Modeling and Quantification of Nucleation, Dissolution and Transportation of Bubbles in Primary Coolant System of Sodium Fast Reactor

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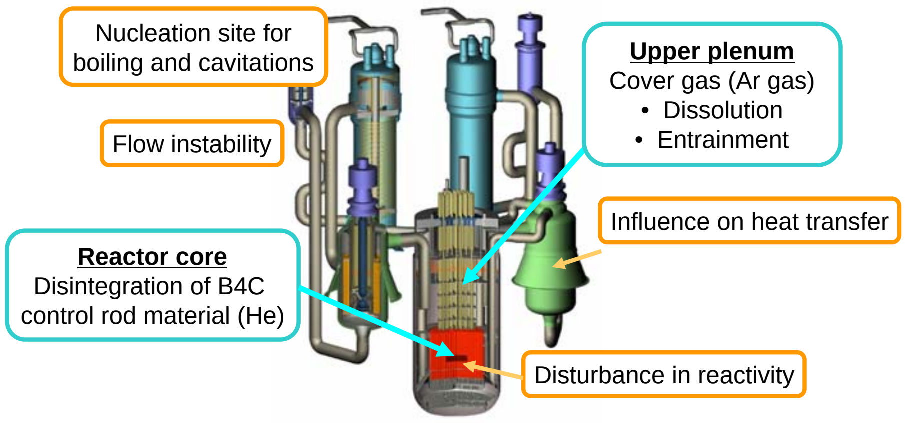
1. Introduction

□ *Sodium-cooled fast reactor (SFR)*

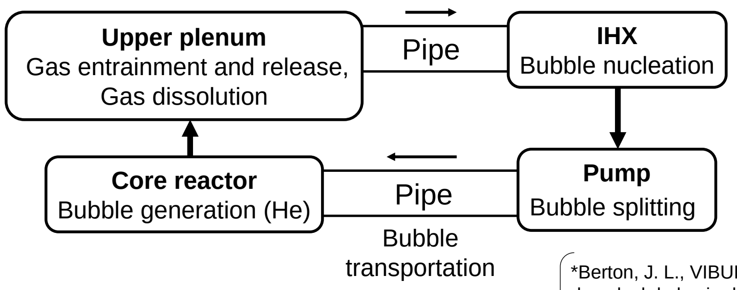
– Inert gas in primary coolant system of SFR



Quantitative estimation in the coolant system is needed.

□ *VIBUL code* : Plant dynamics code for dissolved and free gas*

– Modeling of primary coolant system of SFR



*Berton, J. L., VIBUL, 1991, "Un modèle de calcul de la vie des bulles en réacteur", NTCEA, SSAE, LSMI91, 023.

Simple models of bubble dynamics in plenum flow

✓ One point approximation
✓ No flow distribution

→ not enough to describe bubble behavior

Purpose

- **Development of a numerical simulation method coupled a flow field with bubbles and dissolved gas.**
- **Modeling of bubble behavior by computational experiments.**
- **Implement of the model to a system dynamics code.**

2. Modeling of Bubble Behavior in Upper Plenum of SFR

□ *Numerical method (bubble behavior analysis)*

– **Flow field analysis (Eulerian)**
Navier-Stokes equation

– **Bubble analysis (Lagrangien)**
✓ Momentum conservation of a single bubble (Runge-Kutta)

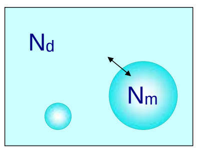
$$\frac{d\mathbf{V}_G}{dt}=\mathbf{g}\left(\frac{\rho_L-\rho_G}{\rho_G}\right)+\frac{3}{8r}C_D\frac{\rho_L}{\rho_G}|\mathbf{V}_L-\mathbf{V}_G|(\mathbf{V}_L-\mathbf{V}_G)$$ (assumed spherical bubble)

✓ Mass conservation of a single bubble (Eulerian explicit method)

$$\frac{dN_m}{dt}=-k4\pi r^2(N_d'-N_d)$$

$$N_d'=H_c\left(P_l+\frac{\sigma}{2r}\right)$$

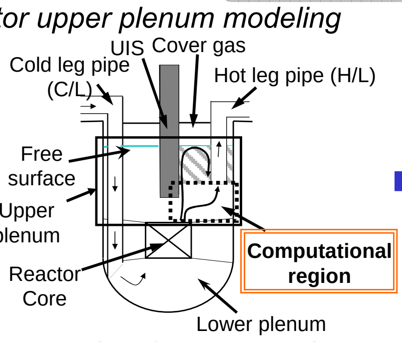
N_d': Molar amount of a saturated gas in a unit volume of sodium [mol/m³]
H_c: Henry's constant



