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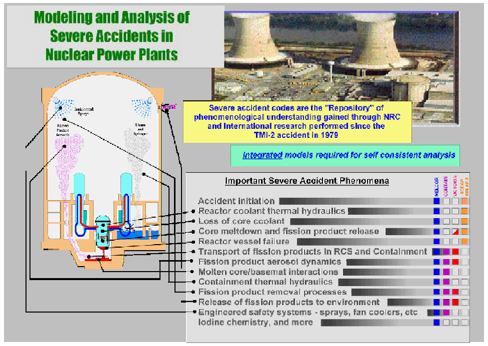

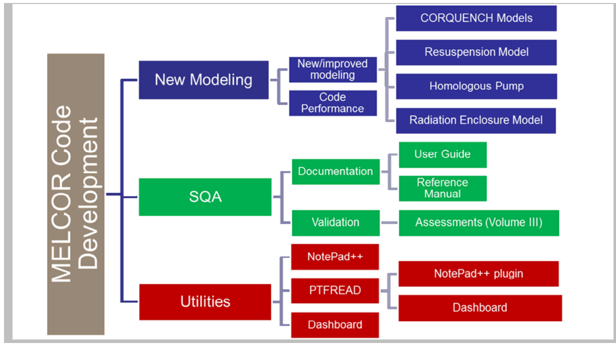

STATUS OF MELCOR SODIUM MODELS DEVELOPMENT

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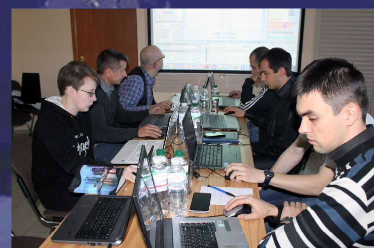
Outline

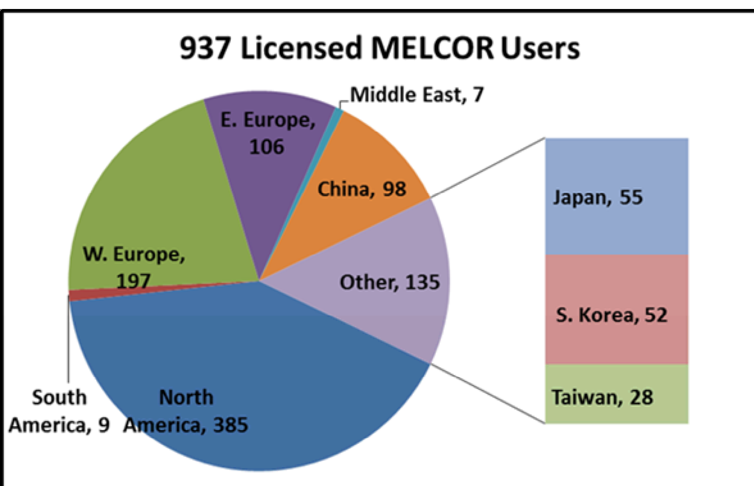
- Work scope
- MELCOR code usage and workshops
- CONTAIN-LMR code and models
- Implementing status into MELCOR
- Development of NAC Package in MELCOR
- Testing Status
- Future Planning for MELCOR sodium model completion

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
      - 30 years development
    - New modeling added to MELCOR will be enabled only when sodium models are specified by user, and will not impact code performance.

MELCOR Users, Workshops & Meetings





2016 European MELCOR User Group (EMUG)

- Hosted by Imperial College London & AMEC (April 6-7, 2016)

MELCOR User's Workshop in Ukraine

- Hosted by SSTC in Kiev (April 25-28, 2016

2016 CSARP/MCAP

- No Workshop (September 12, 2016
- Bethesda, MD

2016 Asian MELCOR User Group (AMUG)

- Hosted by SPICRI & NRSC (Beijing)
- October 17-21, 2016
- MELCOR/MACCS Workshop

