SAND2012-9830P

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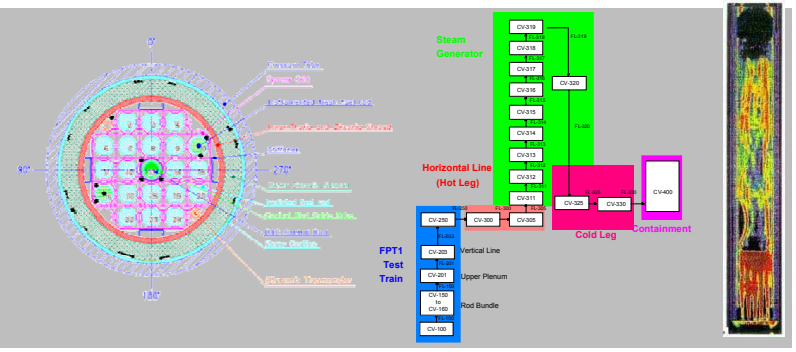
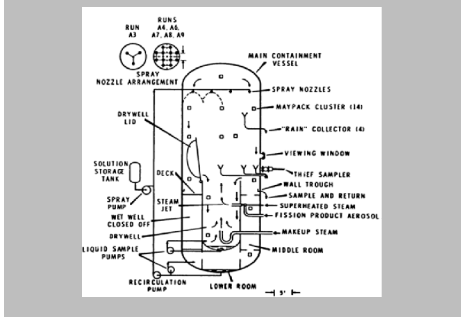
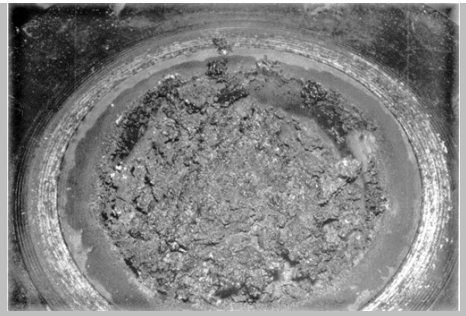






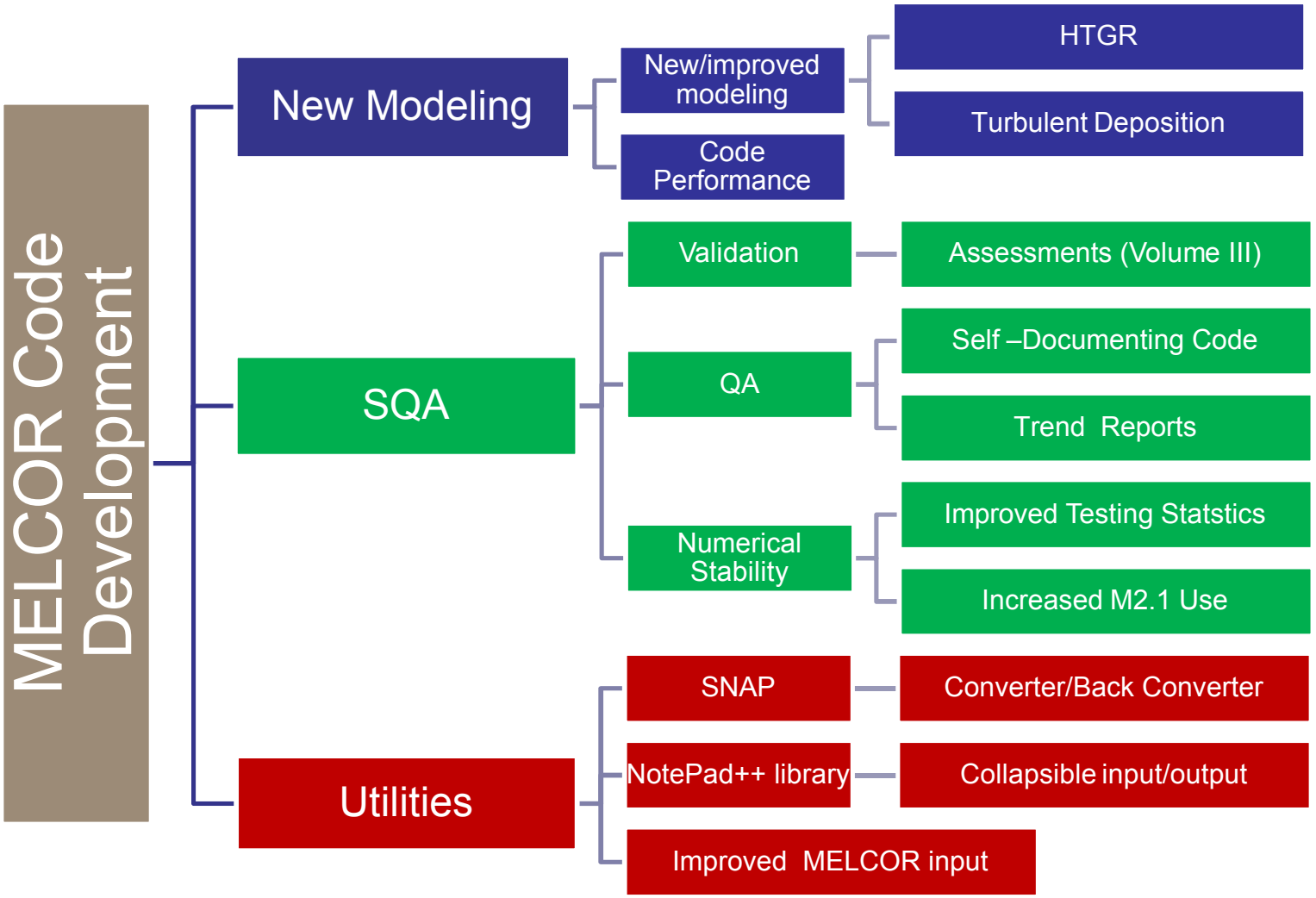
MELCOR Code V&V and SQA

Workshop on Operational Experience and Advances in MELCOR Modeling

Shenzhen, China, November 19-23, 2012

Presented by Larry Humphries (llhumph@sandia.gov)

MELCOR Code Development



MELCOR Software Quality Assurance Best Practices

Sandia National Laboratories

Emphasis is on Automation

Affordable solution

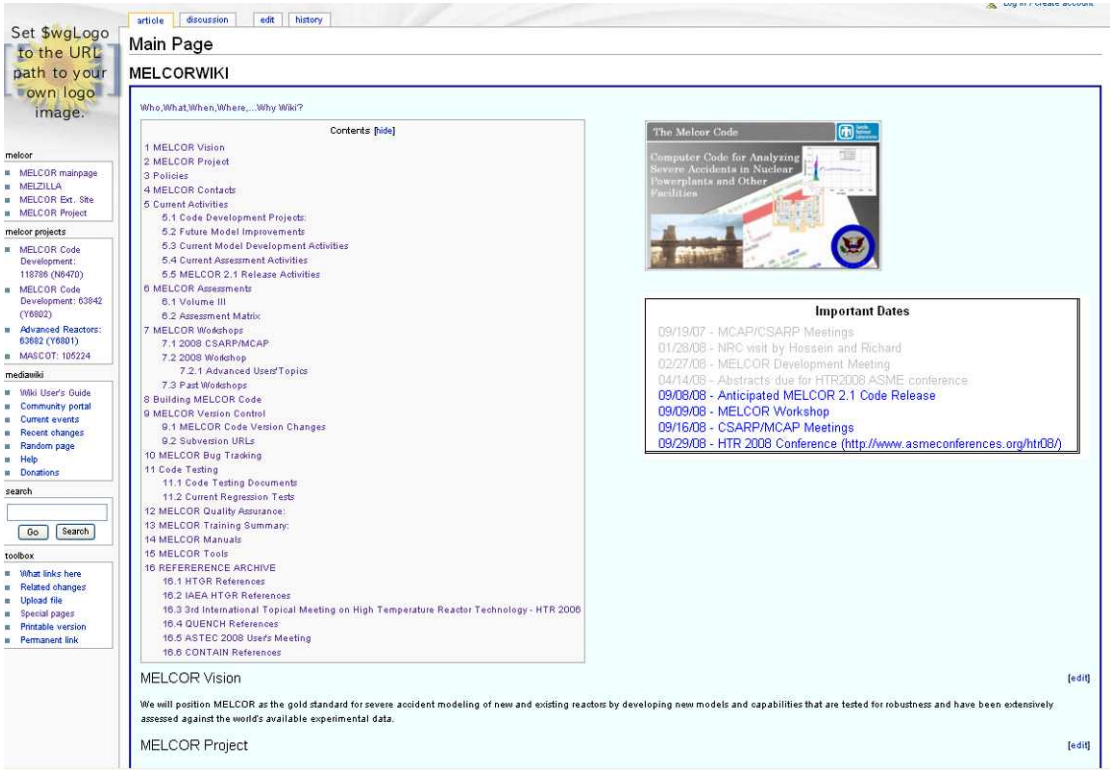
Consistent solution

- 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 Developers Wiki Site – Internal Use

Sandia National Laboratories

- MELCOR Developers Wiki
  - Archive records
    - Requirements, design, and testing
    - Regression tests
    - Assessment work
  - Information Sharing
    - Debugging Policies
    - Testing Policies
    - Code Development practices
    - Coding Conventions
    - Lessons Learned
    - Software Risk Management
    - Version Changes
    - Reference Library



Software Configuration Management (SCM)

- Methodology for managing code changes in a team development environment
- All SCM systems provide the following essential features:
  - Concurrency Management
    - Concurrency refers to the simultaneous editing of a file by more than one person.
      - Resolve places where code changes conflict
  - Versioning
    - Tracks file versions
    - Makes it possible to roll back changes or recreate a version
  - Synchronization
    - Update changes made by other developers

