Review of the Aerosol Mass Tracking Method in the ISFRA Fission Product Transport Module for SFR Accident Analyses

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Purpose and Ultimate Goal

Purposes : To review and understand the aerosol mass tracking method of the ISFRA fission product transport analysis module

Ultimate Goal : Improvement of the ISFRA aerosol models by modifying the existing FAI aerosol correlations

ISFRA Aerosol Fission Product Model

ISFRA(Integrated Sodium Fast Reactor Analysis) Program:

- Best-Estimate computer code to simulate the consequences of accidents and BDBA transients in the PGSFR design.
- Developed for the period from 2014. 8. to 2017. 9. by FAI co., under the contract with KAERI.

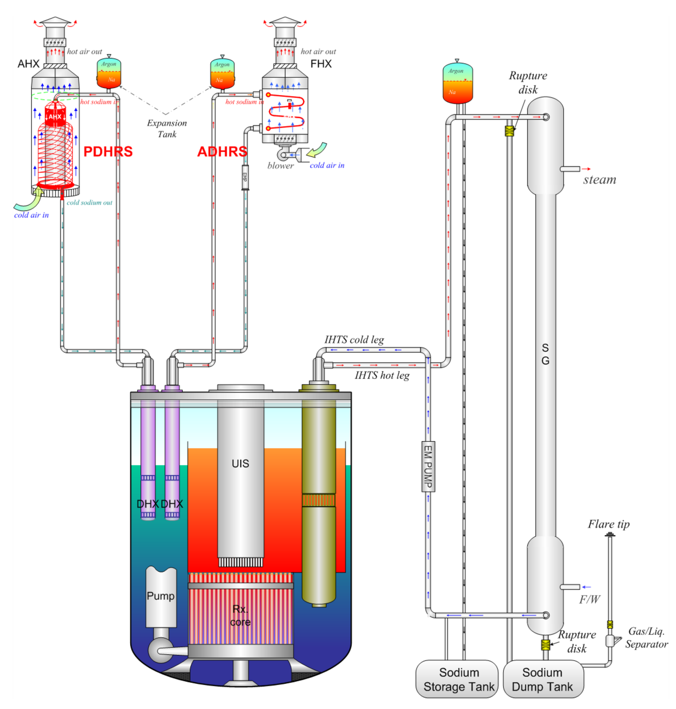


Fig. PGSFR Schematic Diagram

Aerosol Mass Tracking Method:

- 'Self-preserving form' of size spectrum assumed: As time increase, the particle size distribution becomes independent of the initial distribution of sizes.
- Complete aerosol size distribution is not solved. → Total suspended (+deposited) mass is tracked.
- Adapted in MAAP, APRIL, and SIRIUS codes as well as ISFRA.

Aerosol Mass Tracking Method (Epstein, 1988)

· **Aerosol Dynamic Equation:**

$$\frac{\partial n(v,t)}{\partial t} = \frac{1}{2}\int_0^v K(\bar{v}, v-\bar{v}) n(\bar{v},t) n(v-\bar{v},t) d\bar{v} - \int_0^\infty K(\bar{v},v) n(\bar{v},t) n(v,t) d\bar{v} - \frac{n(v,t)u(v)}{h} + \dot{n}_p(v)$$

· **Total Aerosol Mass Variation:**

$$\frac{dm(t)}{dt} = -\lambda(t) m(t) + \dot{m}_p$$

where $m(t) = \rho \int_0^\infty v n(v,t) dv$

$$\lambda(t) = \frac{\int_0^\infty v n(v,t) u(v) dv}{h \int_0^\infty v n(v,t) dv}$$

$$\dot{m}_p(t) = \rho \int_0^\infty v \dot{n}_p(v,t) dv$$

Table. ISFRA FP Grouping

Group	Fission Products
1	Noble gases (Xe, Kr)
2	Iodine (I_2)
3	Sodium Iodide (NaI)
4	Tellurium (Te_2)
5	Alkali metals (Cs, Rb)
6	Sodium (Na)
7	Refractory materials (Ru, Mo, Rh, Tc)
8	Barium (Ba)
9	Strontium (Sr)
10	Lanthanides (La, Pr, Nd, Sm, Y, ...)
11	Cerium group (Ce, Np, Pu, U)

· **By Similarity Analyses,**

$$\tau = \left(\frac{\alpha g \rho K_0}{\chi^2 \gamma \mu h^2}\right)^{1/2} \cdot t \quad , \quad \upsilon = \left(\frac{\gamma g \rho}{\alpha^{1/3} \mu K_0}\right)^{3/4} \cdot v$$ **, etc.**

