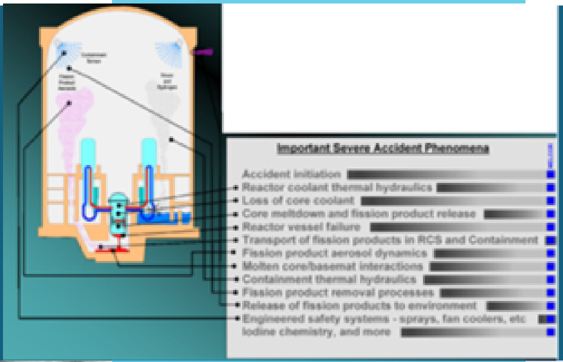
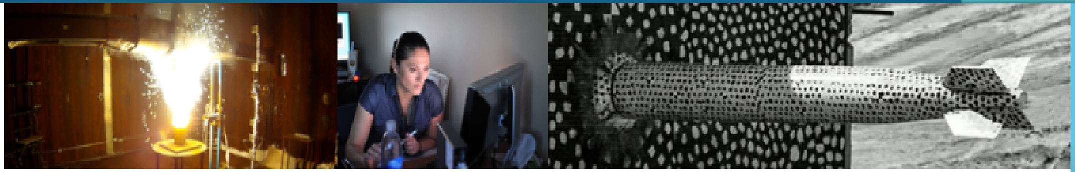
SAND2022-7246C

US-Japan BLC-CNWG

Sandia National Laboratories

MELCOR Validation Study of the Sodium Pool Fire Model with Comparison to SPHINCS





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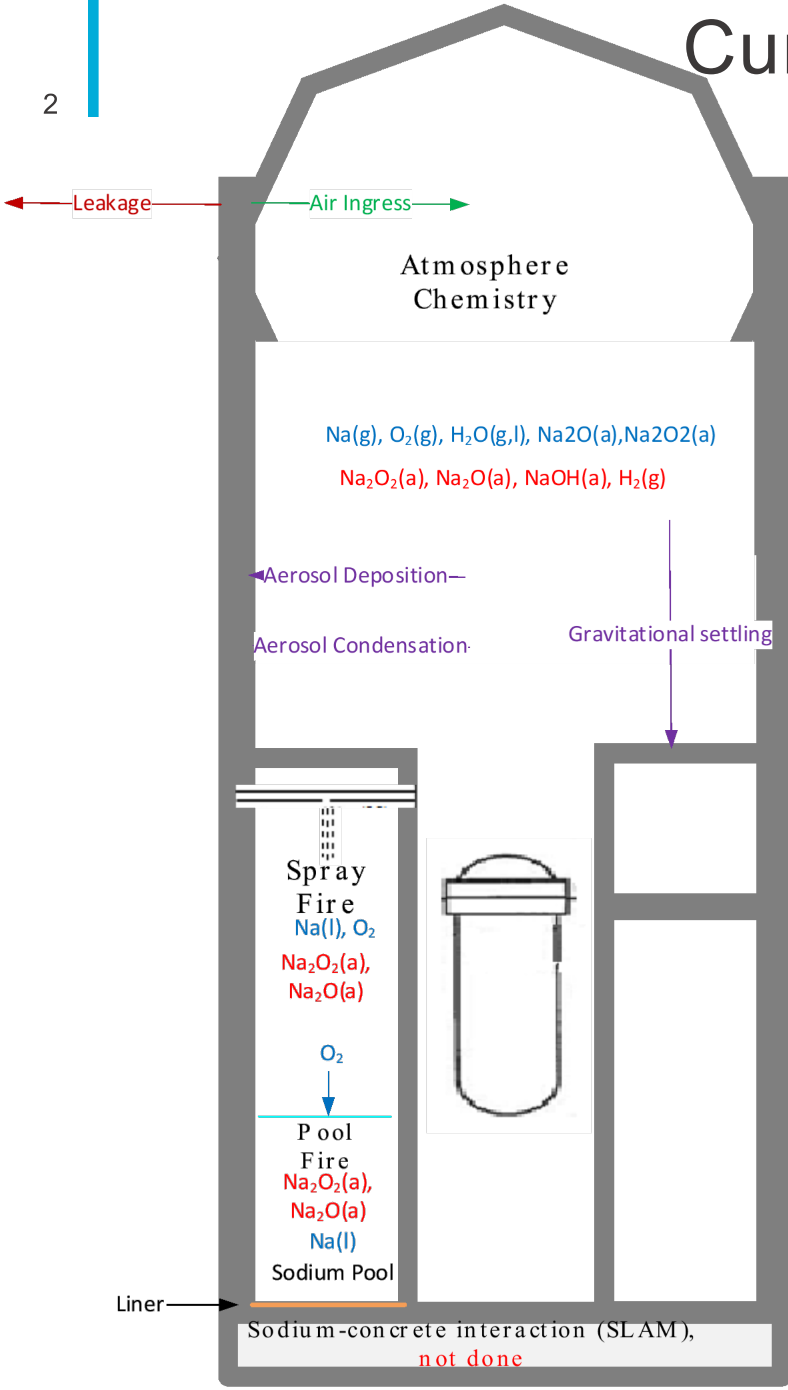
Current Sodium Fire Models in MELCOR



