# NUMERICAL ASSESSMENT OF SODIUM FIRE INCIDENT

Japan Atomic Energy Agency
Takashi TAKATA

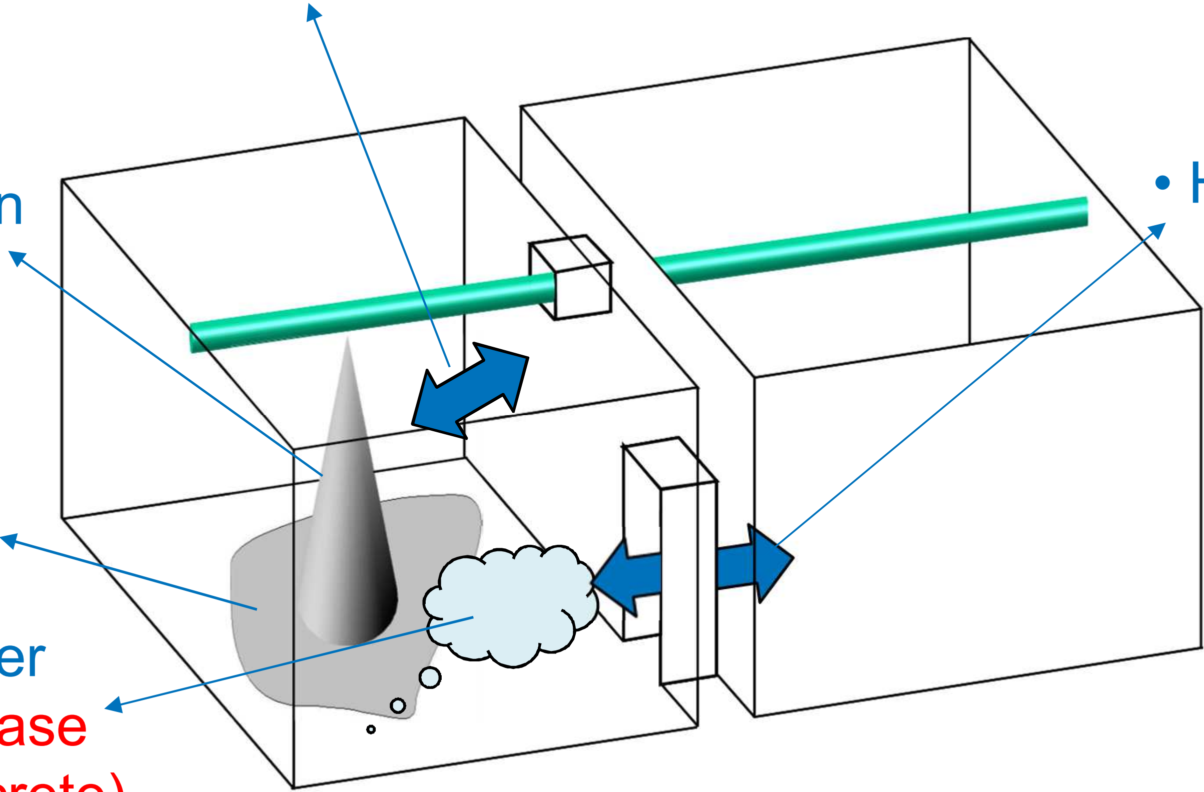
*Sector of Fast Reactor and Advanced Reactor Research and Development*

SeFARD

# Contents

# Motivation

Sodium fire incident is a key issue for plant and environmental safety for sodium-cooled fast reactor (SFR) regardless of its size.




Key Physics in Sodium Fire

# Water Release from Concrete

Since concrete includes free and bonding water, water will release to atmosphere when the concrete is heated due to sodium fire.