Scaling Coefficients for Macroscopic Aerosol Properties

Time, τ	Particle volume, υ	Particle number density, N
$\left(\frac{\alpha g \rho K_0}{\chi^2 \gamma \mu h^2}\right)^{1/2} \cdot t$	$\left(\frac{\gamma g \rho}{\alpha^{1/3} \mu K_0}\right)^{\frac{3}{4}} \cdot v$	$\left(\frac{\gamma^3 K_0^5 \mu^5 h^4}{\alpha g^5 \rho^5}\right)^{1/4} \cdot n$
Mass density, M	Decay constant, Λ	Particle production rate, $\dot{N}_p$
$\left(\frac{\gamma^9 g h^4}{\alpha^3 K_0 \mu \rho^3}\right)^{\frac{1}{4}} \cdot m$	$\left(\frac{\gamma \chi^2 \mu h^2}{\alpha K_0 g \rho}\right)^{1/2} \cdot \lambda$	$\left(\frac{\gamma^5 \chi^4 K_0^3 \mu^7 h^8}{\alpha^3 g^7 \rho^7}\right)^{\frac{1}{4}} \cdot \dot{n}_p$

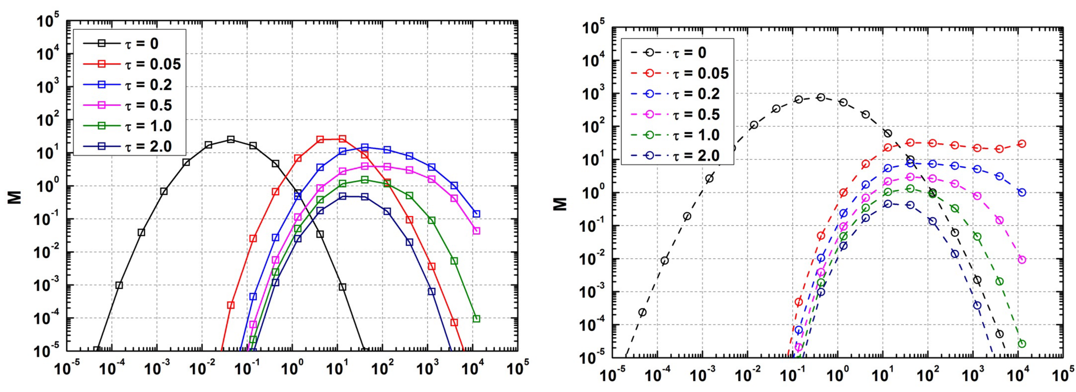
Nomenclature:

- h effective height for aerosol deposition [m]
- k Boltzmann constant
- $K(v, \tilde{v})$ kernel representing the frequency of binary collisions between particles of volume v and ṽ
- K_0 normalized Brownian collision coefficient (= 4kT/(3μ))
- m total mass concentration of the suspended aerosols [kg/m³]
- $\dot{m}_p$ aerosol mass production rate [kg/m³/s]
- M dimensionless total suspended aerosol mass
- $\dot{M}_p$ dimensionless source rate
- n particle size distribution function [m⁻³]
- $\dot{n}_p$ source rate of particles [m⁻³s⁻¹]
- $N(v,\tau)$ dimensionless particle distribution function
- v particle volume [m³]
- t time [s]
- T carrier gas temperature [K]
- u particle deposition or removal velocity [m/s]
- α density correction factor [-]
- χ particle settling shape factor [-]
- $\varepsilon(v, \tilde{v})$ capture coefficient [-]
- γ collision shape factor [-]
- λ aerosol removal rate constant [s⁻¹]
- Λ dimensionless decay constant
- μ viscosity of the carrier gas [kg/m/s]
- ρ density of the aerosol material [kg/m³]
- τ dimensionless time
- N dimensionless particle volume

