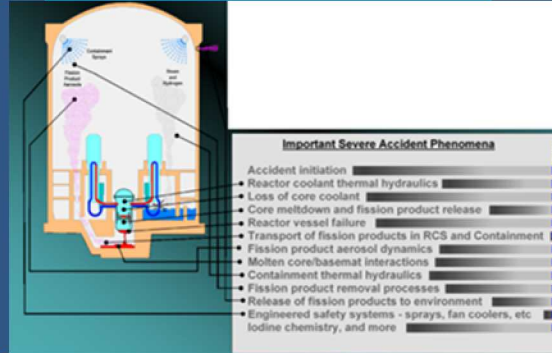




Sodium Pool Fire Model Enhancement in MELCOR



PRESENTED BY

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MELCOR Sodium Pool Fire Model

- Based on CONTAIN-LMR implemented model which was adapted from the SOFIRE II code.
 - Only considers a simplified oxygen consumption as a function of the pool area
 - Simplifies oxygen diffusion – pressure and temperature
 - Allows stoichiometric combustion ratio of sodium to form sodium peroxide and monoxide
 - Parametric values can be input to
 - direct heat to pool or atmosphere (or air)
 - Aerosol fraction in air and in pool
 - Model to turn off
 - Oxygen diffusion model switch. Code default to $D_{\text{diff}} = \frac{6.4312 \times 10^{-5}}{P_g} \left[\frac{(T_{\text{surf}} + T_g)}{2} \right]^{1.823}$
 - Additional switch to allow spreading of sodium in pool
- Control Function features have been added for model improvement explicitly



Sodium Fire Model

- Current sodium pool fire model in MELCOR do not model the influence of the oxide crust on pool phenomenology. For example:
 - Release of aerosols from pool
 - Air ingress and diffusion of oxidizer (e.g., air) to the pool surface/flame zone
 - Modeling these effects is important for several reasons:
 - Formation of oxide crust can affect how further reactions and aerosol generation
 - Lead to better characterizing the oxygen diffusion to sodium





Liquid Sodium Spreading

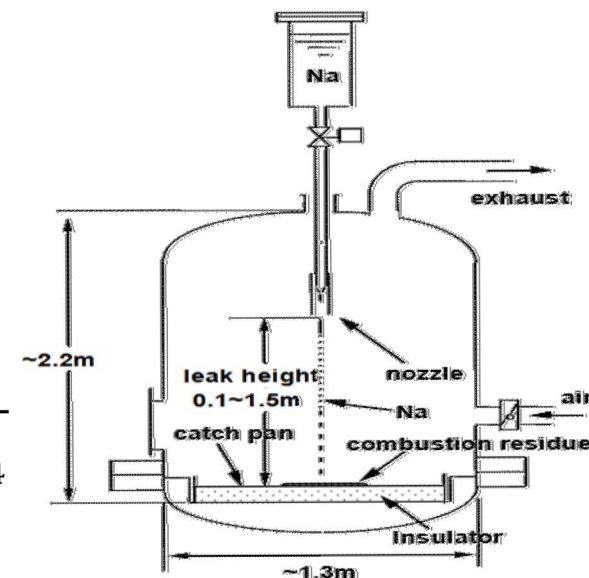
- A simplified pancake spreading model: viscous versus gravitational forces:

$$\mu \frac{u}{H^2 R} \propto \rho g H$$

$$\frac{dR}{dt} = C \frac{\rho g V^3}{\mu \pi^3 R^7}$$

$$R(t) = \sqrt[8]{R(t_0)^8 + C \cdot \frac{\rho g}{\mu \pi^3} V^3 (t - t_0)}$$

$$R(t) = \sqrt[8]{R(t_0)^8 + C \cdot \frac{g}{\mu \pi^3 \rho^2} \dot{m}^3 (t - t_0)^4}$$



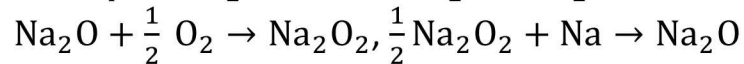
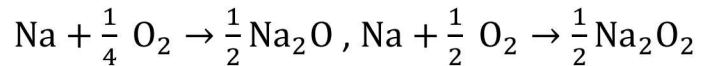
JAEA Pool Fire Apparatus