2017 EMUG

- Hosted by CIEMAT (April 6-7,2017)
- No Workshop

CONTAIN-LMR Background

- 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
- 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
- Similarities with the MELCOR code
  - CORCON MOD-3
  - MAEROS Aerosol physics
  - SPARC model

Containment Sodium Chemistry

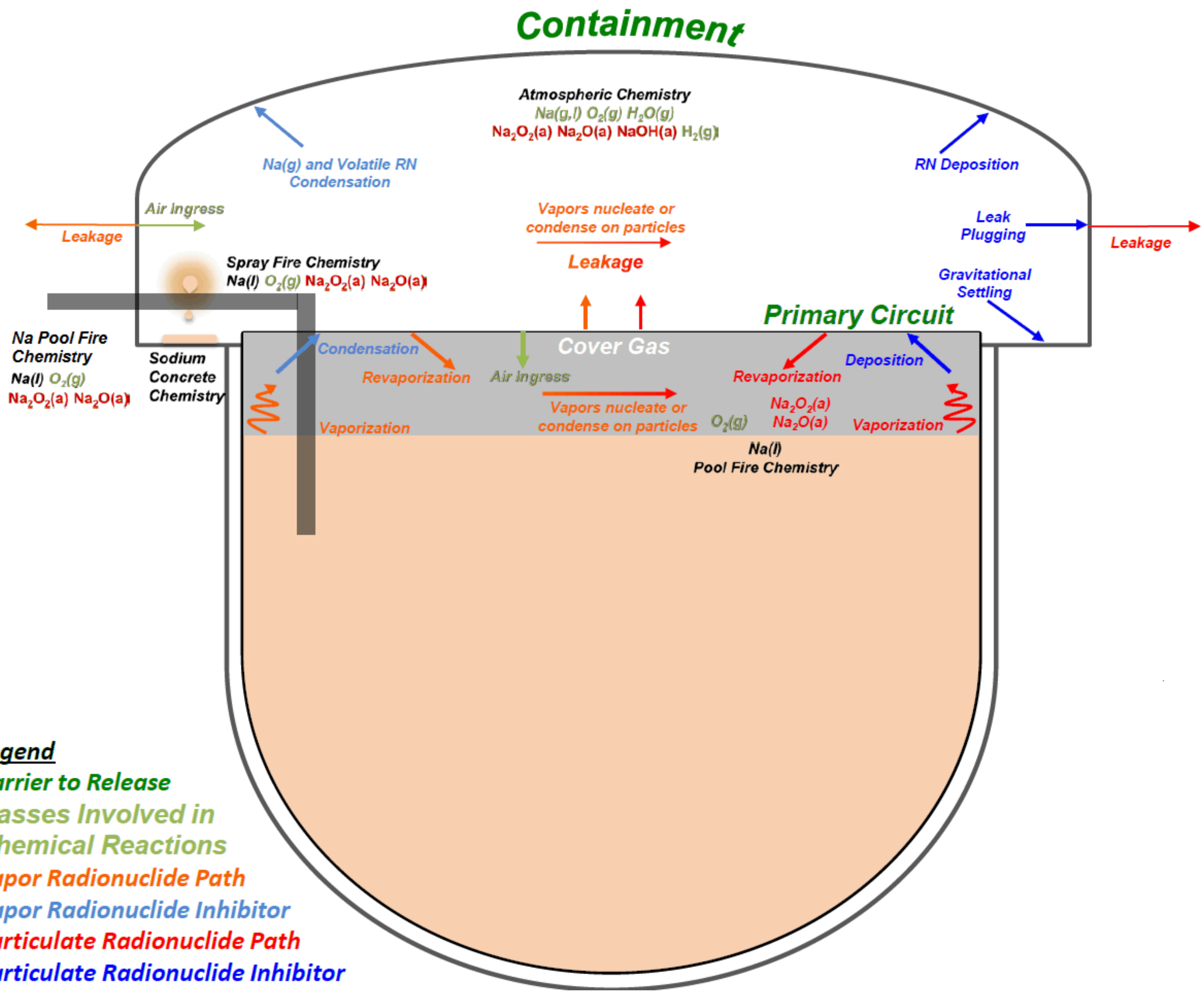


Figure adapted from ANL-ART-3

Development Issues

- Sodium equation of state has been implemented
  - Fusion Safety Database – file input
    - Many liquid metal can be modeled (i.e., FLIBE, K, NaK)
  - SIMMER (SAS4A) Database – Coded in MELCOR
- MELCOR only allows one condensable to be modeled
- Solid phase of coolant may not be modeled
  - Introduction of ALLOWNATOFREEZE
- Non-equivalent model for separate temperature values for pool and atmosphere need to examine closely

CONTAIN-LMR Code Models

- Sodium Spray Fire
  - Based on NACOM code
  - Implemented
- Sodium Pool Fire