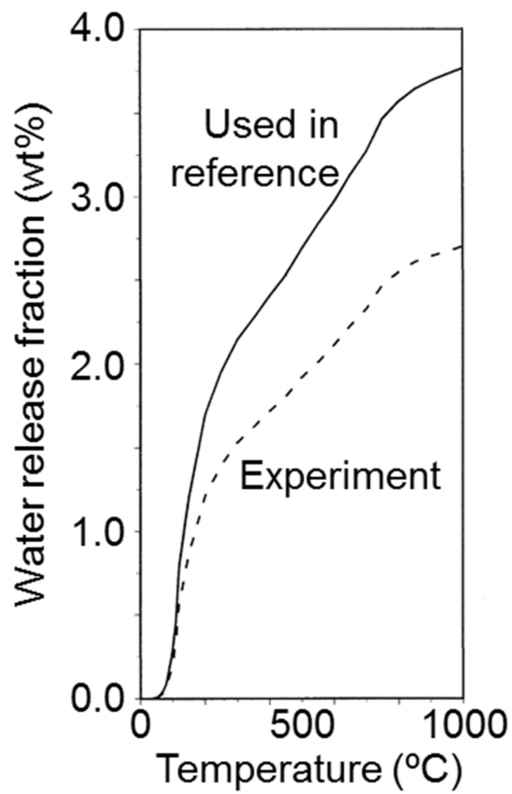
➡ Hydrogen will be generated even in a dry air condition.

Surface area / volume will increase as a compartment becomes compact.

➡ Risk of hydrogen generation will increase in small and medium sized or modular reactor (SMR).

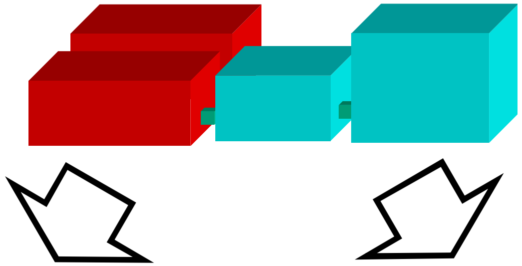
⬇

Numerical investigation has been carried out.
(Target of sodium fire: Pool combustion)

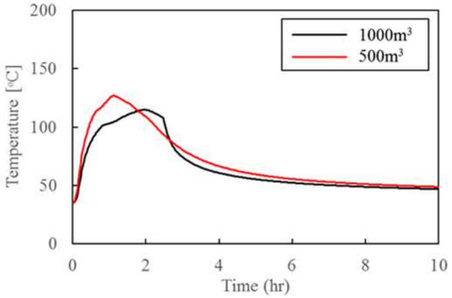


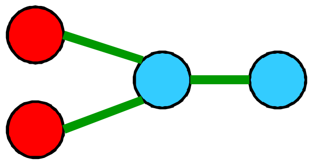

Water release from concrete
(JNC TN2400 2003-005, 2004)

# Sodium Fire Related Analytical Tools in JAEA



(Lamped mass)

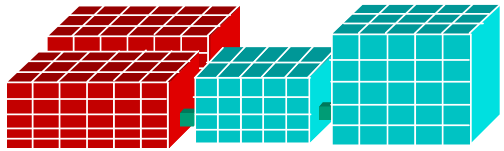


Zone model

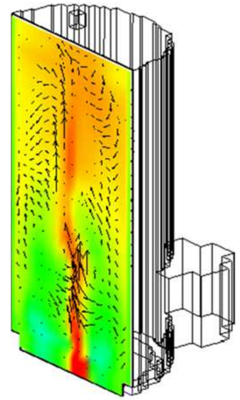
SPHINCS

(CFD)



Field model

AQUA-SF



- Chemical reaction (Stoichiometric calculation)

