SAND2016-3909PE

Fukushima Forensics: Combustible Gas Effects

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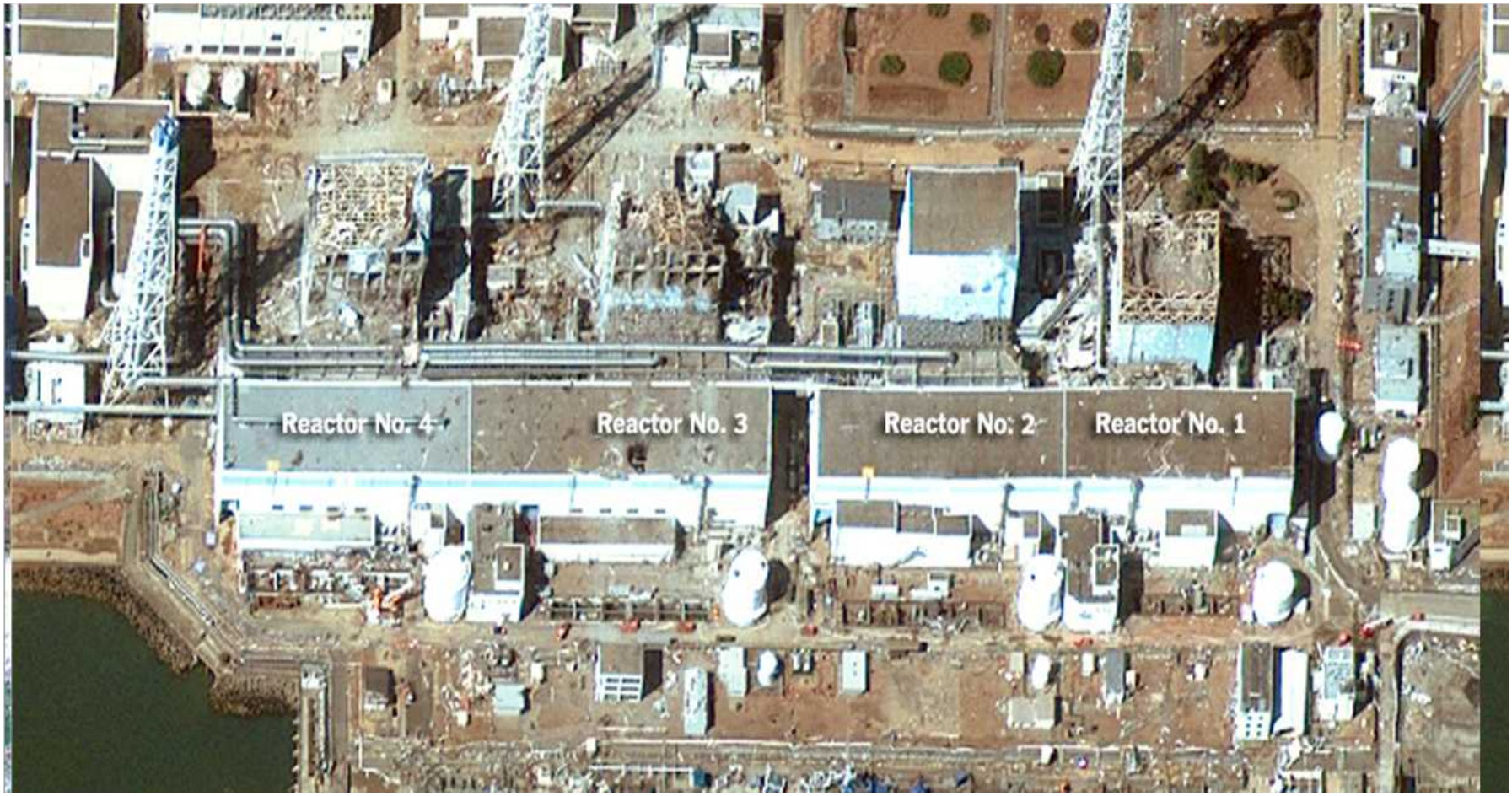
Presentation Overview

- Information available
- TEPCO Reports
- Explosion Characteristics
  - 1F1, 1F3, 1F4
- Videos of Events
- Insights for Plant Data
- Summary of Insights
- Recommendations

Forensic Information Obtained

Item	What/How Obtained	Data Available[1]
RB-3a	Photos/videos of damaged walls and structures (1F1)	A
RB-3b	Photos/videos of damaged walls and structures (1F3)	A
RB-3c	Photos/videos of damaged walls and structures (1F4)	A
RB-4	Photos/videos of damaged walls and components and radionuclide surveys (1F2)	A
RB-6	Radionuclide surveys and sampling of ventilation ducts (1F4)	NA
RB-7	Isotopic evaluations of obtained concrete samples (1F2)	NA
RB-9	DW Concrete Shield Radionuclide surveys (1F1, 1F2, and 1F3 - after debris removed in 1F1 and 1F3)	NA
	Photos/videos around mechanical seals and hatches and electrical penetration seals (as a means to classify whether joints were in compression or tension).	A
RB-10	Photos/videos of 1F1 (vacuum breaker), 1F1, 1F2, and 1F3 PCV leakage points (bellows and other penetrations).	A
RB-11	Photos/videos and available information on 1F1, 1F2, and 1F3 containment hardpipe venting pathway, standby gas treatment system and associated reactor building ventilation system	NA
RB-13	Photos/videos of 1F1, 1F2, and 1F3 main steam lines at locations outside the PCV.	A
PC-1	Tension, Torque, and Bolt Length Records (prior and during removal); Photos/videos of head, head seals, and sealing surfaces (1F1, 1F2, and 1F3).	NA
PC-3	c) If vessel failed, photos/video, RN surveys, and sampling of 1F1, 1F2, and 1F3 pedestal wall and floor.	NA
	d) If vessel failed, 1F2, and 1F3 concrete erosion profile; photos/videos and sample removal and examination	NA
PC-4	Photos/videos of 1F1, 1F2, and 1F3 recirculation lines and pumps	NA