  - Based on SOFIRE II Code
  - Implemented
- Atmospheric Chemistry
  - Mechanistic model – aerosol, surface and gas reactions
  - Implemented
- Sodium-Concrete Interaction (Reaction)
  - Based on SLAM[1] Code developed at Sandia
  - Not yet implement

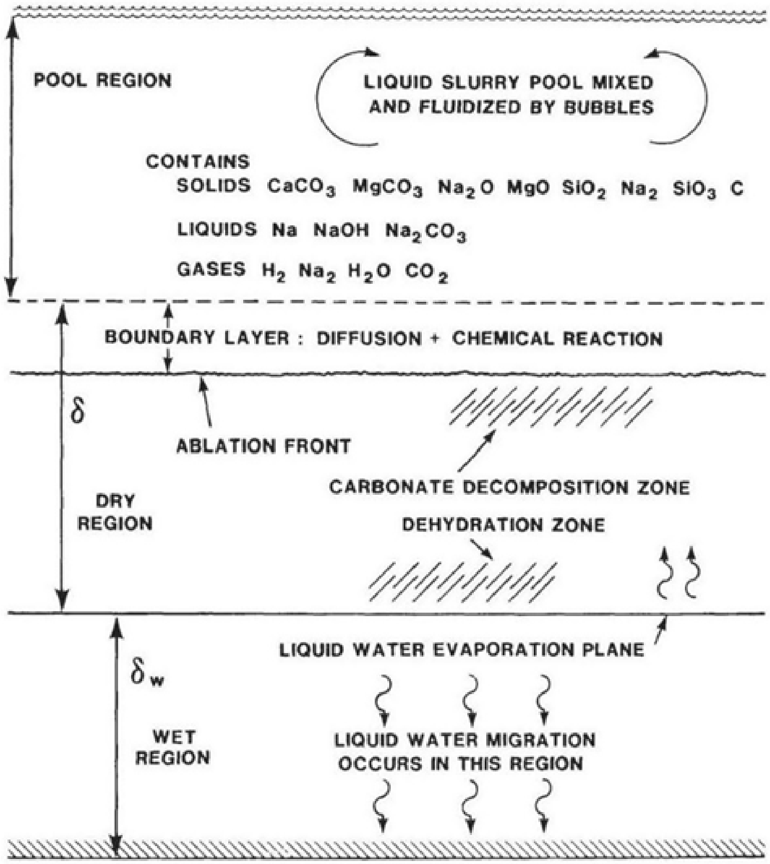
[1] Sodium Limestone Ablation Model

Atmospheric Chemistry

- A number of reactions have been considered:
  - (A1) $Na(l) + H_2O\ (l)\ \rightarrow NaOH(a) + \frac{1}{2}H_2$
  - (A2) $2\ Na(g,l) + H_2O\ (g,l)\ \rightarrow Na_2O(a) +\ H_2$
  - (A3) $2\ Na(g,l,a) + \frac{1}{2}O_2$ or $O_2 \rightarrow Na_2O(a)$ or $Na_2O_2(a)$
  - (A4) $Na_2O_2(a) + 2\ Na(g,l) \rightarrow 2\ Na_2O(a)$
  - (A5)
    - $Na_2O(a) + H_2O\ (g,l)\ \rightarrow 2NaOH(a)$
    - $Na_2O_2(a) + H_2O\ (g,l) \rightarrow 2NaOH(a) + 0.5O_2$
- All these reactions are assumed to occur:
  - Atmosphere (g), aerosol, surfaces (i.e., HS)
  - The order of the reactions are given