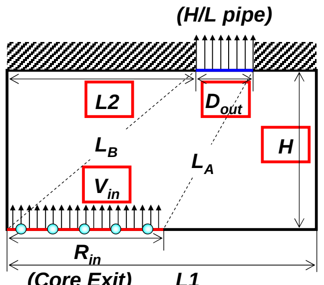
Mass transfer between a bubble and liquid

→ ***One-way-coupling***
Bubble behavior analysis in a postulated flow field

□ *Reactor upper plenum modeling*



Cross section of reactor vessel



[Bubble radius: 1~300μm] □ :Parameters

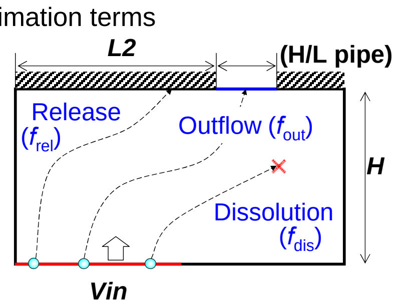
Computational region

□ *Parametric analyses and estimation terms*

– Parameters

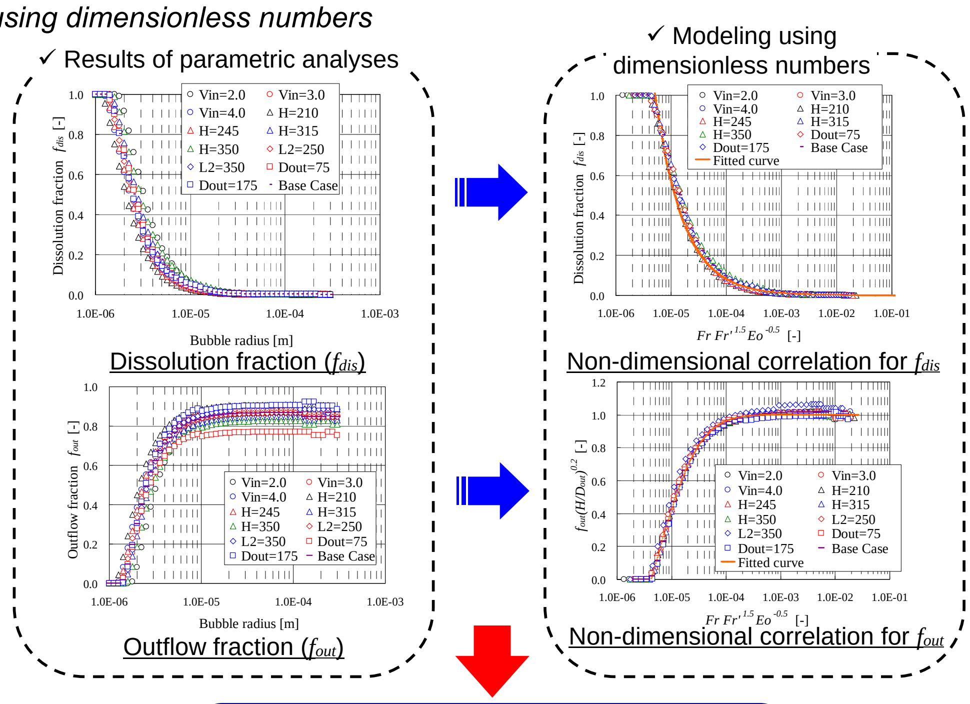
parameter			Reference Case		
H [m]	2.10	2.45	**2.80**	3.15	3.50
$L2$ [m]		2.50	**3.00**	3.50	
D_{out} [m]		0.75	**1.25**	1.75	
V_{in} [m/s]	2.0	3.0	**3.3**	4.0	

– Estimation terms



➢ Dissolution fraction into liquid sodium : f_{dis}
➢ Outflow fraction to H/L pipe : f_{out}
➢ Release fraction at free surface : f_{rel}

□ *Results of parametric analyses and modeling of gas behavior using dimensionless numbers*