Hydrogen Explosions



Containment Over-pressurization Led to Release of H2 into Buildings

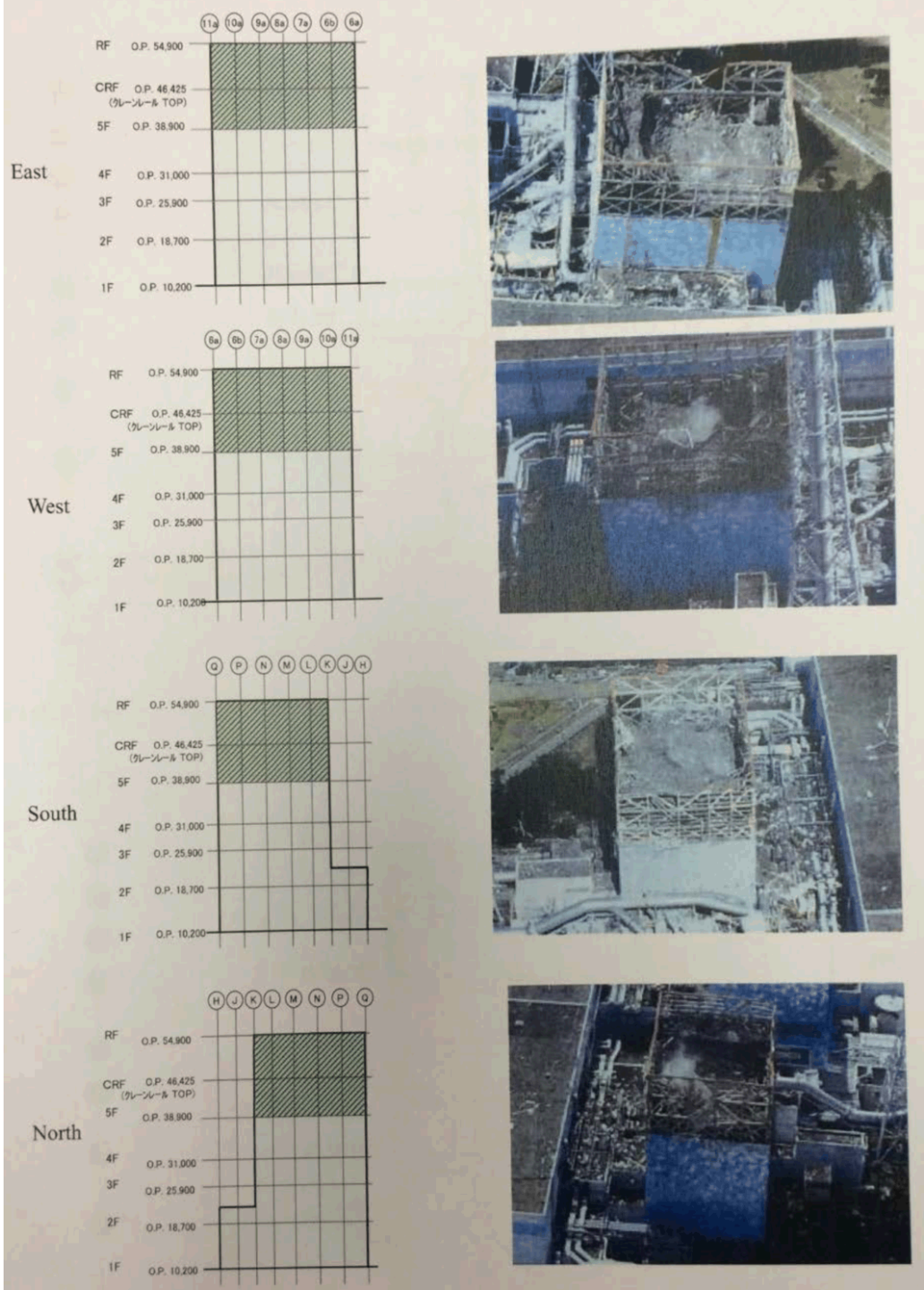
Unit 1 Hydrogen Explosion

Unit 3 Hydrogen Explosion

1F1 End State

- Damage following explosion
- Shows all four sides of the building

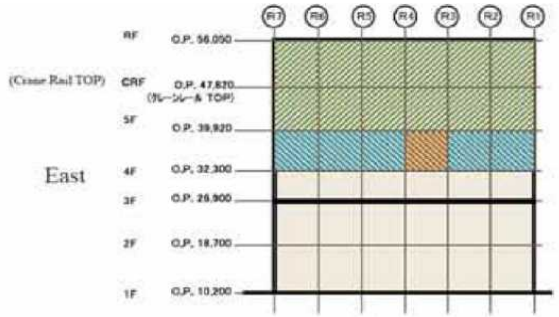
Intact Portion
Damaged Portion
Damage on Outer Surface
Wall Portion not Considered

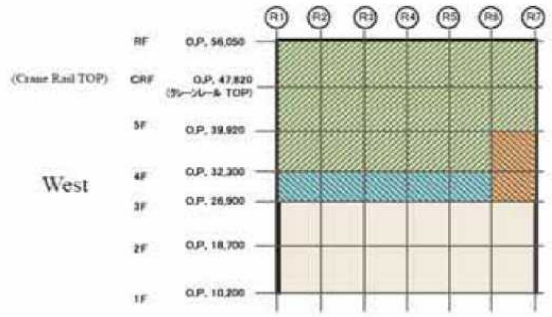


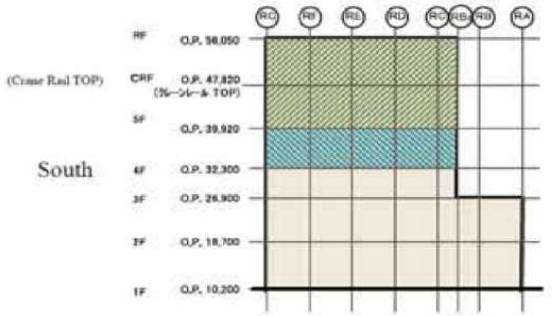
1F3 End State

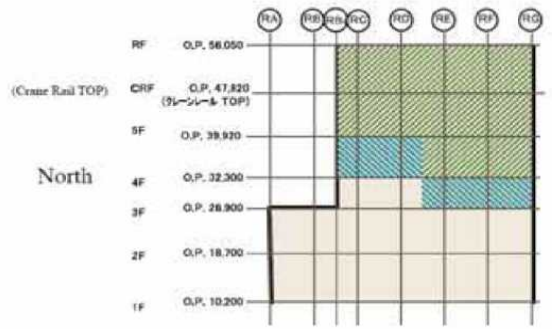
- Damage following explosion
- Shows all four sides of the building

Intact Portion
Damaged Portion
Damage on Outer Surface
Wall Portion not Considered





