CFD Simulation of Hydrogen Risk Analysis During Severe Accidents in a Nuclear Power Plant Using CFX Code

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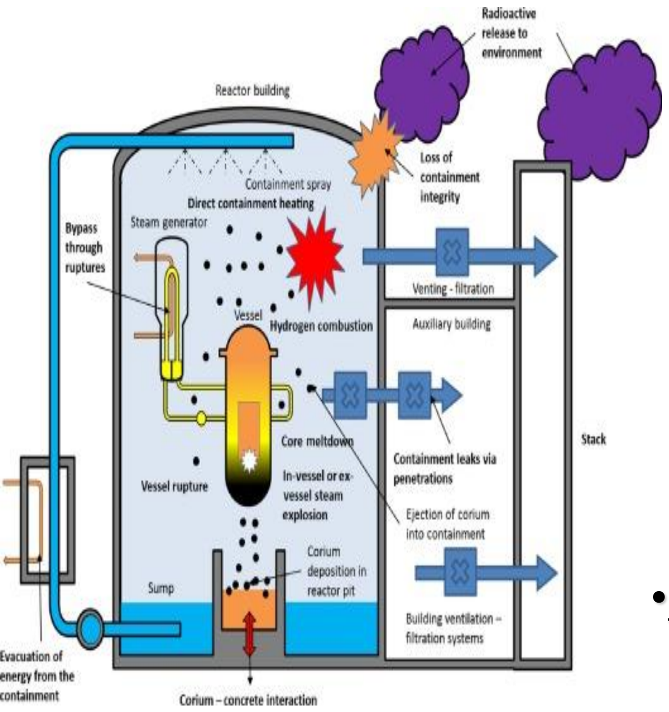
Introduction

- On 11 March 2011, a massive earthquake of Richter scale 9.0 followed by a tsunami 1 h later with waves of 10 to 14 m struck the Fukushima Daiichi (FD) nuclear complex operated by Tokyo Electric Power Company (TEPCO).

- CFD is used to determine the evolution the hydrogen distribution within the containment for a relatively large number of postulated accident scenarios

- After a brief summary of project organisation and aims, this presentation indicates how to calculate the hydrogen distribution in the containment using CFD Code[1], to provide evidence on hydrogen behaviour and management in water-cooled rectors through a severe accident [2], and to recommend mitigation strategies to prevent future accidents [3].

Problem to be simulated



- ***Origin***

$$Zr + 2H_2O \longrightarrow ZrO_2 + 2H_2 + heat$$

- Heat generated heats up the core and accelerate core melting process.

- ***Consequence***

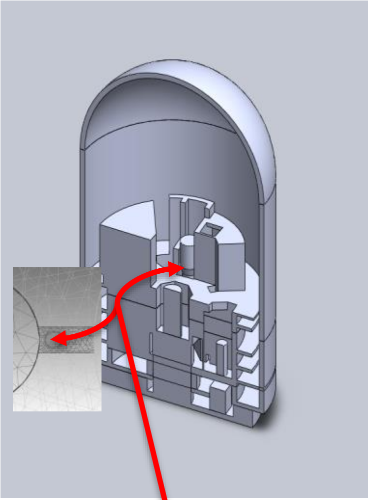
- H2 may burn in RPV, and in the containment after RPV failure
- H2 reduces the depressurization of containment by spraying

- ***Research***

- Control rods, Cladding, fuel melting progress
- Hydrogen generation
- Hydrogen distribution in the containment
- Evaluation of hydrogen risk

Modeling of the Plant, Setup & simulation of hydrogen distribution

Step1:
Geometry Simplification.