Na_chemistry_Diagram_vCa.vsdx

Legend
Reactants
By-products

Under U.S. DOE Advanced Reactor Technologies – Fast Reactor Program

- Most sodium fire models from CONTAIN-LMR had been implemented:
  - Most input parameters for the models are constant
  - Original spray fire model enhanced to include an upward spray sub-model
  - Atmospheric chemistry model assumes the water vapor as an ideal gas
  - CF input approach improves the model flexibility and allows sensitivity studies
    - Added CF capability to input key fire model parameters.
- Previous validation works include benchmarks using ABCOVE AB5

Model improvements under Civil Nuclear Energy Research and Development Working Group Efforts between Sandia National Labs (SNL) and Japan Atomic Energy Agency (JAEA)

A Joined Research was identified to improve the MELCOR pool fire model using F series pool fire tests from JAEA

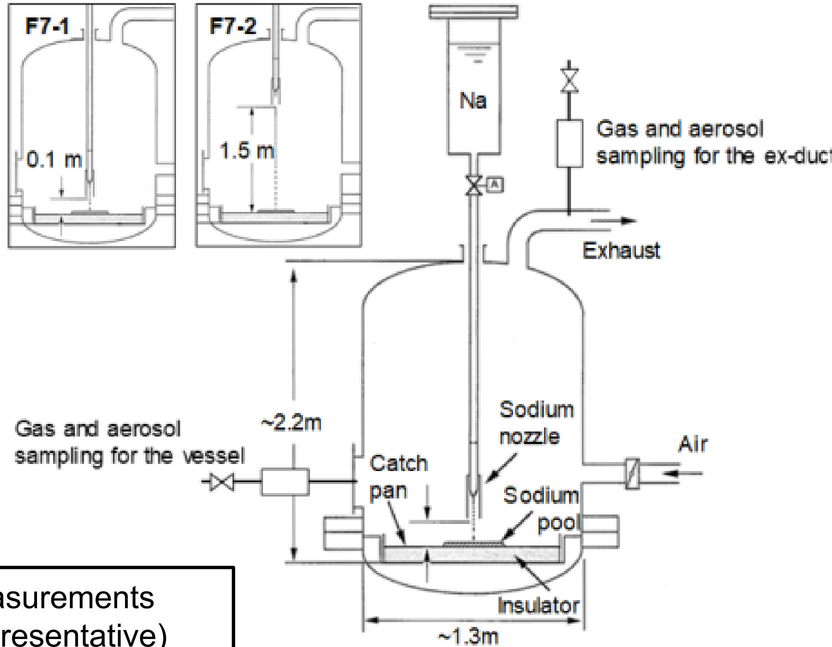
Current Sodium Pool Fire Model in MELCOR