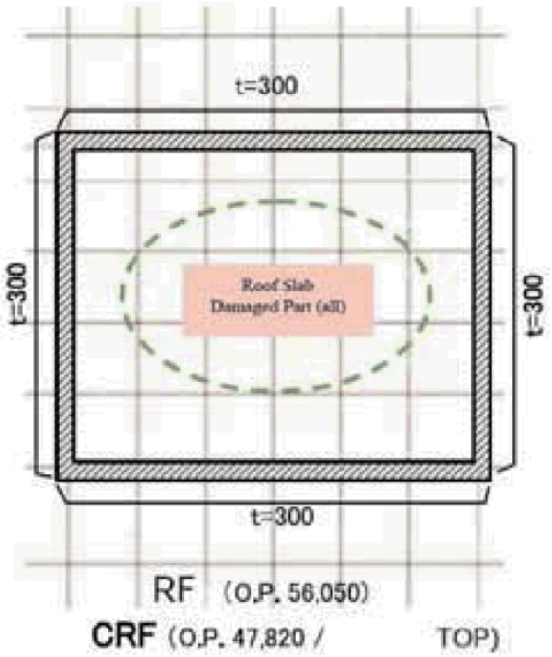


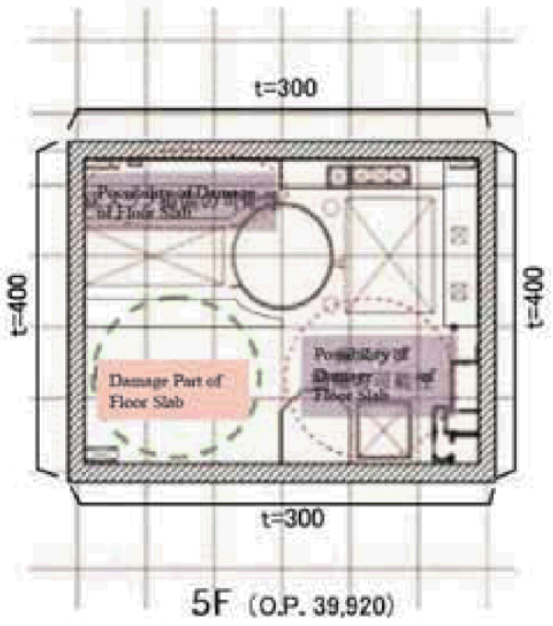


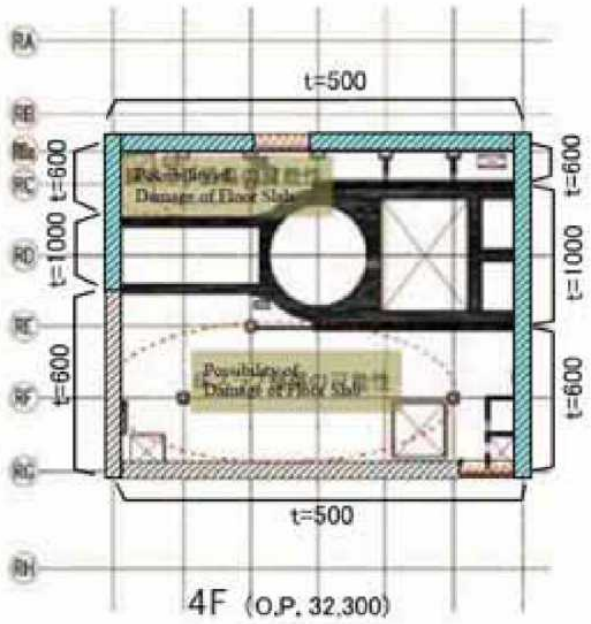
1F3 End State

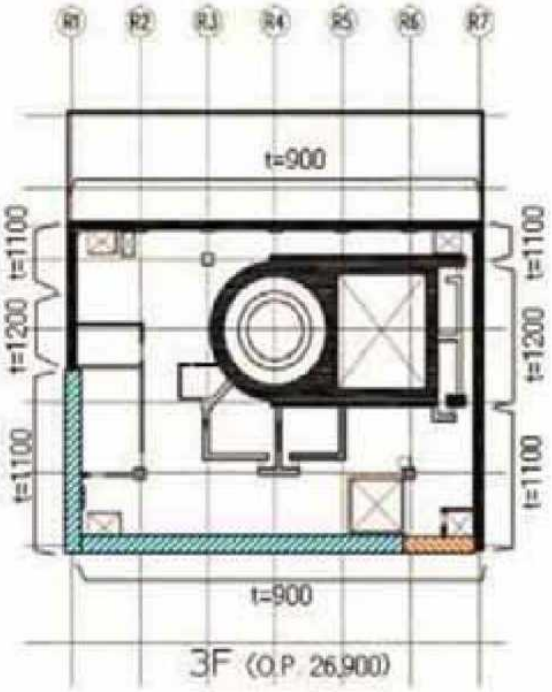
- Floor plan

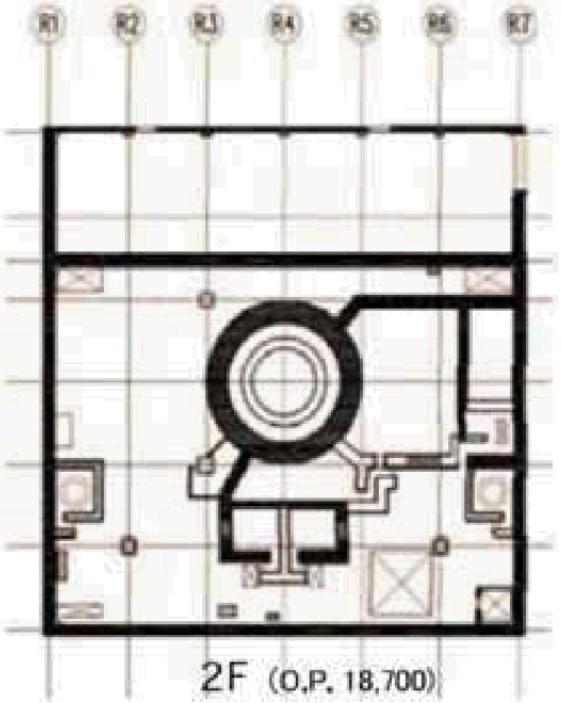
Damaged Portion
Damage on Outer Surface
Wall Portion not Considered







