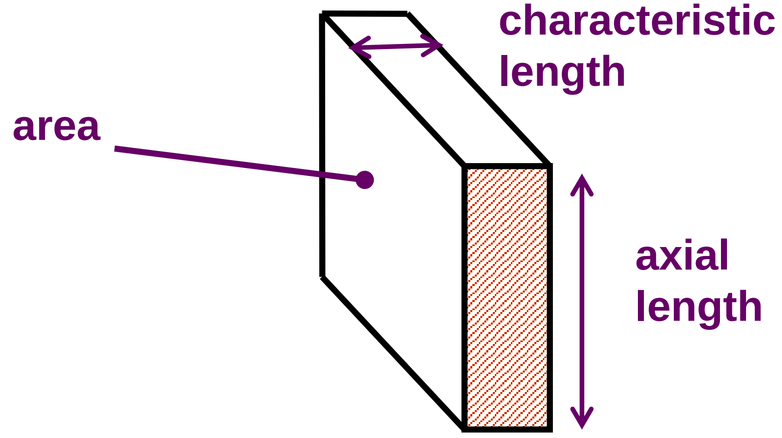


Numer[illegible] forced ≤0.98). Limits adjustable with sensitivity coefficient array 4071

Calculation of Pool Fraction Dependent on Geometry

- **Rectangular** $$x_{pool} = Z / L \cos(\alpha)$$
- **Cylinder (vertical)** $$x_{pool} = Z / L$$
- **Cylinder (horizontal)** $$x_{pool} = \Theta / \pi \qquad \Theta = \cos^{-1}[(R - Z)/R],$$
- **Cylinder (inclined)** $$X_{pool} = R \sin(\alpha)[TERML(Z) + TERMR(Z)] / b$$
$$TERML = \frac{1}{\pi}\left\{[1 - XL^2]^{1/2} - \frac{XL}{\cos(XL)}\right\}$$
- **Sphere** $$x_{pool} = Z / 2R$$
- **Hemisphere** $$x_{pool} = Z / R$$

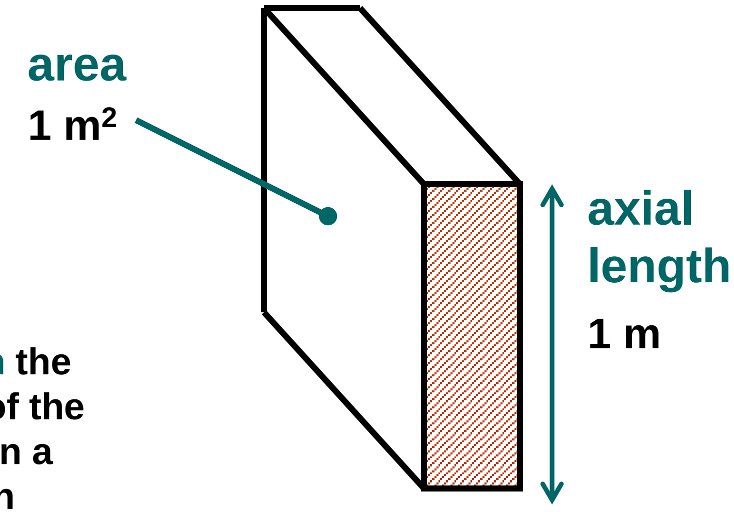
Additional Data for Convective BC



- Area of boundary surface of the given heat structure
- Axial length of boundary surface. The dimension of the boundary surface of the given heat structure in a direction perpendicular to the direction of energy flow
- Characteristic length of boundary surface used to calculate quantities such as the Reynolds number, Nusselt number, etc.

Additional Data for Boundary Surface

- **HS_LBS** (or **HS_RBS**) **is required when B.C. is convective (type two)**



HS_LBS 1.0 0.1 1.0

- **1.0** — **area of boundary surface**
- **0.1** — **characteristic length used to calculate quantities like Reynolds and Nusselt numbers**
- **1.0** — **axial length the dimension of the given HS in a direction perpendicular to the direction of energy flow**

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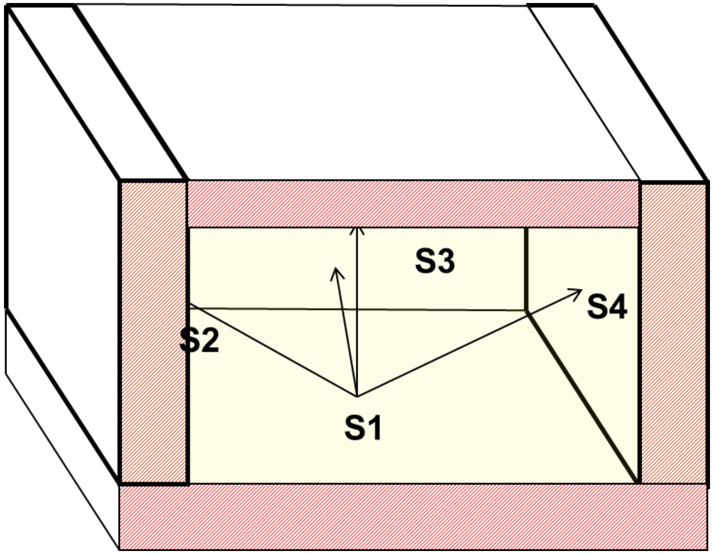
Radiation Modeling

- Radiation heat transfer can be specified between a heat structure surface and the boundary volume atmosphere.
  - Two options available: “gray” gas and “equivalent band” model
- MELCOR includes a simple model for radiation between surfaces of heat structures (surface to surface radiation)
  - Until recently, did not have an enclosure model
    - Radiation between pairs of surfaces are independent of other surfaces or intervening medium
    - Permits sequential processing for each pair (not iterative)
    - Issues a warning if sum of all view factors for a surface exceeds 1.0



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Structure-to-Structure Radiation

- The HS package includes a simple model for radiation between surfaces of heat structures
  - Surfaces must involve control volumes (second BC group)
    - Independent of radiation to fluid model
  - Requires user input for each pair of surfaces
- Radiation automatically calculated from COR package surfaces to boundary heat structures

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Radiation Model

Radiation from surface:

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

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

Radiation from surface i to surface j:

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

Radiation to atmosphere:

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

$$\varepsilon_m = (1 - \tau_{ij})$$

E_{bi} = total blackbody emissive power of ith surface
J_i, = total energy flux leaving the i-th surface
G_i = radiation flux incident on surface i

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

Structure-to-Structure Radiation Input

- **Basic input for each surface pair**

HS_RD	2				
	! first surface	side	second surface	side	view factor
1	HS1	LEFT	HS2	LEFT	0.15
2	HS1	RIGHT	HS2	RIGHT	0.075

! left side of HS1 sees left of HS2
! right side of HS1 sees right of HS2

- **To override built-in emissivity model**

HS_RD	1						
1	'HS1'	LEFT	'HS2'	LEFT	0.15	NO	CFemissivity
						'NO' means that the emissivity as a function of temperature is determined by core	control function whose value is the emissivity of surface 2.

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Radiation to Fluids

- Radiation between surface and gases
  - Calculated only if input record HS_LBR or HS_RBR included
  - Two options, “equivalent band model” and “gray” gas

HS_LBR	0.9	gray-gas-a	0.1
	wall emissivity of surface		radiation path length

- Emissivity is constant for the transient
- Radiation to H2O, CO, and CO2.
  - Not to other non-condensible gases
  - Not to aerosols
- Mechanistic model is used for radiation on film covered surfaces

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Gray Gas Model Beam Length

- ***Equivalent path length representing the average contribution of different beam lengths from the gas body to the surface.***

Geometry:	L
Sphere: internal radiation	0.65 x D
Hemisphere: Radiating to element at center of base	0.5 x D
Circular cylinder of infinite height: Internal radiation	0.95 D
Circular cylinder of semi-infinite height	
Element at center of base	0.9 D
Entire base	0.65 D
Circular cylinder of height equal to two diameters radiating to:	
Plane end	0.43 D
Cylindrical surface	0.46 D
Entire surface	0.45 D
Cube radiating to any face	0.6 x edge
Gas volume outside infinite bank of tubes radiating to a single tube (P = pitch)	
Equilateral-triangle array:	
P=2D	3.0(P-D)
P=3D	3.8x(S-D)
Square Array	3.5x(S-D)
Arbitrary shape of volume V	3.6 V/A

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Multi HS Radiation Enclosure Model

- **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**
    - **View factors are constants and cannot change**
    - **Does not account for surfaces submerged below pool.**
  - **Participating gas**
    - **Transmissivity accounts for reduction in radiation between surfaces**
    - **Only 1 CV associated with all surfaces**
      - **Does not account for rising pool in CV (yet)**
    - **User supplies beam length (similar to COR package)**

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Multi HS Radiation Enclosure Model

- **The space between surfaces may or may not be filled with a participating medium,**
  - Participating gas may absorb, emit, and scatter radiation emitted by the surfaces.
- **Each surface is assumed to be isothermal, opaque, diffuse, and gray, and are characterized by uniform radiosity.**
  - The absorptivity (a) of a surface is equal to the emissivity (e) and the sum of the absorptivity and reflectivity (r) is 1.0

$$\varepsilon_i = \alpha_i = 1 - \rho_i$$

- **Reciprocity is also assumed between surface pairs**
- **It is assumed the sum of the view factors from a surface to all surfaces in the enclosure network, is equal to 1.0.**
  - a surface may also radiate to itself.

$$\sum_{i=1}^{N} VF_{i,j} = 1.0$$

The surface radiosity is defined as the total heat flux that departs from an area (reflected and emitted)

$$J_i = \rho_i \cdot G_i + \varepsilon_i E_{b,i}$$

where

G_i= radiation flux incident on surface I from radiation from all other surfaces,

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

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

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

$$q_i = A_i (J_i - G_i)$$

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

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Radiation Enclosure Input HS_RAD Record

HS_RAD –Radiation Enclosure
Optional

(1) NUMBERHS
Number of heat structure surfaces in the network.
(type = integer, default = none, units = none)

(2) NetworkName
User specified network name
(type = character*16, default = none, units = none)

(2) NetworkNumber
User specified network number
(type = integer, default = none, units = none)

Next data are input as a table with number or rows = NUMBERHS:

(1) i
Index for HS in network.
(type = integer, default = none, units = none)

(2) IHSRDi
Name of heat structure i.
(type = character*16,default = none)

(3) LRBNDi
Option to identify the side of surface IHSRDi.
-1 or LEFT
Left side surface of the given heat structure.
1 or RIGHT
Right side surface of the given heat structure.
(type = integer / character*5, default = none, units = none)

(4) ICFRDi
Optional constant value for emissivity of the surface (real) or real-valued control function name (character*16) whose value is the emissivity of the surface. If neither is specified, MELCOR calculates the emissivity using the COR package relation for oxidized steel surfaces.
(type = real or character*16, default = '-', units = none)

(5) BEAMLi
Radiation path length for the boundary gas associated with the surface i. If the beam length is zero, then the gas is non-participating.
(type = real, default =0.0, units = m)

(5+ NUMBERHS) $VIEW_{i,NUMBERHS}$
View factor between surface i and surface NUMBERHS, which must lie in the range of 0.0 to 1.0. If '-' is entered and i<>NUMBERHS, then the viewfactor is calculated by reciprocity from $VIEW_{NUMBERHS,i}$
(type = real or character*16, default = none, units = none)

Example using placeholder in view factor input

- The radiation enclosure model allows the user to specify a placeholder '-' for a view factor if that missing view factor can be calculated implicitly by reciprocity

$$V_{i,j} A_i = V_{j,I} A_j$$

- The sum of view factors from a surface to all other surfaces in the network is equal to 1.0. If it sums to something less, the difference is accounted for by adjusting the self-radiation term.

MELGEN Input:

```
HS_RAD 7 NET3  3!
!n                      B   1  2  3  4  5    6    7
 1  HS1B    LEFT 'EM3' 0.  -   0.  0.  0.  0.  0.50  0.20     !Area = 10.0
 2  HS2B    LEFT 'EM3' 0.  0.  -   0.  0.  0.  0.50  0.20     !Area = 10.0
 3  HS3B    LEFT 'EM3' 0.  0.  0.  -   0.  0.  0.50  0.20     !Area = 10.0
 4  HS4B    LEFT 'EM3' 0.  0.  0.  0.  -   0.  0.50  0.20     !Area = 10.0
 5  HS5B    LEFT 'EM3' 0.  0.  0.  0.  0.  -   0.50  0.20     !Area = 10.0
 6  HS6B    LEFT 'EM3' 0.  -   -   -   -   -   -     0.0      !Area = 150.0
 7  HS7B    LEFT 'EM3' 0.  -   -   -   -   -   0.0   -        !Area = 100.0
```

MELCOR Output:

RADIATION ENCLOSURE NETWORK: NET3

HS NAME		SURFACE	BEAM L	VIEW FAC						
1	HS1B	LEFT	0.000E+00	0.300	0.000	0.000	0.000	0.000	0.500	0.200
2	HS2B	LEFT	0.000E+00	0.000	0.300	0.000	0.000	0.000	0.500	0.200
3	HS3B	LEFT	0.000E+00	0.000	0.000	0.300	0.000	0.000	0.500	0.200
4	HS4B	LEFT	0.000E+00	0.000	0.000	0.000	0.300	0.000	0.500	0.200
5	HS5B	LEFT	0.000E+00	0.000	0.000	0.000	0.000	0.300	0.500	0.200
6	HS6B	LEFT	0.000E+00	0.033	0.033	0.033	0.033	0.033	0.833	0.000
7	HS7B	LEFT	0.000E+00	0.020	0.020	0.020	0.020	0.020	0.000	0.900

$VF_{7,1}=VF_{1,7}*A_1/A_7$

$0.02=0.2*10.0/100.0$

Other Input

- **Internal power source (required record)**

HS_ID	'HSTEST'	
HS_SRC	NO	internal power source data, NO or 0, no source

- **Multiplicity (optional)**

HS_ID	'HSTEST'	
HS_MLT	10000.0	Multiplicity record, 10000 is the number of identical structures

- **Boundary fluid temperature to use in heat transfer calculations (optional), most often used with core-boundary structures**

HS_LBF	CV	CV1	← use fluid temperature in CV1 for left surface
HS_RBF	CF	CFright	← use CF for fluid temperature for right surface

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Condensation on Surfaces

- When a surface temperature drops below the dew point, condensation can occur
- When a surface temperature exceeds the dew point, evaporation can occur
- Steam-only Environment
  - Condensation rate limited only by heat transfer through the system
- Non-condensable gases
  - Condensation rate limited by transport of steam to surface
  - Turbulence will enhance transport to surface
- Mass/heat transfer analogy

$$Sh = C\,Nu^{a} Sc^{b} \Pr^{d}$$

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HS Films

- Forms from condensation, drainage from another HS, sources from other packages, or external user sources.
- Only Permitted on Surfaces involving control volumes
- Temperature of film surface is distinguished from temperature of surface of solid structure
- Water film becomes additional material mesh
- All included in implicit solution of FDEs

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Film Tracking Model

- User can override default disposition of water film drained from structure surfaces (all to local pool)
- Specify fractions that are
  - Deposited into local pool (default)
  - Flow to surfaces of other structures
  - Fall as “rain”, with modeling by the SPR package
- User can specify sources directly on surfaces

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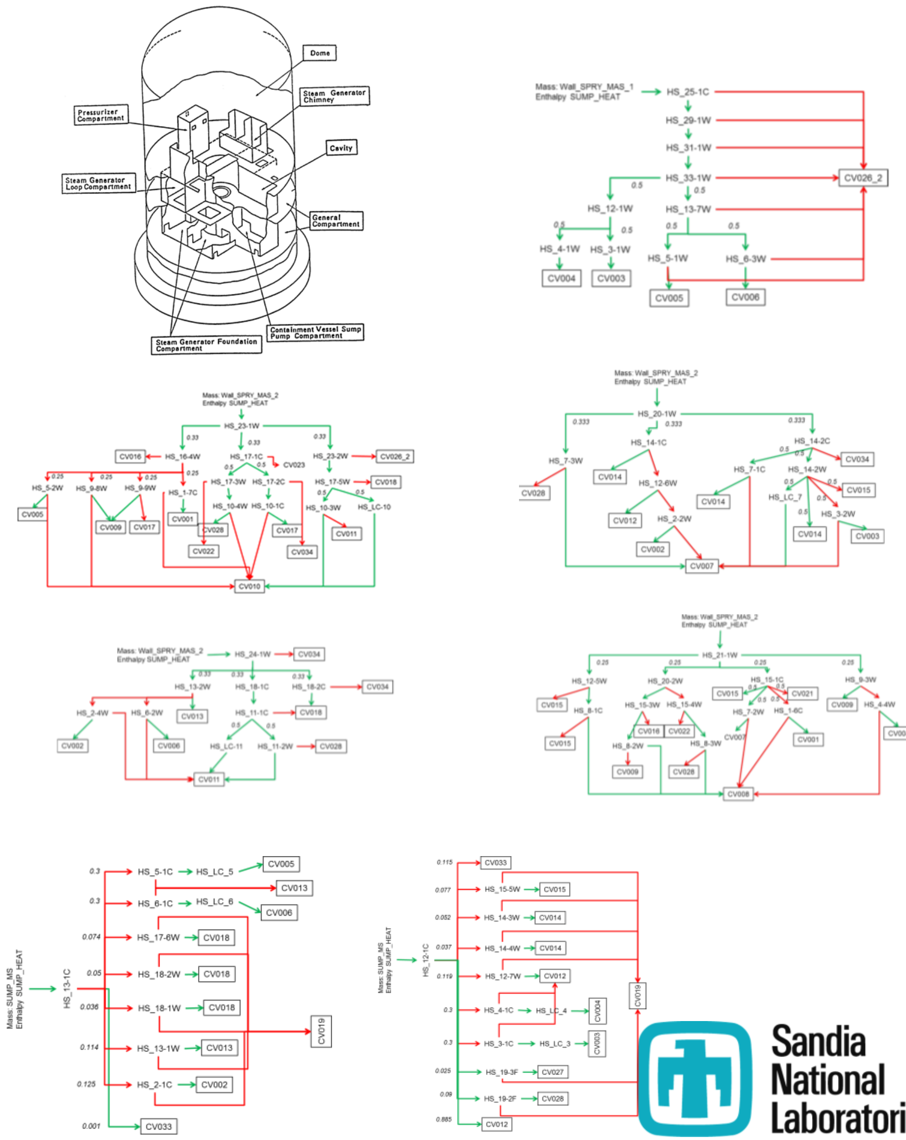
Film-Tracking Example

- NUPEC Containment Validation Experiment
- Spray water is diverted onto seven separate film flow networks
  - Allows flow down each of the four steam generator compartments
  - Also models water draining down the containment walls from the dome
- Motivation: Since the heat structure film temperature and the spray temperature were close, it was expected that this model would better represent the uniform cooling of both structures and gases observed in the test



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Film Tracking Model

- HS_FT record must be ON for each heat structure film-tracking model.
- Heat structures must be listed on the HS_FTDRN record
- FDRNL and FDRNR are the fractions of drainage that goes to the surface of heat structure
- FRAINL and FRAINR on record HS_FTLBF and HS_FTRBF are the fractions of drainage transferred to Spray Package
- The sum of drainage fractions for each surface of a heat structure in the network must not exceed one.
- If the sum of drainage fractions for a surface is less than one, then the excess drainage will go to the pool of the CVH volume associated with that surface.

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Film Tracking Model Input

HS_ID HS0

....

Film-tracking model on/off → HS_FT ON

data for drainage HS, required → HS_FTDRN 2 ← heat structure HS0 drains to 2 heat structures

1 HS1 0.5 0.7 ←
- HS1 is the name of heat structure receiving drainage
- fraction of drainage from left surface=0.5
- fraction of drainage from right surface=0.7

2 HS2 0.5 0.2

HS_FTLBF 0.0 ← fraction of the total drainage from the left surface of the heat structure that is transferred to the Spray package as "rain"

data for external mass or enthalpy sources (left), optional →

HS_FTLBM NO

HS_FTLBE NO

HS_FTRBF 0.0

HS_FTRBM TF TF123 — TF (or 1) means the water source is obtained from TF

HS_FTRBE CF CF456 — CF (or -1) means the energy source is from CF

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Degassing Model

- Structures can decompose
  - Heated concrete can emit H_2O and CO_2
  - Ice condensers can melt, releasing liquid water
  - Heated steel structures can also melt, releasing molten steel
    - Must be COR boundary structures
    - Must be horizontal or vertical
  - All three treated by "degassing" model
- Source released at structure surface
  - Released over range of temperatures
    - Total release linear in temperature
    - Irreversible, based on maximum attained $C_p + \Delta h_R \rho_{gas} / \Delta T_{gas}$
    - Energy required for release included in conduction equation
  - Released water and gases added to CVH
  - Molten steel added to COR
  - Separate source for each material, structure, and side

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Degassing Input Example

HS_DG	SRC1	HS1	GAS	LeftBnd	2	H2O-VAP
	gas source name	HS from which gas is released	degassing model	release H2O-VAP from left-hand side of structure over 2 mesh intervals		

Gas Source Characterization Data, required → HS_DGSRC

HS_DGSRC	100.	5.E6	300.	750.
	density of gas source	heat of reaction of gas source	lower temperature	upper temperature

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Materials Properties Introduction

- **Properties of hydrodynamic fluids (water, noncondensible gases) in NCG Package**
- **Materials other than hydrodynamic fluids in MP Package**

Default Material Names

ZIRCALOY	URANIUM-METAL
ZIRCONIUM-OXIDE	GRAPHITE
ZRO2-INT	CONCRETE
URANIUM-DIOXIDE	ALUMINUM
UO2-INT	ALUMINUM-OXIDE
STAINLESS-STEEL	CADMIUM
STAINLESS-STEEL-OXIDE	STAINLESS-STEEL-304
BORON-CARBIDE	LITHIUM-ALUMINUM
B4C-INT	URANIUM-ALUMINUM
SILVER-INDIUM-CADMIUM	CARBON-STEEL

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Material Properties

- Built-in data can be modified by user input
- New materials and properties can be defined
- Must input MP_ID for all materials
- Properties mnemonic names:
  - Constant values on record MP_PRC:
    - Density, RHOM
    - Melt temperature, TMLT
    - Latent heat of fusion, LHF
  - Functions of temperature on record MP_PRTF:
    - Enthalpy, ENH
    - Specific heat, CPS
    - Thermal conductivity, THC
    - Density, RHO

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Materials Properties Input

- Replace built-in data for library material

```
MP_INPUT
MP_ID       'stainless steel oxide'
MP_PRTF     1
       1       RHO     TFdensity
 ........
TF_INPUT
TF_ID      TFdensity
........
```

redefine the density of stainless steel oxide using tabular function

- Definition of new material for HS

```
MP_ID 'magic'
MP_PRTF      3
        1      THC      'THC Magic'   TF
        2      CPS      'CPS Magic'
        3      RHO      'RHO Magic'
......
TF_INPUT
TF_ID  'THC Magic' . . .
TF_ID  'CPS Magic' . . .
TF_ID  'RHO Magic'  . . .
......
```

conductivity defined with TF (can have CF with THC)
specific heat defined with TF
density defined with TF

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End of Heat Structures

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MELCOR RN Package Aerosol and Vapor Physics

Presented by

MELCOR Development Team

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What is RN? (1)

- **RN is a "Package" (major piece) in MELCOR**
  - Originally intended to treat behavior (release, transport, interactions) of RadioNuclides in nuclear reactor accidents
  - Some models (and some coding) are extracted from other codes, but implemented in a more-consistent form
- **Basic assumptions**
  - RN materials are "traces", hosted by other materials or objects
    - » Fuel and/or debris
    - » Hydrodynamic materials (pool and atmosphere)
    - » Surfaces of heat structures
  - Mass, volume, heat capacity, are negligible
    - » Temperature, when needed, taken as that of host
  - RN Package models various properties and interactions, transfer between hosts

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What is RN? (2)

- **RN is divided into two parts**
  - **RN1 models mainly within-volume processes, calculated before hydrodynamic advancement**
    - **Releases, interactions, …**
  - **RN2 models mainly between-volume processes, calculated during or after hydrodynamic advancement**
    - **Advection with fluids, removal by filters**
- **RN in MELCOR can also be used for tracking "trace" materials in non-reactor situations**
  - **Transport of radiological releases, toxins, and biohazards in buildings, building complexes**
  - **"Leak-path factor analysis" (Google it)**
  - **Wikipedia: "[MELCOR] is sometimes, though incorrectly, said to be an acronym of Methods for Estimation of Leakages and Consequences of Releases"**

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What are RN Classes?

- **The RN package distinguishes RN *classes*, groups of materials with properties that are "similar enough" to treat together**
  - **"Actual" radionuclides (see next slide)**
    - **Ideal gases (Xe, Kr), alkali metals (Cs, Rb), etc. (default is 17 classes)**
    - **Important compounds (CsI, Cs_2MoO_4)**
  - **Boron (from reactor control elements)**
  - **Concrete (oxides from molten core/concrete interactions)**
  - **Water (water aerosols that interact with other aerosols)**
  - **Other trace materials (solid or vapor)**
    - **Species in Iodine pool model**
    - **User-defined materials, in reactor or non-reactor calculations**

What are DCH Classes (?)

- **Actual radionuclides are sources of decay heat, radiological activity**
  - **Heat calculated by DCH package in MELCOR**
    - » **(DCH name long preceded Direct Containment Heating)**
  - **Activity models added by IBRAE**
  - **Heat and activity sources relocate with radionuclides (in fuel or fluid, on walls, …)**
    - » **MELCOR modeling of feedback was a major advancement in capabilities**
- **For each class, RN database contains**
  - **Radioactive masses for which DCH calculates decay heat**
    - » **Heat may be zero**
  - **Total mass including OH in CsOH, O_4 in Cs_2MoO_4, etc., and possible nonradioactive elements from non-fuel sources**
    - » **Total mass important for aerosol physics**

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What's the Difference?

- **DCH class generally corresponds to RN class**
  - **Contains all isotopes of all elements in the class at the time of reactor shutdown, *and all their decay daughters***
  - **Non-radionuclide classes included with zero decay heat and activity**
- **Currently requires redundant input**
  - **Need for consistency between two packages**
    - » **Input differs between MELCOR 1.8.6 and MELCOR 2.1**
      - **2.1 Can't run RN1 without DCH unless all radioactive masses are zero**
      - **Most existing output aimed at radioactive masses**
- **Further confusion from long vs. short names**
  - **Long names like 'NOBLE GASES' and 'CONCRETE'**
  - **Short names like 'XE' (characteristic element) and 'CON'**
  - **Not clear which to use in input**
    - » **Can end up defining unintended new class**

Objective of This Presentation

- Give some understanding of a few within-volume models in MELCOR RN1 Package
  - MAEROS
    - » Aerosol physics
  - TRAP-MELT
    - » Condensation and evaporation involving aerosols and surfaces
  - Water aerosol models
    - » CVH "fog"
    - » Hygroscopic model
- Introduce a new visualization tool to simplify interpretation of results
  - Helps understand calculations
  - Should help in identifying and fixing bugs

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MAEROS (1)
Multicomponent AEROSol model

- Calculates time history of aerosol particle size distribution and CHEMICAL COMPOSITION
  - Calculates changes in masses of each component (material) in each section as a function of time. Prior to this development, material composition of aerosol was unavailable and all particles were assumed to be of the same chemical composition regardless of particle size.
  - Currently limited to requiring that all aerosol components (materials), have the same material density.
  - Solves multi-sectional, multi-component formulation of dynamic equations for deposition and agglomeration.

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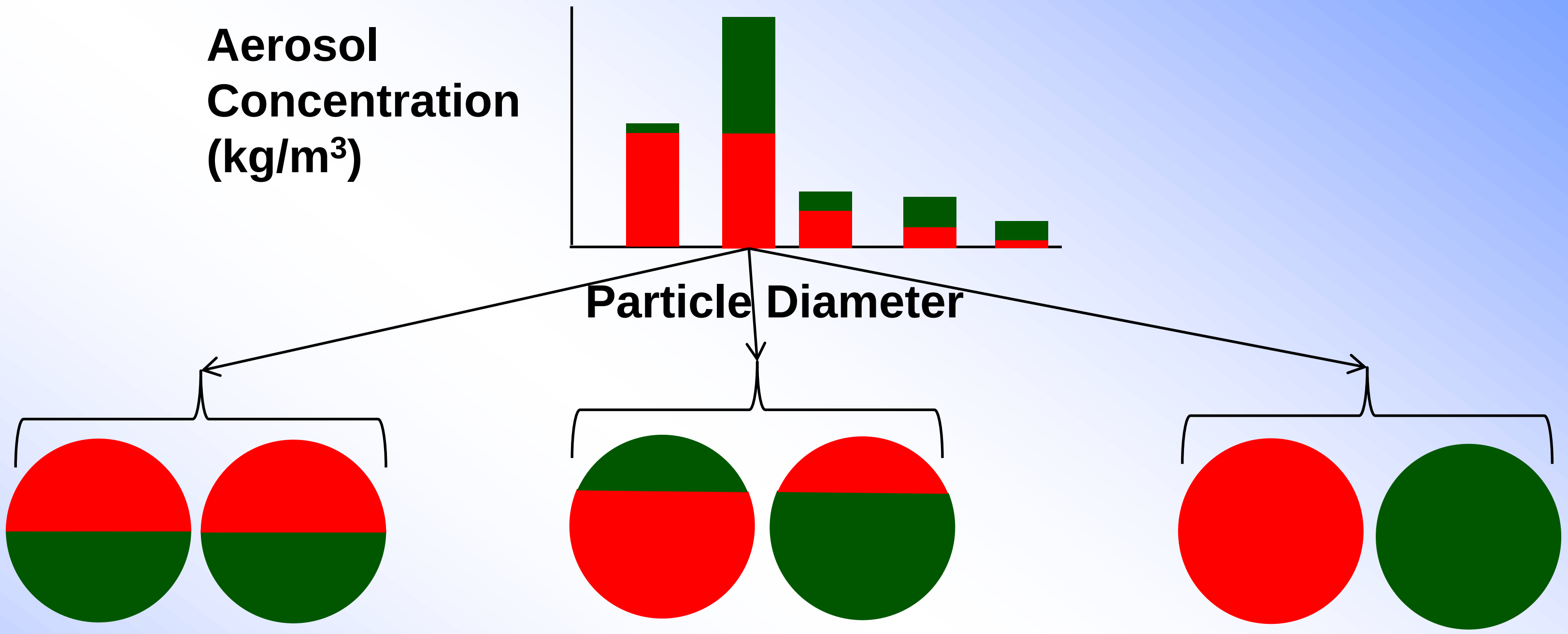
Basic Conceptual MAEROS Model (2)



Mass of each aerosol component as a function of particle diameter is used to determine health effects, but that is not a unique representation.