Parameter	Description
FO2	Fraction of the oxygen consumed that reacts to form monoxide. The value 1.0-FO2 is the remaining oxygen fraction for the reaction to form peroxide.
FHEAT	Fraction of the sensible heat from the reactions to be added to the pool. The balance will go to the atmosphere.
FNA2O	Fraction of the Na_2O remaining in the pool. The balance will be applied to the atmosphere as aerosols.
FNA2O2	Fraction of the Na_2O_2 remaining in the pool. The balance will be applied to the atmosphere as aerosols.
TOFF	Model deactivation time. This is useful for modeling experiments.
DAB	Oxygen diffusion coefficient model switch. The default diffusion correlation will be used if a real value of greater than or equal to 0.0 is specified.

Using the Control Function input capability to enhance models with code modification for the proposed models:

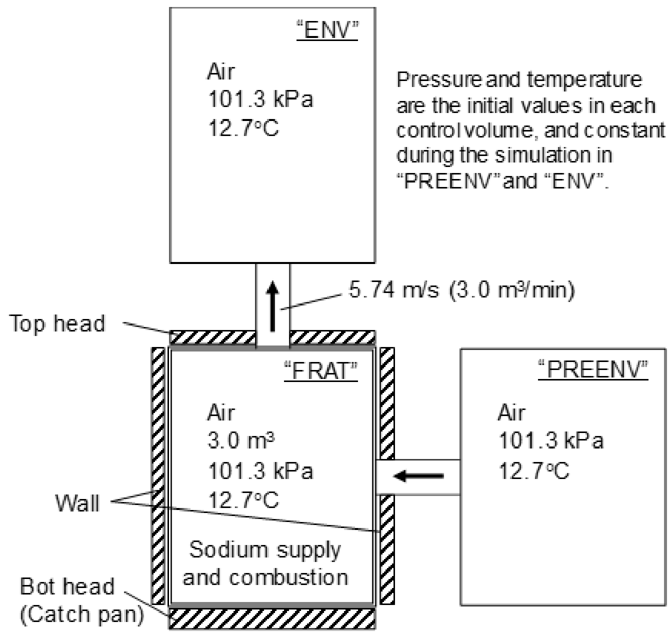
- Highlighted input parameters were enhanced last year
  - DAB
    - Account the effect of oxide layer buildup
  - FNA2Ox
    - Allows better prediction of the suspended sodium aerosols
- Both FO2 and FHEAT are being enhanced in this year
- Other enhancement were made
  - Pool-Pan heat transfer – enhanced with pool radius functionality
  - Liquid sodium spreading
    - Viscosity dependent spreading

