Issues and Modeling of Fission Product in HTGR at KAERI

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I. Nuclear Hydrogen Projects

■ Nuclear Hydrogen Key Technologies Development Project

- Develop Key and Basic Technologies for NHDD Project
- 12 Year National R&D Program supported by MEST
- Launched in 2006

■ NHDD* Project

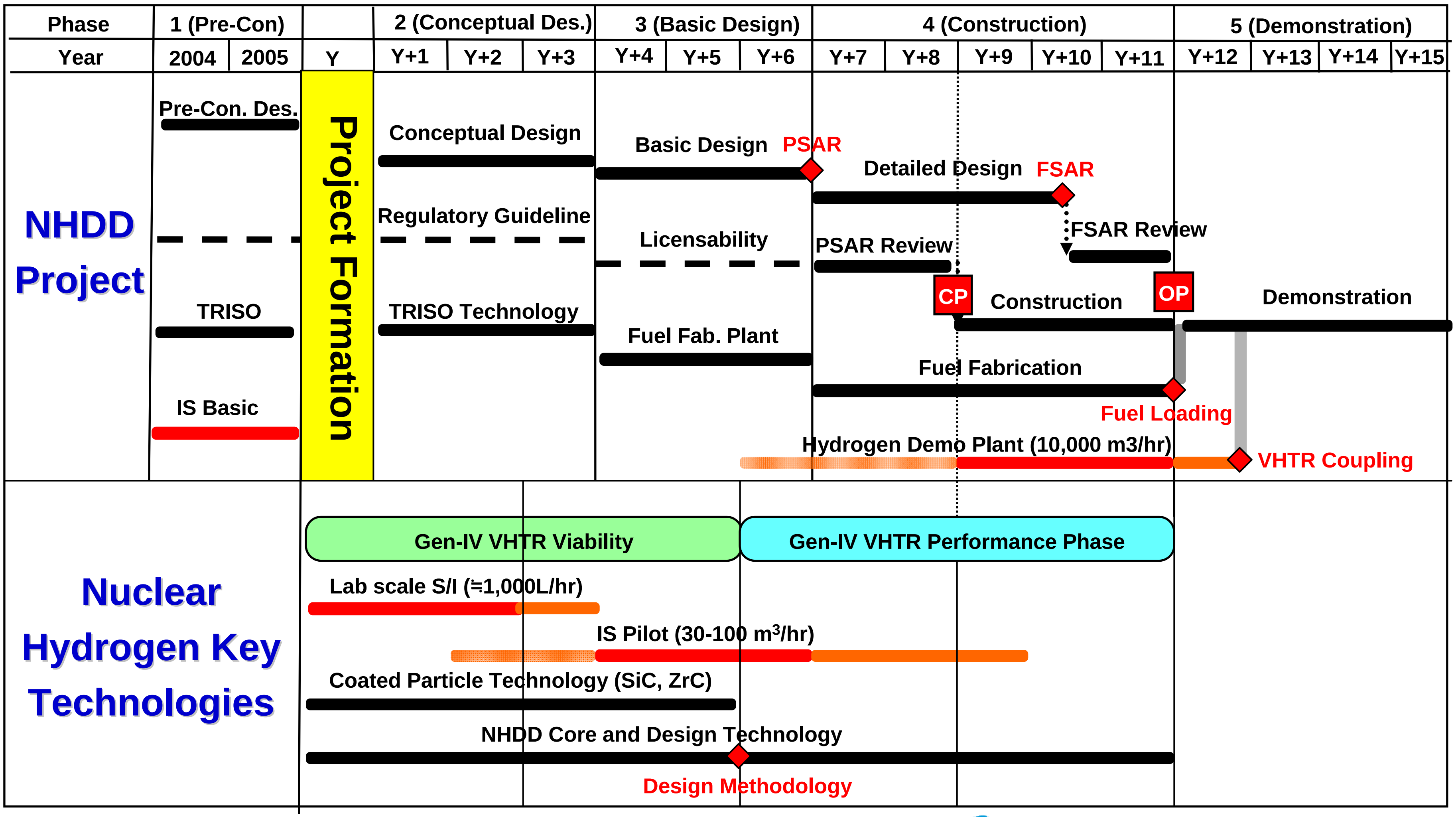
- Design, Construct and Demonstrate Nuclear Hydrogen System
- 16 Year National Project supported by MEST, MKR and Industry
- Expected to start in 2010 or after

NHDD: Nuclear Hydrogen Development and Demonstration

MEST: Ministry of Education, Science and Technology

MKR: Ministry of Knowledge and Economy

Project Milestones



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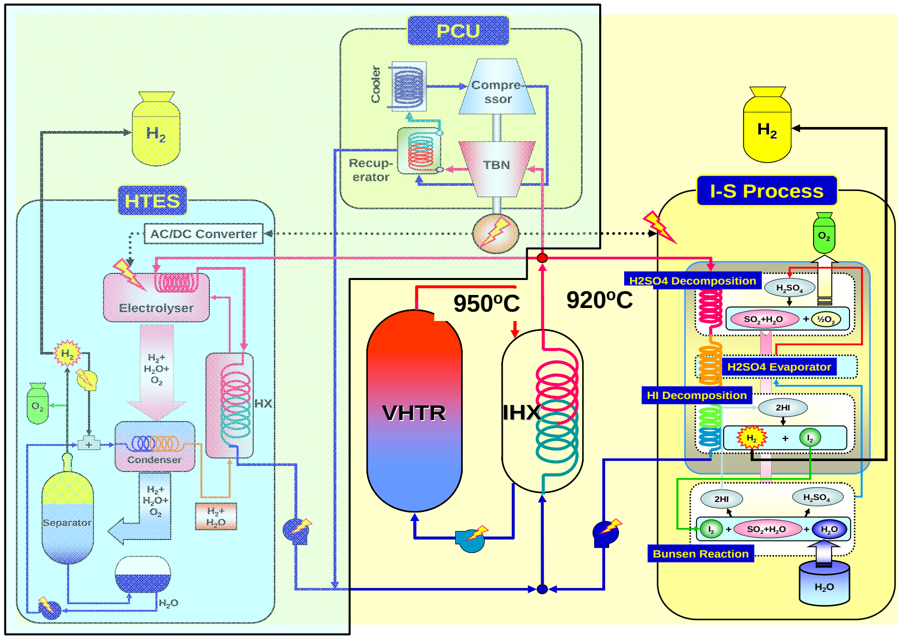
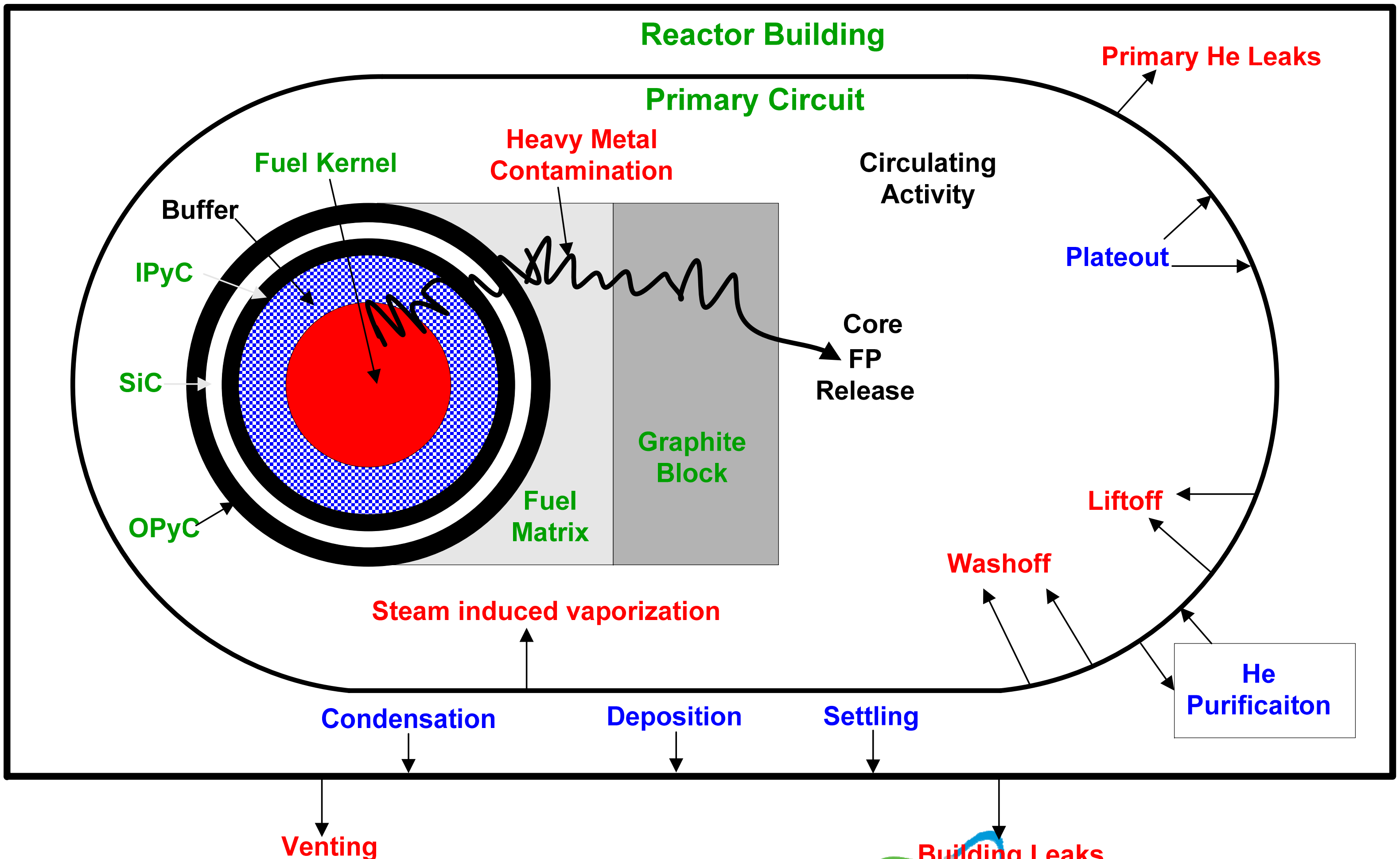
Nuclear Hydrogen System

- **NHDD System: Scaled-Down Demo. Plant (~ 200MW$_{th}$)**
  - VHTR dedicated to Hydrogen Production
    - VHTR Options
      - Prismatic
      - Pebble
    - Operating Conditions
      - T_{out} = 950°C
  - Intermediate Loop Options
    - Gas: He, N_2-He, …
    - Molten Salt
  - Hydrogen Production Options
    - Iodine-Sulfur Thermo-Chemical
    - High Temperature Electrolysis (TBD)