BISHOP

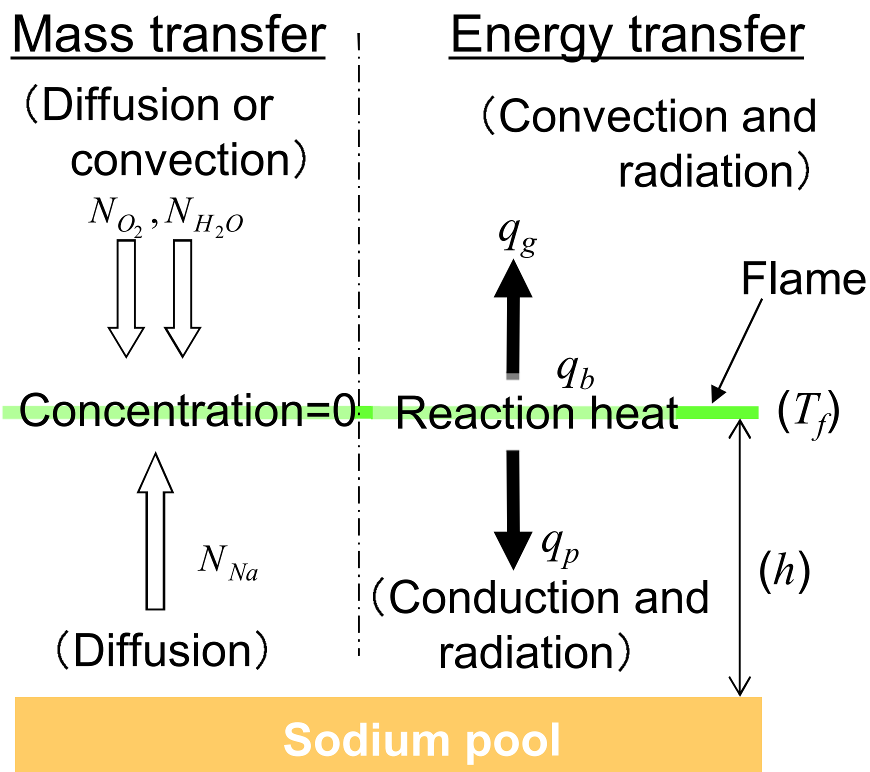
(Gibbs free energy minimization)
$Na_2O$, $Na_2O_2$, NaOH

- Aerosol behavior (agglomeration and adhesion)

ABC-INTG

# Numerical Model: Pool Combustion

## Mass and energy conservation on infinite thin flame (Flame sheet model)




- Mass conservation

$$N_{Na} = \sum_j \frac{N_j}{i_j}$$

$$N_{Na} = \frac{C_{Na} D_{Na}}{h} \ln \frac{P}{P - P_{Na}^{sat}}, \quad N_j = \left(\frac{x_j}{1 - x_j}\right) \frac{C_g D_j}{l} Sh_j$$

$$Sh_j = 0.14 (Gr \times Sc_j)^{1/3}$$

- Energy conservation

$$q_b = q_g + q_p$$

$$q_g = q_g^{conv} + q_g^{rad} = \frac{Nu \lambda}{l} (T_f - T_g) + \sigma \varepsilon_g (T_f^4 - T_g^4)$$

$$q_p = q_p^{cond} + q_p^{rad} = \lambda \left.\frac{dT}{dz}\right|_{flame} + \sigma \varepsilon_p (T_f^4 - T_p^4)$$

$$Nu_j = 0.14 (Gr \times Pr_j)^{1/3}$$

➡ Functions of $T_f$ and $h$

# Recombination of Hydrogen

Hydrogen does not coexist with oxygen in equivalent state.
(Recombination ratio is unit (=1).)

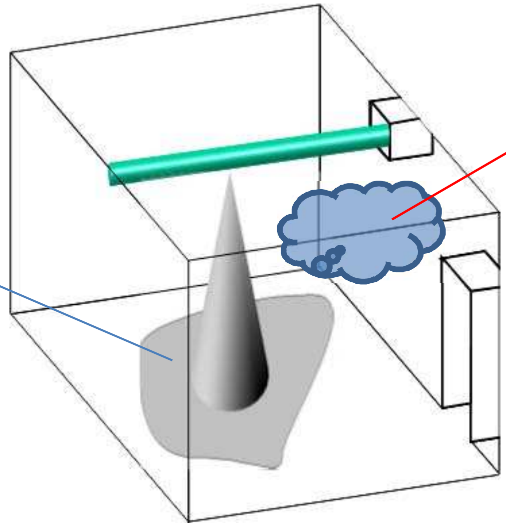
However, it coexists with oxygen practically.