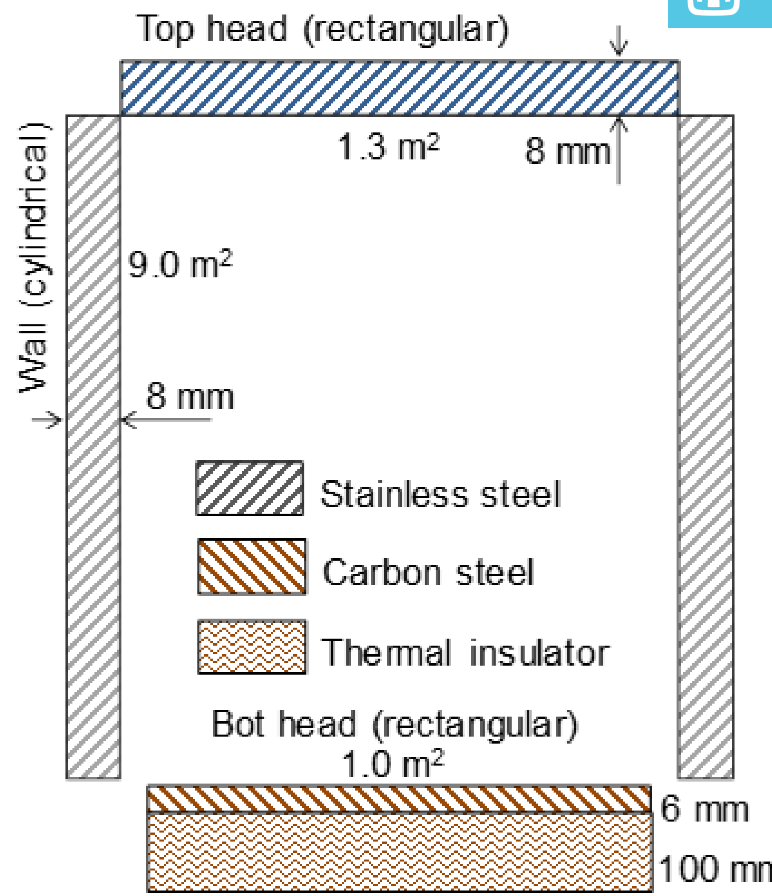
F7 pool fire experiments/MELCOR Model



Measurements (representative)

- Temperature (gas, sodium pool, catch-pan, vessel wall)
- Concentration (oxygen, aerosol)





Sodium Fire Models used

- Spray fire
- Pool fire

Enhancement to MELCOR Pool Fire Model

- Oxidation is limited by diffusion (DAB) through the oxide layer
  - Normal pool combustion

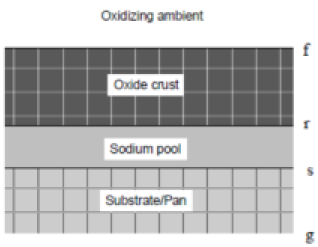
$$\dot{m}_{O2} = A_s H \rho_g Y_{O2} \qquad H = 0.14 D_{diff}\left(g S_c \frac{\beta}{\nu^2}\left|T_{surf} - T_g\right|\right)^{1/3} \qquad D_{diff} = \frac{6.4312\times10^{-5}}{P_g}\left[\frac{(T_{surf}+T_g)}{2}\right]^{1.823}$$

  - Oxygen diffusion through the oxide layer [Oliver 2010]

=DAB: default

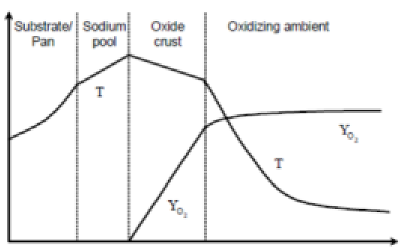
$$\dot{m}_{O2} = A_s\left[\left(\frac{Sh}{L}\right)\frac{D}{1+\delta/\Delta_1}\right]\rho_g Y_{O2,\infty} \qquad H^* = \left(\frac{Sh}{L}\right)\frac{D}{1+\delta/\Delta_1}$$

$$D_{diff} = \frac{\left(\frac{Sh}{L}\right)\frac{D}{1+\delta/\Delta_1}}{0.14\left(g S_c \frac{\beta}{\nu^2}\left|T_{surf} - T_g\right|\right)^{1/3}} \rightarrow D_{diff} = \frac{D}{1+\delta/\Delta_l}$$



Schematic of the pool layers, temperature Profile (T), and Oxygen Fraction (YO2) [Olivier 2010]

The oxide layer thickness δ is given by the amount of oxide formed in the pool with an assumed porosity function.



[Olivier 2010] Olivier, T.J., et al., Metal Fires and Their Implications for Advanced Reactors Part 3: Experimental and Modeling Results, SAND2010-7113, Sandia National Laboratories, Albuquerque, NM, October 2010.