SLAM Model

- Major Reactions Modeled
  - $H_2O \rightarrow NaOH + 0.5\ H_2$
  - $CO_2 + 2\ Na \rightarrow 4Na_2O + C$
  - $3\ CaCO_3 + 4\ Na \rightarrow 2Na_2CO_3 + 3\ CaO + C$
  - $3\ MgCO_3 + 4\ Na \rightarrow 2\ Na_2CO_3 + 3\ MgO + C$
  - $2\ NaOH + CaCO_3 \rightarrow CaO + H_2O + Na_2CO_3$
  - $2\ NaOH + SiO_2 \rightarrow Na_2SiO_2 + H2O$
- Divide the 1-D reaction model into 3 regions:
  - Pool – source of sodium reactants
  - Dry – interface where ablation occurs
  - Wet – source of reactant material from concrete



Sodium Chemistry (NAC) Package Development

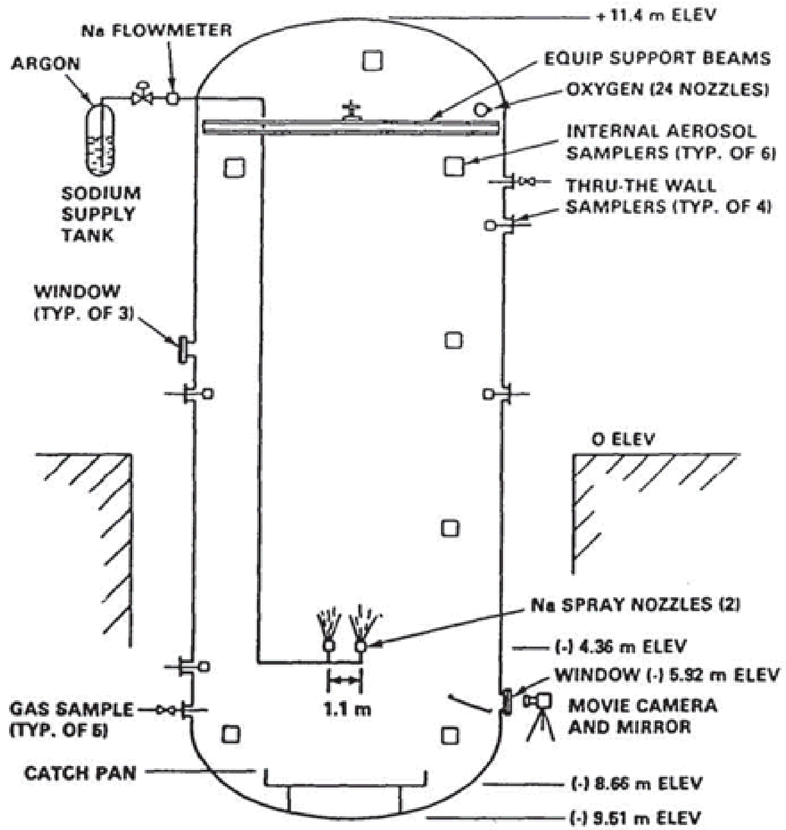
- To better manage the sodium related models, particular for chemistry models
- Create "new" NAC Package
  - Data structures – in module (M_NAC)
    - NaCL(5), old-new variables, input parameters
  - RN to NAC class structure – tracks aerosol products
  - Na modeled as condensable, H2O modeled as aerosol
  - Interface variables, interface with many packages, for examples:
    - NCG – O_2 and H_2
    - HS – condensate, deposits
    - CVH – H_2O, reaction energies
    - RN – aerosol interactions
  - Calling sequence for NAC model executions
    - Implemented models – Atmospheric chemistry, Spray fire, Pool fire.
    - Planning stage – Sodium-concrete interaction (reaction)

