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An Aerosol Transport Analysis in the Marviken Test by SIRIUS Code

강형석*, 손동건, 하광순
*hskang3@kaeri.re.kr

한국원자력연구원(KAERI)

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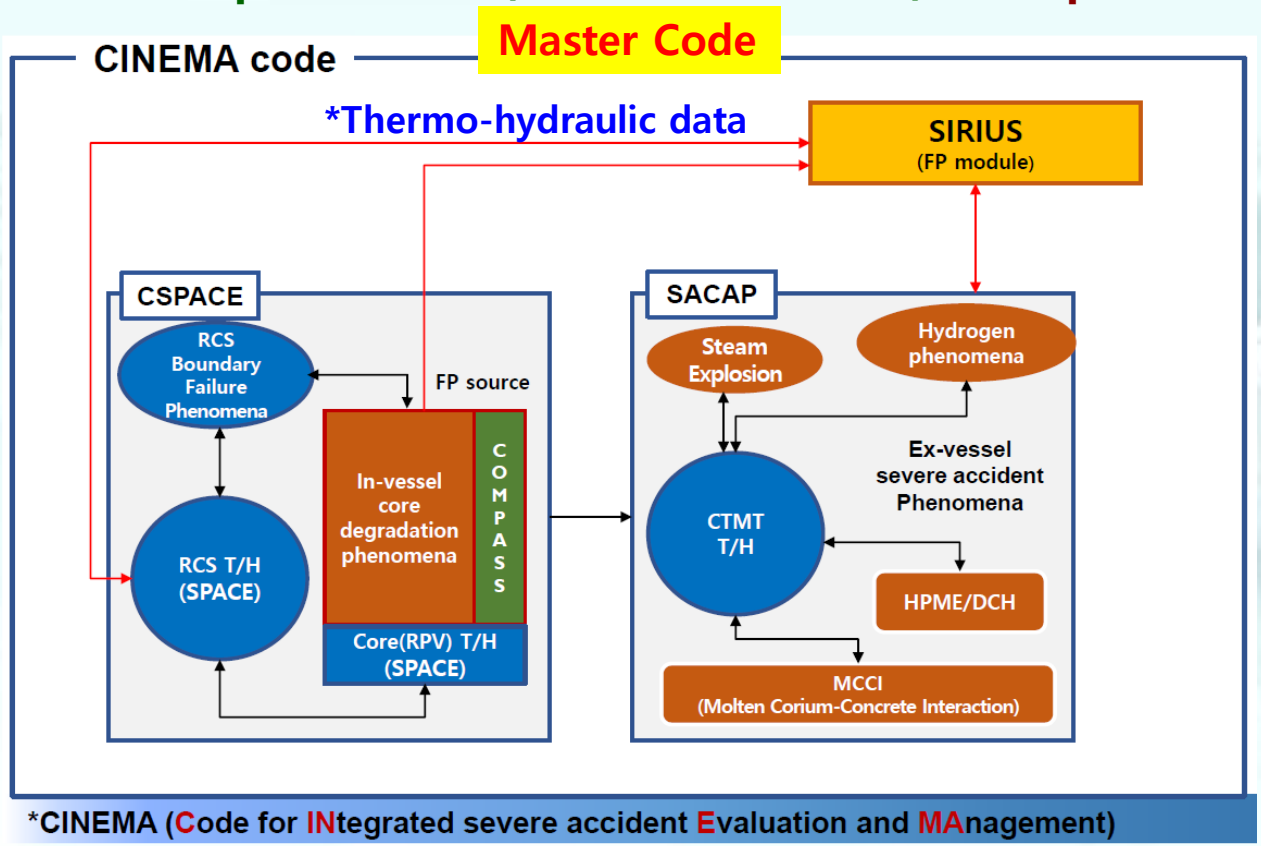
Coupled Calculation between CSPACE and SIRIUS