- Pool oxide fractions (FNA2Ox) – can influence the by-product sodium aerosol distribution

$$FNA2OX = a_1 \cdot \varepsilon^{a_2} + a_3 \cdot \varepsilon + a_4$$

Non-Sodium pool model enhancement

Liquid sodium spreading

- The spreading rate was improved using a viscosity dependent model adapted from the ex-vessel corium spreading model in MELCOR

Adapted corium spreading model:

$$\mu \frac{u}{H^2 R} \propto \rho g H \qquad \frac{dR}{dt} = C1 \frac{\rho g}{\mu \pi^3} \frac{V^3}{R^7}$$

$$R(t+\Delta t) = \sqrt[8]{R(t)^8 + C1 \cdot \frac{g}{\mu \pi^3 \rho^2} m^3 \Delta t}$$

Ramacciotti correlation:

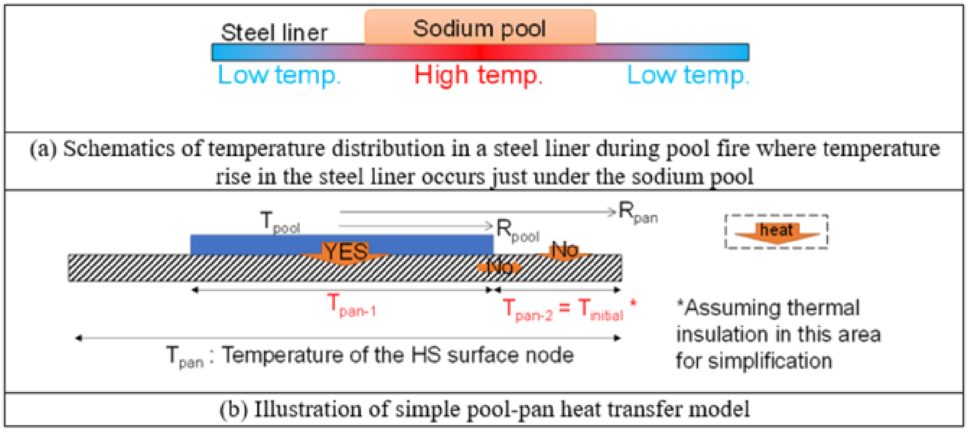
$$\mu = \mu_0 \cdot \exp(2.5 \cdot C \cdot \varepsilon)$$

Solid fraction

$$\varepsilon = \frac{\Sigma \frac{m_j}{\rho_j}}{\Sigma \frac{m_i}{\rho_i}}$$

Pool-to-pan heat transfer

- Addressing the limitation of 1-dimensional heat structure model in MELCOR
  - A quasi 2-dimensional heat transfer model developed



(a) Schematics of temperature distribution in a steel liner during pool fire where temperature rise in the steel liner occurs just under the sodium pool