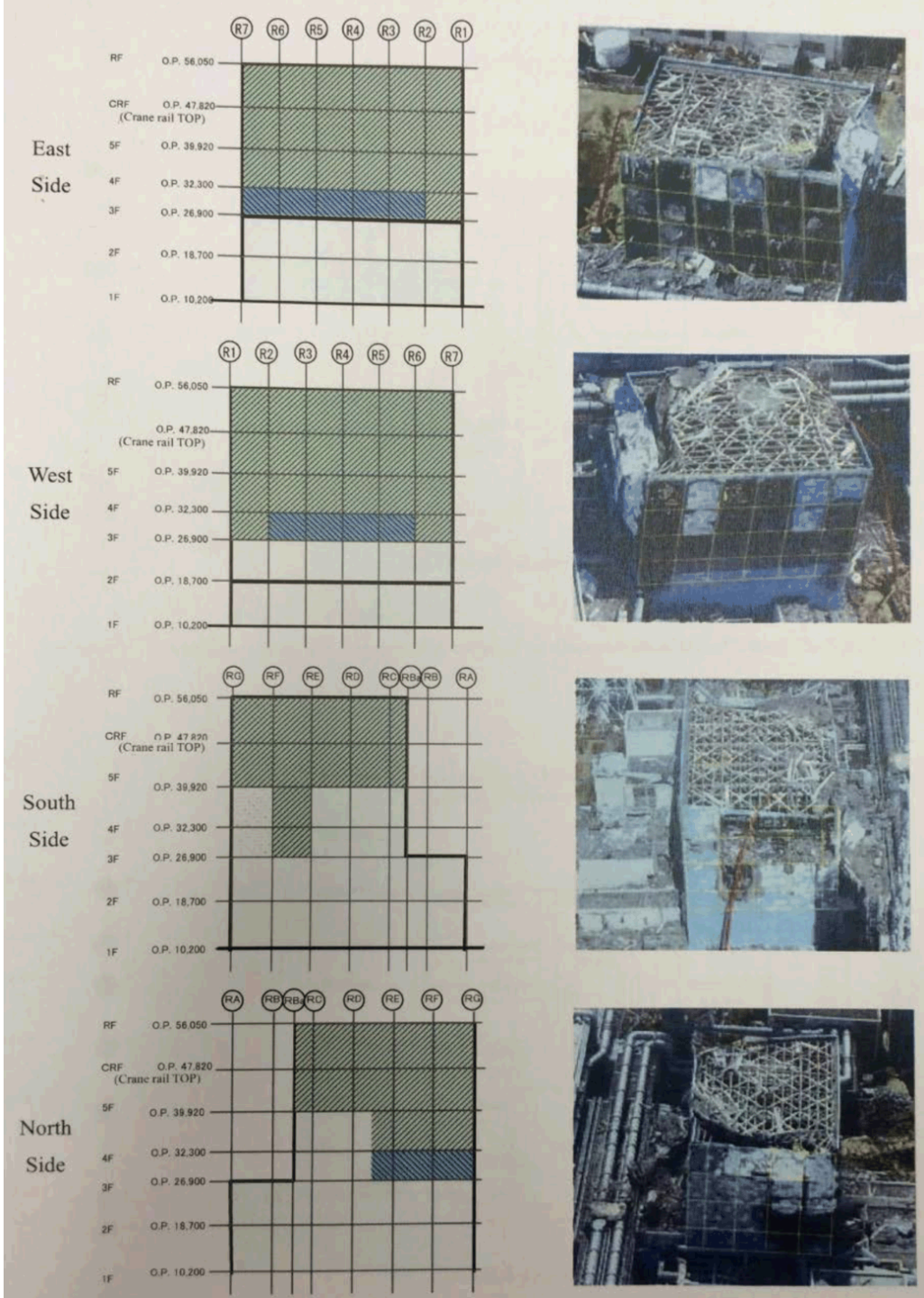




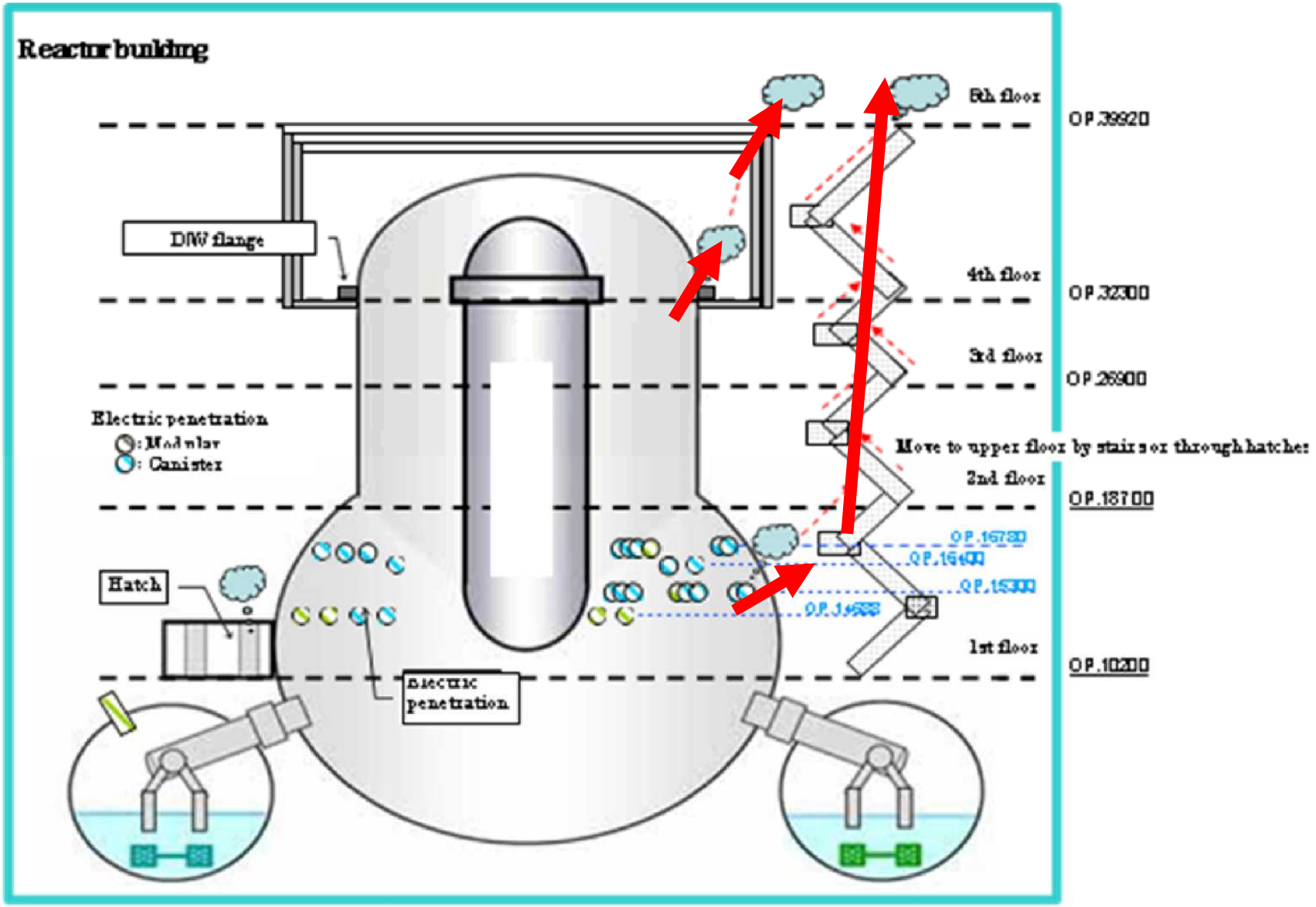
1F4 End State

- Damage following explosion
- Shows all four sides of the building

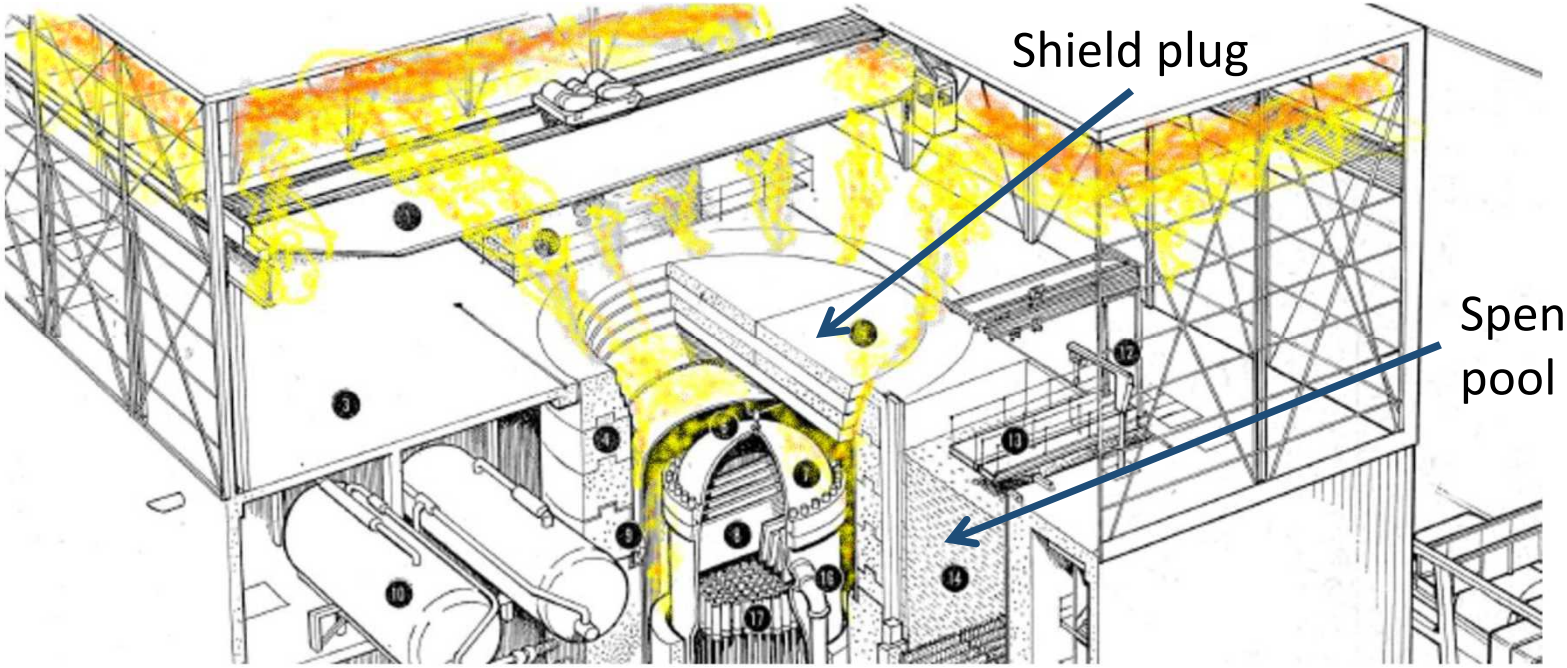
Intact Portion
Damaged Portion
Damage on Outer Surface
Wall Portion not Considered