Testing of MELCOR Sodium Chemistry Models

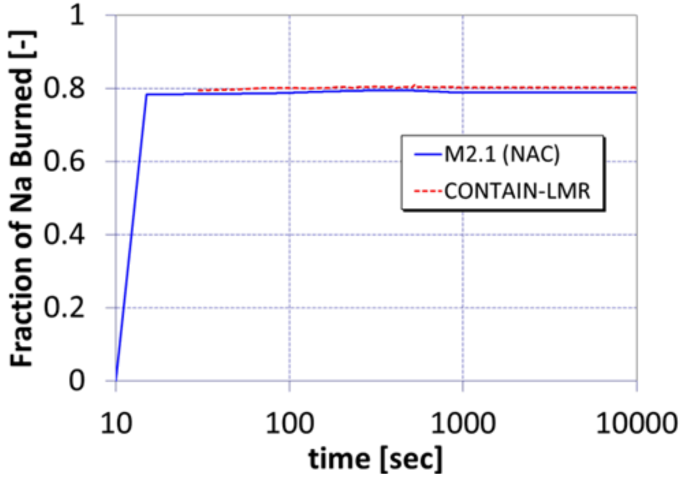
- Development testing on the implemented models started
  - Spray fire model – ABCOVE AB5, Surtsey T-3
  - Pool fire model – ABCOVE AB1
  - Atmospheric chemistry model –ABCOVE AB5
    - There are not specific experiments tailored for the atmospheric chemistry model
      - Aerosol, gas, and surface reactions
    - Functional test is being performed
    - Modified ABCOVE AB5 to allow activation of the atmospheric chemistry model

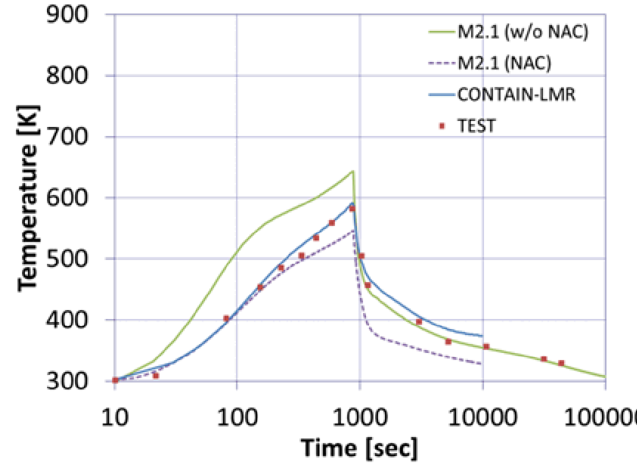
ABCOVE AB5 Description for Spray Fire Model