Code Review

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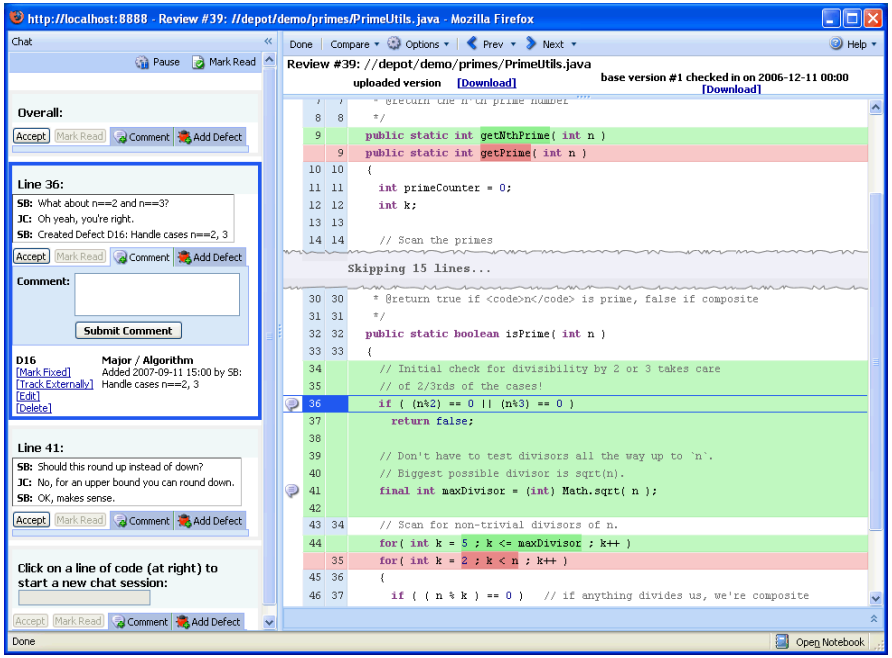
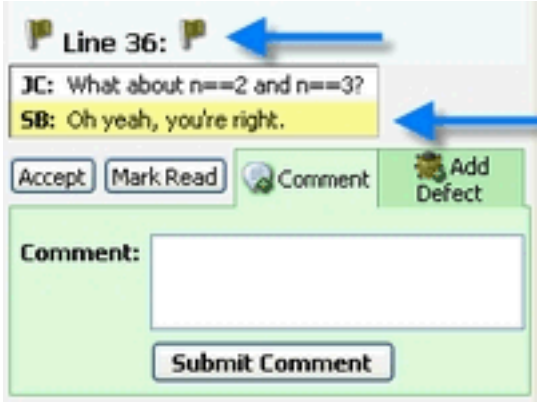
- SQA Requirements:
  - As outlined in both Sandia Corporate Procedure:IM100.3.2 and ASME NQA-1, an important aspect of a Software Quality Assurance program involves review and documentation for the entire life cycle of software development, from requirements and design to implementation and testing.
- Benefits
  - Code reviews can reduce number of defects in new code
  - Code reviews can lead to better documentation of code & better understanding of new modeling among team members
  - Code reviews provide a process by which seasoned programmers can pass experience and knowledge to less experienced programmers.
  - Improves code readability
- Problems
  - Code reviews can be time consuming or cursory
  - Code reviews are not well documented
  - Reviews can be adversarial and not productive

CodeCollaborator

Sandia National Laboratories

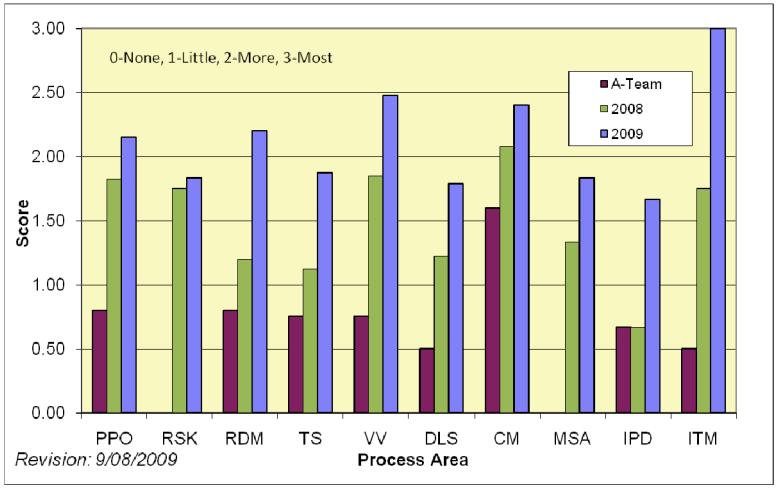
- HTML based collaboration
  - Browser is all that is needed to access
  - Shared licenses for multiple users
- Threaded, contextual chat
  - File changes, chat conversations, and defects are linked together.
  - Each conversation is threaded by file and line number and can be viewed simultaneously with file content.
  - Choose between multiple views, or download differences to your local machine for further inspection and testing.
  - Hyperlink directly to a file or line numbers
- Version Control Integration
  - Integrates with Subversion
- Asynchronous Review
  - Perform and manage reviews even when participants are separated by many timezones.
  - Comments are tracked like newsgroups
  - Review PDFs or Image files

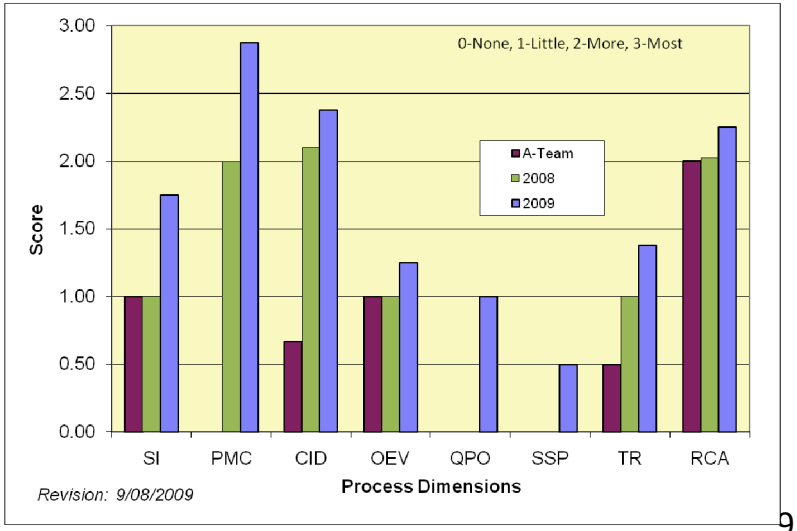




Software Quality Assurance Annual Re-evaluation

- Process areas
  - Project planning and oversight, PPO
  - Risk Management, RSK
  - Requirements Development and Management, RDM
  - Technical Solution, TS
  - Verification and Validation, VV
  - Development and Lifecycle Support, DLS
  - Configuration Management, CM
  - Measurement and Analysis, MSA
  - Integrated Product, IPD
  - Integrated Teaming, ITM
- Process Dimensions
  - Stakeholder Involvement , SI
  - Ongoing Process Monitoring and Control, PMC
  - Collected Improvement Data, CD
  - Objective Evaluations, OEV
  - Quantitative Objectives Defined for Processes, QPO
  - Stable Subprocess Performance, SSP
  - Training , TR
  - Problem Reporting & Corrective Action, RCA





Full Compiler/Linker Options Encoded in MELCOR

- Code pedigree printed in output and diagnostic file
  - Provides a QA check for reproducing results

```
MELGEN diagnostic output    ILEHBLT     5/09/12   07:16:21
TestCav
This is an official build.
MELGEN 2.1.4443
Executing on: Intel(R) Xeon(R) CPU           E5410  @ 2.33GHz
Configuration information:
Configuration RL_NL_060
Subversion revision: 4443

Build Processor: Intel(R) Xeon(TM) CPU 3.20GHz

Compiler: Intel(R) Visual Fortran Compiler Professional for applications runnin
g on IA-32, Version 11.1    Build 20100203

Compiler settings:
/fpp /nologo /O2 /Oy- /fpp /DLICENSING_INACTIVE /DWINDOWS /DWIN_32 /DSNAP /DARC
H_INT  /DGET_CPU_INFO /I..\compiled_modules /assume:nocc_omp /noaltparam /error
_limit:25 /warn:errors /nodebug /real_size:64 /Qauto /Qprec-div /Qprec-sqrt /as
sume:protect-parens /check:none /libs:static /threads /iface:cvf /align:rec8byt
e /align:dcommons /align:records /QaxSSE4_2,SSE4_1,SSSE3,SSE3,SSE2,SSE /traceba
ck /fp:source /module:..\compiled_modules /check:none

Linker settings:
/NODEFAULTLIB:LIBCMT /verbose:lib /LIBPATH:..\RL_NL_060_Library /LIBPATH:C:\Pro
gram Files\Microsoft SDKs\Windows\v7.0\Lib  /LIBPATH:C:\Program Files (x86)\Int
el\Compiler\11.1\60\lib\ia32 /LIBPATH:..\licensing\lib /LIBPATH:..\LibDependenc
ies /LIBPATH:..\SNAPAdapter\lib
```

Reported:

- Compiler/Linker options
- SVN version of source
- Compiler Version
- Type of machine used to build code
- Type of machine used to execute code
- Files excluded from optimization

- Is also accessible by running executable with command-line arguments

  Melcor.exe -config

Optimization Studies

- Optimization can lead to different results
  - Uninitialized Variables (this is just one possible reason)
  - Can make it difficult to reproduce errors observed in the release version in the debugger
- Optimization Utility to test optimization of each file
  - Optimized and unoptimized versions of all object files are built
    - An entire module is tested for optimization first (optimized library is linked with debug library for all other modules)
    - A fast running test deck is run and the output is compared with the debug version for differences
  - If differences are observed, each file in the module is tested individually.
    - Testing of optimized files is performed in parallel
- Results indicate that only a few files cannot yet be optimized.
- Optimized executables are built with these files unoptimized
  - Give identical results to debug version !!!

MELCOR Testing Overview

- Unit Testing
  - All input options should be tested
  - Ranges of input should be tested.
    - Values outside of reasonable input should be tested for error messages
- Automated Build & Test
  - Test all revisions and 'catch' revisions that break the build
  - Build on multiple platforms (currently only Windows) and compilers (CVF & Intel)
  - Suite of fast-running test problems
  - Objective is to correct problems sooner
  - MOE utility for searching output for specified test for success criterion
- Code Release Testing
  - Larger suite of test cases
  - Test recent bug fixes
  - Test new modeling
- Code Test Coverage
- Code Profiling

MELCOR Code Testing

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- Build Testing
  - Automated to perform Nightly Builds
    - MELCOR 1.8.6 Windows Compaq Visual FORTRAN (CVF)
    - MELCOR 2.X Windows CVF
    - MELCOR 2.X Windows Intel Visual FORTRAN (IVF)
    - MELCOR 1.8.6 Linux IVF
    - MELCOR 2.X Linux IVF
  - Using CMAKE to generate make files for use on Unix variants to extend building on other platforms & other compilers
- Code Testing
  - Performed Daily (at least frequently)
  - Standard test cases chosen for physics coverage over 140 test cases
    - New cases added regularly
    - Debug & optimized versions tested
    - Testing of developmental branches
  - Comparison of results
    - Consistent results between Windows & Unix
    - Consistent results between SNL & IBRAE

Case	BUR	CAV	CF	COR	CVH	DCH	FCL	FDI	FL	HS	NCG	PAR	RN	SPR
M-8-1 NoMix			X		X				X	X	X			
M-8-1 SYM			X		X				X	X	X			
Lace7			X		X	X			X	X	X		X	
Lace8			X		X	X			X	X	X		X	
Vanam-M3			X		X				X	X	X		X	
Molten Salt			X	X	X				X	X	X			
PHEBUS-B9			X	X	X				X	X	X			
FPT1			X	X	X	X			X	X	X		X	
LOFT			X	X	X	X			X	X	X			
Test Inow	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SURRY (LBLOCA)	X	X	X	X	X	X	X	X	X	X	X		X	X
Zion (SBO)		X	X	X	X	X	X	X	X	X	X	X	X	X
PeachBottom (SBO)	X	X	X	X	X	X			X	X	X		X	X
Grand Gulf (SBO)	X	X	X	X	X	X		X	X	X	X		X	

