
Study on the Issues about Hydrogen Explosion at Fukushima Dai-ichi NPS

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Outline

- ❑ **Background**
- ❑ **Hydrogen Explosion at Unit 1 and Unit 3**
- ❑ **Cause of explosion at R/B of Unit 4**
- ❑ **Summary and Remarks**

Background

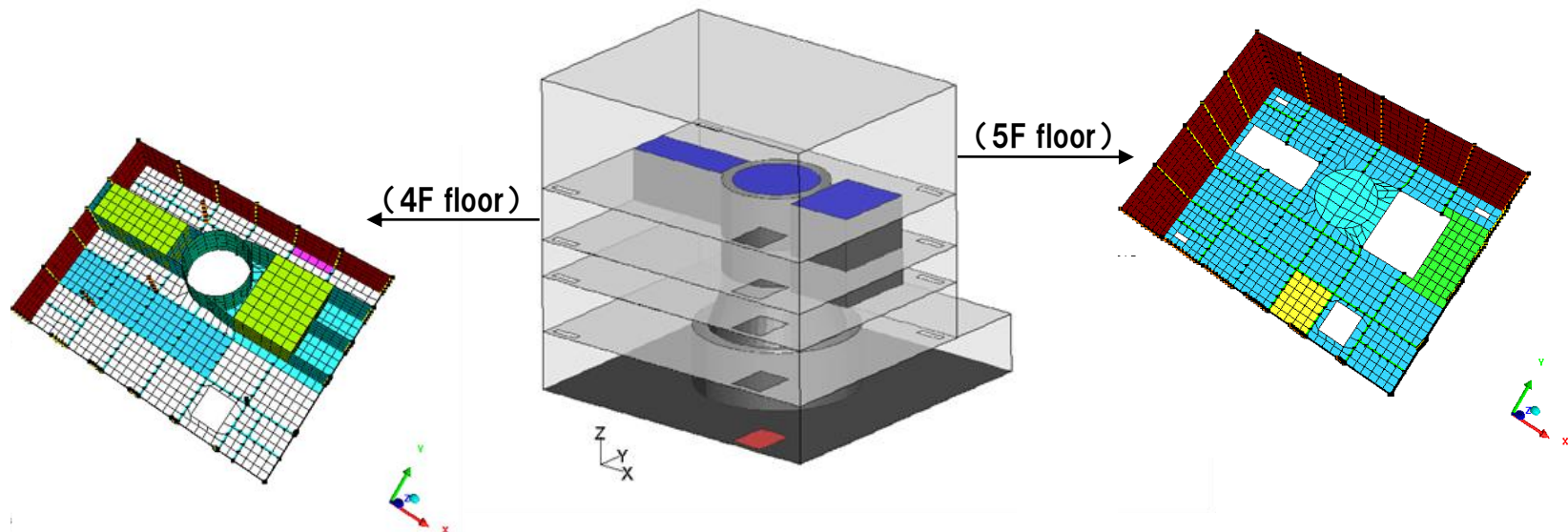
- ❑ **Hydrogen explosion occurred in the R/Bs of Unit 1, Unit 3 and Unit 4 during accident progression at Fukushima Dai-ich NPS in March 2011.**
- ❑ **R/B has safety functions of confinement to protect from FP release to the environment as well as installment of many safety equipments in it.**
- ❑ **Explosion in the R/B made obstacles against operators to mitigate the accident at the site.**
- ❑ **Investigate the cause of hydrogen explosion in the R/B to investigate Fukushima accident and to study countermeasures for such hydrogen explosion.**
- ❑ **In this presentation, describe about the hydrogen explosion at Unit 1 and Unit 3 at first, then the cause of explosion at Unit 4.**

Hydrogen Explosion at Unit 1 and Unit 3

- ❑ Investigate the cause of hydrogen explosion at Unit 1 and Unit 3 by explosion analyses comparing with the existing conditions of R/B after explosion.
- ❑ Total amount of hydrogen gas released into R/B from PCV and its released rate were used referring the accident progression analysis results of Unit 1 and Unit 3 by severe accident analysis code MELCOR.

