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An Evaluation of a Hygrosopic Model in the SIRIUS Code

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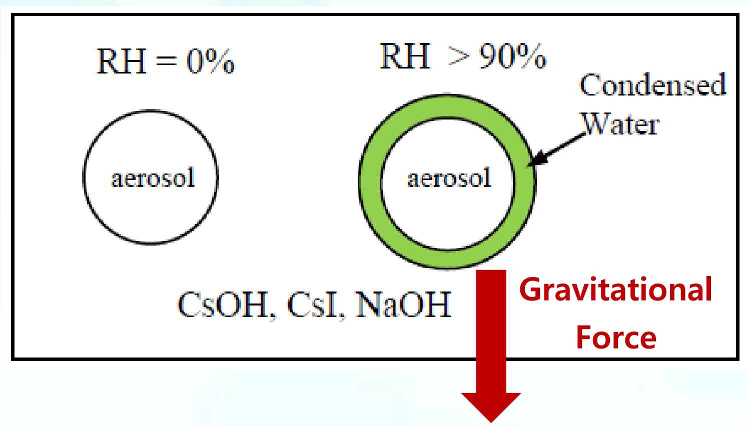
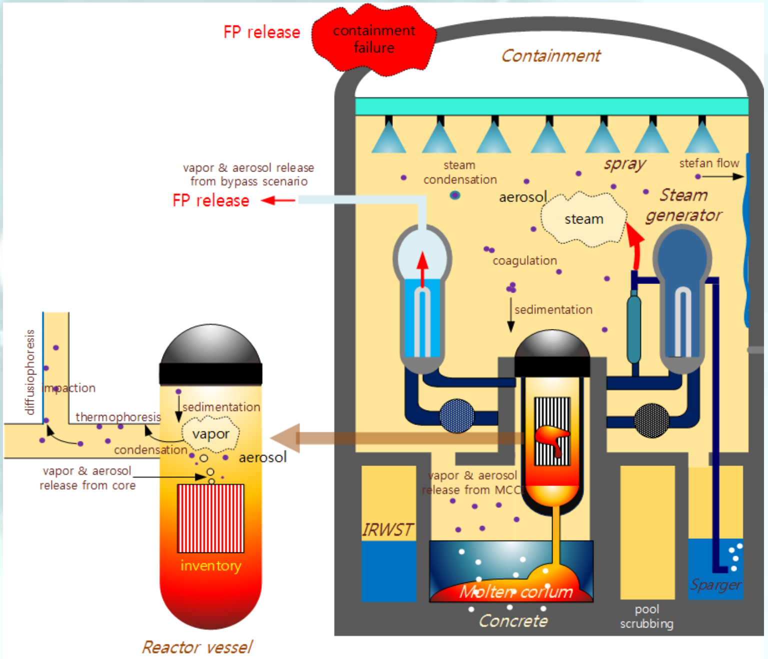
Importance of FP & Aerosol Behavior in a NPP

❑ Amendment of Nuclear Safety Action(2015)

- Accident Management Program(AMP) – Effective date: 23 June 2016
- Safety Target
  - Site boundary dose < 250 mSv
  - Release to environment : Cs-137, 100 TBq < 10^{-6}/ry
- FP & Aerosol almost locates in the humid environment
  - CsOH, CsI, NaOH : aerosol size increases in a humid condition → its settling rate increases

Growth of Hygroscopic Aerosol





Structure of SIRIUS (1)

FP INPUT

- Fuel Information
  - ✓Fuel type
  - ✓Thermal power
  - ✓Fuel cycle
- FP group Information
  - ✓No. of groups
  - ✓User defined groups
- Source information
  - ✓FP release model
  - ✓Gap release fraction
  - ✓User defined source
- Aerosol Information
  - ✓Aerosol factors
  - ✓Sedimentation area
  - ✓Jet impaction area, dia.
  - ✓Heat surface area
- Numerical Information
  - ✓Numerical scheme
  - ✓Time control parameters