❑ SIRIUS module for predicting an aerosol transport

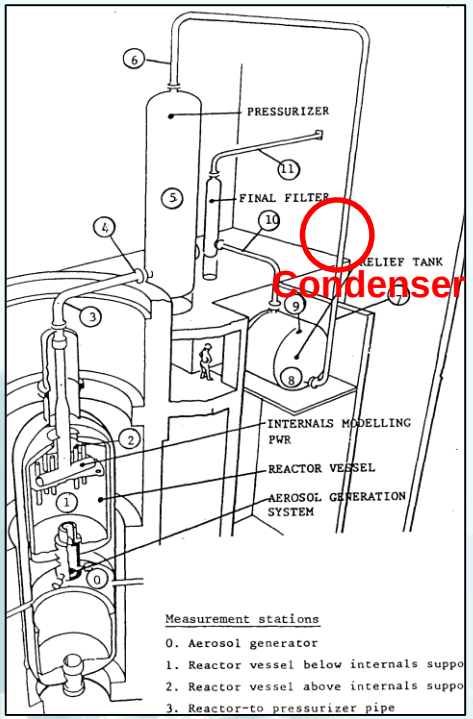
- ❍ CINEMA code development (2011. 7 – 2017. 6) : Separated calculation
  - ⏩ 2017, KNS Autumn Meeting, H.S. Kang,et al.
- ❍ CINEMA code improvement (2019. 5 – 2023. 4) : Coupled calculation



Marviken Test-202b (1)

❑ Test Procedure & TH Results

- ❍ Test duration : 118 min.
- ❍ Steam injection to Facility : 40 g/s, 400 ℃
  - ⏩ H_2 : 0.015 g/s, N_2 : 1.4 g/s, Water : 3.1 g/s
- ❍ Aerosol injection to PZR
  - ⏩ Cs : 9.65 g/s, Te : 1.62 g/s, I : 0.83 g/s
  - ⏩ CsOH (70.11 kg), CsI (11.07 kg), Te (11.07 kg)



Location	Start of Test		End of Test	
	Gas °C	Wall °C	Gas °C	Wall °C
Vaporization chamber peak	5000(est)*	-	5000(est)	-
Vaporization chamber bulk	2000(est)	1600(est)	2000(est)	1600(est)
Pressurizer bottom	340 - 380	285 - 325	385 - 420	340 - 385
Pressurizer middle	295 - 310	272 - 286	340 - 355	317 - 330
Pressurizer top	288	275	328	315
Pipe L041**	272	252	313	298
Pipe L063**	158	96	167	101
Relief tank	29	25	34	30

No steam condensation

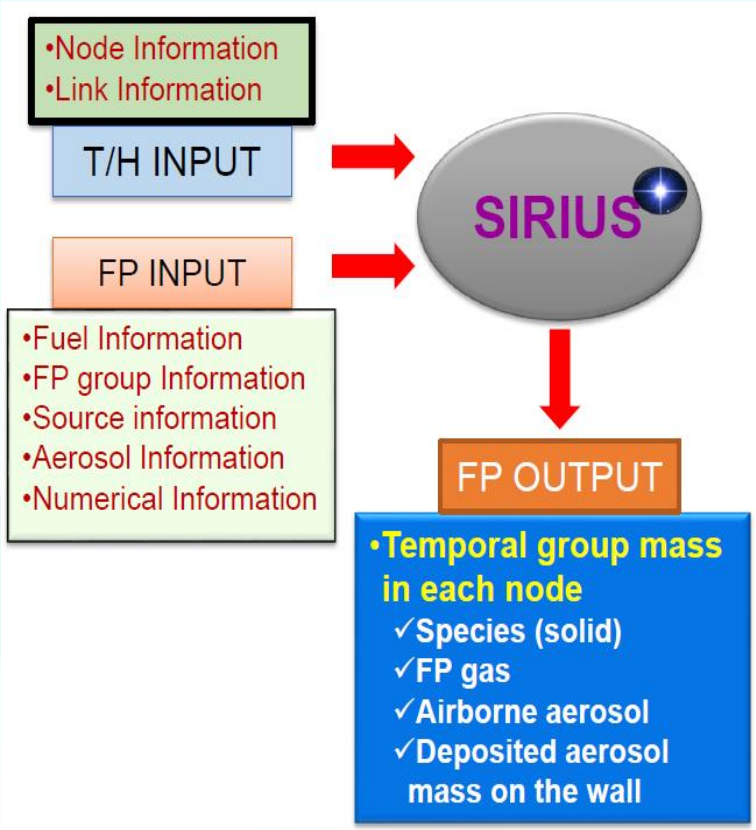
Marviken Test-202b (2)

