Exceptional service in the national interest

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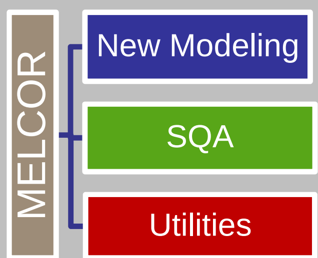

MELCOR Code Development Status

Presented by Larry Humphries

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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MELCOR Code Development

- MELCOR is developed by:
  - US Nuclear Regulatory Commission
  - Division of Systems Analysis
- MELCOR Development is also strongly influenced by the participation of many International Partners through the US NRC Cooperative Severe Accident Research Program (CSARP)
  - Development Contributions – New models
  - Development Recommendations
  - Validation

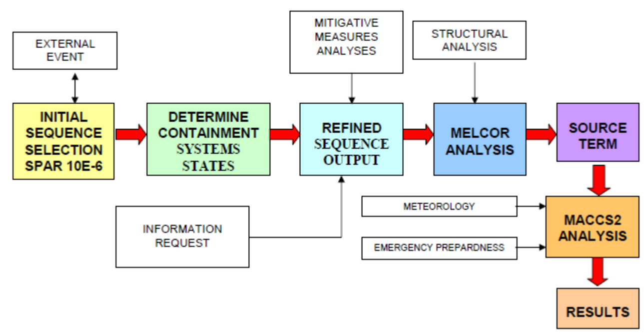
What is the MELCOR Code

- Designed for reactor severe accident and containment DBA simulation
  - PWR, BWR, HTGR, PWR-SFP, BWR-SFP
- Fully Integrated, engineering-level code
  - Thermal-hydraulic response in the reactor coolant system, reactor cavity, containment, and confinement buildings;
  - Core heat-up, degradation, and relocation;
  - Core-concrete attack;
  - Hydrogen production, transport, and combustion;
  - Fission product release and transport behavior
- Desk-top application
  - Windows/Linux versions
  - Relatively fast-running
  - SNAP for post-processing, visualization, and GUI

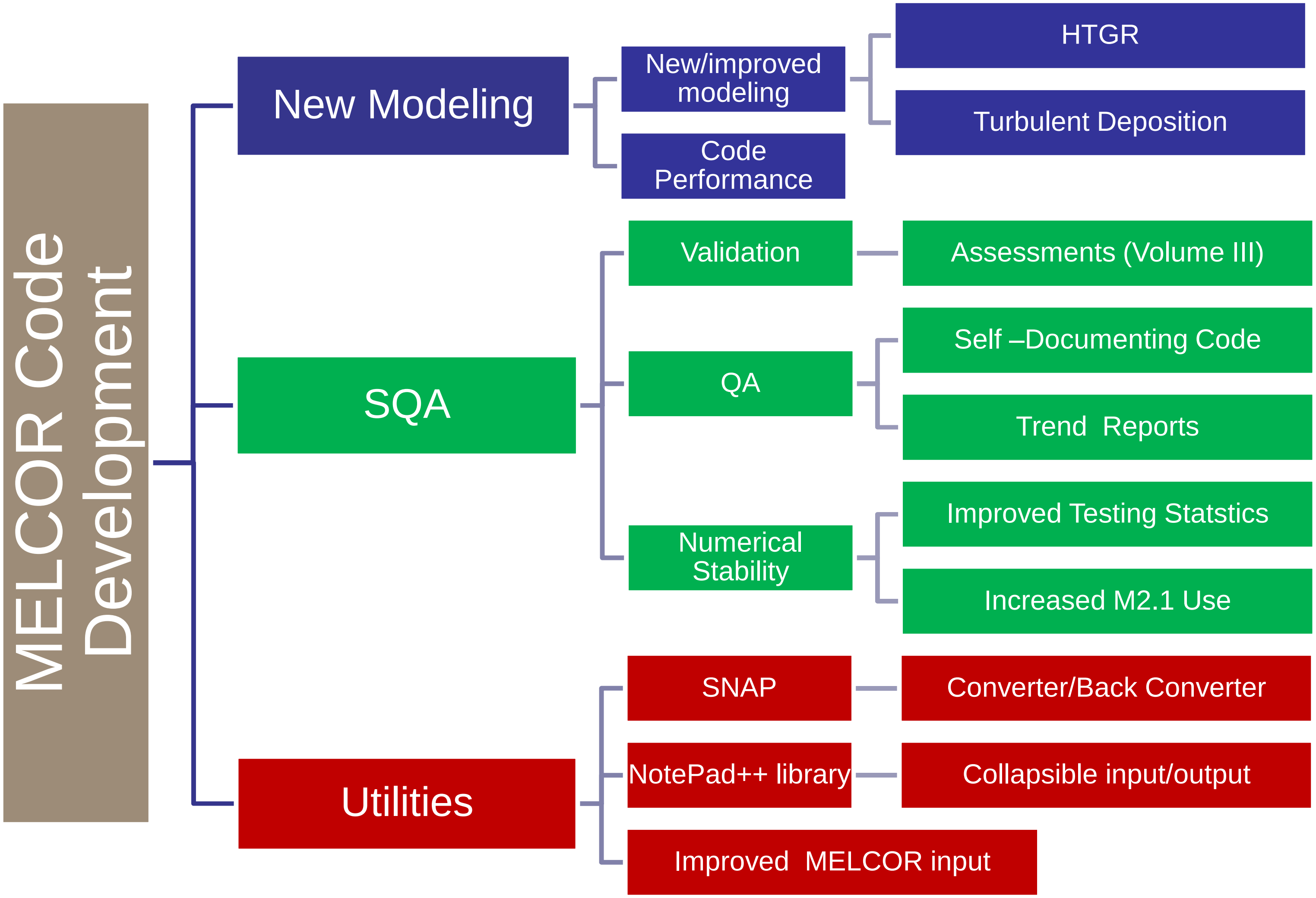
MELCOR Applications

- Forensic analysis of accidents – Fukushima, TMI, PAKS
- State-of-the-art Reactor Consequence Analysis- SOARCA
- License Amendments
- Risk informed regulation
- Design Certification
- Preliminary Analysis of new designs
- Non-reactor applications
  - Leak Path Factor Analysis

SOARCA PROCESS



MELCOR Code Development



MELCOR
New Modeling
SQA
Utilities

MELCOR Code Development History

- MELCOR 1.8.2 (1993)
  - One of the earliest versions for widespread release.
  - Version not recommended for use
- MELCOR 1.8.3 (1994)
  - BH Package
  - CORCON-MOD3
  - Version not recommended for use
- MELCOR 1.8.4 (1997)
  - Retention of molten metals behind oxide shells
  - Vessel creep rupture model
  - Flow blockage model
  - Radiant heat transfer between HSs
  - Hygroscopic aerosols,
  - chemsorption on surfaces,
  - SPARC 90
- MELCOR 1.8.5 (2000)
  - CF arguments could be added to plotfile
  - Consistency checks on COR/CVH volumes
  - Iterative flow solver added
  - Diffusion flame model
  - SS & NS components added for structural modeling
  - Upward & downward convective & radiative heat transfer from plates
  - Particulate debris in bypass introduced
  - Improvements to candling, debris slumping, and conductive, radiative, and candling heat transfer
  - PAR model was added
  - CsI added as a default class
  - Improvements to hygroscopic model
  - Iodine pool modeling
  - Carbon steel was added to MP package

MELCOR

New Modeling

SQA

Utilities

MELCOR Code Development History

- MELCOR 1.8.6 (2005)
  - An option was added to generate input for the MACCS consequences model.
  - Input was added to simplify conformance with the latest best practices (now defaults in 2.x)
  - New control functions (LM-CREEP & PIP-STR) for modeling pipe rupture
  - Modeling of the lower plenum was revised to account for curvature of the lower head
  - Formation and convection of stratified molten pools
  - Core periphery model for PWRs to model core baffle/formers and the bypass region
  - Reflood quench model
  - Oxidation of B4C poison
  - Release of AgInCd control poison
  - Column support structures was added
  - Interacting materials added to allow modifying enthalpy tables
  - Spent Fuel Pool modeling
  - Flashing model
  - Modified CORSOR Booth release model added
  - Jet impaction model
  - Hydrogen chemistry models

- MELCOR 2.x (Beta release in 2006)
  - Code internal structure greatly modified
  - Dynamic memory allocation
  - New input format
  - Formula type control functions
  - New HTGR modeling (PBR, PMR)
  - Counter-current flow model
  - Point kinetics model
  - Smart restart
  - Simplified accumulator model
  - Ability to track radionuclide activities
  - Turbulent deposition model & bend impaction
  - Control function for deposition mass for each deposition mechanism.
  - MELCOR/SNAP interaction in real-time
  - Full report to user of sensitivity values
  - Cell-based porosity
  - Spent fuel pool models
  - Intermediate heat exchanger /machinery models
  - Hydrogen chemistry models

MELCOR Aerosol Deposition

- MELCOR has long had aerosol deposition models for various mechanisms
  - Gravitational
  - Brownian diffusion to surfaces
  - Thermophoresis (Brownian process causing migration to lower temperatures)
  - Diffusiophoresis (induced by condensation of water vapor onto surfaces)
- Newly added deposition mechanisms
  - Turbulent deposition in pipe flow
    - Wood's model for smooth pipes
    - Wood's model for rough pipes
    - Sehmel's model for perfect particle sinks (VICTORIA)
  - Bend Impaction Models
    - Pui bend model
    - McFarland bend model
    - Merril bend model

Definitions: Deposition Velocity

- Particle deposition is modeled in terms of a deposition velocity V_d, defined as the ratio of the time-averaged particle flux to the surface to the time-averaged airborne particle concentration in the duct. This is then implemented into MELCOR in calculating the rate of deposition on a surface:

$$\frac{1}{A}\frac{dM_C}{dt} = V_d C$$

where

V_d	-	deposition velocity
C	-	particle mass concentration
M_C	-	Mass deposition rate
A	-	Surface area of deposition surface

Definitions: particle relaxation time

- It is common to correlate the deposition velocity with the particle relaxation time, τ.
- This is the characteristic time for a particle velocity to respond to a change in air velocity.
- For spherical particles of diameter d_p and density r_p in the Stokes flow regime, it is calculated as:

$$\tau = \frac{\rho_m D_p^2 C_{slip}}{18\mu_g}$$

C_{slip} - slip correction factor (-)