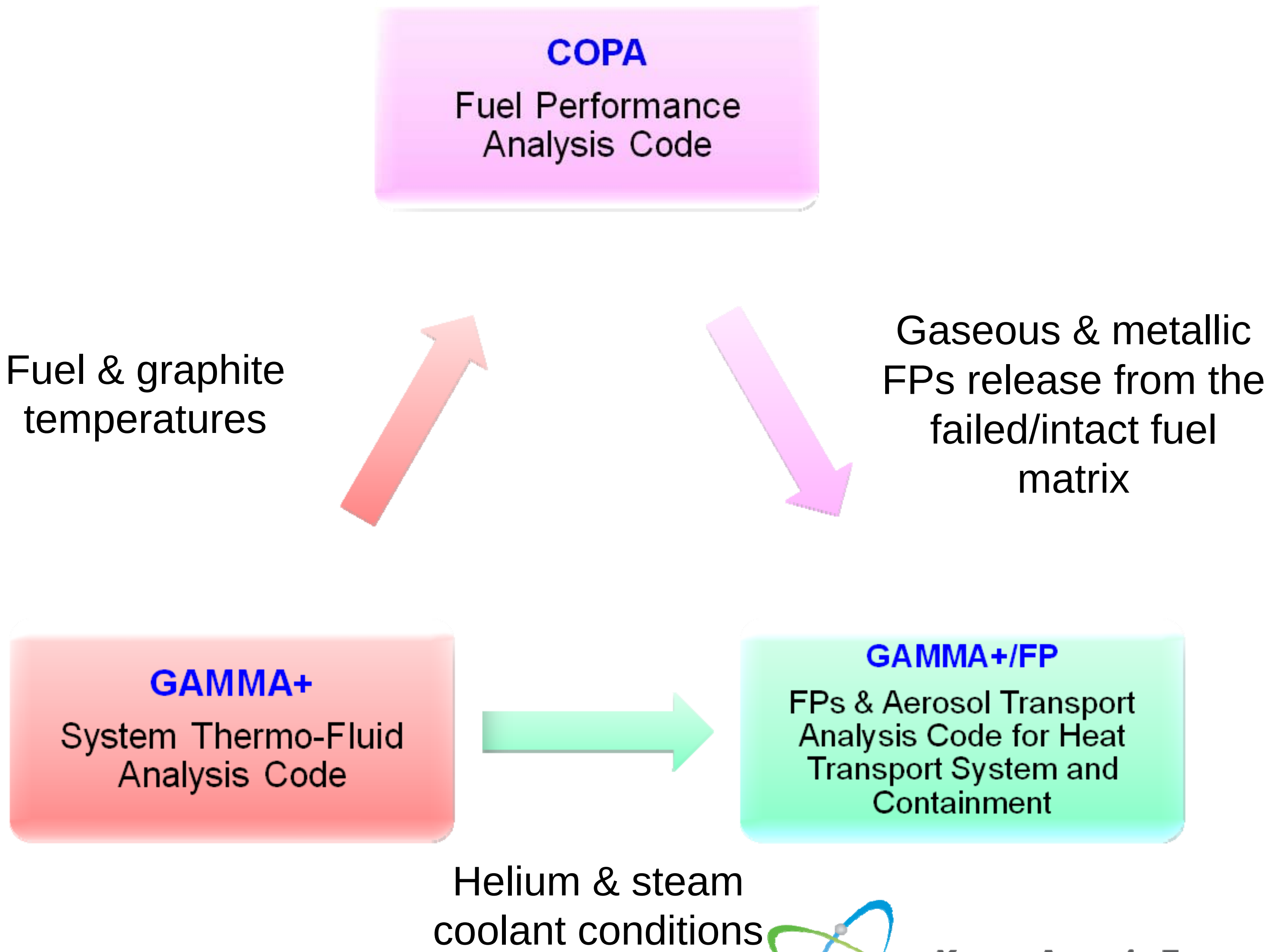


II. Activities on FP Modeling in HTGR

Radionuclide Behaviors in VHTR



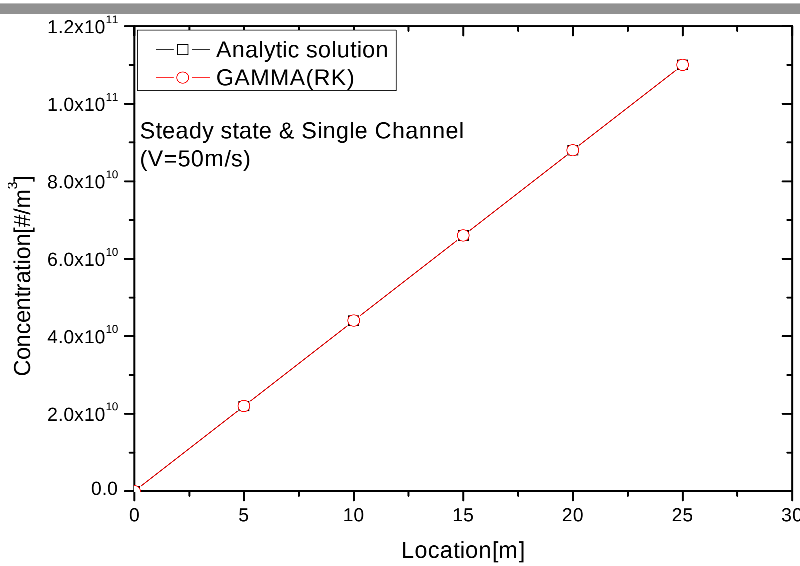
FPs & Aerosol Analysis Schematics



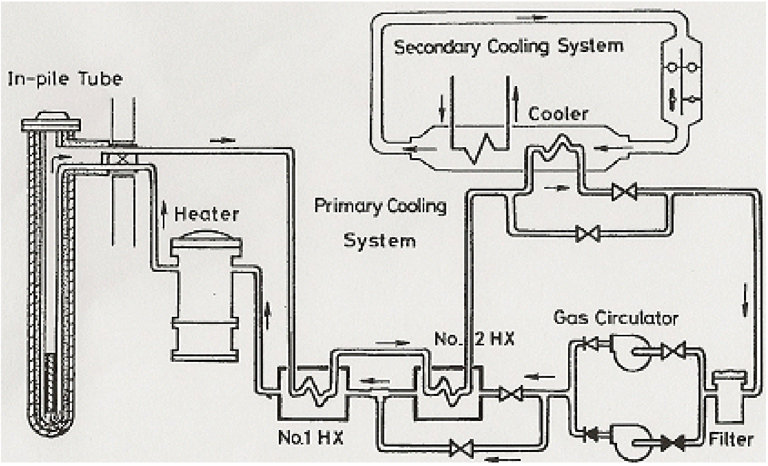
FP Transport & Deposition (I)

- **Fission Product Sources**
  - COPA code to treat gaseous & metallic FP releases from intact/failed TRISO particles and graphite matrix
- **FP Transport Model in coolant and plate-out on the surface (GAMMA+/FP)**
  - Analysis Method
    - **General species equation – source, decay and transport**
    - **Deposition - Sorption Isotherm**
  - Numerics - Fractional step method
    - **Embedded Runge-Kutta in Control Volume**
    - **Implicit scheme for Transport between CVs**
- **MELCOR-GCR FP Model Development**
- **Validation & Verification**
  - Analytic solution (Numerical test)
  - JAEA OGL experiment (JAERI)
  - VAMPYR experiment (FZJ)

FP Transport & Deposition (I)

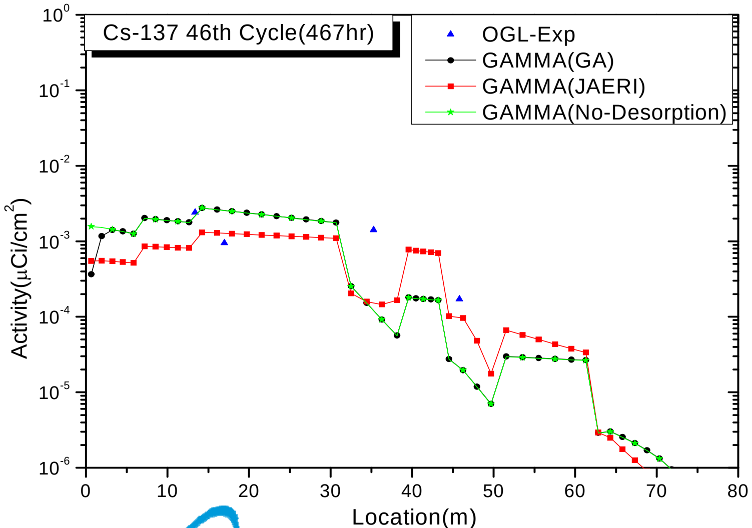


<GAMMA vs. Analytic solution>



<JAEA OGL-Experiment>

Time(s)	Analytic	GAMMA(RK)	Crank-Nicholson	Error(%) (GAMMA/C.N)
0	0	0	0	0
5	22000000000	22000000000	21905083172	0 / 0.43
10	44000000000	44000000000	43810166343	0 / 0.43
15	66000000000	66000000000	65715249515	0 / 0.43
20	88000000000	88000000000	87620332687	0 / 0.43
25	110000000000	110000000000	109525415858	0 / 0.43



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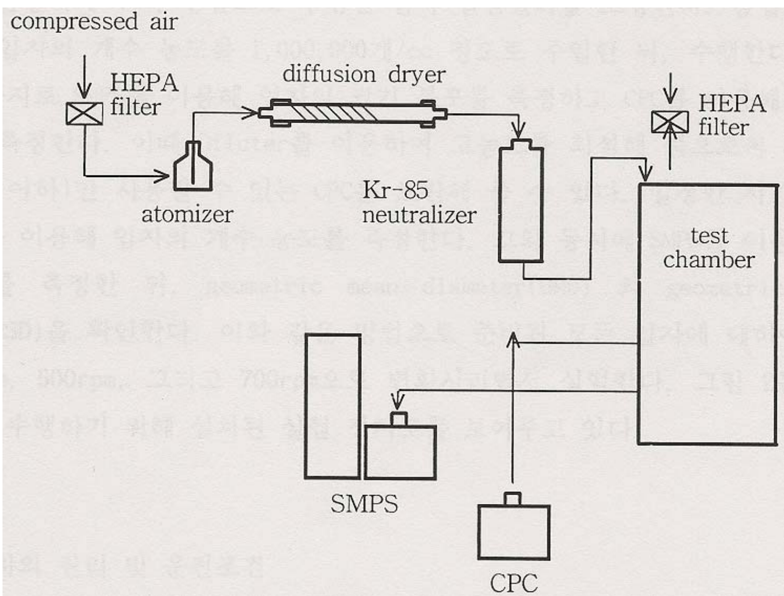
FP Aerosol Behavior (II)