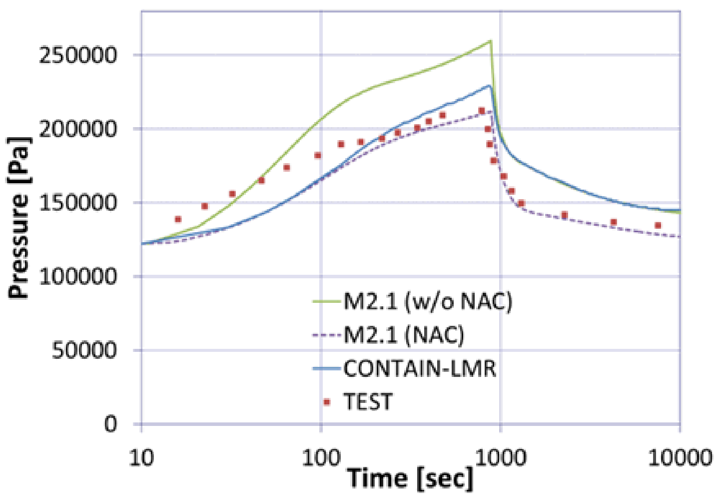
INITIAL CONTAINMENT ATMOSPHERE	PARAMETER
Oxygen Concentration	23.3±0.2%
Temperature (mean)	302.25K
Pressure	0.122MPa
Dew Point	289.15±2K
Nominal Leak Rate	1%/day at 68.9kPa
Na SPRAY	**PARAMETER**
Na Spray Rate	256±15g/s
Spray Start Time	13s
Spray Stop Time	885 s
Total Na Sprayed	223±11 kg
Na Temperature	836.15 K
Spray Drop Size, MMD	1030±50 μm
Spray Size Geom. Std. Dev., GSD	1.4
OXYGEN CONCENTRATION	**PARAMETER**
Initial O_2 Concentration	23.3±0.2 vol %
Final O_2 Concentration	19.4±0.2 vol %
Oxygen Injection Start	60 s
Oxygen Injection Stop	840 s
Total O_2	47.6 m^3 (STD)
CONTAINMENT CONDITIONS DURING TESTS	**PARAMETER**
Maximum Average Atmosphere Temperature	552.15 K
Maximum Average Steel Vessel Temperature	366.65 K
Maximum Pressure	213.9 kPa
Final Dew Point	271.65 K