Table 1-1: Physics Package Coverage

MELZILLA Bug Reporting

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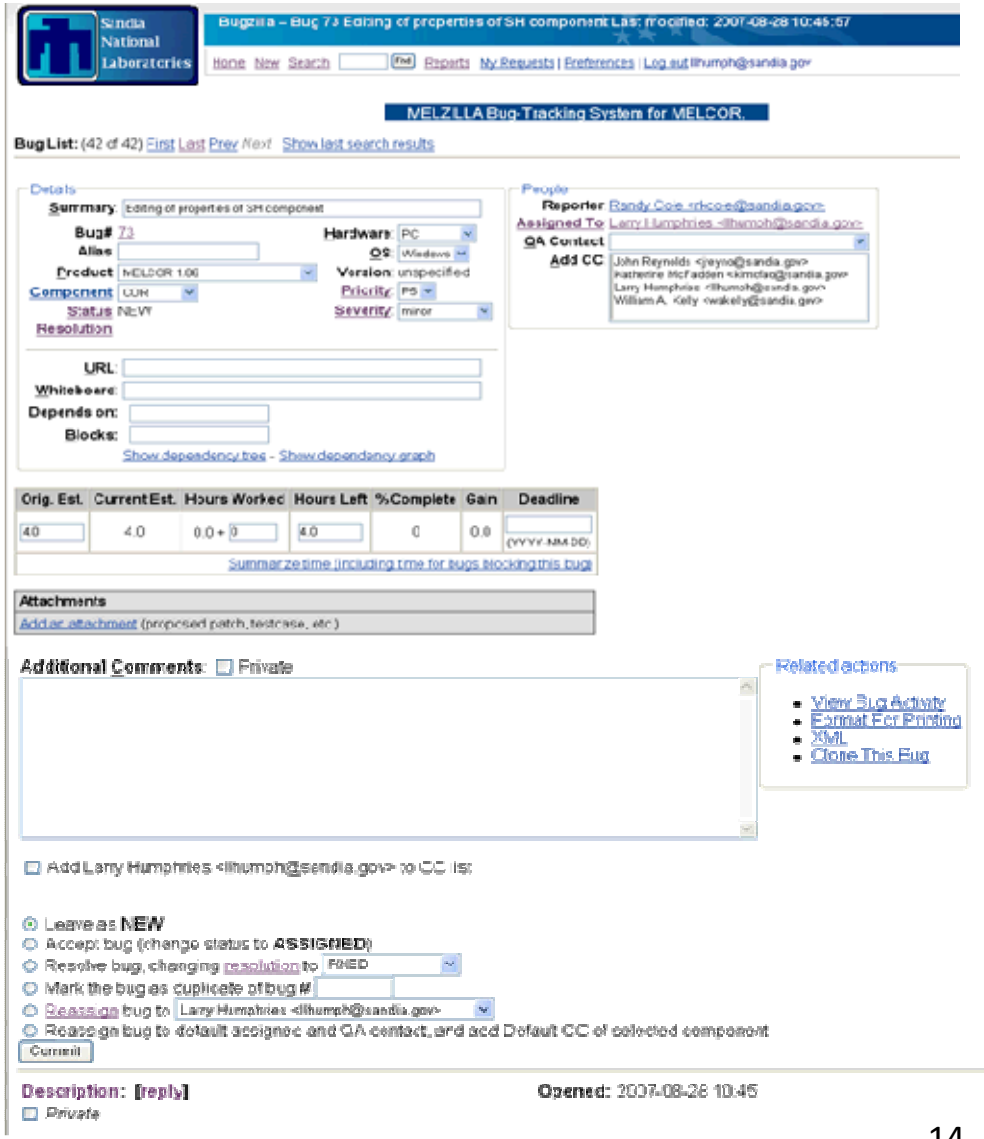
- Bugzilla site for bug reporting, tracking, and information
  - Available from SNL web page
- Users submit bugs and details
  - OS, Hardware, affected packages, severity
  - Bug description
  - Attachments
- Comments and attachments can be marked private and not visible to other users

MELCOR 1.8.6 (since 7/07)	
Number of Bugs Reported	**105**
Number of Bugs Resolved:	**72**
Number of Bugs Unresolved:	**33**
Number of Bugs Reported (this year):	**36**
Number of Bugs Resolved (this year):	**27**
Number of Bugs Unresolved (this year):	**9**
Number of Unresolved User Bugs :	**15**
MELCOR 2.1 (since 9/07)	
Number of Bugs Reported	138
Number of Bugs Resolved:	98
Number of Bugs Unresolved:	40
Number of Bugs Reported (this year):	84
Number of Bugs Resolved (this year):	77
Number of Bugs Unresolved (this year):	7
Number of Unresolved User Bugs :	15



SVN/Bugzilla/Visual Studios/Testing Integration

- Integrates Subversion with Windows explorer
  - All commands are available directly from the windows explorer.
  - See the status of files directly in the Windows explorer
  - Allows moving files by right-dragging them in the windows explorer
- Integration with issue tracking systems
  - A separate input box to enter the issue number assigned to the commit, or coloring of the issue number directly in the log message itself
  - When showing all log messages, an extra column is added with the issue number. You can immediately see to which issue the commit belongs to.
  - Issue numbers are converted into links which open the web browser directly on the corresponding issue
  - Optional warning if a commit isn't assigned to an issue number
- Integration with MSWord compare
- Integration with Visual Studio
  - All modifications apparent within Visual Studios
  - Easy to see and check in all modified files (still not automatic)

MELCOR: Self-Documenting Code

Sandia National Laboratories

- 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 Quality Assurance: Tracking Code Changes

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- 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

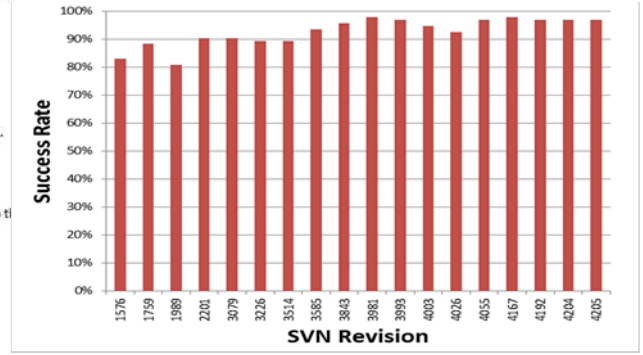
This is a list of important changes in MELCOR since revision 3228, which was released at the 2011 MELCOR User's Workshop. Content in this document was adapted from the the MELCOR source code configuration system change log. Some details were removed to improve readability. Other details have been expanded 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.

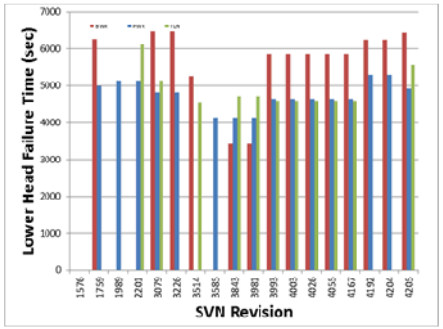
Where bug numbers are listed, a hyperlink is provided to allow you to read the details in Melzilla, our defect-tracking system. Please note that bug numbers don't necessarily mean there actually was a bug to fix. These numbers are generated for feature requests as well as defects.

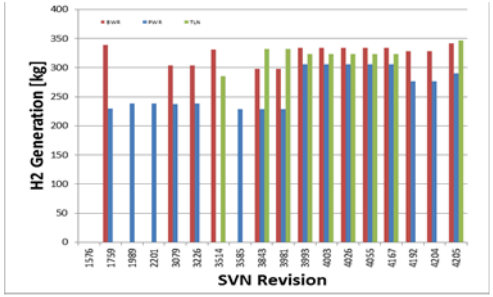
Revision: 4011
Official 2.1.4011 release.

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







Importance of Code Validation

- Code Developers
  - provide the necessary guidance in developing and improving models
  - Desirable to have validation test at time of model implementation
- Code Users
  - Increased confidence in applying code to real-world application
  - Improved understanding of modeling uncertainties

Historical Assessments

Sandia National Laboratories

- **Validations should be performed by both**
  - **Developers**
    - **More intimate understanding of the model nuances**
  - **Code Users**
    - **Greater knowledge of real-world applications**
- **Validations should focus on what can be learned from the exercise**
  - **Should avoid trying to 'tune' results**

Gauntt, R. O., Cash, J.E., Cole, R. K., Erickson, C. M, Humphries, L.L., Rodriguez, S. B., Young, M. F., 2005, "MELCOR Computer Code Manuals, Vol. 1: Primer and User's Guide, Version 1.8.6," NUREG/CR 6119, Vol. 1, Rev. 3, U.S. Nuclear Regulatory Commission, Washington, DC.

Tills, J, Notafrancesco, A.,Longmire, P., "An Assessment of MELCOR 1.8.6: Design Basis Accident Tests of the Carolinas Virginia Tube Reactor (CVTR) Containment (Including Selected Separate Effects Tests)", SAND2008-1224 (2008).

Souto, F.J., Haskin, F.E., Kmetyk, L.N., "MELCOR 1.8.2 Assessment: Aerosol Experiments ABCOVE AB5, AB6, AB7, and LACE LA2," SAND94-2166 (1994),

Tautges, T.J., "MELCOR 1.8.2 Assessment: The MP-1 and MP-2 Late Phase Melt Progression Experiments," SAND94-0133 (1994)

Kmetyk, L.N., "MELCOR 1.8.3 Assessment: CSE Containment Spray Experiments," SAND94-2316 (1994).

Tills, J., Notafrancesco, A, Longmire, P., "An Assessment of MELCOR 1.8.6: Design Basis Accident Tests of the Carolinas Virginia Tube Reactor (CVTR) Containment (Including Selected Separate Effects Tests)," SAND2008-1224 (2008).

Tautges, T., "MELCOR 1.8.2 Assessment: The DFI-4 BWR Damaged Fuel Experiment," SAND93-1377 (1993).

Tautges, T., "MELCOR 1.8.3 Assessment: GE Large Vessel Blowdown and Level Swell Experiments," SAND94-0361 (1994).

Kmetyk, L.N., "MELCOR 1.8.2 Assessment: IET Direct Containment Heating Tests," SAND93–1475 (1993).

Kmetyk, L.N., "MELCOR 1.8.1 Assessment: LACE Aerosol Experiment LA4," SAND91–1532 (1991).

Kmetyk, L.N., "MELCOR 1.8.1 Assessment: LOFT Integral Experiment LP-FP-2," SAND92–1373 (1992).

Kmetyk, L.N., "MELCOR 1.8.1 Assessment: Marviken-V Aerosol Transport Tests ATT-2b/ATT-4," SAND92–2243 (1993).

Gross, R.J., "PNL Ice Condenser Aerosol Experiments," SAND92–2165 (1993).

Kmetyk, L.N., "MELCOR 1.8.1 Assessment: FLECHT SEASET Natural Circulation Experiments," SAND91-2218 (1991).