- **FP Aerosol Behavior**
  - Treatment of FP aerosols and Dust in primary circuit and containment
  - Models for each aspect of aerosol behavior
    - Nucleation and growth, agglomeration, deposition, resuspension
  - Analysis Method
    - Current option - Based on MAEROS model (F. Gelbard, 1980)
      - Evolution of aerosol size and chemical composition distribution
      - Coagulation, condensation, particle source and removal
    - Future option – CHARM model (C.J. Wheatley, 1988)
      - Better for rapidly changing transient conditions

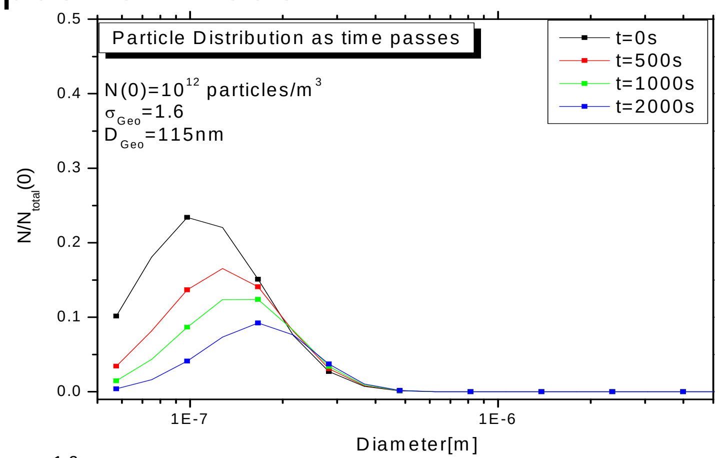
- **Validation & Verification**
  - Nuclear aerosol experiment (K.W.Lee et al., 2002)

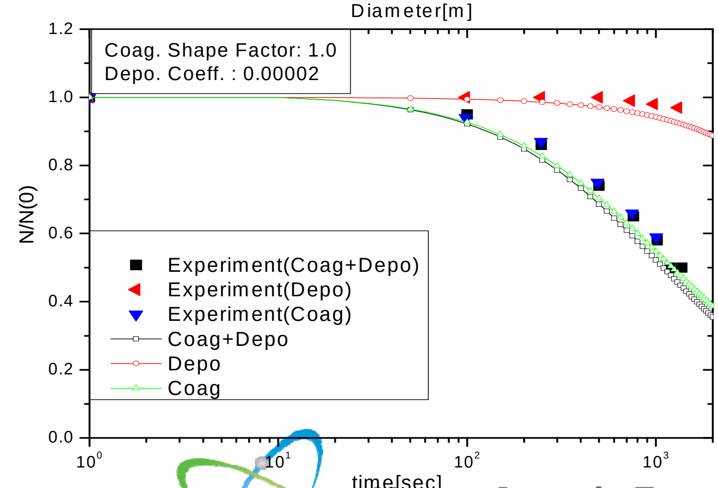
FP Aerosol Behavior (II)

- **Nuclear Aerosol Experiment (K.W.Lee et al., 2002)**
  - Objective
    - Validation of coagulation and deposition model



<Nuclear Aerosol Experiment, K.W.Lee (2002)>





III. International Collaborations

- **GIF VHTR SSC (System Steering Committee)**
  - Computational Method Validation and Benchmarks (CMVB) Project
    - WP4 : Chemistry and Transport
      . Air Ingress for NACOK block and pebble
      . Radionuclide Transport and Plate-out
      . Tritium Transport and Code
      . Graphite Dust Production (transportation) and Characteristics
  - Fuel and Fuel Cycle Project
  - Material Project
  - Hydrogen Production Tech. and Nuclear Process Heat Appl. Project
- **IAEA CRP**
- **I-NERI between U.S. DOE and MEST in Korea**
- **Bilateral Agreement with GA, INET, PBMR, JAEA**

IV. Further Works in FP Area

■ Development of FP Transport & Deposition Model

- Validation & Verification of GAMMA+/FP Code
  - Improvement of FP module to predict the plate-out behavior
    : Diffusion Coefficient, Surface Condition
  - Acquisition of proper experimental data
- Improvement of MELCOR FP Model for HTGR
  - Important parameters are identified and various experimental data are required to adjust parameters.
  - Is it sufficient to predict the plate-out phenomena with "Vapor Condensation Model" in MELCOR?

■ Development of Aerosol/Dust Transport Model

- Just in Progress, with Preparation of GAMMA+/FP/MEROS
- Characterization of graphite dust and its Behavior

Development of Analytical Model for the Fission Product Plate-out

- Introduction
- General Theory & Physical Models
- Numerics
- VAMPYR-I Experiment for Code Validation
- Results
- Conclusions

Introduction

Objective

- Development of analysis module for fission products (FPs) transport and plate-out behavior in a gas cooled system for VHTR applications
- To find out major factors contributing to overall uncertainties in predicting the plate-out phenomena

Background

- FP transport and plate-out phenomena has been an important safety issue for VHTR to be demonstrated, but there is no suitable analysis tool to be applied in Korea
- Need to develop integrated safety analysis module which can be applied to various reactor conditions

General Theory & Physical Models

■ What's plate-out?

- Accumulation of atoms or molecules onto the adsorbent's surface by either chemical or physical attraction (=adsorption)
- The prediction is quite challenging due to various uncertain factors

■ Plate-out Mechanism in a Gas Cooled System

- Dominant removal mechanism for the condensable FPs
- Large influence on the shielding design of the gas-cooled system (i.e., shielding materials, planning of maintenance works)
- In a depressurization accident, plated out FPs would be forced to re-entrain or lift off

Accurate prediction is required for the plate-out distributions!!

General Theory & Physical Models

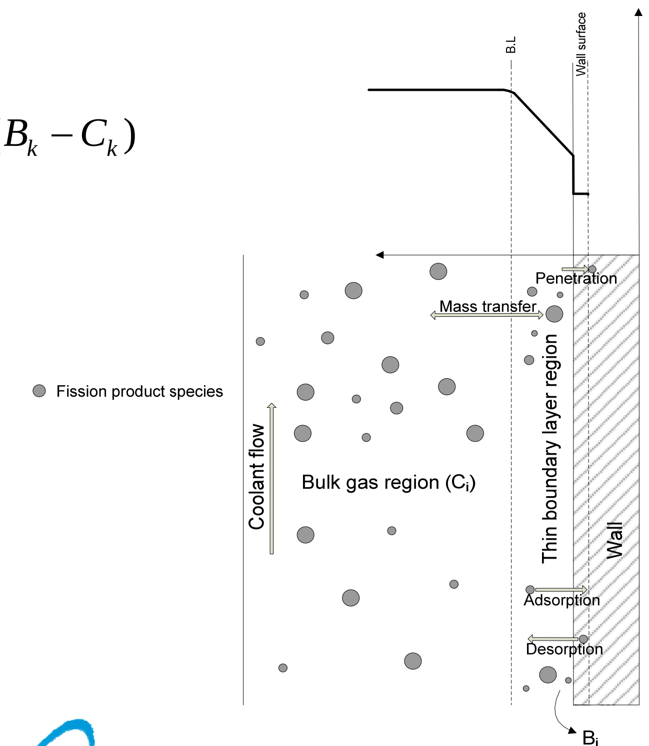
Governing Equations

- 3 regions (i.e., coolant bulk, thin boundary layer, structural surface) are used to model the FP transport and plate-out
- Mass conservation throughout the coolant and surface region for each species, *k*

$$\frac{\partial C_k}{\partial t} = q_c - \lambda_k \cdot C_k + \frac{1}{A_z} \cdot \frac{\partial}{\partial z}\left(A_z \cdot D_k \cdot \frac{\partial C_k}{\partial z} - A_z \cdot v_z \cdot C_k \right) + \frac{P_w}{A_z} \cdot h \cdot (B_k - C_k)$$

$$\frac{\partial S_k}{\partial t} = q_s - \lambda_k \cdot S_k - h \cdot (B_k - C_k)$$

K: Species
C: Bulk concentration in the coolant [m^{-3}]
S: Surface concentration [m^{-2}]
B: Concentration within boundary layer [m^{-3}]
λ: Decay constant [s^{-1}]
h: Mass transfer coefficient [$m\ s^{-1}$]
q_c: Volumetric source rate [$m^{-3}\ s^{-1}$]
q_s: Surface source rate [$m^{-2}\ s^{-1}$]
D: Diffusion coefficient [$m^2\ s^{-1}$]



General Theory & Physical Models

Sorption Models

- 2 equations & 3 unknowns
- Experimental forms of sorption isotherms are adopted in order to evaluate the B_k with ideal gas law (IAEA, 1997)
- Significant role in predicting FP behavior near the surface of components

$$B_k = \frac{N_A p_{B.L.}}{RT} \rightarrow p_{B.L} = \sum_{l=1}^{3} b_l S_l^{\,n_l} \quad \text{(for cesium)}$$

$$\searrow p_{B.L} = \frac{S_l}{a_l \cdot (K - S_l)} \quad \text{(for Iodine)}$$

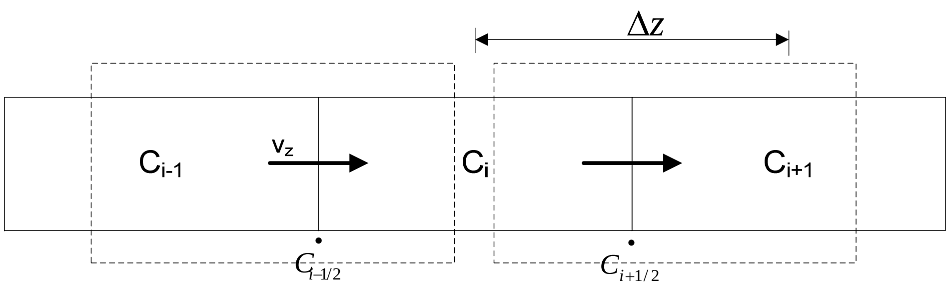
Diffusion & Mass Transfer Coefficient

- Diffusion coefficients based on kinematic theory or experiments (i.e., Chapman-Enskog, Fuller et al…)
- Heat and mass transfer analogy for the mass transfer coefficient