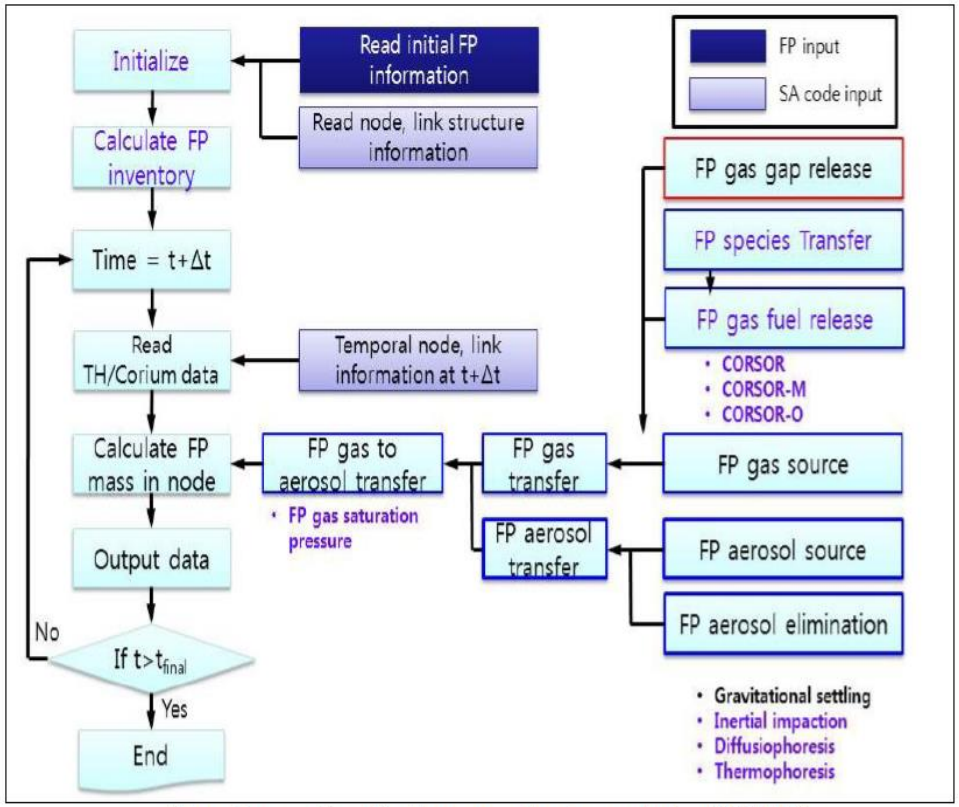
Test Data

- Approximately 50% of the injected aerosol mass was discharged to the relief tank.
- Approximately 10% of the injected aerosol mass was not recovered.

PART OF THE SYSTEM	Cs		I		Te	
	kg	%	kg	%	kg	%
VAPORIZATION CHAMBER	1.04	1.66	0.07	1.32	0.23	2.24
WALL RUN-OFF TRAYS	0.73	1.16	0.07	1.32	0.10	0.97
PRESSURIZER BOTTOM	23.55	37.51	1.92	38.12	3.71	35.72
PRESSURIZER LOWER PART	2.22	3.53	0.17	3.42	0.36	3.45
PRESSURIZER MID PART	0.39	0.62	0.03	0.53	0.12	1.13
PRESSURIZER UPPER PART	0.40	0.64	0.03	0.66	0.06	0.57
PRESSURIZER TOP	0.41	0.66	0.03	0.65	0.07	0.64
PIPE LO4*	0.20	0.33	0.01	0.22	0.05	0.52
PIPE LO5*	2.64	4.21	0.23	4.51	0.19	1.78
PIPE LO6*	0.18	0.29	0.01	0.27	0.08	0.77
RELIEF TANK	30.45	48.50	2.42	47.98	5.33	51.39
FINAL PARTICLE FILTER	0.02	0.03	0.00	0.08	0.01	0.13
MISCELLANEOUS	0.54	0.85	0.05	0.94	0.07	0.69
TOTAL MASS RECOVERED	62.78	100	5.04	100	10.38	100
TOTAL MASS FED	68.24	-	5.80	-	11.07	-
TOTAL MASS/TOTAL FEED	-	92.00	-	86.85	-	93.76