- This is nondimensionalized by dividing by the average lifetime of eddies near the walls:

$$\tau^* = \frac{\tau \rho_g (u^*)^2}{\mu_g}$$

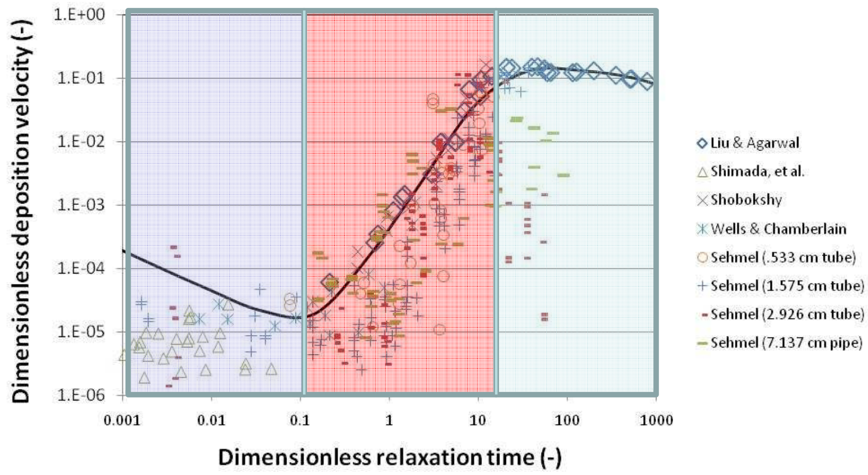
u^* - friction velocity

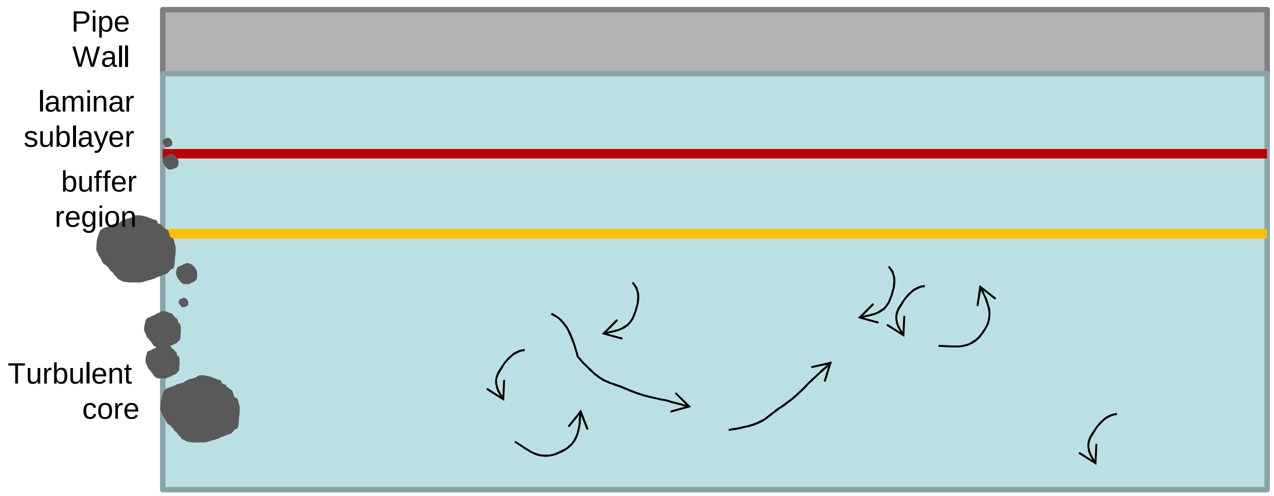
Wood's Model for Turbulent Deposition

- Turbulent particle diffusion for very small particles where Brownian motion is important to transport particles across the viscous sub layer.
- Eddy Diffusion-impaction regime for larger particles dominated by eddy diffusion where particles are accelerated to the wall due to turbulent eddies in the core and buffer layer and coast across the viscous sub layer.
- Inertia Moderated Regime- very large particles which are subject to reduced acceleration by the turbulent core and little or no acceleration to small eddies in the buffer near the wall.

Turbulent Deposition Cartoon

- Inertia moderated regime
- Eddy diffusion impaction regime
- Turbulent particle diffusion





Turbulent particle diffusion regime

- Brownian diffusion is important
  - Davies equation

$$u_{t,s} = \frac{Sc^{-2/3}\tilde{v}}{14.5\left\{\frac{1}{6}\ln\left[\frac{(1+\varphi)2}{1-\varphi+\varphi^2}\right]+\frac{1}{\sqrt{3}}atan\left[\frac{2\varphi-1}{\sqrt{3}}\right]+\frac{\pi}{\sqrt{3}}\right\}} \quad (1)$$

Where

$u_{t,s}$ = turbulent deposition velocity for submicron particles (m/s)

$\tilde{v}$ = friction velocity (m/s), defined by the following expression:

$$\tilde{v} = U\sqrt{\frac{f}{2}}$$

f = Fanning friction factor (dimensionless)

φ = $SC^{1/3}/2.9$

  - Wood's approximation: $V_d^* = \frac{u_{t,s}}{\tilde{v}} = \frac{3\sqrt{3}}{29\pi}Sc^{-2/3}$
    - Approximating function of ϕ:

$$V_d^* = \frac{3\sqrt{3}}{29\pi\tau_*^{1/3}}Sc^{-2/3} \quad \tau_*^{1/3}$$

    - In terms of dimensionless relaxation time:

Eddy Diffusion-impaction regime

- A second term is added to the equation for deposition velocity:

$$V_d^* = \frac{3\sqrt{3}}{29\pi\tau_*^{1/3}} Sc^{-2/3} \quad \tau_*^{1/3} + K\tau_*^2$$

- K is often determined empirically

Investigator	K
Kneen & Strauss (1969)	3.79×10^{-4}
Liu & Agarwal (1974)	6×10^{-4}
Wood (1981b)	4.5×10^{-4}
Papavergos & Hedley (1984)	3.5×10^{-4}

- Or calculated from a Fick's law equation (Wood)

$$N = (D_p + \varepsilon)\frac{dc}{dy}$$

where

N = particle flux ($\#/m^2$-s)
D_p = particle diffusion coefficient (m^2/s)
ϵ = particle turbulent eddy-diffusivity (m^2/s)
c = particle concentration ($\#/m^3$)
y = distance from surface (m)

Inertia Moderated Regime

- Large particles (~> than a micron)
  - Deposition velocity is either constant

$$V_d^* = \sqrt{\frac{f}{2}} \qquad 10 \le \tau_* < 270$$

  - Or may decrease with increasing dimensionless relaxation time

$$V_d^* = \frac{2.6}{\sqrt{\tau_*}}\left(1 - \frac{50}{\tau_*}\right) \qquad \tau_* \ge 270$$

VICTORIA Modeling

- Three regimes of turbulent deposition as was predicted by Woods model
  - Davies Model is also used for small particles in the turbulent particle diffusion regime
  - Correlation by Sehmel added for particle impaction regime
    - Correlation fit overexperiments for which sticking was promoted (used in VICTORIA).

$$u_{t,s} = 1.47 * 10^{-16}\left(\frac{\rho_a}{1000}\right)^{1.01}\left(\frac{2 * 10^4 r_a}{D_H}\right)^{2.1} Re^{3.02}\tilde{v}$$

    - Correlation fit over a more general data set (not used in MELCOR)

$$u_{t,s} = 1.0 * 10^{-16}\left(\frac{\rho_a}{1000}\right)^{1.83}\left(\frac{2 * 10^4 r_a}{D_H}\right)^{2.99} Re^{3.08}\tilde{v}$$

- A maximum is placed on the non-dimensional deposition velocity not to exceed a value of 0.1.

Merril's Model for Deposition in Pipe Bends

- To calculate the inertial deposition of aerosols in pipe bends, the centrifugal force acting on the particle as the fluid turns a pipe bend is used to calculate a terminal velocity in the radial direction:

$$F_c = \frac{\pi}{6}(\rho_p - \rho_f)d_p^3 \frac{u_f^2}{r_b} \approx m_p \frac{u_f^2}{r_b}$$

$$u_{p\perp} = BF_c$$

- The radial distance a particle drifts in this turn is the product of bend travel time and the particle radial velocity:

$$S = \Theta_b B m_p u_f$$

- Assume the fraction of particles that collide with the wall is given by s/D
  - Assumes the particle concentration is uniform

Nomenclature

d_p = particle diameter (m)
u_f = fluid velocity (m/s)
r_b = bend radius of pipe (m)
ρ_p = particle density (kg/m^3)
ρ_f = fluid density (kg/m^3)
m_p = particle mass (kg)
Θ_b = bend turning angle (radians)
S = the particle radial drift (m)
B = the particle mobility

$$= \frac{1}{(3\pi\mu_g d_p)}$$

PUI Model for Deposition in Pipe Bends

- Based on experiments by Pui et al. For conditions of $10^2 < Re < 10^4$
- Correlates the deposition efficiency, η_b due to flow irregularity $\eta_b = 1 - 10^{-0.963\,St}$
  - Where $St = \frac{C_c \rho_p d_p^2 U_{ave}}{9 \mu D_h}$
  - Represents the fraction of aerosol particles that deposit near the pipe bend because of inertial effects induced by curvature of the fluid streamlines.
  - Converted to deposition velocity in Victoria by the following definition: $u_b = \eta_b \frac{U}{L} \frac{V_B}{A}$

u_b = deposition velocity for flow through a bend
V_B = volume of bulk gas subregion (m^3), as defined in chapter 3
A = surface area for aerosol deposition (m^2)

McFarland Bend Model

- McFarland's model is purely empirical
  - Based on fitting an equation to data obtained from physical experiments and Lagrangian simulations.
  - Applicable to arbitrary bend angles and radius of curvature.

$$\eta_b = 1 - 0.01\exp\left(\frac{4.61 + a\theta St}{1 + b\theta St + c\theta St^2 + d\theta^2 St}\right)$$

$$a = -0.9526 - 0.0568\delta$$

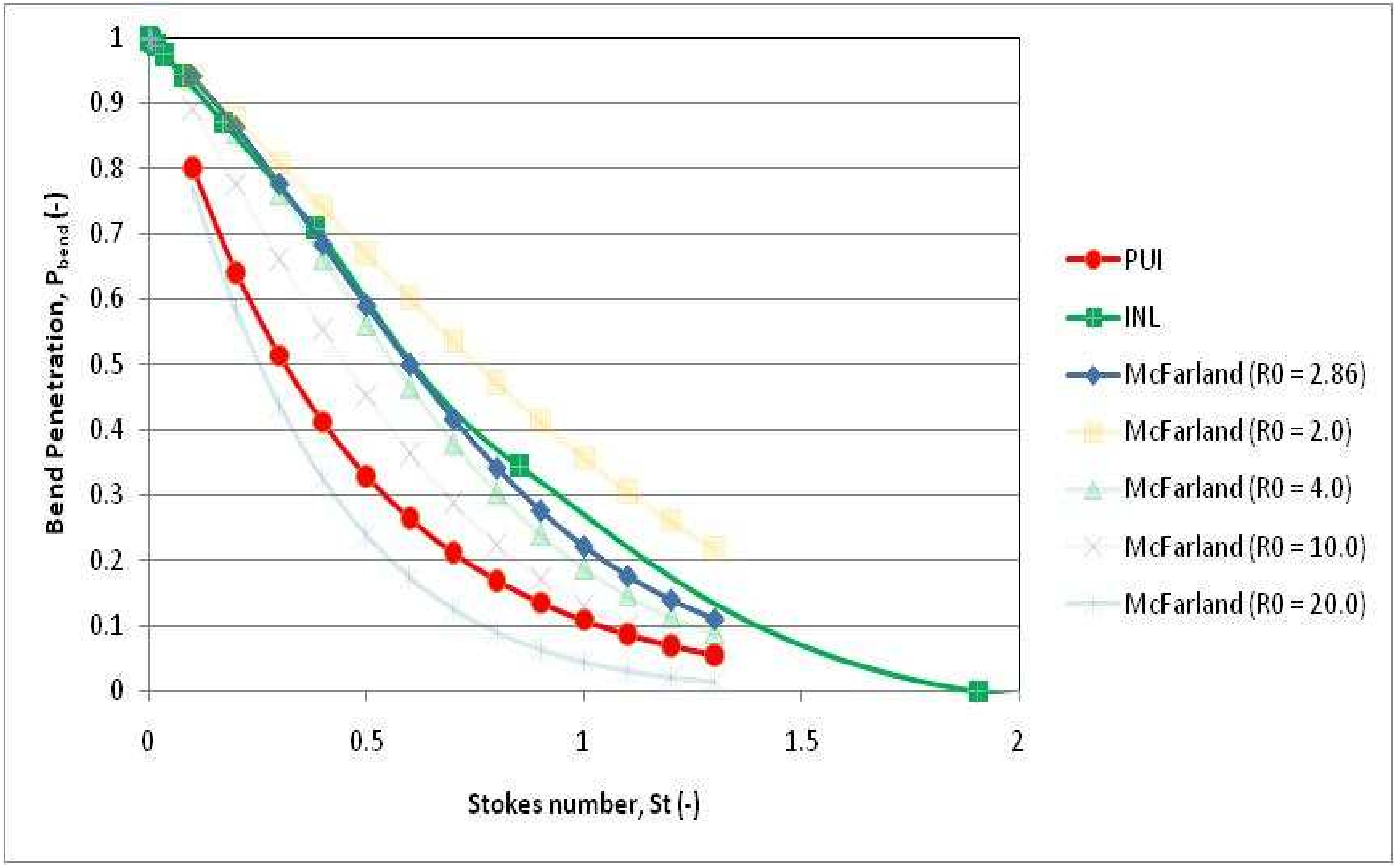
$$b = \frac{-0.297 - 0.0174\delta}{1 - 0.07\delta + 0.0171\delta^2}$$

$$c = -0.306 + \frac{1.895}{\sqrt{\delta}} - \frac{2.0}{\delta}$$

$$d = \frac{0.131 - 0.0132\delta + 0.000383\delta^2}{1 - 0.129\delta + 0.0136\delta^2}$$

$$\delta = \frac{2R_{bend}}{h}$$

MELCOR Bend Models



Assumptions of MELCOR Models

- It is assumed that each deposition mechanism acts independently and the total deposition velocity can be calculated from the sum of the deposition velocities for each mechanism
- Turbulent deposition (when activated) takes place only on heat structure surfaces and not on any other surfaces
- Other effects due to high velocity, such as resuspension or re-entrainment are not modeled
- The influence of the aerosol particles on the flow stream is negligible.
  - Not only does this mean that the micro effects on the turbulent flow field, but the macro effects from deposition on surfaces with the subsequent reduction in flow area is not modeled.