SIRIUS

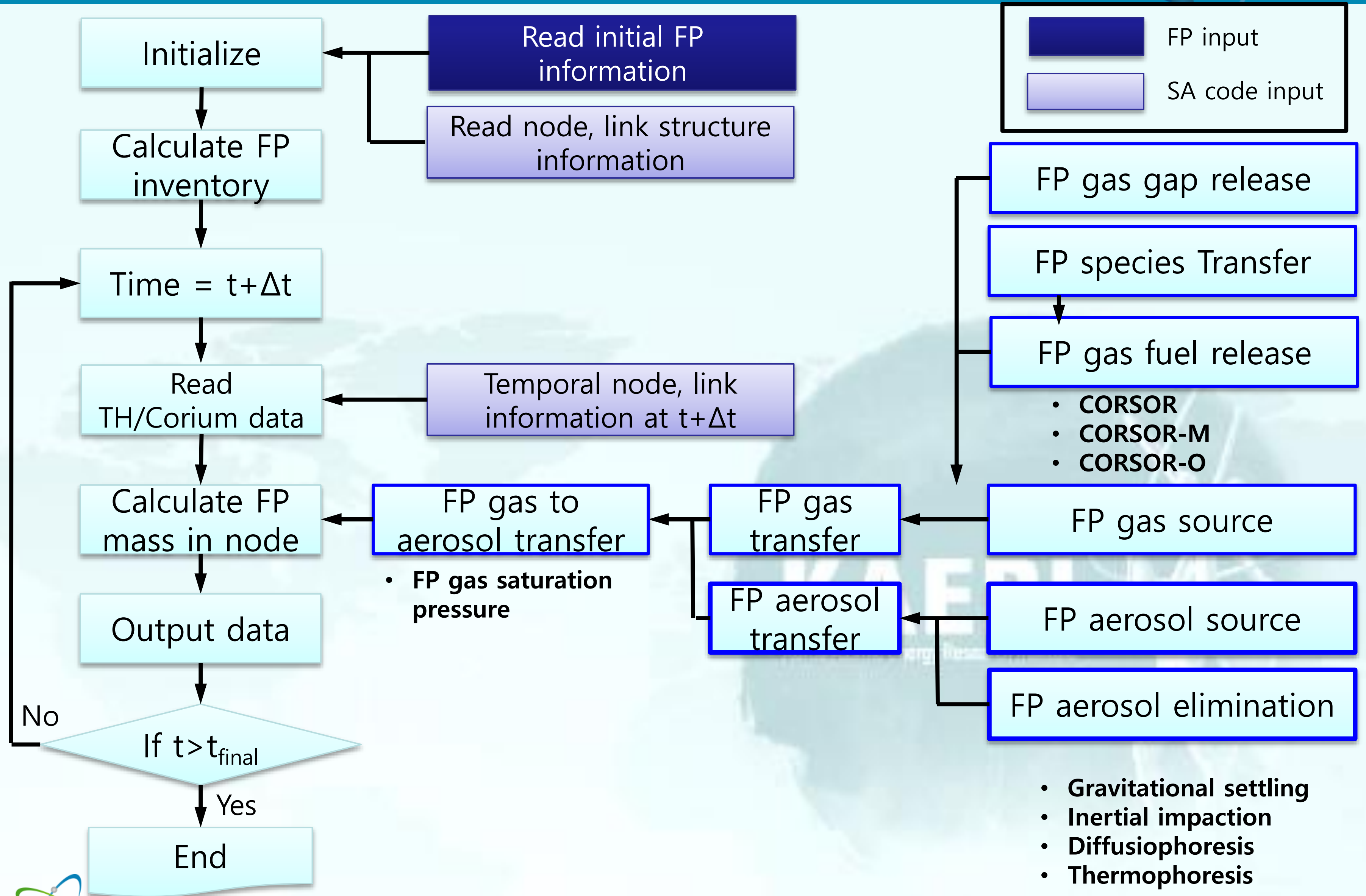
T/H INPUT

- Node Information
  - ✓No. of nodes
  - ✓Geometry: area, length
  - ✓T/H: P, T, carrier gas properties
  - ✓Corium : UO_2, Zr, ZrO_2, B_4C, Inconel, SUS mass
- Link Information
  - ✓No. of links
  - ✓Geometry: area, node connection
  - ✓T/H: carrier gas transfer
  - ✓Corium transfer