Structure of SIRIUS Code



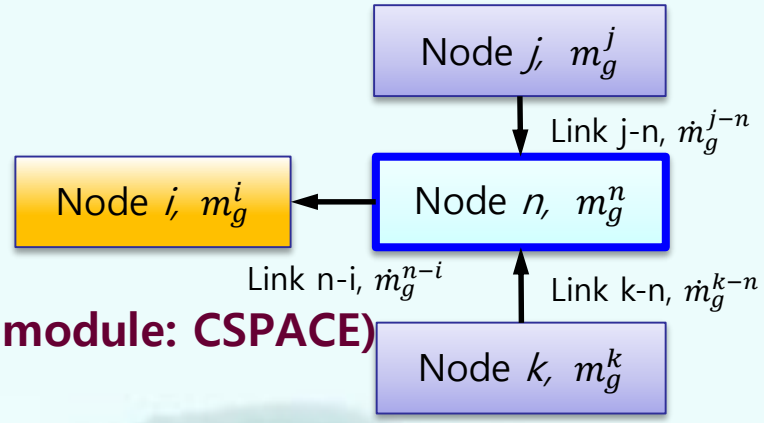


Structure of a fission product module (SIRIUS)

Transport Equation in SIRIUS Code

❑ FP gas & aerosol transportation

- ❍ Role
  - ⏩ Calculate FP transfer to nodes
- ❍ Major parameters
  - ⏩ Carrier gas mass transfer rate (T/H module: CSPACE)
- ❍ Modeling method
  - ⏩ General method
    - Based on the carrier gas mass transfer
  - ⏩ Current method
    - i-group FP gas transfer $\frac{dm_{v,i}^n}{dt} = \dot{m}_{v,i,in}^n - \dot{m}_{v,i,out}^n + \dot{G}_{v,i}^n$
    - i-group FP aerosol transfer
- ❍ Required input
  - ⏩ T/H module
    - Link properties: carrier gas mass transfer rate
    - Node properties: carrier gas mass
  - ⏩ FP : N/A