1F1 Hydrogen Accumulation

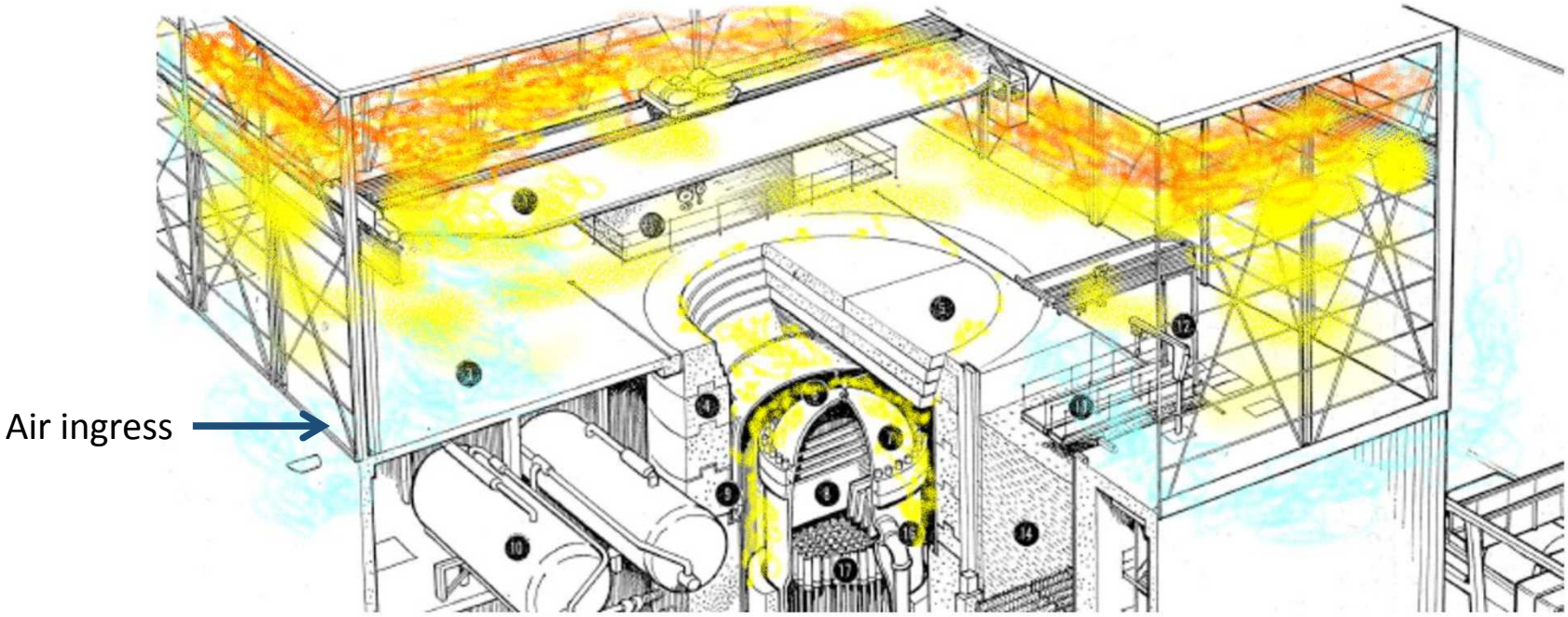


Hydrogen Accumulation in 1F1 – Alternative



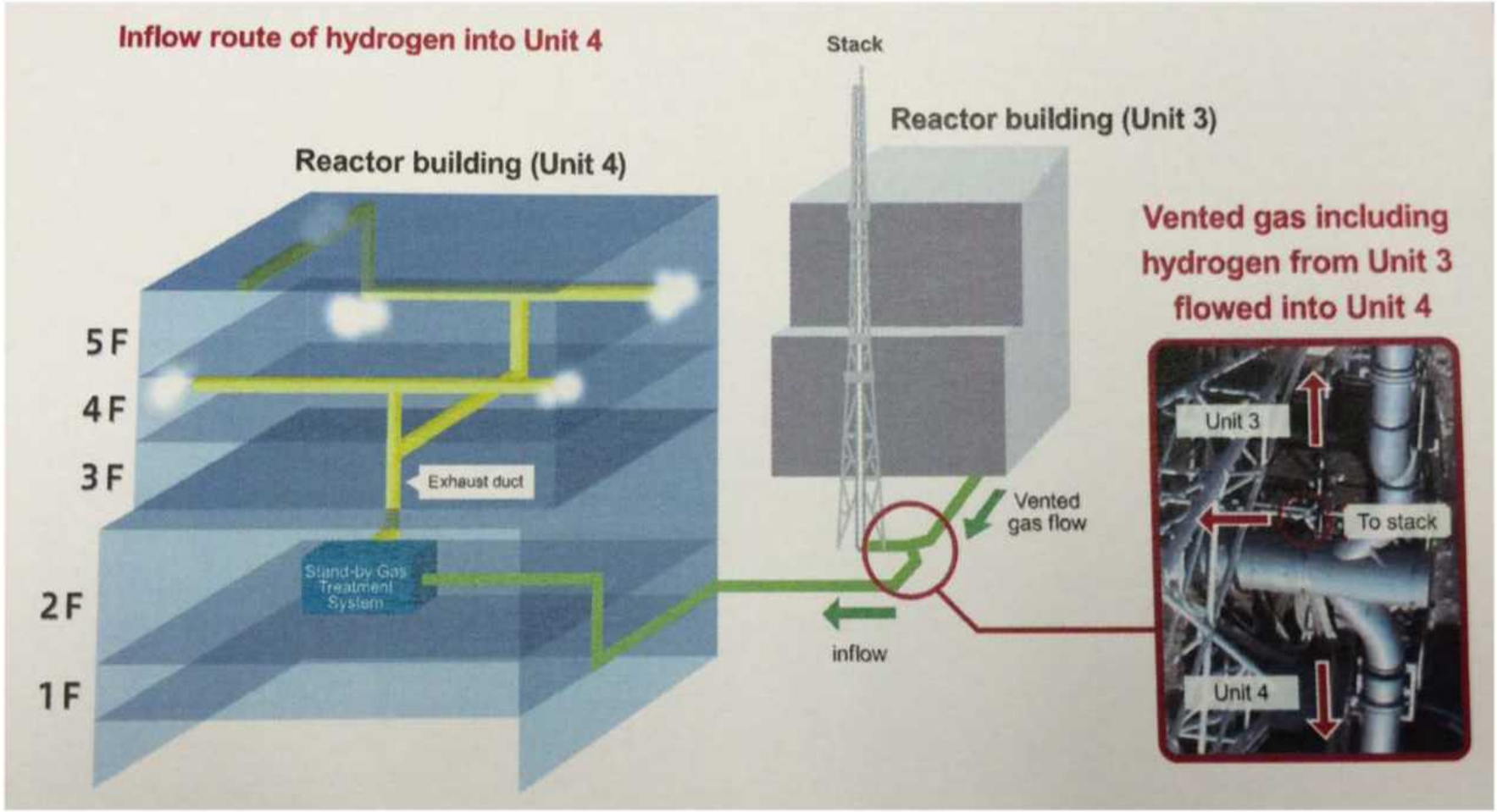
- Between ~12 hours and ~23 hours, steam and hydrogen leaks from drywell head flange and enters RB via shield plug seams
- Hydrogen, CO and steam rises to roof and spreads laterally
- Steam produced in MCCI and from emergency water injection
- Condensation in refueling bay depletes steam in hot layer and enriches hydrogen
- Mixture displaces air from building
- Steam mole fraction exceeds 50% - inert conditions prevent combustion