FP OUTPUT

- Temporal group mass in each node
  - ✓Species (solid)
  - ✓FP gas
  - ✓Airborne aerosol
  - ✓Deposited aerosol mass on the wall
  - ✓Decay heat distribution

Structure of SIRIUS (2)



Hygroscopic Model in SIRIUS

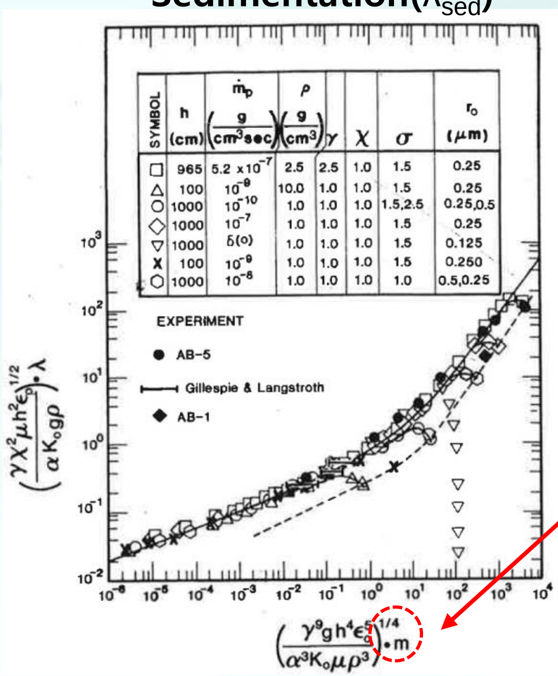
❑ Aerosol Removal Model in the SIRIUS Code

- ❍ Sedimentation, Inertial Impaction, Diffusiophoresis, Thermophoresis
- ❍ Aerosol Transport Eq.

$$\lambda_t = \lambda_{sed} + \lambda_{imp} + \lambda_{diff} + \lambda_{th} + \lambda_{tub}$$

$$\frac{dm_{a,i}^n}{dt} = \dot{m}_{a,i,in}^n - \dot{m}_{a,i,out}^n - \lambda_{t,i}^n m_{a,i}^n + \dot{G}_{a,i}^n$$

Sedimentation(λ_{sed})



Hygroscopic Effect (Aerosol Mass Increase)

$$(\emptyset - 1)r^4 - \frac{2\sigma}{\rho_w R_w T R_0} r^3 + \left(1 - \emptyset + \frac{M_w \rho_a}{M_a \rho_w}\right) + \frac{2\sigma}{\rho_w R_w T R_0} = 0$$

$$M_{aw} = (V_{wet}\,\rho_W)(r^3 - 1) \qquad r = \frac{R_{eq}}{R_0} \qquad \emptyset = \frac{P_{st}}{P_{sat}}$$

M_w : Molecular weight of water
M_a : Molecular weight of aerosol
P_{st} : Water vapor pressure at the aerosol surface
P_{sat} : Saturated water vapor pressure at the particle surface temperature
R_o : Minimum radius of aerosol

Ref. : M. Epstein, NED 107, pp 327-344 (1988)

