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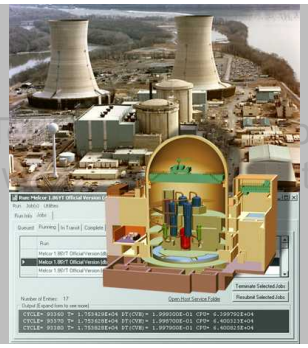

Integration of CONTAIN Liquid Metal Models into the MELCOR Code

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ICONE22-30288

July 7-11, 2014

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Work Scope

- Project Motivation and Objective
  - Address the regulatory infrastructures requirements regarding accident analyses for reactor systems,
    - A sodium coolant accident analysis code is necessary to provide regulators with a means to perform confirmatory analyses for future sodium reactor submissions.
- Solution Strategy
  - Implementation of models for sodium phenomenology simulation into an integrated, full-featured, actively maintained, severe accident code
    - CONTAIN-LMR models implemented into the MELCOR code
    - MELCOR is a mature integrated severe accident code
      - Used by NRC for level 2 and level 3 PRA analysis for LWR as well as
      - Used for containment DBA analysis

MELCOR Background

- MELCOR is developed by:
  - US Nuclear Regulatory Commission
  - Division of Systems Analysis and Regulatory Effectiveness
  - Office of Nuclear Regulatory Research
- 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

MELCOR Code Important Severe Accident Phenomena

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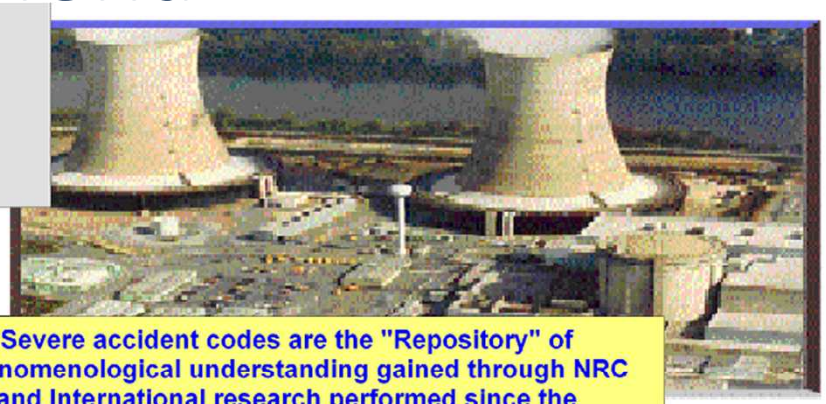
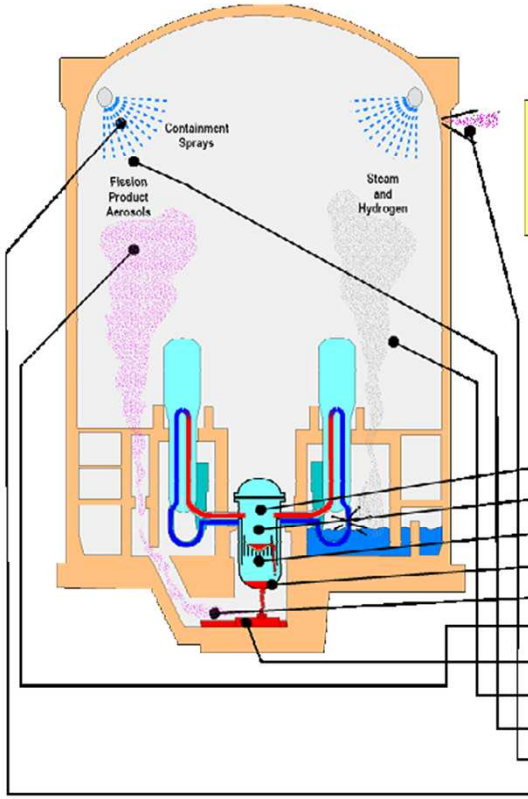
Modeling and Analysis of Severe Accidents in Nuclear Power Plants





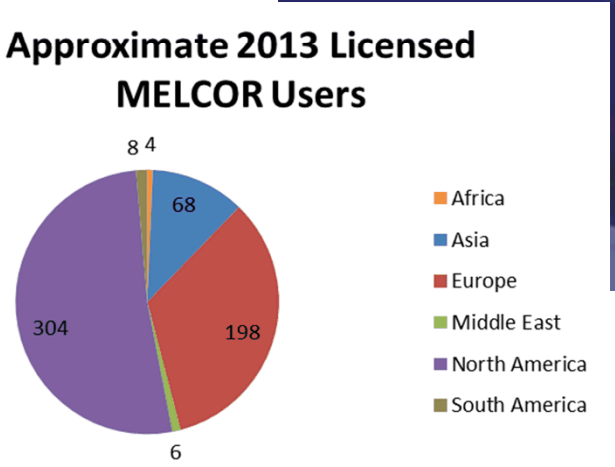
Severe accident codes are the "Repository" of phenomenological understanding gained through NRC and International research performed since the TMI-2 accident in 1979