Hydrogen Explosion Analysis

- ❑ Purpose:
 - Investigate what exactly has happened in the reactor buildings
- ❑ Approach:
 - Mixing analysis with FLUENT code
 - Explosion (detonation) analysis with AUTODYN code



Mixing model and explosion model

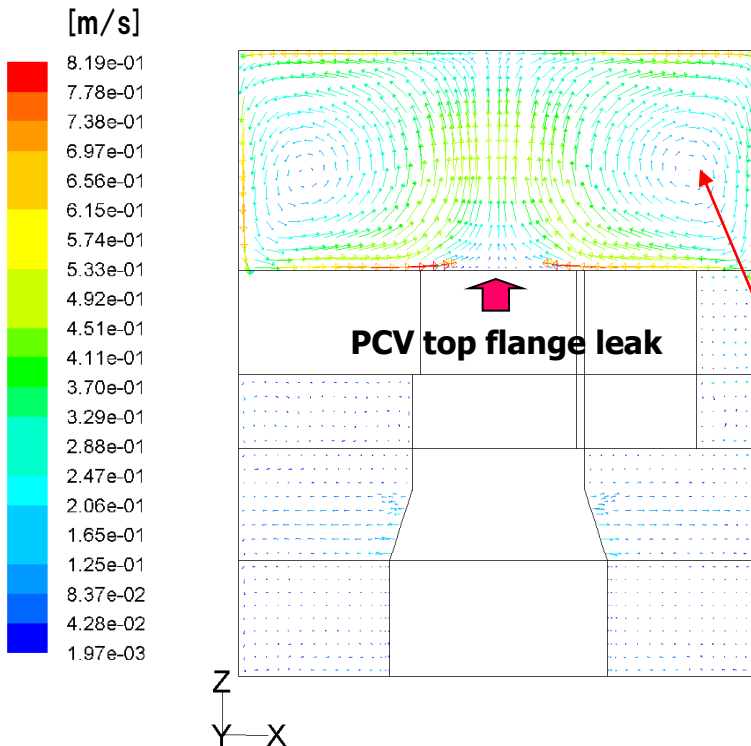
Hydrogen mixing in R/B (Unit 1)

【Assumptions】

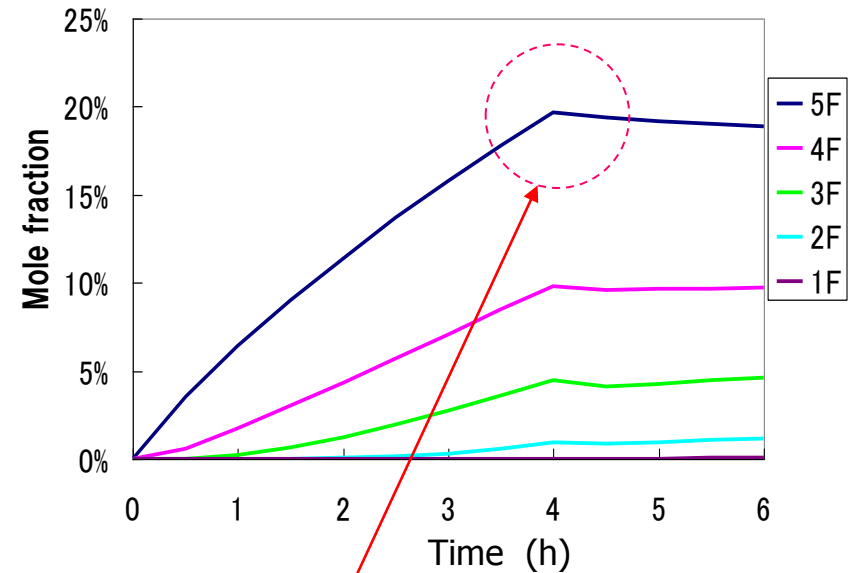
Hydrogen gas of 400kg released to the top floor (5F) of R/B from the PCV top flange

Released flow rate of hydrogen gas was 100kg/h for 4 hours

Hydrogen gas flow velocity



Hydrogen gas conc.