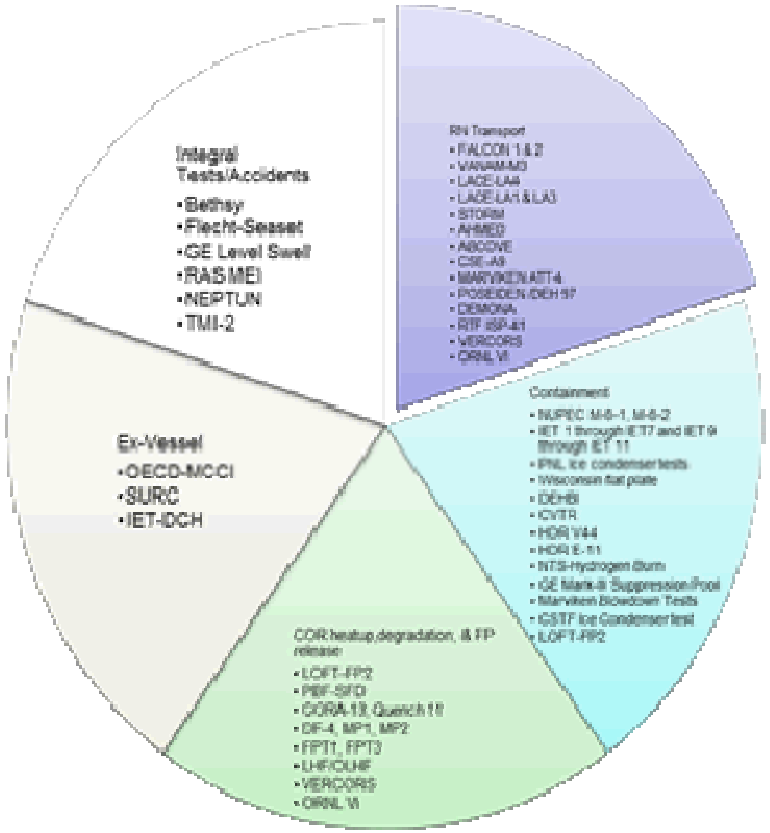
Kmetyk, L.N., "MELCOR 1.8.1 Assessment: ACRR Source Term Experiments ST-1/ST-2", SAND91-2833 (1992).

Selection of Validation Test Cases

- Separate Effects Tests
  - Designed to focus on an individual physical process
  - Eliminates complications from combined effects
  - May be difficult or impossible to design a single test to isolate a single process
  - Sometimes geometry or boundary conditions for SETs are difficult to model within an integral code
- Integral Tests
  - Examines relationships between coupled processes
  - Tests should be selected that are applicable to the calculation domain of the code.
- Actual Plant Accidents
  - TMI, Chernobyl, Fukushima, etc.
  - Captures all relevant physics
  - Poorly 'instrumented'
- International Standard Problems
  - Well documented
  - Often there are code-to-code comparisons to compare modeling approaches

Validation Code Coverage

- 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
  - Pool scrubbing
  - Iodine pool chemistry
  - Suppression pool level response
  - Vent clearing
  - Engineering Safety Features
    - Sprays
    - Ice Condensers



Coolant Boil-off

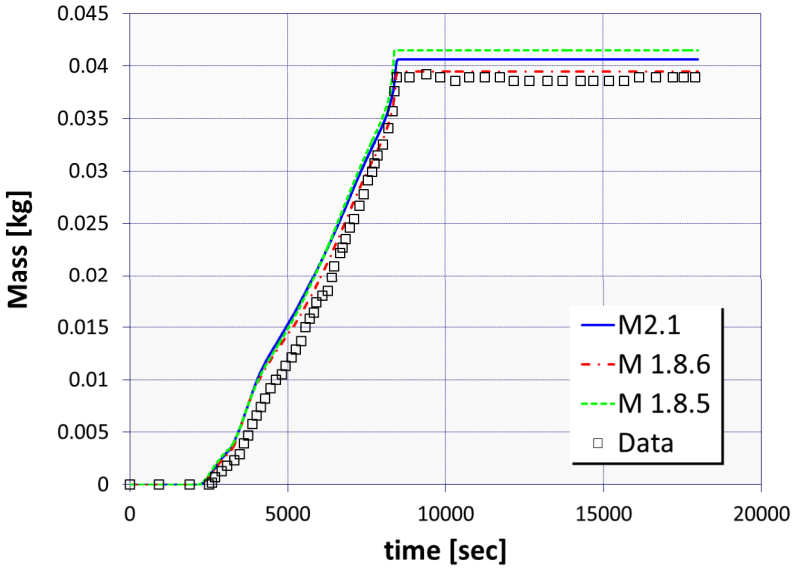
- Modeling
  - Standard heat transfer coefficients
  - Equation of state for water
  - Inclusion of non-condensible gases
  - Bubble separation model assumes that the volume flow of bubbles varies linearly along a CV, from zero at the bottom and a maximum at the top
    - Does not account for bubbles flowing from adjacent CVs
- Challenges/Findings
  - Level swell is better predicted by a single control volume than from a finely subdivided stacked volume
  - Model for bubble rise and phase separation needs to be modified for multiple CVs
- Validation Cases
  - NEPTUN 5006, 5007, GE Level Swell, Bethsy-6.9c

Oxidation – Hydrogen Generation

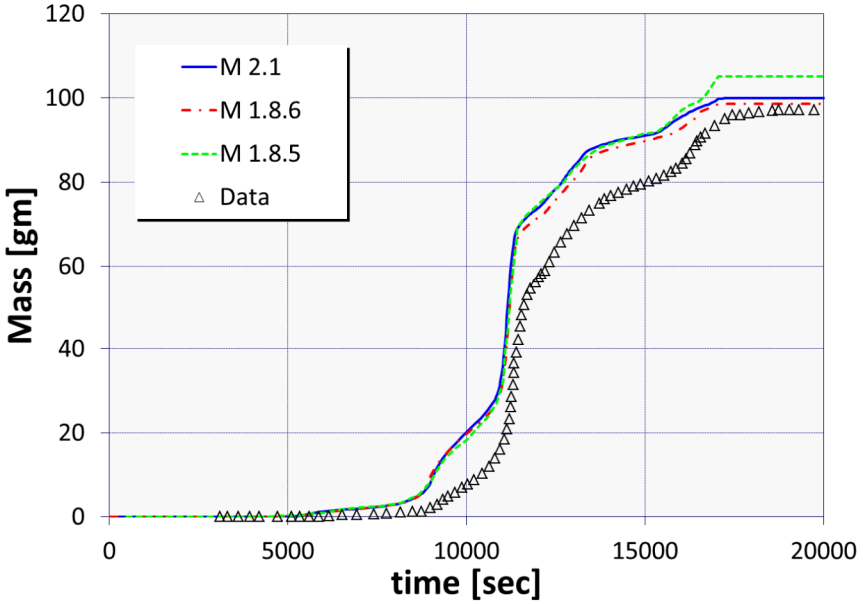
- Modeling
  - Standard parabolic kinetics, with appropriate rate constant expressions
    - Zircaloy
      - Urbanic-Heidrich constants
    - Steel
  - For very low oxidant concentrations, gaseous diffusion may limit reaction rate.
- Challenges
  - Difficult or impossible to discriminate between Zr and Steel oxidation in experiments
  - Differences in oxidation can be masked by differences in core degradation
- Validation Cases
  - Phebus B9, FPT1, FPT3, CORA-13, LOFT-FP2, PBF SFD, Quench-6

Oxidation – Hydrogen Generation

PHEBUS-B9 hydrogen generation



FPT-1 hydrogen generation



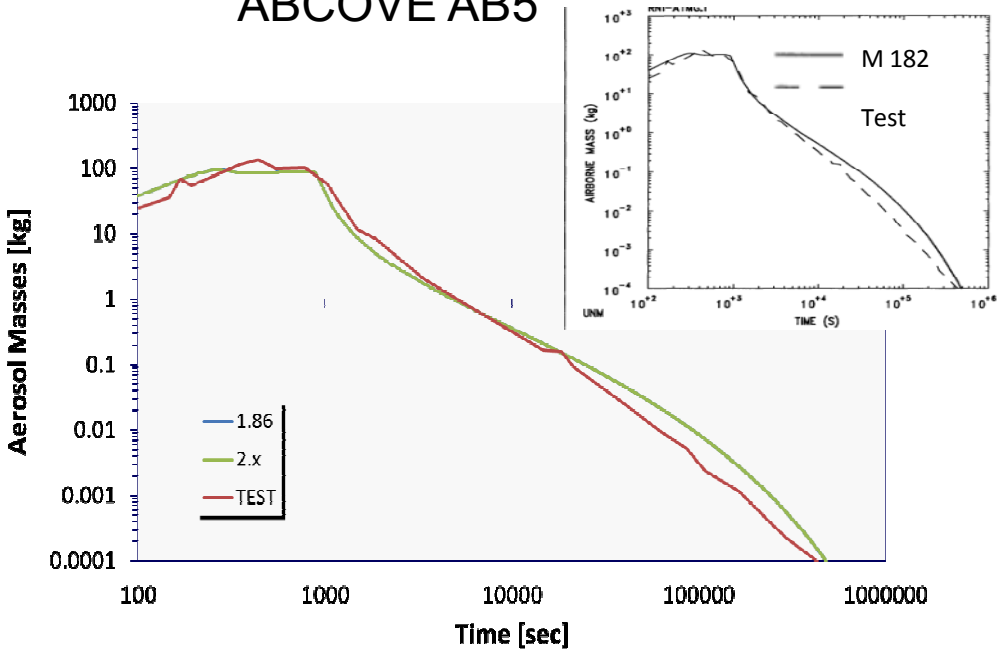
Aerosol Dynamics Models

- Modeling
  - MAEROS
    - Multisection (size), multicomponent (type of aerosol)
    - Agglomeration
    - Deposition
      - Gravitational, Brownian diffusion, thermophoresis, diffusiophoresis
  - Condensation and Evaporation at surfaces
    - Decoupled from MAEROS
    - TRAP-MELT2 code
- Validation Cases
  - Simple geometry: ABCOVE (AB5 & AB6), LACE(LA4),
  - Multi-compartment geometry: VANAM (M3), DEMONA(B3)
  - Deposition: STORM, LACE(LA1, LA3)