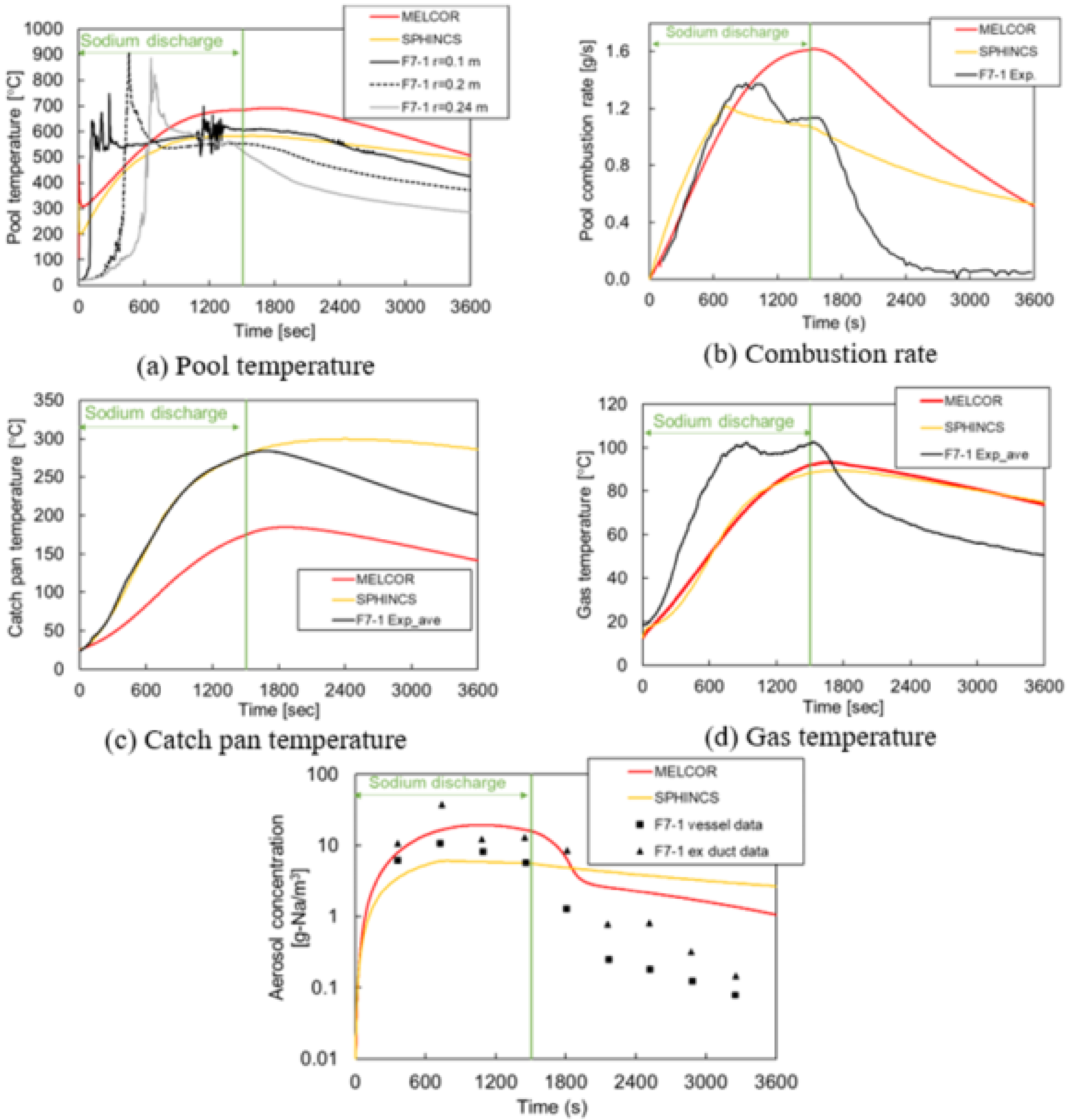
(b) Illustration of simple pool-pan heat transfer model

Sodium Pool Fire Model in SPHINCS

- SPHINCS is developed by JAEA

  - Sodium fire analysis code – lumped mass model for control volumes with 1-dimensional flow model network (similar to MELCOR)
    - Flame sheet model employed for pool combustion - between
      - pool and flame sheet
      - atmosphere and flame sheet
    - Accounts for the oxide layer effect on pool combustion
    - Liquid pool spreading is modeled by surface tension and gravitational forces
    - SPHINCS has a 2-dimensional heat transfer model between pool and substrate