❑ Test Facility, Condition & Results

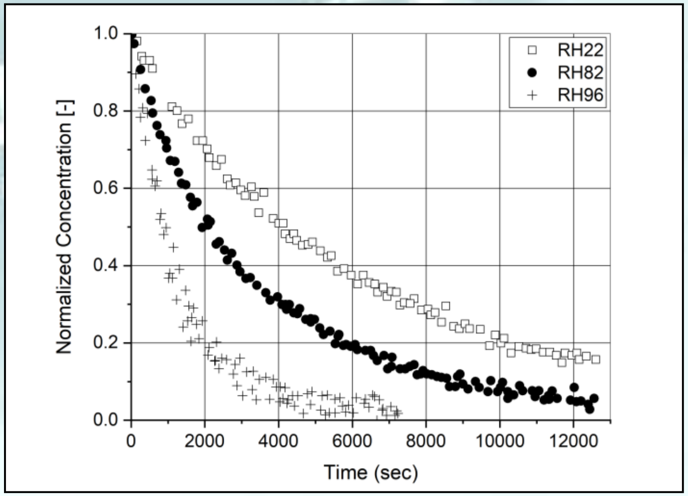
Vessel Effective Volume	1.81 m^3
Vessel Radius	0.635 m
Vessel Effective Height	1.425 m
Sedimentation Area	1.27 m^2
Approximate Diffusion Area	9.42 m^2
NaOH atomic weight	40 g/mol
Pressure	1.013×10^5 Pa
Leakage Rate (RH constant during test)	206% of volume/24h (~2.6 liters per minute)
NaOH density	2130.0 kg/m^3
Dry NaOH particle size (AMMD/GSD)	$2.4\text{x}10^{-6}$ m / 1.64

AHMED Test Facility (by VTT)

Test Condition

Run	Relative Humidity (%)	Temperature (K)	Initial Mass Concentration (mg/m^3)
RH22	22	323.15	112
RH82	82	300.15	208
RH96	96	296.15	218

NaOH Airborne Concentration

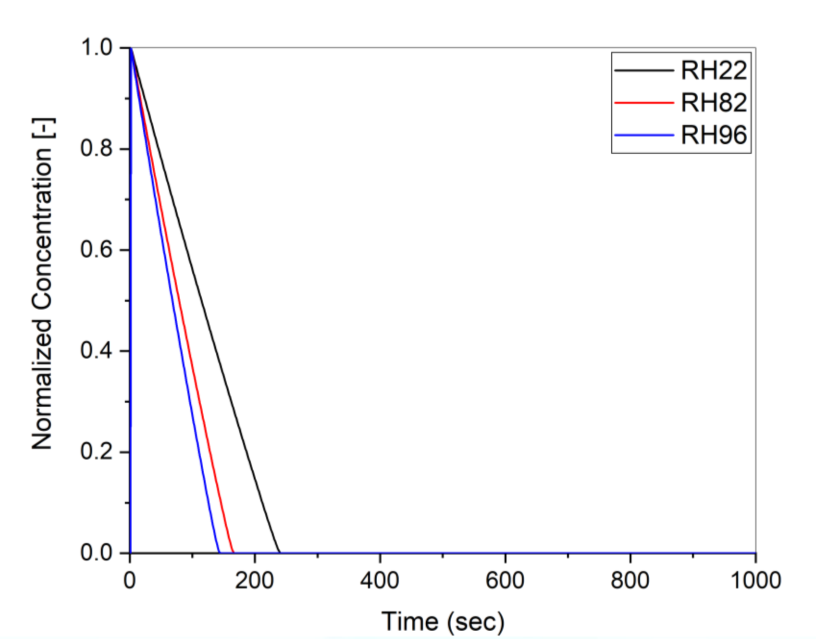


Ref. : MELCOR Manual, Vol. 3

SIRIUS Calculation Results

❑ SIRIUS Calculation for AHMED RH22/RH82/RH96

- Nodalization for AHMED : single node
- NaOH mass concentrations were given as the initial condition
- Pressure, Temperature, and RH conditions as time passes were given using a SIRIUS input file
- Transient calculation : 13,000 sec with a time step size of 1 s



***SIRIUS results show a faster concentration decrease as the RH condition increases which is similar to the test data.**

***However, predicted results show much faster decrease than the test data for all cases**

***This may mean that the hygroscopic growth of the NaOH aerosol predicted by SIRIUS was greatly increased in a short time when compared to the test data.**

***The reason may be explained by the fact that this SIRIUS calculation did not consider the size distribution. The hygroscopic effect generally occurs at larger size aerosols(>10μm).**