Numerics

■ Discretization

- Upwind scheme + Implicit manner in the staggered mesh layout (GAMMA+)



- Using different time advancement schemes to advance different terms (Fractional step method)

Step1

$$\frac{C_i^* - C_i^n}{\Delta t} = \dot{q}_c - \lambda_i \cdot C_i^* + \frac{P}{A_z}\cdot h\cdot(B_i - C_i^*)$$

$$\frac{S_i^* - S_i^n}{\Delta t} = \dot{q}_s - \lambda_i \cdot S_i^* + h\cdot(B_i - C_i^*)$$

Step2

$$\frac{C_i^{n+1}-C_i^*}{\Delta t} = \frac{1}{A_z}\cdot\frac{\partial}{\partial z}\left(A_z\cdot D\cdot\frac{\partial C_i^{n+1}}{\partial z} - A_z\cdot v_z\cdot C_i^{n+1}\right)$$

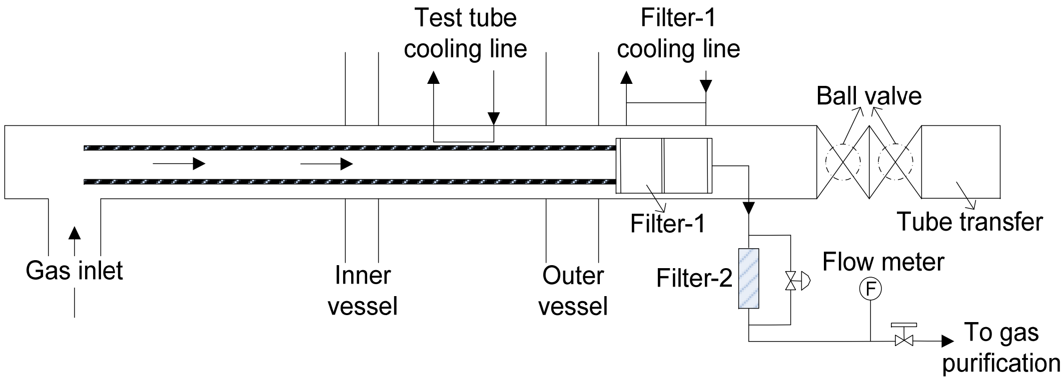
VAMPYR-I Experiment for Code Validation

VAMPYR-I Test Facility

- A hot gas sampling tube installed in the AVR reactor
- To investigate the deposition and diffusion profiles at various materials under laminar flow conditions
- Surface materials investigated were Ti, Cr-Mo, etc.

<Principal features of VAMPYR-I test facility>

Length [m]	**2.2**
Diameter [mm]	**20**
Flow rate [g/sec]	**0.66**
Pressure [MPa]	**1.1**
Temperature [°C]	**80~900**

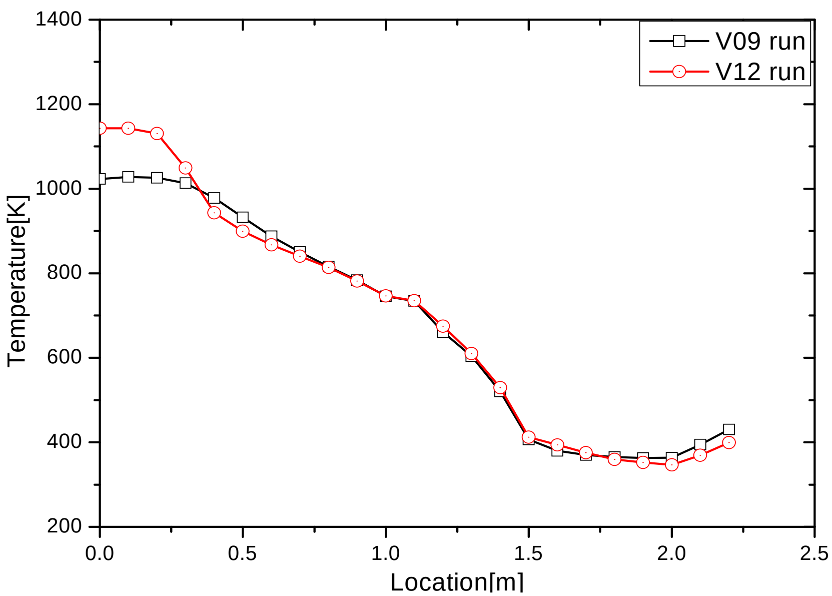


<A schematic illustration of VAMPYR-I>

VAMPYR-I Experiment for Code Validation

Experimental Conditions for Validation

- Experimental runs with sufficient and post experimental data
- Plate-out distributions for I-131 and Cs-137 have been investigated along the test tube
- Temperature profiles along the test tube

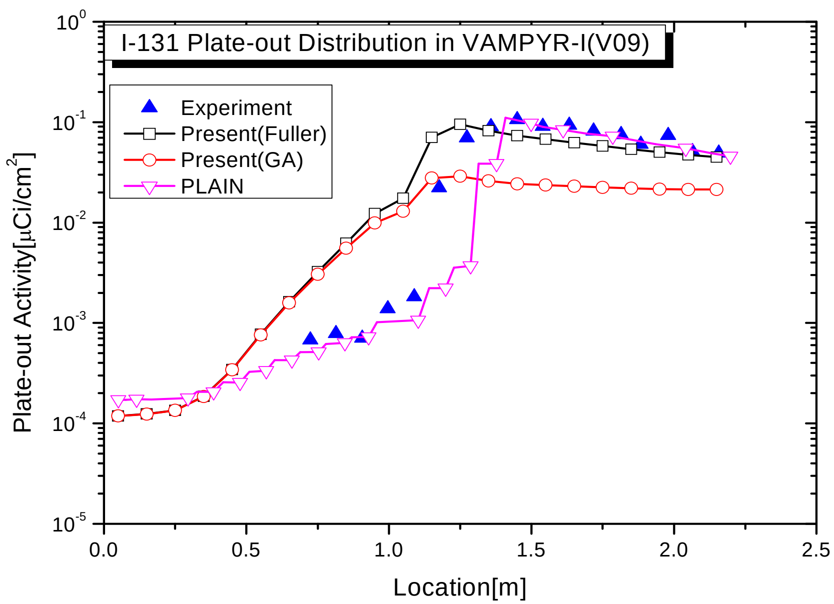


[IAEA, 1997; SAWA et, al., 1993]

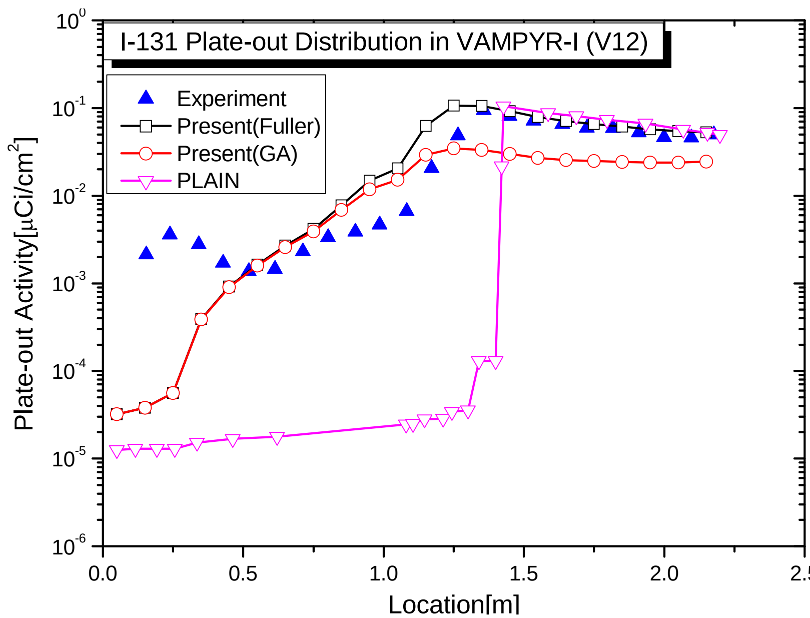
Results

■ Plate-out Distributions for I-131

- The plate-out is dominant over the lower temperature region
- Diffusion coefficient plays an key role in predicting the adsorption of I-131



<Plate-out activities for I-131 (V09)>

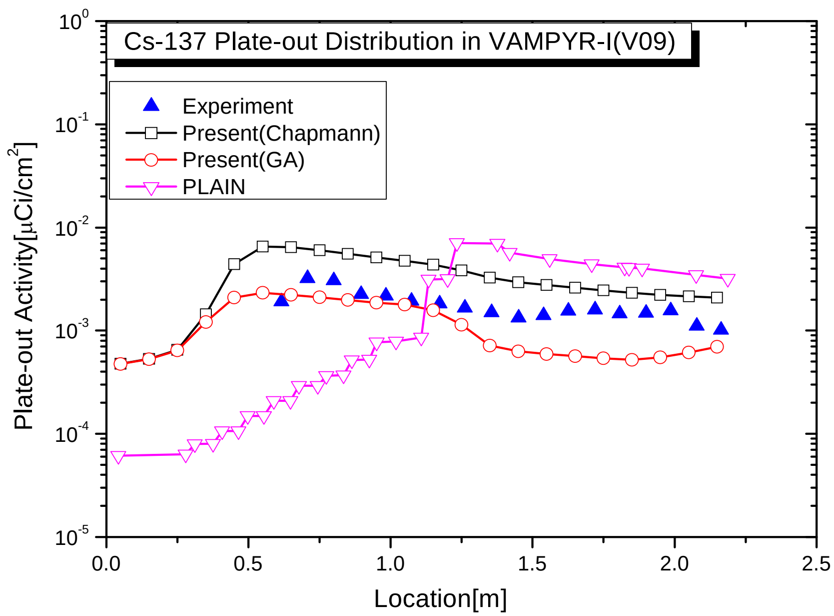


<Plate-out activities for I-131 (V12)>

Results

■ Plate-out Distributions for Cs-137

- Smaller dependency on the temperature profile than I-131
- The measured data are mainly located between the two results calculated by the two diffusion coefficient formulas.