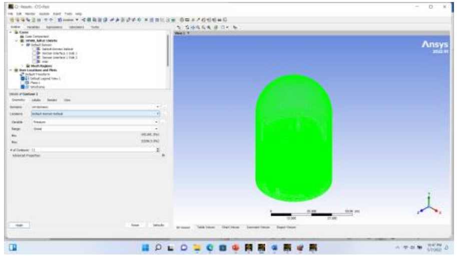
The failure locations are assumed on the pressurized tube surface

Step 2: Meshing

The total number of grids is 2700,000 and the grids are generated using CFD codes. (Hexagonal Mesh)

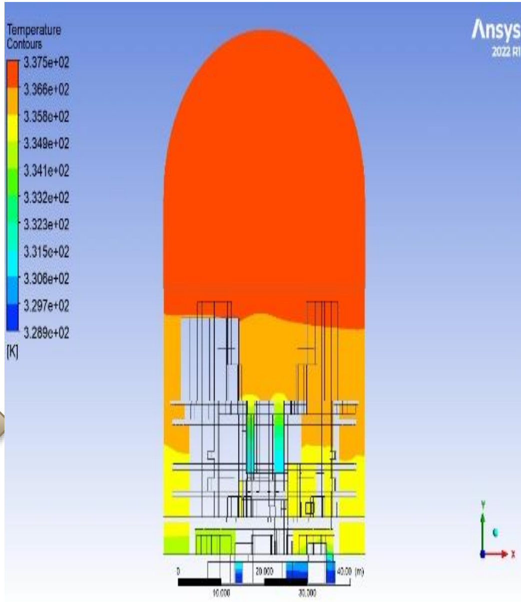
Passive autocatalytic recombiners (PARs)

Step 3: simulation setting



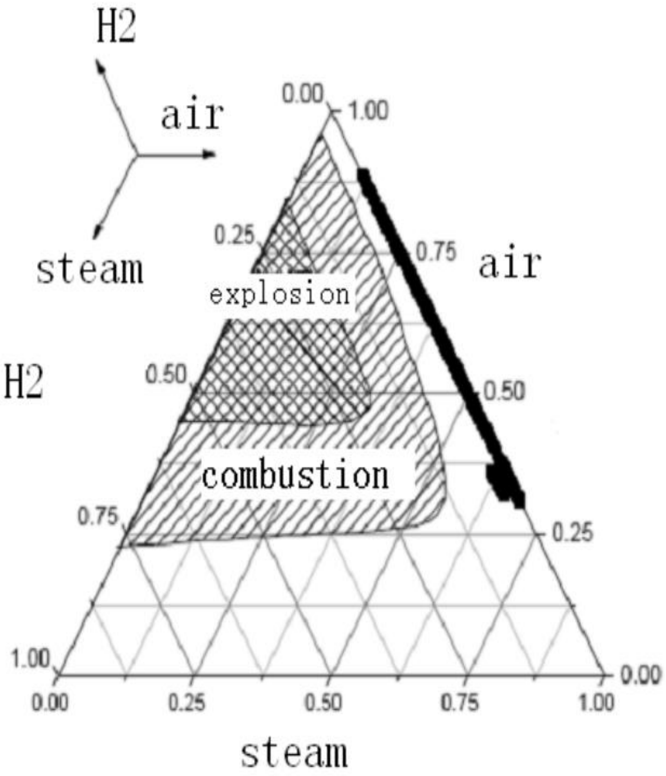
parameters	value
Reactor full power/ MW	3040
Hot leg temperature in steady state/ K	603.23
Cold leg temperature in steady state/ K	566.06
Core temperature in steady state/ K	605.16
RPV outlet mass flow rate/ kg • s^{-1}	1.47E4
RCS pressure in steady state/MPa	15.122
SG secondary side pressure in steady state /MPa	6.77
Containment pressure in steady state /MPa	0.11
Minimum thickness of cladding/m	0.0001
Fail temperature of penetration/K	1273.15
Fail pressure of relief tank/MPa	>Pc[a] + 0.8
Low fail pressure of containment/MPa	0.52
High fail pressure of containment /MPa	1.027
Critical mole fraction for blasting of H_2	0.1