New MELCOR Control Function Argument

RN1-DEPHS(HS,Sur,class,mechanism)

Total radionuclide mass of class deposited on side ('RHS or LHS') of heat structure HS (name or number) for turbulent deposition model. The deposition mechanisms that are tracked are as follows:

- 'DIFF', Diffusion deposition
- 'THERM', Thermophoresis
- 'GRAV', Gravitational settling
- 'TURB', Turbulent deposition in straight sections
- 'BEND', Deposition in pipe bends

(units = kg)

MELCOR Software Quality Assurance Best Practices

MELCOR
New Modeling
SQA
Utilities

Sandia National Laboratories

Emphasis is on Automation

Affordable solution

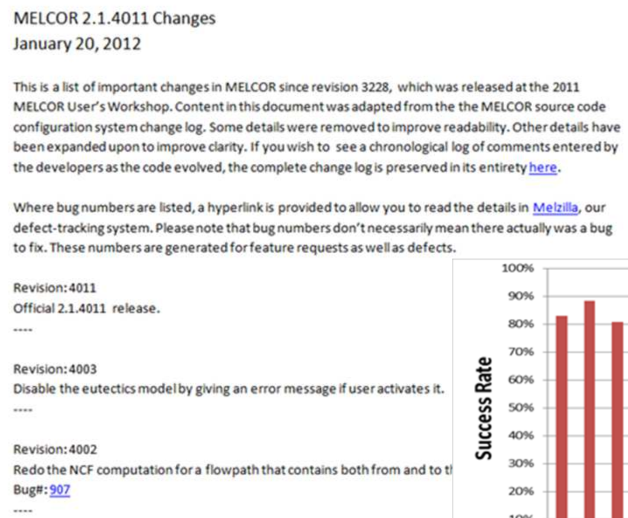
Consistent solution

- MELCOR Wiki
  - Archiving information
  - Sharing resources (policies, conventions, information, progress) among the development team.
- Code Configuration Management (CM)
  - 'Subversion'
  - TortoiseSVN
  - VisualSVN integrates with Visual Studio (IDE)
- Code Review
  - Code Collaborator
- Nightly builds & testing
  - DEF application used to launch multiple jobs and collect results
  - HTML report
  - Regression test report

- Regression testing and reporting
  - More thorough testing for code release
  - Target bug fixes and new models for testing
- Bug tracking and reporting
  - Bugzilla online
- Validation and Assessment calculations
- Documentation
  - Available on Subversion repository with links from wiki
  - Latest PDF with bookmarks automatically generated from word documents under Subversion control
    - Links on MELCOR wiki
- Sharing of information with users
  - External web page
  - MELCOR workshops
  - Possible user wiki

MELCOR Quality Assurance: Tracking Code Changes

- Changelist
  - List of code issues and modifications by revision
  - References to bugzilla site
- MELCOR Trends
  - Provide a very general assessment of code modifications
    - Code stability
    - Performance
    - Metrics
      - H2 generated, Cs deposition, deposition on filters, CAV ablation
  - Provided with each public code release
  - Automated as part of testing



MELCOR 2.1.4011 Changes
January 20, 2012

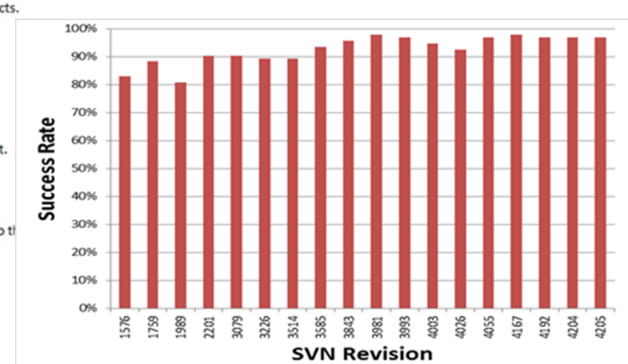
This is a list of important changes in MELCOR since revision 3228, which was released at the 2011 MELCOR User's Workshop. Content in this document was adapted from the the MELCOR source code configuration system change log. Some details were removed to improve readability. Other details have been expanded upon to improve clarity. If you wish to see a chronological log of comments entered by the developers as the code evolved, the complete change log is preserved in its entirety here.

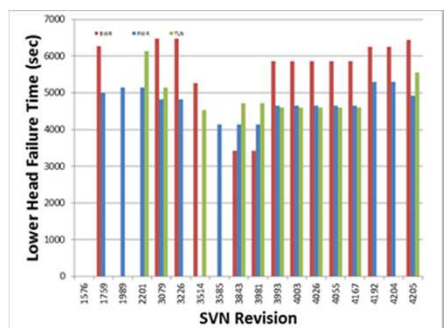
Where bug numbers are listed, a hyperlink is provided to allow you to read the details in Melzilla, our defect-tracking system. Please note that bug numbers don't necessarily mean there actually was a bug to fix. These numbers are generated for feature requests as well as defects.

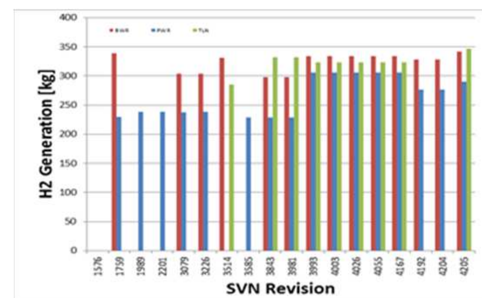
Revision: 4011
Official 2.1.4011 release.

Revision: 4003
Disable the eutectics model by giving an error message if user activates it.

Revision: 4002
Redo the NCF computation for a flowpath that contains both from and to t
Bug#: 907







MELCOR | New Modeling | SQA | Utilities

MELCOR: Self-Documenting Code

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- MELCOR generates a complete list of MELCOR Keywords
  - Global record ‘PrintInputRecords <filename>’
  - Part of required input processing routine means that all records recognized by MELCOR are printed
- MELCOR generates a list of control function arguments recognized by MELCOR
  - Enabled by ‘PrintInputRecords’
- MSWord Macro that scans the user guide document for input records and CF arguments
  - Comparison with MELCOR list enables identification of undocumented keywords

```
**********************************
*    LIST OF MELGEN INPUT RECORD *
**********************************

Global INPUT RECORDS
   Name Default Output
     MEL_DIAGF     MEL_DIAGFILE     MEG_OUTPUTF     MEG_OUTPUTFILE     MESSAGEFILE
     MESSAGEF     MEG_HTML     MEG_HTMLFILE     MEL_HTML     MEL_HTMLFILE
     MEG_DIAGF     MEG_DIAGFILE     MEL_OUTPUTF     MEL_OUTPUTFILE     MEG_RESTARTF
     MEG_RESTARTFILE     MEL_RESTARTF     MEL_RESTARTFILE     STATUSFILE     STATUSF
     STOPFILE     STOPF     EXTDIAGFILE     EXTDIAGF     PLOTFILE
     PLOTF
   Optional variables
     NOTEPAD++     PROGRAM     ALLOWREPLACE     MELMACCS2PLOT     MELMAC
     WRITENEWINP     MEL_RFMOD     DEFAULTNAMEDCOMMENTBLOCK     VARIABLEVALUE     COMMENTBLOCK
     DEFINEVARIABLESFILE     DEFINEVARIABLESF     DEFAULTDIRECTORY     RN1VISUALF     RN1VISUALFILE
     MEL_INSTALL     MELCOR_INSTALL     T_CONTOUR     T_CON     EXCELFILE
     EXCEL     KEYWORDFILE     KEYWORDF     PRINTCURRENTSC     PRINTDEFAULTSC
     PRINTINPUTRECORDS

EXEC INPUT RECORDS
   Unique Records
     EXEC_INPUT     EXEC_DTTIME     EXEC_TSTART     EXEC_RUNONLY     EXEC_TITLE
     EXEC_JOBID     EXEC_COMTC     EXEC_CPULEFT     EXEC_CPULIM     EXEC_CYMESF
     EXEC_DTINCR     EXEC_DTSUMMARY     EXEC_EDITCF     EXEC_FORCEPLOT     EXEC_NOCOPY
     EXEC_PLOTCF     EXEC_RESTARTCF     EXEC_SOFTDTMIN     EXEC_TEND     EXEC_WARNINGL
     EXEC_WARNINGLEVEL     EXEC_DTMAXCF     EXEC_STOPCF     EXEC_UNDEF     EXEC_NOFLUSH
     EXEC_CFEXFILE     EXEC_PLOTLENGTH     EXEC_GLOBAL_DFT     EXEC_SS     EXEC_WRT

   Unique Tables
     EXEC_EXACTTIME     EXEC_TIME     EXEC_PLOT

NCG INPUT RECORDS
   Unique Records
     NCG_INPUT
   Object Identifiers
```

```
Control Function Arguments
      FDI-FMREL     FDI-FMRELT     FDI-ETRAN     FDI-ETRANT     FDI-STGEN
      FDI-STGENT     FDI-OXRAT     FDI-OXTOT     FDI-ATM-POWR     FDI-ATM-HEAT
      FDI-DEBRIS-T     FDI-OX-ENRGY     FDI-MASS-ADD     FDI-ENTH-ADD     FDI-ATM
      FDI-SXRAT     FDI-SXTOT     FDI-SRF-POWR     FDI-SRF-HEAT     FDI-TBD-SURF
      FDI-SX-ENRGY     FDI-MASS-SET     FDI-ENTH-SET     FDI-SRF     CAV-ACTIVE
      CAV-MTOT     CAV-HTOT     CAV-DHR     CAV-MASS     CAV-M
      CAV-T     CAV-RHO     CAV-THICK     CAV-VOL     CAV-VF
      CAV-MAXRAD     CAV-MINALT     CAV-TMEX     CAV-MEX     CAV-QREA
      CAV-QCNCT     CAV-QSURF     CAV-TGASMOL     CAV-R     CAV-Z
      CAV-ASURF     CAV-CRUSTB     CAV-CRUSTT     CAV-TSURF     CAV-MASSERR

      CAV-ENERGYERR     CAV-CPUT     CAV-CPUC     CF-VALU     BUR-CPUC
      BUR-CPUE     BUR-CPUR     BUR-CPUT     BUR-N-SE     BUR-LOG
      BUR-RAT     BUR-TOT     BUR-POWER     BUR-ENERGY     BUR-FTOT
      BUR-FENERGY     ESF-PCCS-VNTFL     ESF-PCCS-TOTENG     ESF-PCCS-TOTSTM     ESF-ICS-VNTFL
      ESF-ICS-TOTENG     ESF-ICS-TOTSTM     ESF-QFC-RAT     ESF-QFC-TOT     ESF-MFC-RAT
```

