Study on Severe Accident Progression and Source Terms in Fukushima Dai-ichi NPPs

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1. Investigation Reports

• After Fukushima Daiichi accident, several investigation reports were published

• These reports pointed out lessons learned from the accident

• New regulation, reflecting the lessons, was enacted last year

• NRA launched new committee to investigate unsolved issues
New Investigation Committee

- Possibility of small break LOCA at Unit 1
- Activation of S/RV at Unit 1
- Flooding on 4th floor of Unit 1
- Isolation condensers of Unit 1
- SFP of Unit 3
- Hydrogen explosion at R/B of Unit 4
Possibility of SBLOCA at Unit 1

- Diet investigation report pointed out possibility of small break LOCA and S/RV was not activated
- If SBLOCA occurs, RPV pressure decreases rapidly and is inconsistent with observed data

Ref.: WWW.nsr.go.jp/comittee/yuushikisha/jiko_bunseki/data/004_05.pdf (in Japanese)
Flooding on 4th floor of Unit 1

- S/NRA/R calculated sloshing of SFP (Unit 1) and structure
- Analyses suggest below
  - Water flooded from SFP to duct due to sloshing
  - Water leaked from duct due to break by dynamic loading

Ref.: WWW.nsr.go.jp/comittee/yuushikisha/jiko_bunseki/data/003_01.pdf (in Japanese)
Hydrogen Explosion at Unit 4

- CFD calculations suggest hydrogen flow from Unit 3 to Unit 4 through common stack
- Outlet of STGS (Unit 4) was contaminated higher than inlet
- NRA investigated R/B of Unit 4 and found ducts were significantly damaged

Dose rate of filters in Unit 4 were measured

Ref. 1: WWW.nsr.go.jp/archive/jnes/content/000125907.pdf
Ref. 2: WWW.nsr.go.jp/comittee/yuushikisha/jiko_bunseki/data/004_01.pdf
2. Research on Fukushima in S/NRA/R

- **Experimental programs**
  - Pool scrubbing test
  - Sea water injection

- **Computational analyses**
  - Accident progression (lumped parameter code)
  - CFD approach
    - Containment integrity
    - Hydrogen distribution
    - Diffusion of fission products
Thermal Stratification of S/P

- Calculations of lumped S/P model (uniform temperature distribution) show significant difference from actual measurement.
- These calculations imply thermal stratification of S/P under long term SBO.

Calc. shows slow pressurization

Calc. shows D/W pressure quickly increases

Early Pressurization of PCV

PCV is pressurized due to thermal stratification of S/P during RCIC operation

Experimental results show nonuniform temperature distribution

Ref.: M. Pellegrini, et al., “Suppression pool testing at the SIET labs (3) Experiments on Steam Direct Contact Condensation in a Vertical Multi-holes Sparger,” Proc. of The 10th International Topical Meeting on Nuclear Thermal-Hydraulics, Operation and Safety (NUTHOS-10), Okinawa, Japan, December 14-18, 2014 (provided by the senior author)
Depressurization of W/W

- Depressurization of W/W due to activation of spray system
- Discharge from D/W to W/W through vent pipe
- Enhance mixing of S/P and break thermal stratification

- Spray activation
- Steam condensation
- Depressurization

- Discharge from D/W to W/W through vent pipe
- Mixing of S/P

- Break of thermal stratification of S/P
New Attempt of S/C Nodalization

Divide Suppression chamber volume into 20 volumes for Unit 2,3.

Each radial volume is divided into 2 volumes for the vertical direction.

Consider radial thermal distribution and vertical thermal stratification
Leakage from PCV (1/2)

Ref.: TEPCO, “Evaluation of the situation of cores and containment vessels of Fukushima Daiichi Nuclear Power Station Units-1 to 3 and examination into unsolved issues in the accident progression Progress Report No. 2,” Aug. 6, 2014
Leakage from PCV (2/2)

Leakage from PCV (Analysis)

Flow velocity

Temperature

PCV top head flange

Leakage from SRV gasket

1800 sec after leakage from S/RV gasket
External Water Injection

- External water injection
- MCCI is important to estimate amount of external water injected to the core
- Core status
Bypass of External Water Injection

- If whole external water, fed by fire engine, was injected to the core, core ought to have been cooled.
- External water injection, to the core, is less than the record.
- TEPCO identified potential bypass path e.g. 10 paths for unit 1.
- Actual amount injected to the core significantly affects core status, hydrogen generation, MCCI, etc.

Ref.: TEPCO, “Evaluation of the situation of cores and containment vessels of Fukushima Daiichi Nuclear Power Station Units-1 to 3 and examination into unsolved issues in the accident progression Progress Report No. 2,” Aug. 6, 2014
Melt Spread in PCV

- Shell attack, direct melt-attack of the liner, is identified as one of the important PCV failure modes for Mark-I containment
- Investigation of inside PCV is in progress by TEPCO

Investigation inside of PCV (Unit 2)


Ref.: TEPCO, “Evaluation of the situation of cores and containment vessels of Fukushima Daiichi Nuclear Power Station Units-1 to 3 and examination into unsolved issues in the accident progression Progress Report No. 2,” Aug. 6, 2014
Nodalization to estimate melt spread

MELCOR nodalization is modified to estimate melt spread and MCCI

Control Rod Opening

Pedestal Doorway

Control Rod Opening

Pedestal Doorway

Transport Direction of Debris
3. Estimation of Source Terms

- Source terms suggest core degradation & PCV leakage
- Isotope ratio is fingerprint of radionuclide source & leak paths
Possible Release from Unit 2

- FP release, which corresponds to pressure peak of Unit 2, was measured*
- Aerosol, discharged from RPV to D/W, was released to the environment without pool scrubbing

New Development for Source Terms

New development:
- In order to compare the source terms obtained by MELCOR with the monitoring data at the main gate, CFD calculations are being done for airstream around the site by using the terrain data and GPV meteorological data (140km x 140 km).

Preliminary results of airstream around the site:

4. Further Investigation

Information from Onsite R&D
--- partially --- future

External Water Injection

Core Degradation

MCCI

PCV Integrity

Hydrogen Generation

Explosion

Source Terms

Inverse estimation
4. Further Investigation

Information from Onsite R&D

--- partially --- future

External Water Injection

Core Degradation

MCCI

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Explosion

Source Terms

Reduce uncertainties of forward estimation
5. Conclusion

- In the light of Fukushima Dai-ichi NPP accident, the NRA developed the new design requirements and established the new regulatory framework to ensure the safety of NPPs and other nuclear facilities.
- NRA launched new investigation committee for Fukushima Daiichi accident.
- NRA examined R/B to investigate impact of tsunami, hydrogen explosion, etc.
- Various analyses are in progress to estimate core status, PCV integrity, source terms, etc.
- TEPCO continues investigation with decommissioning
- Further investigation is still needed. However, multiple approaches are applied to reduce uncertainty.
Thank you for your kind attention