<u>Basic Approximations</u>

- **The total mass of a particle determines how the particle deposits, agglomerates, and grows.**
- **(Currently) All component material densities are the same.**

MAEROS (3)

- ***Sections*** **are particle size bins based on particle mass.**
- **Default is 10 sections between 0.1 μm and 50.0 μm in geometric diameter**
  - **Diameter boundaries: 0.100, 0.186, 0.347, 0.645, 1.20, 2.24, 4.16, 7.75, 14.4, 26.9, 50.0 μm**
  - **Can change number of sections, limits set through user input**
    - » **To simplify analysis, agglomeration of two particles can't produce mass beyond next-larger section (particle size bin)**
    - » **Requires diameter ratio > $2^{1/3}$ = 1.26**
    - » **For 0.1 to 50 μm diameter, maximum of 26 sections ($2^{n/3}$ < 50/0.1), n = 26.**
    - » **Rule of thumb: Up to 9 sections per decade of particle diameter**

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MAEROS (4)

- ***Components*** **are materials**
  - **Each component has an independent size distribution**
  - **Conventional to take all densities as nominal 1000 kg/m^3**
    - **» Particles are rarely single spheres, so aerodynamic diameter is often used instead**
      - **Aerodynamic diameter (d_a) is the diameter of a sphere with a material density of 1000 kg/m^3 with the same settling velocity as the particle**
      - **Dynamic shape factor (χ) and agglomeration shape factor (γ) are included to compensate for nonspherical effects**
      - **$d_a = d_e (\rho/1000)^{0.5}$, d_e = volume equivalent diameter**

Phenomena Treated by MAEROS (1)

- **Deposition on surfaces**
  - Modeled as always sticking to surfaces contacted
  - Several mechanisms drive aerosols to surfaces
    - » Gravity ("falling to the floor") usually dominates
    - » Brownian diffusion to surfaces
    - » Migration to cooler surfaces by thermophoresis
    - » Migration to surfaces by diffusiophoresis
- **Agglomeration of aerosols**
  - Several mechanisms cause collisions and sticking to produce larger particles
    - » Brownian diffusion (random relative motions)
    - » Differential gravitational settling ("sweep up")
    - » Turbulent agglomerating by shear and inertial forces

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Phenomena Treated by MAEROS (2)

- Condensation and evaporation
  - Disabled in MELCOR in favor of TRAP-MELT
- Disposition of particles that grow larger than computational domain (to conserve mass)
  - Ordinarily "settle" immediately
  - This requires at least one available surface in each volume
    - Ordinarily "floor" or other surface redefined as "floor"
- MELCOR adds additional "settling surfaces" to represent common boundaries of volumes
  - Treated as deposition surfaces
  - Allows aerosols to fall from one volume to another
  - Can also provide destination for oversize particles
    - Settling from a volume to itself is permitted, but considered an "evil practice"

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Conceptual Modeling of Settling (1)

- **Basic MELCOR approach: All control volumes with aerosol are modeled as spatially well-mixed aerosol within the control volume.**
- **Settling therefore removes particles homogeneously, and NOT by creating depleted regions within a well-mixed volume.**
- **Implication: The total horizontal area and NOT just the projected floor area is available for removal by settling.**

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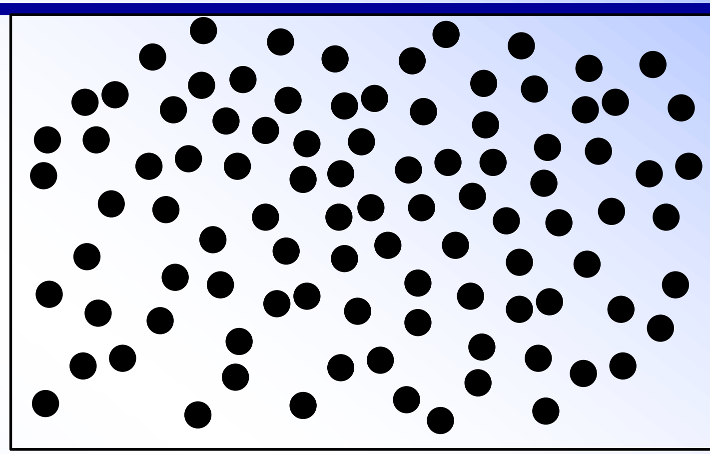
Conceptual Modeling of Settling (2)

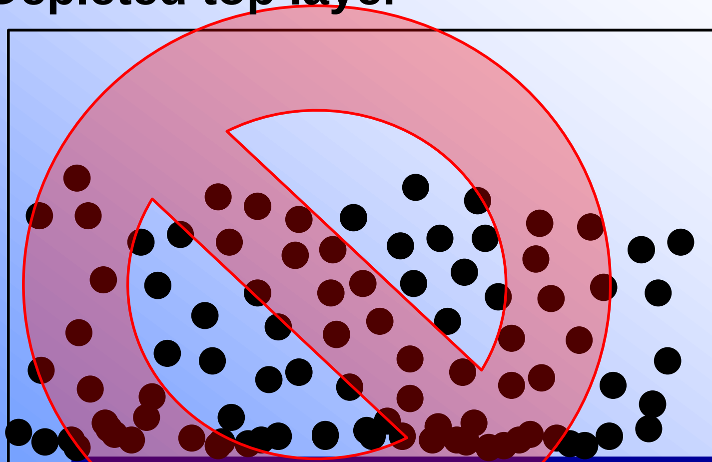


Linear decay of aerosol concentration with time

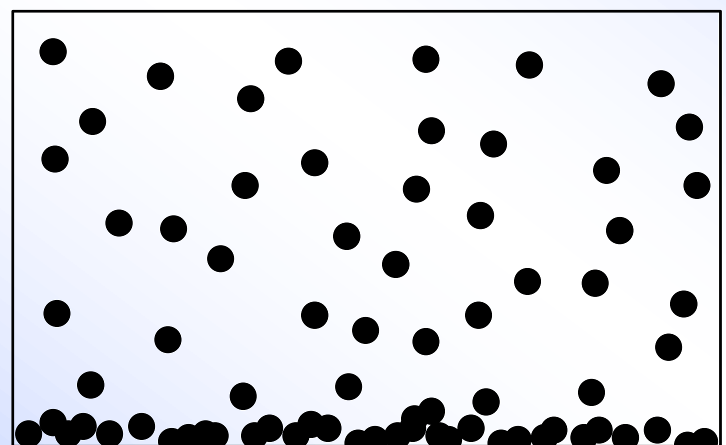
Same removal rate for short times when projected floor area=total horizontal area

Exponential decay of aerosol concentration with time

Depleted top layer



Well-mixed removal



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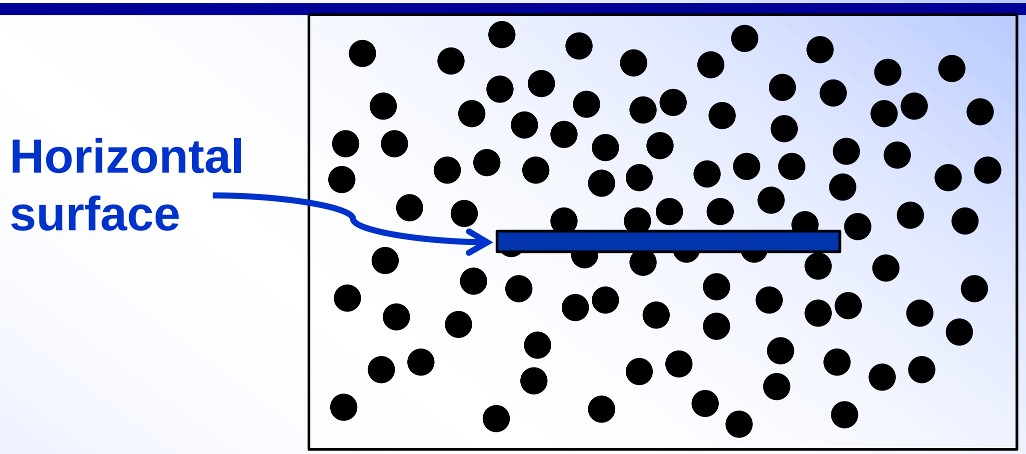
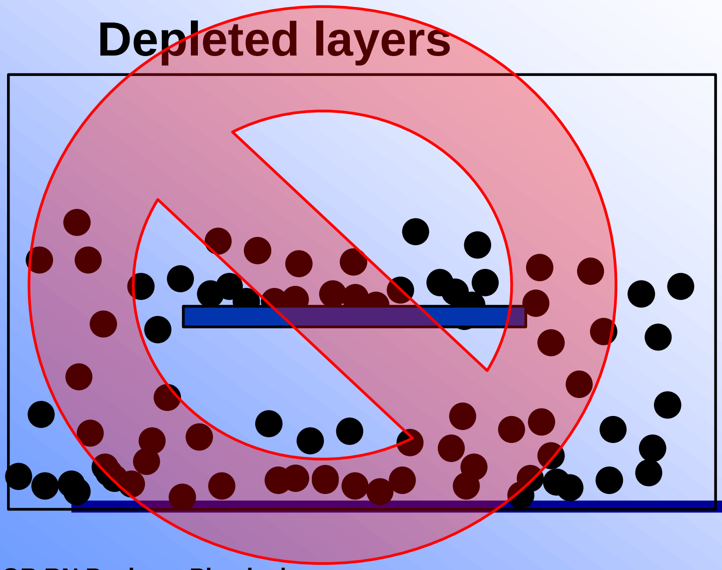
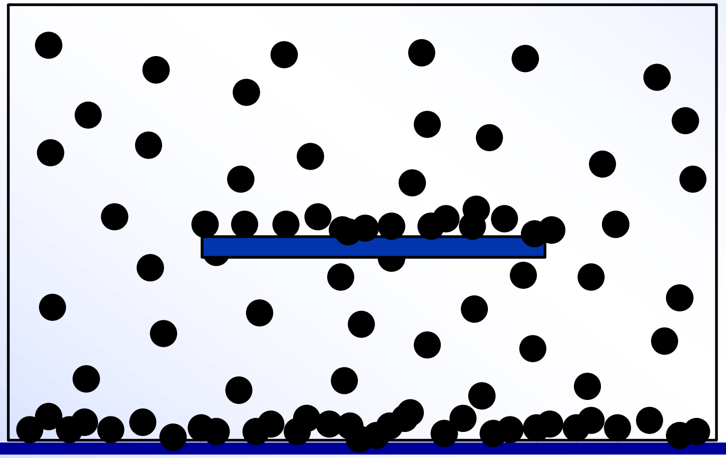
Conceptual Modeling of Settling (3)



Use to total horizontal area to be consistent with well-mixed model of control volume





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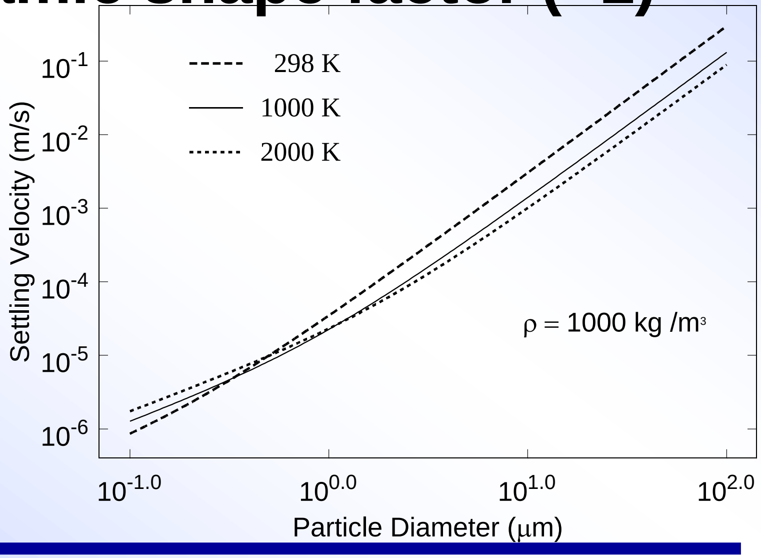
Gravitational Deposition

- **Gravitational deposition is often the dominant removal process**
- **Deposition rate is equal to the deposition velocity times the surface area/volume ratio**

$$v_{grav} = \frac{d_p^2 \rho_p g}{18 \mu \chi}$$

d_p=diameter, ρ= density, χ=dynamic shape factor (~1)

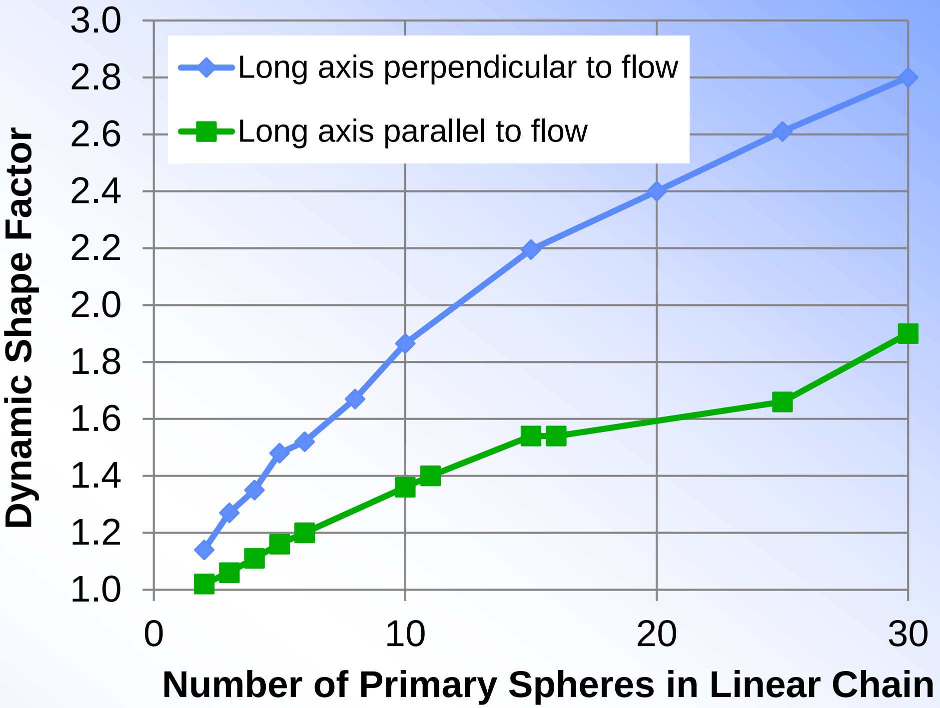
- **Leading size dependence is $\rho\, d_p^2$**
  - **Note velocity ~3 mm/s for a 10 μm sphere with ρ=1000 kg/m³**



Shape Factors: What to Use and Why

Shapes	χ
Sphere	1.00
Cube	1.08
4 sphere cluster	1.17
Sand	1.57
Talc	2.04

W. C. Hinds, Aerosol Technology, 1982.



Kasper, G., T. Niida, and M. Yang, "Measurements of viscous drag on cylinders and chains of sphere with aspect ratios between 2 and 50," *J. Aerosol Science*, 16 (6), 535-556, 1985.

Recommendation: use 1.00 unless data available.

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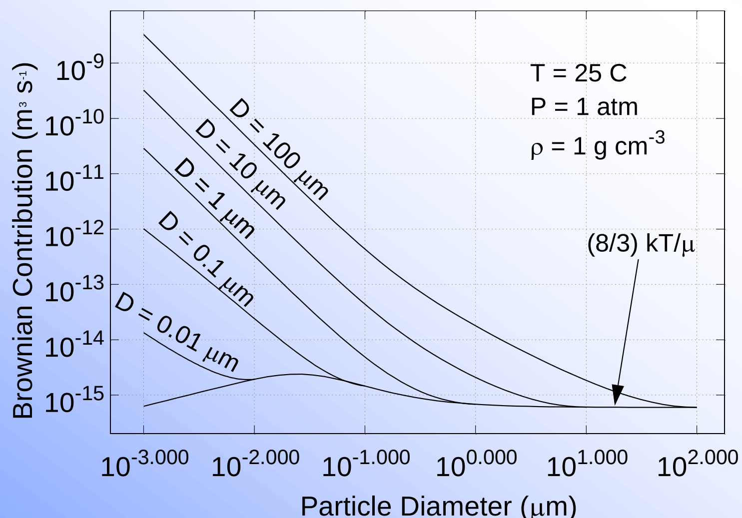
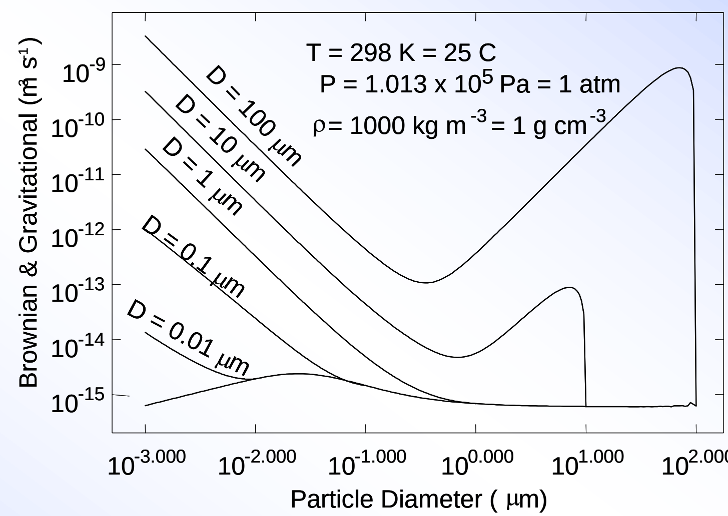
Agglomeration

- **Agglomeration becomes more significant for more concentrated aerosols**
  - **Particles collide, stick, and become larger particles; Rate ~ $\beta N(D_i)\, N(D_j)$ where N is the number density (m^{-3})**
  - **Brownian mechanism dominates for small particles, differential gravitational for large ones**





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Composition of Individual Particles

- **MAEROS tells you only the mass of each material in particles in each size bin**
  - **It *does not* tell you the composition (or distribution of compositions) of any particle**
- **Deposition and agglomeration depend only on mass, diameter, and shape factors**
  - **Assume that the densities of the materials are the same and the shape factors depend at most on particle size**
  - **Then, independent of composition**
    - » **All particles in each section deposit at same rate**
      - **If fraction *x* in section ℓ is component *n*, than fraction *x* of deposition from this section will be component *n***
    - » ***On average*, particle collisions will involve the same masses of each component**
      - **Section-to-section transfers will carry same mass of each component from section to section**

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Note on MAEROS Coefficients

- **Coefficients used by MAEROS are not calculated during transient**
  - **Require integrals over sections for deposition, double integrals for agglomeration**
    - **Calculations are relatively time-consuming**
  - **Values pre-calculated at corners of a finite (*P*,*T*) domain**
    - **Values interpolated for each volume at appropriate (*P*,*T*)**
      - **Recent versions of MELCOR use bilinear interpolation in P^a and T^b,**
    - **Properties of *air* used in pre-calculation**
      - **Should be accurate in normal containment calculations**
      - **May be inaccurate in other cases**

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Improve on MAEROS?

- The basic assumptions (same density, same shape factors) for all particles in a section could be relaxed, but:
  - General theory for shape factors for all particle sizes and all events needs further research (usually select perfect sphere model for now)
  - Can include separate material densities of different materials. This will increase aerosol computation, but computer time for this is no longer limiting.
- New numerical methods can sharpen results
  - Can upgrade numerical technique for particle growth by vapor condensation due to hygroscopic effect (incorporate better algorithm for speed and accuracy)
- Conclude that (at this time) MAEROS formulation is mostly adequate

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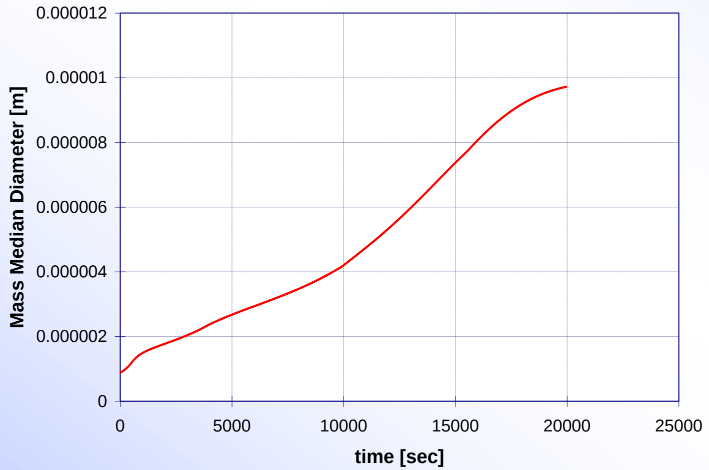
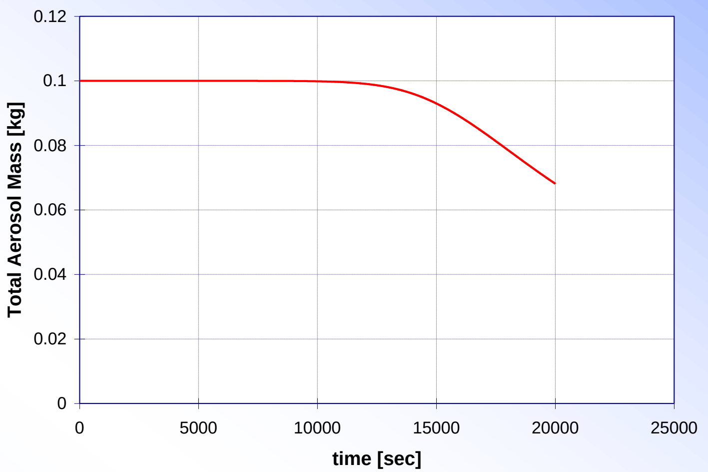
Simple Agglomeration Calculations

- **Single material, nominal density = 1000 kg/m^3, tiny surface to effectively eliminate deposition**
- **Three cases with single d_p ~1μm or ~10μm**
  - **Case 1: d_p=0.880μm, ρ =1000kg/m^3, 10^{-10} m^2 surface**
  - **Case 2: d_p=10.57μm, ρ =1000kg/m^3, 10^{-10} m^2 surface**
  - **Case 3: d_p=10.57μm, ρ =1000kg/m^3, 10^{-10} m^2 surface, settle back to same volume through 15 m^2 "settling surface"**

Results of Agglomeration Calculations

- **Line graphs don't provide much insight**
- **For Case 1**





  - **Mean diameter increased from ~ 1 μm to almost 10 μm**
  - **Some mass must have been deposited (or settled)**
  - **But what *really* happened?**
- **Other cases are *much* more difficult**

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Visualization Tool

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

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

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

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

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

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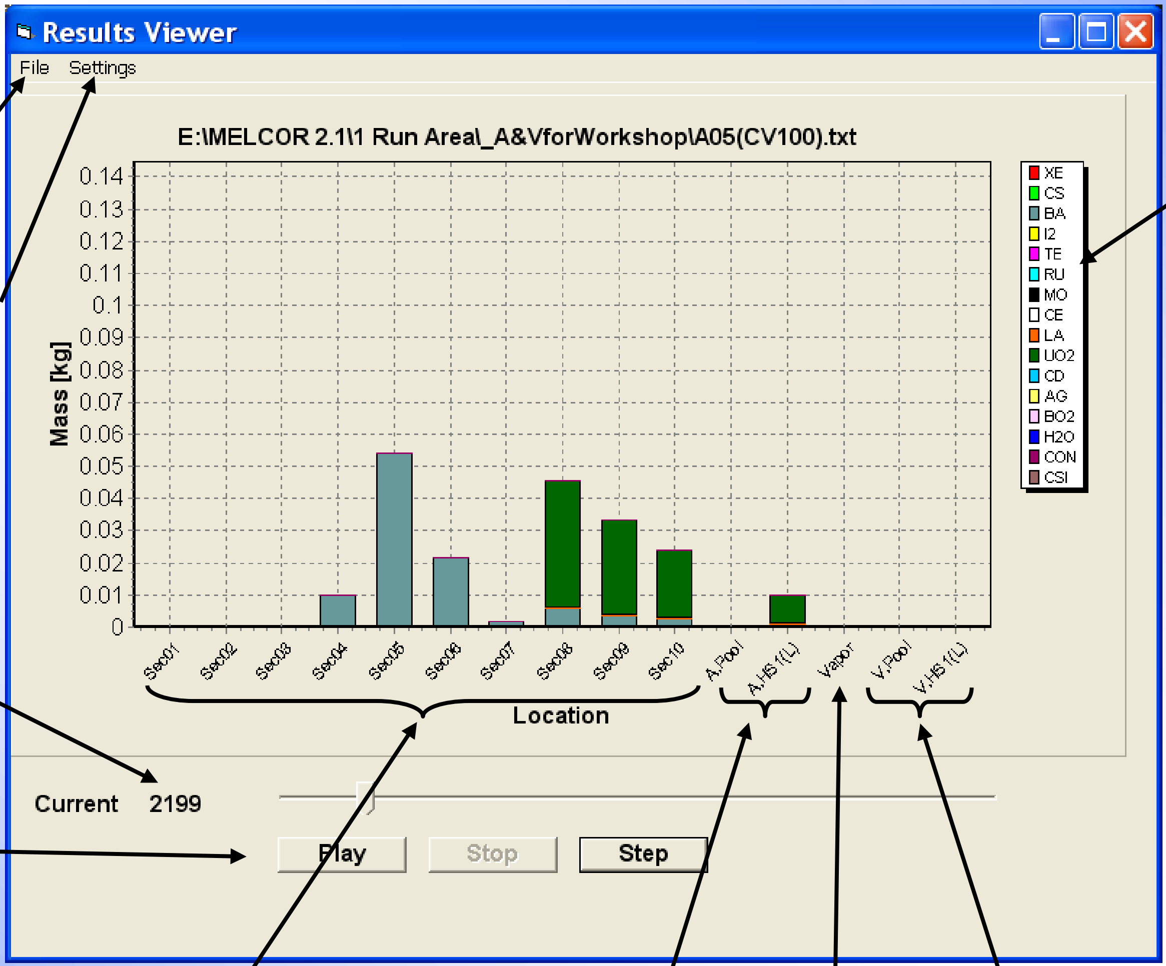
Results Viewer

Open
(File Navigation)
Exit

Limits
(Auto|Manual)



Color Key,
RN Classes

Current Time

Playback
Controls

Aerosol Sections

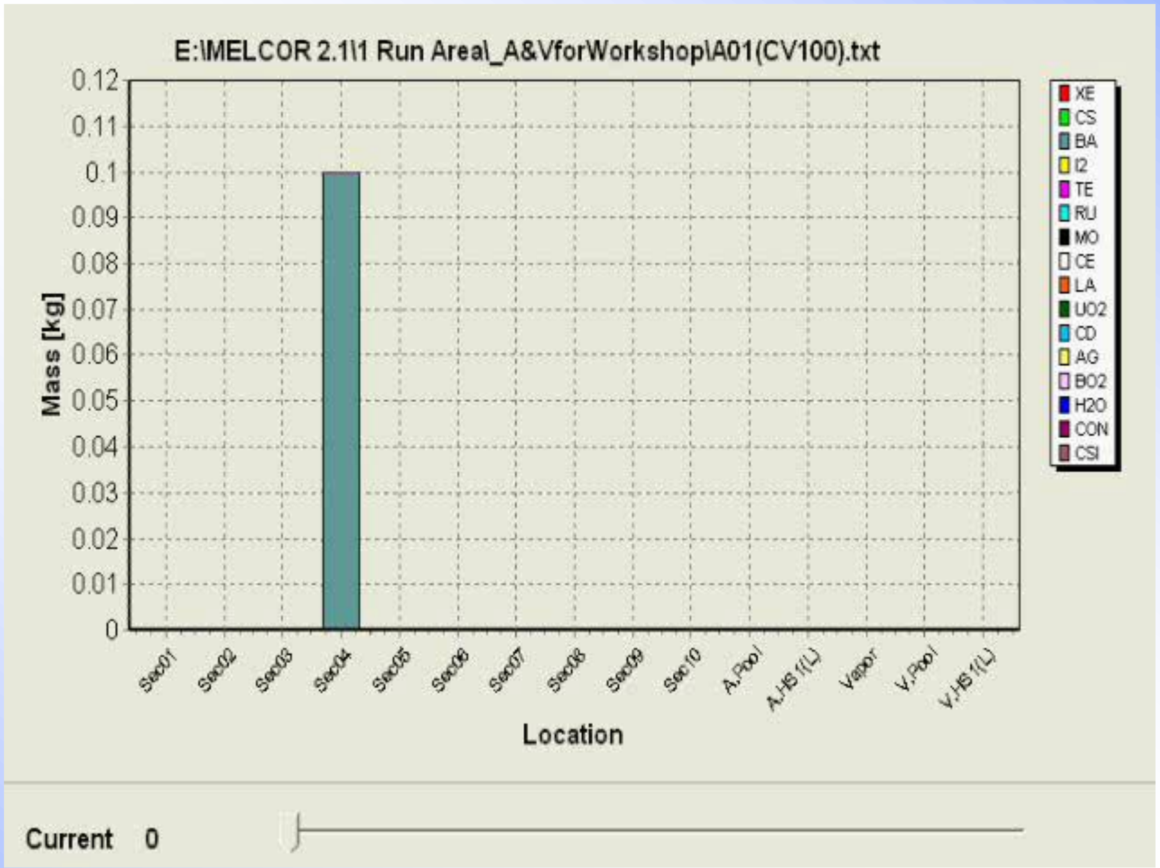
Deposited Aerosols

Vapors

Deposited Vapors

Visualization of Results, Case 1

- **Display MAEROS results as stacked bar graph for Case 1**



  - **See creation of larger aerosols, settling of those larger than limit of computational domain**

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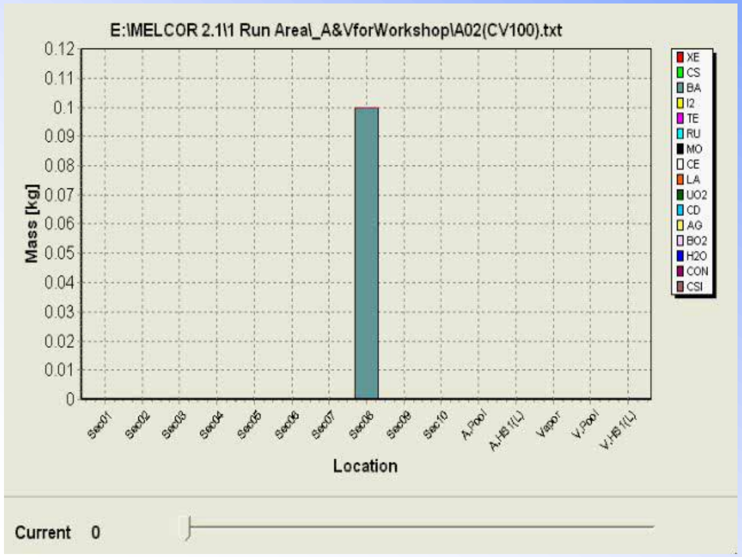
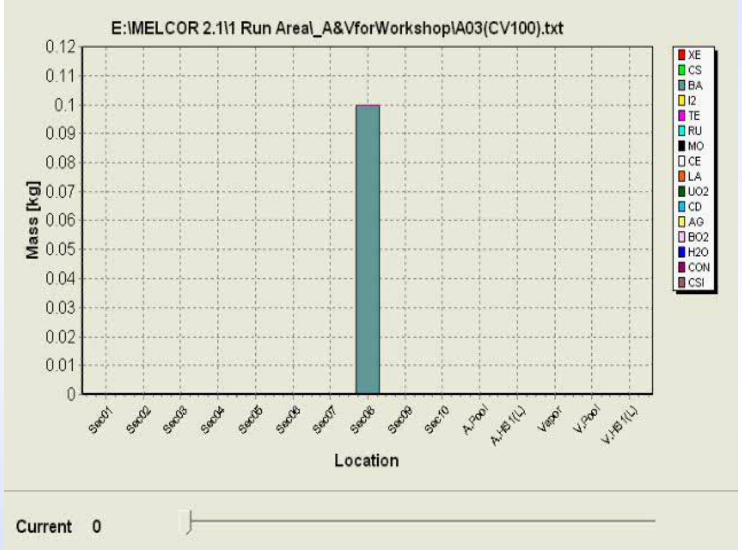
Visualization of Results, Cases 2 and 3