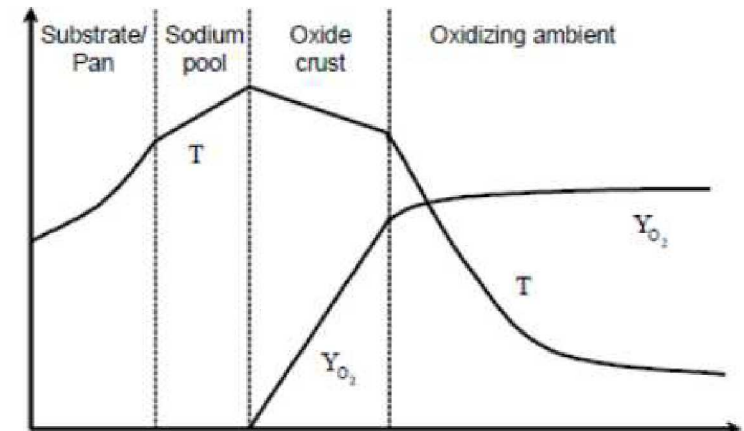
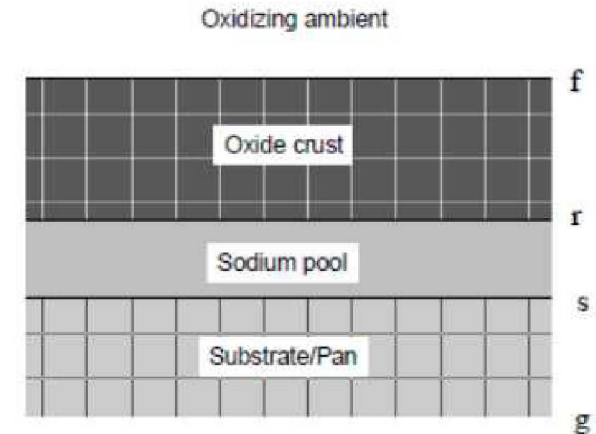
1-D View of Sodium Pool Fire#

Oxidation Reactions*:



4 Layers geometry from SAND2010-7113:

- Oxidizing ambient – provide oxygen for fire
- Oxide crust – a layer between liquid Na and air
 - Na_2O formation – adequate oxygen
 - Na_2O layer – reacts with $\text{O}_2 \rightarrow \text{Na}_2\text{O}_2$
 - Melt at 1132 °C
 - Na_2O_2 formation – inadequate oxygen
 - Na_2O_2 layer – reacts with $\text{Na} \rightarrow \text{Na}_2\text{O}$
 - Melt at 675 °C
- Oxide-sinking period
- Oxide-crust period
- Oxide crust characteristics
- Oxygen mass rate for reactions



#Improved pool model was obtained from SAND2010-7113, *Moisture reaction is not considered here.





Formation of Oxide Layers

- Oxide crust formation above pool
- Sufficient gas-phase void fraction, ϕ_g observed
 - Porosity structure formed
 - Oxide layer can further react due to sodium/air ingress
 - $\text{Na}_2\text{O} + \frac{1}{2} \text{O}_2 \rightarrow \text{Na}_2\text{O}_2$, $\phi_g = 1 - \phi_{\text{Na}_2\text{O}_2}$
 - $\frac{1}{2} \text{Na}_2\text{O}_2 + \text{Na} \rightarrow \text{Na}_2\text{O}$, $\phi_{\text{Na}} = 1 - \phi_{\text{Na}_2\text{O}}$
 - Crust thickness defined as $\delta_i - \delta_i^0 = \frac{1}{\phi_i \rho_i} \int_0^t \dot{m}_i'' dt$



Oxide Layers

- Oxide-sinking Period

- ϕ , volume fraction for Na and Na oxide – vary along pool depth, ϕ_{Na} reduced to $\phi_{\text{Na,lim}}$ which is 0.95.
- F_{st} , sticking fraction – may be empirical value

$$\dot{m}''_{\text{Na}_2\text{O}} = -\frac{F_{\text{st}}}{2} \frac{MW_{\text{Na}_2\text{O}}}{MW_{\text{Na}}} \dot{m}''_{\text{Na}}, \quad \dot{m}''_{\text{Na}_2\text{O}} = -\left(\frac{2F_{\text{st}}}{2-F_{\text{st}}}\right) \frac{MW_{\text{Na}_2\text{O}}}{MW_{\text{O}_2}} \dot{m}''_{\text{O}_2}$$

$$\dot{m}''_{\text{Na}_2\text{O}_2 \text{ (aerosol)}} = -\frac{(1-F_{\text{st}})}{2} \frac{MW_{\text{Na}_2\text{O}_2}}{MW_{\text{Na}}} \dot{m}''_{\text{Na}}, \quad \dot{m}''_{\text{Na}_2\text{O}_2 \text{ (aerosol)}} = -2 \left(\frac{1-F_{\text{st}}}{2-F_{\text{st}}}\right) \frac{MW_{\text{Na}_2\text{O}_2}}{MW_{\text{O}_2}} \dot{m}''_{\text{O}_2}$$

$$\frac{d\delta_{\text{Na}}}{dt} = \frac{\dot{m}''_{\text{Na}}}{\rho_{\text{Na}}} + \frac{\dot{m}''_{\text{Na}_2\text{O}}}{\rho_{\text{Na}_2\text{O}}}, \quad \frac{d\phi_{\text{Na}}}{dt} = \frac{1}{\delta_{\text{Na}}} \left[(1 - \phi_{\text{Na}}) \frac{\dot{m}''_{\text{Na}}}{\rho_{\text{Na}}} + \phi_{\text{Na}} \frac{\dot{m}''_{\text{Na}_2\text{O}}}{\rho_{\text{Na}_2\text{O}}} \right]$$