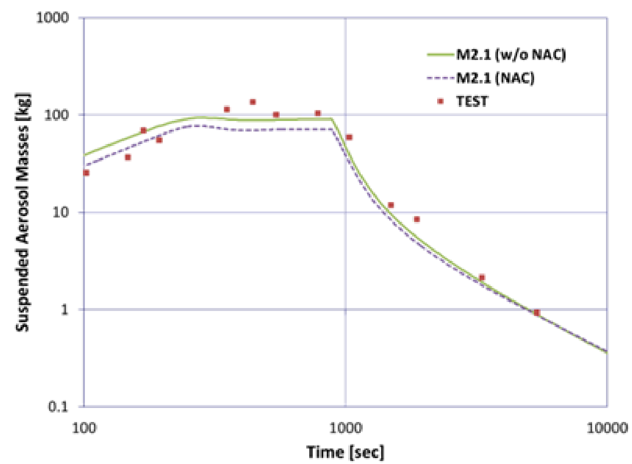


Preliminary Results – ABCOVE AB5



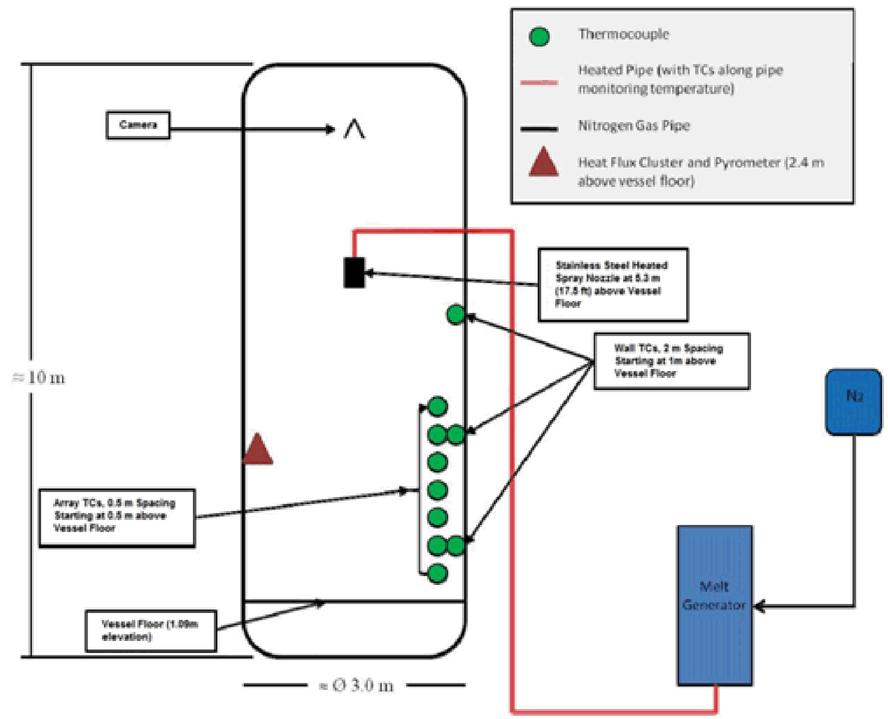






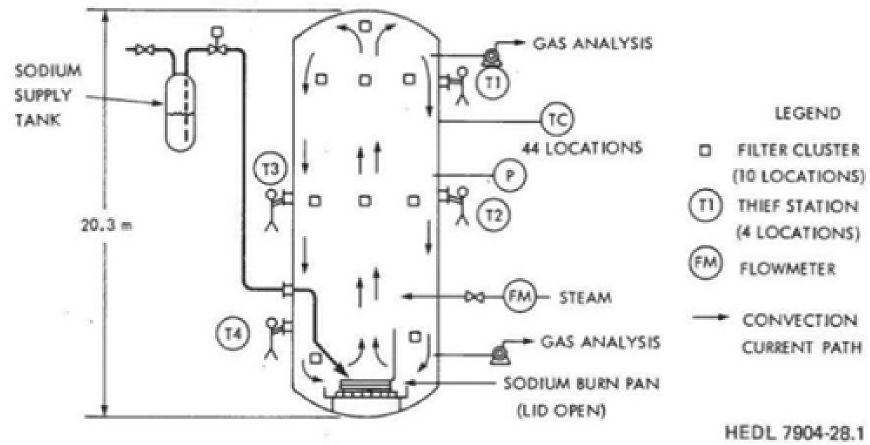
Surtsey T-3 Test

SURTSEY DIMENSION	***PARAMETER***
Vessel Free Volume	99 m^3
Vessel Wall and Heads Thickness	1 cm
Na SPRAY	***PARAMETER***
Na Spray Rate	1 kg/s
Spray Start Time	0 s
Spray Stop Time	20 s
Total Na Sprayed	20 kg
Na Temperature	473.15 K
Spray Drop Size, diameter	3-5 mm
Spray Height	5.3 m
VESSEL CONDITIONS DURING TESTS	***PARAMETER***
Peak Air Temperature (0.33 m from wall)	753.15 K
Peak Overpressure	0.006 MPa
Peak Heat Flux (1.46 m from center)	< 1 kW/m^2



ABCOVE AB1 Test for Pool Fire Model

INITIAL CONTAINMENT ATMOSPHERE	PARAMETER
Oxygen Concentration	19.8%
Temperature (mean)	299.65K
Pressure	0.125MPa
Dew Point	283.15K
Na POOL	PARAMETER
Na Source Rate	11.1 g/s
Source Start Time	0 s
Spray Stop Time	3600 s
Total Na Spilled	410 kg
Initial Na Temperature	873.15 K
Burn Pan Surface Area	4.4 m^2
Burn Time	3600 s
Total Sodium Oxidized	157 kg
OXYGEN CONCENTRATION	PARAMETER
Initial O_2 Concentration	19.8 vol %
Final O_2 Concentration	14.7 vol %
Oxygen Injection Start	60 s
Oxygen Injection Stop	840 s
Total O_2	47.6 m^3 (STD)
CONTAINMENT CONDITIONS DURING TESTS	PARAMETER
Maximum Average Atmosphere	552.15 K
Temperature	366.65 K
Maximum Average Steel Vessel	0.142 MPa
Temperature	233.15 K
Maximum Pressure	39.9 kg
Final Dew Point	0.255
Total Aerosol Released as Na	
Fraction of Oxidized Na Released	



Summary and Conclusion

- This paper summarizes development status of MELCOR sodium chemistry models
- Majority of sodium chemistry models for containment analysis has been implemented and being tested
- Debugging of the sodium EOS in MELCOR continues
- Sodium-concrete interaction (reaction) model is scheduled to be implemented into MELCOR in this fall.