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

$$\dot{m}_{v,i,in}^n = \sum_{k=1}^{N} \dot{m}_g^{k-n} \frac{m_{v,i}^k}{m_g^k}$$

$$\dot{m}_{v,i,out}^n = \sum_{k=1}^{N} \dot{m}_g^{n-k} \frac{m_{v,i}^n}{m_g^n}$$

$$\dot{m}_{a,i,in}^n = \sum_{k=1}^{N} \dot{m}_g^{k-n} \frac{m_{a,i}^k}{m_g^k}$$

$$\dot{m}_{a,i,out}^n = \sum_{k=1}^{N} \dot{m}_g^{n-k} \frac{m_{a,i}^n}{m_g^n}$$

Aerosol Deposition Model in SIRIUS Code

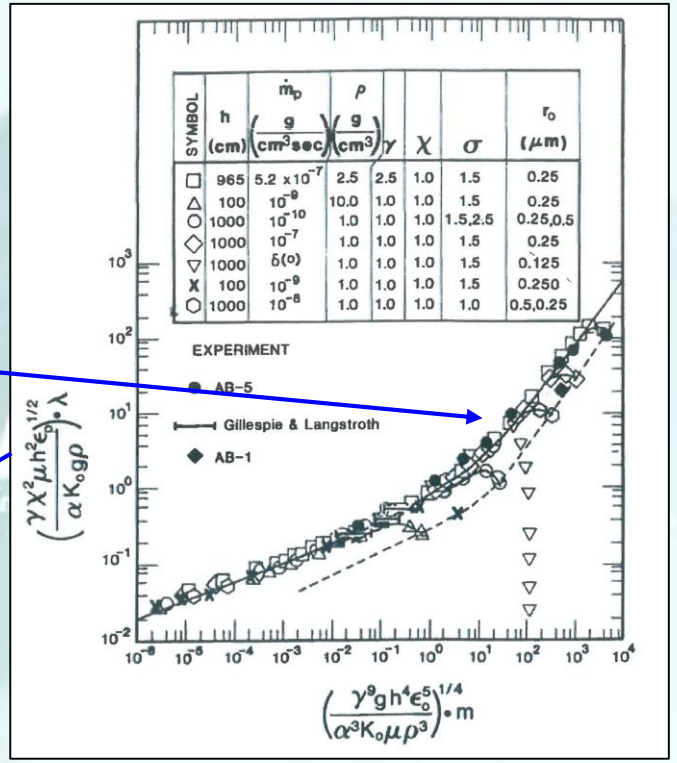
❑ Aerosol deposition model

- ❍ Ref : NED, Vol. 107, pp. 327-344 (1988), Michael Epstein
- ❍ $\lambda_t = \lambda_{sed} + \lambda_{imp} + \lambda_{diff} + \lambda_{th} + \lambda_{tub}$
  - ⏩ sed : sedimentation
  - ⏩ imp : inertia impaction
  - ⏩ diff : diffusiophoresis
  - ⏩ th : thermophoresis
  - ⏩ turb : turbulent flow

$$\Lambda_{sed}^{SS} = 0.266 M_{sed}^{0.282} \left(1 + 0.189 M_{sed}^{0.8}\right)^{0.695}$$

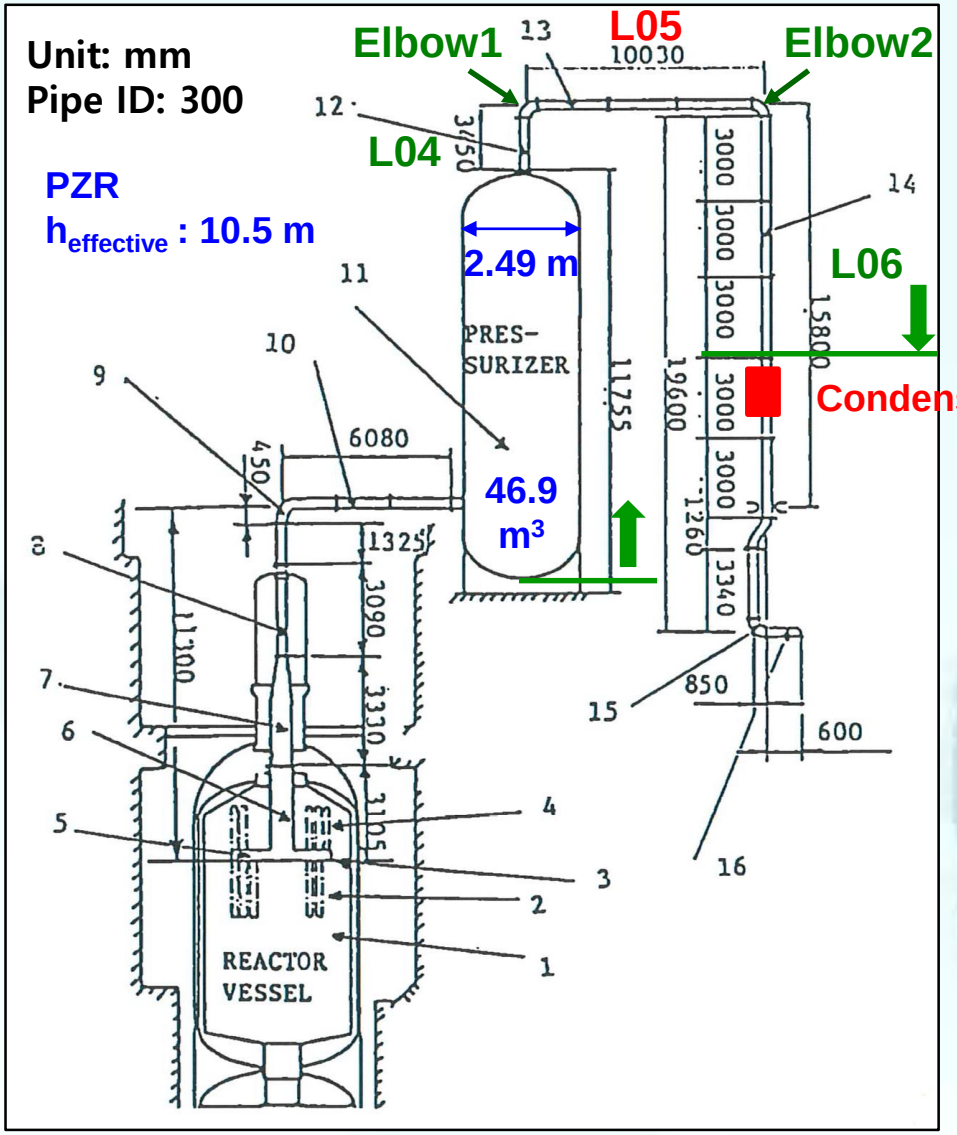
$$\Lambda_{sed} = \left(\frac{\gamma \varepsilon_o \chi^2 \mu h_{eff}^2}{\alpha K_o g \rho}\right)^{1/2} \cdot \lambda_{sed}$$