Dissolution fraction (f_{dis})
Non-dimensional correlation for f_{dis}
Outflow fraction (f_{out})
Non-dimensional correlation for f_{out}

$$f_{dis}=a(Fr\,Fr'^{1.5}\,Eo^{-0.5})^b \qquad (a,b:\ Const.)$$

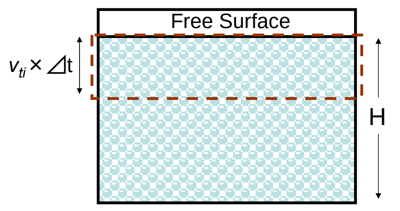
$$f_{out}=(D_{out}/H)^{0.2}(1-c\exp(dX^2+eX+f))$$

$$X=\ln(Fr\,Fr^{1.5}\,Eo^{-0.5}), \quad (c,d,e,f:\ Const.)$$

$$f_{rel}=1-f_{dis}-f_{out}$$

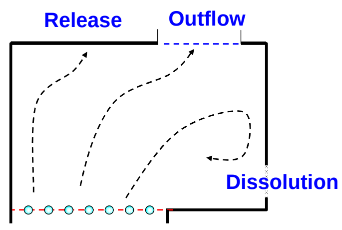
3. Application of the Present Model into VIBUL Code

□ *VIBUL model and Present model*



VIBUL model (one point approximation)

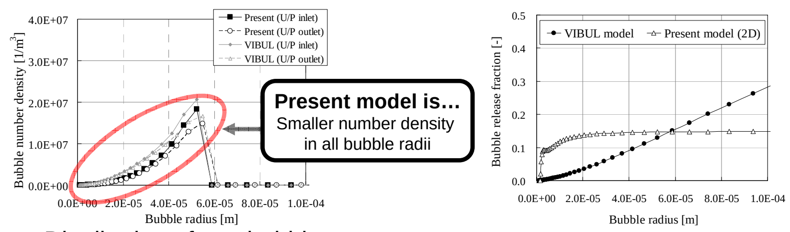
- Instant mixture of bubbles in a plenum
- Bubbles included in the area of $v_{ti}\times\Delta t$ are released at free surface
(v_{ti}:terminal velocity of a bubble)



Present model (2D analysis)

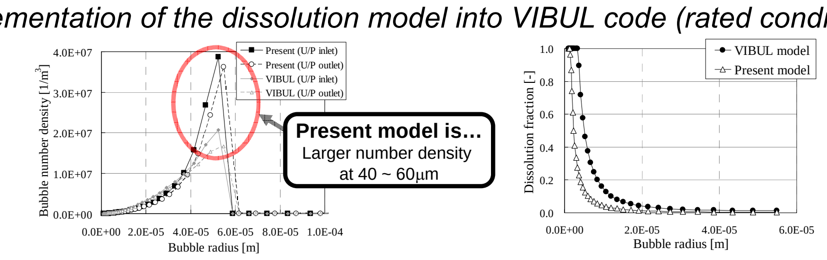
- Derived to non-dimensional correlation for dissolution fraction, outflow fraction, and release fraction using dimensionless numbers

□ *Implementation of the release model into VIBUL code (rated conditions of SFR)*



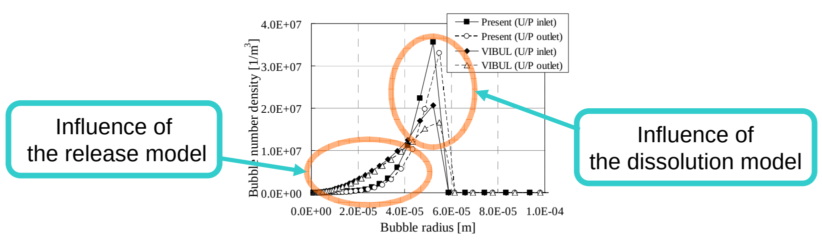
Distribution of gas bubbles — Bubble release fraction

□ *Implementation of the dissolution model into VIBUL code (rated condition of SFR)*



Distribution of gas bubbles — Bubble dissolution fraction

□ *Implementation of the both models into VIBUL code (rated condition of SFR)*



Distribution of gas bubbles at upper plenum inlet and outlet
(Comparison between VIBUL model and present model)

4. Conclusions and Future Works

□ *Conclusions*

- Development of a tool to estimate bubble behavior using One-way-coupling method.
- Modeling of gas bubble behavior in upper plenum using dimensionless numbers.
- Application of the present model into VIBUL code for a dynamics of gas behavior in a primary coolant system.

□ *Future Works*

- Estimation of three-dimensional effects on gas behavior in upper plenum.
- Experimental validation of the present model.