SAND2020-10209C

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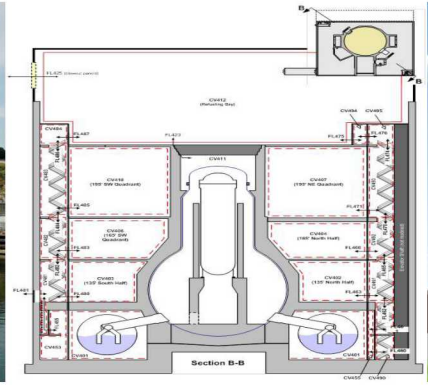

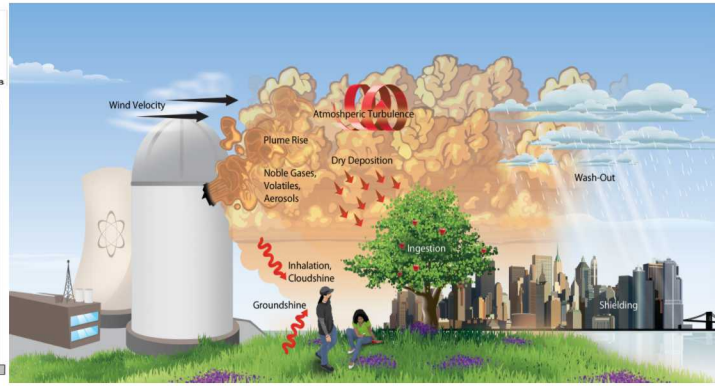

Benchmark Study of the Accident at Fukushima (BSAF) Overview

R.O. Gauntt

Severe Accident Analysis Department, Sandia National Laboratories

CSARP/MCAP Meeting, Bethesda MD

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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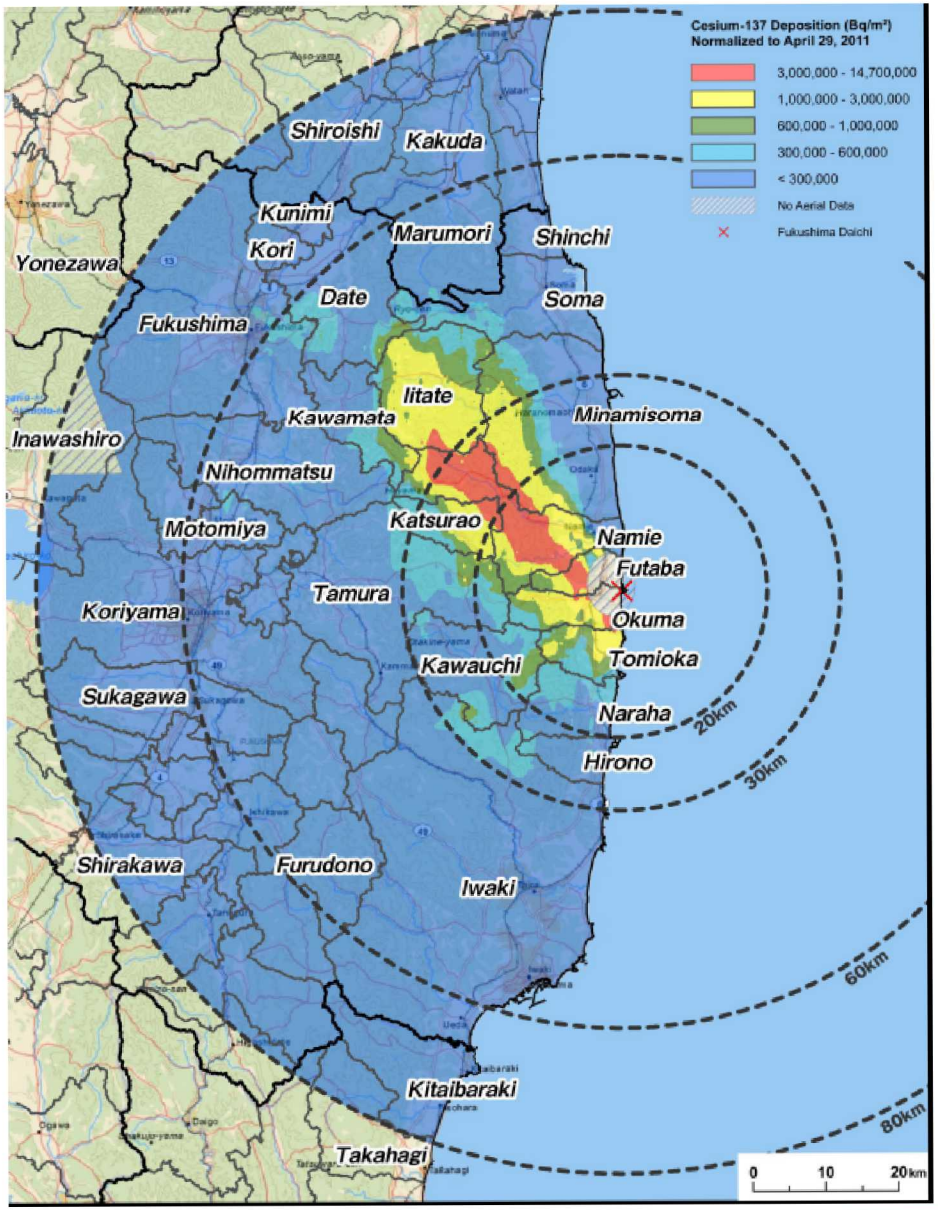
WHAT STARTED IT ALL