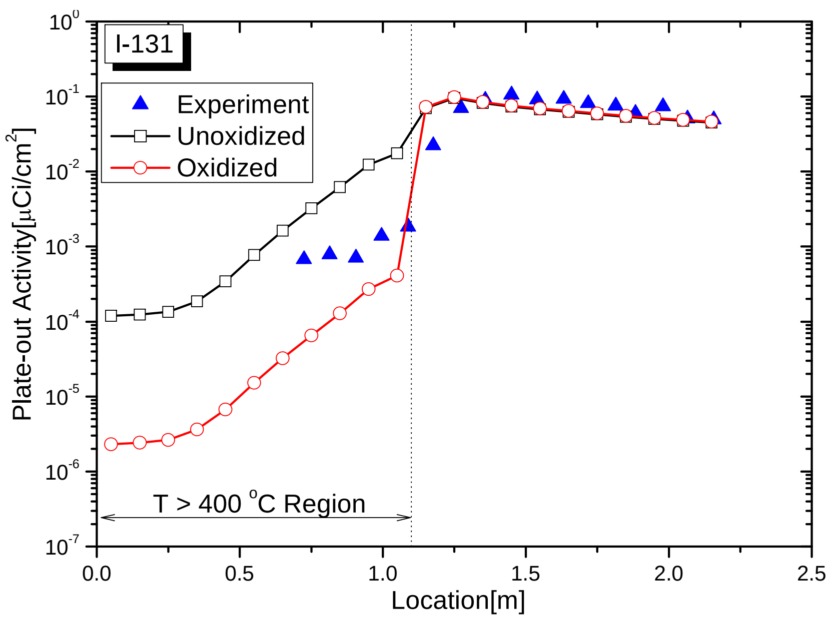


<Plate-out activities for Cs-137 (V09)>

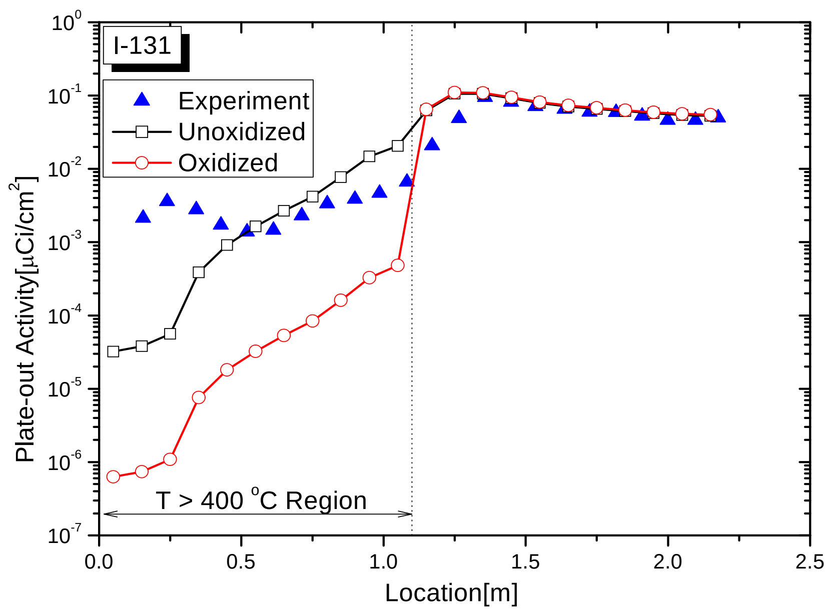
Results

Sensitivity Analysis for surface oxidation (I-131)

- Additional calculations for oxidized surface condition
- Oxide layer on the high temperature region dramatically reduces the deposition amount of I-131



<The effect of surface oxidation on I-131 plate-out (V09) >

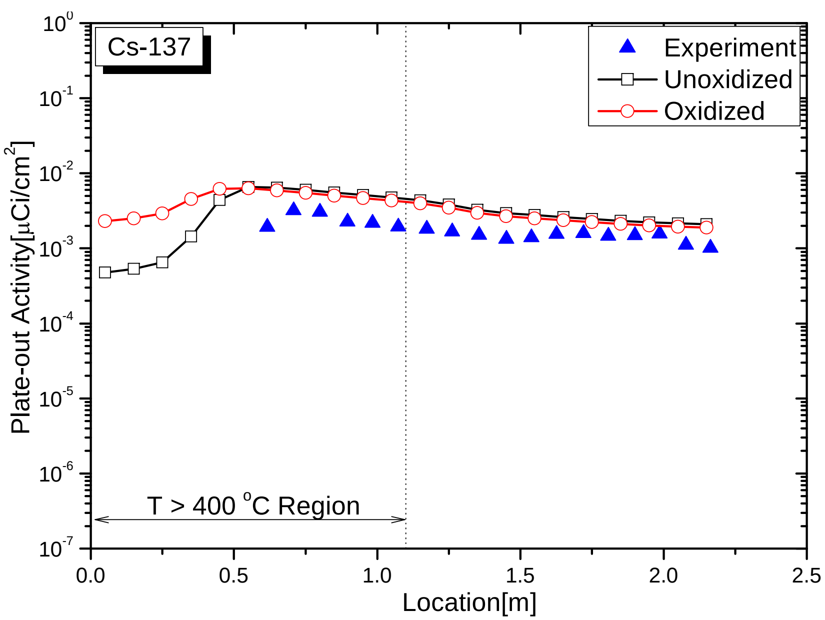


<The effect of surface oxidation on I-131 plate-out (V12) >

Results

■ Sensitivity Analysis for surface oxidation (Cs-137)

- Surface oxidation promotes the deposition of Cs-137 on the high temperature region
- Formation of chemical compound of Cs element in AVR? [Moorman, 2008] → different desorption energy & diffusion coeff.



<The effect of surface oxidation on Cs-137 plate-out (V09) >

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Conclusions (I)

- **A one-dimensional FP transport calculation module has been developed to predict the FP transport and plate-out behavior in a gas-cooled system**
- **The developed module has been applied to the experimental circuits of VAMPYR-I**
- **It was found that the module can describe the plate-out phenomena reasonably**
  - Overall differences between the prediction and the measurements are less than a few orders of magnitude
  - Such amount is comparable with the existing code, PLAIN
  - Various uncertain factors such as surface condition, dust effect, chemical forms, etc…

Conclusions (II)

- **Two meaningful factors on the plate-out phenomena were found through sensitivity analyses**
  - *Diffusion coefficient* was found to play an important role in predicting the adsorption of I-131 and Cs-137
  - *Surface conditions* of the coolant circuit can also be major source of the uncertainty in the prediction of the plate-out activity of I-131
- **Thus, the impacts from the surface oxidation condition as well as the diffusion coefficient have to be quantified in the prediction of the FP plate-out if there is no experimental evidence**

Appendix II

Modeling of the FP plate-out with MELCOR

- Objectives
- MELCOR for HTGR
- OGL Experiment for Code Validation
- Results of MELCOR Simulation
- Summary and Discussion

Objectives

- Improve MELCOR so that it can simulate the FP phenomena in a HTGR.
  - Plate-out H3 and Dust
- Current Models for Thermal hydraulic, Aerosol, FP release, transport and removal in MELCOR will provide the basic structure to "MELCOR for HTGR"

Phase-1 : Improve "plate-out" model

Phase-2 : Implement the function to simulate H3 behavior

Phase-3 : Application of aerosol model to the dust behavior

Phase-4 : Model Integration and V&V

Review of Current FP models

Model \ Codes	MELCOR (SNL)	PADLOC (GA)	PLAIN (JNES)
Time dependent data (T_g, P_g, dm/dt)	Code calcul	User input	User input
FP vapor source generation	Calcul / input	input	input
Number of components to be accounted	2 (Bulk Wall surface)	3 (Bulk Bound-layer Wall surface)	3 (Bulk Bound-layer Wall surface)
Decay during the transport	No	Yes	Yes
Adsorption/desorption on the wall	(No)	Yes	Yes
Mass transfer coefficient	Need Modify	Yes	Yes
Type of surface B.C	Only one (saturation)	3 types (Linear, Freundlich, Langumir)	Direct solve
Diffusion of 'Ag' atom into a metal	(No)	Yes	Yes

MELCOR model improvement is needed to simulate the "plate-out"

Estimation & Improvements of MELCOR for VHTGR

- Estimation and Improvement of "Vapor Condensation Model (=plate-out)" in MELCOR.

  ① Effect of 'new mass transfer coefficient' being predicted from PADLOC code and the user defined "Lennard-Jones" values (σ,ε/κ) on the plate-out

  ② Effect of multi-nodalization of the regions (where the changes of gas temperature are rapid) on the amount and distribution of the plate-out

  ③ Comparison of analytical solution for the plate-out between MELCOR and PADLOC.

  ④ Derivation of new analytical solution that can consider the decay phenomena in calculating the plate-out and their numerical test.

- Each items has been assessed using OGL-1 test data.

Analysis Model for simulating the OGL-1 with MELCOR

Assumption

- The FP release rate was un-measured, therefore their rates were assumed arbitrary values and it was injected into the exit of core.
  - Cs-137 release rate=1.0×10^{-11} kg/s [124 μCi/s]
  - I-131 release rate= 1.0×10^{-12} kg/s [0.87 μCi/s] were kept over the transient
- No chemical interaction between iodine & cesium during transport was assumed (Cs, I_2).
- Once through modeling, I.e, ; It was assumed that the released FPs was completely filtered at the end of circuit, i.e., the released FP can not be returned

Analysis Model

- The TH conditions such as pressure, temperature and flow velocities were followed as that of the OGL-1 test data.