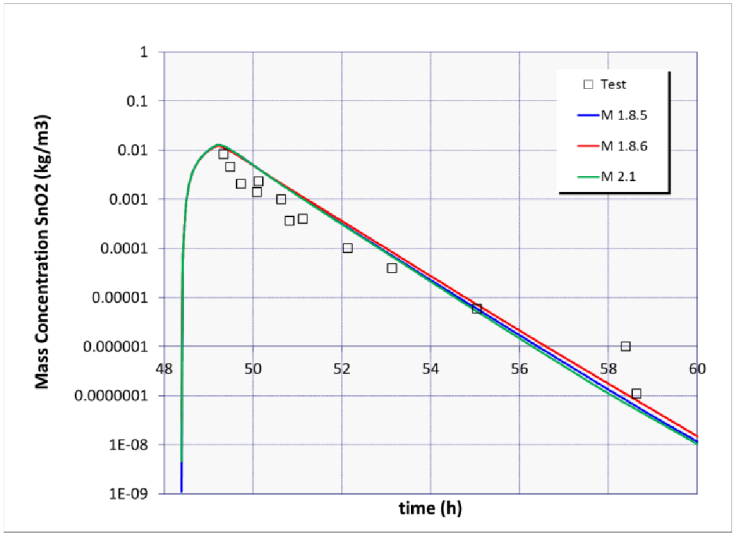
Aerosol Physics Modeling

Sandia National Laboratories

ABCOVE AB5



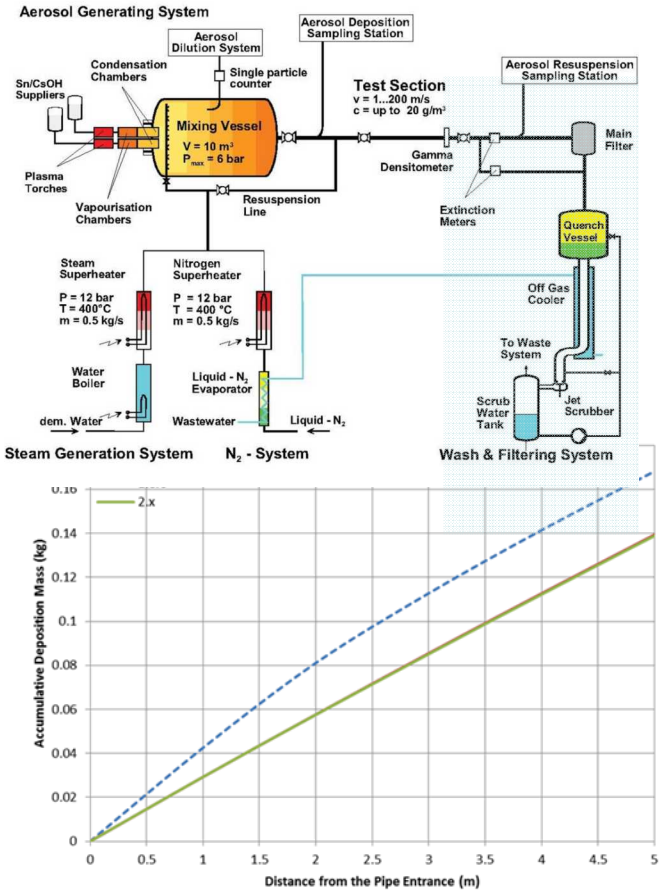
DEMONA-B3



RN Deposition - Thermophoresis

Sandia National Laboratories

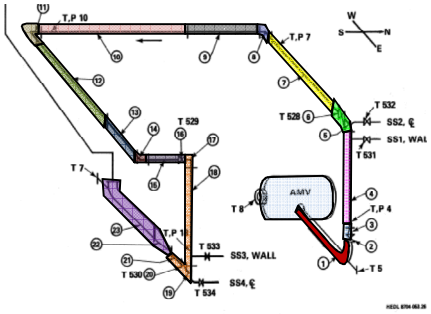
- ***General Description:***
  - The STORM test SR-11, was intended for examining aerosol deposition and resuspension in pipes and included two distinct phases: (1) the aerosol deposition by thermophoresis and eddy impaction, and (2) aerosol resuspension under a stepwise increasing gas flow. MELCOR does not have a resuspension model and the second phase was not modeled.
- Recent analysis
  - Modest under prediction of deposition along the test train. Currently under investigation.
  - Turbulent Deposition is slightly important

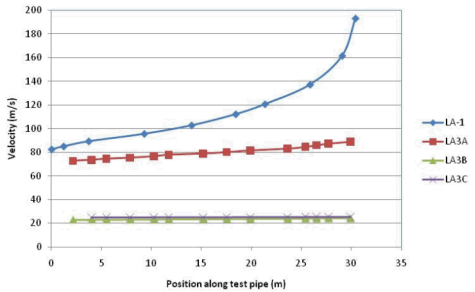


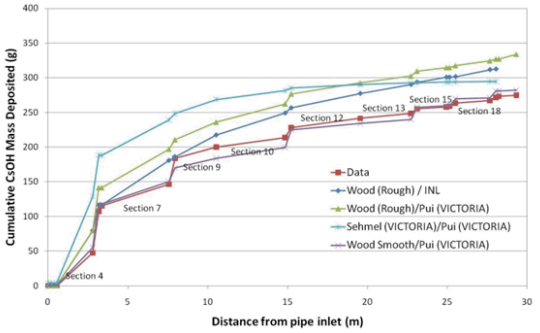
RN Deposition – Turbulent Deposition

Sandia National Laboratories

- ***General Description:***
  - The LACE LA1 and LA3 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. The effects of gas velocity, aerosol composition and aerosol size were considered.
- ***Important Physics:***
  - Turbulent deposition of aerosols in pipes. Deposition of aerosols in pipe bends.
- ***Results & Findings:***
  - MELCOR provides a reasonable estimate of deposition, even for coarse nodalization
  - Bend models are able to capture deposition in pipe bends
  - Resuspension and entrainment of deposited material important for high Re number







Hygroscopic Model

Sandia National Laboratories

- ***General Description:***
  - A series of hygroscopic aerosol experiments were conducted at the AHMED Test Facility by injecting NaOH in aerosol form into an atmosphere with controlled humidity.
- ***Important Physics:***
  - Hygroscopic effects under differing humidity conditions and the impact on aerosol masses available for release.
- ***Results & Findings:***
  - Both MELCOR 2.x and 1.86 simulations were performed at various RH and their results were compared with experiment data. At these RHs, the MELCOR simulations always yielded results that were close to the test data.

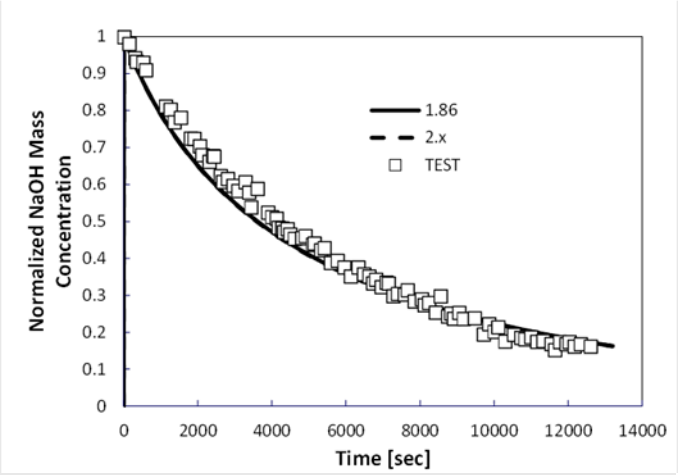


Figure 1. Normalized NaOH concentraions at RH=22%.

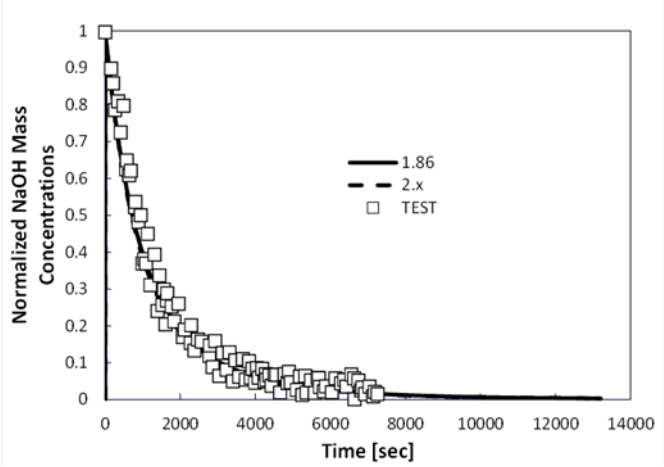
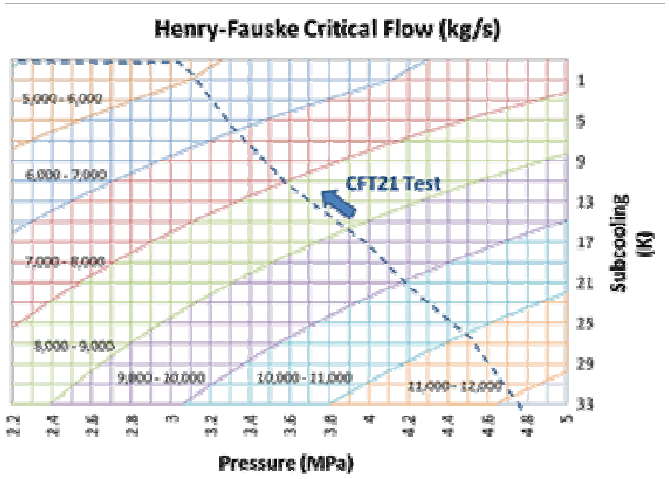


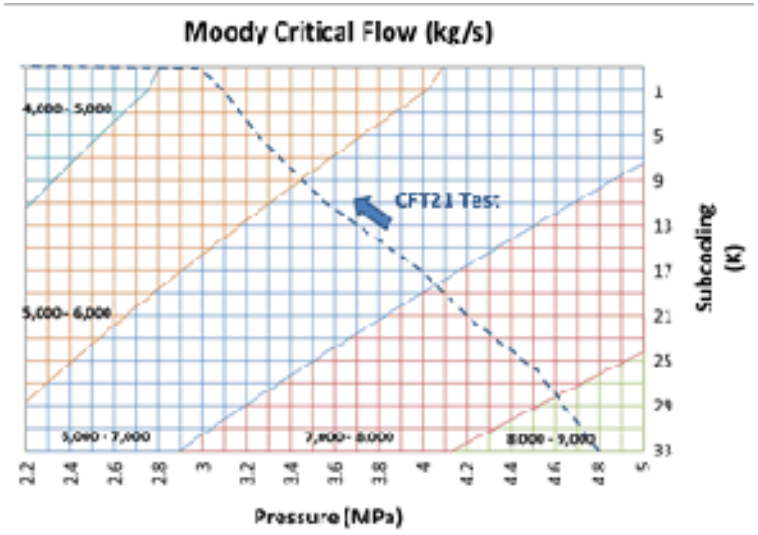
Figure 1. Normalized NaOH concentraions at RH=96%.