Step 4: post processing

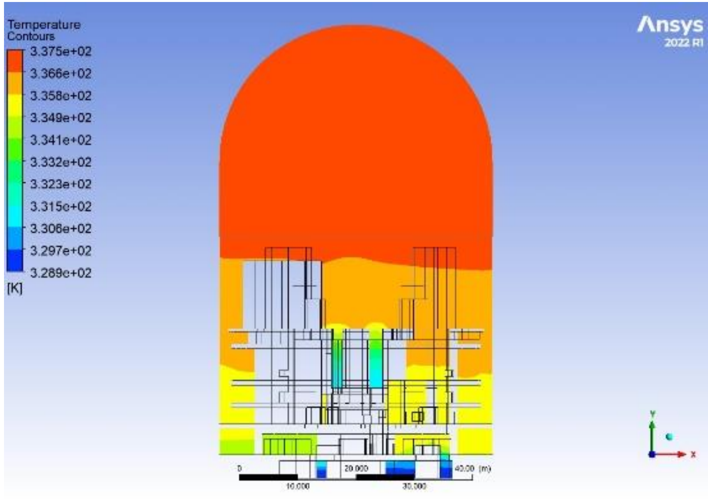


Results

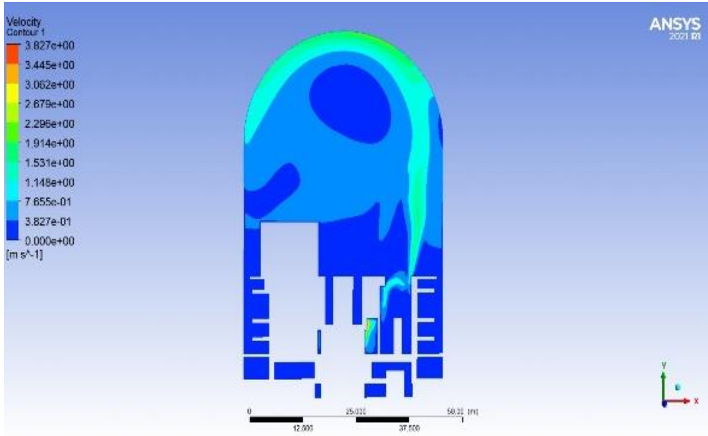
Hydrogen Behavior was analyzed with CFD code to check the concentration in doom and local compartments in transients.



Predicted contours of hydrogen concentration (by vol.) on symmetry plane at t = 21 s



Experiment, t = 21.33 s



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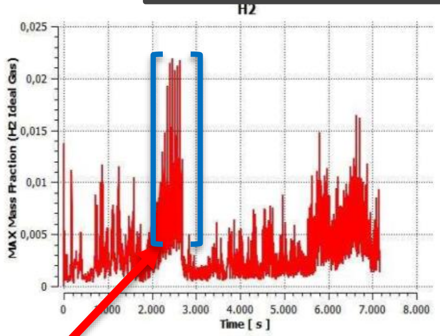
Accident Assumption

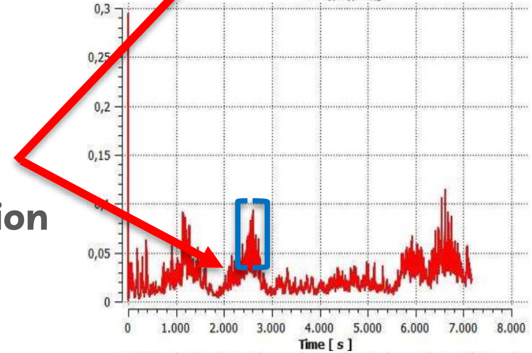
Calculation results from MAAP

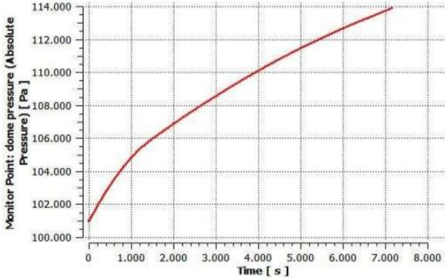
LOCA accident

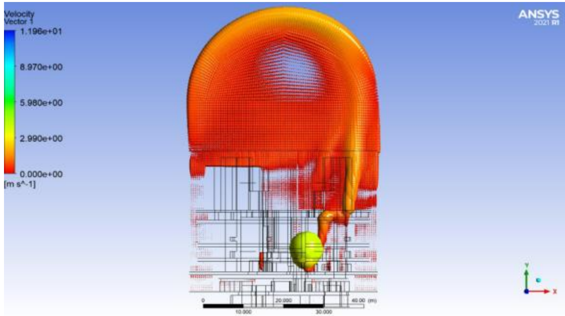
- ➢Steam generator compartment
- ➢Hydrogen generates after 1400s