MELCOR Results for AHMED Test

❑ MELCOR Calculation Results for AHMED Test

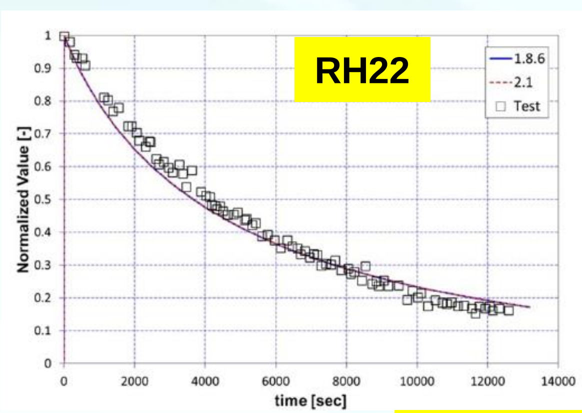
❍ Sectional method(size distribution model) was used

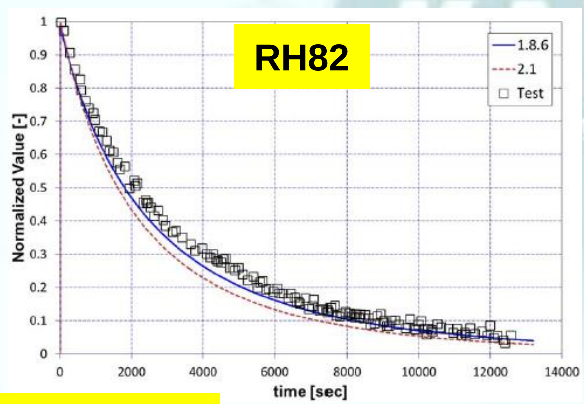
```
* RN input
*
RN1000  0
RN1001  30   1   15  14  13  1   0
RN1100  1.0E-8  30.E-6  1000.
RNACOEF 1
RNACOND  0
RNPT000  9.0E4   1.5E5   275.   400.
RNMS000  1.0  1.0  1.257  1.0   0.001   0.05  1.0  1.0E-5
RNAS000 001   2    2   0.0  4.0544E-5  200 2
RNAS001   1.65E-6  1.64
*RNCC000  1 1  1 1 1 1 1 1 1 1 1 1 1 2 1
*RNAG000   001  2  0.0  0.0  0.0  0.0  0.0  0.0
*RNAG001   0.22035  0.0  0.0  0.0  0.0
RNDS001  00001   LHS   FLOOR
RNSET001  002  002  -10.  2.
```

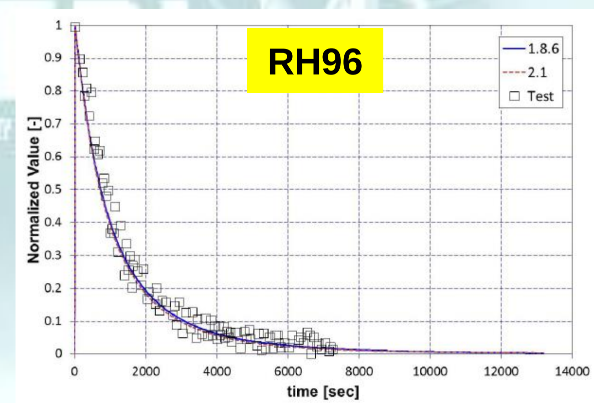
30 sections → 1.0×10^{-8} < aerosol size < 30.0×10^{-6}

Ref. : NEA/CSNI/R(95)23
"AHMED Code Comparison Exercise Comparison Report"

> Under favourable conditions particles may grow to sizes larger than 10 μm. These particles will settle rapidly, after which a small fraction of micron-sized (or less) particles remain airborne.







Ref. : MELCOR Manual, Vol. 3

Conclusion and Further Work

❑ Conclusion

- We evaluated the hygroscopic model in the SIRIUS code without considering the size distribution effect against the AHMED test performed by VTT.
- The SIRIUS results showed much faster growth than the test data even though the aerosol settling according to RH conditions was accurately simulated.

❑ Further Work

- SIRIUS calculation for the AHMED test will be done using a size distribution model implemented in the SIRIUS code.