Released hydrogen gas accumulated evenly in the top floor (5F) with high concentration of about 20vol%

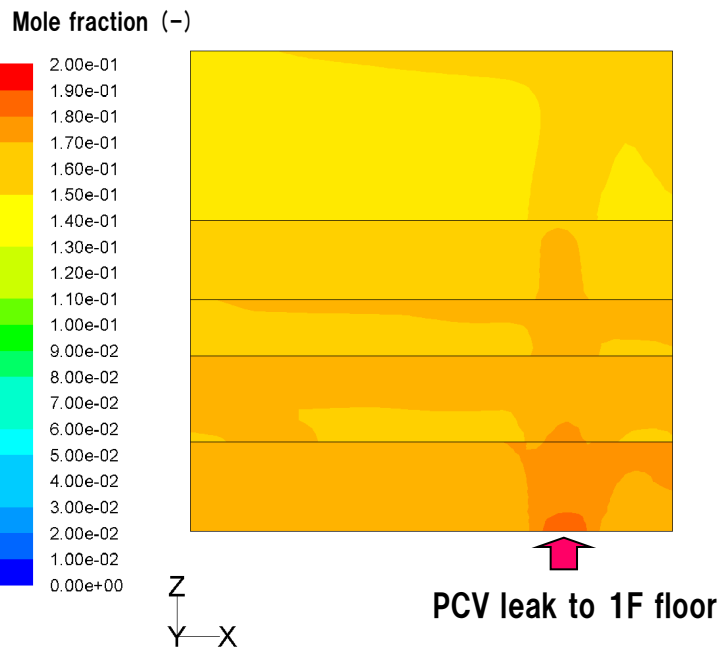
Hydrogen mixing in R/B (Unit 3)

【Assumptions】

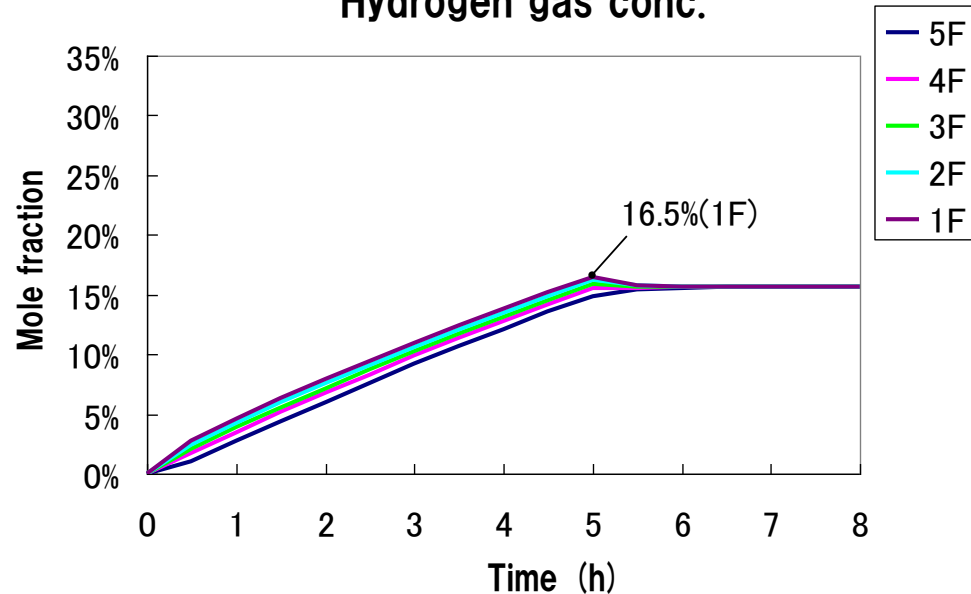
Hydrogen gas of 1000kg released to the first floor (1F) of R/B from PCV penetration, S/C or etc.

Released flow rate of hydrogen gas was 200kg/h for 5 hours

Hydrogen gas distribution



Hydrogen gas conc.