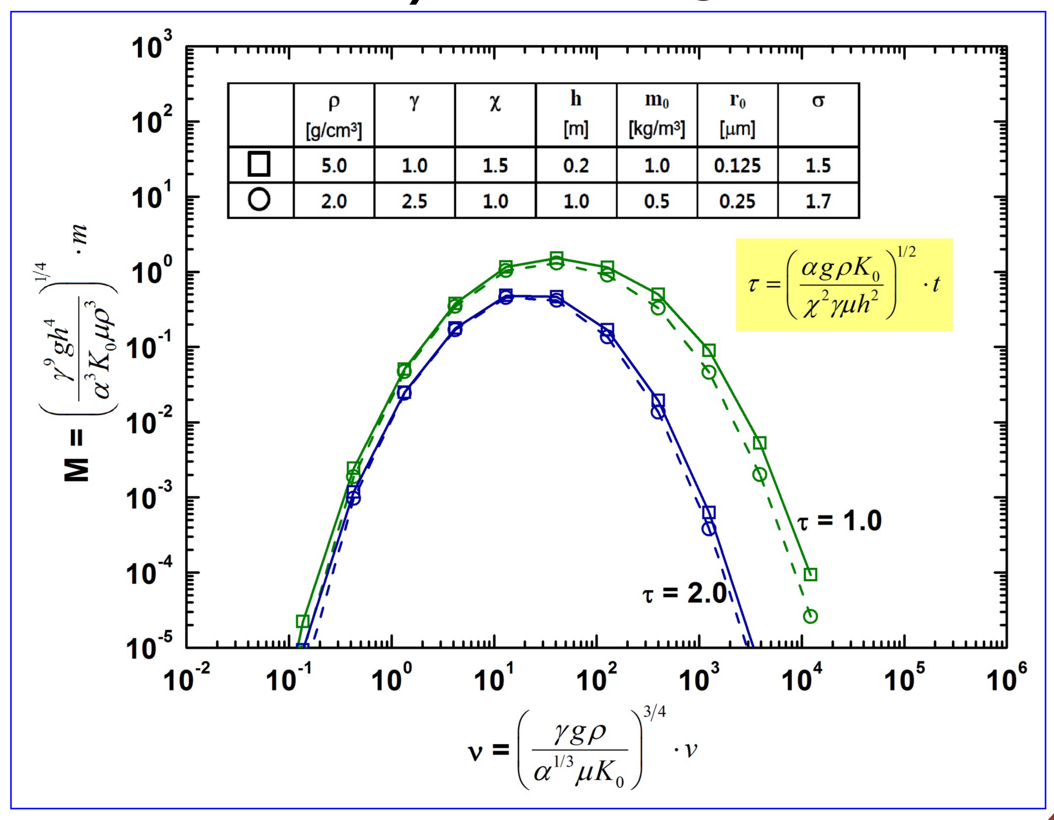
Confirmation of Aerosol Similitude

Aerosol Similitude: Two different aerosols display essentially similar behavior.

Similar Behavior: After the initial conditions are forgotten, aerosol particle size spectrum approaches a self-preserving form.



Simulation Method: MAEROS runs (Using sectional method) for □ and ○ aerosols.



ISFRA Aerosol Mass Reduction Correlations

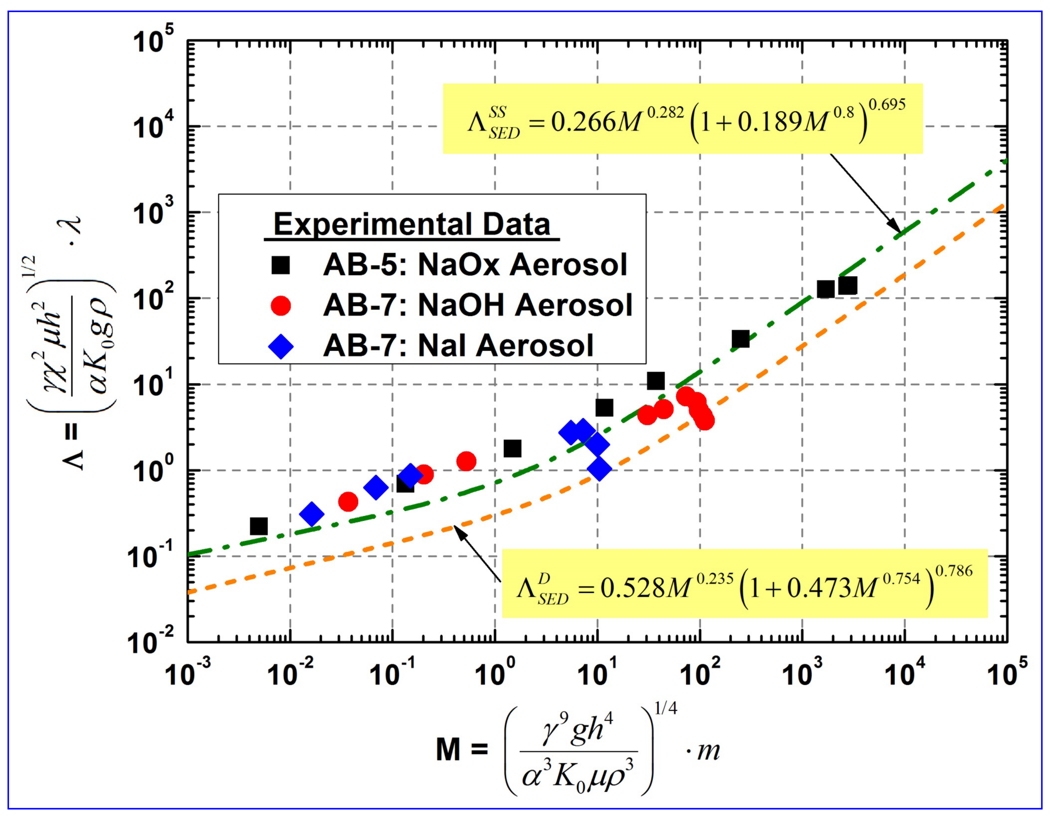


Fig. Dimensionless aerosol removal rate constant for sedimentation as a function of dimensionless suspended mass concentration

For steady-state condition:

$$\frac{dM}{d\tau} = -\Lambda_{SED}^{SS}(M) \cdot M + \dot{M}_p = 0$$

For decaying condition:

$$\frac{dM}{d\tau} = -\Lambda_{SED}^{D}(M) \cdot M + \dot{M}_p$$

Superscript 'SS': Steady-state, 'D': Decaying, & Subscript 'SED': Sedimentation.