- **Case 2**
  - **Initial ~10 μm (section 8)**
  - **Tiny (10^{-10} m²) deposition area**
  - **Rapid growth to section 10 and larger**
    - » **Mass settles to heat structure surface despite tiny area**



- **Case 3**
  - **Like Case 2 *but* 15 m² settling area from volume to itself**
  - **All mass stays suspended**
    - » ***Huge* population in section 10 sweeps up all smaller aerosols**
    - » ***Not physical***



Multi-Material Aerosols

- **RN Package and MAEROS each treat more than one material, but treatments differ**
  - **Main RN database includes distinct size distribution for each RN class (Cs, Ba, UO2, …)**
  - **MAEROS considers only a limited number of *components***
    - **Each contains one or more RN classes**
      - **Component masses in each section calculated at start of MAEROS advancement as sums of class masses; sub-compositions saved**
      - **Post-advancement component masses are distributed to RN class distributions using sub-compositions**
    - **User can define number of components and the classes assigned to each**
      - **Default is 2, with one component reserved for water and all other classes in the other**
      - **Recommend 3 which (absent further input) will further assign the volatiles (Cs, I2, CsI, CsM) to a separate component**
      - **Can modify these, or add other components to track classes of interest or classes with very different release histories (like CON from ex-vessel core/concrete interactions)**

Two-Material Agglomeration Calculations

- **Ran two versions of a 2 material case**
  - **Initial 0.1 kg of Ba aerosol, d_p=0.880μm**
  - **Initial 0.1 kg of UO2 aerosol, d_p=10.57μm**
  - **ρ =1000kg/m^3, 10^{-10} m^2 surface**
- **Case 4: default component assignments**
  - **Both Ba and UO2 assigned to component 1**
- **Case 5: custom component assignments**
  - **Ba assigned to component 1, UO2 to component 4**

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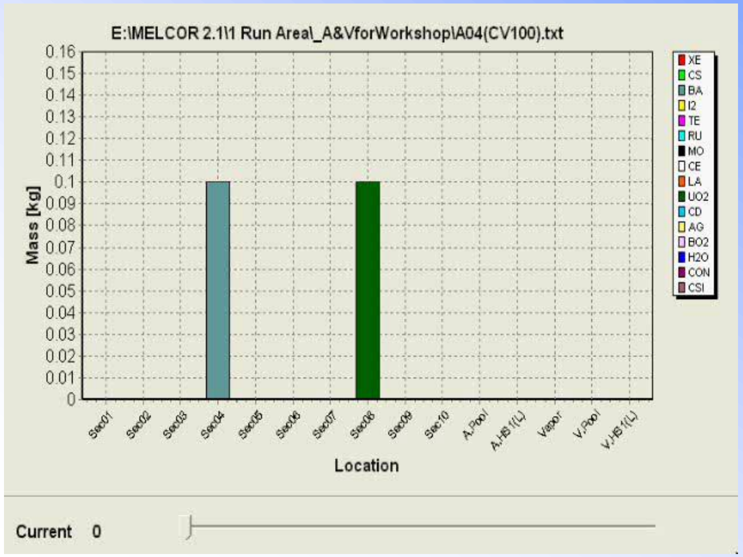
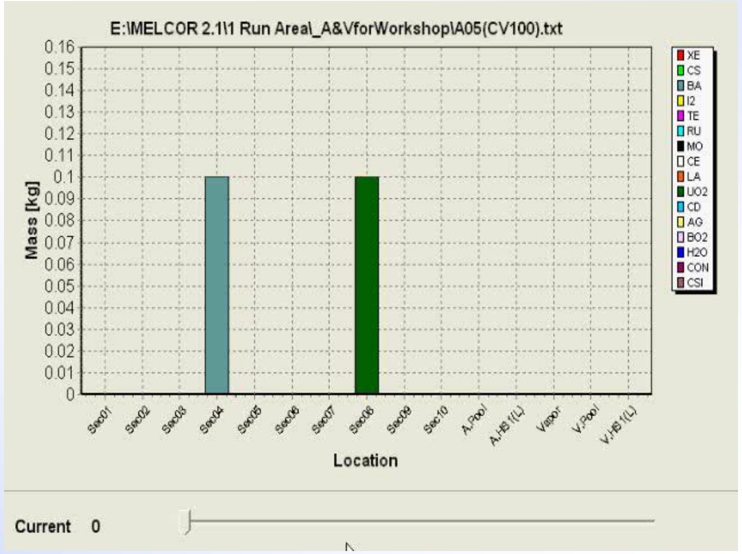
Visualization of Results, Cases 4 and 5

- **Case 4 (same component)**
  - **MAEROS does not maintain distinction**
    - » **Aerosol distribution “homogenized” on first advancement**
      - **Puts half UO2 mass into smaller section, half Ba mass into larger one**



- **Case 5 (distinct component)**
  - **MAEROS maintains distinction**
    - » **Agglomeration of small and large aerosols slowly moves some Ba mass into larger sections**



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TRAP MELT

- **Models condensation and evaporation of RN vapors involving aerosols and surfaces (replaces treatment in stand-alone MAEROS)**
- **Volatile radionuclides (e.g., CsOH, I_2, CsI, Cs_2MoO_4), have finite vapor pressures that increase with temperature**
  - **Concentration in atmosphere limited by vapor pressure at T_{atm}**
  - **Mass can be transported to/from condensed phase on aerosol surfaces and/or structural surfaces**
    - » **Aerosols are at atmosphere temperature**
    - » **Structure surfaces may be hotter or colder**
    - » **Rate limits apply**

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TRAP MELT Equations

- **Conservation of mass, and rate equations are**

$$\frac{dM_a}{dt} + \sum_i \frac{dM_i}{dt} = 0 \qquad \frac{dM_i}{dt} = A_i k_i \left(C_a - C_i^s\right)$$

  - ***M* is mass, *C=M/V* is concentration, subscript *i* refers to surface, superscript *s* is saturation at surface temperature**
    - » **Surfaces include aerosols, section by section**

- **Model evaluates closed-form solution for full MELCOR timestep, Δ*t***

$$C_a = M_a / V = \frac{\beta}{\alpha} - \left(\frac{\beta}{\alpha} - C_{a0}\right) e^{-\alpha\Delta t} \qquad M_i = M_{i0} + A_i k_i \left(\frac{\beta}{\alpha} - C_i^s\right) \Delta t - A_i k_i \left(\frac{\beta}{\alpha} - C_{a0}\right) \left(\frac{1 - e^{-\alpha\Delta t}}{\alpha}\right)$$

$$\alpha = \sum_i A_i k_i / V \qquad \frac{\beta}{\alpha} = \frac{\sum_i A_i k_i C_i^s}{\sum_i A_i k_i}$$

  - **Iteration may be needed if any surface mass falls to zero**

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Condensation Aerosols

- **Ran test cases with the 45 m^3 room and Cs (actually, CsOH) vapor source**
  - **Temperature raised to 780 K, where mass corresponding to saturation is 0.00685 kg**
  - **Cs-class vapor mass added at 10^{-5} kg/sec**
    - » **Takes 685 s to reach saturation**
  - **Chemisorption model turned off**
  - **Two cases**
    - » **Case 1: no initial vapor or aerosol**
    - » **Case 2: no initial vapor, initial 0.01 kg non-volatile (Ba) aerosol ~0.88 μm**

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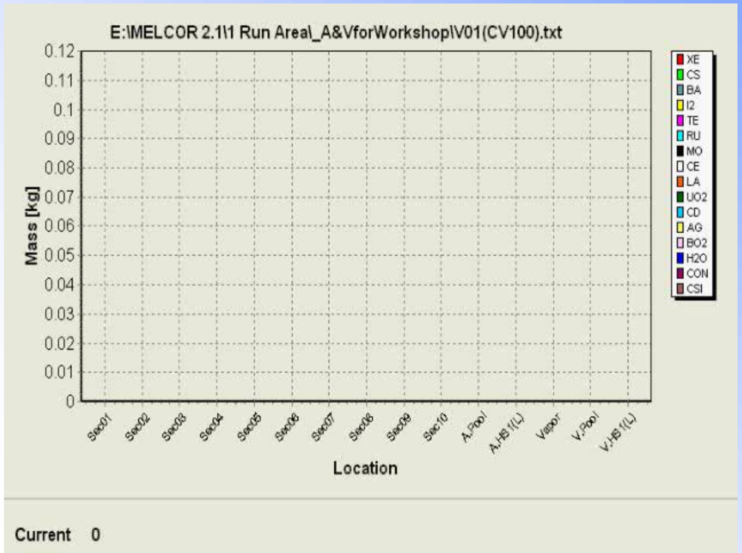
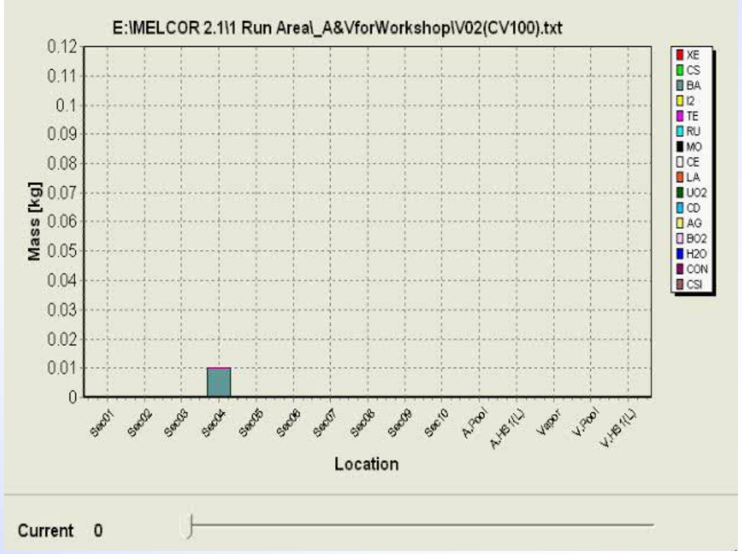
Condensation Aerosol Results

- **Case 1**
  - **Cs concentration rises to saturation**
  - **First aerosols form in smallest section, then agglomerate rapidly**
  - **Further condensation on existing aerosols**



- **Case 2**
  - **Same rise to saturation**
  - **Most early condensation on existing Ba aerosols**



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Comments on Condensation Calculations

- See almost no direct condensation on walls
  - Wall and aerosol areas comparable (within factor of 10)
  - Mass transfer coefficient for wall is *much* smaller
    - » Characteristic length in Sherwood number (analog of Nusselt number) is much larger, m *vs.* μm
- Could construct other cases
  - Smaller aerosol concentrations
  - Multiple walls
    - » Different temperatures
    - » Initial deposited vapors
  - Encourage others to try variations
- Omitted to allow time for Water Aerosol cases

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Water Aerosols

- Water also forms aerosols, but water vapor is a hydrodynamic material
- Mass, volume, heat capacity of RN vapors and aerosols is ignored by hydrodynamics
- Condensation/evaporation for water aerosols can't be solved as for other aerosols
  - Interactions too complicated to solve simultaneously

Water Aerosol Models

- **MELCOR provides two models**
  - **Original model**
    - » **Water aerosol identified with CVH "fog" (liquid water in atmosphere)**
  - **Hygroscopic model**
    - » **RN "takes possession of" all liquid water in atmosphere**
      - **Necessary to account for hygroscopic and Kelvin effects that modify vapor pressure of water in aerosol form so that it is different from water in the rest of MELCOR (CVH, HS, …)**
    - » **Condensation taken from CVH water vapor, evaporation returned to it**
      - **Also takes any fog that CVH produced on preceding time step**
    - » **Water aerosols deposited on pool and HS surfaces as ordinary water**
    - » **Mass/energy conservation accounting in CVH and HS adjusted for these transfers**

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Original Model for Water Aerosols (1)

- **Hydrodynamic model determines fog mass in each volume using equation of state**
  - **Mass and energy inventories in atmosphere imply mass of liquid water at equilibrium**
- **RN Package accepts new fog mass (after CVH) as new total water aerosol mass, then imposes the change in size distribution**
  - **Uses MAEROS coefficients based on sectional integration of Mason equation (later slide). Equations are**

$$\frac{dQ_{\ell,k}}{dt} = \ldots + {}^{1}\overline{G}_{\ell,k} Q_{\ell} - \sum_{i=1}^{N_a} \left[{}^{2}\overline{G}_{\ell,k} Q_{\ell,k} - {}^{2}\overline{G}_{\ell\pm1,i} Q_{\ell\pm1,k} \right]$$

    - » **Terms account for condensation, loss by move to adjacent section, gain by move from adjacent section**

Original Model for Water Aerosols (2)

- **Calculate condensation explicitly, normalized so that sum over sections matches net change**

$$\Delta m_w = \sum_{\ell} Q_{\ell} {}^1\overline{G}_{\ell,w} \; X \, \Delta t$$

  - **This gives *X*, a measure of the average driving force**

- **Calculate sectional transfers implicitly, using post-condensation masses** $Q^{o+}_{\ell,k}$
  - **For condensation, particles grow—only have up-transfers**
    - » **Solve for new mass in smallest section** $Q^{n}_{1,k} = \dfrac{Q^{o+}_{1,k}}{1 + X \, \Delta t \; {}^2\overline{G}_{1,w}}$
    - » **Single pass upwards through sections to evaluate others** $Q^{n}_{\ell,k} = \dfrac{Q^{o+}_{\ell,k} + X \;\; \Delta t \; {}^2\overline{G}_{\ell-1,w} Q^{n}_{\ell-1,k}}{1 + X \, \Delta t \; {}^2\overline{G}_{\ell,w}}$
  - **For evaporation, particles shrink—only have down-transfers**
    - » **Evaluate mass in largest section, then work downwards**

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Hygroscopic Model for Water Aerosols

- **Hygroscopic model**
  - **Based on single-step implicit solution of Mason equation, which accounts for conduction of latent heat (a term) and diffusion of water vapor (b term)**

$$\frac{dr}{dt} = \frac{1}{r}\frac{(S - S_r)}{a + b} \qquad a = \left(\frac{\Delta h_f^2 M_w \rho_w}{R T_\infty k_a^*}\right) \qquad b = \left(\frac{R T_\infty \rho_w}{D_v^* M_v p_{sat}(T_\infty)}\right)$$

  - ***S* is saturation ratio (relative humidity), S_r is effective saturation ratio at particle surface**

$$S_r = A_r \cdot \exp\left(\frac{2 M_w \sigma}{R T_\infty \rho_w r}\right) \qquad A_r = \exp\left[-\sum_i \frac{\nu_i n_i}{n_w}\right]$$

    - **Activity factor A_r accounts for ionization of dissolved soluble aerosols. This *reduces* equilibrium vapor pressure over solution (usually below saturation)**
    - **Exponential multiplier accounts for Kelvin effect, where surface tension effects "resist" condensation. This *increases* equilibrium vapor pressure (can be greater than saturation)**
  - **Solution requires double iteration to determine end-of-step partial pressure and saturation pressure for water**

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Full Disclosure (1)

- There are problems with the hygroscopic model, both in MELCOR 2.1 and in 1.8.6
  - The model in MELCOR 1.8.5 "functioned", but agreement with experiments for validation needed improvement
  - A new formulation was developed that worked much better for strongly hygroscopic cases
  - Realized that it doesn't work correctly for others
    - » Can have *no* water aerosol, significant "fog" mass can appear, and/or water can get "lost" from calculations
- Improvements were made to MELCOR 2.1 Rev.2013-on, were retrofit to 1.8.6
  - Currently make consideration of Kelvin effect optional, default is to neglect
  - Still being tested
    - » Much improved results for simple calculations
    - » Haven't fully checked VANAM (ISP37)

Possible Improvements to Implementation

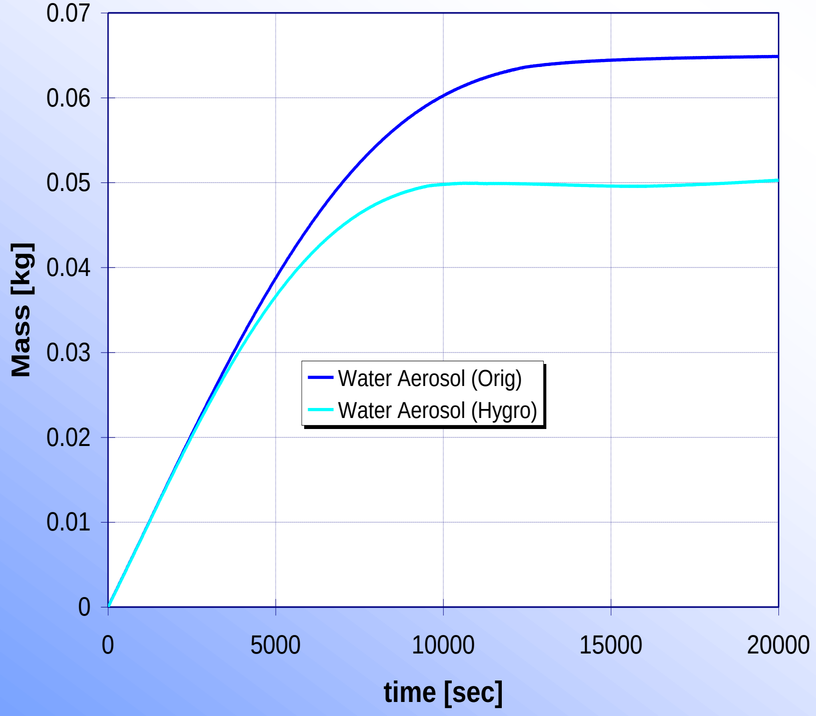
- **Fundamental issue in treating Kelvin effect**
  - **Saturation ratio *S>1* is required for water aerosols in absence of hygroscopic effects**
  - **MELCOR thermodynamics does not include a supersaturated regime**
- **This can probably be dealt with**
  - **Can almost certainly reduce the saturation pressure *used within the model* (with no change to CVH) to allow necessary water to condense**
  - **Would require changes to iteration strategy, untested at this time**

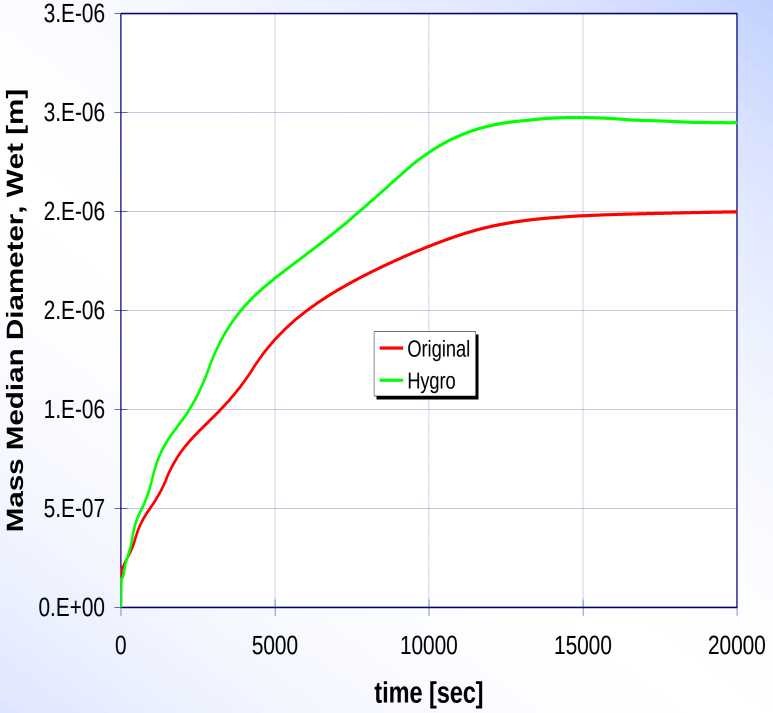
Water Aerosol Calculation

- **Ran test cases with the 45 m³ room, again at 310 K, but now saturated with water vapor**
  - **Water vapor added (to CVH) at 10^{-5} kg/sec**
    - » **Added with *liquid* enthalpy to avoid heating**
  - **No initial aerosol**
    - » **Case 1: original model**
    - » **Case 2: hygroscopic model**
  - **Initial 0.001 kg inert (Ba) aerosol ~0.88 μm**
    - » **Case 3: original model**
    - » **Case 4: hygroscopic model**
  - **Initial 0.001 kg hygroscopic (Cs) aerosol ~0.88**
    - » **Results using original model look just like inert (Ba) aerosol case (exercise for student)**
    - » **Case 5: hygroscopic model**

Results (No Initial Aerosol)

- **In a "perfect" world, both models would give the same results**
- **In current version of MELCOR, results are similar, but not exactly the same**





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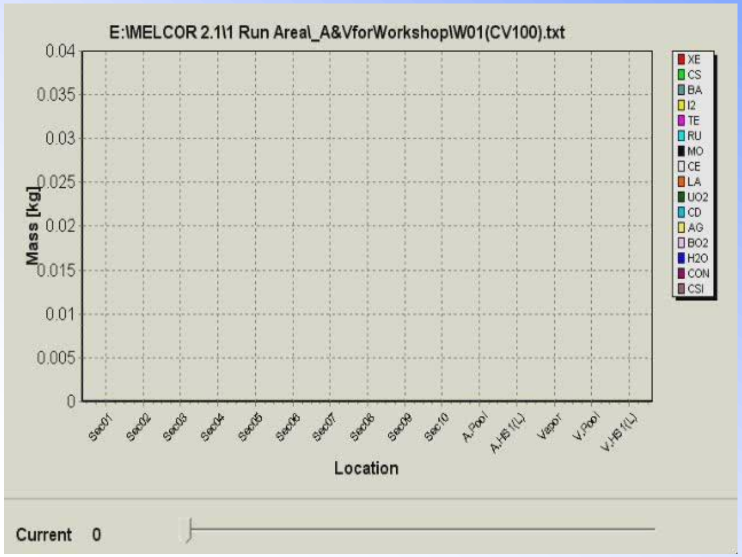
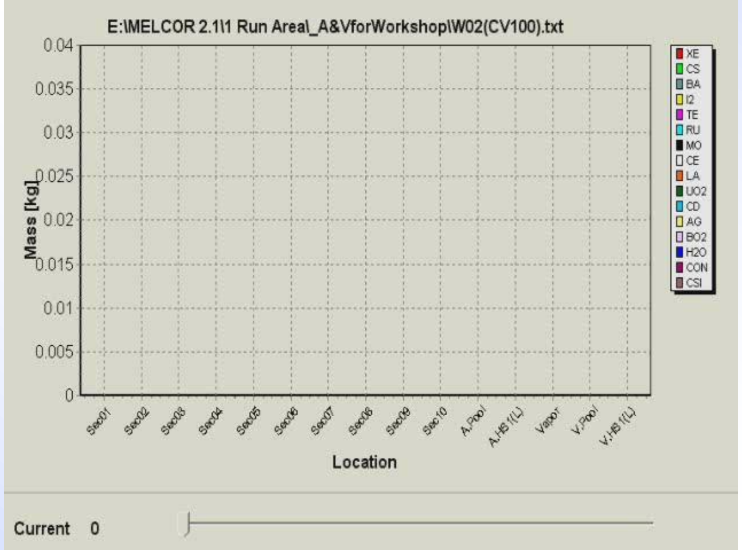
Visualization of Results (No Initial Aerosol)

- **Case 1 (Original Model)**
  - **First aerosols form in smallest section, then agglomerate rapidly**
  - **Further condensation on existing aerosols**



- **Case 2 (Hygro. Model)**
  - **Some differences probably result from different numerical implementation of growth equation**
  - **Others from addition to smallest aerosol section of condensation in excess of rate based on *end-of-step* conditions**



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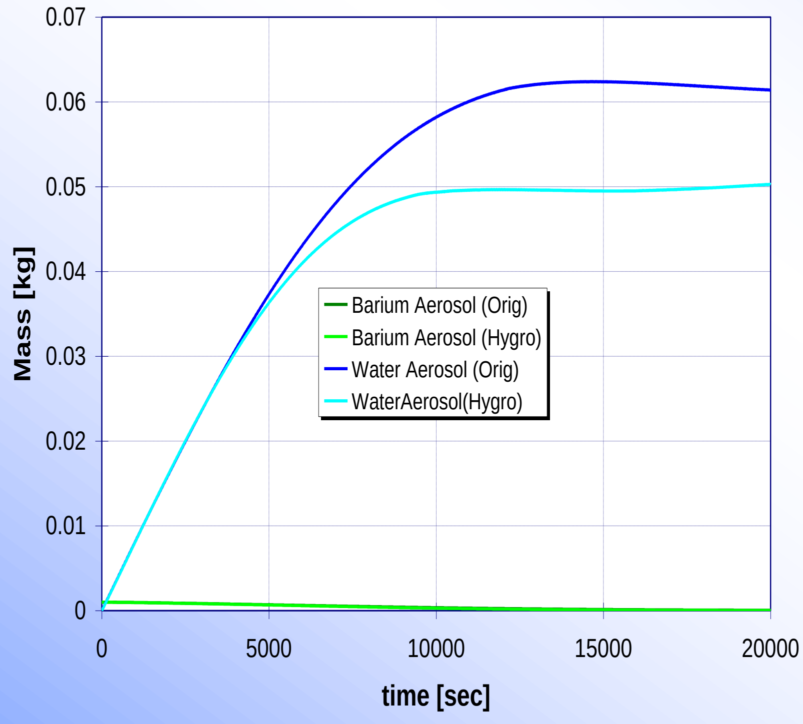
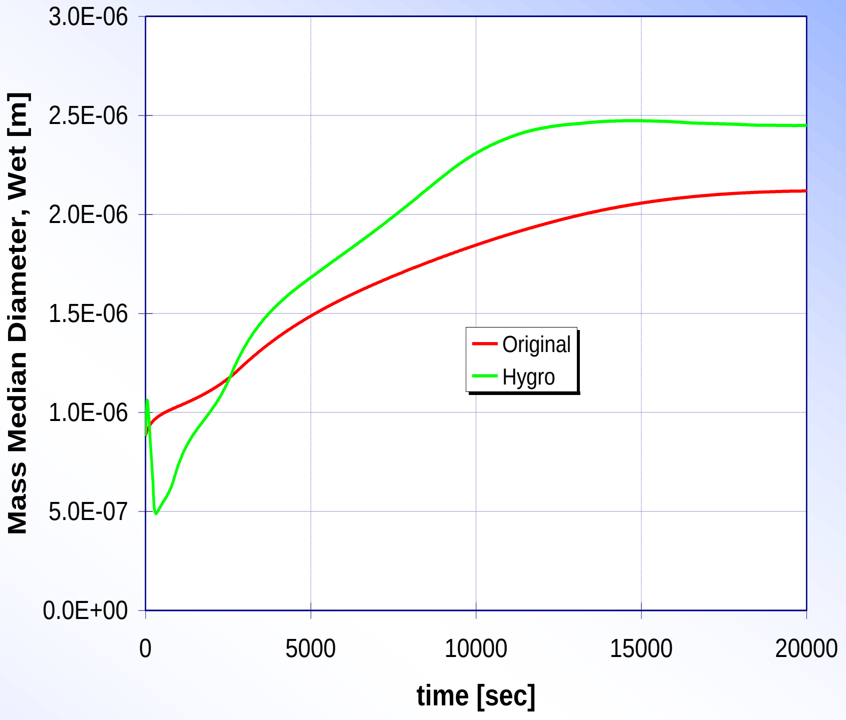
Results (Initial Ba Aerosol)

- Again, results using the two models are similar, but not exactly the same





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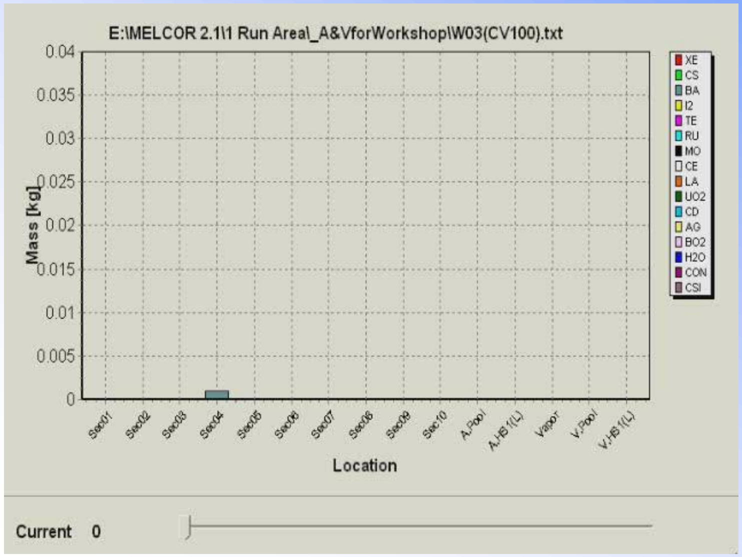
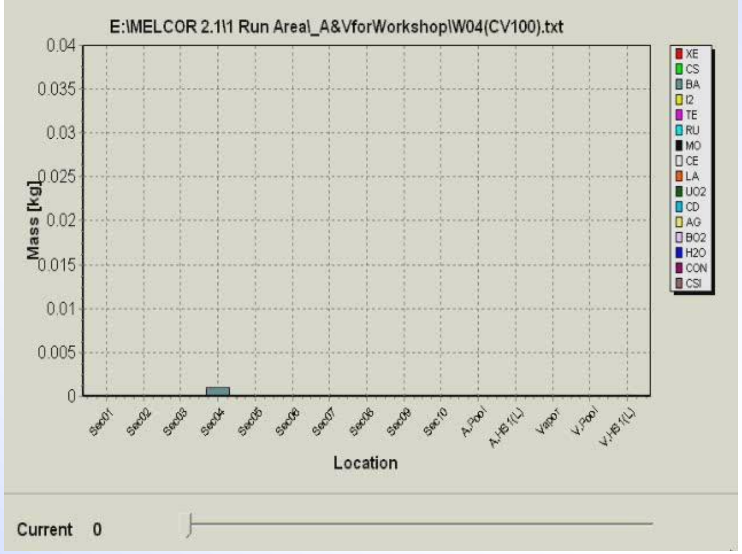
Visualization of Results (Initial Ba Aerosol)