Released hydrogen gas accumulated evenly in the whole of R/B with high concentration of 16–17vol%

Hydrogen explosion in R/B (Unit 1)

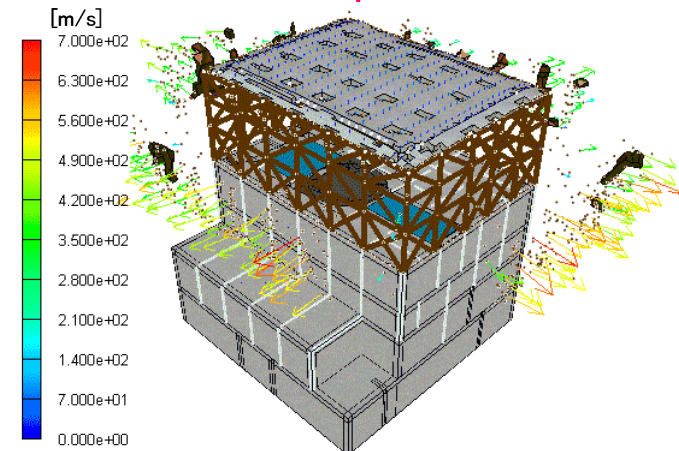
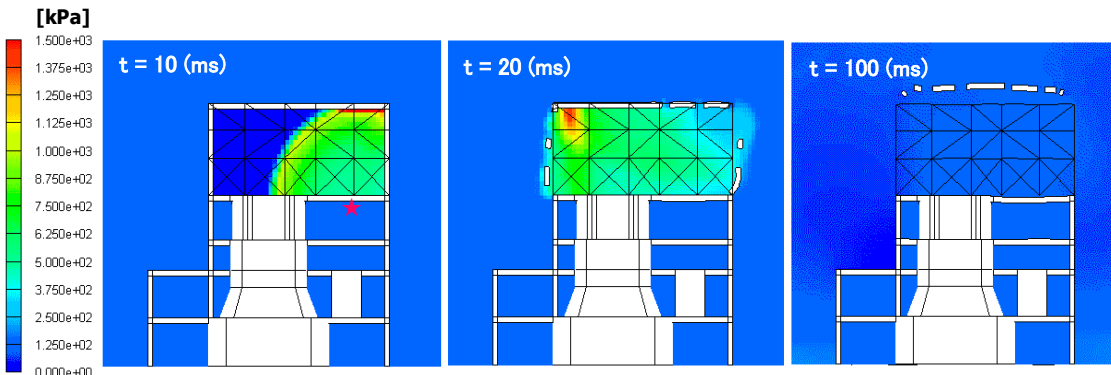
Detonation analysis with AUTODYN:

【Assumption】

Hydrogen gas of 400kg released to the top floor (5F) of R/B

Walls and roofs of top floor (5F) were largely destroyed and debris scattered around the R/B

Good simulation of the actual explosion at Unit 1



Propagation of detonation pressure in the reactor building of Unit 1

Hydrogen explosion in R/B (Unit 3)

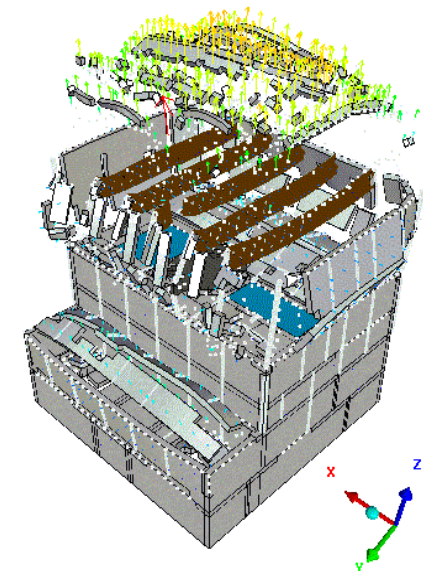
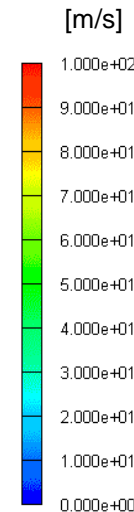
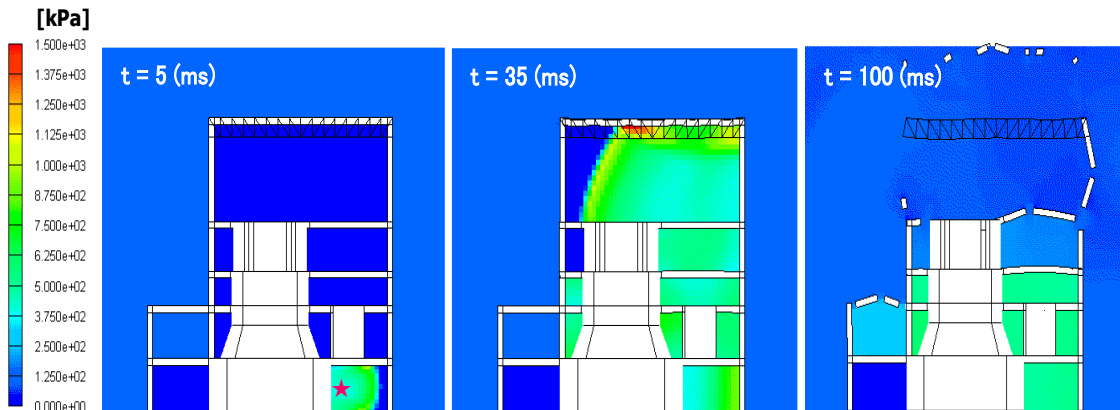
Detonation analysis with AUTODYN:

【Assumption】

Hydrogen gas of 1000kg released to the first floor (1F) of R/B

Walls and roofs of top floor (5F) and 4F were largely destroyed and debris scattered around the R/B

Good simulation of the actual explosion at Unit 3

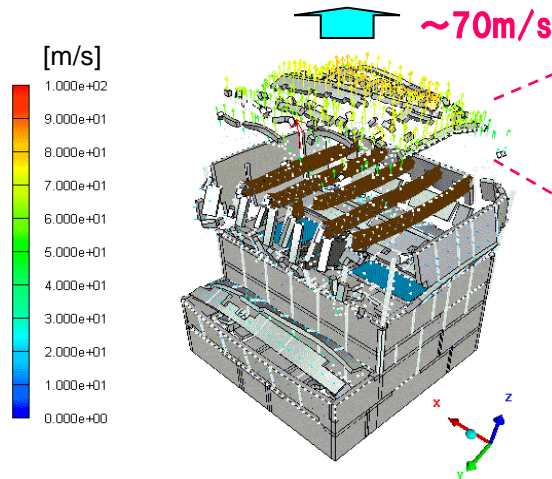


Propagation of detonation pressure in the reactor building of Unit 3

Hydrogen explosion and debris scattering (Unit 3)

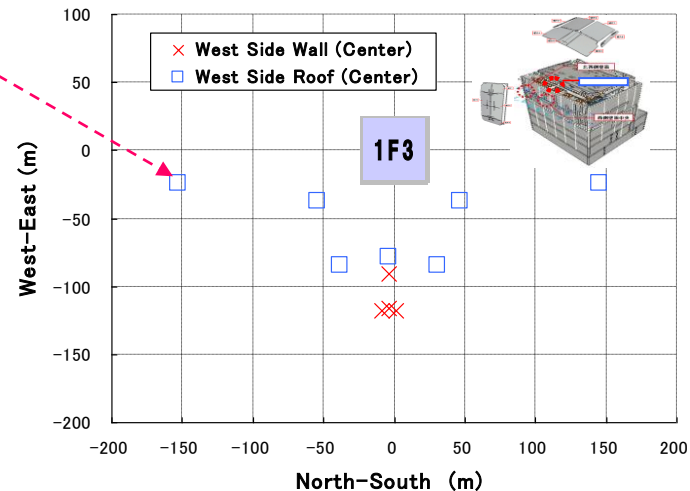
- Debris with initial velocity of 70m/s can reach to about 250m height from the top of R/B in 7 seconds.
- Agreed with the actual phenomena observed at the Unit 3.

TV broadcast picture



Debris with initial velocity of 20 m/s to 70 m/s

- Distribution of scattered debris of walls and roofs of the west side of Unit 3 agreed with the actual distribution.



Scattered debris on the ground around Unit 3

Summary of R/B hydrogen explosions

- ❑ Analyzed R/B hydrogen explosion phenomena during Fukushima Dai-ichi accident with FLUENT code and AUTODYN code getting insight of the R/B hydrogen explosion at Unit 1 and Unit 3.