MELCOR

New Modeling

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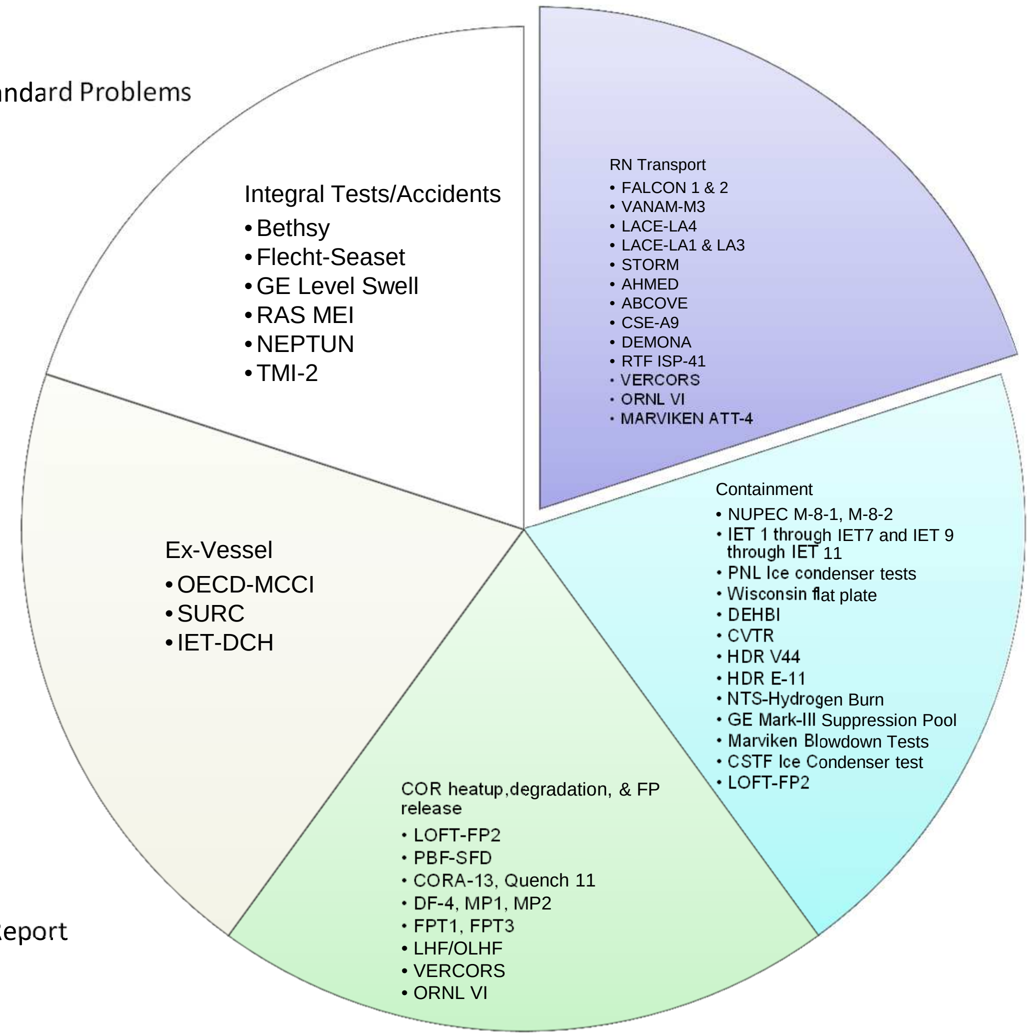
MELCOR Code Validation

- Both Separate Effects and Integral Tests
- Part of our regression test suite
- Participation in multiple International Standard Problems
- Coverage of most important physics
  - Heatup/Heat transfer
  - Oxidation
  - Reflood
  - Degradation
  - Molten pool
  - FP Release
  - Vessel failure
  - Critical Flow
  - MCCI
  - DCH
  - Condensation
  - Containment stratification
  - Hydrogen Burn
  - Hygroscopic effects
  - Aerosol deposition
  - RN transport
  - Iodine pool chemistry
  - Suppression pool level response
  - Vent clearing
  - Engineering Safety Features
    - Sprays
    - Ice Condensers
- Many of these are ongoing analyses
- Sensitivity Analysis of Input Analysis
- Published as Volume III Documentation Report



MELCOR

New Modeling

SQA

Utilities

Assessment Process

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Phase I (almost complete)

- Assemble all decks (convert decks if necessary)
- Collect supplementary documentation
- Runs calculation to completion Phase II
- Check that calculation gives reasonable results
- Run calculation in 2.1

Phase II (ongoing)

- Update/ initiate assessment
- Update spreadsheet
- Presentation at weekly assessment meeting
- Commit all files (decks, XLS, Word) to repository
- Transfer test case to another analyst for Phase III review

Assessment should be complete

Phase III (ongoing)

- Second review (presentation if necessary)
- Re-run with final code version
- Clean up input deck
- Draft of write-up

After phase III

- Documents go to editor for final review
- Review & Approval

MELCOR

New Modeling

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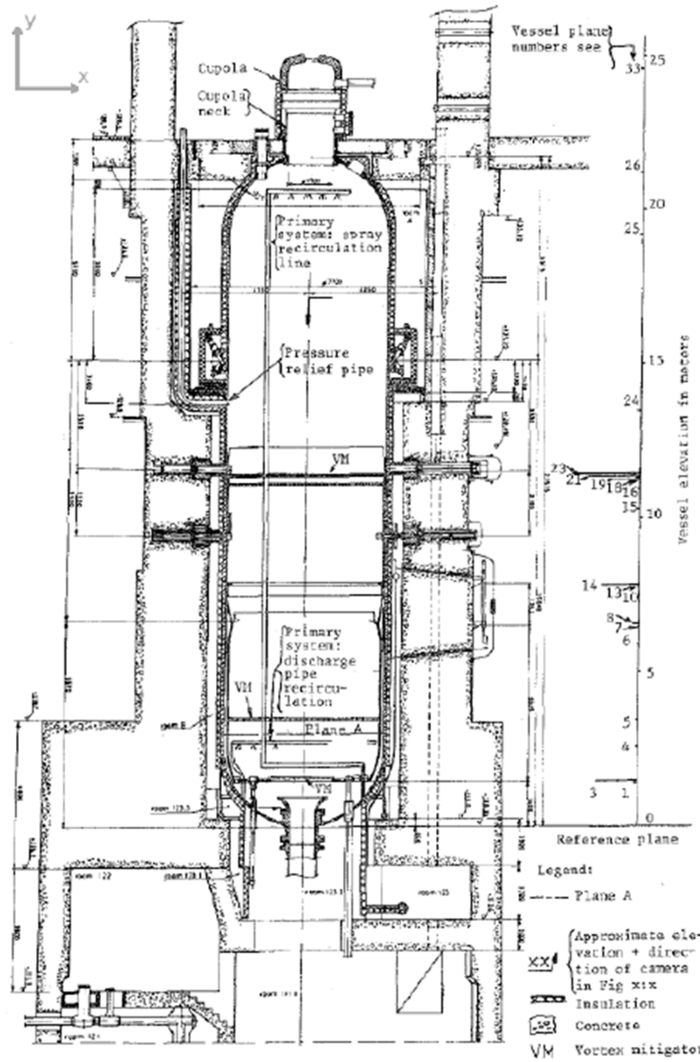
Utilities

Marviken Critical Flow Experiments

Sandia National Laboratories

Assessments: Marviken Critical Flow Exp.

- Historical background
  - Tests conducted 1978-1979
  - Marviken power station
    - 100 km SW of Stockholm
    - Designed as a 130 MWe heavy water moderated reactor
    - Never commissioned
    - Oil-fired power station
- MARVIKEN Tests
  - Critical flow tests (CFT-21 reported here)
  - Jet impingement tests (JIT-11 reported here)
  - Aerosol transport tests (ATT-4 test included in volume III)



MELCOR

New Modeling

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Utilities

MARVIKEN Test conditions

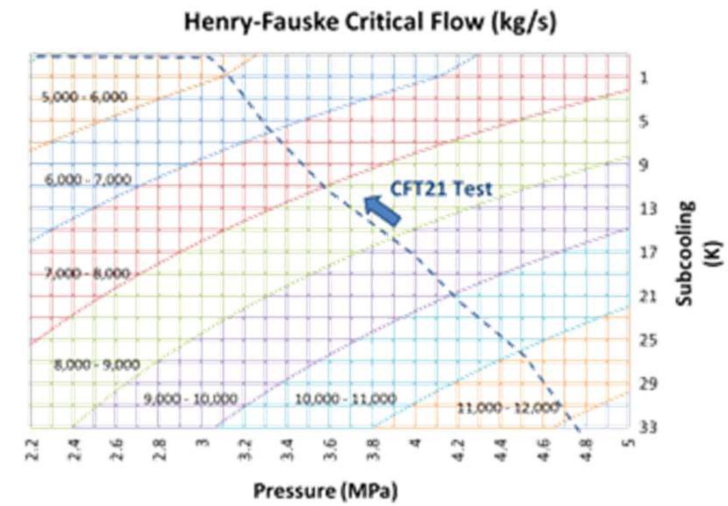
Sandia National Laboratories

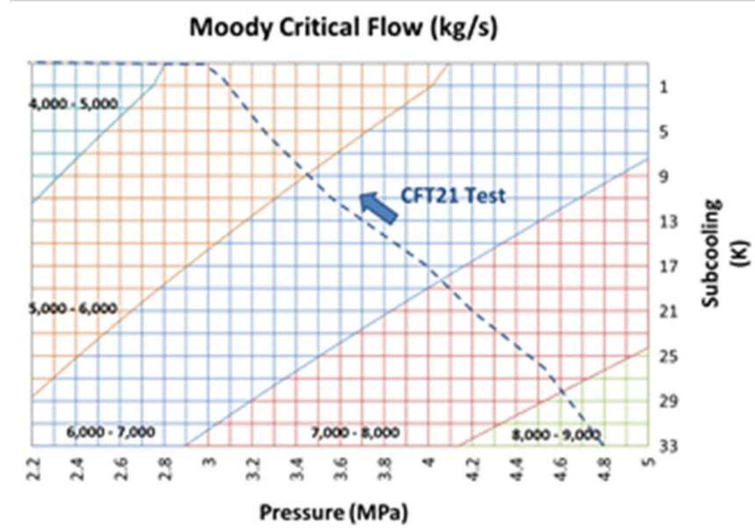
Assessments: Marviken Critical Flow Exp.

	CFT-21	JIT-11
Vessel volume (m^3)	420	420
Vessel inside diameter (m)	5.22	5.22
Standpipe: height (m)	-	18
outside diameter (m)	-	1.04
wall thickness (m)	-	8.8
Discharge nozzle: diameter(m)	0.500	0.299
area (m^2)	0.1963	.0702
length (m)	1.5	1.18
Initial Pressure (MPa)	4.9	5.0
Final pressure (MPa)	2.5	1.88
Initial water level (m)	19.9	10.2
Final water level (m)	<0.8	8.0
Initial inventory: water (kg	330×10^3	145×10^3
Steam (kg)	6×10^2	5×10^3
Maximum subcooling (K)	33	< 3

MELCOR Critical Flow Modeling

- Only Atmosphere
  - sonic flux at the minimum section in the flow path
- Only Pool
  - Subcooled water
    - Henry-Fauske
  - Two-phase water
    - Moody
- Atmosphere & Pool
  - weighted average for the two phases





MELCOR

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MELCOR Nodalization

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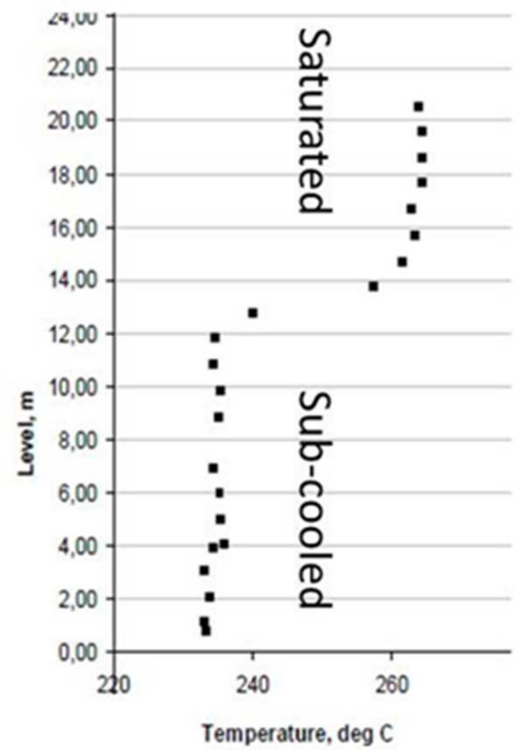
Assessments: Marviken Critical Flow Exp.