- **Case 3 (Original Model)**
  - Early condensation on existing Ba aerosols
  - Further condensation on existing Ba and Water aerosols
  - Most Ba deposited relatively quickly



- **Case 4 (Hygro. Model)**
  - Differences similar to water-only case



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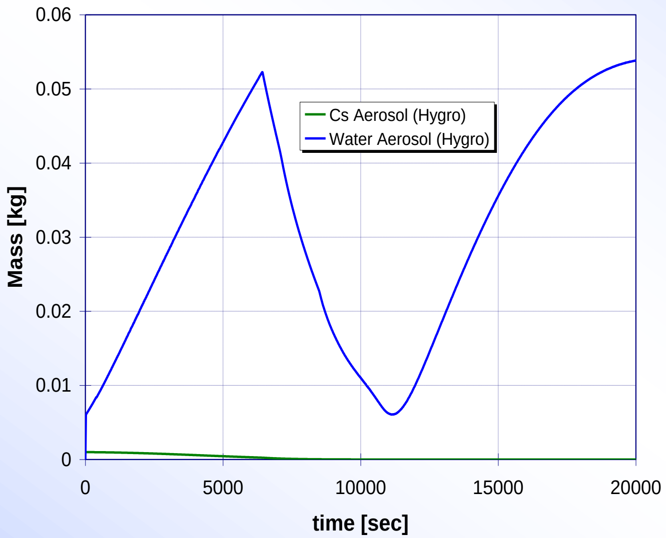
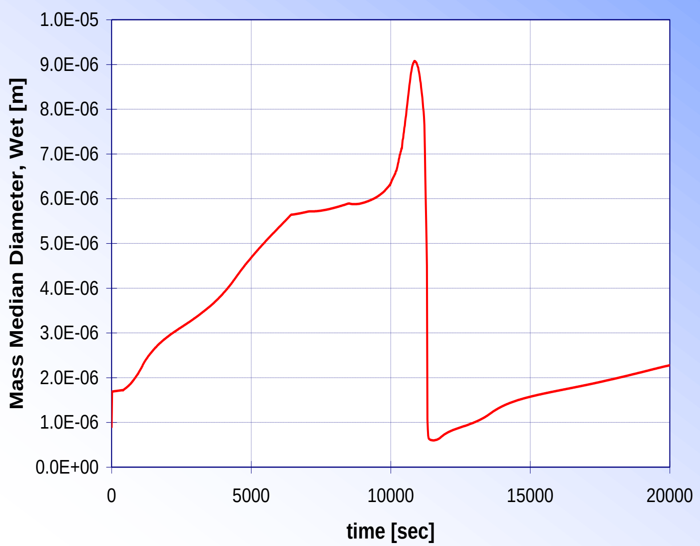
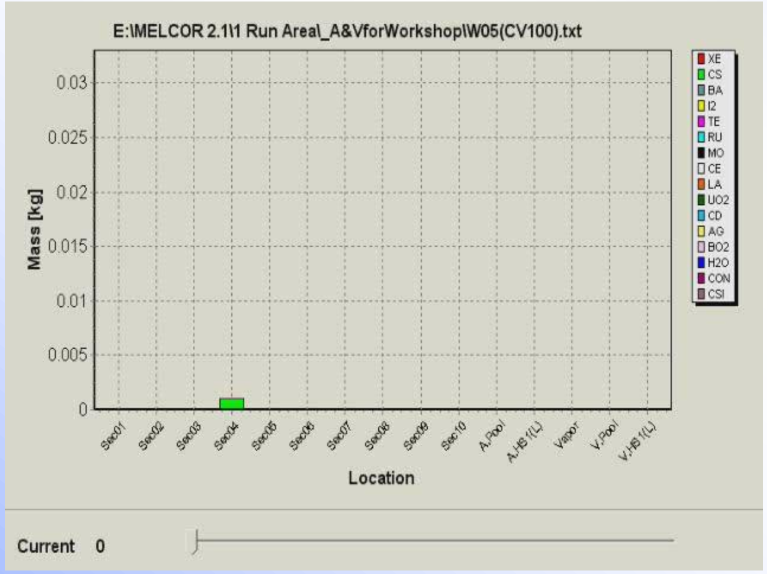
Results Case for 5 (Initial Cs Aerosol)







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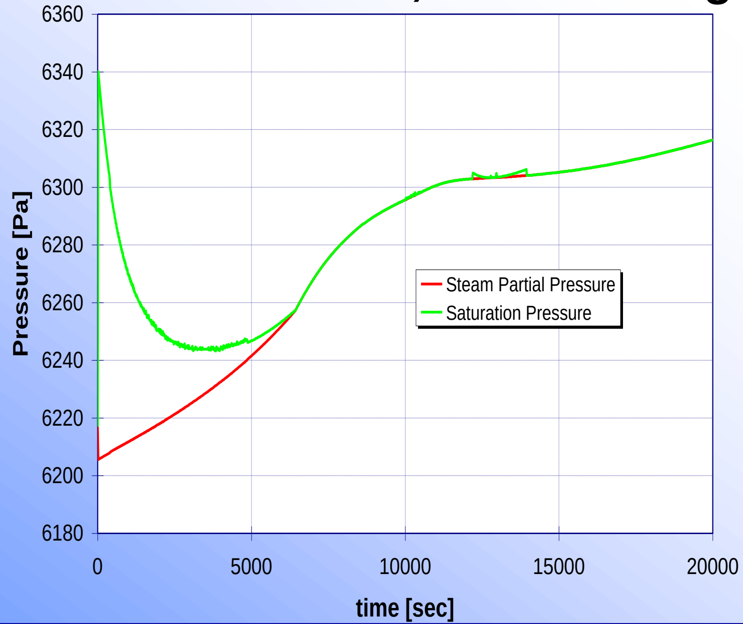
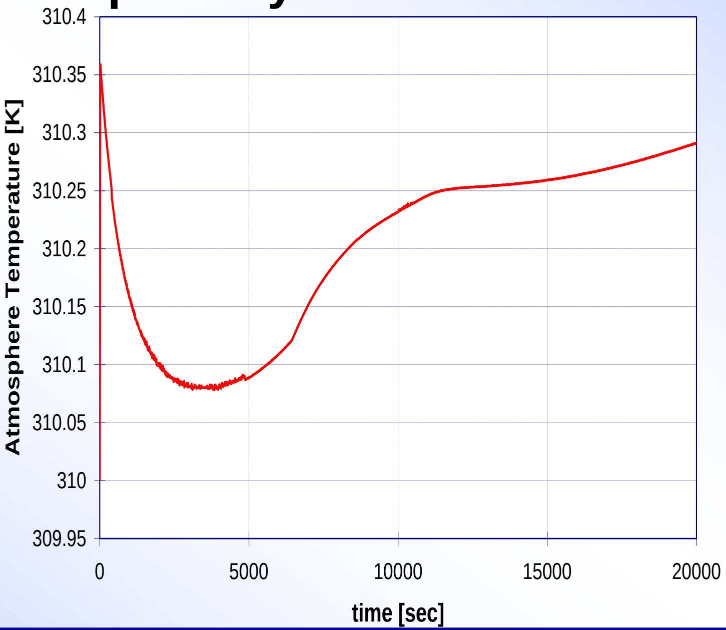
That's Weird - What's Happening?

- **Initial state is *far* from equilibrium**
  - **Pure CsOH extremely hygroscopic**
  - **Initial interaction condenses a lot of water**
    - » **Condensation reduces partial pressure of water vapor; latent heat raises atmosphere temp., saturation press.**
  - **Most of Cs-containing aerosol deposited by ~6000 s**
  - **Total surface area too small to support condensation rate at ~11000 s, start forming new crop of tiny aerosols**





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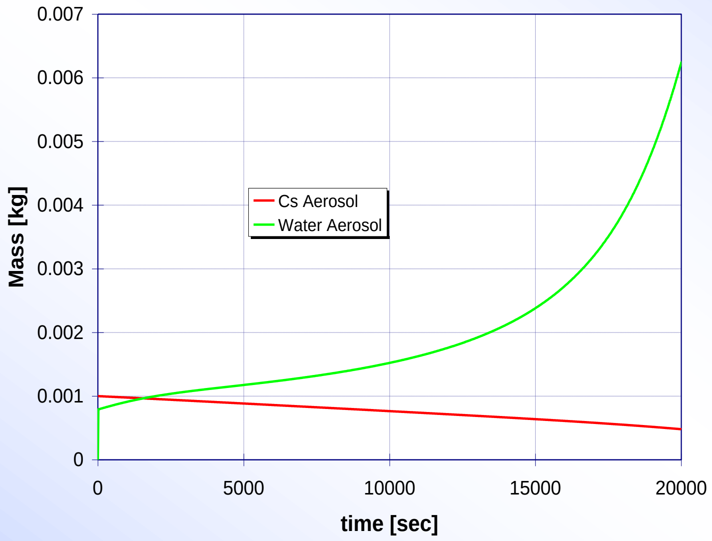
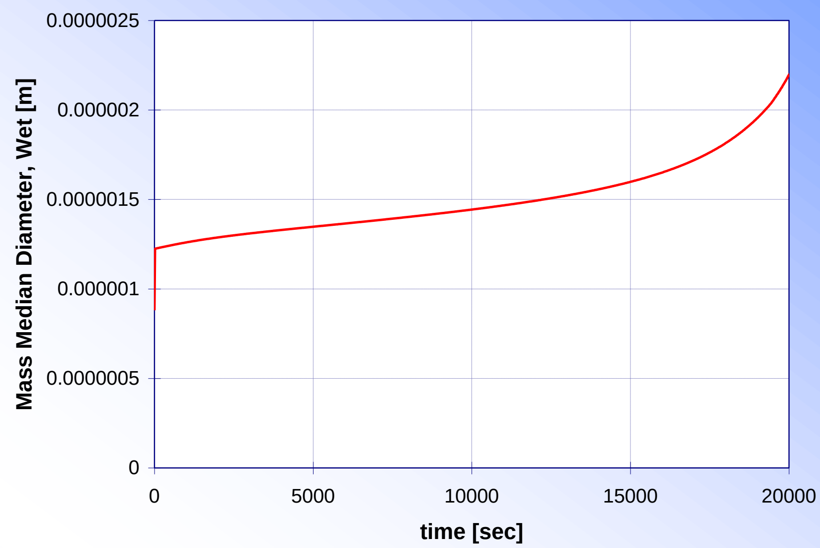
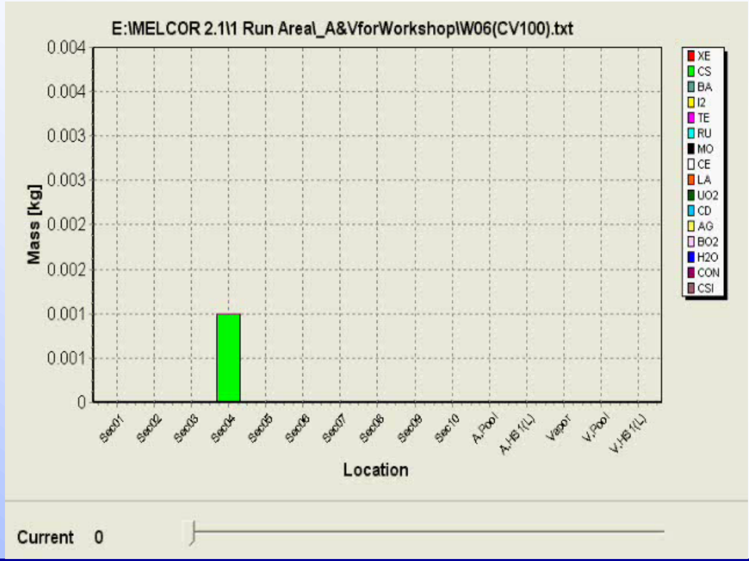
Cs Aerosol, Reduced Initial RH, 85% (1)







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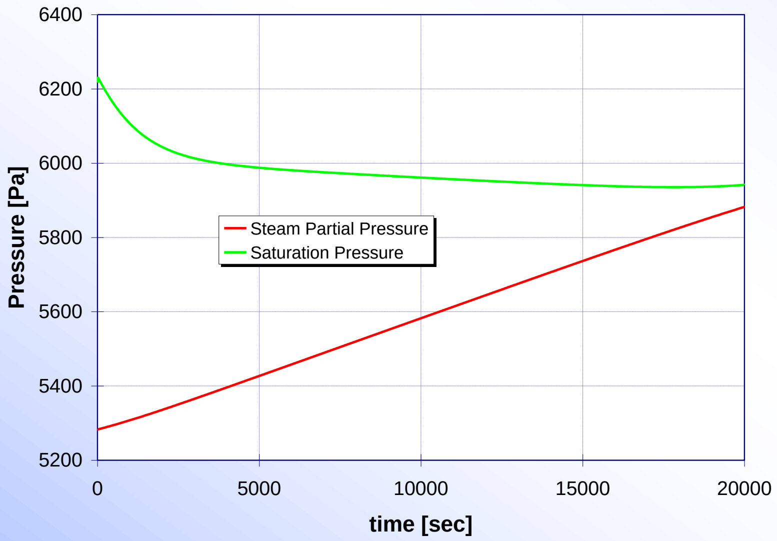
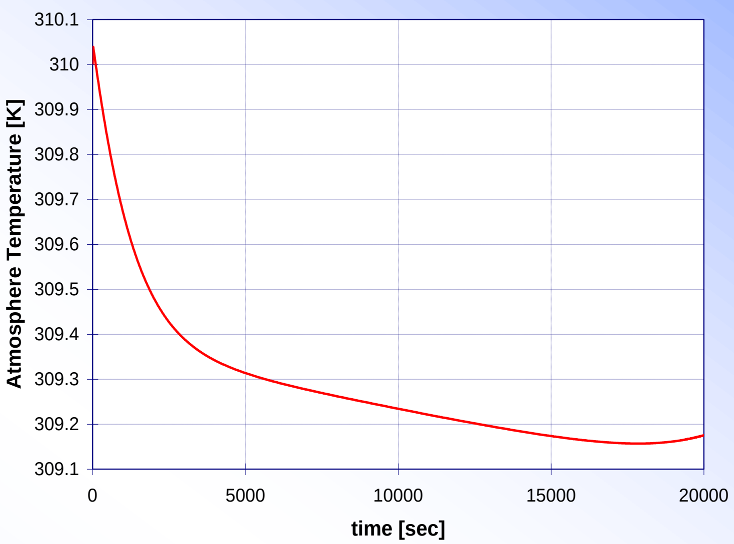
Cs Aerosol, Reduced Initial RH, 85% (2)

- **Results look more reasonable**
  - **Would still see odd behavior if run to later times**





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Conclusions

- Most of current modeling of aerosol and vapor physics is adequate
- May be a need to account for gas composition in MAEROS coefficients
- Further work may be needed on implementation of hygroscopic model
- New visualization tool should help with testing

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Exercises

- **Input files for examples used in this presentation are in Exercises\Session 4 folder**
  - **Note new input to get output file for visualization**
- **Make heavy use of “Named Comment” feature to include many cases in single file**
  - **Very convenient for presentation**
  - **May be an annoyance in developing new examples**
- **Run one case and look at new output file**
  - **Open with Results Viewer**
  - **Perhaps try copying data for one time into Excel and creating plot**
- **Try any variation(s) that you chose**
  - **Easy way to get “clean” MELGEN input without named comment blocks to use as a starting point**
  - **Run a similar case and copy echo of input *actually used* from the MELGEN text output file**

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MELCOR COR Package

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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**
- **It *does not* model boundary structures**
  - **Core shroud, barrel, vessel, upper internals**

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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

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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

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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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
- 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

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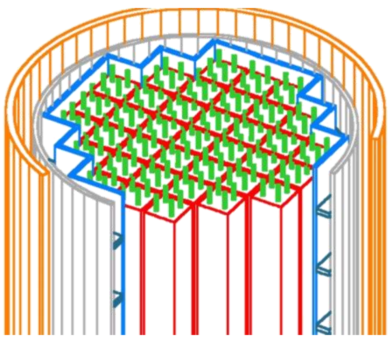
MELCOR Core Modeling
Basic Approach

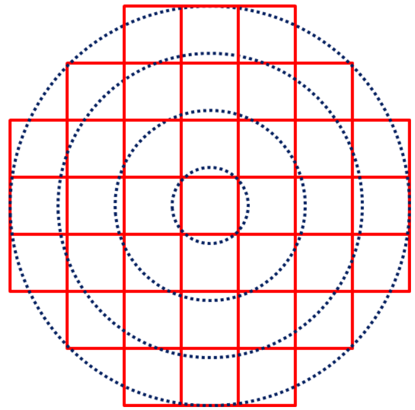
- Take boundary conditions from CVH and HS
  - Standard approaches and heat transfer correlations
- Nodalization may be more detailed than hydro
  - Local temperature profiles inferred where necessary
- Build core structures from "components"
  - Limited number of "building blocks"
  - Components have 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

MELCOR Core Modeling
Core Nodalization

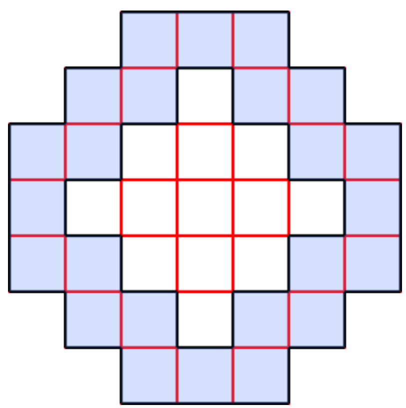
- **Core and lower plenum divided axially and radially into cells**



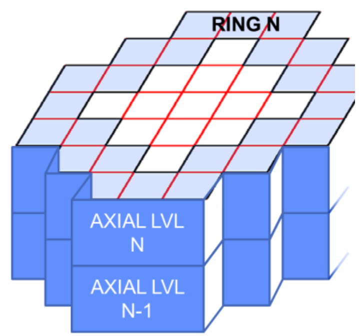
Core Geometry

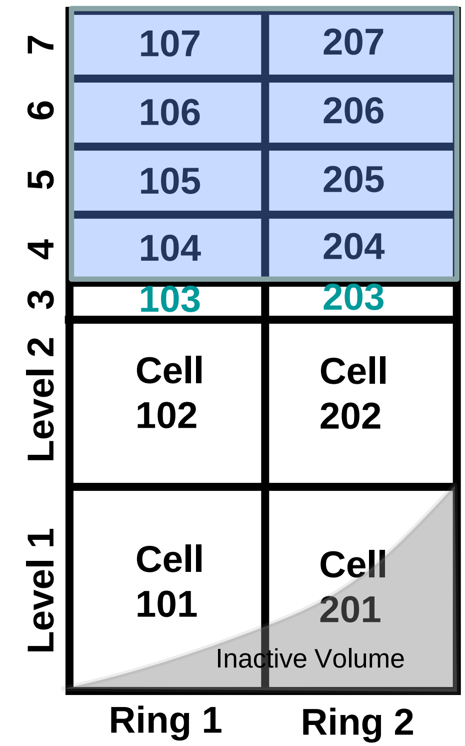


Conceptual Rings



Modeled 'rings'





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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**
  - **Distinction only in core region of a BWR or outer peripheral core ring of PWR**
  - **Common to interface several cells to a single CVH volume**

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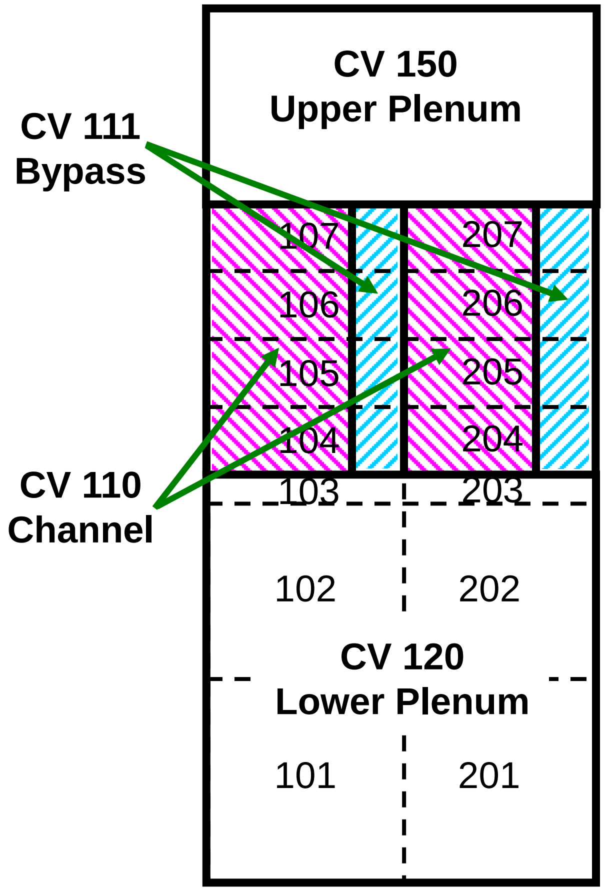
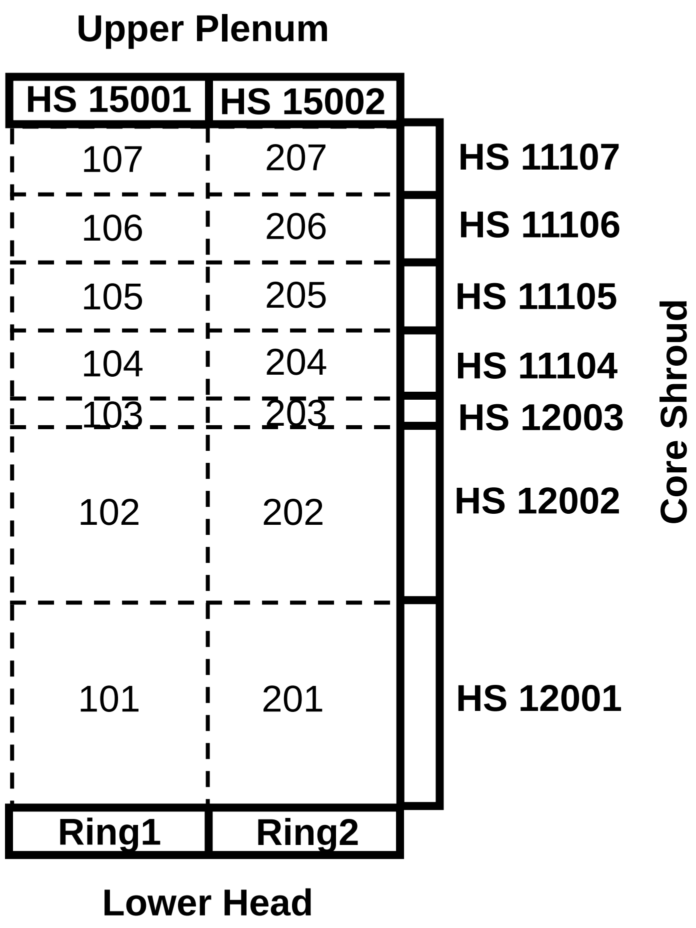
MELCOR Core Modeling
Core Boundary Conditions





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 <u>adjacent</u> 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	Non-supporting 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)
-	-	The lower head is a unique structure associated with the COR package

Components in green are specific to BWRs
Components in red are specific to PWRs
Components in yellow are created when intact components fail.

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Location of COR Components

Reactor Type	Volume: CH Surface: CH Single-sided	Volume: CH Surface: CH/BY 2-sided	Volume BY Surface BY Single-sided
PWR	FU, CL, PD, SS, NS, MP1, MP2	SH	FM, PB, MB1, MB2
BWR	FU, CL, PD, MP1, MP2	CN, CB	SS, NS,, PB, MB1, MB2
SFP-PWR	FU, CL, PD,SS, NS, MP1, MP2		RK,
SFP-BWR	FU, CL, PD, MP1, MP2	CN, CB,	SS, RK, PB, MB1, MB2
PMR	FU, CL, PD, SS, NS, MP1, MP2	RF	PB, MB1, MB2,
PBR	FU, CL, PD, SS, NS, MP1, MP2	RF	PB, MB1, MB2

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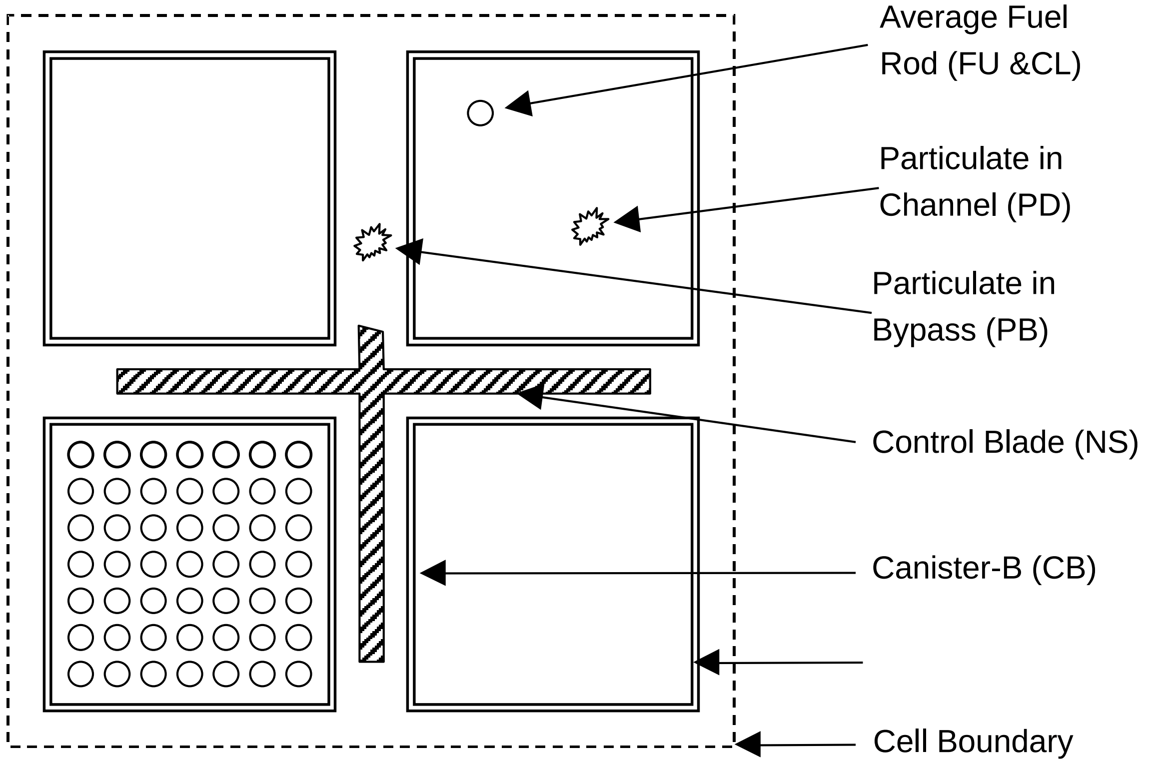
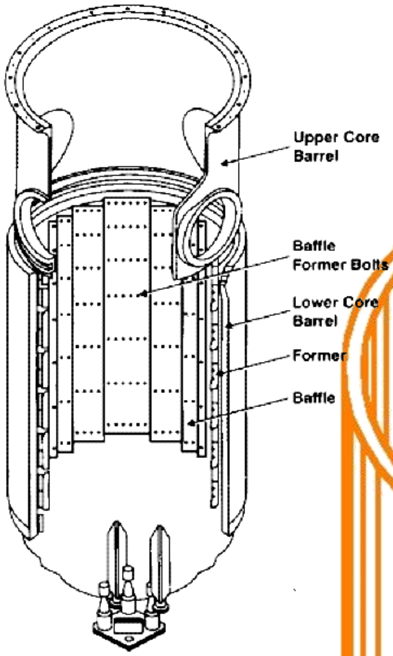
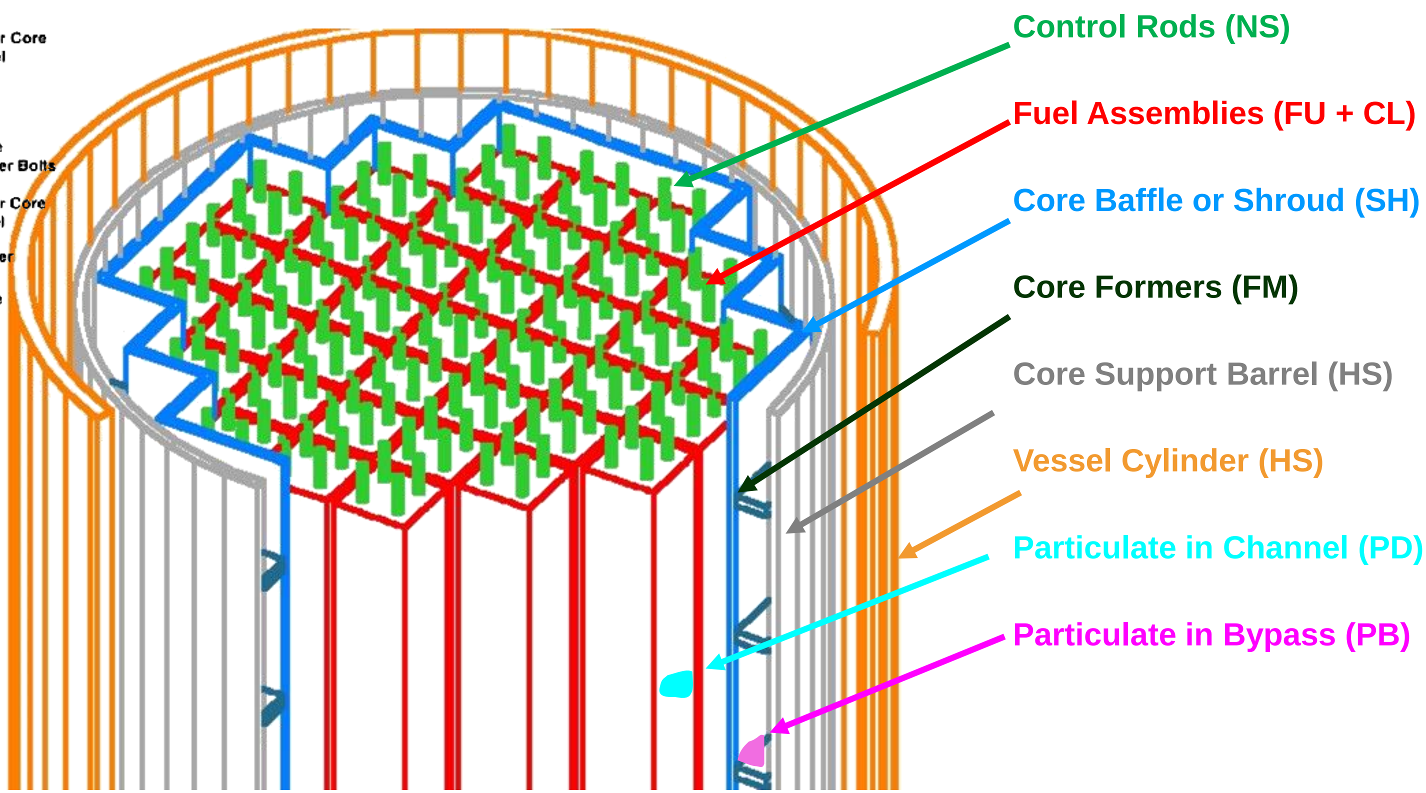
MELCOR Core Modeling
Visualization of Core Components (BWR)