***Integrated* models required for self consistent analysis**

Important Severe Accident Phenomena

	MELCOR	CONTAIN	VICTORIA	SCDAP RELAP 5
Accident initiation	■			■
Reactor coolant thermal hydraulics	■			■
Loss of core coolant	■			■
Core meltdown and fission product release	■		◪	■
Reactor vessel failure	■			■
Transport of fission products in RCS and Containment	■	■	■	
Fission product aerosol dynamics	■	■	■	
Molten core/basemat interactions	■	■		
Containment thermal hydraulics	■	■		
Fission product removal processes	■	■	■	
Release of fission products to environment	■	■	■	
Engineered safety systems - sprays, fan coolers, etc	■	■		
Iodine chemistry, and more	■			

MELCOR Users Worldwide



MELCOR Workshops and Meetings

- European MELCOR User Group (EMUG)
  - KTH 2013
- MELCOR Workshop
  - September 16, 2013
  - Almost 100 registered
  - Containment Modeling
- MELCOR Code Assessment Program (MCAP)
  - September 19-20, 2013

Software Quality Assurance

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- MELCOR SQA Standards
  - Sandia Corporate Process Requirement IM100.3.5
    - The software management framework adapted from two internationally recognized standards
      - Capability Maturity Model Integration (CMMI) ®
      - ISO 9001
  - NRC SQA standards
    - NRC NUREG/BR-0167
- These standards provide elements of traceability, repeatability, visibility, accountability, roles and responsibilities, and objective evaluation

MELCOR Software Quality Assurance Best Practices

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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

CONTAIN-LMR Background

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- Analysis tool for predicting the physical, chemical, and radiological conditions inside the containment and connected buildings of a nuclear reactor in the event of an accident.
- Developed by Sandia National Laboratories for the US Nuclear Regulatory Commission
  - Used for severe accident and design basis accident conditions
- Applied to nonreactor problems.
- CONTAIN Code Models
  - Intercell gas flow, including natural circulation
  - Two-phase atmospheric thermodynamics
  - Conduction in structures
  - Convective and radiant heat transfer
  - Condensation/evaporation at structure and pool surfaces
  - Hydrogen combustion
  - Multi-component aerosol processes
  - Transport and decay heating from fission products
  - Ablation of concrete by core debris
  - Does not model reactor core/vessel and accident initiation

CONTAIN Code Release History

Version	Date	Improvements
1.0	1984	First Release of Code
1.06	1987	CORCON-Mod2, VANESA, Water dropout,..
1.11*	1991	Moving-grid technique for solving aerosol growth by water vapor condensation
1.12	1991	Add DCH modeling, reactor cavity models for high pressure debris dispersal and vessel blowdown,..
1.2	1995	Film flow on wall structures, energy and mass conservation tracking, CORCON Mod3,..
2.0	1997	Improvements in the DCH and hydrogen burn models

*Note that CONTAIN-LMR was derived from CONTAIN 1.11. A version of CONTAIN-LMR from Japan Atomic Energy Agency has been obtained. SAND91-1490,"CONTAIN LMR/1B-Mod. 1, A Computer Code for Containment Analysis of Accidents in Liquid-Metal-Cooled Nuclear Reactors."

Work Scope Breakdown

- Phase 1 – Implement sodium as replacement to the working fluid for a MELCOR calculation
  - Implement properties & Equations Of State (EOS) from the fusion safety database
    - Calculated from stgna code
      - Soft-sphere model free energy equation
      - J. E. Tolli, EG&G Idaho,
  - Implement properties & EOS based on SIMMER-III
    - "Thermodynamic properties and equations of state for fast reactor safety analysis," NED.
      - K. Morita, E.A. Fischer, 1998
    - "Thermodynamic and Transport Properties of Sodium Liquid and Vapor,"
      - ANL/RE-95/2, 1995.
  - Testing to verify properties

Work Scope Breakdown (concluded)

- Phase 2 – CONTAIN-LMR
  - Place CONTAIN-LMR under modern SQA practices
    - Merge CONTAIN-LMR & CONTAIN2
  - Review of CONTAIN-LMR
    - Development of design documents for model implementation
  - Implement models for condensation of sodium onto aerosols to MELCOR
- Phase 3 – Implementation/Validation of CONTAIN physics models:
  - Sodium spray fires
  - Sodium pool modeling
  - Sodium pool fires
- Phase 4 – Implementation/Validation of CONTAIN chemistry models:
  - Atmospheric chemistry
  - Sodium pool chemistry
  - Debris bed/concrete cavity interactions.