Critical Flow Modeling

Sandia National Laboratories

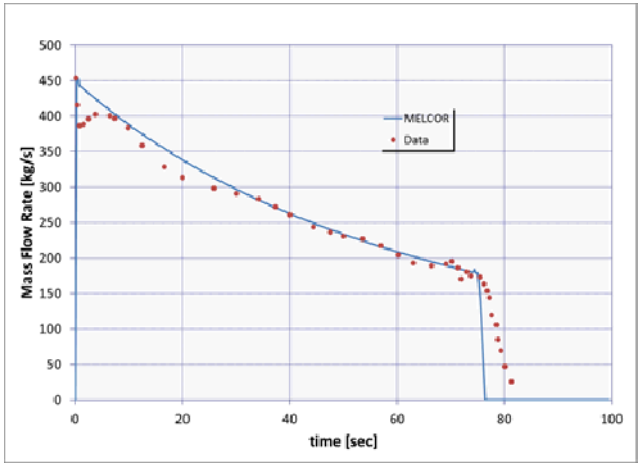
- Modeling
  - Only Atmosphere
    - sonic flux at the minimum section in the flow path
  - Only Pool
    - Subcooled water
      - Henry-Fauske
    - Two-phase water
      - Moody
  - Atmosphere & Pool
    - weighted average for the two phases
- Observations
  - Atmosphere and subcooled conditions well-predicted
  - Two-phase water predicts higher critical flow rates
- Experiments
  - MARVEKIN CFT-21 & JIT-11
  - GE Level Sell,

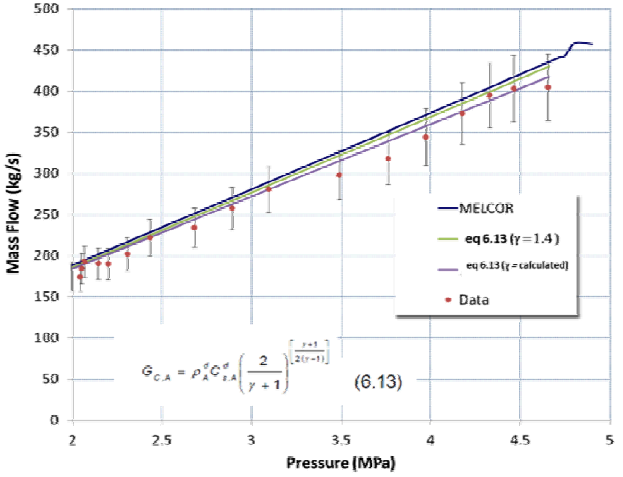




Critical Flow: Only Atmosphere

- Time variation of flow calculated by MELCOR is consistent with test data
- Mass flow rate vs vessel pressure
  - mass flow rate is independent of the downstream pressure
  - Experimental uncertainty of 5% indicated by error bars



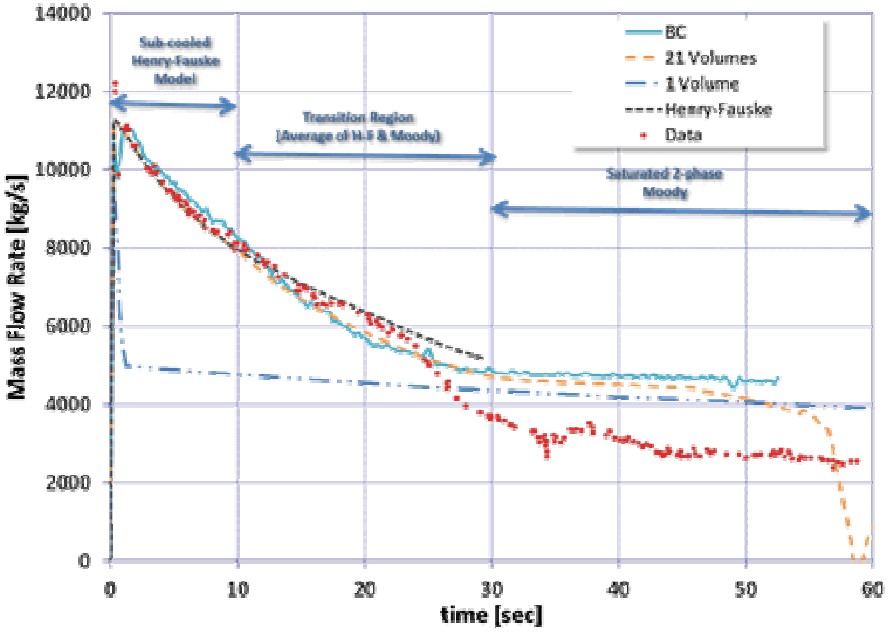


Critical Flow: Sub-Cooled and 2-Phase Flow

Sandia National Laboratories

- 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%.

MARVIKEN CFT-21



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

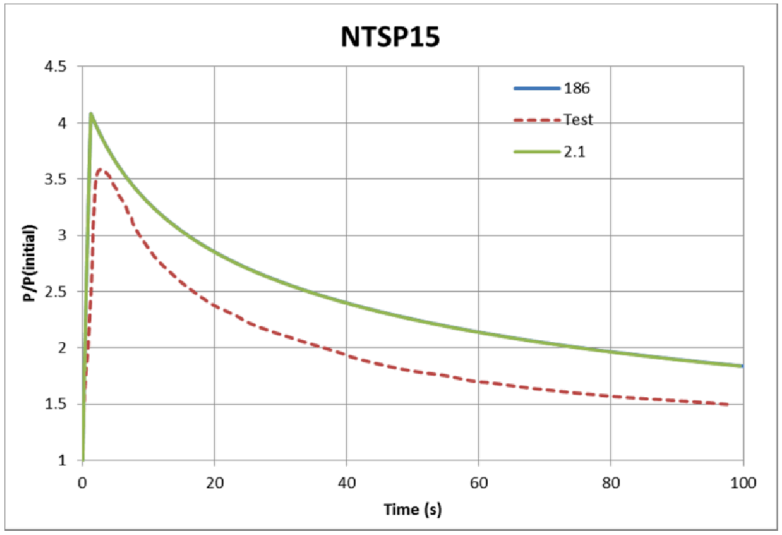
Hydrogen Burn Modeling

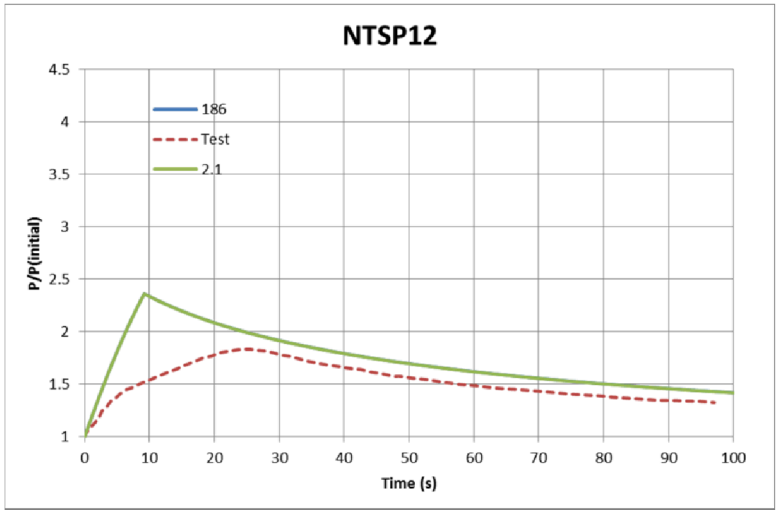
- Model
  - Based on HECTR 1.5 code
    - Effects of burning on a global basis without modeling the actual reaction kinetics or tracking the actual flame front propagation
      - Ignition criteria based on LeChatlier's formula
      - Combustion completeness based on LeChatelier formula
      - Burn duration calculated from user-specified characteristic dimension
    - Deflagration (no detonation)
  - Code Versions
    - Implemented in MELCOR 1.8.0
    - Diffusion flame model added to 1.8.5
- Observations
  - MELCOR adequately predicts peak pressures
  - MELCOR consistently predicts higher peak pressure and peak temperatures
- Validation Cases
  - Nevada Test Site (NTS) Hydrogen burn (1984): NTSP01, 12, 15, & 20

Hydrogen Burn Modeling

Sandia National Laboratories

Test ID & InitialH2 & H2O Concentrations			P(max)/P(initial)			
Test ID	**H_2, v/o**	**H_2O, v/o**	**M 1.8.5**	**M1.8.6**	**M2.1**	**Test**
Standard Tests						
NTSP01	5.3	4.2	1.71	1.70	1.70	1.48
NTSP15	9.9	4.2	4.11	4.08	4.08	3.61
Steam-Laden Tests						
NTSP12	6.9	28.3	2.37	2.36	2.36	1.831
NTSP20	12.9	27.8	3.97	3.95	3.95	3.87



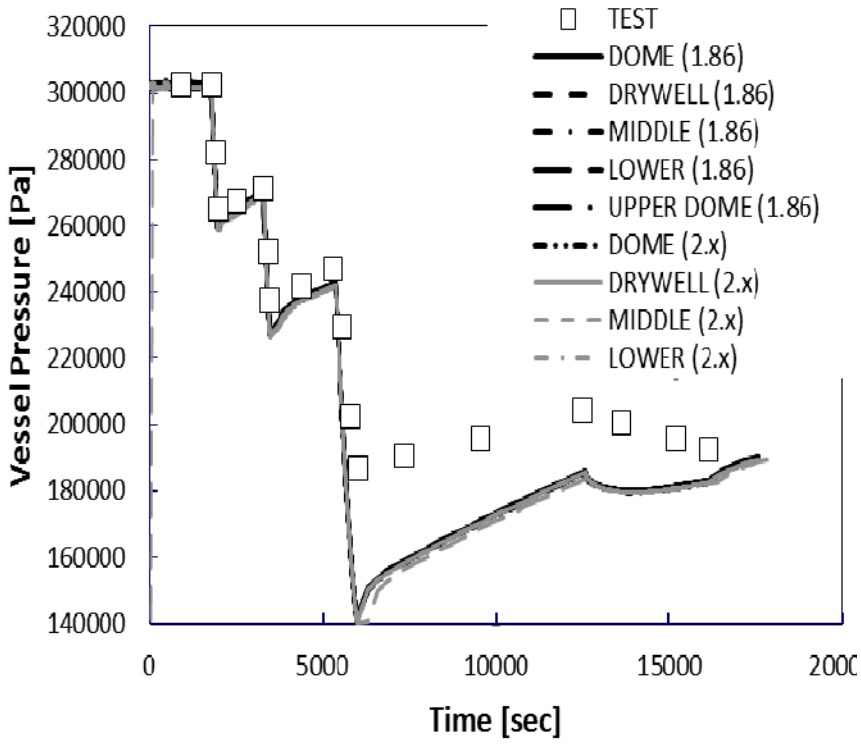


Containment Spray Pressure Response

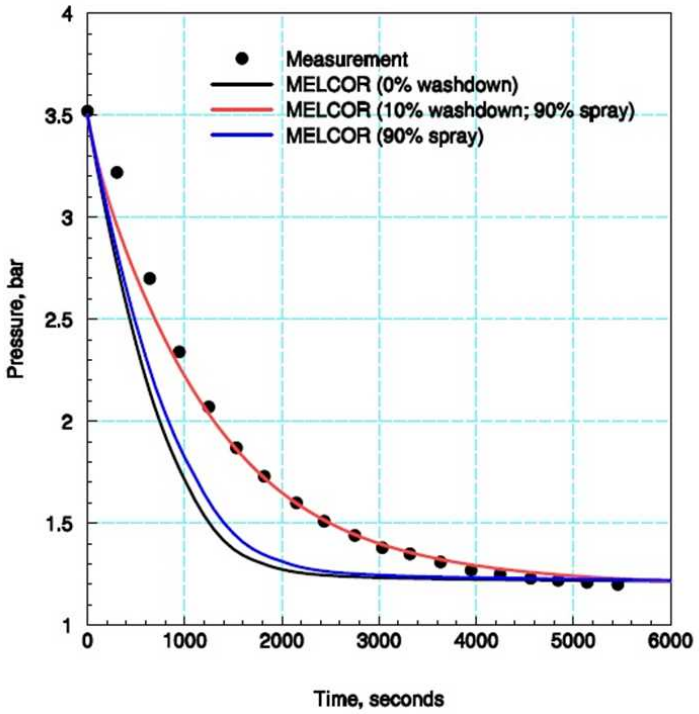
- Model
  - Based on the HECTR 1.5
  - Assumptions
    - Spray droplets are spherical and isothermal
    - User specified size distribution
    - Droplets fall with their terminal velocity
    - Spray droplets fall through a volume atmosphere at rest
    - Sprays are fully mixed with atmosphere in volume
- Observations
  - Pressure reduction trends predicted well by code
  - Excellent agreement between CONTAIN and MELCOR
- Validation Cases
  - Containment Spray Experiments (A-4, A-6, A-7, A-8, A-9, A-10, A-12)
  - CVTR (CVTR-4, CVTR-5)
  - JAERI Spray Tests (PHS-6, PHS-1)