- **Horizontal section of BWR core**



MELCOR Core Modeling
Visualization of Core Components (PWR)





PWR Geometry

MELCOR Core Modeling
Boundary Conditions for Cells

- **Axial boundary conditions for each COR cell**
  - Sees cells in adjacent axial levels
  - Top level sees a boundary heat structure
    - Should be distinct structure for each ring
  - Lowest level sees the lower head
- **Radial boundary conditions for each COR cell**
  - Sees cells in adjacent radial rings
  - Below the Lower Plenum
    - Outer active cell sees lower head
  - Above the Lower Plenum
    - Outer ring sees a boundary heat structure
    - Must be distinct structure for each level
- **Sees fluid in associated control volumes**
  - Local gas temperature inferred by so-called dT/dz model (including axial profile if more than one cell in CV)
  - Partially-implicit treatment (for stability) in either case

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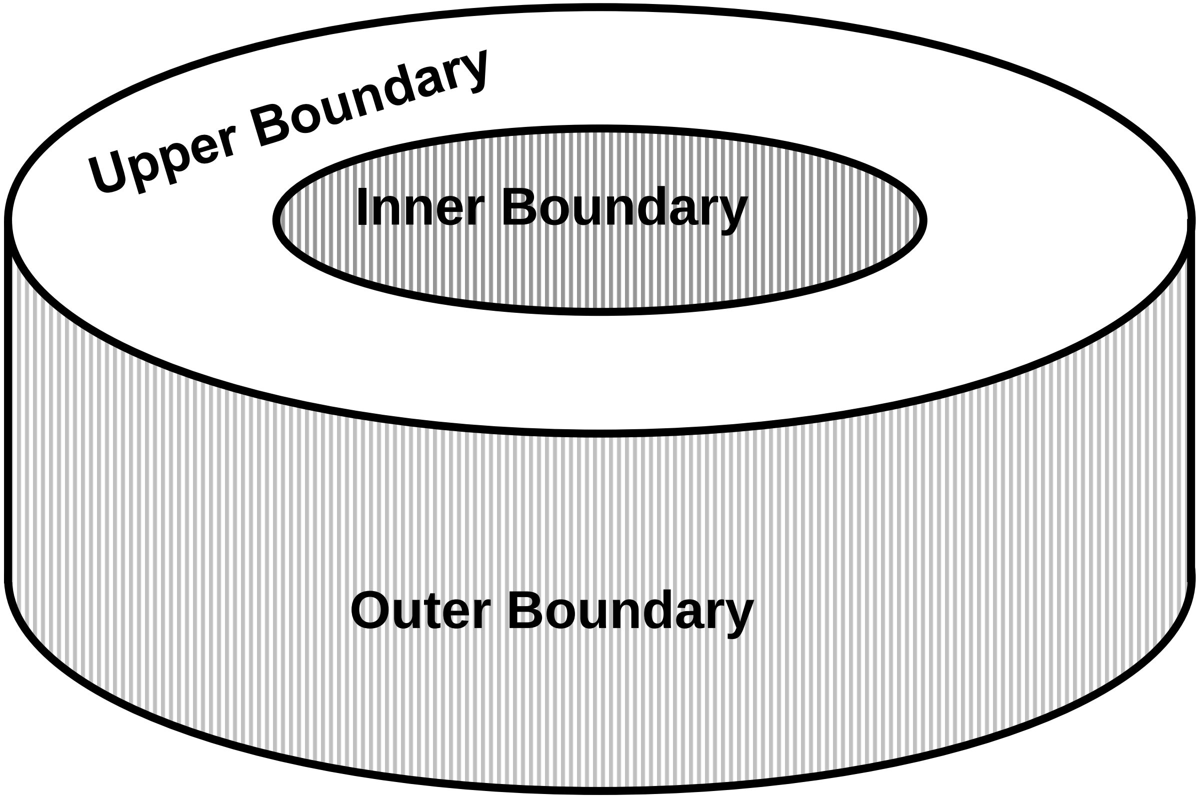
MELCOR Core Modeling
Core Cell Interfaces



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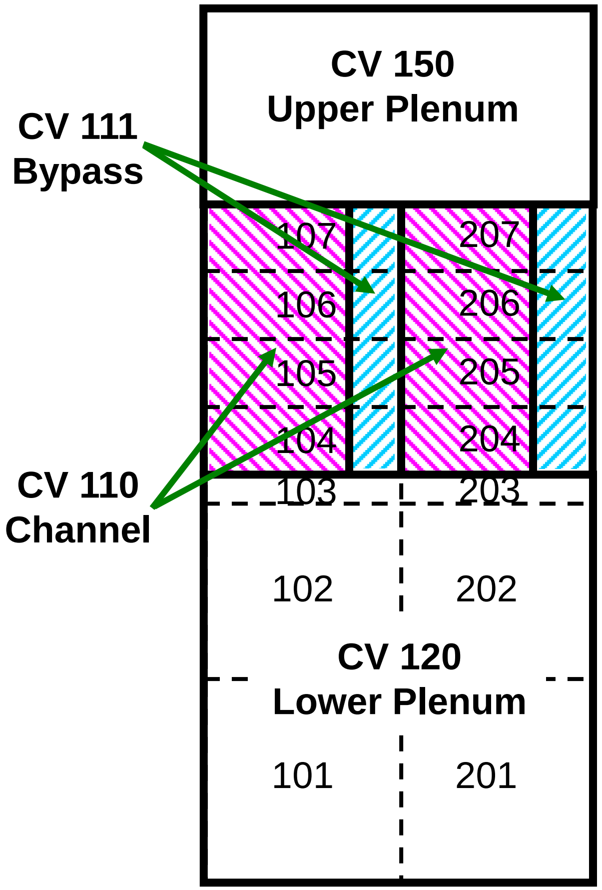
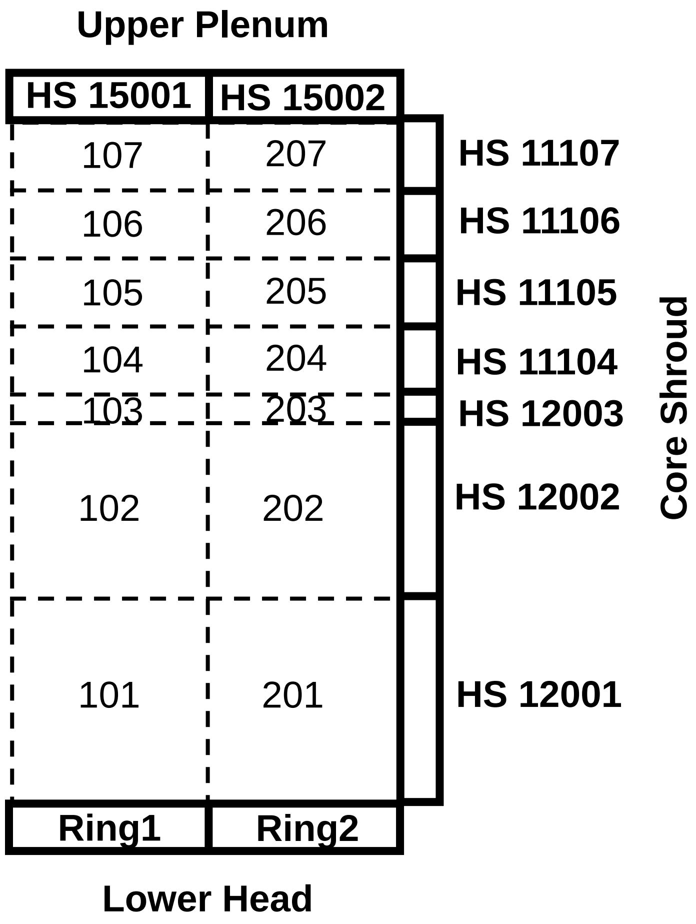
MELCOR Core Modeling
Core Boundary Conditions





MELCOR Core Modeling
COR Input General Overview

- **COR_XYZ general records (COR_GP, COR_RT, COR_VP etc.)**
  - **General COR input and global parameters (COR_XYZ is record identifier)**
  - **Reactor type, nodalization, geometric parameters, vessel parameter, global blockage parameters, debris exclusion parameters, support rules, loading and failure rules, etc.**
- **COR_ZP tabular record**
  - **Axial Level Input**
  - **Axial elevations, axial lengths, particulate porosity, radial boundary HS, support flags, axial power density profiles, OS failure temperatures, etc.**
- **COR_RP tabular record**
  - **Radial Input**
  - **Radial ring radii, total cross-sectional ring areas, upper boundary HS, radial power density profiles, ring flow direction control functions, etc.**
- **COR_XYZ cell tabular records (COR_RBV, COR_CCM etc.)**
  - **Cell input**
  - **Component masses, CVH volume associations,**

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MELCOR Core Modeling
General Input

```
Reactor Type
COR_RT   IRTYP   MCRP    MATHT
```

COR_RT Reactor Type

This record specifies the reactor type, the control rod poison material, and the electric heating element material. This record is not required, but if it is included, at least the first field must be present. Three-character-string fields are allowed.

Optional

Note: IRTYP, MCRP, MATHT were previously found on the COR00002 record

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MELCOR Core Modeling
Geometric Input

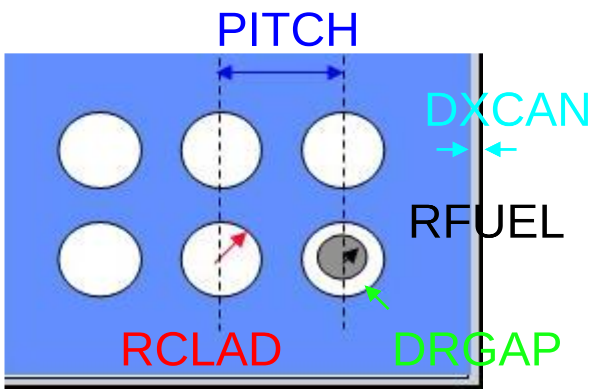
COR_GP RFUEL RCLAD DRGAP PITCH

COR_GP - Thickness of OS.

This record specifies key geometric information for the fuel rods, the control rods, and (for BWRs) the canister boxes. If this record is present, it may contain from zero to seven fields. Default values will be retained for those fields that are not present and for any that contain negative numbers. Different default values are defined for a BWR (including an SBWR) or a PWR, based on IRTYP input on record COR_RT. These are marked as '(B)' and '(P)', respectively, in the list below.

Note that DZLH has been moved to the COR_VP record.

Optional

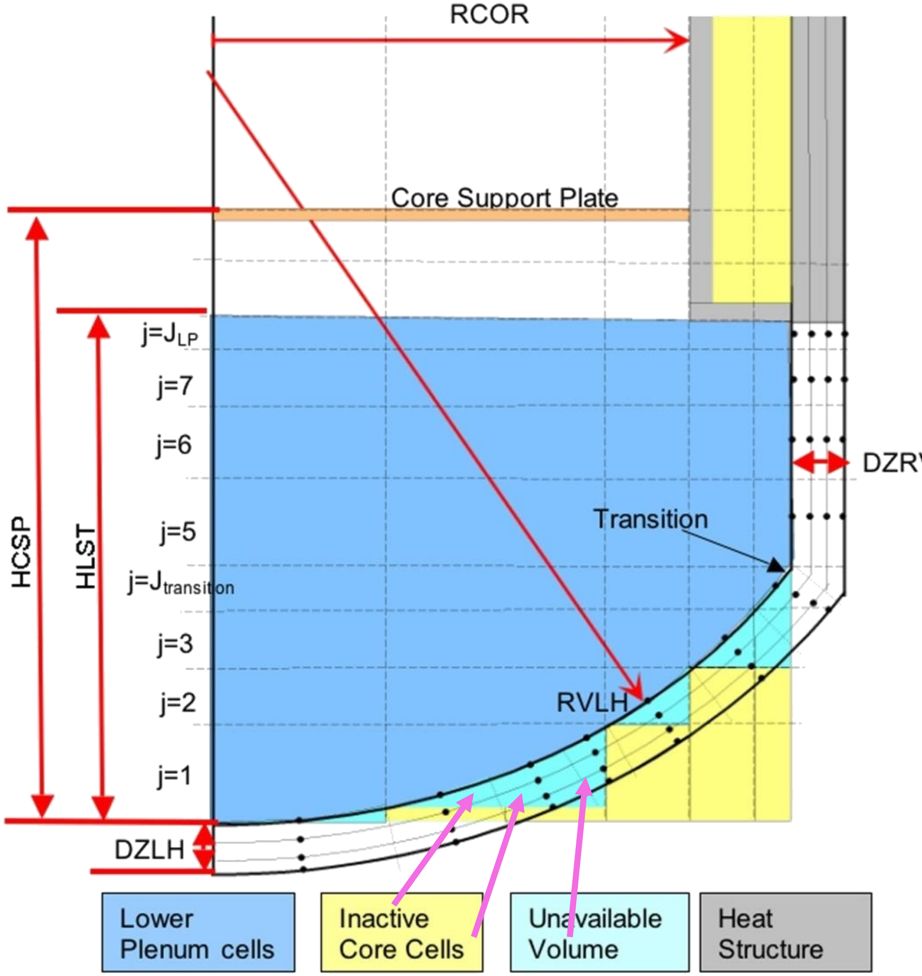


These fields get used for things like gap resistance, radiation path lengths, and the thickness of conglomerate that will bridge the space between rods

Note: RFUEL, RCLAD, DRGAP, PITCH were previously on record COR00001. DXCAN and DXSS (previously on COR00001) were removed as they are no longer used.

MELCOR Core Modeling
Lower Head Geometry

- Lower head defined in segments
  - Outer radius defined independently of core cells
    - Used to calculate area and inclination
  - Each communicates with core cell above, control volume outside, and adjacent segments
- Total thickness DZLH with NLH nodes
  - Default is CARBON STEEL, equally-spaced nodes
    - Can modify to add liner or insulation
- Unavailable volume
  - Cells that lie below the curved lower head surface can be specified as “Null” cells

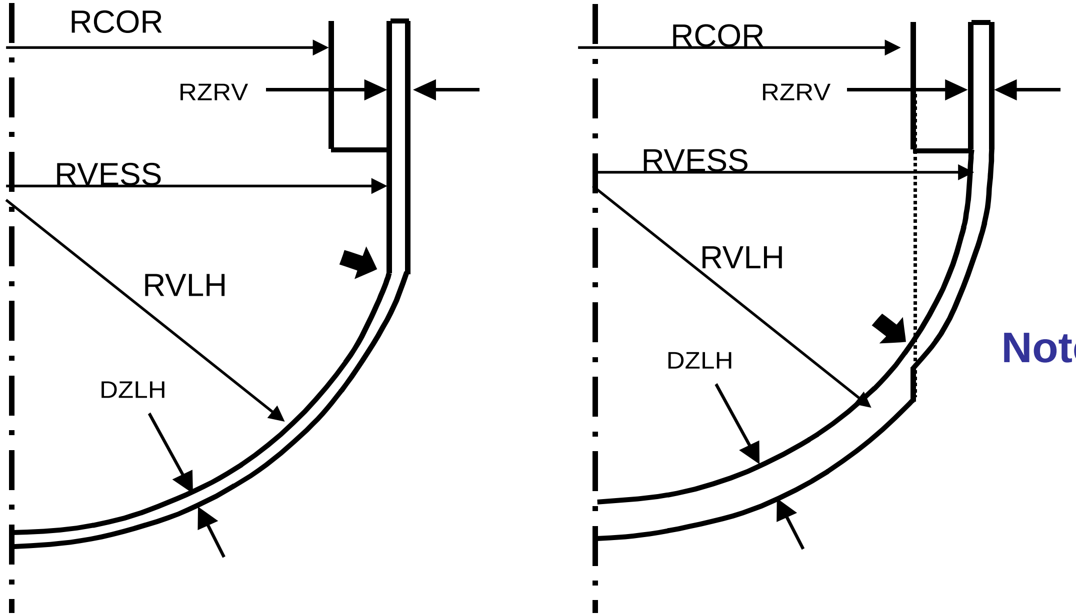


MELCOR Core Modeling
Input for Lower Head (1)

COR_VP   RCOR   RVLH   RVESS   ILHTYP   ILHTRN   DZRV   DZLH

COR_VP record

This record specifies key geometric information for the vessel, including the core region. Different default values are defined for a BWR (including an SBWR) or a PWR, based on IRTYP input on record COR_RT. These are marked as (B) and (P), respectively, in the list below.



Note: The COR_VP record table is analogous to the COR00001A record.

MELCOR Core Modeling
Consistency with Hydrodynamic Models

- **Materials in COR can relocate – displacing CVH volume**
- **Initial COR/CVH fluid volumes defined independently**
  - **CVH uses input volume/altitude tables**
    - ***must not* include volume of assemblies, etc**
  - **COR uses input flow area*cell height**
- **Inconsistent input can cause severe problems**
- **To match vertical distribution of volumes, elevations in CVH must match those in COR**

Changes in displaced volume are tracked separately by CVH and COR
Nodalizations may differ
- CVH tracks each volume with resolution limited by the volume/altitude table
- COR tracks each core cell, separately for channel and bypass if they are distinguished

MELCOR Core Modeling
Consistency with Hydro. Models (2)

- **Inconsistencies noted in Output**
  - **Elevations**: CVH elevation does not match COR elevation
  - **Volumes**: COR Fluid Volume > CVH Volume

```
--------------------------------------------------------
CONSISTENCY CHECK ON VOLUME REPRESENTATIONS IN COR AND CVH
--------------------------------------------------------

 IN THE VOLUME/ALTITUDE TABLE FOR C.V. 120
   There is no point at the top of core level   1 at Z+DZ =    3.908140    (m)
   There is no point at the bottom of core level   2 at Z =    3.908140    (m)
...
 CV  BETWEEN ELEVATIONS (M) IN CVH       FLUID VOLUME (M3) IS
        VOLUME/ALTITUDE TABLE                 IN CVH         IN COR

120    3.600000        4.000000              0.6554500      1.327213      ***
       4.000000        4.468220              4.105920       3.427370
       4.468220        5.229180              9.888870       9.877261
```

MELCOR Core Modeling Consistency with HS Models

- **Core components "see" local temperature inferred by dT/dz model**
  - **Calculation includes effects of radial boundary heat structures in the outer ring of the core**
  - **The structures are assumed to be in the bypass when present**
- **For consistency, heat structures must see same temperatures**
  - **Boundary fluid temperature allows for this**
  - **Serious problems if HS sees bulk temperature**
    - **Most likely result is a calculated temperature (local in COR *or* volume in CVH) going to 273.15 K or 5000 K**
- **Input check can result in fatal error**

```
HS_LBF DTDZ  IA   IR ! Positive (left only) for local COR temp
```

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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MELCOR Core Modeling
Non-Supporting Structures

- **Non-supporting structure (NS) can support only other NS**
- **User input defines treatment in each core cell**
  - **Type of structure modeled**
  - **Failure criteria**
- **Three basic input options**
  - **'ABOVE', like a PWR control rod**
  - **'BELOW', like a BWR control blade**
  - **'FIXED', like the stiffeners in Phebus experiments**
    - **NS in a cell will not collapse until it fails locally.**
- **More general global options**
    - **'BLADE' (default for BWR) ≡ 'BELOW'**
    - **'ROD' (default for PWR) ≡ 'FIXED' at upper end, 'ABOVE' elsewhere**

PWR Control Rod Assembly

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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**

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

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

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

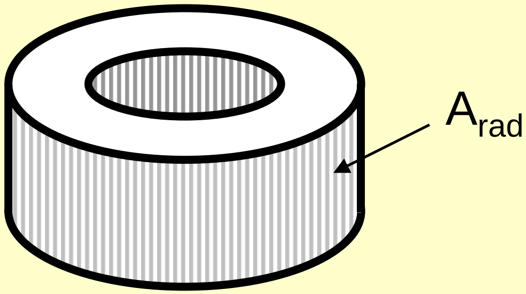
$$A_i = \frac{V_{tot,comp,i}}{\Delta z_i}$$

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

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.
- **Fuel pellet and the fuel-cladding gap**
  - Currently h_g is hard-coded as 0.2 W/m-K

Radial



$$A_i = \frac{V_{tot,comp,i}}{V_{tot,cell,i}} A_{rad}$$

$$\Delta x_i = \frac{V_{tot,i}}{2\,A_{rad}}$$

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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**

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

- **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:

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

Urbanic Heidrich evaluation of rate constant, K

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

$$\frac{\mathrm{d\,W}}{\mathrm{dt}} = \frac{\mathrm{MW}\;\;k_c\;\;P_{ox}}{\mathrm{n}\;\;\mathrm{R}\;\;T_f}$$

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

Additional Oxidation 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 can be disabled on a cell-by-cell basis by CF
  - Flow blockage modeling
  - COR_NOX record
- Oxidation calculated for submerged surfaces
  - Gas film between unquenched surfaces and pool
- 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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End of Lecture
Open Discussion on COR Package

MELCOR COR Degradation

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
  - Failure at temperature
- **Core Support & 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
- **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
- **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

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Interface of COR Package with Other Packages

- RN Package
  - Radionuclides are hosted on COR materials
    - Provide decay heat to components
    - Relocate with materials
    - Released from COR materials to CVH
- CVH Package
  - Materials in COR can relocate, displacing CVH Volume
    - Changes in displaced volume are tracked separately by CVH and COR
- FL Package
  - Blockages in COR can obstruct flow
- 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

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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

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MELCOR Support Logic

Component	Supports components	Failure Criteria
RD(FU,CL)	RD(FU,CL)	Temperature (FU & CL), DRZRMN, lifetime rule, CF (heating element fixed)
NS	NS: above (PWR), below (BWR), fixed (stiffeners)	DRNSMN and TNSMAX
SS	SS, Other dependent on type (discussed below)	"PLATE," "PLATEG," "PLATEB," and "COLUMN", CF, TSSFAIL, DRSSMN
CN,(CB)	CN (CB)	DRZRMN, temperature, CF
PD,(PB)	PD,(PB)	Already failed
MP1, (MB1)	MP1, MP2 (MB1, MB2)	Already failed
MP2,(MB2)	MP2, (MB2)	Already failed
SH	SH	DRSSMN and temperature
FM	PB, SH	DRSSMN , and temperature
RK (SFP)		DRSSMN, and temperature
RF (HTGR)		DRZRMN and temperature

MELCOR Core Modeling
Supporting Structures

- **Supporting structure can support itself, other components (including particulate debris)**
- **There are five named options for basic model**
  - **'PLATE', 'PLATEG', 'PLATEB', 'COLUMN', and 'ENDCOL'**
  - **Each has different properties, 'PLATEG' is default**
- **Two classes of failure models**
  - **Parametric, as in versions before 1.8.5 (default)**
    - **Failure on maximum temperature (default, at 1273.15 K)**
    - **Failure defined by value of a LOGICAL control function**
  - **Stress-based structural models**
    - **Load and stress calculations depend on basic model**
      - **Engineering handbook equations, based on simple parameters**
    - **Failure by creep rupture, yielding, or buckling (COLUMN)**

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Supporting Structure Models

	PLATE	PLATEG	PLATEB	COLUMN
Typical Application	PWR edge supported plate	PWR grid support	BWR	BWR CRGTs
Supported Components	- itself - fuel assemblies - particulate debris	- itself - fuel assemblies - particulate debris	- itself - particulate debris	- columns above - Carries transferred load of fuel assemblies
Dependencies	Outer rings support inner rings Outermost ring is self-supporting	Rings fail independently	Rings fail independently	Upper columns and any transferred loads Bottom ring is self-supporting
Disposition at failure	On failure in a ring, 'PLATE' and everything supported by it (including inner rings) *collapses as particulate debris*	On failure in a ring, supported components and particulate collapse, but *'PLATEG' remains in place until it melts*	On failure in a ring, supported particulate collapses, but fuel assemblies remain supported by CRGTs, and *'PLATEB' remains in place until it melts*	On failure in a ring, 'COLUMN' and everything supported by it *collapses as particulate debris*

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MELCOR Core Modeling
Supporting Structure Models

Parametric Failure

```
COR_SS NUMSTR
        NSTR IA IR ISSMOD  ISSFAI  TSSFAI !Failure Temperature
        NSTR IA IR ISSMOD  ISSFAI  ISSLCF !Control function
```

ISSMOD - Structural model option for SS.

Examples: PLATE PLATEG PLATEB COLUMN ENDCOLUMN <NAME>

(type = real, default = -1.1, units = K)

- **'PLATE' models an edge-supported plate**
  - Supports and is loaded by fuel assemblies (may include NS supported from below) and particulate debris
  - Outer rings support inner rings; outermost self-supported
  - On failure in a ring, 'PLATE' and everything supported by it (including inner rings) collapses as particulate debris

Stress-based Failure – From Engineering Handbook Equations

PLATE PLATEG PLATEB COLUMN

PLATE: COR_SS NUMSTR

NSTR IA IR ISSMOD THICK AKM0 AKM1

$$\sigma_e(r;r_0) = 6\,AKM0\,\frac{1}{\pi}\frac{1}{THICK^2}\left[1 - AKM1\left(\frac{r}{a}\right)^2\right]\left[1 + \left(\frac{r_0}{r}\right)^2\right]W_{total}$$

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MELCOR COR Modeling
User-Defined SS Type

COR_UDSS NUMUDS

N CSSUDF CSSOPT1 CSSOPT2 CSSOPT3

COR_UDSS

Optianal

The user may define one to three “types” off SS in addition to the built-in types. Each is assigned a name, and its support capabilities are defined by input on a string of COR_UDSS tabular record. Until failure, all user-defined types are currently assumed to be self-supporting, and the ability to support other intact components and/or particulate debris is defined by user input. The fate of the SS itself after failure is also defined by user input.

Only paremetric failure options (TSSFAI or ISSLCF) are allowed

If a CSSOPT keyword is absent, the corresponding capability is assumed to be absent. There is no dependence on the order of keywords, but at least one of them must be present.