MELCOR – SPHINCS Comparison on F7-1 Test



(a) Pool temperature

(b) Combustion rate

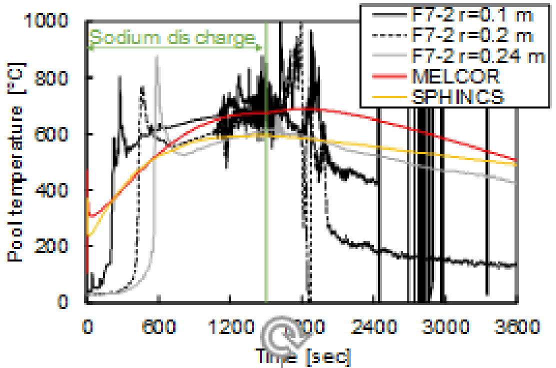
(c) Catch pan temperature

(d) Gas temperature

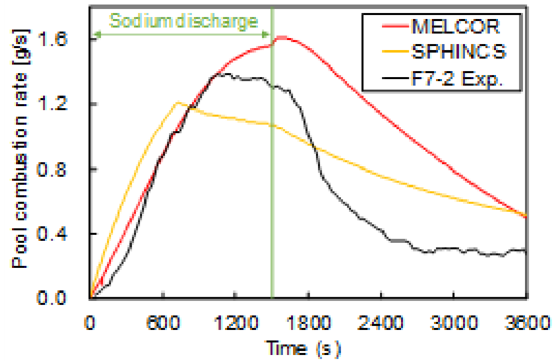
(e) Suspended aerosol

- Results indicate:
  - Similar predictions on pool combustion rate up to 600s
  - Pool temperatures are similar
  - Large catch pan temperature difference remained
  - MELCOR generally predicted better aerosol concentration

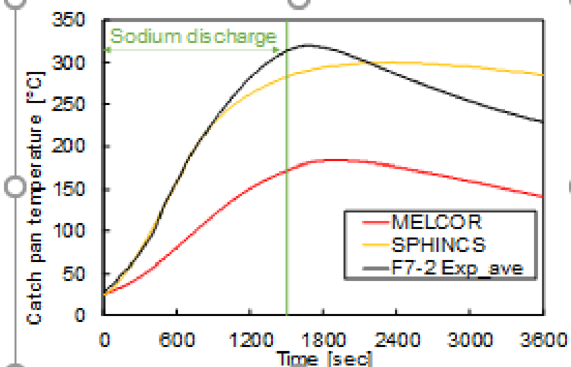
MELCOR – SPHINCS Comparison on F7-2 Test



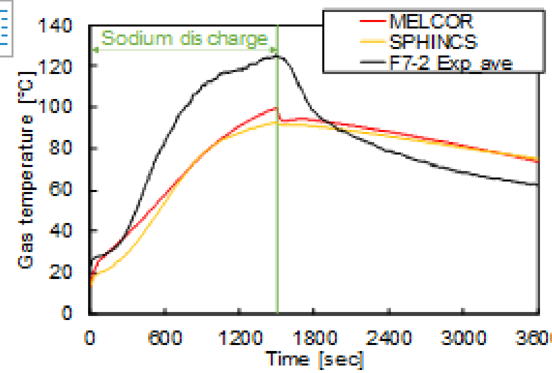
(a) Pool temperature



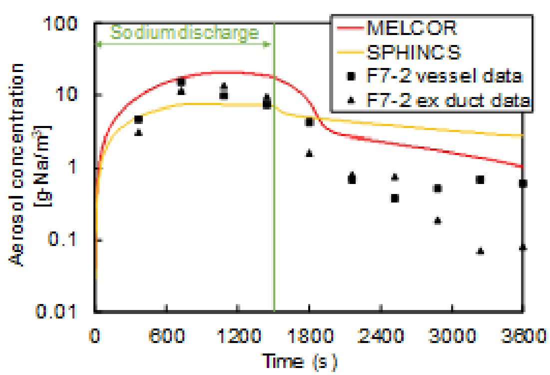
(b) Combustion rate



(c) Catch pan temperature



(d) Gas temperature



(e) Suspended aerosol

- Results indicate:
  - Similar predictions on pool combustion rate up to 1200s
  - Pool temperatures are similar
  - Large catch pan temperature difference remained
  - MELCOR generally predicted better aerosol concentration

Summary and Conclusion

- This paper presents the progress on sodium fire collaboration between SNL and JAEA
- Validation study including for code-to-code comparison was possible using the JAEA's F7 experimental results
- The code-to-code comparison between MELCOR and SPHINCS demonstrated significant improvement on the agreement on many key parameters

THANK YOU