Naoto Kan
Japanese prime minister
guardian.co.uk

Perspectives……

- ~20,000 dead or missing from the tsunami
- 2 industrial deaths at Fukushima Nuclear power plant
- No radiation induced fatalities
- 150,000 people displaced from homes
- All 50 nuclear power plants in Japan shut down
- What happened?



BSAF Phase 1

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- OECD/NEA activity hosted by Japan Institute of Applied Energy
- Benchmark Study of the Accidents at Fukushima
- Partly severe accident code benchmarking
- Partly forensics study into causes and progression of accident building on clues (sparse measurements and ill defined boundary conditions)
- Major severe accident competent nations
  - USA, Japan, Spain, Switzerland, Germany, Finland, Russia ….
  - MELCOR, MAAP, ASTEC, SAMPSON, SOCRAT
- Focus on reactor and containment damage during first days of accidents

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Photos placed in horizontal position with even amount of white space between photos and header

The Accidents

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Earthquake Led to Loss of Offsite Power

- Seismic events disrupted roads and power lines
- Regional blackout isolated Fukushima station from power grid
- Reactors shut down
- Site operated by onsite diesel generators

Circuit Breaker damaged

Collapsed tower


Date : 2011/3/11 15:42


Date : 2011/3/11 15:43


Date : 2011/3/11 15:44


Date : 2011/3/11 15:57

Daiichi Site was Inundated by Tsunami

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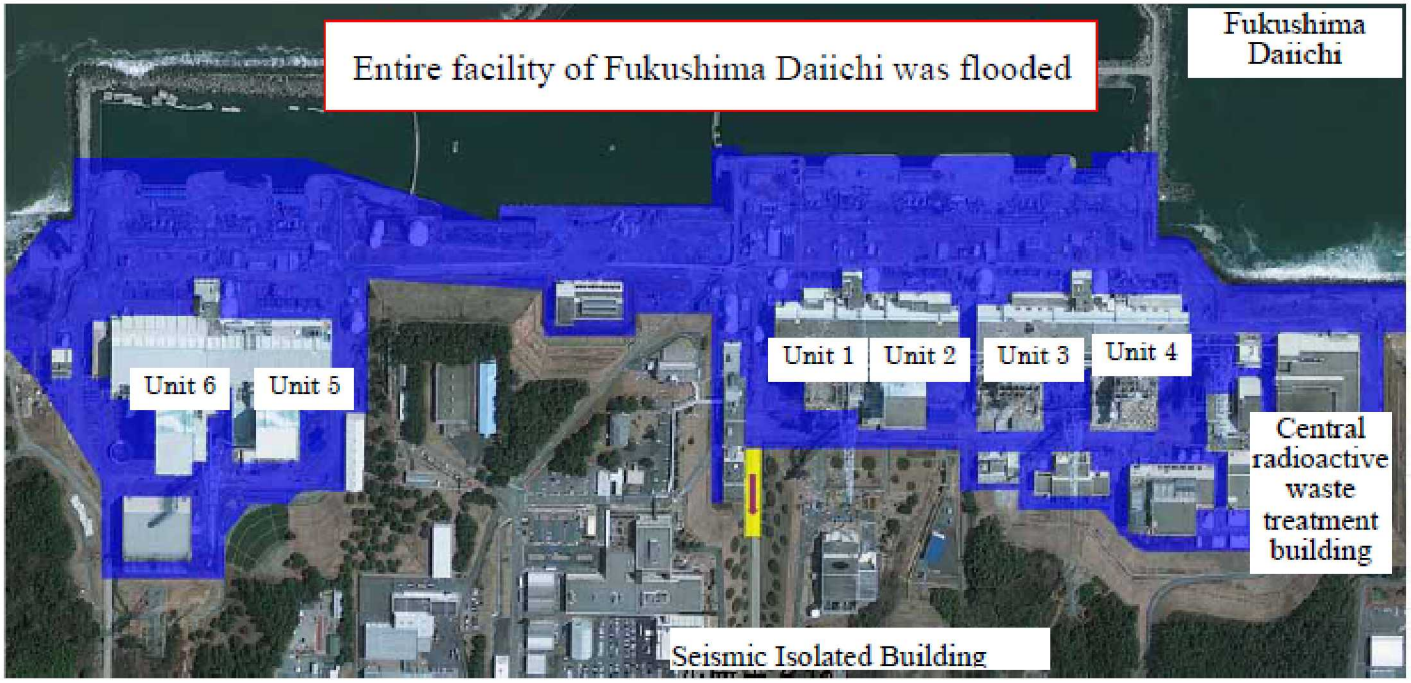