Sedimentation



h_{eff} = Volume / Bottom Area

CSPACE Input

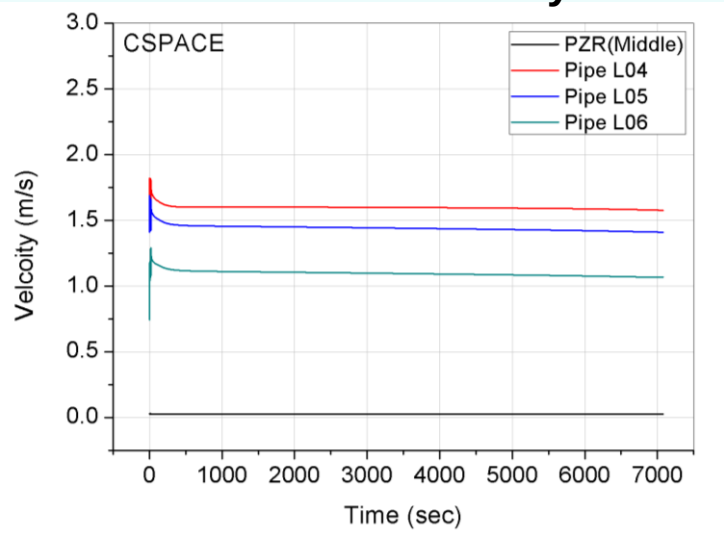


CSPACE Analysis Model

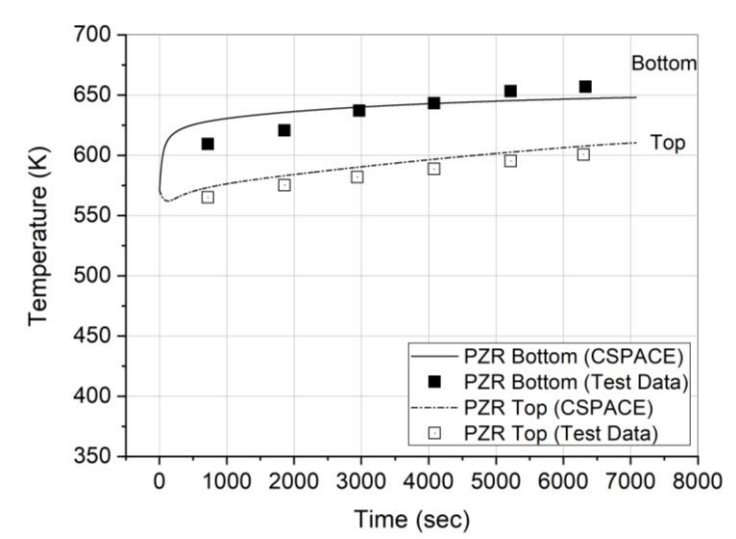
- Nodalization (Total 30 cells)
  - PZR : 5 cells
  - Elbow : 1 cell
  - Pipe L04 : 4 cells,
  - Pipe L05 : 10 cells
  - Pipe L06 : 9 cells
- Time Step Control
  - 1.6E-06 s – 0.1 s
- Steam Injection
  - 0.43 g/s, 400 ℃
- Wall Temp.
  - Test data