Containment Spray Pressure Response

Containment Systems Experiment (CSE-9)



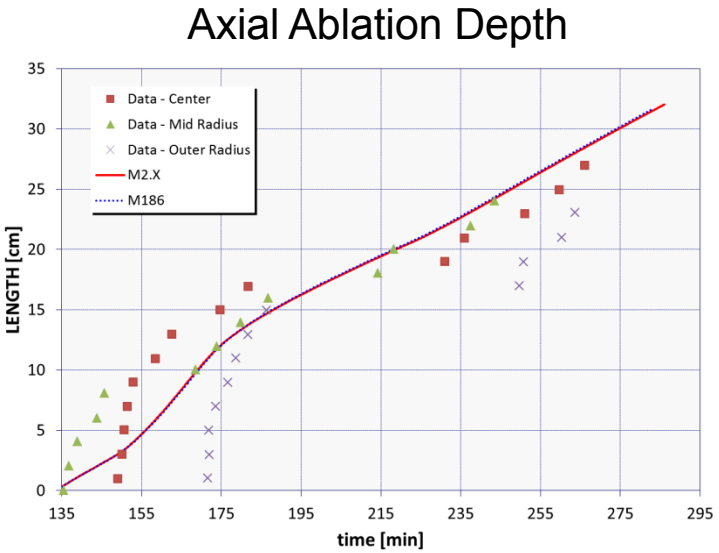
JAERI Spray Tests(PHS-1)



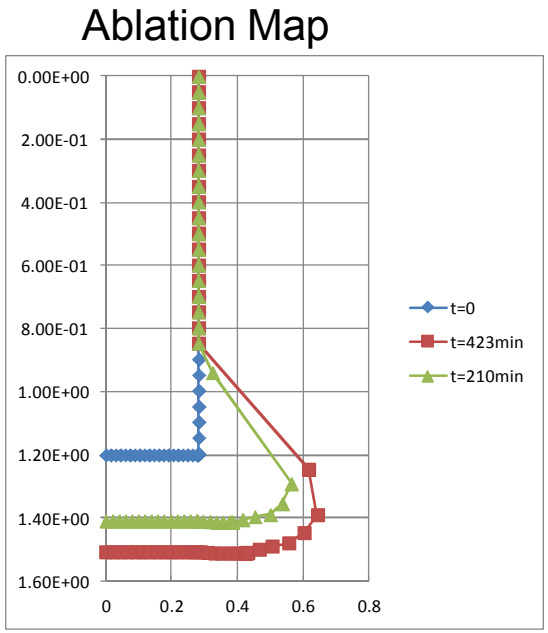
Molten Core / Concrete Interactions (MCCI)

- Modeling – 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
- Observations/challenges
  - Extremely difficult to model some experiments
    - SURC (no radial ablation), CCI (non-axisymmetric geometry)
  - Ray treatment is challenging, results may be sensitive to ray origin
  - No treatment of melt cooling via surface eruptions
  - No precursor heating (no dryout)
- Validation Cases
  - SURC (1 & 2), CCI (1 & 2)

Molten Core / Concrete Interactions (MCCI)



SURC-1

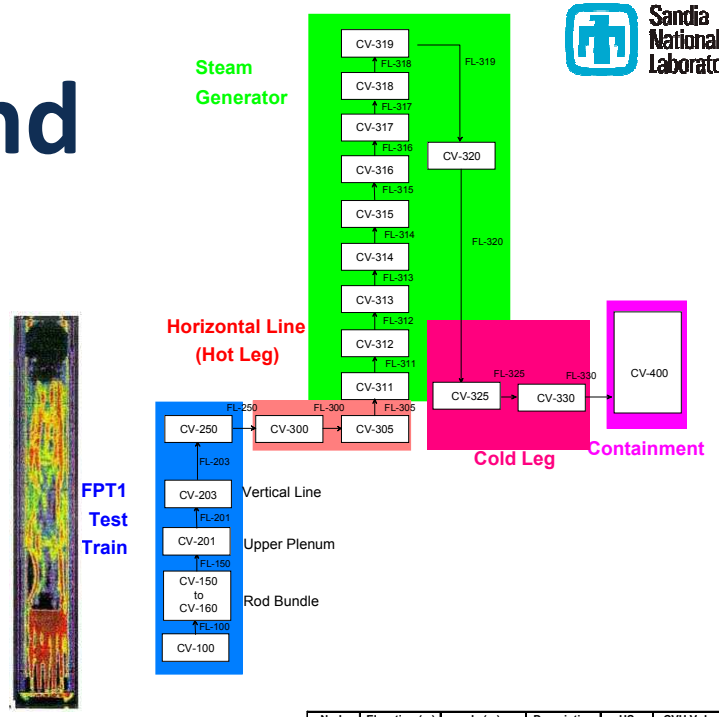


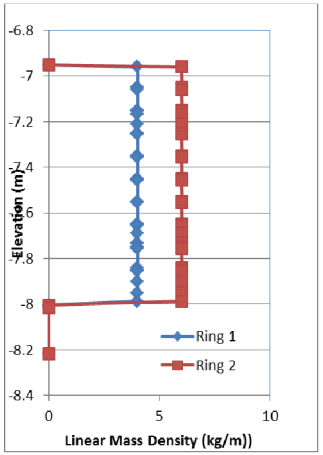
CCI-2

- **CCI-2**
  - **Sidewall ablation depth, 30cm**
  - **Basemat, 30cm**
- **MELCOR**
  - **Max axial depth = 30.8cm**
  - **Max radial depth = 36.1cm**
  - **Axial rate = 4.4cm/h**
  - **Radial rate = 3.8cm/h**

FPT1 (ISP 46): Background

- ***General Description:***
  - The FPT-1 system consisted of an in-pile fuel bundle assembly and upper plenum region, an external circuit including a steam generator U-tube and connecting lines, and a containment section. The objective of the fuel bundle assembly was to assess fuel degradation and fission product release from a degraded fuel assembly. In the circuit, the objective was to determine fission product transport and deposition in steam generator tubes.
- ***Important Physics:***
  - Thermal modeling was assessed from thermocouple responses and temperature profiles.
  - Oxidation (thermocouple responses and measurements of hydrogen generation)
  - Material relocation (thermocouple and radiography and transmission tomography for the end state).
  - Fission product release, transport, and deposition (Emission tomography of the fuel bundle and steam generator as well as measurements of activity along the external line to the containment).

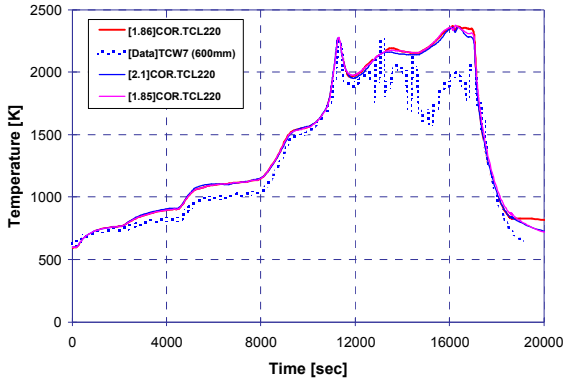


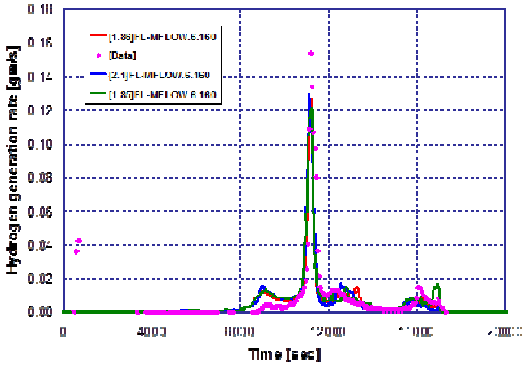


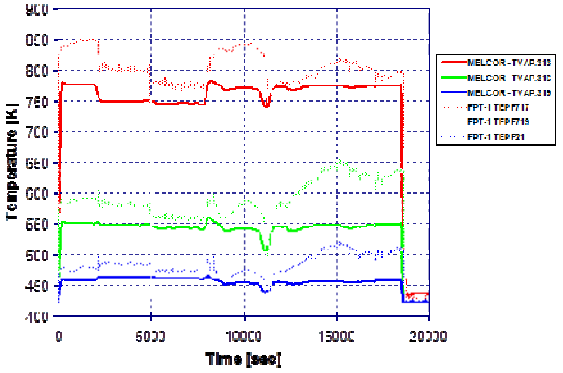
Node	Elevation (m)	dz (m)	Description	HS	CVH Volumes
31	-6.95	0.0815	Cladding	15031	
30	-6.959	0.00925		15030	CV160
29	-7.05	0.09075		15029	
28	-7.059	0.00925		15028	
27	-7.15	0.09075	Active fuel	15027	CV 159
26	-7.155	0.005		15026	
25	-7.168	0.0135		15025	CV 158
24	-7.212	0.043	Spacer grid	15024	
23	-7.25	0.0385		15023	
22	-7.255	0.005		15022	CV 157
21	-7.35	0.095		15021	
20	-7.355	0.005		15020	CV 156
19	-7.45	0.095		15019	
18	-7.455	0.005	Active fuel	15018	CV 155
17	-7.55	0.095		15017	
16	-7.555	0.005		15016	CV 154
15	-7.65	0.095		15015	
14	-7.655	0.005		15014	
13	-7.688	0.0335		15013	CV 153
12	-7.732	0.043	Spacer grid	15012	
11	-7.75	0.0185		15011	
10	-7.755	0.005		15010	
9	-7.841	0.08575		15009	CV 152
8	-7.85	0.00925	Active fuel	15008	
7	-7.855	0.005		15007	
6	-7.9	0.045		15006	CV 151
5	-7.95	0.05		15005	
4	-7.987	0.037	Depleted UO2	15004	CV 150
3	-8.005	0.0175	Cladding	15003	
2	-8.017	0.012	Support plate	15002	
1	-8.217	0.2	Core inlet	10002	CV 100

FPT1 (ISP 46) Findings

- ***Results & Findings:***
  - (Report) The overall thermal assessment of the FPT-1 experiment by MELCOR 2.1, MELCOR 1.8.6, and MELCOR 1.8.5 simulations is generally good. All three versions of the code, however, still predict bundle and shroud temperatures higher than those measured in the test. Improvements in the predicted shroud temperatures may be possible by improving the gap closure model. Gap closure dependency was calculated as a function of the local gap temperature and not a function of the bulk shroud temperature, which is more likely responsible for thermal expansion of the insulator and ultimately gap closure.