- Site flooding initiated “Station Blackout”
- Unit 1 and Unit 2 lost DC batteries
- Unit 2 maintained uncontrolled “Emergency Core Cooling System”
- Unit 3 retained some DC power and controlled ECCS
- ***All reactors isolated from ultimate heat sink (Ocean)***

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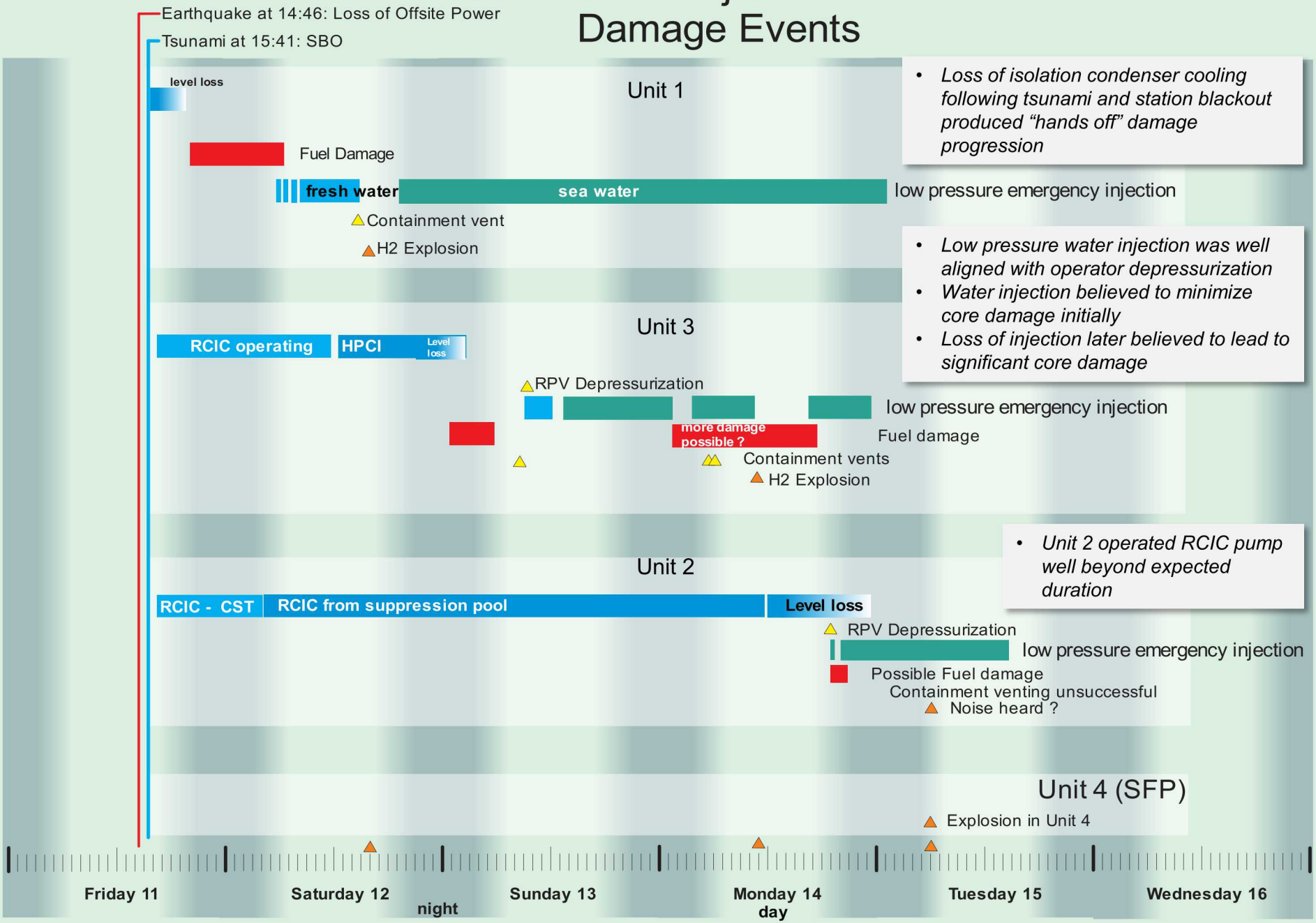
Timeline of Major Fukushima Damage Events