CSPACE Results

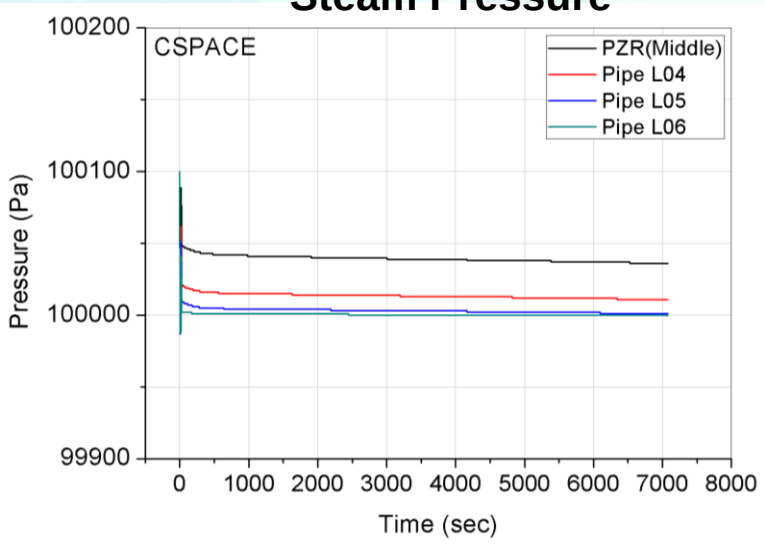
Steam Velocity



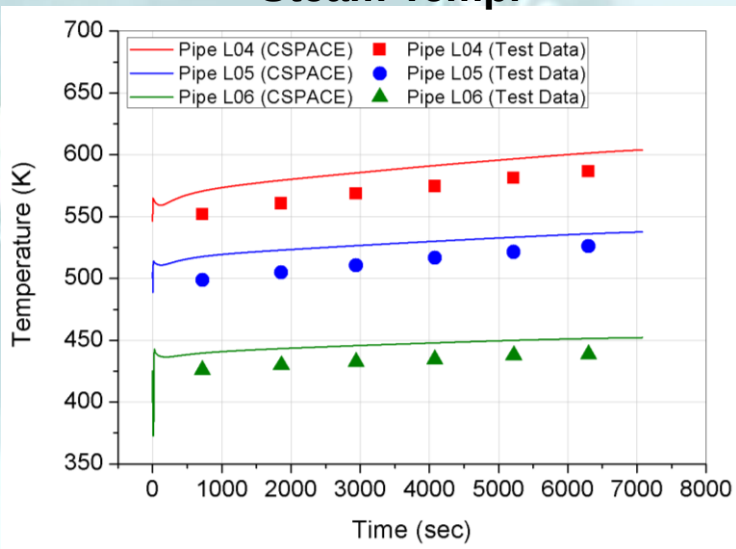
Steam Temp.



Steam Pressure



Steam Temp.



SIRIUS Input & Model

- **Marviken Test-202b**
  - PZR : 5 Node
  - Aerosol injection rate
    - CsOH : 9.9 g/s (0 – 7080 s)
    - CsI : 1.69 g/s (60- 7080 s)
    - Te : 1.62 g/s (240- 7080 s)
  - Model constants
    - Collision shape factor(γ) : 1.0
    - Settling shape factor(χ) : 1.0
    - Density correction factor(α) : 1.0

Applied deposition model

	Sedimen-tation	Inertia Impaction	Thermo-phoresis	Diffusio-phoresis
PZR	O	X	O	O
L04	X	X	O	O
Elbow1	X	O	O	O
L05	X	X	O	O
Elbow2	X	O	O	O
L06	X	X	O	O