Quick Review on the FP Condensation Model in MELCOR

For FP, k species

$$\frac{dM_a}{dt} + \sum_i \frac{dM_i}{dt} = 0$$

$$\frac{dM_i}{dt} = A_i K_i (C_a - C_i^s)$$

solution

$$C_a V = M_a = \frac{\beta}{\alpha} - \left(\frac{\beta}{\alpha} - M_a(0)\right) e^{-\alpha \Delta t}$$

$$M_i = M_{i,o} + \frac{A_i k_i}{V}\left(\frac{\beta}{\alpha} - M_i^s\right)\Delta t - \frac{A_i k_i}{V}\left(\frac{\beta}{\alpha} - M_{a,o}\right)\left(\frac{1 - e^{-\alpha \Delta t}}{\alpha}\right)$$

HS package
mass transfer of steam through air

$$K_{HS} = Sh\, D_{st,a} / L_c$$

mass transfer of FP 'k' to surface 'i' through bulk gas 'g'

$$K_i = K_{HS} \frac{D_{k,g}}{D_{st,a}} = Sh \frac{D_{k,g}}{L_c}$$

Mass diffusivity of 'k' in bulk gas mixture 'g'

$$D_{k,g} = \frac{1 - y_k}{\sum_n (y_n / D_{k,n})}$$

where y_k = mole number of FP k, y_n = mole number of gas n (n=He)
$D_{k,n}$ = binary diffusivity of FP k in gas n

$$D_{k,n} = 0.0018583 \frac{\left[T^3 \left(M_k^{-1} + M_n^{-1}\right)\right]^{1/2}}{P \sigma_{kn}^2 \Omega_{D,kn}} \qquad \sigma_{k,n} = (\sigma_k + \sigma_n)/2 \qquad \varepsilon_{k,n} = \sqrt{\varepsilon_k \varepsilon_n}$$

Saturation concentration of FP 'k' on the surface 'i' temperature

$$C_i^s = \frac{P(T_i) M_w}{R T_i}$$

Vapor pressure for FP 'k'

$$\log_{10}(P) = -A/T + B + C \log_{10}(T)$$

Recalculation of the diffusion coefficient ($D_{k,g}$) of FP, k

- **From PADLOC code**

Refer: PADLOC code manual, GA-A14401 UC-77, appendix-A

$$D_{k,g} = 0.1682\left(\frac{Tc}{1000}\right)^{1.65}\left(\frac{23.83}{P_g}\right)\sqrt{\frac{\frac{1}{M_k}+0.25}{0.257}}$$

where D = FP diffusion coefficient in He [cm²/s]

T_c= He gas temperature [k]

P_g = He pressure [atm]

M= fission product molecular weight [g/mol]

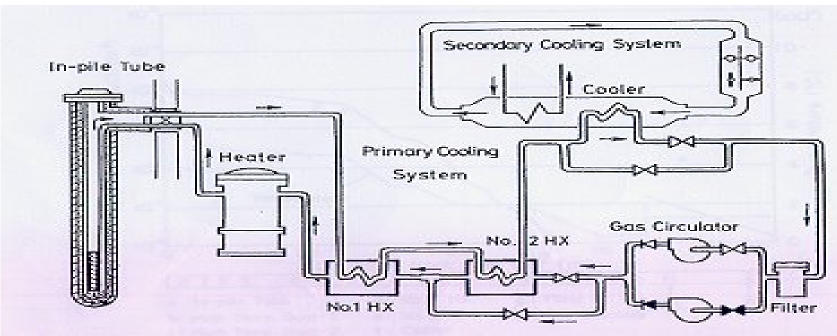
- **To predict the FP vapor diffusivity under high temperature (SC7111)**
  - Now, " Lennard-Jones " values in MELCOR are limited to some FP such as Xe, I_2.

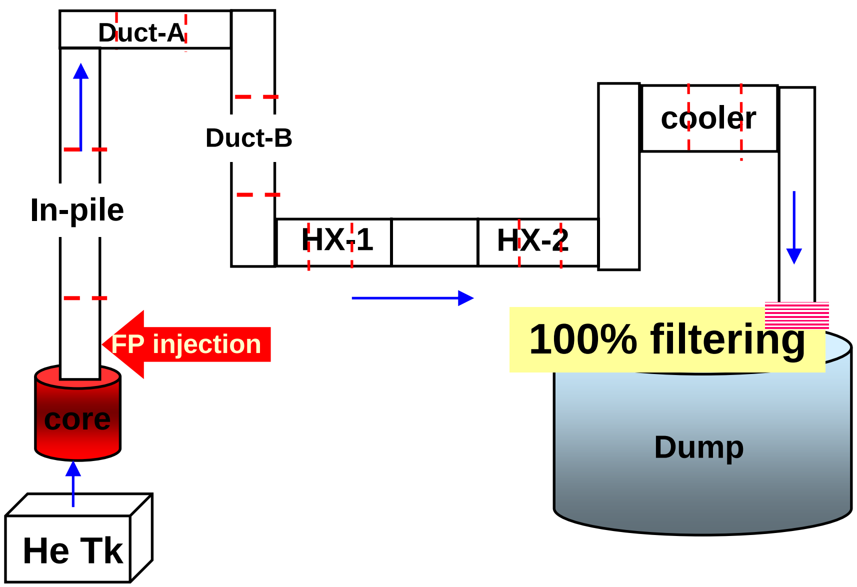
    , I_2 (σ = 4.982, ε/κ = 550.0) [1]
  - In this study, the LJ values for Cs (σ = 4.764, ε/κ = 842.157) came from [2]
  - LJ values for FP under high temperature more than 1000 K are rare.

[1]: R. Byron Bird, "Transport Phenomena", John Wiley & Sons, Inc, 1960, pp 744-745.

[2]: J. chem. phys. 126, 014302 (2007), "hard-wall potential function for transport properties of alkali metal vapors"

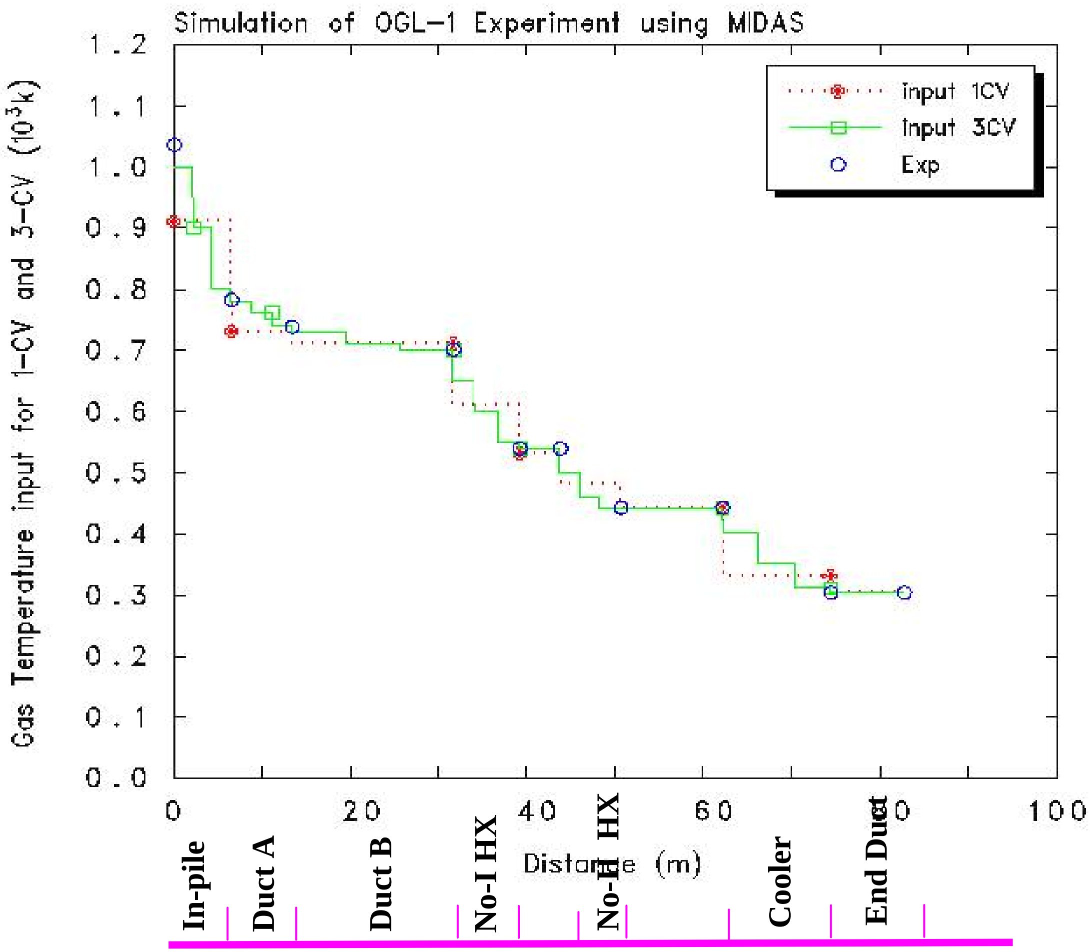
OGL-1 Experiment





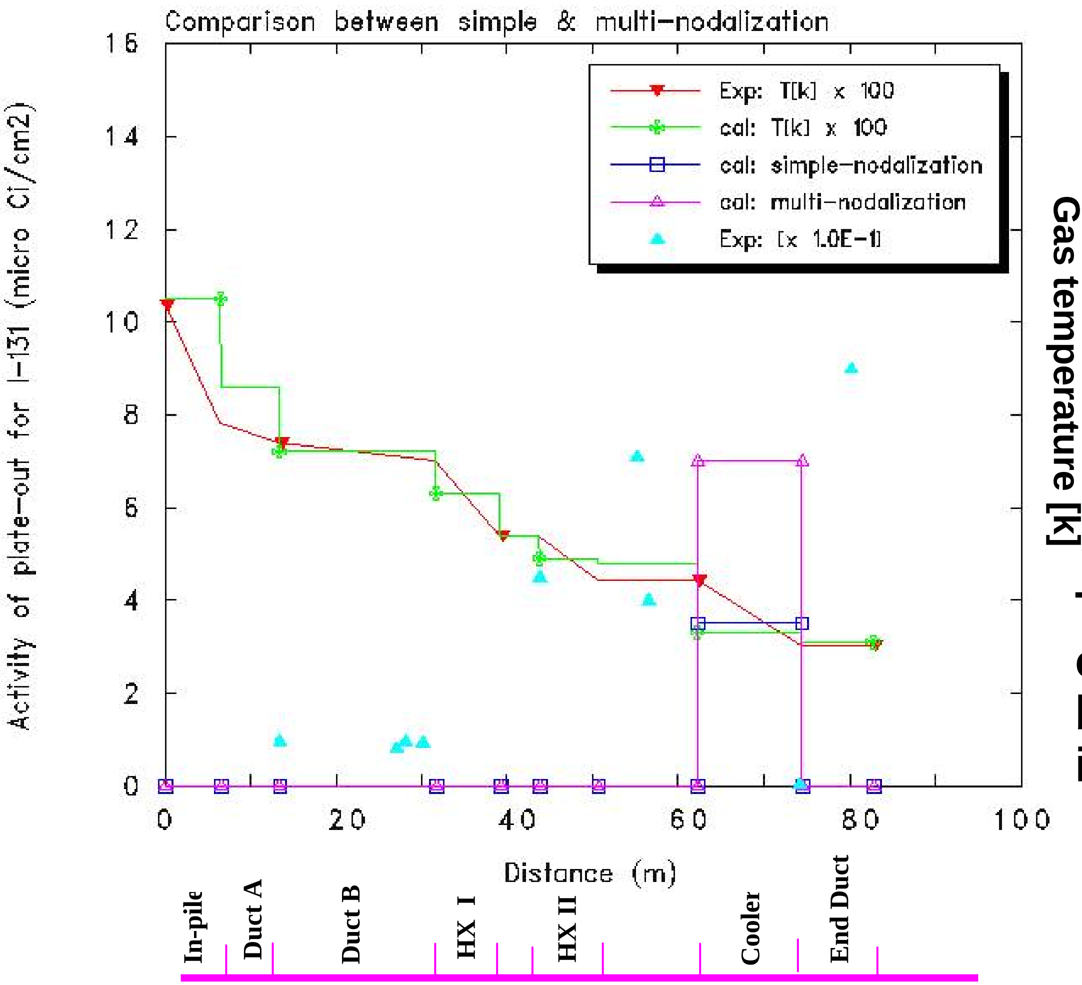
- ✓ OGL-1 experimental facility is in the JMTR in JAERI.
  - study on the FP behavior in the primary circuit in HTGR (plate-out)
- ✓ Total experimental circuit was about 100 m
- ✓ The measurement was done after 500 hr operation.
- ✓ The system pressure was 3 Mpa.
- ✓ The helium injection rate was 45 g/s for cycle-47.
- ✓ The flow velocity was in the range from 10 to 60 m/s.
- ✓ FPs were released from fuel (TRISO-II) but their rate were not measured.