(Application of the ratio (=0.9 from engineering judgment))

$$H_2 + O_2 + 2Na \rightarrow 2NaOH$$

(Recombination of hydrogen in sodium fire)

Considering recombination ratio in combustion model



No consideration of recombination ratio in atmospheric chemical reaction

(Conservative treatment of hydrogen concentration)

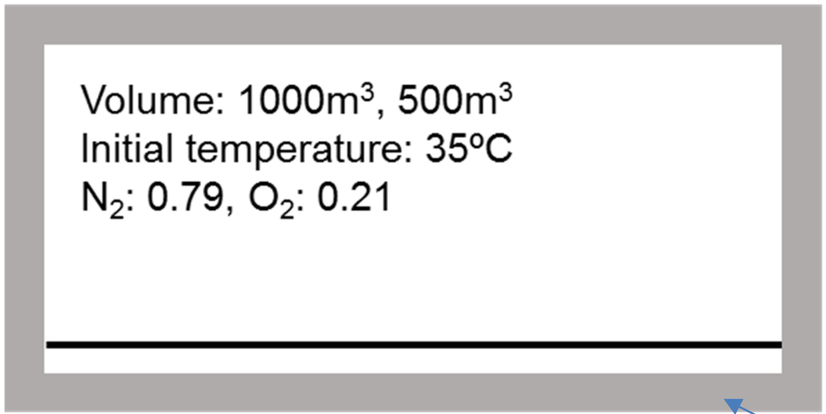
# Numerical Assessment: Condition (1)

Two size of closed compartments

✓ Geometrical and initial condition

○ 500m$^3$ (10mW × 10mD × 5mH), 1000m$^3$(10mW × 20mD × 5mH)

[Ceiling]
Area : 200m$^2$(1000m$^3$)
100m$^2$(500m$^3$)
Adiabatic Concrete : 0.500m




[Side wall]
Area : 600m$^2$(1000m$^3$)
400m$^2$(500m$^3$)
Concrete : 0.500m

Adiabatic

Adiabatic [Floor]
Area : 200m$^2$(1000m$^3$)
100m$^2$(500m$^3$)
Steel liner : 0.005m
Air gap : 0.100m
Concrete : 0.500m

No water release from floor concrete

# Numerical condition (2)

✓ Sodium fire condition

* Similar with MONJU incident, 1994

- Only pool fire (no spray fire)
- Sodium temperature : 500 ºC
- Sodium leakage rate : 50 g/s*
- Duration : 2 hr

(Total amount of leakage : 180 kg)

- Enlargement of pool : yes (sodium height = 0.01m)
- Recombination ratio : 0.9

✓ Parameters

- Size of compartment : 500, 1000 $m^3$
- Water (vapor) release : yes, no

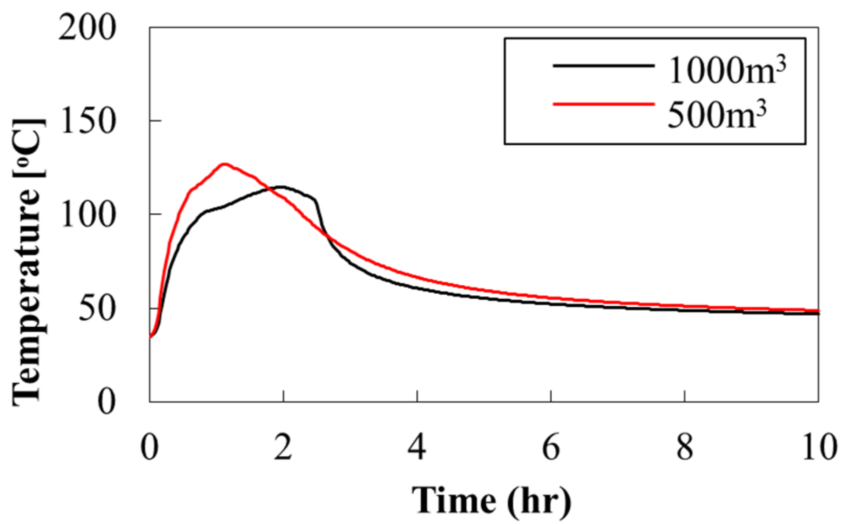
(Water release fraction)

| Temperature (ºC) | Release fraction (wt%) |
|---|---|
| 30 | 0.0 |
| 80 | 0.1 |
| 200 | 1.5 |
| 1000 | 3.0 |