- ❑ Estimation by the hydrogen explosion analysis:
 - Hydrogen gas ($\sim 400\text{kg}$) leaked from PCV upper flange and exploded in the top floor of R/B (Unit 1)
 - Hydrogen gas ($\sim 1,000\text{kg}$) leaked to the 1F of R/B and exploded in the whole R/B (Unit 3)
(Observed high radiation around the equipment hatch (1F) by inspection)

Cause of explosion at R/B of Unit 4

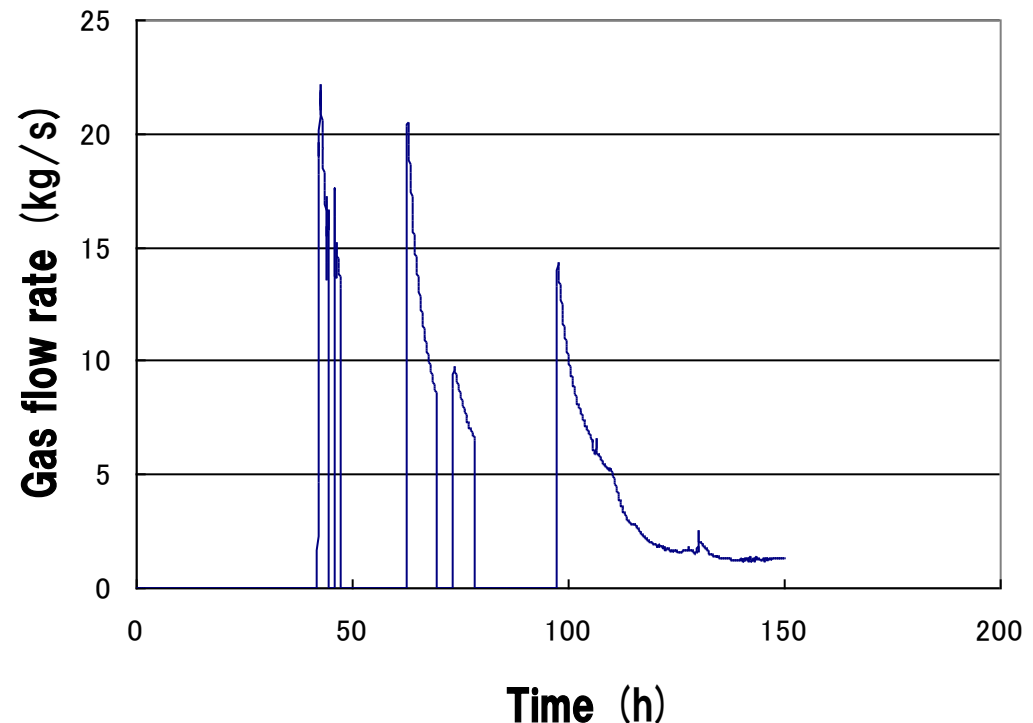
- ❑ **To investigate the cause of explosion in the R/B of Unit 4 by evaluating analytically reverse transportation of the vented gas from Unit 3 to the R/B of Unit 4 through vent lines.**
- ❑ **To survey the way of inspection to confirm the analytical results**

Containment venting at Unit 3

□ Containment venting flow rate of Unit 3

- MELCOR results (*)
- Vent gas flow rate:
0 ~ 20 kg/s

(*) Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety – IV. Occurrence and Development of the Accident at the Fukushima Nuclear Power Stations, June 2011.