Input of Circuit Temperature B.C by multi-nodalization



The circuit temperature have effect on the amount of plate-out and its distribution.

Effect of multi-nodalization on the I^{131} plate-out for OGL-1 experiment (cycle-47)



I-131 plate-out zone

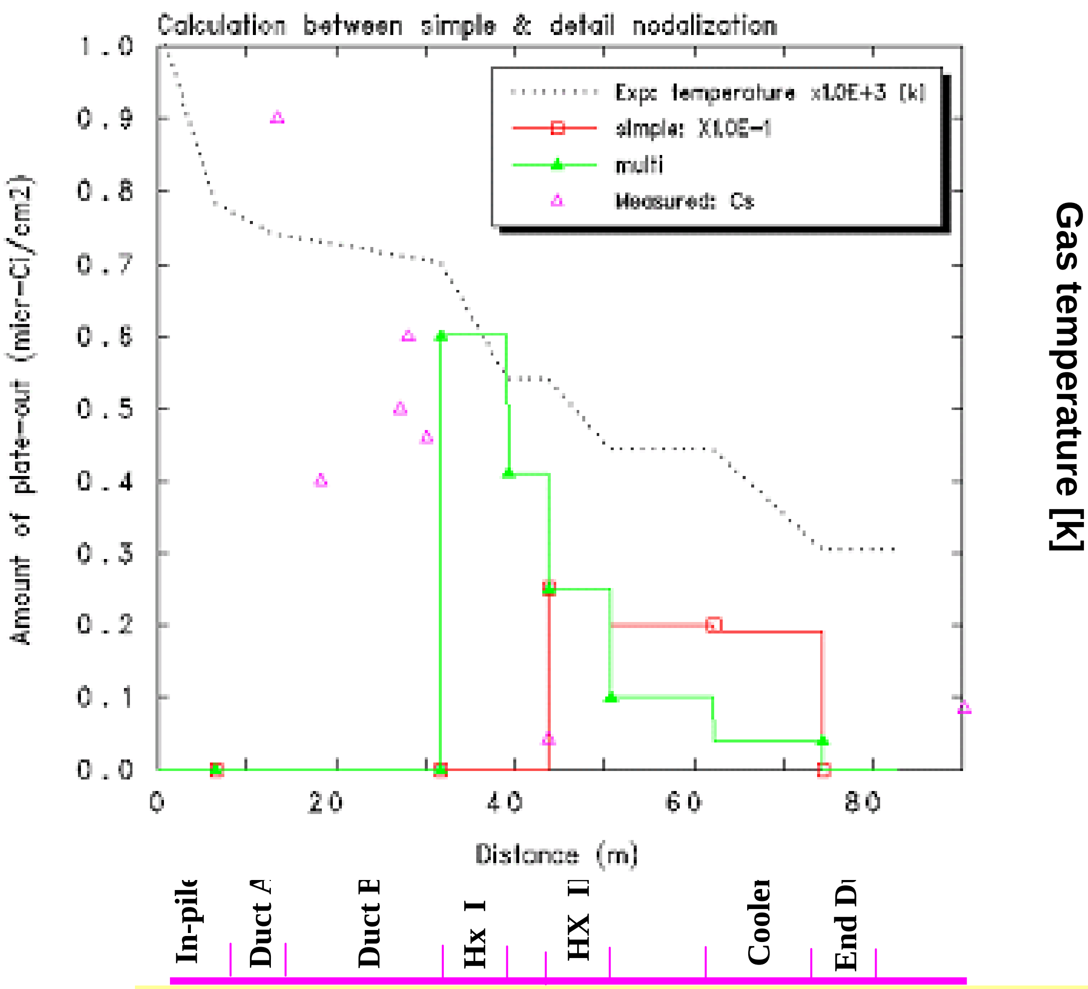
Exp: 750~350 K

MELCOR : 350~450 K

The plate-out of I^{131} could only be occurred when the injection rate become to increase upto unrealistically high value !

MELCOR default model could not predict the I-131 plate-out at all over the circuit.

Effect of multi-nodalization on the Cs^{137} plate-out for OGL-1 experiment (cycle-47)



Cs-137 plate-out zone

Exp: 900~550 K

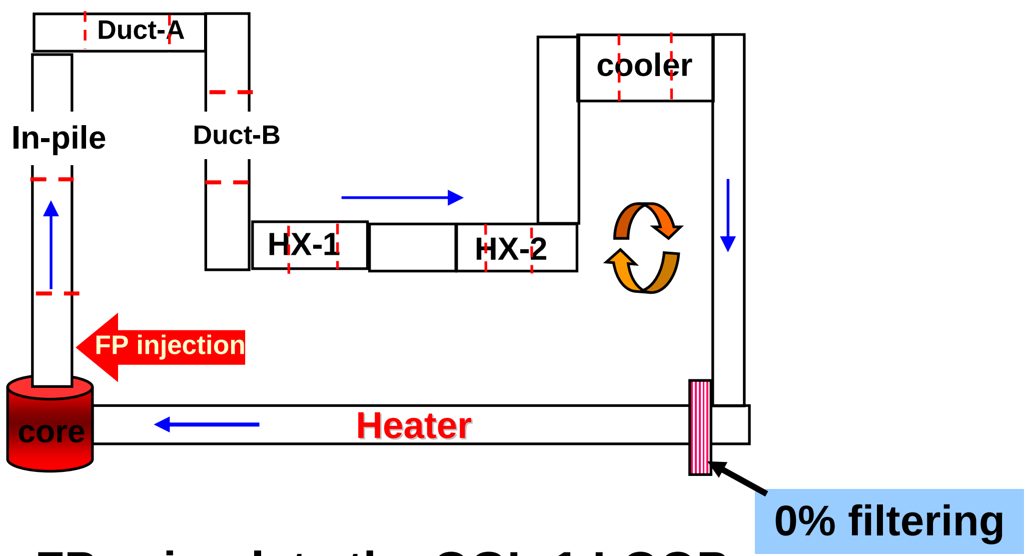
MELCOR : 700~300 K

Sensitive to

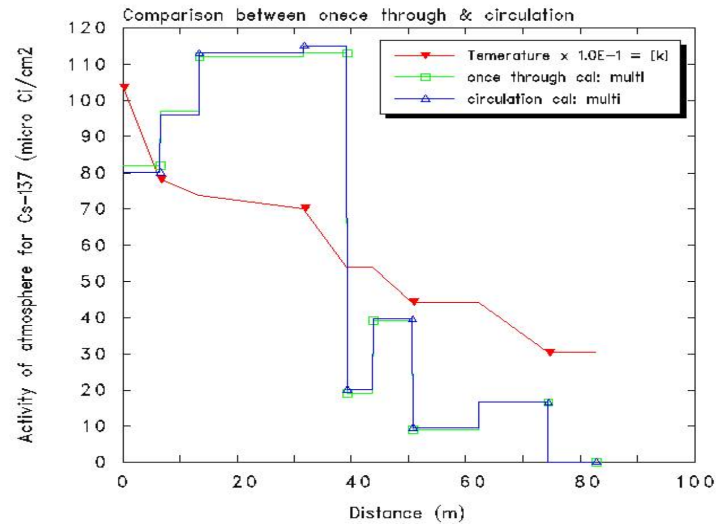
- Amount of FP release rate from core (Cal: ~1.0E-4 kg/s, Exp: non-exist)
- Flow velocity (Cal: 10 m/s, Exp 60~10 m/s)
- Lennard-Jones value
- The wall surface temperature (but overcomed by the multi-nodaliz)
- Chemical form of Iodine & Cs under high temperature and helium gas

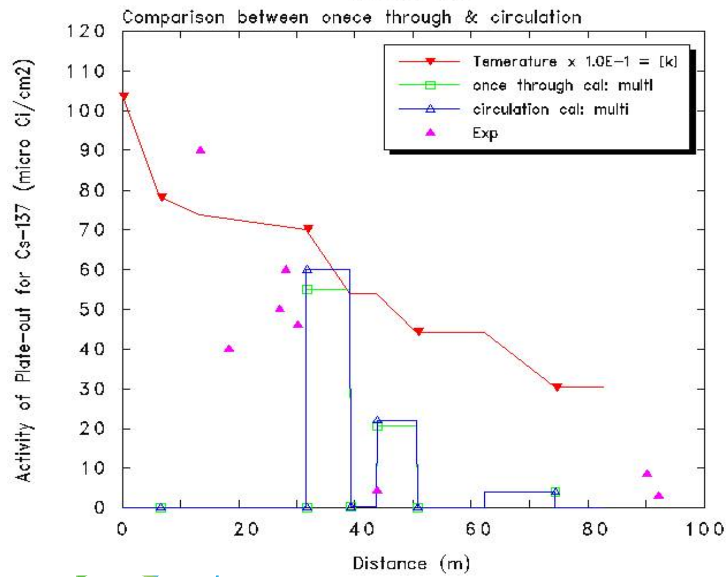
MELCOR follows the Cs-137 plate-out data only at the low temperature range (700~300K).