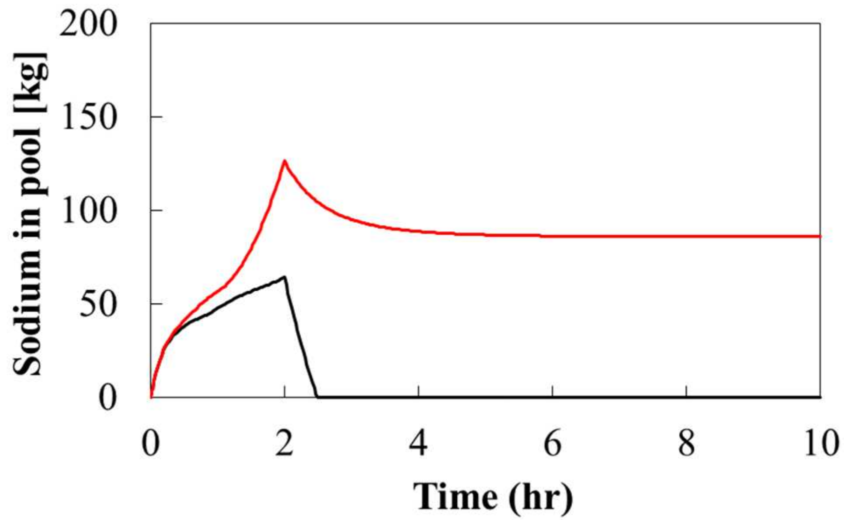
# Results and Discussion (1)

✓ No water release condition

| | 1000m³ | 500m³ |
|---|---|---|
| **Maximum values** | | |
| **Gas temp. (ºC)** | 114.8 | 127.0 |
| **Gas pressure (kPa gage)** | 15.9 | 17.9 |
| **Concrete surface temp. of side wall (ºC)** | 65.3 | 66.2 |
| **Concrete surface temp. of ceiling (ºC)** | 67.4 | 68.3 |
| **Pool area ($m^2$)** | 10.2 | 18.4 |
| **Average pool temperature (ºC)** | 641.7 | 615.2 |
| **Minimum value** | | |
| **Oxygen concentration (vol%)** | 7.5 | 0.002 |




Gas temperature




Unburnt sodium in pool

No significant influence on components

# Results and Discussion (2)

✓ Water release from concrete

| | $1000m^3$ | $500m^3$ |
|---|---|---|
| **Maximum values** | | |
| **Gas temp. (ºC)** | 120.4 | 136.1 |
| **Gas pressure (kPa gage)** | 18.2 | 21.1 |
| **Concrete surface temp. of side wall (ºC)** | 68.5 | 73.2 |
| **Concrete surface temp. of ceiling (ºC)** | 70.8 | 75.6 |
| **Pool area ($m^2$)** | 9.5 | 14.7 |
| **Average pool temperature (ºC)** | 647.0 | 621.2 |
| **Concentration of water vapor (vol%)** | 6.69 | 5.88 |
| **Concentration of hydrogen (vol%)** | 0.15 | **4.11** |
| **Total amount of released water vapor (kg)** | 84.0 | 66.8 |
| **Minimum value** | | |
| **Oxygen concentration (vol%)** | 9.19 | 0.52 |

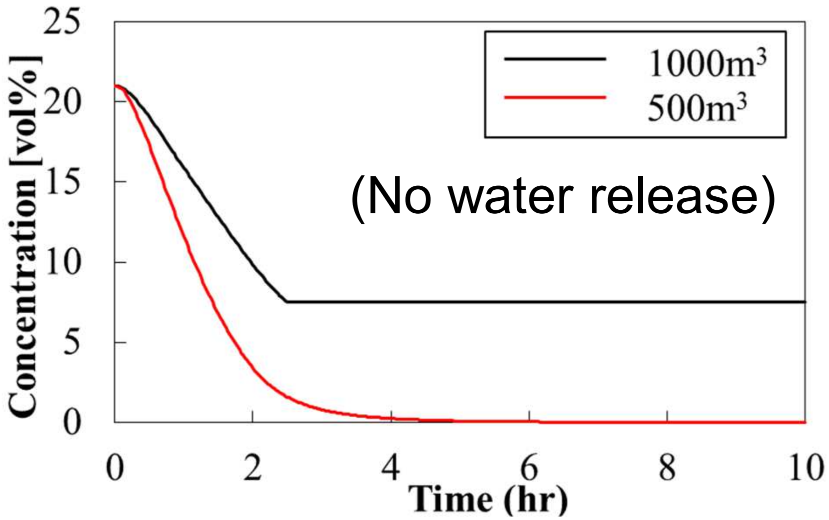
Hydrogen concentration increases dramatically in $500m^3$.