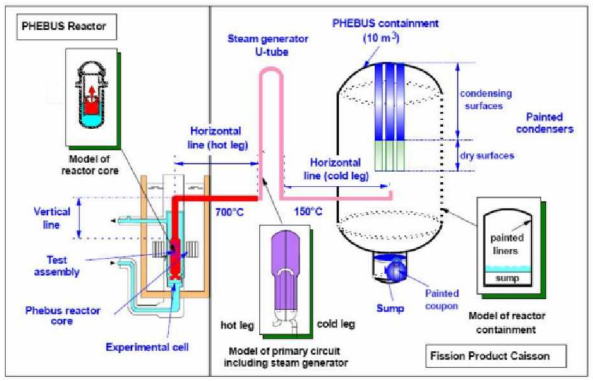


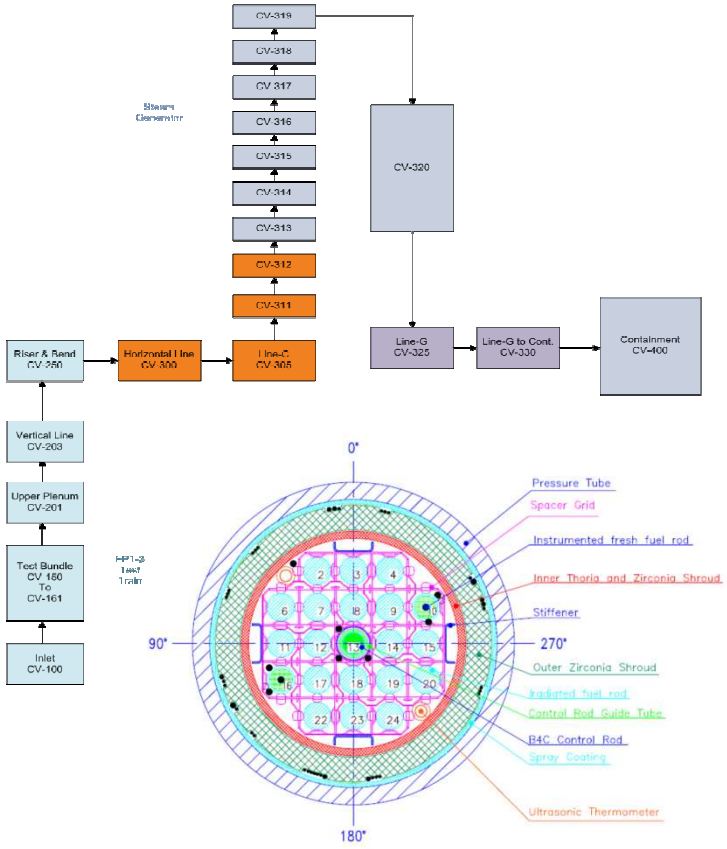




FPT-3: Background

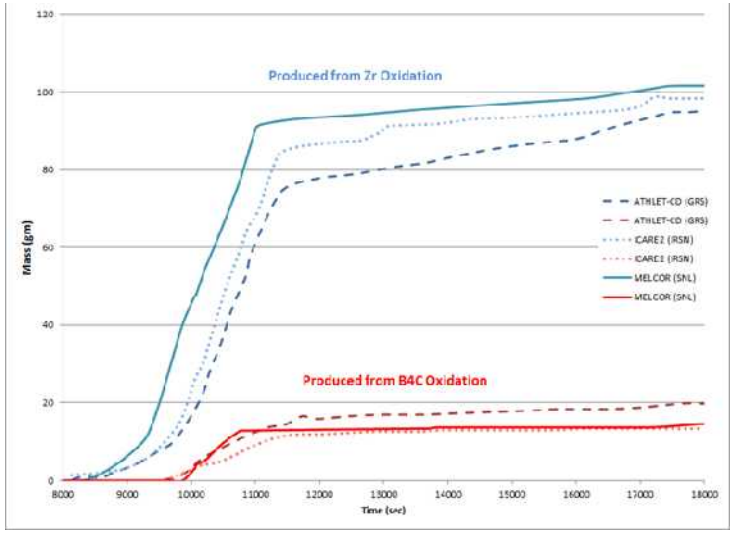
- ***General Description:***
  - The FPT-3 system consisted of an in-pile fuel bundle assembly and upper plenum region, an external circuit including a steam generator U-tube and connecting lines, and a containment section.
  - The objective was to assess fuel degradation and fission product release from a degraded fuel assembly. In the circuit, the objective was to determine fission product transport and deposition in steam generator tubes.
  - FPT-3 differs from FPT-1 in that a B4C control rod was used instead of Ag-In-CD, and it was in a steam-poor environment
- ***Important Physics:***
  - Thermal Response, Hydrogen generation, B4C Control rod oxidation, debris relocation

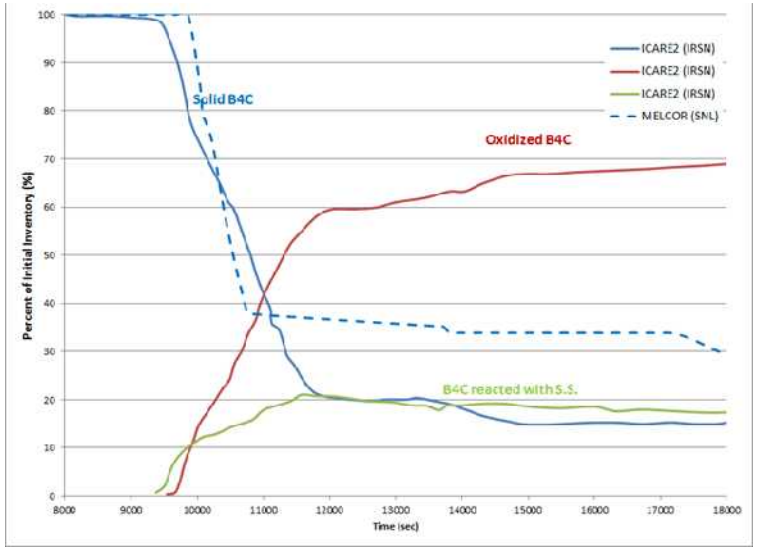




FPT3: Status

- ***Results & Findings:***
  - In general, bundle thermal behavior is well characterized by MELCOR 2.1
    - No comparisons with 186
  - Total amount of H2 generated in MELCOR comparable to test data and other codes
  - Using B4C rod option seems to improve results in H2 generation
    - Better mechanistic treatment of B4C oxidation behavior in the absence of liquid B4C-SS-Zry
    - Hydrogen generation was also seen to begin slightly earlier in MELCOR than in the experiment or other codes.

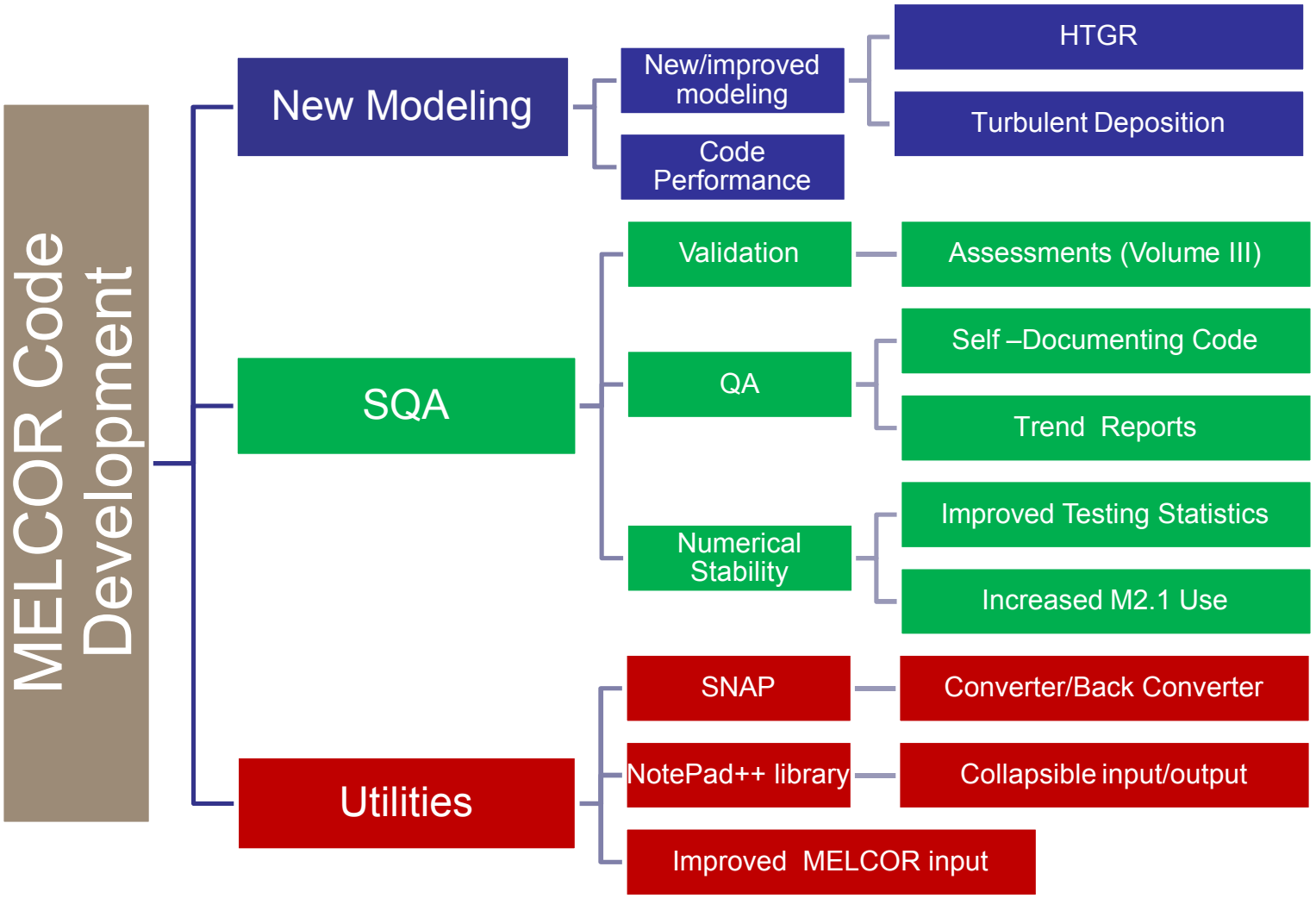




MELCOR Volume III: Code Assessment Report

- MELCOR Documentation
  - Volume I: User Guide
  - Volume II: Reference Manual
  - Volume III: Code Assessment Report
  - Volume IV: Modeling Guide
- Currently completing the Volume III Assessment report
  - Reviewing and re-running historic assessments
  - Adding new assessments for un-assessed physics
    - POSEIDEN (Pool scrubbing – SPARC-90)
    - MARVIKEN CFT-21 & JIT-11 (Critical Flow)
    - LACE LA1 & LA3 (Turbulent Deposition)
    - LHF, OLHF (Lower Head Failure)

Questions?


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