Combustible Conditions Follow PCV Venting in 1F1 - Alternative

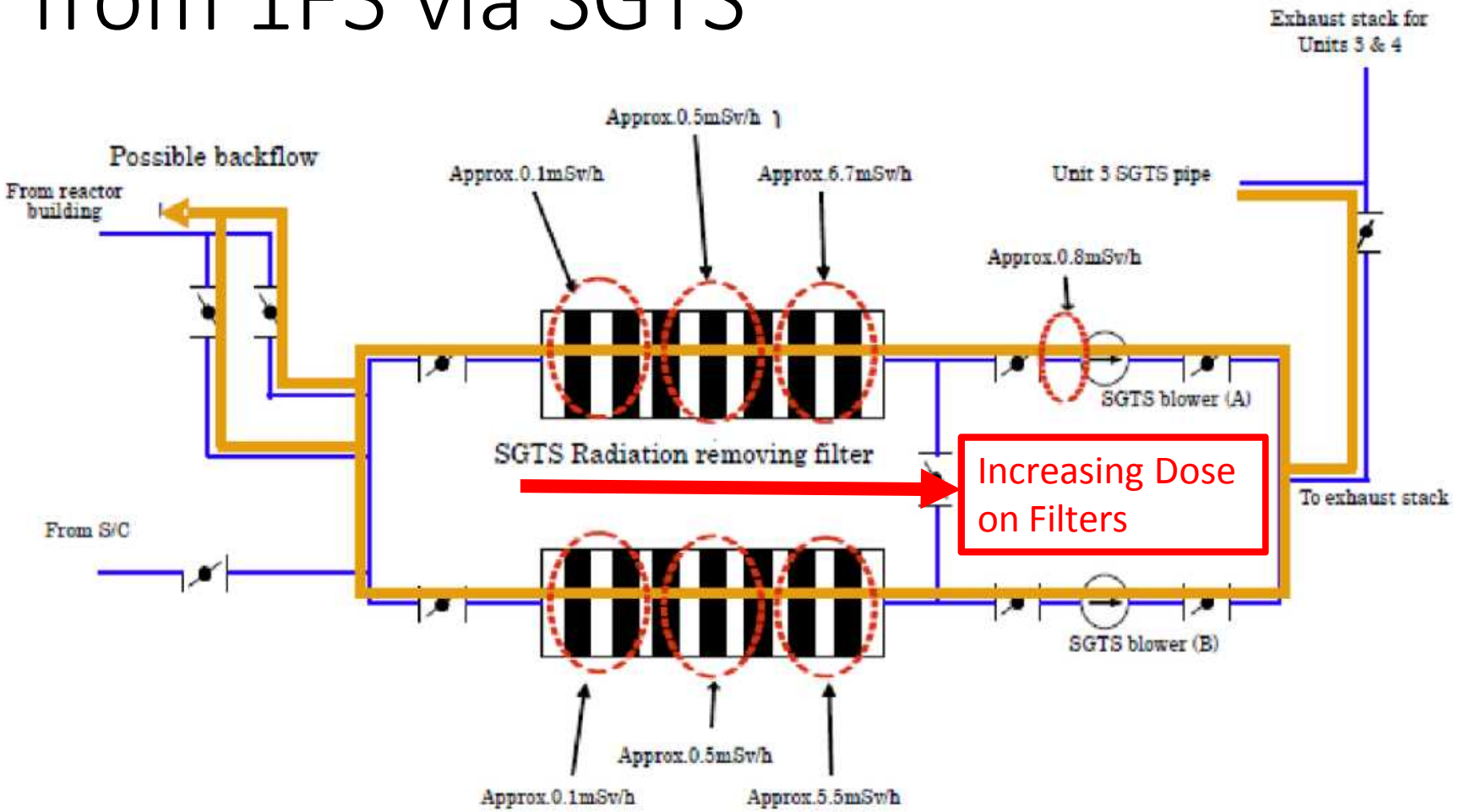


- At around ~23 hours, steam and hydrogen leakage from PCV greatly reduced
  - Water injection was stopped
  - PCV was depressurized by operator venting action
- Continuing condensation without steam source….
  - Reduces steam molar fraction to below 50% in refueling bay, and
  - Produces partial vacuum that draws in outside air
- Air ingress and steam condensation leads to conditions favoring combustion
- Hydrogen stratification produces flammable or detonable concentrations of H_2/O_2