Phase I Complete

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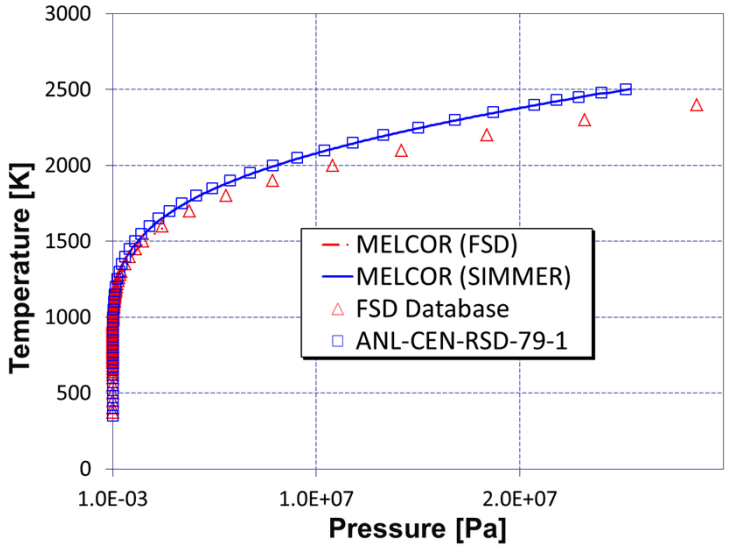
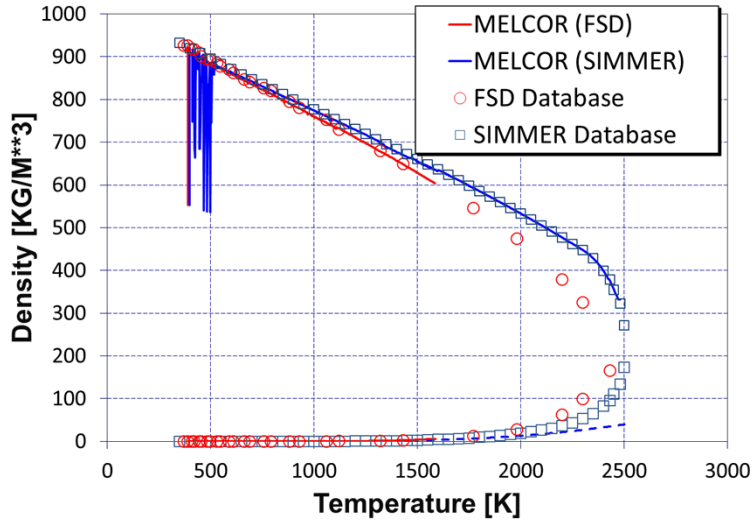
- Completed implementation of sodium equation of state for both the fusion safety database and the SIMMER-III code
- Testing Implementation to verify that:
  - Properties are reproduced
  - Calculations are stable
  - Code performance is acceptable
  - Phase transitions well-behaved
  - Compressible vapor phase well represented

Testing Results - Saturation Curve

- FSD – Fusion Safety Database
  - More stable at very low temperatures
  - Calculations reproduce the saturation pressure and density curves for the database.
- SIMMER Database
  - More stable over a wider range of temperatures.
  - Calculations reproduce the saturation pressure and density curves for the database except for atmosphere densities at temperatures approaching the critical point.





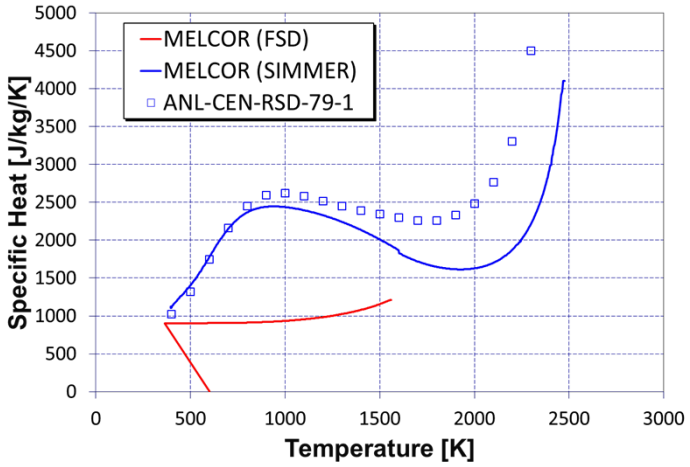
Testing Results
Specific Heat at Constant Pressure