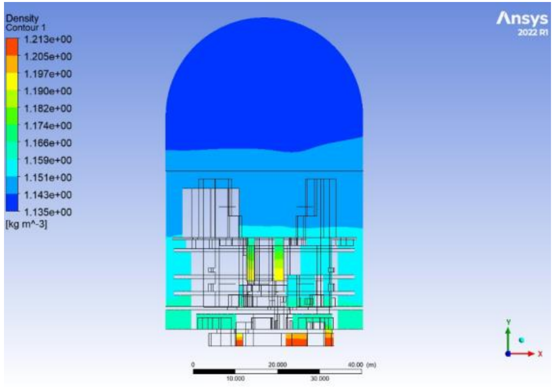
CFD simulation









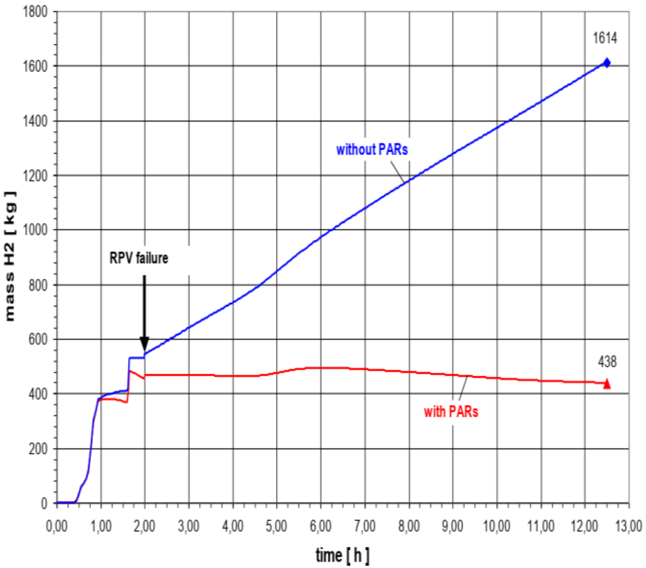


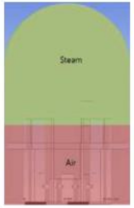
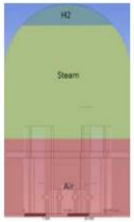
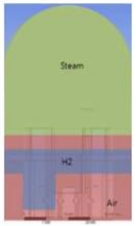
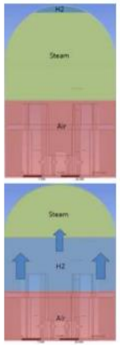
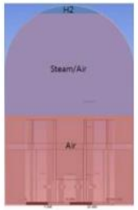
Results

Under severe accident conditions, the total amount of hydrogen generated in the core depends on the specific accident process and the reactor structure. In this research, about 1600kg (without PARs), and 440kg (with PARs) of hydrogen were generated in the containment. However, in the containment accident,

Techniques for Mitigating and Reducing the Chance of a Serious

- Accident
- Igniters Operation
- Reduction of Oxygen Mass
- Monitoring Devices



Stage	1	2	3	4	5
Simplified gas distribution chart					
Description	No risk of hydrogen explosion (only steam is released in this stage)	Almost no risk of hydrogen explosion (hydrogen released in steam cloud, no contact with air)	Possibly risk of localized hydrogen explosion (a minor scale of hydrogen explosion may take place at the bottom part of containment)	Reduced risk of localized explosion (a small amount of hydrogen suspended around the compartment, could have contact with air)	High risk of hydrogen at the top of the containment, where hydrogen layer formed could contact with large amount of air would lead to a massive scale of hydrogen

Conclusion

- A simulation lasted for 15 h to observe the process changes of a hydrogen explosion in the containment when an SBLOCA occurred.

- The risk of hydrogen explosion largely depends on the combination of air, hydrogen, and the presence of steam in the containment which acts as an insulator to prevent the contact between hydrogen and air.

- The first risk of hydrogen explosion throughout the time may happen at stage 3 (7000–14,000 s). There is a possibility of a localized hydrogen explosion that could occur among the compartments in the lower part of the containment.

- A massive scale hydrogen explosion could bring damage to the containment structure. Better knowledge of the potential risk locations can facilitate the PAR installation and promote a more effective countermeasure against hydrogen explosion.

REACH OUT TO ME WITH ALL YOUR QUESTIONS

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