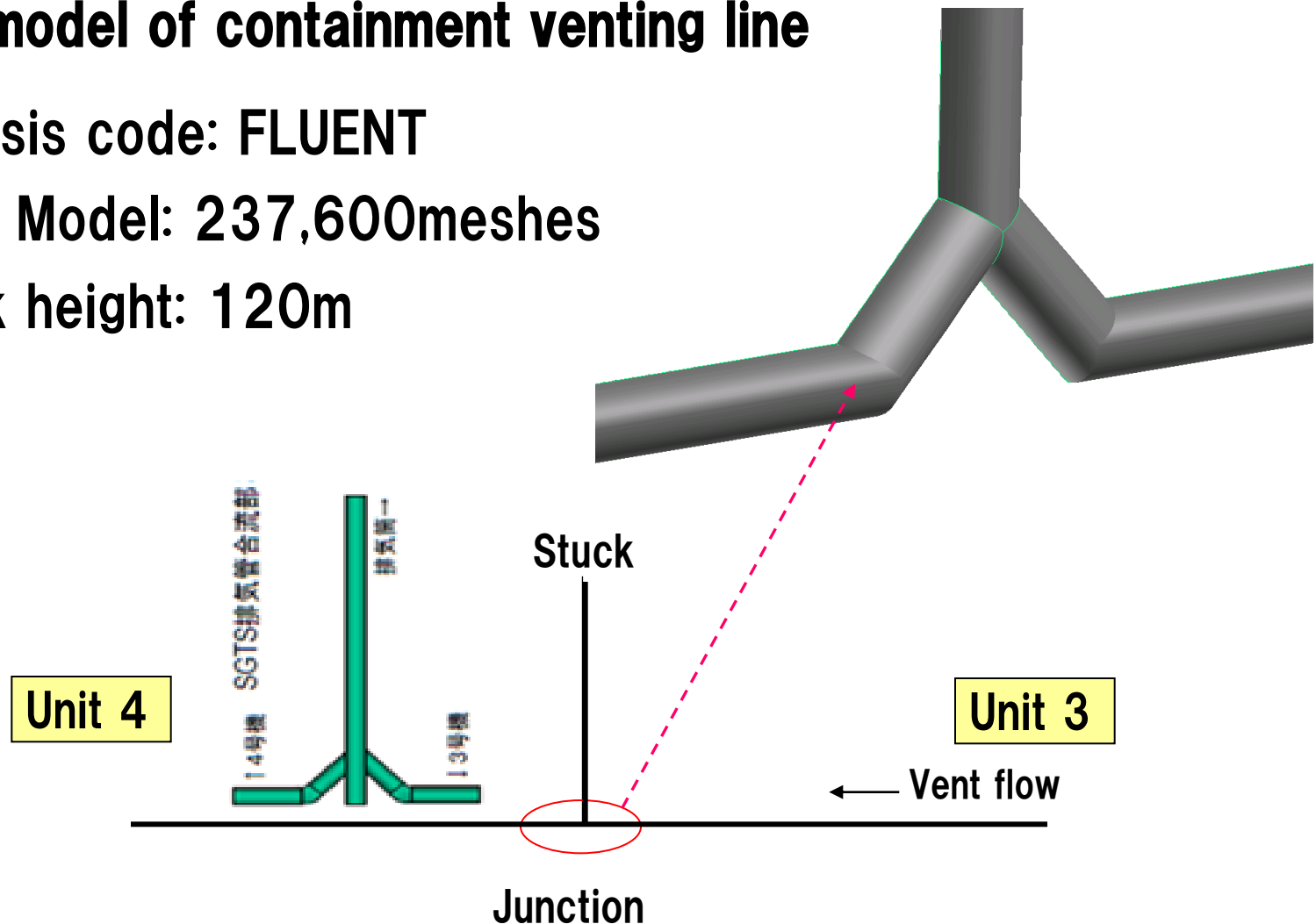


Mass flow rate of containment venting
(Unit 3)