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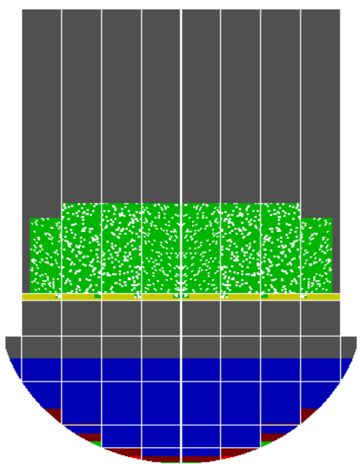
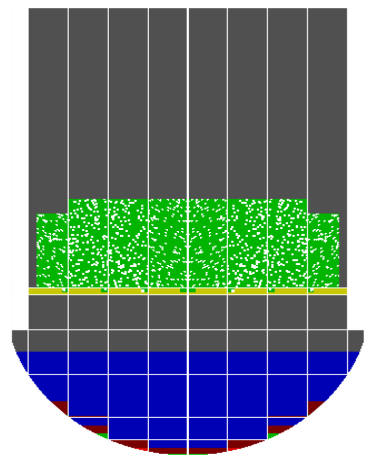
User-Defined SS Type Demonstration

Grid



26 (sec)

Edge



26 (sec)

40

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MELCOR COR Modeling
Control Function Component Failure

- **Local failure by loss of integrity**
  - **Based on critical minimum thickness of unoxidized metal**

COR_CCT DRCLMN DRSSMN

- **Failure by loss of support**
  - **No required Input**

- **Failure by Control Function**

COR_CFF NUMSTR
NSTR IA IR ICOMP ICFAI

- Rods and canisters must be supported by something in the cell below
  - Rod supported below by rod or competent support structure
  - Canister supported below by canister or competent support structure
  - Failure of rod or canister in any cell results in failure in all higher cells in the same ring
- Nonsupporting structures have several options
  - Support from below can also be provided by a competent support structure

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Mechanical Failure of Components (Formation of Particulate Debris)

- Formation of particulate debris (in channel and bypass)
  - Debris Behavior
  - Debris Porosity and Surface Area
  - Debris Exclusion :
- Fuel rods:
  - Failure of oxidized rods
  - Failure of unoxidized fuel rods
    - Inert environment or candling of all ZrO_2
    - Metal thickness < DRCLMN
  - Or failure by control function
    - Possible failure based on a cumulative damage function)
- 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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MELCOR CORE Modeling
Failure of Fuel Rods (1)

```
! COR_ROD INPUT
!
!         Tabular Function describing
!         fuel rod life time remaining as
!         a function of cladding temperature
!         |
!         |                  Minimum unoxidized clad thickness
!         |                  under which the default failure
!         |                  criterion is no longer used
!         vvvvvvvvvvvvvvvv   vvvvvv
COR_ROD   ‘FUEL-FAIL-TIME’   1.0E-3
...
!
TF_ID     ‘FUEL-FAIL-TIME’   1.0
TF_TAB   4
!           (K)       (SECONDS)
        1 1000.0  6.00E+31    ! INFINITE AT 1000K
        2 1001.0  3.60E+03    ! 60 MIN AT 1001 K
        3 2100.0  1.80E+03    ! 30 MIN AT 2100 K
        4 2500.0  6.00E+01    ! 1 MIN IF > 2500 K
```


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MELCOR Core Modeling
Failure of Non-Supporting Structures

- **Two failure criteria for NS**
  - **Minimum thickness of unoxidized structural metal**
  - **Maximum temperature**
- **Material becomes particulate debris**
- **Different defaults for PWR and BWR, with flexible input to override them**

Previously on COR000NS, CORZjjNS, CORRIINS, and CORijjNS

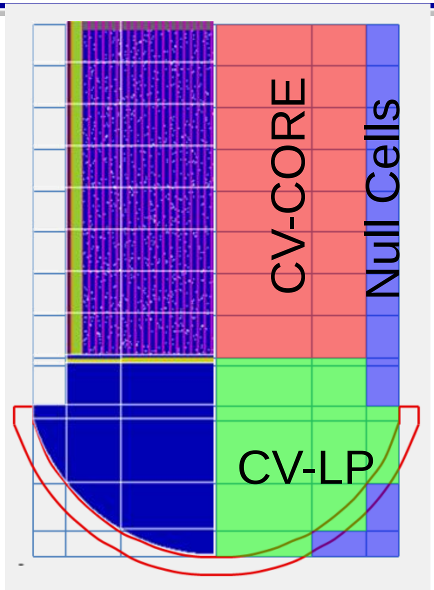
```
COR_NS 1 !N IA  IR  INSSUP METAL TNSMAX  DRNSMN
          1 ALL ALL BLADE  STEEL 1400.0  0.0001
```

Failure on Minimum Thickness

- Minimum thickness of unoxidized structural metal
- Default minimum thickness 0.0001 m
- Structural metal can be steel (default) or Zircaloy

PWR Test Problem

- **Initial Conditions**
  - **3200 MW (operating power)**
  - **Reactor Scram at t=0**
  - **No pump flow**
- **Two Cases**
  - **Rod Collapse model**
    - **Rods fail at 936 s**
    - **Slightly more hydrogen generation since rods fail later**
  - **Default failure model**
    - **Rods fail at 810 s**



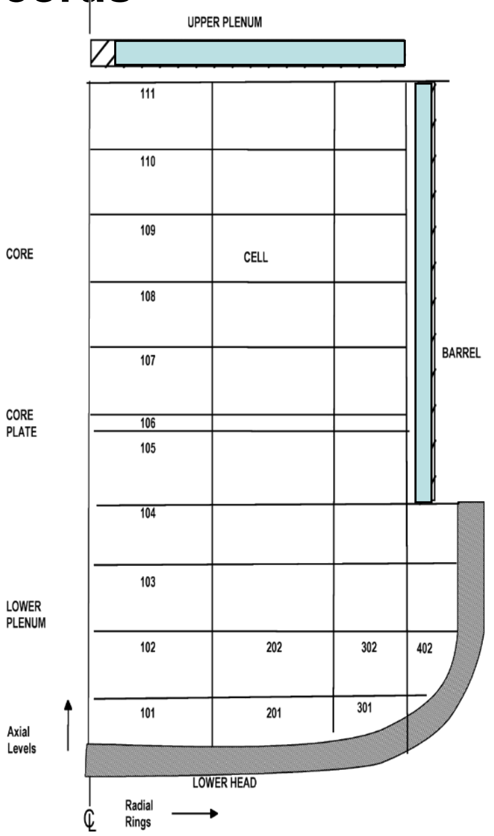
DZXMN	Minimum ZrO2 thickness required to hold up molten Zr in CL (0.0001 m).
TZXMX	Maximum ZrO2 temp permitted to hold up molten Zr (2400 K)
DRZRMN	Critical minimum thickness of unoxidized metal (0.0001 m)
TRDFAI	Temp to which ox fuel rods can stand in absense of unox Zr in cladding

MELCOR Core Modeling
Melting Heat Structures

- **Core boundary heat structures can melt**
  - **Only the structures on COR_ZP and COR_RP records**
  - **Metal becomes part of particulate debris**
  - **Code uses same approach as for degassing**

HS_DG NAMESRC NAMEHS TYPESRC ISRCHS ISDIST GASNAM

HS_DGSRC RHOSRC HTRSRC TEMPL TEMPU



HS_DG - General Gas Source Data

(2) The structures for which SS degassing is desired must lie either along the core or above the core. If along the core, then a structure must align with one of the COR package axial segments as identified by input record CORZ_ZP. Structures are not permitted to span across COR axial segments. If the degassing structure lies above the core, then its lowermost elevation must exceed the uppermost core elevation as modeled by the COR package

Required

MELCOR Core Modeling
Debris Exclusion Model Input

- **Implemented by allowing intact components to block access to particulate debris**
- **Defaults**
  - **Intact fuel rods block entire channel volume**
  - **PWR control rods alone have no effect**
  - **Intact control blade (NS in a BWR) blocks 70% of bypass**
  - **Intact canister not by blade (CN) blocks 30% of bypass**
- **Flexible input to modify defaults**

Previously on COR000DX, CORZjjDX, CORRiiDX, and CORijjDX

```
COR_DX NUMSTR
    NSTR IA IR FCHXRD  FBYXRD  FBYXCN  FBYXCB  FBYXNS  FBYXSS
```

```
COR_DX -
This record allows the global definition of volumes from
which particulate debris will be excluded by the simple
presence of various other components. The exclusion
volumes are specified as fractions of the associated
total volume, either channel or bypass.
```

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)

MELCOR Core Modeling
Falling Debris Quench Model, Input

- **Debris supported by core plate at time of failure gets special treatment**
  - **Considers finite fall velocity and heat transfer to pool**
    - **Finite velocity imposed on *all* axial relocation of debris**
  - **Mitigates high pressure from "instantaneous" displacement of pool, sudden increase in steaming**

```
! COR_LP defines parameters for falling debris quench
!      Axial level containing core plate
!      | Heat Trans. Coeff., falling debris to pool (W/m**2 K)
!      | |     Differential pressure to fail lower head (Pa)
!      | |     |      Velocity of falling debris
!      v vvvvv vvvvv  vvv
COR_LP 3 100.0 2.0E7  1.0 ! Defaults shown, except level
! If record absent, plate assumed to be in level NTLP
```

- **Model *on* by default in MELCOR 2.1 (and 1.8.6)**
  - **Versions earlier than MELCOR 1.8.5 defaulted heat transfer coefficient to 0**

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**
    - **As a core cell becomes completely filled, flow resistance will approach infinity**
  - **Failure of BWR canisters or PWR shroud opens path between channel and bypass volumes**
- **Flow blockage model captures these effects**
  - **Requires input to the FL package**
    - **Can't be automatically invoked, because of flexibility in user definition of nodalization**
    - **Canister failure requires definition of additional flow paths**

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MELCOR Core Phenomenon
Core Fluid Flow Blockage Modeling (2)

- **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 (radial flow in the channel only is not allowed)**
  - **Can open path on failure of BWR channel box (canister) or PWR shroud**
- **Ergun equation is used for debris bed**
  - **New core blockage enhancement factor (multiplier on porosity for resistance calculation)**
- **Initial (intact) resistance used until then**
  - **Small area correction for possible conglomerate debris**

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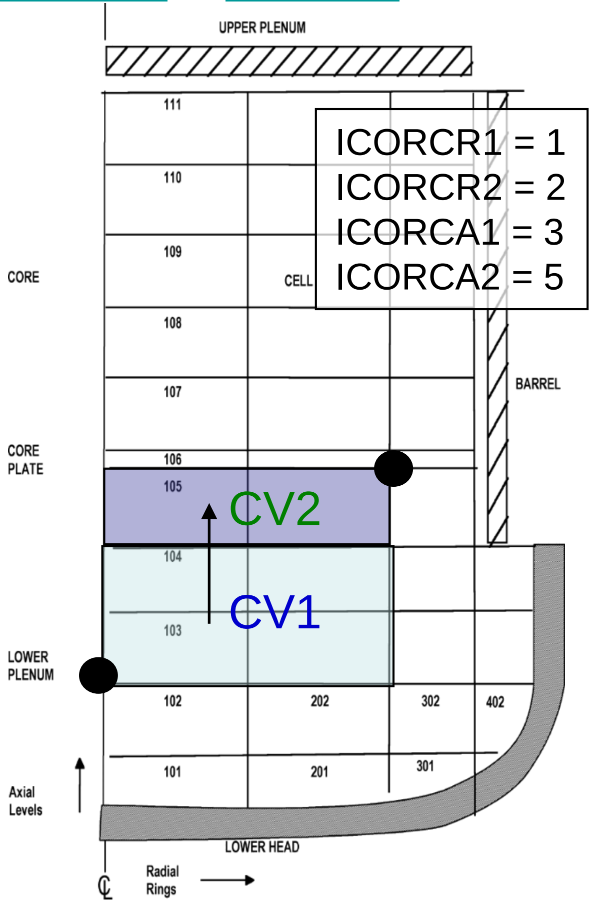
MELCOR Core Modeling
Core Flow Blockage Model Input

FL_BLK OPTION ICORCR1 ICORCR2 ICORCA1 ICORCA2 FLMPTY

FL_BLK - Data for blockage of flow by another package

Blockage of flow in response to change of geometry in another package (reduction of flow area, redefinition of friction) will be calculated if data are entered on this record. If a dataset is entered, no other control of the flow area is possible, and inclusion of a valve (FL_VLV) record is not permitted. Only one blockage dataset may be entered for a flow path.

Optional



Note: The FL_BLK record table is analogous to the FLnnBK record type.

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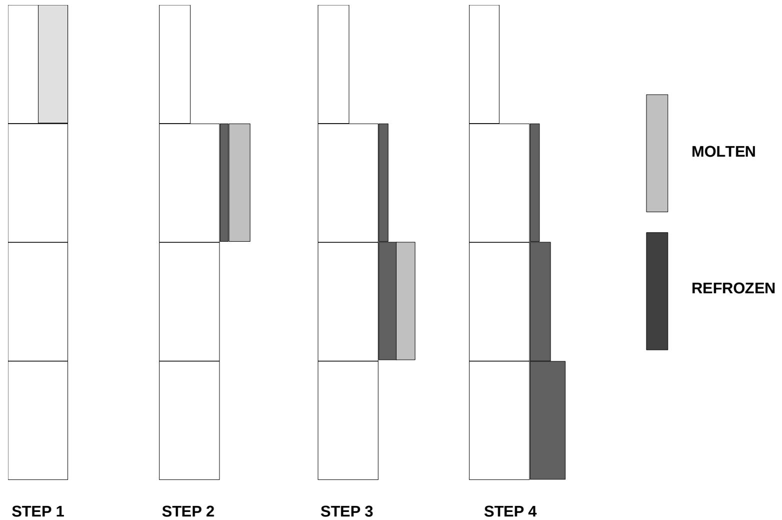
Lower Head Failure Criteria

- **Creep-rupture failure of a lower head ring occurs**
- **Temperature dependent failure**
  - **Failure Temperature, TPFAIL, set on COR_LHF card**
- **Failure dependent on control function**
  - **Control function identified on COR_RP records**
- **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**

Downward Relocation of Molten Material

- Candling - Downward flow of molten core materials and subsequent refreezing (creation of 'conglomerate')
  - Semi-mechanistic
    - Based on fundamental heat transfer principles with user-specified refreezing heat transfer coefficients for each material
  - 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 if non-existent at lower elevation



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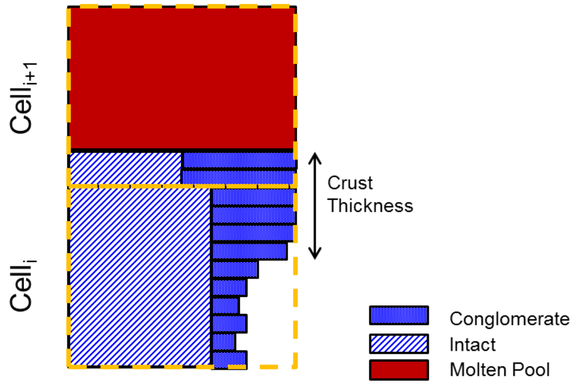
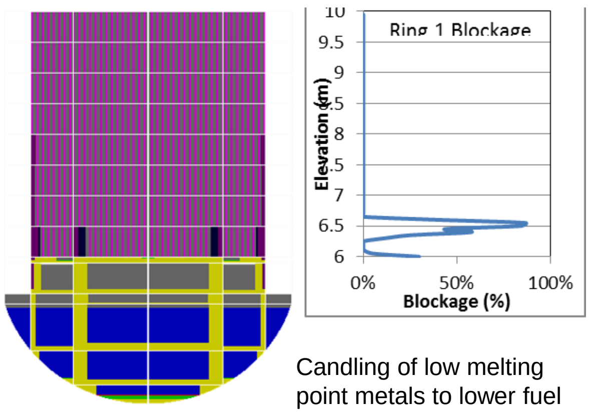
MELCOR Crust

- **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**

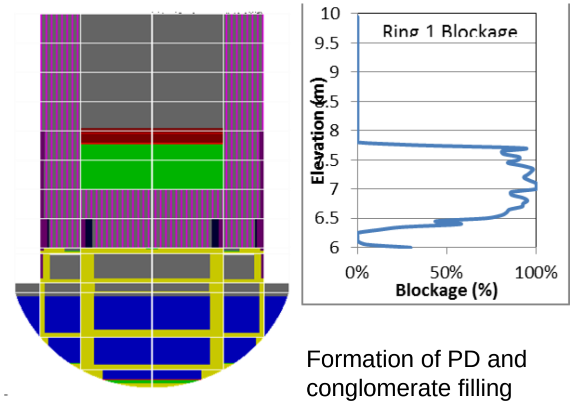


Sub-Grid Model Prediction of Blockages



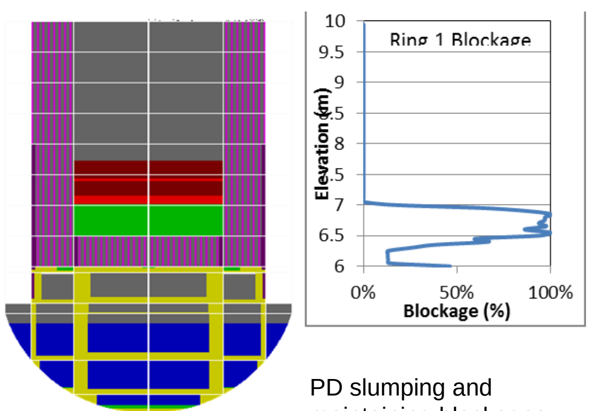
1998 (sec)

Candling of low melting point metals to lower fuel rods



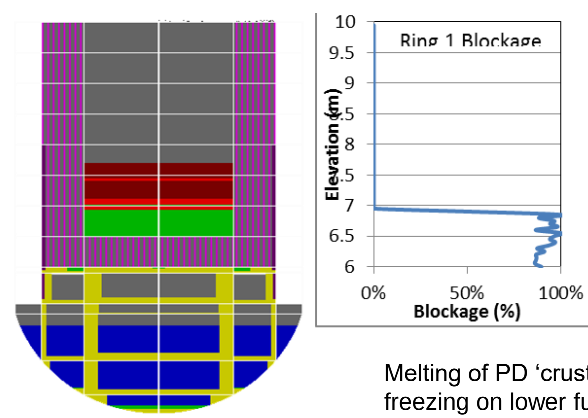
2008 (sec)

Formation of PD and conglomerate filling interstitials



2414 (sec)

PD slumping and maintaining blockages



2462 (sec)

Melting of PD 'crust' and freezing on lower fuel rods

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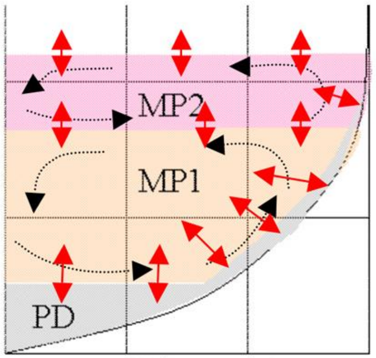
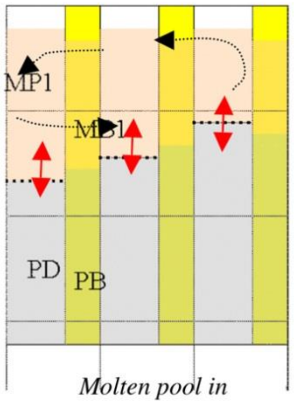
MELCOR Core Phenomenon
Stratified Molten Pool Model (1)

- **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.**
    - **User can specify partitioning factor on RN1_MPCR record**



Molten pools in lower plenum



Molten pool in upper core

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Stratified Molten Pool Model

- **Molten material may be part of contiguous molten pool**
  - **Homogenized after heat transfer and relocation**
    - **Redistribute mass and energy**
    - **Redistribute radionuclides**
  - **Higher-level treatment of pool heat transfer**
    - **HTC based on pool Rayleigh number**
    - **HTC distribution correlation**
- **Stray (noncontiguous) molten pool material**
  - **Heat transfer treated same as conglomerate PD**
  - **Relocation treated as molten pool material**
  - **Temperature and composition distinct from convecting pool**

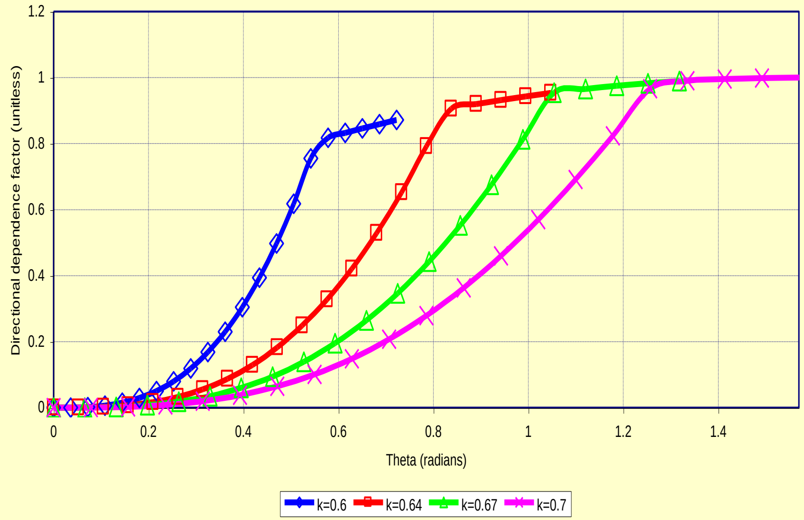
Heat transfer correlation angular dependence

$$\theta \le \arccos(1 - k(i)\tfrac{H}{R})$$

$$\frac{\varphi}{\varphi_{max}} = c(i)\cdot\theta + b(i)\cdot\theta^2 + a(i)\cdot\theta^3$$

$$\arccos(1 - k(i)\tfrac{H}{R}) < \theta \le \arccos(1 - \tfrac{H}{R})$$

$$\frac{\varphi}{\varphi_{max}} = f(i)\cdot\theta + e(i)\cdot\theta^2 + d(i)\cdot\theta^3$$



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Molten Pool Convective Heat Transfer

Energy Balance on MP1:

$$MC_{p,MP1}\frac{T_{MP1}^{n}-T_{MP1}^{o}}{\Delta t}=\dot{Q}_{MP1,decay}-\sum_{s\in seg}h_{MP1\rightarrow s}A_{s}\left(T_{MP1}^{n}-T_{s}\right)-h_{MP1\rightarrow MP2}A_{1,2}\left(T_{MP1}^{n}-T_{MP2}^{n}\right)-\left(h_{MP1-fluid}A_{f}(T_{MP1}-T_{fluid})-\sigma\varepsilon_{eff}A_{up}(T_{MP1}^{4}-T_{ambient}^{4})\right)$$

Energy Balance on MP2:

$$MC_{p,MP2}\frac{dT_{MP2}^{n}}{\Delta t}=\dot{Q}_{MP2,decay}-\sum_{s\in seg}h_{MPs\rightarrow s}A_{s}\left(T_{MP2}^{n}-T_{s}\right)+h_{MP1\rightarrow MP2}A_{1,2}\left(T_{MP1}^{n}-T_{MP2}^{n}\right)-h_{MP2-fluid}A_{f}\left(T_{MP2}^{n}-T_{fluid}\right)-\sigma\varepsilon_{eff}A_{up}(T_{MP2}^{4}-T_{ambient}^{4})$$

- 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

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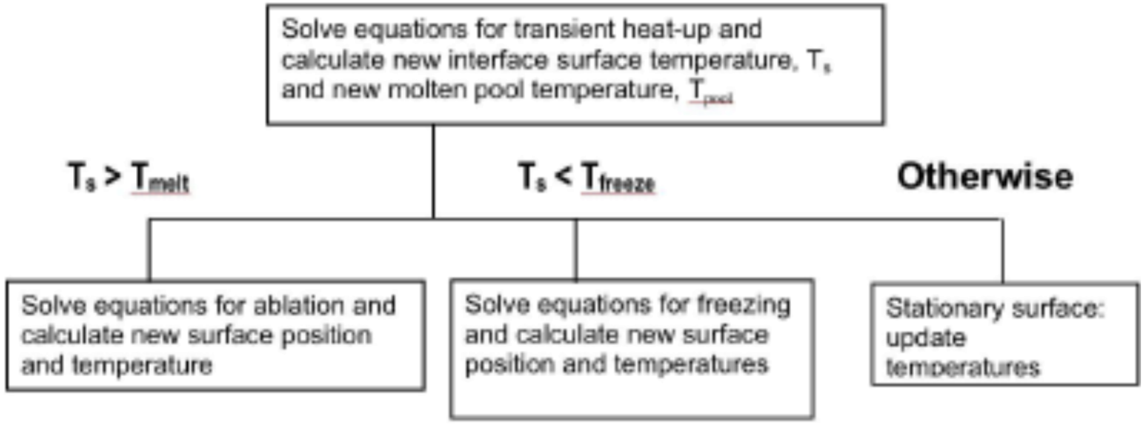
Integral Solution to Stefan Problem

- **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**



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MELCOR Lower Head Failure Models

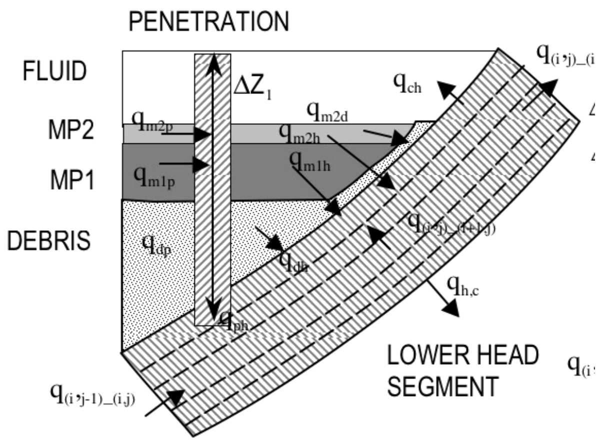
- **Failure based on Robinson's Rule, i.e., lifetime rule from Larson-Miller parameter**
- **Two models are available in MELCOR:**
  - **Zero-Dimensional Model**
    - **Default Model**
  - **One-Dimensional Model**
    - **Selected by setting sensitivity coefficient SC1600(1) = 1**
    - **Recommended 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**

One- Dimensional Model

- Larson-Miller Parameter evaluated at local temperature through vessel wall.
- Larson-Miller Parameter evaluated at local engineering hoop stress (initial geometry and time-dependent pressure load).
- Plastic strain determined from Larson-Miller Parameter
- Local stress is limited to local ultimate (yield) stress and excess load is redistributed to other nodes.
- Stress is not uniform across the wall thickness.
- Local elastic strain and local elastic modulus used to determine local stress.
- Thermal strain is considered in determining stress redistribution.
- Total plastic strain varies across vessel wall. COR-VSTRAIN is the plastic strain
- Solved implicitly and iteratively

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

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**

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End of Lecture

CAV Package
Melt Coolability & Concrete Interactions

Presented by

MELCOR Development Team

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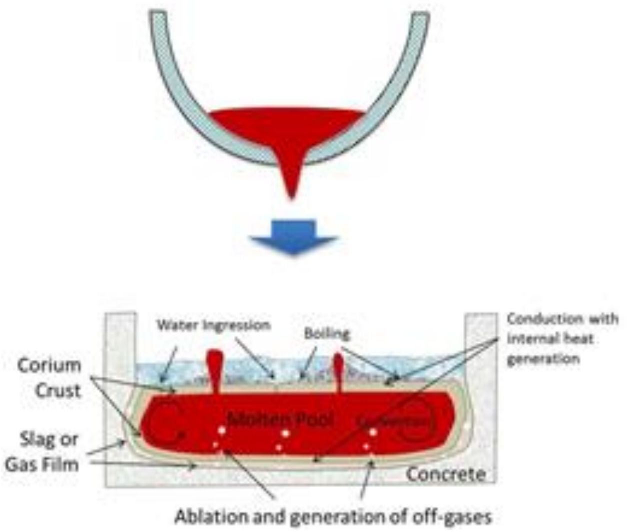
MELCOR/CORCON MCCI Models
Outline of Presentation

- **Overview of MCCI* models in MELCOR**
  - **How MELCOR models ex-vessel debris**
    - **Models inherited from CORCON-Mod3**
    - **Internal interfaces replace stand-alone input**
    - **Generalizations possible in MELCOR application**
    - **Limitations resulting from integration into MELCOR**
- **Details of phenomenological models**
  - **Debris geometry**
  - **Mass and energy transport and conservation**
    - **Concrete ablation**
    - **Chemistry**



*** "MCCI" is "Melt Coolability and Concrete Interactions"**

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MELCOR/CORCON MCCI Models
Physical Processes

- **Debris ejected from vessel attacks concrete**
  - **Attack is primarily thermal: surface ablates**
    - **Concrete decomposes**
    - **Gases (H_2O and CO_2) interact with debris**
      - **Stir and mix it, enhance heat transfer**
      - **Are reduced by active metals to H_2, CO, and possibly C(c)**
      - **Drive release of fission products by reactive vaporization**
    - **Oxides (CaO, SiO_2, Al_2O_3, etc.) add to debris**
- **Top surface communicates with surroundings**
  - **Heat is lost by radiation, convection, or boiling**
  - **Gaseous reaction products pass to atmosphere**
- **Sustained by decay and chemical heat**
  - **Heat balance determines progression**

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MELCOR/CORCON MCCI Models Framework (1)

- MELCOR models based on CORCON-Mod3
  - Uses CCM3 routines for phenomenological models
    - Geometry, heat transfer, chemistry, concrete ablation
  - Obtains boundary condition and source data from other MELCOR packages rather than user input
    - Stand-alone options available (in MELCOR format)
  - Interface to VANESA preserved
    - VANESA is fission product release model
      - Implemented as part of the RN package
      - Separate scrubbing model replaced by general SPARC model
- MELCOR executive replaces top coding levels
  - Controls input, advancement, output
  - Input format consistent with other MELCOR packages
  - Allows integrated restart, plot, and fallback capabilities

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MELCOR/CORCON MCCI Models Framework (2)

- **Generalizations in MELCOR implementation**
  - Internally consistent calculation of boundary conditions
    - Volume conditions (pressure, temperature, and presence of water pool) respond to heat and gases
  - Calculate MCCI in more than one location
    - Allow cavity rupture/debris overflow between locations
- **Limitations in MELCOR integration**
  - CORCON does not use MELCOR elevation reference
    - Z is measured positive *downward*
  - Debris doesn't displace water or gases
  - Hydrodynamic fluids don't "see" concrete
  - Some CORCON user "flexibility" inputs are not accessible
    - These are connected only as a need is perceived

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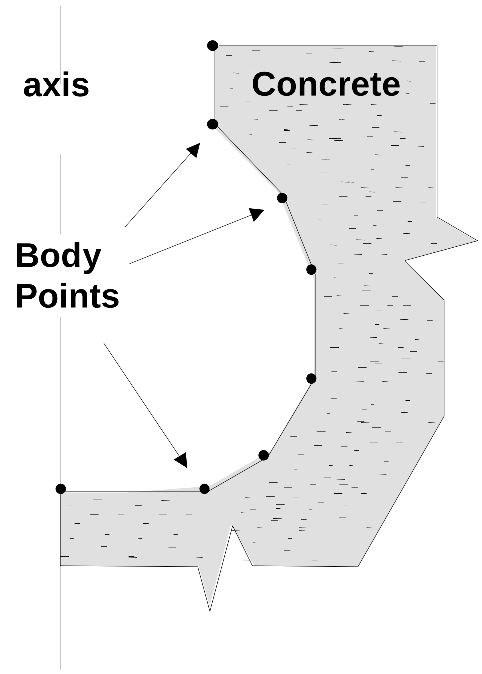
MELCOR/CORCON MCCI Models
Concrete Cavity

- **Domain of MCCI model is a concrete "cavity"**
  - Axisymmetric shape defined by a series of "body points"
  - Flexible definition of concrete properties
  - Contains debris
- **Thermal attack on concrete**
  - Shape changes as concrete erodes
  - Ablated oxides added to debris
  - Evolved gases (H_2O and CO_2) stir debris, react with it (producing H_2 and CO), and rise to surface



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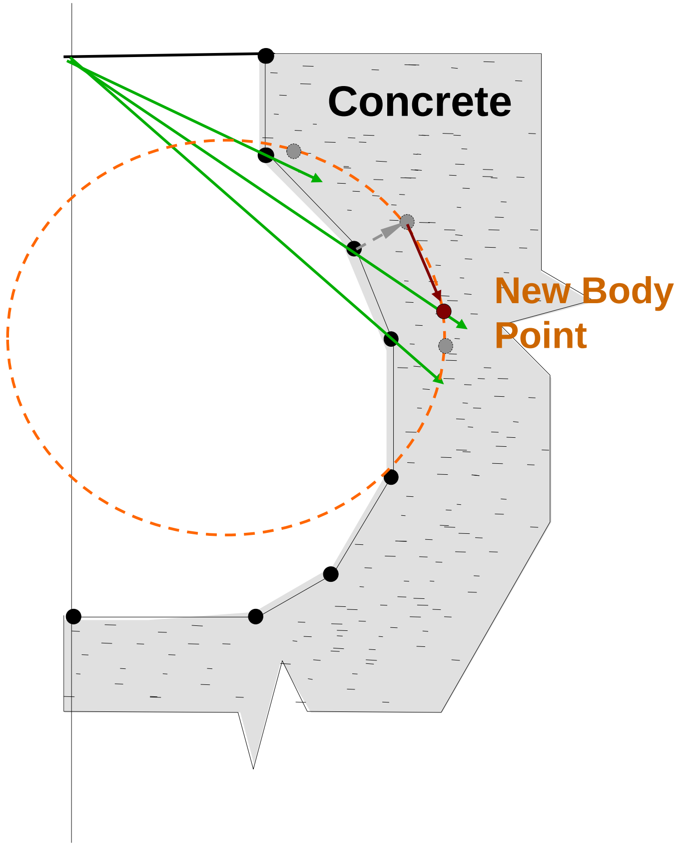
MELCOR/CORCON MCCI Models
Cavity Shape Changes

- Guiding rays emanate from origin on the vertical axis to body points at start of calculation.
  - Exception is the tangent ray
- Assume that concrete recession follows local normal
  - Calculated as bisector of angle formed by lines from the body point to nearest neighbors
- Resulting surface points are projected back onto guiding rays
  - Circle passed through receded point and its two nearest neighbors. Intersection of ray and circle defines new body point



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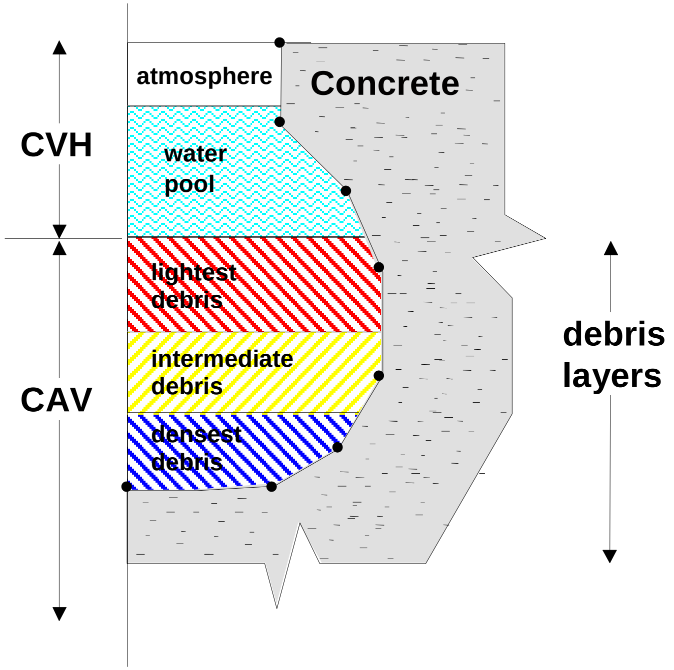
MELCOR/CORCON MCCI Models
Cavity Contents