Oxide Layers (continued)

- Oxide Crust Period when $\phi_{Na} = \phi_{Na,lim}$

$$\dot{m}''_{Na} = \left(\frac{2}{1 + F_e} \right) \frac{MW_{Na}}{MW_{O_2}} \dot{m}''_{O_2}$$

$$\dot{m}''_{Na_2O} = \left(\frac{2F_e}{1 + F_e} \right) \frac{MW_{Na_2O}}{MW_{O_2}} \dot{m}''_{O_2}$$

$$\dot{m}''_{Na_2O_2} = \left(\frac{1 + 2F_e}{1 + F_e} \right) \frac{MW_{Na_2O_2}}{MW_{O_2}} \dot{m}''_{O_2}$$

$$\text{Where } F_e = \frac{MW_{Na}}{MW_{Na_2O}} \frac{\rho_{Na_2O}}{\rho_{Na}} \left(\frac{1 - \phi_{Na}}{\phi_{Na}} \right)$$

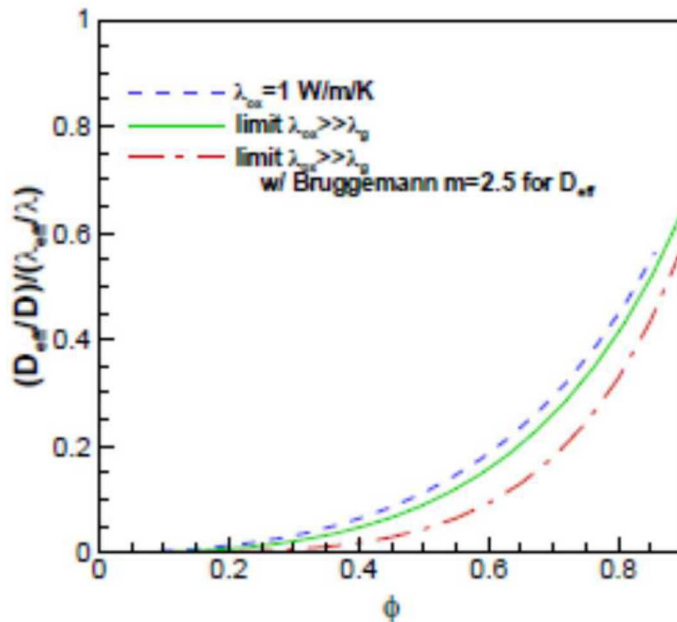


Oxide Layers (concluded)

- Oxide Crust Characteristics

- Thermal Diffusivity: $\frac{\lambda_{\text{eff}}}{\lambda_g} \approx \frac{2\phi_g}{\phi_g}$

- Mass Diffusivity: $\frac{\phi_g D_{\text{eff}}}{D} = \frac{2\phi_g}{3-\phi_g}$



The ratio of to the Effective Mass Diffusivity, D to Thermal Diffusivity, λ through a Porous Oxide Crust as Function of Porosity, ϕ



Oxygen Mass Rate



- Low-temperature oxidation:

$$\dot{m}''_{O_2} = \left(\frac{Sh}{L}\right) \frac{\rho_g D Y_{O_2, \infty}}{1 + \delta/\Delta_l} \text{ where } \Delta_l = \left(\frac{D_{eff}}{D}\right) / \left(\frac{Sh}{L}\right)$$

$$Sh = 0.16(GrSc)^{1/3}, \text{ turbulent flow}$$

$$Sh = 0.7(GrSc)^{1/4}, \text{ laminar flow}$$

$$Gr = \left(\frac{T_f - T_\infty}{T_\infty}\right) \left(\frac{g}{\mu^2}\right) L^3$$

- High-temperature oxidation:

$$\dot{m}''_{O_2} = \left(\frac{Sh}{L}\right) \left(\frac{\rho_g D}{1 + \delta/\Delta_l}\right) \left(Y_{O_2, \infty} + \frac{1}{2} \frac{MW_{O_2}}{MW_{Na}} Y_{Na, r}\right)$$

Implementation to MELCOR



- Additional review is needed
 - Review MELCOR input model from Andrew
 - Assess the new models
- Implement them as control functions if possible
 - Review the MELCOR input parameter list
- Re-run F7-1 Test
 - ensure the heat transfer/heat loss to surrounding
 - assess sodium spreading
 - capture oxidation crust formation
 - Gas mass diffusivity
- Document results in final report