- CFT-21
  - Vessel Boundary Conditions
    - No volumes modeling discharge pipe
  - Vessel Modeled within MELCOR
    - 20 nodes
      - 1 volume modeling discharge pipe & nozzle
      - Necessary to capture moving temperature front (see temperature profile at right)
    - 1 node
      - 1 volume modeling discharge pipe & nozzle
- JIT-11
  - Vessel modeled with 1 node
    - 1 volume in stand pipe
    - 1 volume in discharge pipe

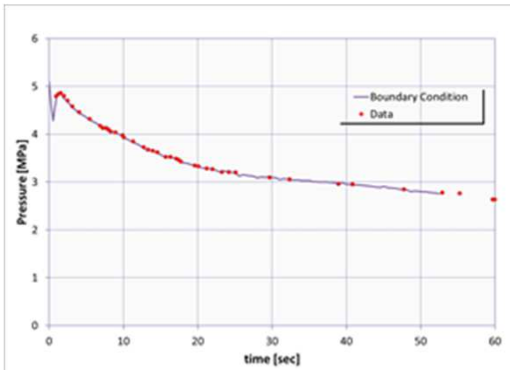


MELCOR CFT-21: Calculated from Applied Boundary Conditions

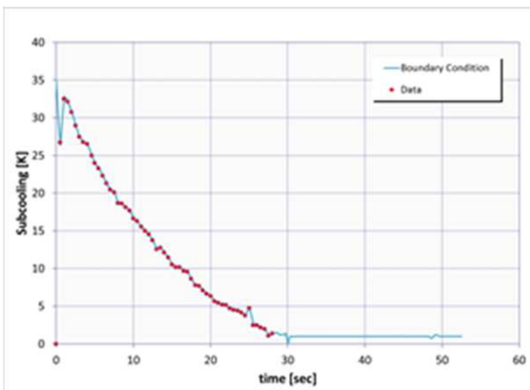
Assessments: Marviken Critical Flow Exp.

- Boundary Conditions

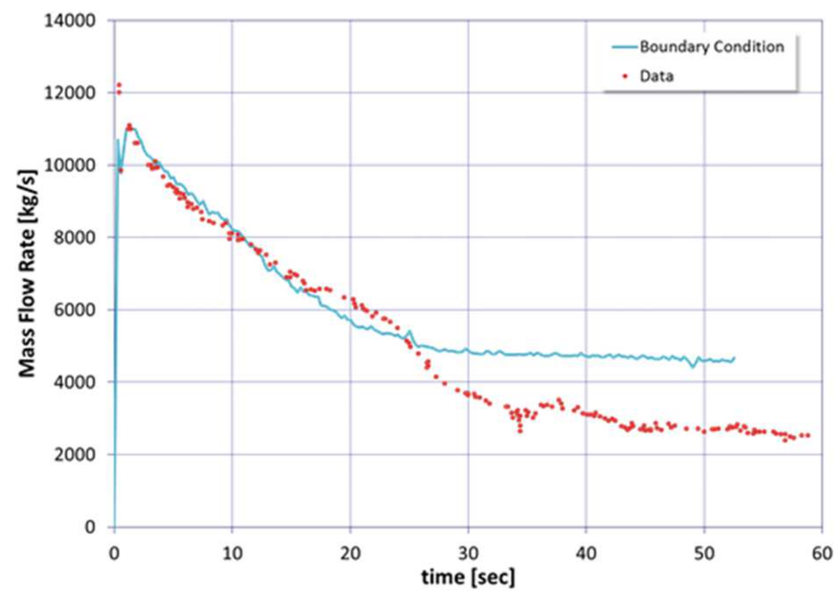
Vessel Pressure



Subcooling



- Calculate Results



This was the approach taken in early RELAP Validation

Ref: NUREG/IA-0007,"Assessment of RELAP5/MOD2 AgainstCritical Flow Data from Marviken Test CFT21 and CFT21, NRC, 9/1986

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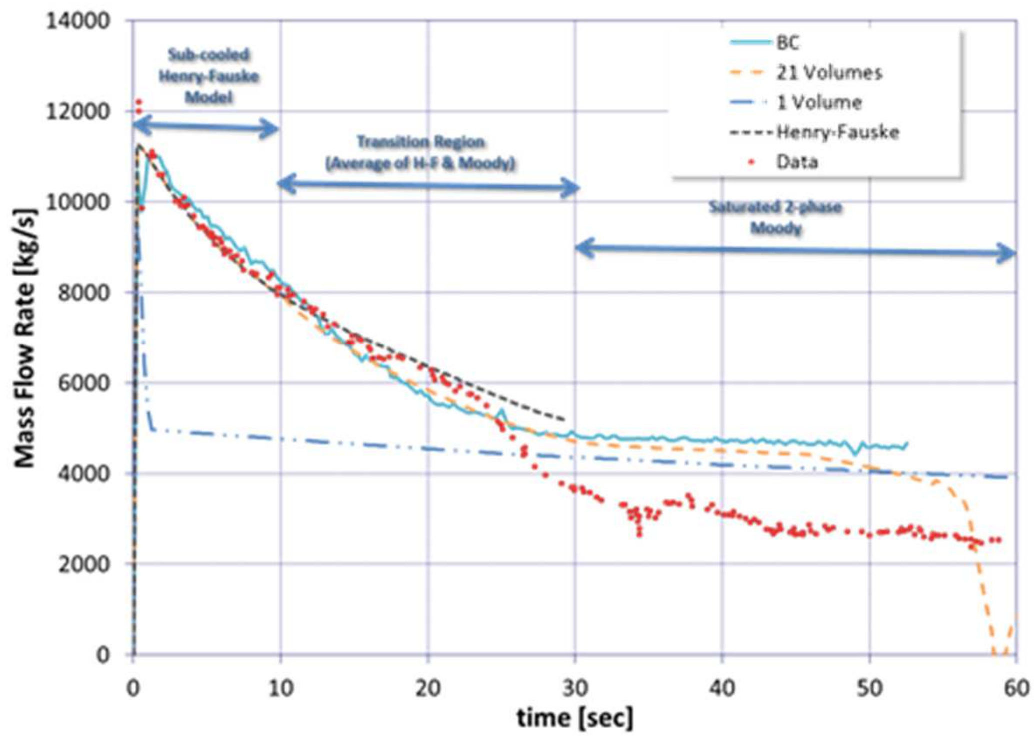
Results of MELCOR CFT-21 Calculation

Assessments: Marviken Critical Flow Exp.

- MELCOR calculation matches closely for sub-cooled conditions at exit (extended Henry-Fauske critical flow)
- MELCOR over-predicts flow for two-phased conditions
  - Moody multiplier, C_M, of 0.6 for area ratio = 0.5 & P = 5 MPa consistent with other data*
  - Moody model always over estimates critical flow.
    - Rapid formation of high vapor concentrations at inlet to exit pipe
    - Moody theory overestimates flowrates for stagnation quality > 1%.

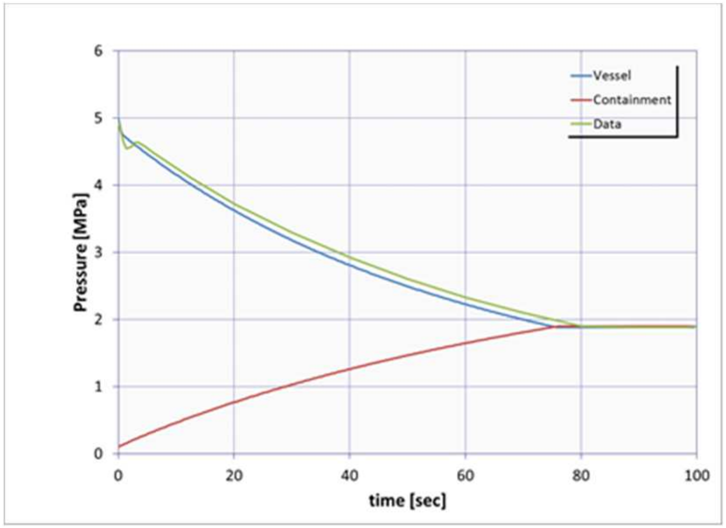


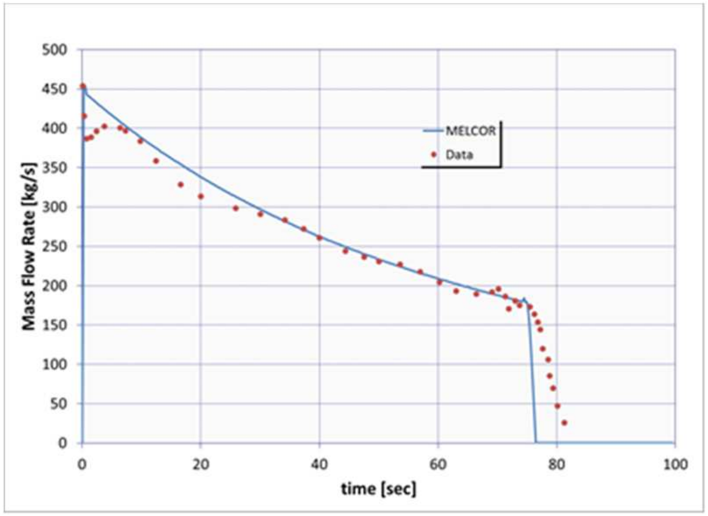
*Ardron, K.H., A STUDY OF THE CRITICAL FLOW MODELS USED IN REACTOR BLOWDOWN ANALYSIS, Nuclear Engineering & Design 39 (1976) 257-266.

Results of MELCOR JIT-11 Calculation

- Containment volume (downstream) was varied to give the correct final pressure

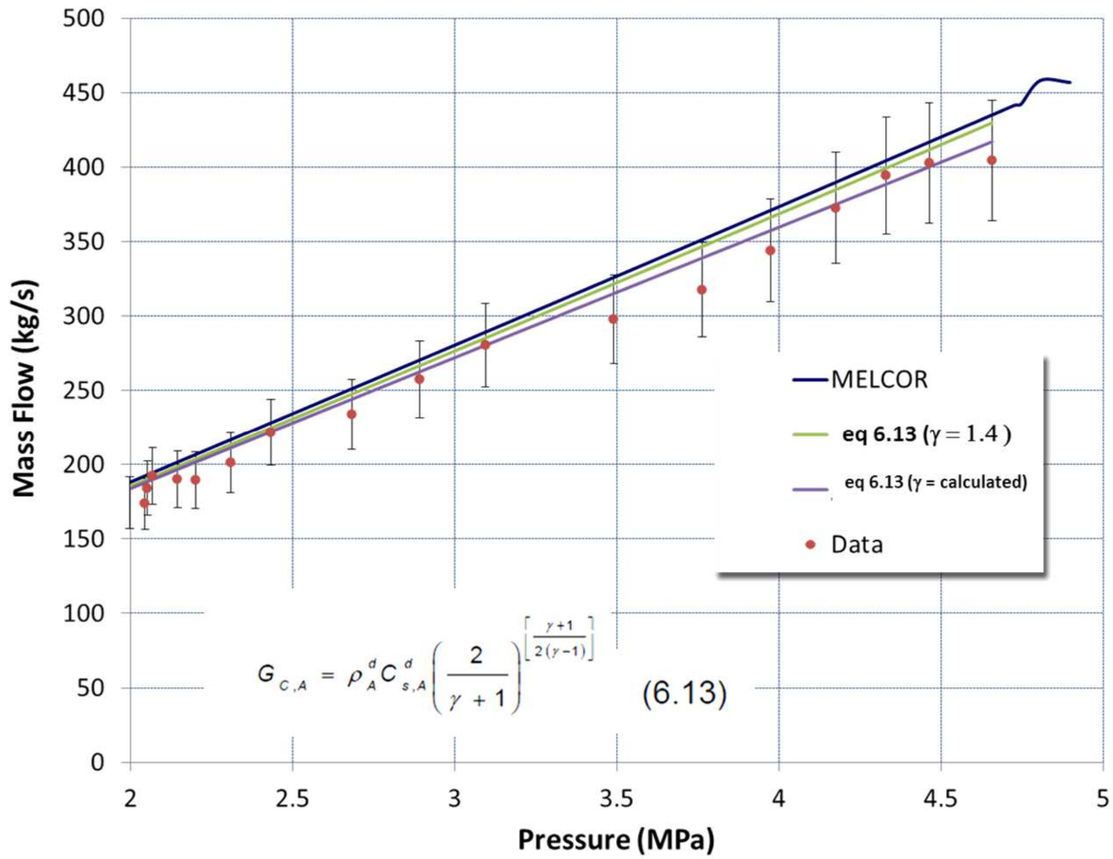
- Time variation of flow calculated by MELCOR is consistent with test data