Diffusiophoresis

(Diffusion Coefficient)

$$u_{diff} = \frac{F\beta_{12}}{\tilde{\rho}_1} \ln\left[\frac{P_v - P_1(0)}{P_v - P_1(\delta)}\right]$$

$$\beta_{12} = \frac{D_{12}\tilde{\rho}_1}{\delta}$$

$$\lambda_{diff} = \frac{u_{diff}}{h_{eff}}$$

Thermophoresis

(Wall Temp., Nu, Pr)

$$u_{th} = \frac{\mu\kappa}{\chi\rho_g L}\left[\frac{T_\infty}{T_w} - 1\right]\left[\frac{1-(\kappa \mathrm{Pr})^{1.25}\left(T_w/T_\infty\right)}{1-(\kappa \mathrm{Pr})^{1.25}}\right] \mathrm{Nu}$$

$$\lambda_{th} = \frac{u_{th}}{h_{eff}}$$

SIRIUS Results

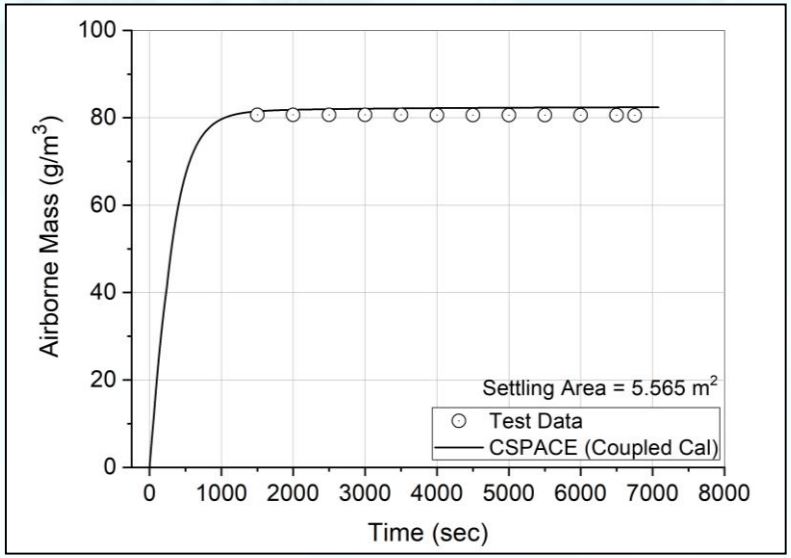
❑ Airborne Aerosol Mass in PZR

- ❍ Calculated results accurately predict the test data with an error range of approximately 3%.

❑ Deposited Aerosol Mass

- ❍ Calculated results predict the test data with an error range of approximately 30%.
- ❍ In the SIRIUS calculation, there is no disappeared mass during the transportation as shown in the measured data.

Airborne Aerosol Mass in PZR



		Test	SIRIUS	Difference [%]
Deposited Aerosol Mass on the PZR Wall [kg]	Cs	23.55	18.02	-23.4
	I	2.18	1.53	-29.8
	Te	4.32	2.94	-31.9
Deposited Aerosol Mass on the Pipe L05 Wall [kg]	Cs	2.64	2.62	-0.7
	I	0.23	0.22	-4.3
	Te	0.19	0.42	+12.1
Discharged Aerosol Mass to Relief Tank [kg]	Cs	30.45	39.73	+30.4
	I	2.42	3.40	+40.4
	Te	5.33	6.65	+24.7
Ratio of injected aerosol to recovered aerosol [%]	Cs	92.00	100	-
	I	86.85	100	-
	Te	93.76	100	-

Conclusion and Further Work

❑ Conclusion

- ❍ We performed the coupled calculation between the CSPACE and SIRIUS codes against the Marviken test-202b to validate the improved CINEMA code.
- ❍ When considering the approximately 10% loss of the injected aerosol mass in the test, the prediction error range of approximately 30% is not high discrepancy.

❑ Further Work

- ❍ Coupled calculation between the CSPACE and SIRIUS codes should be applied to other test data to increase an applicability of the CINEMA code.