- Where the specific heat at constant pressure is needed, it is evaluated from the standard relationship

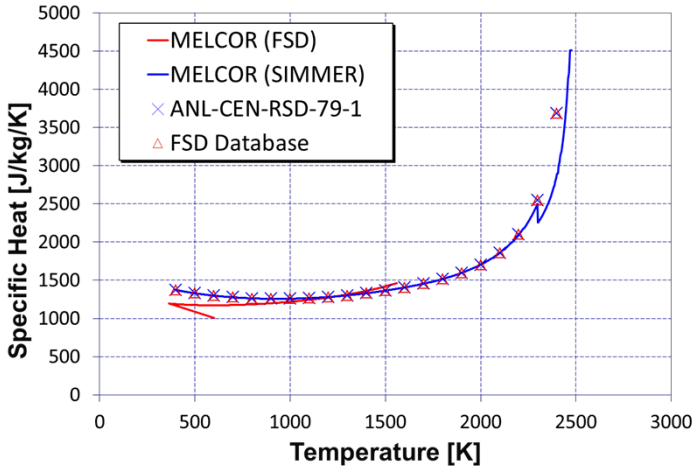
$$c_p = c_v + \frac{T\left(\frac{\partial P}{\partial T}\right)_\rho^2}{\rho^2\left(\frac{\partial P}{\partial \rho}\right)_T} \quad .$$

- Comparison of this variable with the database provides a good test on the derivatives used by MELCOR
  - Indicator of code stability

Atmosphere

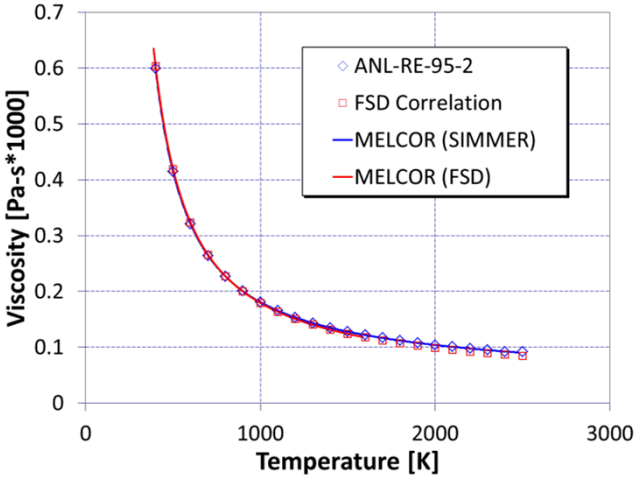


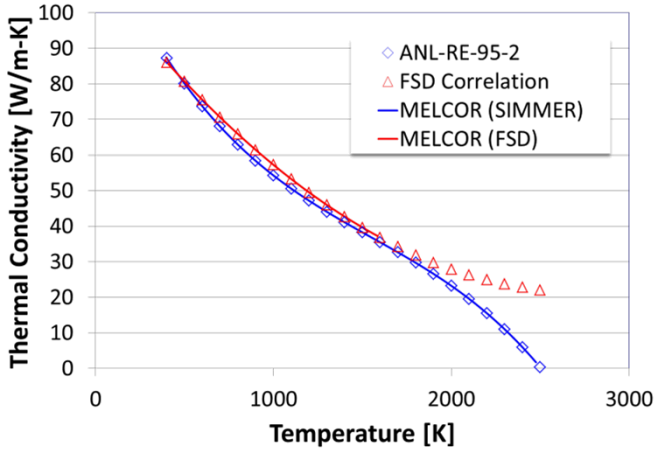
Pool



Testing Results
Correlated Fluid Properties

- Simple fluid properties such as thermal conductivity and viscosity are reproduced by the calculations.
- These properties do not enter into the calculation of the equation of state and are dependent on temperature only so that they are much easier to reproduce.





Phase 2 (In progress)

- Restore CONTAIN-LMR capabilities (completed)
  - Develop a visual studio project for the code
  - Compile and make code changes necessary for modern compilers
  - Place the source code under SQA requirements
  - Testing that exercise the various LMR features.
- Development of Design Documents for CONTAIN-LMR models
  - In progress
- Aerosol Condensation (in progress)
  - Examine models for condensation of sodium onto aerosols will be examined in CONTAIN-LMR
    - Two condensable option in atmosphere – water and sodium
    - Aerosol condensation using moving and fixed grid treatment – water and/or sodium
  - Implementation of models into MELCOR
  - Validation Testing