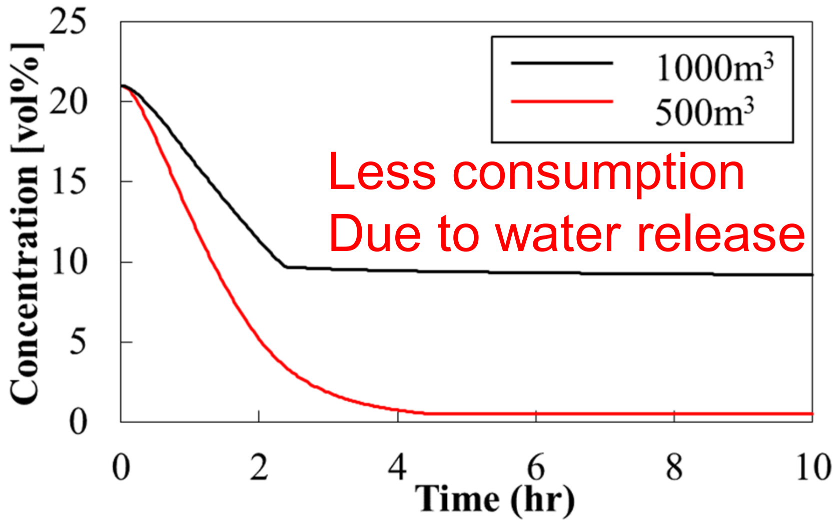
# Influence of Water Release

✓ Concentration of gas species

○ Oxygen

(Water release)

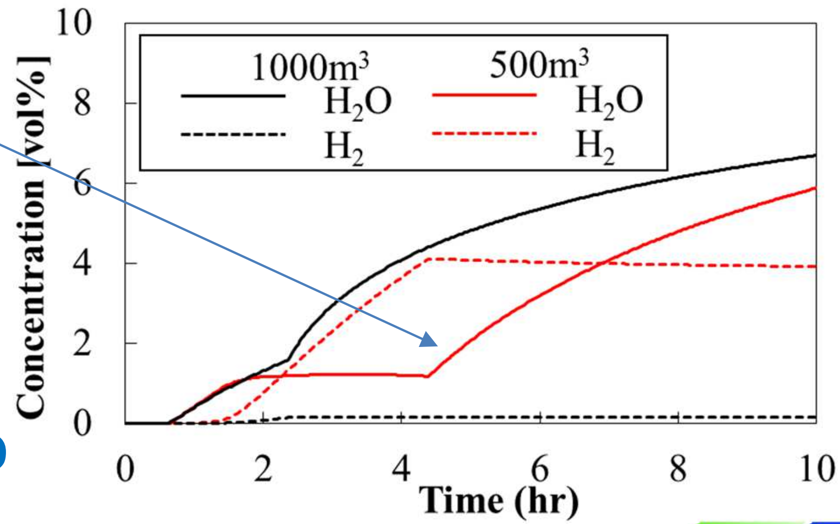



○ Water vapor, Hydrogen

Lower water vapor

Concentration due to reaction




- Higher influence of water release
  500m³ : 66.8kg/500m³ = 0.134 kg/m³
  1000m³: 84.0kg/1000m³ = 0.084 kg/m³
- Less influence of recombination ratio due to lower oxygen concentration