- **Debris and fluids in cavity**
  - **Debris treated by MCCI models**
    - **May be stratified by density**
  - **Pool, atmosphere treated by CVH hydrodynamic models**
  - **Limited interfaces**
    - **CVH defines upper boundary conditions for debris**
      - Temperature, pressure, water
      - Sink for heat and evolved gases
    - **CVH "sees" nothing else**
      - No thermal interaction with concrete wall
      - No volume displaced by debris
      - No volume change by concrete ablation



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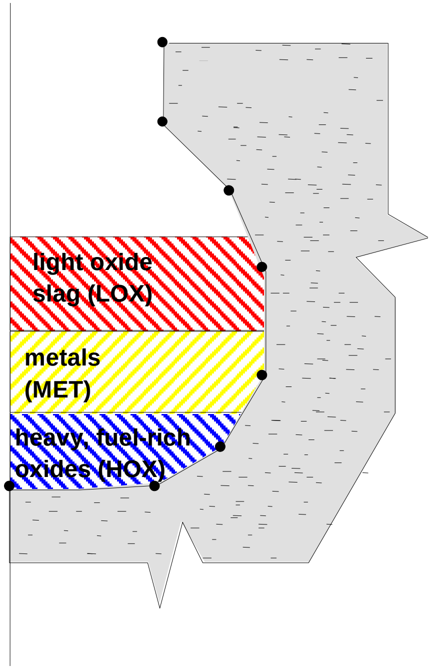
MELCOR/CORCON MCCI Models
Debris Layering and Mixing (1)

- CORCON-Mod2 considered only complete stratification
  - Assumed immiscible metals and oxides
  - Allowed one to three layers
    - Oxide slag layer above metals (LOX)
    - Unoxidized metal layer (MET)
    - Possible denser, fuel-rich oxide layer below metal (HOX)
  - If HOX became less dense than MET (by dilution), debris "flipped"
    - Instantaneous combination of HOX and LOX into LOX



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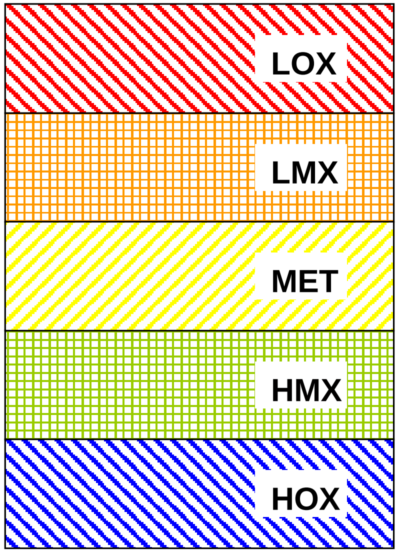
MELCOR/CORCON MCCI Models
Debris Layering and Mixing (2)

- **Structure of CORCON-Mod2 allowed mixed layers, but there were no mixing models**
- **CORCON-Mod3 added mixing models**
  - **Two distinct mixing processes considered**
    - **Metal entrained by rising gases into lighter slag to form a “light mixture” (LMX)**
    - **Heavy (fuel) oxides entrained into metal to form a “heavy mixture” (HMX)**
  - **Mechanistic models for rates**
    - **Balance between entrainment and separation under gravity determines degree of mixing**
- **Density Stratification**
  - **HOX>HMX>MET>LMX>LOX**

Density Stratification

Note: some layers may not co-exist. This graphic is intended just to show density variation



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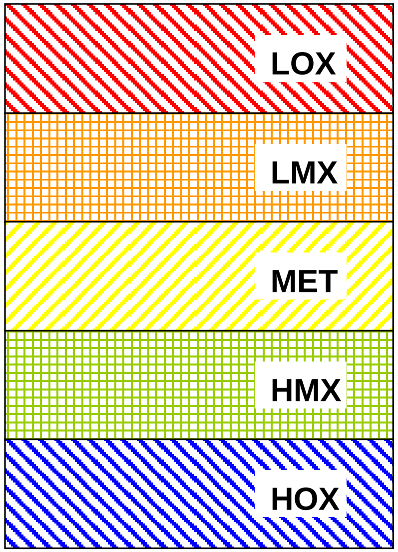
MELCOR/CORCON MCCI Models
Debris Layering and Mixing (3)

- **Possible transport of metals**
  - Entrain from MET or HMX into LMX
    - Can have LMX or LOX, but not both
    - Limit is complete mixing of metals into LMX
- **Possible transport of dense oxides**
  - Entrain from HOX into HMX or LMX
    - Can have HMX or MET, but not both
    - Limit is complete mixing of dense oxides into HMX
- **Many possible debris layerings**
  - Two possibilities for complete mixing
    - Metal-in-light-oxide (LMX)
    - Heavy-oxide-in-metal (HMX)
  - Eight 2- or 3-layer configurations

Density Stratification

Note: some layers may not co-exist. This graphic is intended just to show density variation



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MELCOR/CORCON MCCI Models
Mixing Options

- MELCOR allows three options
  - Enforced Mixing (MELCOR default)
  - Enforced Stratification (as in CORCON-Mod2)
  - Mechanistic Mixing
    - Eliminates "Layer Flip"
  - Calculation of mechanistic mixing rates

Numerical treatment of mechanistic mixing

Use analytic solution, for instantaneous separation rate and entrainment rate at start of step

$$M_D(t) = M_D(0) + \left[M_D^{ss} - M_D(0)\right]\left(1 - e^{-t/\tau_s}\right)$$

Expressed in terms of steady-state droplet mass and time constant for separation

$$M_D^{ss} = \dot{m}_e(0)\tau_s \quad , \quad \tau_s \equiv \frac{L}{v_{settl}}$$

L = thickness of the mixed layer

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MELCOR/CORCON MCCI Models
Heat Transfer

- **Three heat transfer mechanisms within debris**
  - **Natural convection**, based on conventional correlations
  - **Conduction**
  - **Bubble-enhanced convection**, using Kutateladze and surface renewal models
- **Other heat transfer models**
  - **Convection and radiation, or boiling at top surface**
    - **Bubble-enhanced boiling uses Greene correlation**
  - **Added thermal resistance of film adjacent to concrete**

Bubble-enhanced convection

Nusselt (characteristic length, a)

$$Nu_a = 1.5 \cdot 10^{-3} Ku^{2/3} f(\eta)$$

$$f(\eta) = \begin{Bmatrix} 1, if \ \ \eta \le 1 \\ \eta^{-1/2} \ \ if \ \ \eta > 1 \end{Bmatrix}$$

Where a is the Laplace constant

$$a = \left\{ \frac{\sigma_l}{g\left(\rho_l - \rho_g\right)} \right\}^{1/2}$$

Ku is the Kutateladze number

$$Ku = \frac{\Pr p \ j_g}{g \ \mu}$$

With dimensionless gas velocity

$$\eta = \frac{j_g}{V_{tr}}$$

Transition Velocity

$$V_{tr} = 4.0 \cdot 10^{-4} \sigma_l / \mu_l$$

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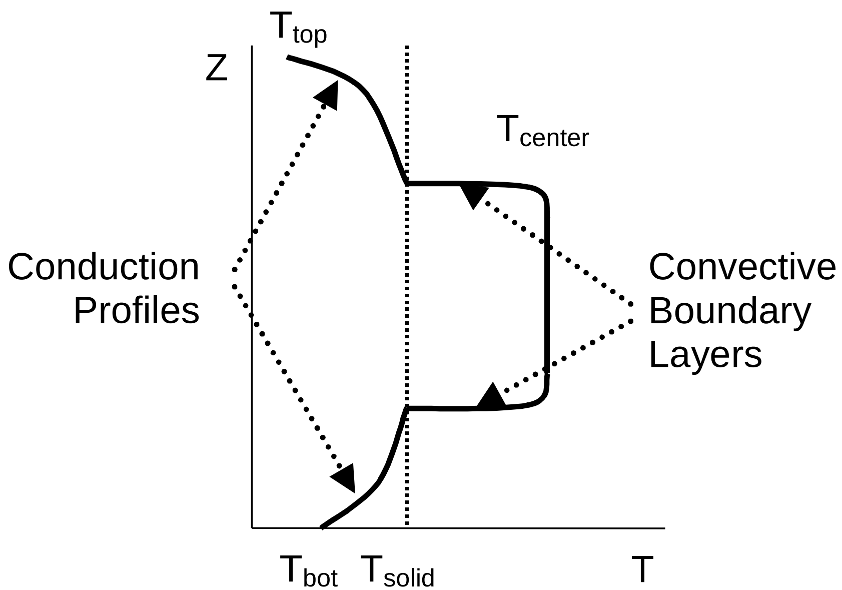
MELCOR/CORCON MCCI Models
Heat Transfer Within a Layer

- **Code determines quasi-steady axial (shown) and radial temperature profiles**
  - **Known average temperature**
  - **Conduction below solidus temperature, thin boundary layers in liquid center**
  - **Constant divergence of heat flux**
  - **Superposition of 1-D axial and radial transfers**
- **Iterate to match boundary conditions**



MELCOR/CORCON MCCI Models
Heat Transfer to Concrete (1)

- **Film of concrete decomposition products between debris and concrete adds resistance**
  - **CORCON-Mod2 assumed gas film (MELCOR default)**
  - **CORCON-Mod3 allows slag film**

Slag film model

- **Model motivated by Epstein analysis for debris on steel**
  - **Transient conduction in three or four layers: molten debris, possible solid debris, molten concrete, concrete**
- **Bradley observed that total calculated resistance, melt to concrete is well fit by**

$$\frac{1}{h_{overall}} = \frac{1}{h_{melt}} + \frac{1}{h_{slag}} = \frac{1}{h_{melt}}\left(1 + \frac{h_{melt}}{h_{slag}}\right) \approx \frac{1}{0.29\, h_{melt}}$$

- **Thus, the slag film model reduces to**

$$h_{slag} = 0.41 h_{melt}$$

where h_{melt} is calculated from the bubble-enhanced or natural convection models used within molten debris

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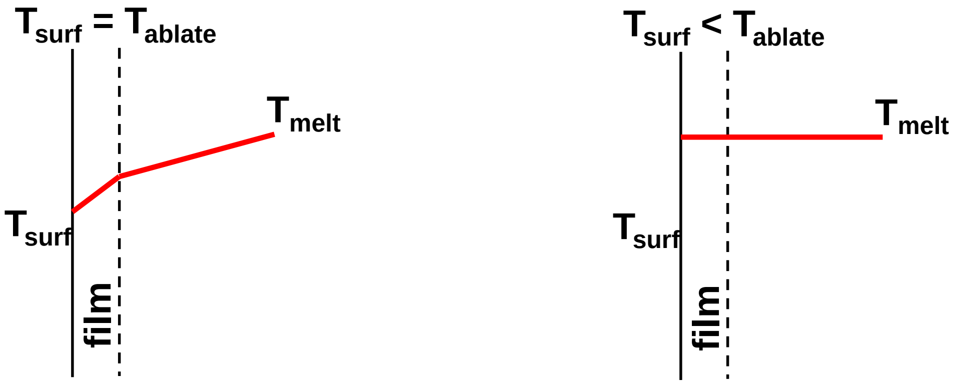
MELCOR/CORCON MCCI Models
Concrete Ablation

- **CORCON considers only ablation of concrete**
  - **No precursor heating or decomposition**
  - **Valid for modest ablation rates**
    - **Thermal penetration length $\ell \sim \alpha / v_{ablation}$**
      - **On the scale of the aggregate**
  - **Heat to concrete is determined by continuity of heat flux**
    - **Concrete surface temperature is $T_{surface} \leq T_{ablation}$**



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Concrete Ablation (2)

- Heat flux defines ablation rate

$$\dot{q}'' = \rho h_{ablation} \dot{s}$$

- $T_{ablation}$ and $h_{ablation}$ are properties of the concrete
- Heat flux is 0.0 if $T_{surface} < T_{ablation}$

— Ablation rate determines gas generation rate

- Affects all heat transfer coefficients, requiring iteration

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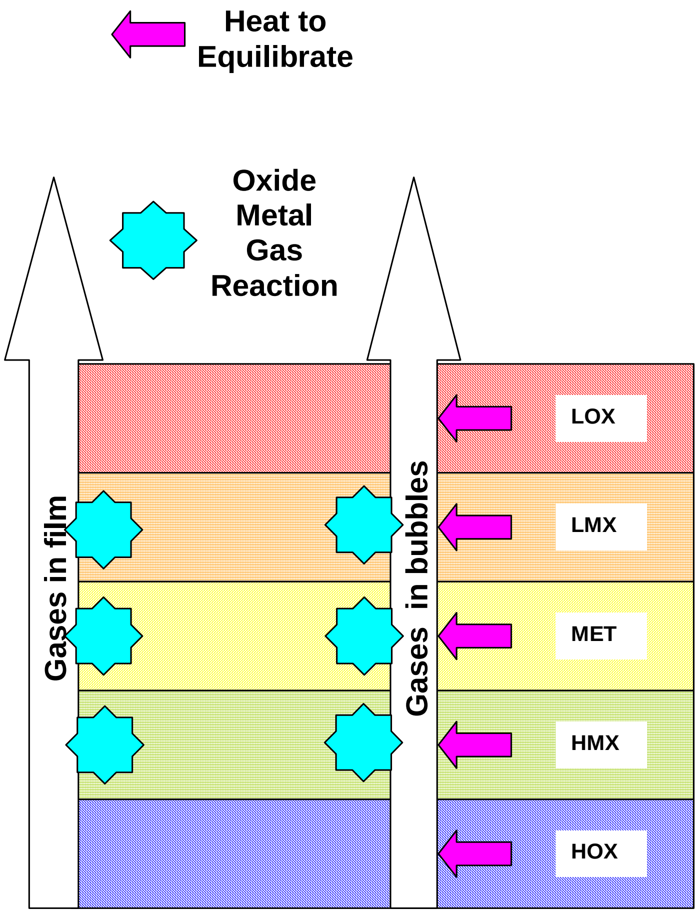
MELCOR/CORCON MCCI Models
Mass/Heat Transfer: Gases

- **Gases leave concrete as H_2O and CO_2**
  - **Some pass through the film between debris and concrete**
    - **Assumed to enter at the average film temperature (which is essentially the ablation temperature)**
    - **React with metals in the debris, at the average debris surface temperature**
  - **Some pass through the debris**
    - **Enter at the average film temperature, thermally equilibrated with debris**
    - **React with metals in the debris, at the average debris layer temperature**



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MELCOR/CORCON MCCI Models Chemistry

- CORCON calculates chemical equilibrium
  - Algorithm
  - Two reaction Locations
- Two options
  - CORCON-Mod2
  - CORCON-Mod3 (MELCOR default)

CORCON-Mod3 Chemistry

- Metal/gas/oxide Equilibration
  - For reaction in MET, reactants are local metals and gases, and any rising oxides; product oxides rise to next oxide-containing layer
  - For reactions in HMX or LMX , reactants are local metals, gases, and oxides
  - Dilution (entropy of mixing) can greatly reduce oxide activity (chemical potential

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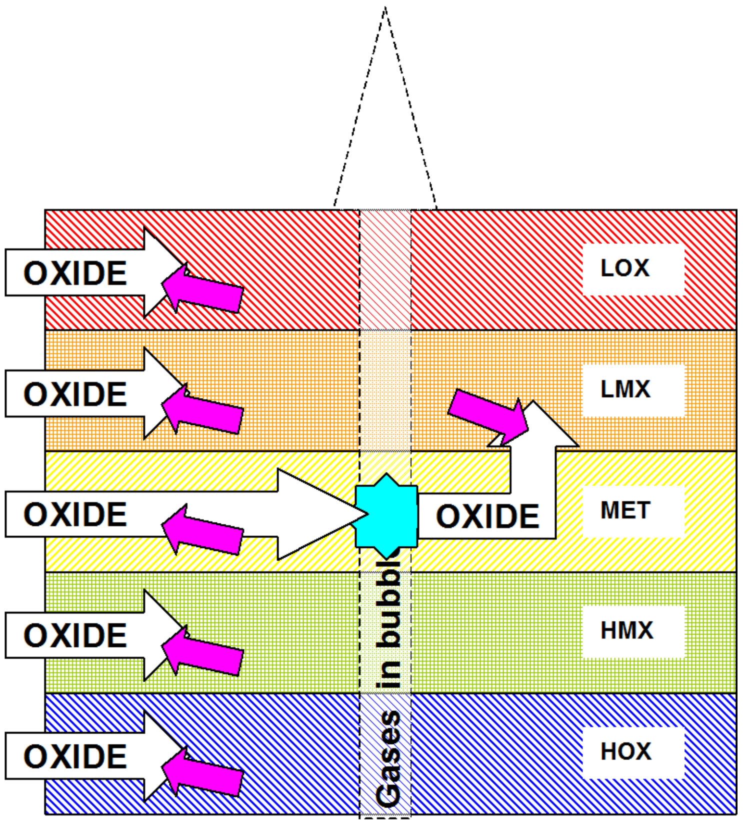
MELCOR/CORCON MCCI Models
Mass/Heat Transfer: Metals & Oxides (1)

Condensed oxides from ablated concrete

- Enter debris at concrete ablation temperature, brought to temperature of ablating layer
- If entering HOX, HMX, LMX, or LOX, added to layer
- If entering MET, rise to become part of LMX or LOX
  - Additional heat transfer



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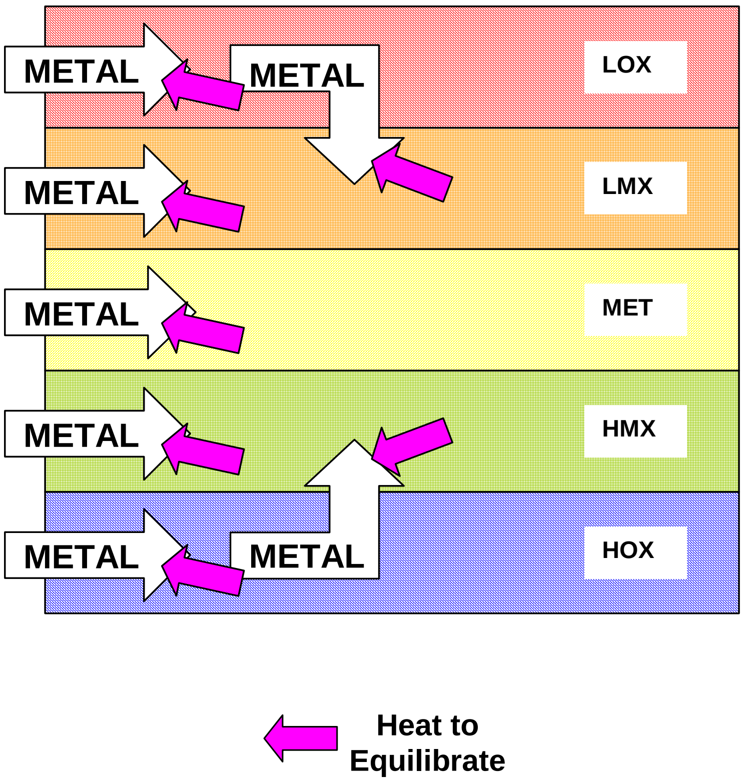
MELCOR/CORCON MCCI Models
Mass/Heat Transfer: Metals & Oxides (2)

- **Condensed metals (rebar) from ablated concrete**
  - **Enter debris at concrete ablation temperature, brought to temperature of ablating layer**
  - **If entering HMX, MET, or LMX, added to layer**
  - **If entering LOX, sink to become part of MET or HMX**
    - **Additional heat transfer**
  - **If entering HOX, rise to become part of MET or LMX**
    - **Additional heat transfer**



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MELCOR/CORCON MCCI Models
Mass/Heat Transfer: Metals & Oxides (3)

- **Core debris (from COR, FDI, or input file)**
  - **Sinks to become part of first suitable layer**
  - **Equilibrated with every layer encountered**
  - **Definition of initial temperature is subtle**
    - **CORCON has independent thermal equations of state, phase diagrams**
    - **Enthalpy may differ from that in source package**
    - **Can match source temperature or enthalpy, not both**
  - **Attempt to match sensible heat and latent heat**
    - **Liquid and solid materials added separately**
    - **Each assigned enthalpy from (possibly extrapolated) CORCON equation of state for same state**

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MELCOR/CORCON MCCI Models
Debris Spreading

- **Internal calculation**
  - **Simple analytic form**
  - **"MODEL" option (default)**

$$R(t) = \sqrt[8]{R(t_0)^8 + C_1 \frac{\rho g}{\mu \pi^2} V^3 (t - t_0)}$$

- **User-defined maximum radius of debris bed**
  - **Specified as function of time by tabular function, control function, or external data file**
  - **If current radius is less than cavity radius, radial surface is considered adiabatic**
    - **Standalone CORCON-Mod3 allows heat transfer to water**

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MELCOR/CORCON MCCI Models Thermochemical Properties

- **CORCON needs chemical potential (Gibbs function) as well as thermal equation of state**
  - **Does not use MELCOR material properties**
  - **Internal properties based on fits to specific heat**

$$c_P(T) = A + 10^{-3}\frac{B}{T} + 10^{-6}CT^2 + 10^5\frac{D}{T^2}$$

  - **Integrals (in analytic form) provide enthalpy and Gibbs function**

$$h(T) = h(T_0) + \int_{T_0}^{T} dT'\, c_P(T')$$

$$g(T) = h(T) - Ts(T) \quad , \quad s(T) = s(T_0) + \int_{T_0}^{T} dT'\, c_P(T')/T'$$

  - **Tables of coefficients and integration constants**
    - **More than one temperature range for some materials**
    - **Discontinuities define phase changes**

MELCOR/CORCON MCCI Models
Other Materials Properties

- **Density**
  - **Constant expansion coefficient for condensed materials**

    $$v(T) = v(T_0)[1 + c(T - T_0)]$$

  - **Ideal gas law for gases**
- **Viscosity**
  - **Andrade form**

    $$\mu = \mu^0 e^{\alpha/T}$$

- **Thermal conductivity and surface tension**
  - **Tabulated constants**
- **Emissivity**
  - **User input**

MELCOR/CORCON MCCI Models
Mixture Properties

- **Density**
  - **Mass-weighted specific volume**
- **Thermal conductivity, surface tension**
  - **Mole-weighted average**
- **Viscosity**
  - **Iron viscosity used for all metals**
  - **FeO, Al_2O_3, UO_2, CaO, ZrO_2, Cr_2O_3 implemented for oxides**
    - **ZrO_2 and Cr_2O_3 by analogy with UO_2 and FeO**
  - **Kendell-Monroe expression used for low-SiO_2 oxides**

$$\mu = \left(\sum_i x_i \, \mu_i^{1/3} \right)^3$$

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MELCOR/CORCON MCCI Models
Mixture Properties (2)

- Shaw correlation used for high-SiO2 oxides

$$\mu = \exp\left[s\left(\frac{10^4}{T} - 1.50 \right) - 6.40 \right]$$

- **Viscosity enhancement multiplier for presence of solids**
  - Kunitz correlation (default)

$$\mu = \mu_m \left[\frac{1 + \phi / 2}{(1 - \phi)^4} \right]$$

  - Ramacciotti (new)

$$\mu = \mu_m e^{2.5 C \phi}$$

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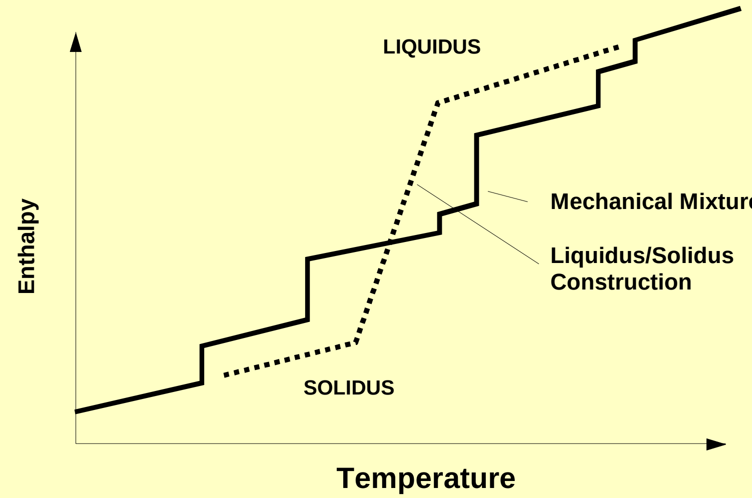
MELCOR/CORCON MCCI Models Phase Diagrams

- CORCON has very **simple phase diagrams**
  - See CORCON-Mod3 Manual for details
- **Neglects** many species and interactions
- Only effect considered is on **melt range**



- Extrapolate solid and liquid enthalpies if necessary
- Add latent heat, linear with temperature, between solidus and liquidus

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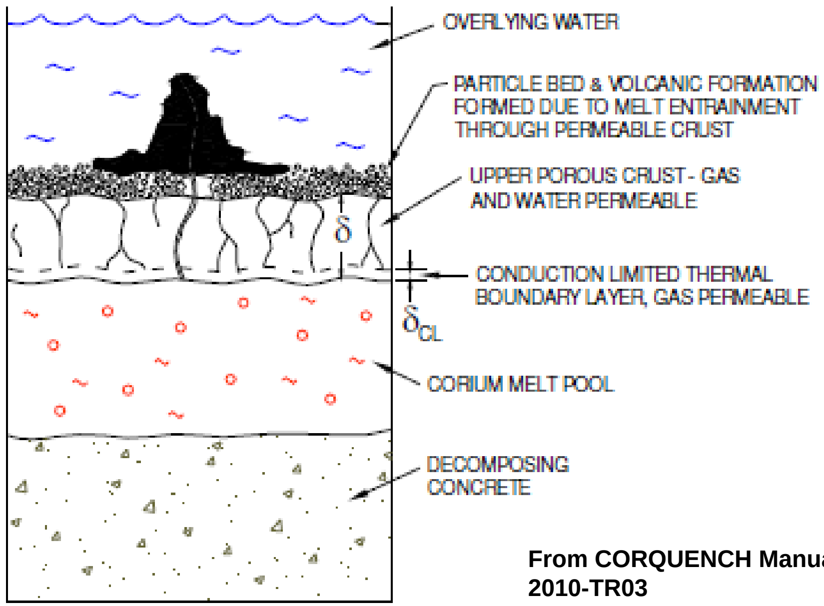
New Models from CORQUENCH

- **MCCI results indicate two new effects**
  - Water ingress into top crust
  - Melt eruption through top crust forming debris layer



From CORQUENCH Manual OECD/MCCI-2010-TR03

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New Models (2)

- **Implemented as new layers in CAV**
- **Water-permeable top crust layer**
  - —Rate of growth, conduction zone thickness from Epstein, "Dryout Heat Flux During Penetration of Water Into Solidifying Rock" (2006)
- **Debris layer**
  - —Formed with user-input debris size, void fraction
  - —Entrainment rate from Ricou-Spalding correlation

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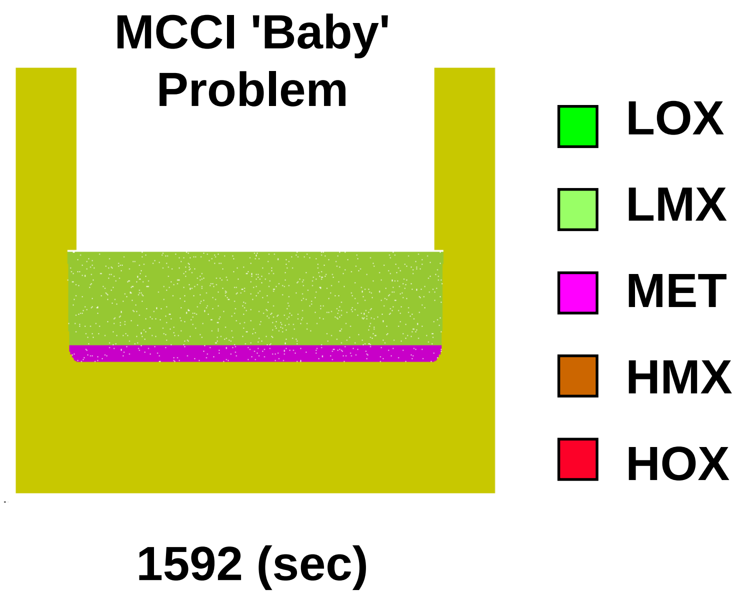
MELCOR/CORCON MCCI Models Demonstration 'Baby' Problem

- **Initial Inventory**
  - Oxides (TEMP = 2300.)
    - UO2 1.0E5
    - ZRO2 2.0E4
    - FEO 5.0E4
  - Metals (TEMP = 2300.)
    - ZR 1.0E4
    - FE 7.0E4
    - CR 1.0E4
    - NI 6.0E3



- **Model Assumptions**
  - Limestone/common sand concrete
  - No reinforcing bar
  - Calculated mixing (not MELCOR default)
  - CORCON-Mod2 chemistry (not MELCOR default)