Simulation of OGL-1 Experiment with a Circulation
(comparison between once-through & circulation modeling)



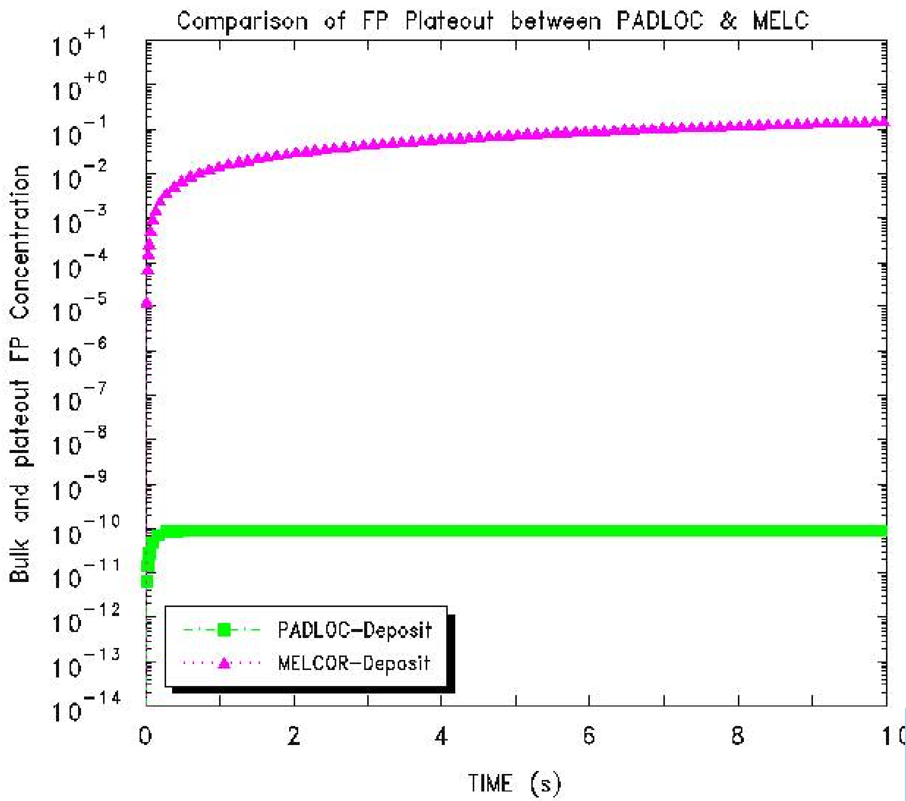
FPs circulate the OGL-1 LOOP





There are no clear difference of plate-out between ‘ once through ’ & ‘ circulation ’ modeling on OGL-1 test.

Comparison of the calculated 'plate-out' concentration between PADLOC and MELCOR using the analytical solutions



PADLOC

$$C_s(t) = -\frac{A}{P}C(t) + \frac{A}{P}C(0)e^{-\lambda t} + C_s(0)e^{-\lambda t}$$

$$C_b(t) = C_b(0)e^{-\omega t} + \frac{C}{\omega}(1 - e^{-\omega t}) + \frac{D}{\omega - \lambda}\left(e^{-\lambda t} - e^{-\omega t}\right)$$

$$\omega = h\left(\beta + \frac{P}{A}\right) + \lambda$$

$$C = \frac{P}{A}h\alpha$$

$$D = h\beta\left[C_b(0) + \frac{P}{A}C_s(0)\right]$$

MELCOR

$$C_s(t) = C_s(0) + \frac{A_i k_i}{V}\left(\frac{\beta}{\alpha} - C_i^s\right)t - \frac{A_i k_i}{V}\left(\frac{\beta}{\alpha} - C_b(0)\right)\left(\frac{1 - e^{-\alpha t}}{\alpha}\right)$$

The analytical solution from MELCOR showed larger amount of plate-out than that of PADLOC.

Effect of the decay phenomena on the plate-out

Governing equations for plate-out considering the decay phenomena

$$\frac{dM_{a,k}}{dt} + \sum_i \frac{A_i k_i}{V}(M_{a,k} - M^s_{i,k}) + \lambda_k M_{a,k} = 0 \quad ①$$

$$\frac{dM_{i,k}}{dt} = \frac{A_i k_i}{V}(M_{a,k} - M^s_{i,k}) - \lambda_k M_{i,k} \quad ②$$

where

V	= a space volume
$M_{a,k}$	= $C_{a,k}$ / V = mass of FP 'k' in bulk space
$M_{i,k}$	= mass of condensed FP 'k' species on the surface i
λ_k	= decay constant of FP 'k'
$M^s_{i,k}$	= saturation concentration of FP 'k' in bulk space at the temperature on the surface 'i'
k_i	= mass transfer coefficient of FP k for the surface i

Derivation of the Analytical Solutions for plate-out

$$M_{a,k}(t) = \frac{\beta}{\xi} - \left(\frac{\beta}{\xi} - M_{a,k}(0)\right)e^{-\xi\Delta t}$$

$$M_{i,k}(t) = M_{i,k}(0)e^{-\lambda_k\Delta t} + \frac{A_i k_i}{V}\left[\left(\frac{\beta}{\xi} - M^s_{i,k}\right)\frac{(1-e^{-\lambda_k\Delta t})}{\lambda_k}\right] - \frac{A_i k_i}{V}\left[\left(\frac{\beta}{\xi} - M_{a,k}(0)\right)\frac{(e^{-\lambda_k\Delta t} - e^{-\xi\Delta t})}{\alpha}\right]$$

where

$$\alpha = \sum_i \frac{A_i k_i}{V}$$

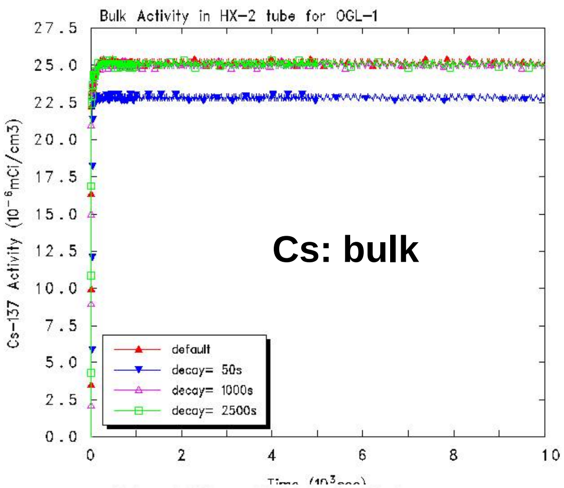
$$\beta = \sum_i \frac{A_i k_i M^s_{i,k}}{V}$$

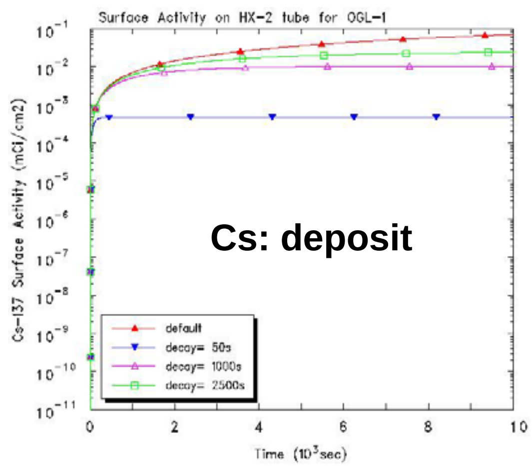
$$\xi = \alpha + \lambda_k$$

Fitting for the case of without the decay model

```
If (-λk*DT .LT. EXPMIN) THEN
   e −(λk*DT) ≈ 1-λk*DT
ELSE
   e −(λk*DT)
ENDIF
```

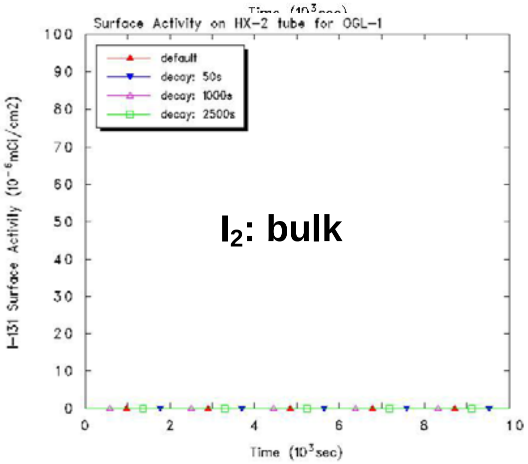
Simulation of OGL-1 with “decay model”

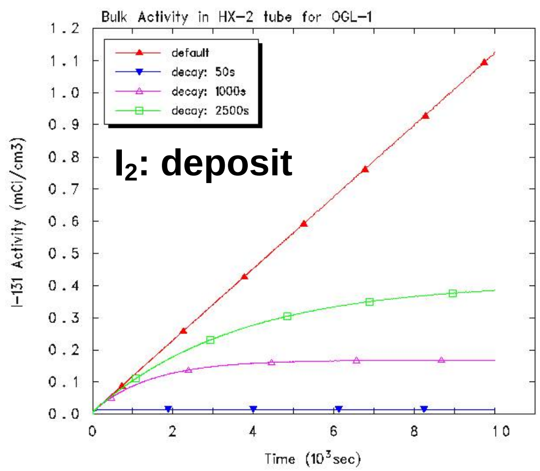




Because of too much Cs deposit and the decay phenomena made bulk-concentration reach equilibrium.

The change of surface concentration could be seen according to the $T_{1/2}$.





Bulk I_2 concentration was increased continuously because of the modeling of the fluid re-circulation and no-occurrence of the I_2 deposit.

The model for simulating the decay phenomena was implemented into the plate-out model in MELCOR code.

Summary & Discussion (1/3)

- KAERI has a plan to apply the MELCOR to simulate the plateout/dust/H3 behavior in VHTGR.

- The MELCOR was applied to simulate the OGL-1 test (cycle-47) and the following results were obtained.

  - Experiment data showed that the plate-out for Cs and iodine were occurred over the entire temperature zones (1000K ~ 300 K).
  - But MELCOR showed that the any plate-out for iodine was not occurred over the entire circuit and the plate-out for Cs in the high temperature zone (700 K≤) could not be predicted.

Summary & Discussion (2/3)

- The influencing parameters on the plate-out phenomena were identified;
  - o FP release rate from the core (TRISO)
    - o Gas velocity
    - o Lennard-Jones parameter values
    - o Degree of the nodalization of circuit
    - o Chemical form of Cs & I under the high tempertaure/He
- The important data for modeling the experiment were not available.
    - o The degree of the gas filtering
    - o FP release rate and Transient FP concentration data in the atmosphere and the surface.
    - o Velocities at each components

■ The analytical solutions considering the decay phenomena were derived for MELCOR and will be implemented after the numerical testing through the modeling of the circulation.

Summary & Discussion (3/3)

- **The comparison of the calculated amount of plate-out between MELCOR and PADLOC showed that MELCOR model have a tendency of over-prediction.**
- **An answer is required whether the MELCOR modeling on the plate-out with using the saturation concentration in the atmosphere based on the surface temperature and its vapor pressure is proper or not.**