Mass flow rate vs. vessel pressure

- Mass flow rate vs vessel pressure
  - mass flow rate is independent of the downstream pressure
  - Experimental uncertainty of 5% indicated by error bars
- Equation 6.13 used by MELCOR
  - MELCOR calculation assumes a fixed value of $\gamma = 1.4$
  - Calculating γ does improves calculation very slightly



LACE Containment Bypass Tests

- The LACE tests experimentally examined the transport and retention of aerosols typical of LWRs through pipes with high speed flow and in containment volumes during rapid depressurization.
- Specific objectives of these tests were to provide validation data that would expose important dependencies in modeling deposition. In particular the following test conditions were examined:
  - Effect of gas velocity through the pipe
  - Effect of aerosol composition
  - Effect of aerosol size distribution

Overview of LACE Containment Bypass Tests

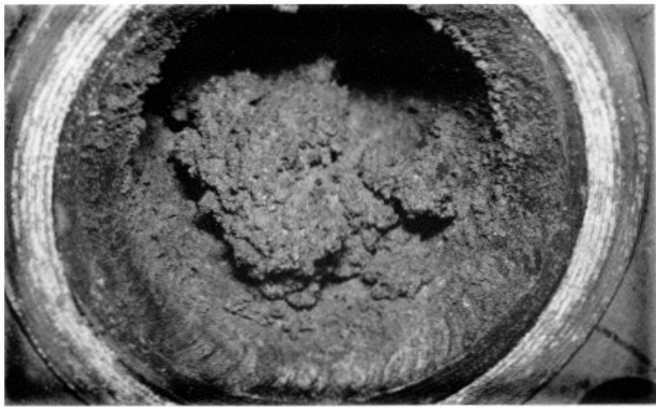
- Test Characteristics:
  - Mixed hygroscopic/nonhygroscopic aerosols
  - 30,000 < Re < 300,000

Test	Aerosol	NaOH or CsOH Mass Fraction	Carrier Gas	Gas Velocity (m/s)	Temp. (°C)	Aerosol Source Rate (g/s)	Aerosol Size AMMD (μm)	Mass Retention Fraction
LA1	CsOH	0.42	Air-steam	96	247	1.1	1.6	> 0.98
	MnO							
LA3A	CsOH	0.18	N_2-steam	75	298	0.6	1.4	> 0.7
	MnO							0.7
LA3B	CsOH	0.12	N2-steam	24	303	0.9	2.4	> 0.4
	MnO							> 0.7
LA3C	CsOH	0.38	N2-steam	23	300	0.9	1.9	> 0.7
	MnO							> 0.7

- Assumed Properties
  - σ=surface tension of possible surface film =0.077 (N/m2)
  - μ =surface viscosity of surface film = 0.0646 (kg/m-s)

Deposition Trends in LACE Containment Bypass Tests

- Very heavy deposition
  - Deposition increased with flow velocity
  - Higher deposition for mixed hygroscopic/dry aerosols
    - Wet deposits possibly flow along pipe walls
    - Dry deposits possibly resuspend
- Deposition density generally highest in 90^o pipe bends
- Partial plugging of section 3 in LA3C test influenced test results



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MELCOR Velocities for LACE Tests

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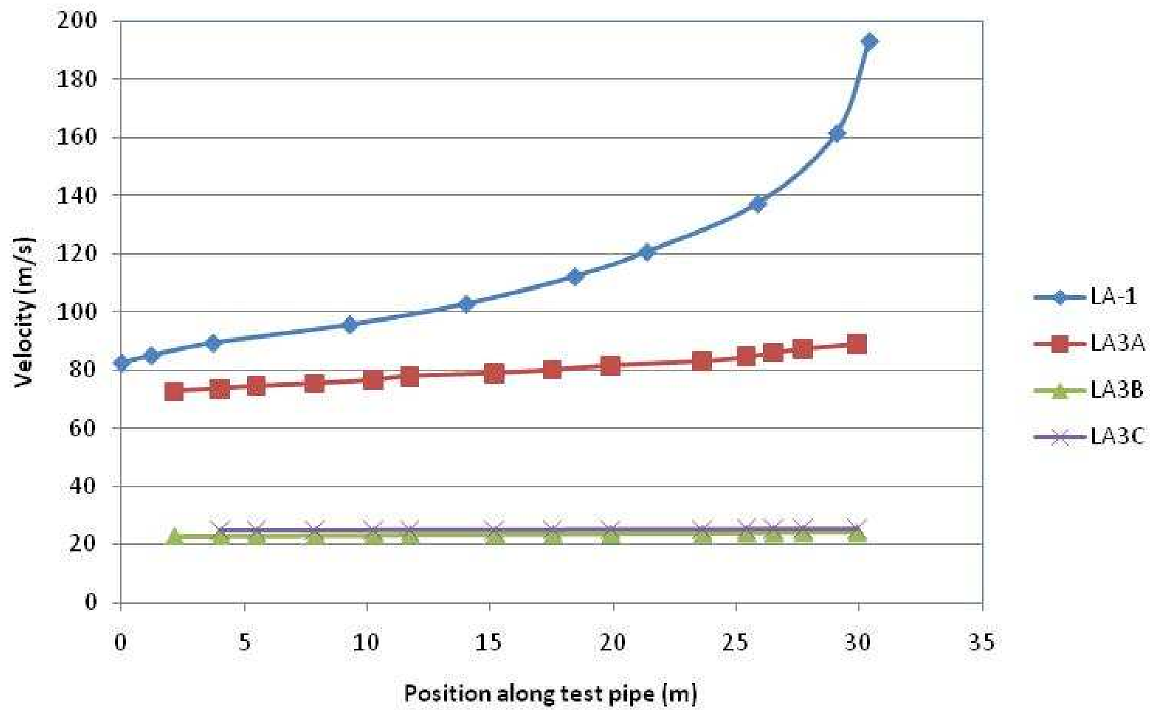
Assessments: Turbulent Deposition Model

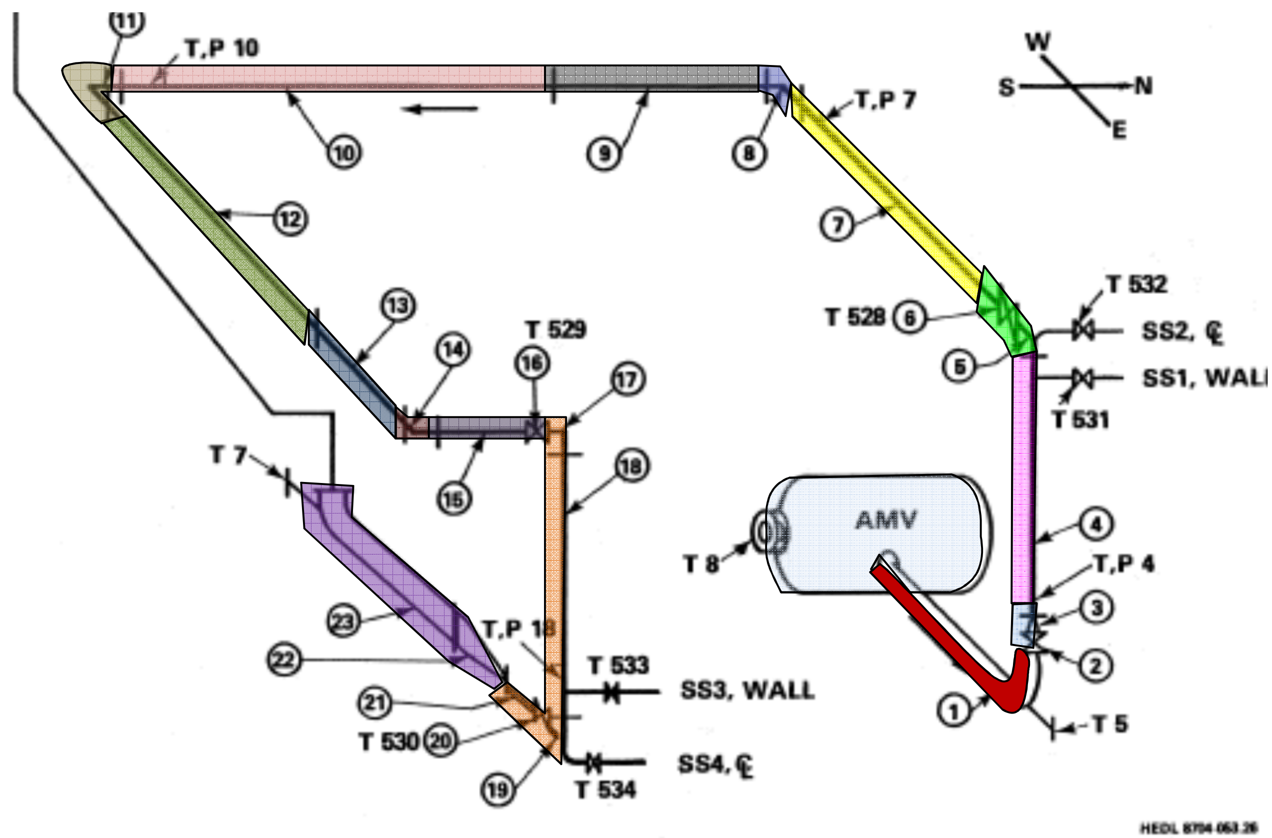
- LACE tests
  - Reynolds number ranges between 30,000 to 300,000
- Woods model
  - validated against data from 10,000 to 50,000
- Victoria models
  - Based on Friedlander & Johnston's data (Re = 2800 – 44,000) and Sehmel's data (Re = 4200 – 61000)



Fine Nodalization
bends isolated from straight pipe sections

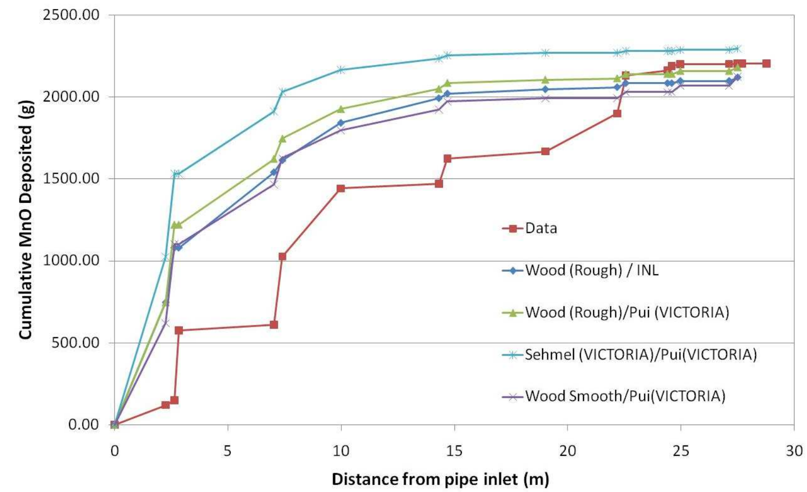
MELCOR Model Nodalization:

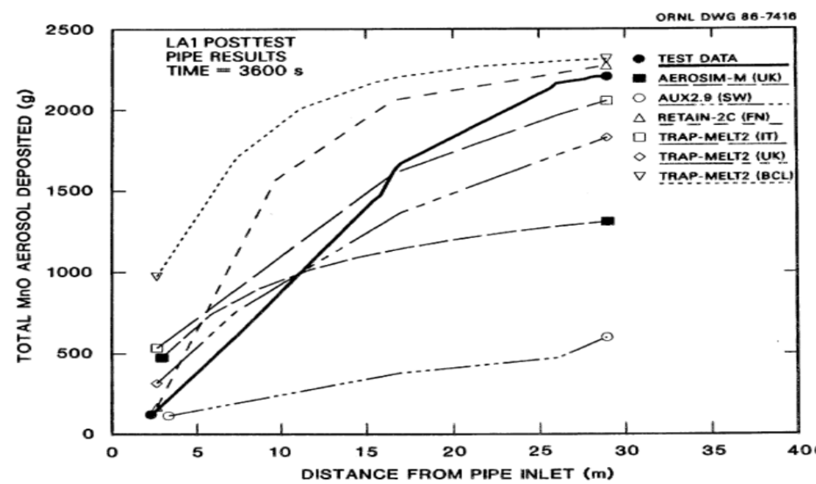
Control Volume	HS	Pipe Sections
CV011	1110	1a,1b,1c
CV012	1120	2,3
CV013	1130	4
CV014	1140	5,6
[illegible]	[illegible]	[illegible]
CV016	1160	8
CV017	1170	9
CV018	1180	10
CV019	1190	11
CV020	1200	12
CV031	1210	13
CV032	1220	14
CV033	1230	15,16
CV034	1240	17,18,19,20,



LA1 (Re ~ 300,000) Code Comparison Report

- Re ~ 300,000
- All MELCOR models are very close in their prediction except Sehmel's model
- All MELCOR models greatly over predict deposition in pipe section 4 (< 2.5 m).
  - Vertical pipe section
- MELCOR models do a better job of predicting overall deposition in test than most of the legacy codes in the code comparison report.