Analytical Model of Containment Vent Line

CFD model of containment venting line

- Analysis code: FLUENT
- Mesh Model: 237,600meshes
- Stuck height: 120m

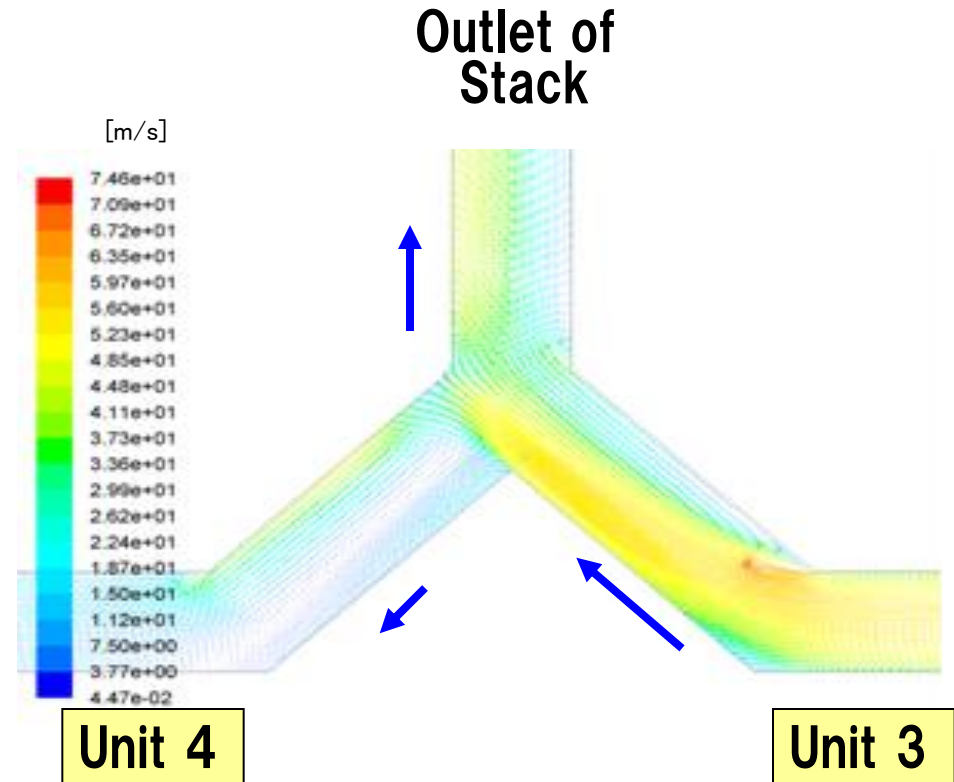


CFD analysis results

Reverse gas flow in to the R/B of Unit 4

– FLUENT results show that:

- All of vented gas from Unit 3 releases to the environment through the stack with low venting flow rate.
- Around one quarter of the vented gas from Unit 3 reversely flows into the R/B of Unit 4 with high venting flow rate of 20kg/s.



Picture of exploded R/B of Unit 3 and Unit 4

Unit 3



Unit 4



(写真: 東京電力ホームページより)

Cause of explosion at R/B of Unit 4

❑ Expected cause of explosion

- Condition of the exploded R/B of Unit 4 was between that of Unit 1 and Unit 3.
 - Indicating the order of total amount of hydrogen gas exploded in the R/B of Unit 4 was between Unit 1 (400kg) and Unit 3 (1,000kg).
 - Reported that the water level of the spent fuel pool kept covering the top of fuels at Unit 4 .
 - Supposed small amount of hydrogen gas generation by radiolysis in a few days before the explosion
- Indicating the vented gas from Unit 3 reversely flowed into the R/B of Unit 4

Cause of explosion at R/B of Unit 4

❑ Validation

- **Hydrogen gas generation in SFP of Unit 4:
Small amount of hydrogen gas generation in the pool.**
 - **Reverse flow of vented gas from Unit 3 to Unit 4:
How did large amount of hydrogen gas flow into the
R/B of Unit 4 from Unit 3?**
- Need of inspection of the junction area of vent lines of Unit 3 and Unit 4 (bottom of stuck) to evaluate the flow distribution at the junction area with radiation monitor or any other ways**

Summary and Remarks

- ❑ **JNES analyzed hydrogen explosion phenomena in R/B of Fukushima Dai-ichi NPS getting insight of the cause of explosions.**
- ❑ **Estimation by the hydrogen explosion analysis:**
 - **At Unit 1: hydrogen gas (~400kg) leaked from PCV upper flange and exploded in the top floor of R/B (Unit 1)**
 - **At Unit 3: Hydrogen gas (~1,000kg) leaked to 1F of R/B and exploded in the whole R/B (Unit 3)**
 - **At Unit 4: Total amount of hydrogen gas between that of Unit 1 and Unit 3 exploded in the R/B (Unit 4), which caused by reverse flow through containment vent line from Unit 3**
- ❑ **Need to continue further investigation to fix above estimation.**