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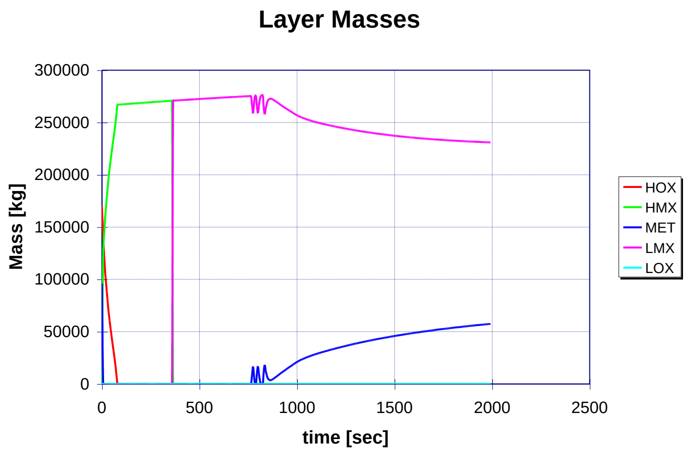
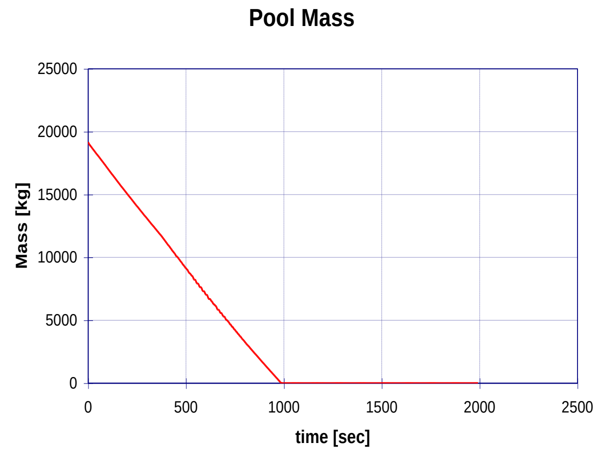
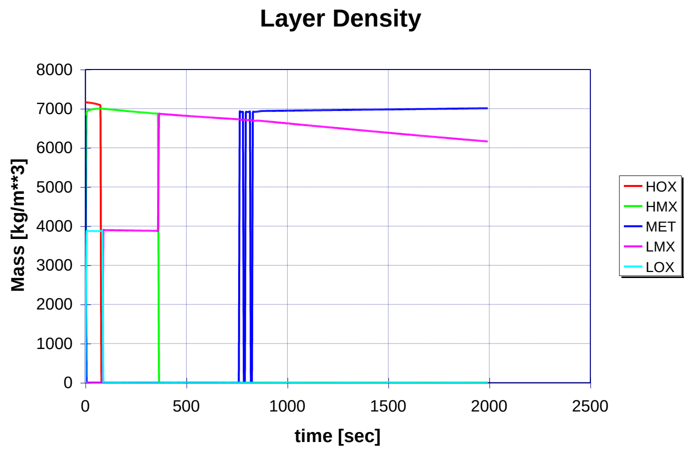
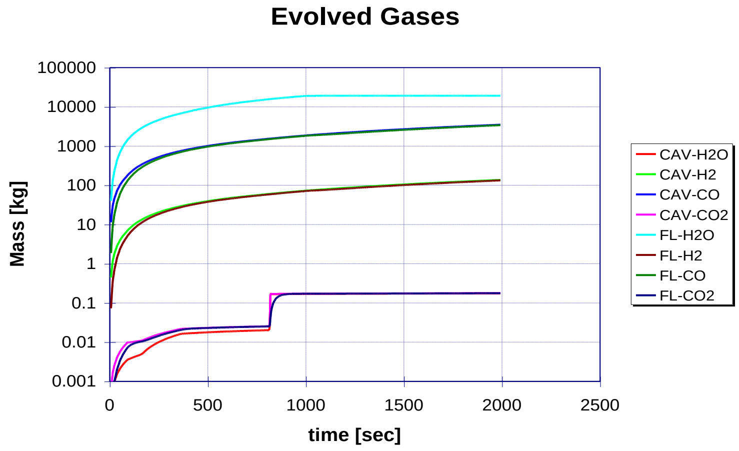
MELCOR/CORCON MCCI Models Examples: Base Case









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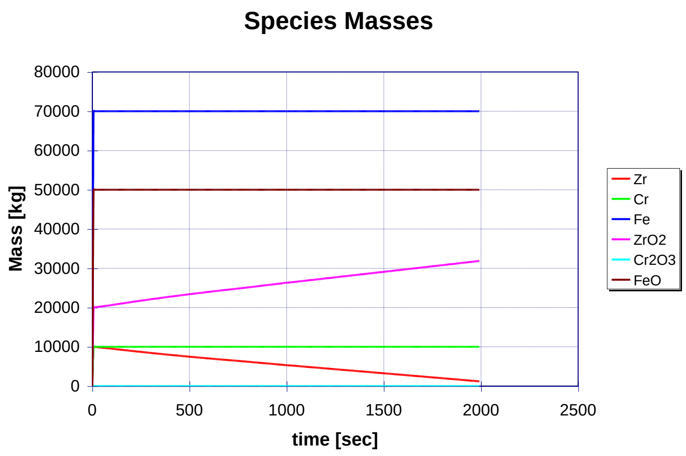
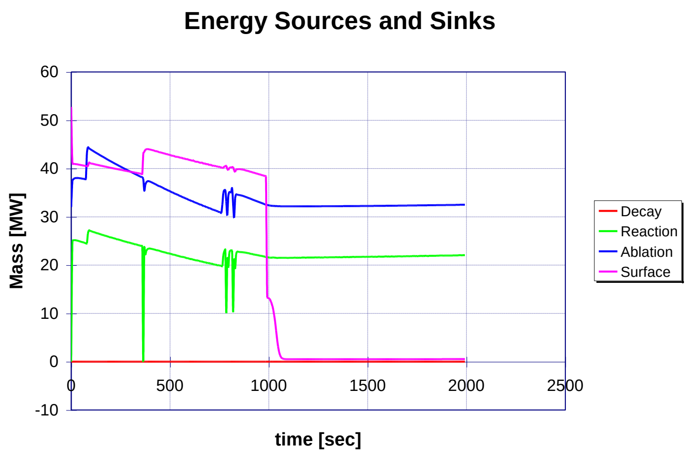
MELCOR/CORCON MCCI Models Examples: Base Case (2)





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The End

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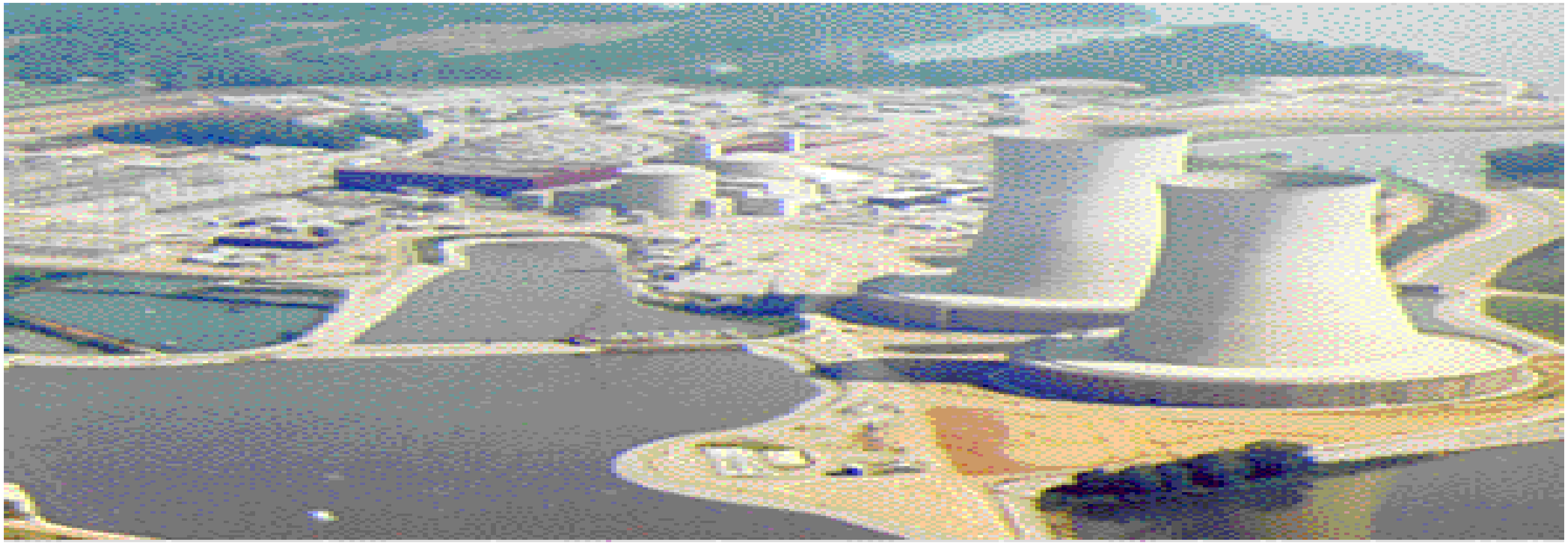
MELCOR RN and Decay Heat



Prepared by
MELCOR Development Team

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MELCOR RN and Decay Heat Overview of Presentation

- Describe relationship between RadioNuclide (RN) and Decay Heat (DCH) Packages
  - Emphasize significance of “reference” core
  - Discuss options to normalize “whole core” power
- Show example input
- Provide information necessary to add appropriate input to complete the input deck

MELCOR RN and Decay Heat Introduction

- **MELCOR intended to capture feedback effects**
  - —Coupling of temperatures, release rates, decay heating
  - —Relocation of heat sources, including deposition
- **Impossible unless radionuclides are tracked**
  - —Simple models tie decay heat to UO_2 in fuel and debris
- **If RN package is active**
  - —Decay heat package associates heat with RN classes
  - —Heat delivered according to location of radioactive masses

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MELCOR RN and Decay Heat Basic Approach

- **Define initial inventory of radioactive material**
  - Usually unreleased, within intact core
  - Can define elsewhere, including the debris in the cavity
- **Define specific decay power for RN classes**
  - Power, in W/kg, applied to class masses in each location
- **Define distribution of heat from radionuclides in various locations**
  - For unreleased, goes to core structures and/or debris
  - For airborne, part goes to surfaces
  - For deposited, part goes to fluids

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MELCOR RN and Decay Heat "Reference" Core

- Huge volumes of data associated with initial inventories and specific decay powers
  - Depend on core design, operating power, point in refueling cycle, and (in principle) on operating history
  - Specific decay power depends on time since shutdown
- MELCOR contains built-in data from ORIGEN calculations for two actual reactor cores
  - 3412 MWt Westinghouse PWR
  - 3578 MWt General Electric BWR
  - Each at four points in equilibrium fuel cycle
  - Full details about assumptions in the code manuals
- Initial inventory and decay power calculated from a constructed "reference" core

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MELCOR RN and Decay Heat "Reference" Core (2)

- Reference core normally defined by scaling built-in data, interpolating for point in cycle
  - Built-in data for the 29 "most important" elements
  - Built-in inventories normalized as $kg_{element}/W_{operating}$
    - Masses at time of shutdown
      - Appropriate to MELCOR treatment of classes
  - Total inventory calculated from operating power
    - Should be applicable to other cores of similar design
  - Built-in decay power for each element normalized as $W_{decay}/W_{operating}$ as function of (time- $t_{shutdown}$)
    - Each includes contribution of decay daughters
  - Scaled values should be applicable to similar cores
- User can also provide complete definition

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MELCOR RN and Decay Heat Class Decay Powers, Normalization

- **Class power defined from element powers**
  - **Recall default assignment of elements to classes**
- **"Whole-core" decay power in MELCOR is total power in the *reference* core**
- **Default for whole-core decay power is sum of the *default* class powers (from ORIGEN)**
  - **User input can modify default data for the reference core**
    - **Initial masses and/or decay curves for elements (change one of the 29 or add data for one or the others)**
    - **Assignment of elements to classes**
  - **If done, default is to normalize sum of *new* class powers to the *original* ORIGEN power**
  - **Otherwise, has no effect**

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MELCOR RN and Decay Heat Normalization of Whole-Core Power

- **User can specify an alternate normalization**
  - —ANS standard
    - Necessary parameters accessible through input or as sensitivity coefficients
  - —Tabular function of time
  - —Control function
- **This defines the total power in the reference core, *not* the total power delivered to the radionuclides in a MELCOR calculation**
  - —*If the inventories don't match, normalization won't help*

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MELCOR RN and Decay Heat Whole-Core Power for Uranium

- **Initial inventory of every class *except* Uranium defined by RN package input**
  - —With normal care, inventory corresponds to reference core
- **Initial inventory of Uranium (class 10) inferred from UO_2 masses on COR and CAV**
  - —Uranium mass, decremented by other fission products
  - —***Will not correspond to reference core***
    - ✶ Concentration of unstable isotopes in total uranium depends on power density
- **Total decay powers won't match**
  - —Normalization won't help
  - —Only complete solution is to modify the reference core

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MELCOR RN and Decay Heat Basic Whole-Core Power for Uranium (2)

- **Default will be to reconcile only class 10 (URANIUM)**
  - **This can be disabled, as we did in Exercise 5**

```
RN1_DCHNORM     ! Disable reconciliation of UO2
```

  - **Other classes can be reconciled also (use with care)**

```
RN1_DCHNORM 2 5 10 ! Reconcile classes 2, 5, 10
```

  - **Note that class mass represents *total* mass of *all* isotopes of *all* elements in the class, so as to calculate proper total aerosol mass and/or vapor density**

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MELCOR RN and Decay Heat
Decay Heat Package Input

- **Define Reactor Operating Power (only required input) if DCH is active.**

```
! Define reactor operating power (thermal)
DCH_OPW      3412.0E6
```

MELCOR RN and Decay Heat Decay Heat Package Input

- **Define reference core (all records optional)**

```
! Define reactor type
DCH_RCT  BWR     ! Options are BWR or PWR (default is PWR)
!
! Define point in refueling cycle (sensitivity coefficient)
DCH_SC 1
       1 3212 1.0 1 !Fraction of cycle elapsed (default 1.0)
!
! Define operating power (W) and split (optional)
!        U235     Pu239     U238      Total
DCH_FPW 2316.0E6 1111.4E6 150.6E6 ! 3578.0E6, default BWR
 . . .  2208.6E6 1059.8E6 143.6E6 ! 3412.0E6, default PWR
```

- **Define whole-core power (all records optional)**

```
DCH_DPW  ORIGEN  ! Options are ORIGEN (default), ANS,
!                    CF-nnn, and TF-nnn
! ANS option uses power split on DCH_FPW record
! Define operating time (s) for use in ANS option
DCH_OPT  5.05E7 ! 80% capacity for two years (default)
```

MELCOR RN and Decay Heat Decay Heat Package Input (2)

- **Specify whether to normalize total power in reference core to whole-core power**
  - Record is optional

```
!         RN Class Normalization Flag – Whole-core
DCH_NRM   YES        ! Options are YES (default) or NO
```

- **Define reactor shutdown time (two options)**

```
!         CF number, or negative to specify absolute time
DCH_SHT   CF ‘Scram’  ! Shutdown by LOGICAL CF ‘Scram’
!
DCH_SHT   TIME 1000.0 ! Shutdown at 1000.0 s (default is 0.0)
```

- **Other options to define/redefine elements, elemental decay heats, class membership**
  - New elements/classes to track trace materials in other models with standard definitions
  - Otherwise, only experts should attempt this method

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MELCOR RN and Decay Heat Initial Inventories

- **Initial RN inventories are defined by user input**
  - **In most cases, they are unreleased masses in intact core**
  - **Can also reside in initial cavity debris, or as initial aerosols or vapors in a variety of locations**
  - ***Unless all class inventories in a MELCOR calculation match those in the reference core, the total decay heat* will not *match the whole core decay power***
- **Comparison Table, by class, in output file**

```
RADIOACTIVE MASS COMPARISON WITH DCH - MASSES IN KG

 CLS    DCH        RN1 INVENTORY
     REF CORE   INITIAL    CURRENT

  1 3.611E+02 4.333E+02 4.333E+02
  2 2.012E+02 2.415E+02 2.415E+02
  3 1.584E+02 1.901E+02 1.901E+02
. . .
```

This case contains 120% of reference core

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MELCOR RN and Decay Heat Initial Inventories (2)

- **Unreleased fission products in intact core**
  - **Total defined for each core cell, with three options**
    - **Gap inventory is *included* in this total**
  - **Easiest to define in terms of fractions of reference core**
    - **Fraction defined as product of radial and axial shapes**
    - **If shapes are normalized, initial inventory will contain 100% of reference core**
  - **Can also define by reference to another core cell**
    - **Multipliers allow different cell sizes**
  - **Third option is to specify absolute mass, class by class**
    - **Very tedious to reconcile with reference core**

MELCOR RN and Decay Heat Input for Initial COR Cell Inventory

```
! Partial input for simple core
!   Fueled levels 4-7, relative powers 20%, 30%, 30%, 20%
!   Fueled rings 1-2, relative powers 60%, 20%
!      (fractions of power, *not* relative power densities)
!   Will define 100% of reference core since shapes normalized
!       Total Rows/Index
!       | Ring number (if>0) or Cavity input (if==0)
!       | | Axial Number/Cav Name
!       | | | Option flag: 0 or DH fraction of reference core
!       | | | |             (same fraction of all classes)
!       | | | |  First multiplier, typically axial fraction
!       | | | |  |     Second mult., typically radial fraction
!       | | | |  |     |
!       v | | |  |     |
RN1_FPN N v v v  vvvv  vvvv
        1 1 4 0  0.20  0.60  * 0.2*0.6 of total in cell 104
        2 1 5 0  0.30  0.60
. . . . . . . . . . . . . .
        5 2 4 0  0.20  0.40  * 0.2*0.4 of total in cell 204
        6 2 5 0  0.30  0.40
. . . . . . . . . . . . . .
```


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MELCOR RN and Decay Heat Input for Initial COR Cell Inventory (2)

- **More precise definition of distribution**

```
! Partial input for another core, cell by cell
!        Ring number (if>0) or Cavity input (if==0)
!        | Axial Number/Cav Name
!        | | Option flag: 0 or DH fraction of reference core
!        | | |             (same fraction of all classes)
!        | | |  Only product of multipliers is significant
!        V v v  VVVV  VVV
      n  1 4 0  0.13  1.0  ! 0.13 of total in cell 104
    n+1  1 5 0  0.17  1.0  ! 0.17 of total in cell 105
```

- **Other options (all input is additive)**

```
!       Core cell number
!       | | Option flag: 1 or Class - mass of individual class
!       | | |  Class Name (Option flag set to 1 activate
!       | | |  |            Class name input)
!       v v v  v   Mass and multiplier
    n   1 4 1 'Ag' 50.0 1.0   ! 50 kg Class 'Ag' in cell 104
!           Option flag: -1 for use of reference cell
!           vv  Reference Cell input activated (IR IA)
   n+4 2 4 -1  1 4  0.66667  1.0  * 2/3 RN mass in cell 104
```


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MELCOR RN and Decay Heat Initial Gap Inventories and Input

- **Gap inventory defined with two options**

```
! Class-by class input of cell fraction (default zero)
!        Table rows/index
!        |    Core cell number (IR IA)
!        |    |  Option flag:  1 or CLASS
!        |    |  |  Class name
!        |    |  |  |    Fraction of RN1_FPN in Gap
!        |    |  |  |    |      Ratio, total/radioactive
!        v    |  |  |    |      |    Required for class
RN1_GAP 12 !vvv  v vvvv  vvvvv  vvv
         1  1 4  1 'Cs'  0.05   1.0  * 5% cell Cs in gap
         . . .
! Multiplier on fractions defined for reference cell
!               Option flag: -1 or CELL for reference cell
!               |    Referenced Cell (IR IA)
!               |    |    Fraction multiplier
!               |    |    |        of reference cell
!               vvvv vvv  vvv
         n  1 5 CELL 1 4  1.0 * Use 1.0*fractions from 104
```


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MELCOR RN and Decay Heat Release Models

- Three basic release models, with options
  - CORSOR, fractional release rate = A exp(B T)
    - With or without correction for surface to volume ratio
    - Sensitivity coefficient arrays 7101, 7104, 7105
  - CORSOR-M, fractional release rate = k_0 exp(-Q/RT)
    - Extended in MELCOR 1.8.5 from the original form to include release of classes 7(Mo), 9(La), and 11 (Cd)
    - With or without correction for surface-to-volume ratio
    - Sensitivity coefficient arrays 7102, 7104, 7105
  - CORSOR-Booth, based on Cesium diffusion D_0 exp(-Q'/RT)
    - High- or low-burn-up fuel
    - Sensitivity coefficient arrays 7103, 7106, 7107
  - Modified CORSOR-Booth

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MELCOR RN and Decay Heat Release Models (2)

- **Option to apply to structural materials**
  - Not considered by default
  - Enabled by sensitivity coefficient array 7100
- **Simple input specifies basic option for fuel**
  - Various sensitivity coefficient arrays

```
! Input record is RN_FP00, record is optional
!       Option default =-5
!       vv
RN_FP00  -2    * -1 for CORSOR with surface/volume correction
!               +1 for CORSOR without S/V correction
!               -2 for CORSOR-M with S/V correction (default)
!               +2 for CORSOR-M without S/V correction
!               -3 for CORSOR-Booth, high-burn-up fuel
!               +3 for CORSOR-Booth, low-burn-up fuel
!               -5 for Revised CORSOR-Booth, high-burn-up fuel
!               +5 for Revised CORSOR-Booth, low-burn-up fuel
```


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MELCOR RN and Decay Heat
Other Release Models

- **Gap release based on cladding temperature**
  - Failure temperature can be defined cell-by-cell
  - Inventory in entire ring release on failure in any level

```
!          Table row/index
!          |   Core cell (IR IA)
!          |   |    Failure temperature (K)
!          vv  |    |
RN1_GAP00 12  vvv  vvvvvv
           1  1 7  1200.0  * Default is 1173.0 K
```

- **Class combination on release**
  - Not default, but conventional for Cs + I → CsI
  - Described in earlier presentation

```
* [Recombination name] [acceptor class] [number of donors]
RN1_CLS ‘Cs+I’ ‘CSI’ 2
      1 ‘Cs’   1.0    * Cs Class - donor class
      2 ‘I2’   0.5    * I2 Class - donor class
! Molecular weights in sensitivity coefficient array 7120
```


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MELCOR RN and Decay Heat Distribution of Power

- Energy carried by fragments, neutrons, α, β, and γ; each has a finite range
- Heat from unreleased radionuclides in fuel
  - —Split among core components and materials in same cell
  - —Defaults based on detailed calculations for a specific core
  - —Splits are user-adjustable (SC arrays 1321, 1322)
- Heat from radionuclides in pool goes to pool
- Heat from radionuclides in atmosphere
  - —By default, 50% (typical γ) to pool and other surfaces in volume, 50% (balance) to atmosphere--but see next slide
  - —Splits can be modified
  - —Atmospheres and structures in other volumes can be included

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MELCOR RN and Decay Heat Distribution of Power(2)

- Heat from radionuclides on structure surfaces
  - By default, 50% to surface, 25% (typical γ) to pool and other surfaces in volume, 25% (balance) to atmosphere
    - Splits can be modified
    - Atmospheres and structures in other volumes can be included
- Modification for small atmospheres
  - Range of βs may exceed volume dimensions, particularly for small volumes with low density atmospheres
  - Actual absorption modified, considering
    - Typical range of a β (1.2 kg/m^2, in SC array 7002)
    - Typical distance in atmosphere ($volume^{1/3}$, modifiable)
- Won't discuss this further

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MELCOR RN and Decay Heat
Other Input

- **Almost everything is adjustable through input or sensitivity coefficients**
  - —Definition and properties of elements
  - —Definitions and properties of classes (molecular weight, vapor pressure, etc.)
  - —Association of class numbers with chemical models
  - —Coefficients in most models and correlations, including release rates (CORSOR)
- **There are few, if any, checks on changes**
  - —It's easy to define things inappropriately
  - —It's hard to determine the cause of the problem
- **In general, best to accept the defaults**
  - —May not be possible in some cases, so *use great care*

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MELCOR Ex-Vessel Modeling Overview of Presentation

- **Give *brief* description of MELCOR modeling of ex-vessel phenomena**
  - **The modeling is specialized, and much of the input is boilerplate**
  - **We will only discuss input**
- **Provide example input for Transfer Process (TP) package that connects the pieces**
  - **The approach is simple, but unique to MELCOR, and tends to confuse new users**

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MELCOR Ex-Vessel Modeling

- Ex-vessel modeling involves three packages
  - Fuel Dispersion Interactions package (FDI) models various interactions of ejected debris
    - Receives debris from COR package
    - Uses two models, switch based on ejection velocity
  - Cavity package (CAV) models interactions of molten debris with concrete
    - Can receive debris directly from COR, or after interactions in FDI
    - Can involve multiple volumes, with transfer of debris based on overflow or erosion through separating concrete
  - Transfer Process package (TP) serves as interface
    - Standardizes format for “handoff” of material
    - Deals with data storage, fallback, and restart

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MELCOR Ex-Vessel Modeling Fuel Dispersal Interactions (FDI)

- **Modeling depends on debris ejection velocity**
  - Switch at ejection velocity of 10 m/s
    - Adjustable through sensitivity coefficient array 4602
  - "Low-pressure" option for low velocity
    - Based on gravitational fall of debris through water pool
    - Simple, integral model of droplet breakup and heat transfer, only input involves fall distance
    - Debris is passed to CAV when it reaches the floor
  - "High-pressure" option for high velocity
    - Parameterized model of high pressure melt ejection and "direct containment heating"
    - Models interactions of debris with atmosphere and deposition surfaces
    - User must specify distribution of debris

MELCOR Ex-Vessel Modeling
High Pressure Melt Ejection Model

- User input defines behavior of HPME model
- Partition debris among volume atmospheres, heat structure surfaces, cavity debris
  - Constant fractions, specified by user input
  - Partition is instantaneous (no flight time)
  - Debris in atmosphere transfers heat, oxidizes, and settles
    - Heat transfer, oxidation, settling rates controlled by user-defined time constants
    - User specifies heat structure surface or cavity for settled debris
  - Debris on heat structure surfaces transfers heat and oxidizes
  - Debris to cavity (directly, or via settling) is passed on to the CAV package

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MELCOR Ex-Vessel Modeling Transfer Process Utility (TP)

- **TP utility functions as a holding facility**
  - Material that can no longer be treated by some package (e.g., debris ejected from COR) is sent to TP
    - Referred to as an "IN" process
  - TP stores the parcel of material until it is called
    - Data include masses, thermodynamic variables, etc.
  - Another package (FDI or CAV) queries TP for waiting parcels, and receives them from TP
    - Referred to as an "OUT" process
    - The contents can be reinterpreted in the OUT process
  - If a large number of un-called-for parcels accumulates, TP will stop the calculation
- **Next slide shows the flow of COR material**

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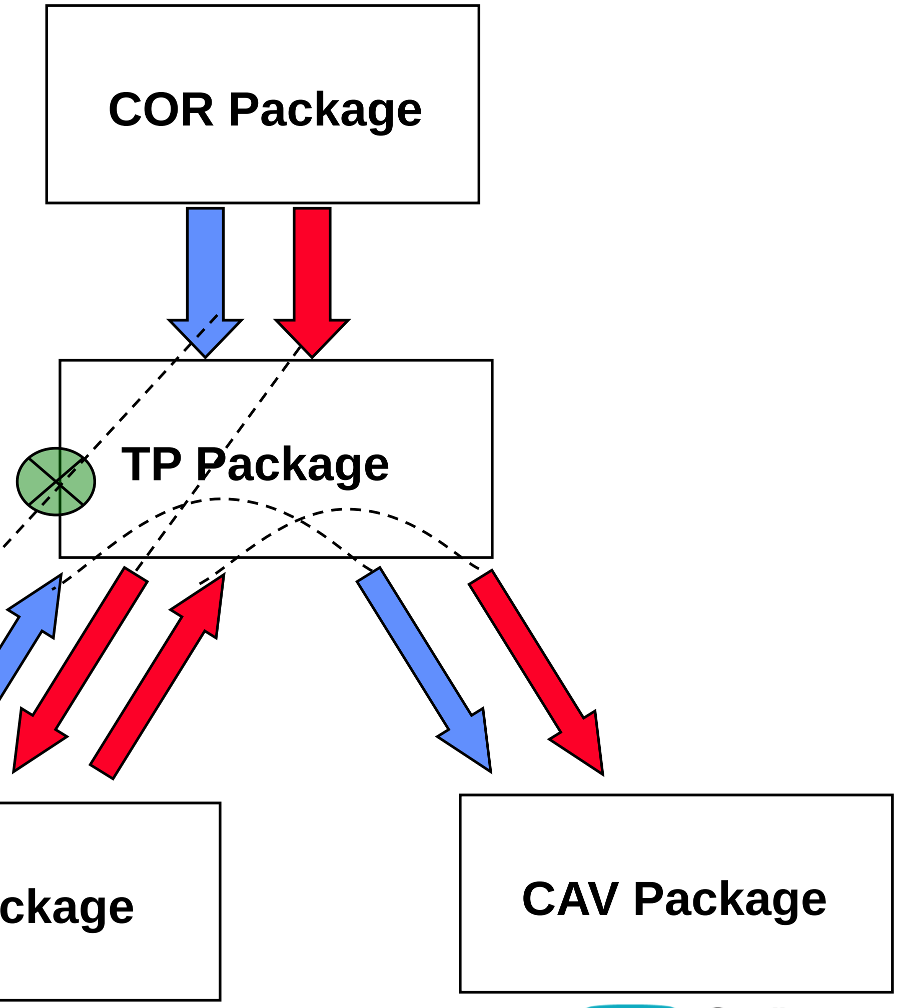
MELCOR Ex-Vessel Modeling Example TP Input

- **Information flow to model ex-vessel accidents**
  - Arrows Pointing to TP are TPIN
  - “” Pointing away TP are TPOUT
  - BLUE – Mass and Energy
  - RED – Accompanying RN products
  - RN must be On to include RN Transfers



MELCOR Ex-Vessel Modeling Example TP Input

```
!            NTPCOR    RNTPCOR   … etc.
COR_TP     'TP101'   'TP601'
! COR sends debris to IN process 'TP101'
! COR sends RN products to IN process 'TP601'
          NFDICV   NFDCAV CAVNAM . . . . . . .
FDI_LOC   CVName    CAV    CAVName …Continued…
TPINAM    RNTPOT   TP
'TP103'   'TP102' 'TP603'   'TP602'
!             NTPOT    RNTPOT
CAV_TP     'TP104'   'TP604'
! Definition of associated "IN" process
TP_IN 4 !Name    Source
      1 'TP101' COR
      2 'TP601' RNCOR
      3 'TP103' FDI
      4 'TP603' RNFDI
! "IN" process 'TP101' is connect to "OUT" process 'TP102'
TP_OUT 4 !TPOUT   TPIN    OutMatrix Number of Masses
       1 'TP102' 'TP101' UIN103    5  ! UO2,Zr,Steel,ZrO2,St.Ox
       2 'TP104' 'TP103' DEF1      5
       3 'TP602' 'TP601' DEF1      17
       4 'TP604' 'TP603' DEF1      17 ! Number of RN/DCH Classes
```

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MELCOR Ex-Vessel Modeling
Example TP Input (2)

- **Transfer Matrix**

```
!
! Vector of masses transformed by matrix UIN103 in the process
!                                       ******                         ******
!               Row   Col               *Mass*                         *Mass*
TP_MTX UIN103 6    5                    *Out *    *  TP_MTX *    * IN  *
1  1.0 0.0 0.0 0.0 0.0 0.0             *UO2 *    1 0 0 0 0 0    *UO2 *
2  0.0 1.0 0.0 0.0 0.0 0.0             * ZR *    0 1 0 0 0 0    * ZR *
3  0.0 0.0 1.0 0.0 0.0 0.0             * ST * =  0 0 1 0 0 0 X  * ST *
4  0.0 0.0 0.0 1.0 0.0 0.0             *ZRO2*    0 0 0 1 0 0    *ZRO2*
5  0.0 0.0 0.0 0.0 1.0 0.0             *STOX*    0 0 0 0 1 0    *STOX*
!                                       ******                   *Pois* (B4C)
!                                                                ******
```


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