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LACE LA3A Tests
Re ~ 133,000

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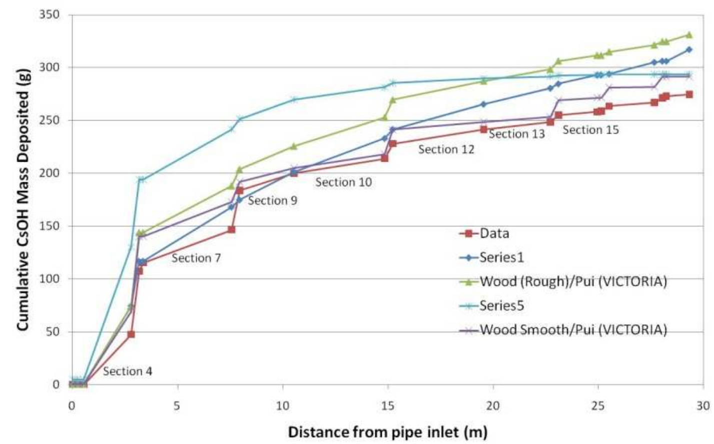
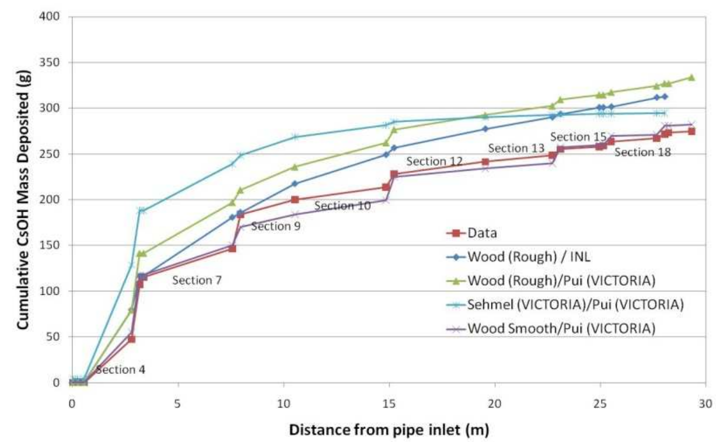
Assessments: Turbulent Deposition Model

- Wood (Smooth)/Pui combination gives best agreement through pipe, though over predicts deposition downstream
- Sehmel/Pui combination gives best cumulative deposition at end of pipe but over predicts deposition upstream
- Pui model does a better job of predicting deposition in bends.
- Dependency on number of sections is small though results are modestly improved

10 Sections



20 Sections



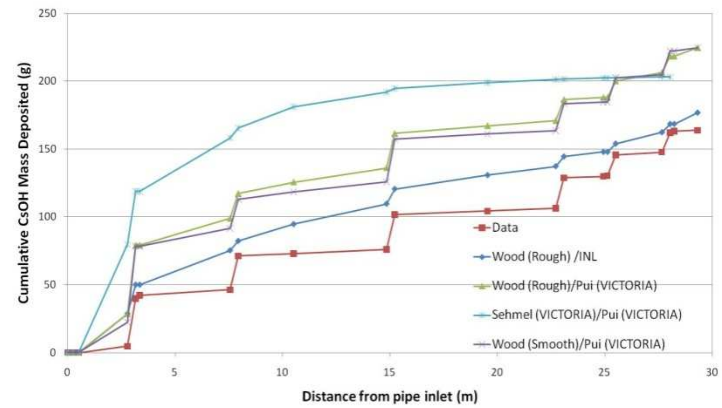
LACE LA3B Tests
Re ~ 31,000

Sandia National Laboratories

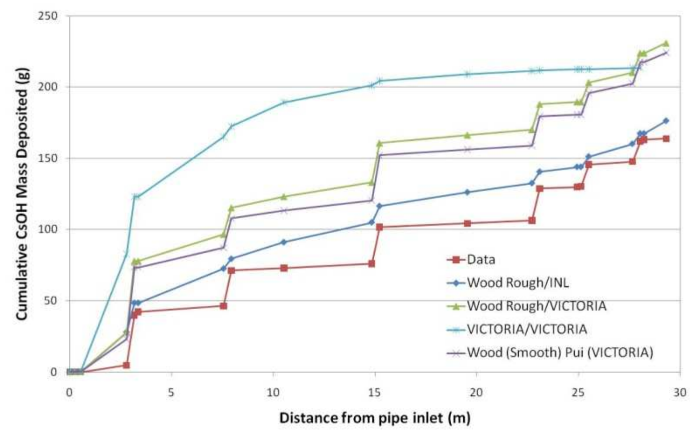
Assessments: Turbulent Deposition Model

- Wood (rough)/INL combination gives best overall results though it overpredicts deposition in straight sections and underpredicts deposition in bends.
- Wood (smooth)/Pui combination gives best results if deposition upstream in pipe section 4 (< 2.5 m) were correctly calculated.
  - Section 4 was a vertical pipe section
- Sehmel /Pui (VICTORIA) does not capture the deposition profiles of the experiment
- Dependency on number of sections is negligible

10 Sections



20 Sections



MELCOR 1.8.6 to 2.X Input Converter

- Previous standalone converter will be phased out
  - Difficult to maintain and debug
- SNAP converter
  - Easier to maintain
  - Available to all MELCOR users
  - Back conversion from 2.x to 186 as well as from 186 to 2.x
    - Useful for users developing 2.x decks and comparing to 186
    - Recent bugs reported by users are easier to identify by performing a "round-trip conversion" and testing because testing of the conversion is essentially performed with the same code version.

Miscellaneous New Input Record Improvements

- MELCOR now 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   0.25000000E+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   0.25000000E+05
CF_ARG   1 ! NARG CHARG              ARSCAL           ARADCN
               1   CF-VALU('OVERPRESS')  1.0     0.0
```

Miscellaneous New Input Record Improvements

- New CVH_THERM Card
  - Original M2.1 input was confusing and over-specified for certain conditions.
  - Implemented for ITYPTH=3
    - Currently optional but will be required
  - Replaces multiple input records
    - CV_PAS, CV_PTD, CV_PAD, CV_VOID, CV_AAD, CV_NCG, CV_FOG, CV_BND
  - Implemented as Table input
    - Data pairs (keyword and value)

```
CV_ID 'ROOM450'  450  !CVNAME, ICVNUM, 186 name: ROOM450
CV_TYP 'CVTYPE08' !CVTYP
CV_VAT   2     !N      CVZ            CVVOL
      1 0.0              0.0
      2 4.0              368.1
CV_THR NonEquil FOG -2   !ICVTHR, IPFSW, ICVACT
CV_PAS SEPARATE OnlyAtm SUPERHEATED   !IPORA, VaporState
CV_THERM 3
         1 PVOL 'TF' 'CV450PVOL'
         2 TATM 'TF' 'CV450TATM'
         3 'N2' 'EDF' 'EDFN2' 1  'O2' 'TF' 'CV450O2'
!*      9 - Next CV data ****************************************
CV_ID 'WEST-VOL500'  500  !CVNAME, ICVNUM, 186 name: WEST-VOL50
CV_TYP 'CVTYPE09' !CVTYP
CV_VAT   2     !N      CVZ            CVVOL
      1 0.0              0.0
      2 4.0              1.0E10
CV_THR NonEquil FOG ACTIVE   !ICVTHR, IPFSW, ICVACT
CV_PAS SEPARATE OnlyAtm SUPERHEATED   !IPORA, VaporState
CV_PTD PVOL    101351.699E+00
CV_AAD TATM 294.3
CV_NCG   2 RHUM 0.0                    !N NAMGAS  MLFR
                              1 'N2' 8.E-01
                              2 'O2' 2.E-01
```

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Miscellaneous New Input Record Improvements

- Alternate format for mass and temperature tables
  - Specify optional component or material after table length
    - If not present, assumes traditional format
  - First field is the axial elevation index
  - Following fields are values for increasing ring number 1, 2, 3, …
- Makes table more readable (able to observe trends)

Traditional Format

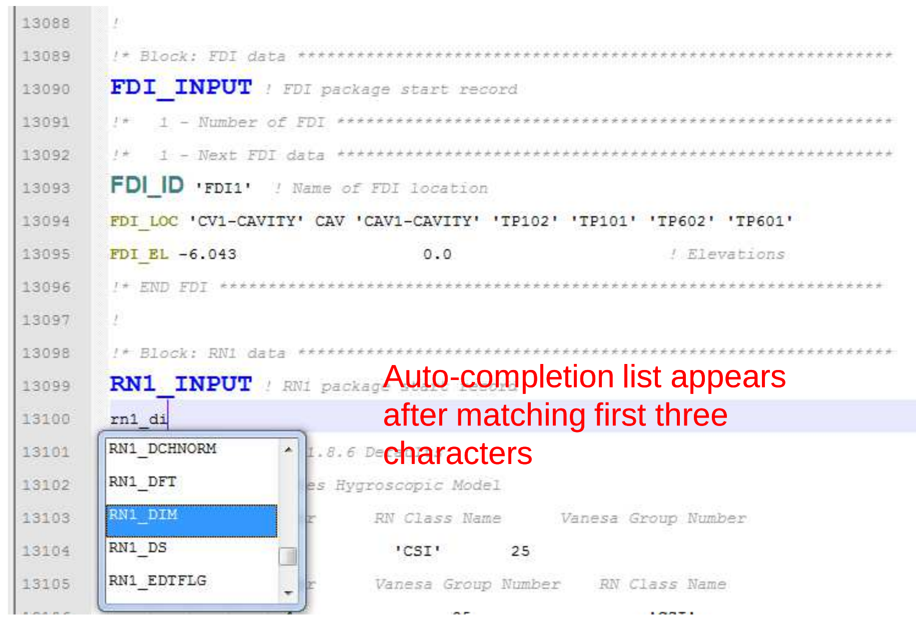
```
COR_CIT    62
!              TFU    TCL    TOS    TCN    TCB    TPD    TSS     TNS
    1  1  1 564.6 564.6 564.6 564.6 564.6 564.6 564.6
    2  3  1 564.6 564.6 564.6 564.6 564.6 564.6 564.!
    3  4  1 564.6 564.6 564.6 564.6 564.6 564.6 564.6
    4  4  2 564.6 564.6 564.6 564.6 564.6 564.6 564.6
    5  4  3 564.6 564.6 564.6 564.6 564.6 564.6 564.6
   19  7  2 716.0 571.9 571.9 571.9 571.9 571.9 571.9
   20  7  3 716.0 571.9 571.9 571.9 571.9 571.9 571.9
   21  7  4 716.0 571.9 571.9 571.9 571.9 571.9 571.9
   22  7  5 716.0 571.9 571.9 571.9 571.9 571.9 571.9
   23  8  1 754.0 575.6 575.6 575.6 575.6 575.6 575.6
   24  8  2 754.0 575.6 575.6 575.6 575.6 575.6 575.6
   25  8  3 754.0 575.6 575.6 575.6 575.6 575.6 575.6
```

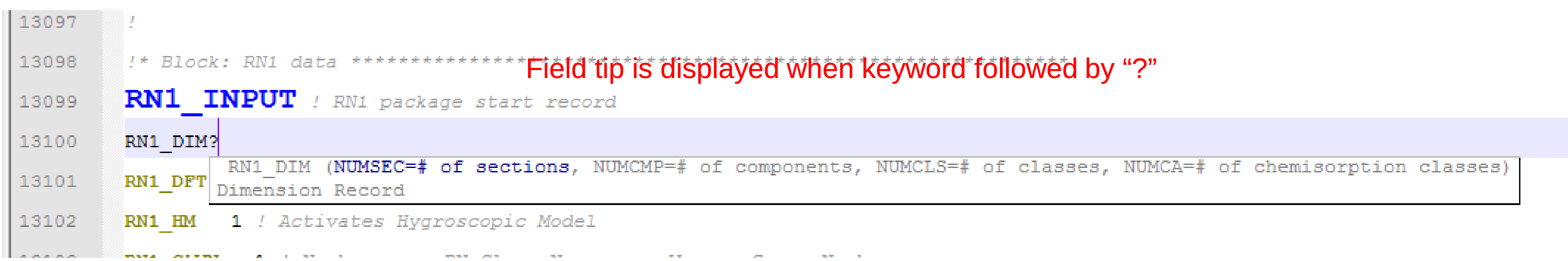
New alternate Format