# Influence of recombination

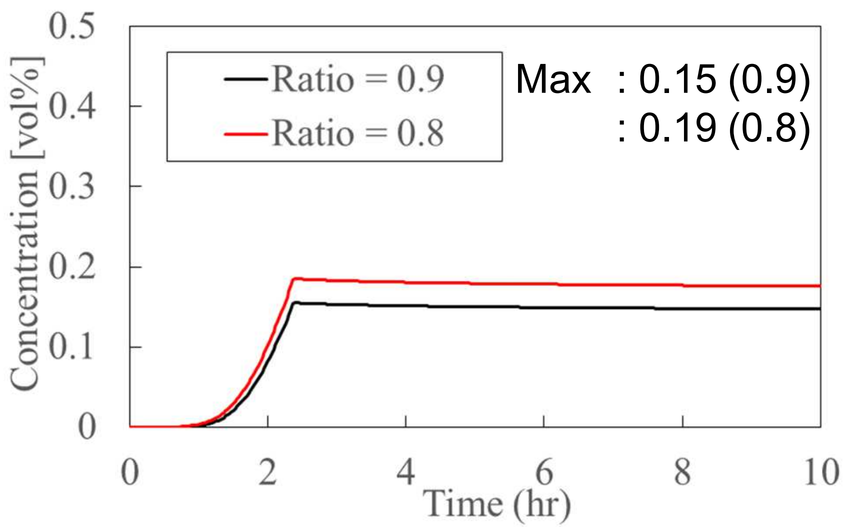
No recombination will take place when there is no oxygen.

- After approximately 4hr in 500m$^3$

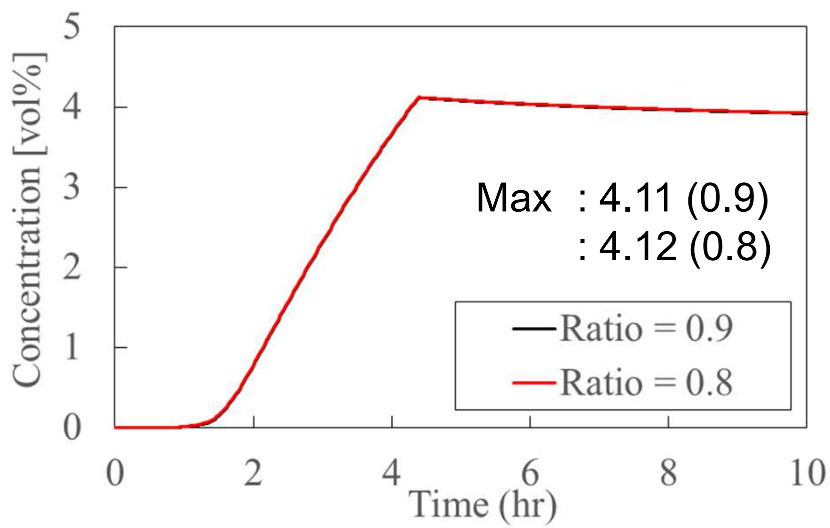
Oxygen has higher reactivity with sodium than hydrogen.

- Recombination of hydrogen suppresses when oxygen concentration becomes low.

(Influence of recombination ratio on hydrogen concentration)




1000m$^3$




500m$^3$

# Challenges in SMR

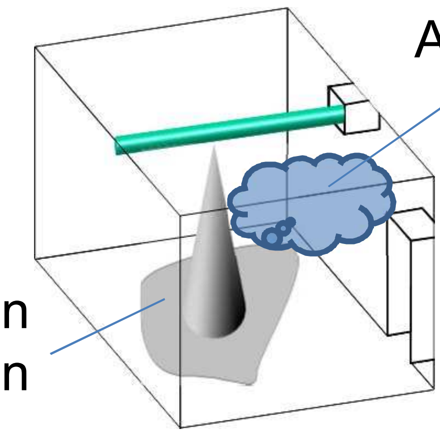
## Enhancement of prediction accuracy of hydrogen gas

- ✓ Water vapor release model
  - ○ Transient release model
  - ○ Experimental database (including transient)
- ✓ Recombination ratio
  - ○ Theoretical and mechanistic approach
    - E.g. reaction rate model (Field), function of temperature, et al. (Zone)
- ✓ Integral effect test (IET)
  - ○ Sodium fire with high concentration of water vapor

(Present release fraction)

(range of concrete temperature in presentation): 30, 80

| Temperature (°C) | Release fraction (wt%) |
|---|---|
| **30** | 0.0 |
| **80** | 0.1 |
| **200** | 1.5 |
| **1000** | 3.0 |



# Conclusion

Dimension of compartment is an important parameter in hydrogen generation during sodium fire due to water release from concrete.

In the SMR design, the risk of hydrogen generation should be investigated carefully.

An improvement of numerical method will be of importance for better understanding and prediction of hydrogen gas behavior under the SMR condition.

Thank you for your kind attention!