Transfer of H_2 to 1F4 from 1F3 via SGTS



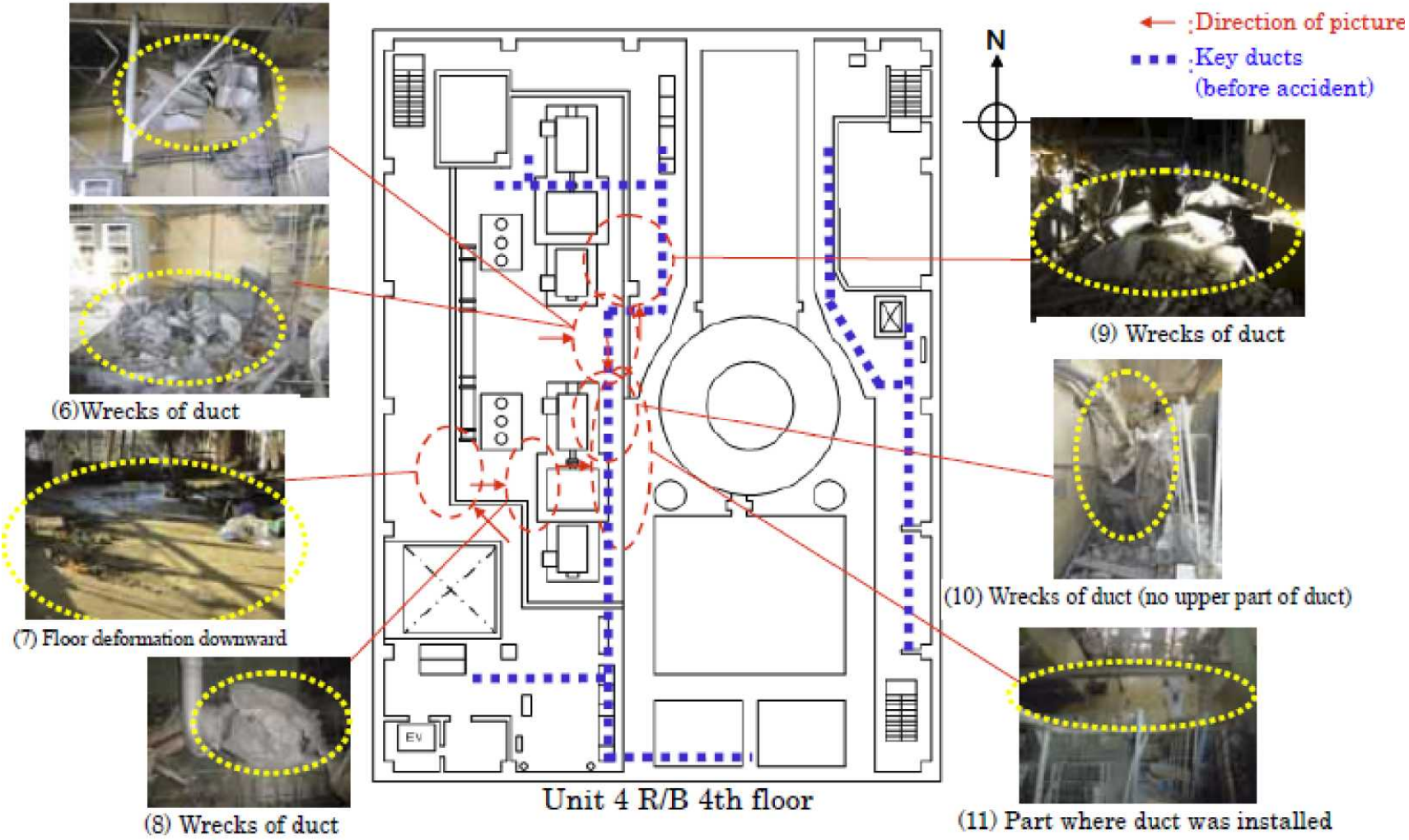
Transfer of H_2 to 1F4 from 1F3 via SGTS



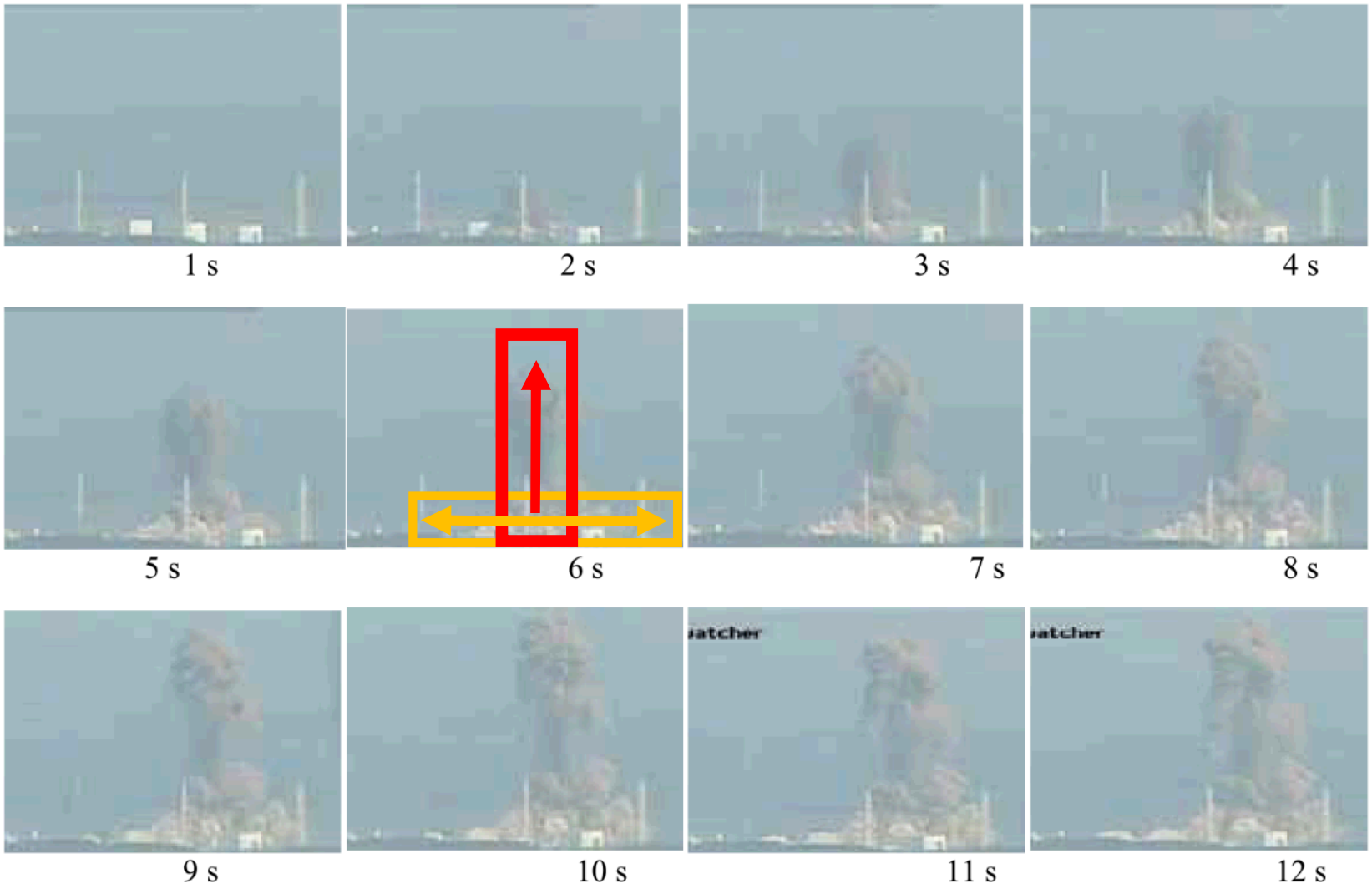
Results of measurement of amount of radiation in Unit 4 SGTS