```
COR_CIT   62   TFU
!    IA    Ring1    Ring2    Ring3    Ring4    Ring5
      1    564.6    564.6    564.6    564.6    564.6
      2    564.6    564.6    564.6    564.6    564.6
      3    564.6    564.6    564.6    564.6    564.6
      4    564.6    564.6    564.6    564.6    564.6
      5    564.6    564.6    564.6    564.6    564.6
      6    644.0    644.0    644.0    644.0    644.0
      7    716.0    716.0    716.0    716.0    716.0
      8    754.0    754.0    754.0    754.0    754.0
```

Notepad++ MELCOR 2.1 Language

- Recognition of MELCOR record identifiers
- Style applied to various levels of MELCOR records (comments are gray italics)
- Auto-completion of record identifiers
- Field tips are provided for record fields
- Can be updated by user
- Can be downloaded from download manager with a readme file for installation





MELCOR
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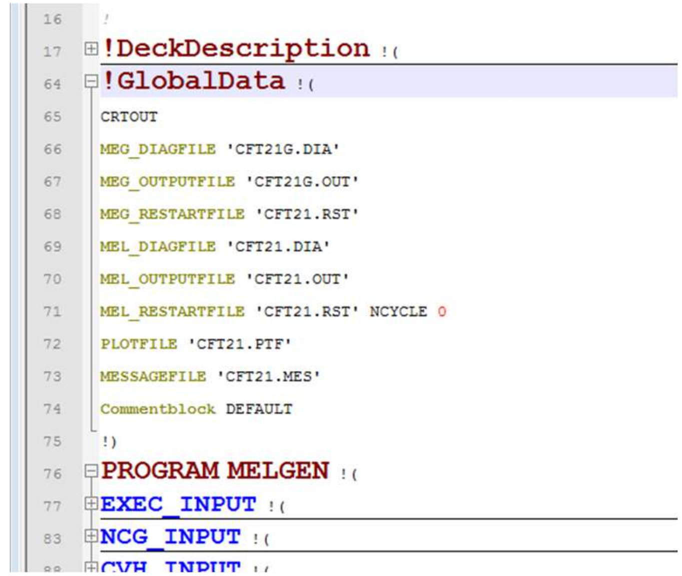
Utilities

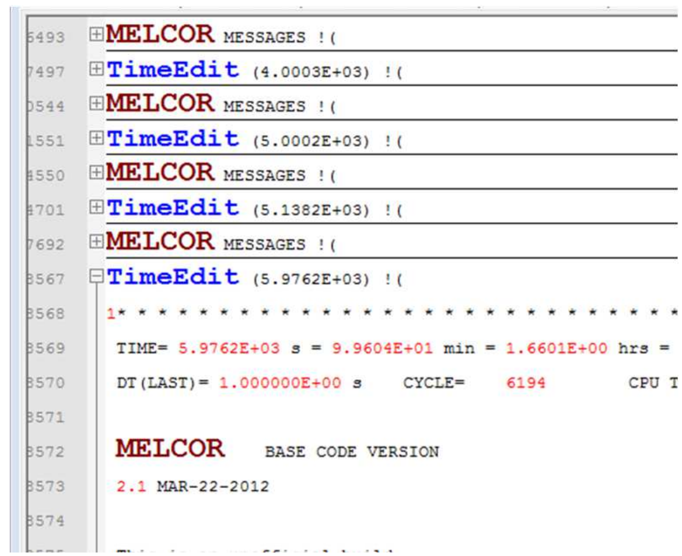
Notepad++ MELCOR 2.1 Collapsible I/O

- 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

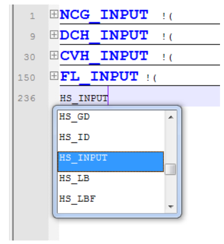


Output

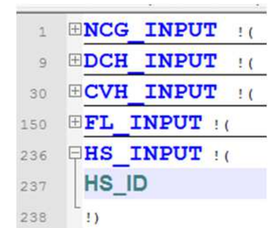


NotePad++ MELCOR Plugin

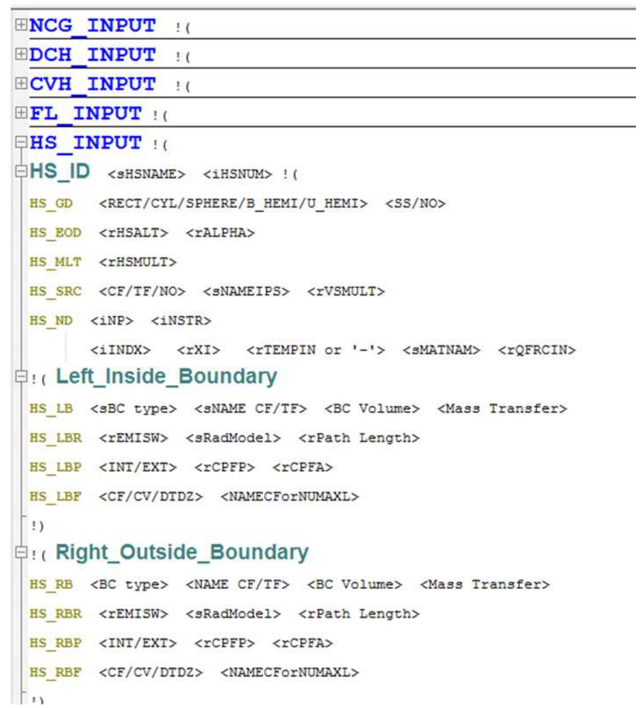
- MELCOR Plugin for NotePad++
  - Currently investigating (not developing)
- User guide information available to text editor
  - Context intelligence
- Navigation sidebar
  - Object recognition
- MELCOR Template
  - QuickText Plugin already allows generation of templates (right) but want to incorporate capability into a MELCOR plugin
  - Typing a MELCOR record identifier, followed by a tab, generates template with user prompts



1)Type in Keyword

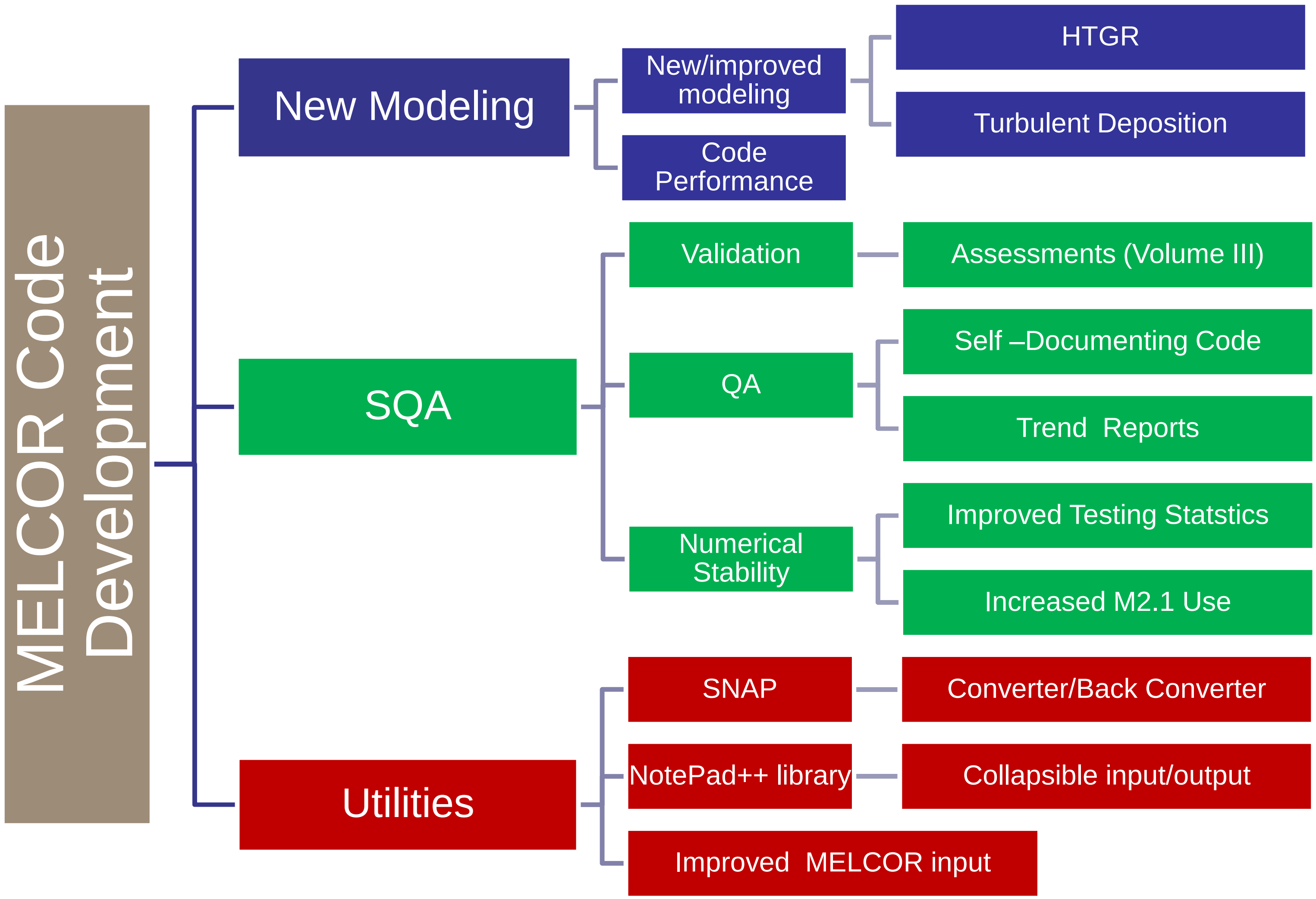


2) Press Tab for HS_INPUT template



3) Press Tab again for HS_ID template

Questions?


MELCOR Code Development
New Modeling
New/improved modeling
HTGR
Turbulent Deposition
Code Performance
SQA
Validation
Assessments (Volume III)
QA
Self –Documenting Code
Trend Reports
Numerical Stability
Improved Testing Statstics
Increased M2.1 Use
Utilities
SNAP
Converter/Back Converter
NotePad++ library
Collapsible input/output
Improved MELCOR input