(conducted on August 25, 2011)

1F4 Field Investigation



Two Separate Explosions at Unit 3



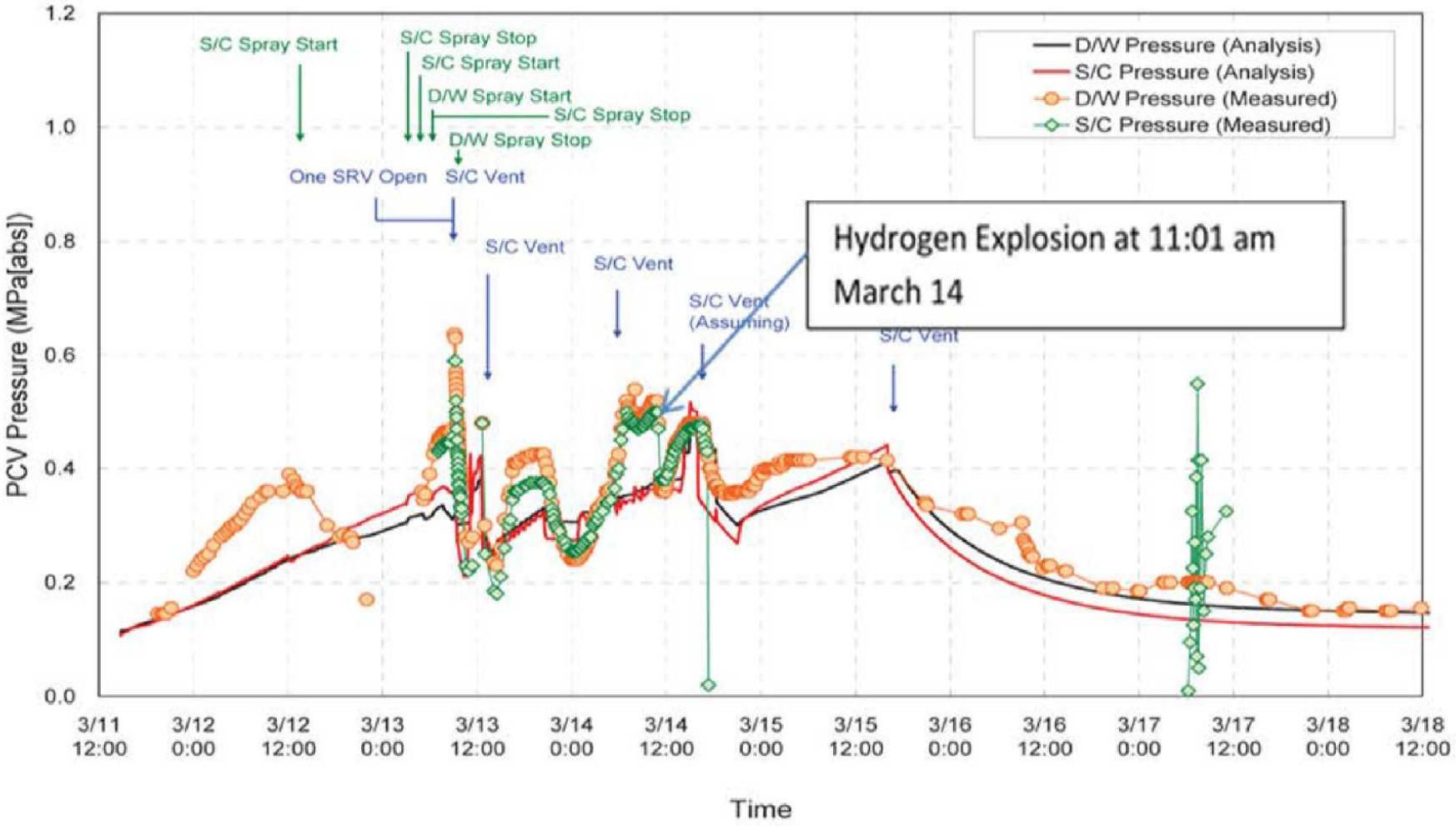
Two Separate Explosions at Unit 3

- There appeared to be at least two explosions
- First:
  - less energetic and directed horizontally (similar to that of 1F1)
  - The color of the explosion “smoke” appears white and orange
- Second:
  - Directed vertically with an almost perfect spherical fireball appearing above the building
  - Shooting up very high into the sky (about 3 times the vent stack height)
  - Large chunks of materials appeared to be carried with the fireball.
- 1F3 images indicate that concrete pillars on the building top floor were highly damaged
- Product gas of the explosion appears to be a darker color, raising questions:
  - Reactor building concrete dust was generated from the explosion?
  - If dust was generated within the drywell due to MCCI?

1F3 Plant Data

Primary containment failure before explosion

- DW head failure
- Bellows failure



Insight Summary

- **The 1F3 explosion was not a stand-alone randomly occurring event.**
  - The 1F3 explosion was most likely initiated by failure of the drywell upper head seal when it was at high PCV pressure of 0.53 MPa.
  - The released hot gas was likely the ignition source and became a source of fuel that supplied to the highly energetic fireball burning at and above the building.
  - The fireball was a dark color (rather than the white color of a water vapor condensation cloud), raising questions, such as whether a significant amount of reactor building concrete dust was generated from the explosion, or whether dust generated from within the drywell was due to MCCI.
- **The damage to the 1F3 building was more extensive compared to damage incurred at 1F1 and 1F4.**
  - To what extent was the damage caused by the energetic explosion as a consequence of drywell head seal failure at high PCV pressure and temperature is a question to be answered.
- **The shared vent stack between 1F3 and 1F4 allowed hydrogen that was vented from 1F3 to enter the 1F4 reactor building.**
  - Radionuclide surveys and examination information confirm that the shared vent stack was the reason for the explosion in the 1F4 reactor building.

Recommendation

- Limited knowledge regarding in-core damage progression can lead to significant differences in code predictions for hydrogen production
  - Differences between code predictions stem from a lack of experimental data that would clarify appropriate modeling assumptions regarding in-core melt progression behavior
  - As a result, the MAAP and MELCOR predict different amounts of in-core hydrogen generation
    - MAAP5 typically predicting lesser amounts of in-core hydrogen generation relative to MELCOR (See xWalk)
- Important consequences for the development of flammable conditions in the 1F1 and 1F3 reactor buildings

Recommendation 6.1:

To address this important knowledge gap in severe accident phenomena, evaluations of combustible gas phenomena should be continued to reduce uncertainties in MAAP and MELCOR predictions.

References – Taken from Report

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