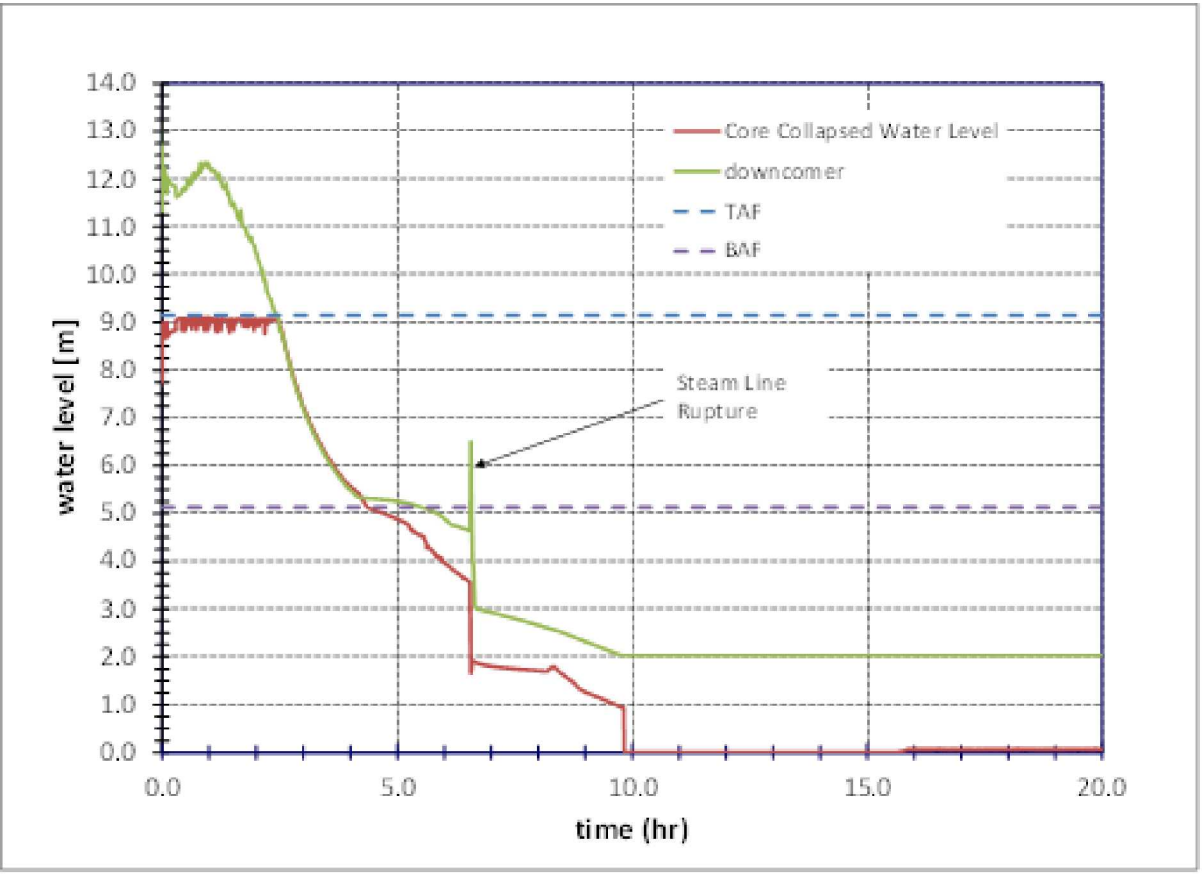


- *Loss of isolation condenser cooling following tsunami and station blackout produced "hands off" damage progression*

- *Low pressure water injection was well aligned with operator depressurization*
- *Water injection believed to minimize core damage initially*
- *Loss of injection later believed to lead to significant core damage*

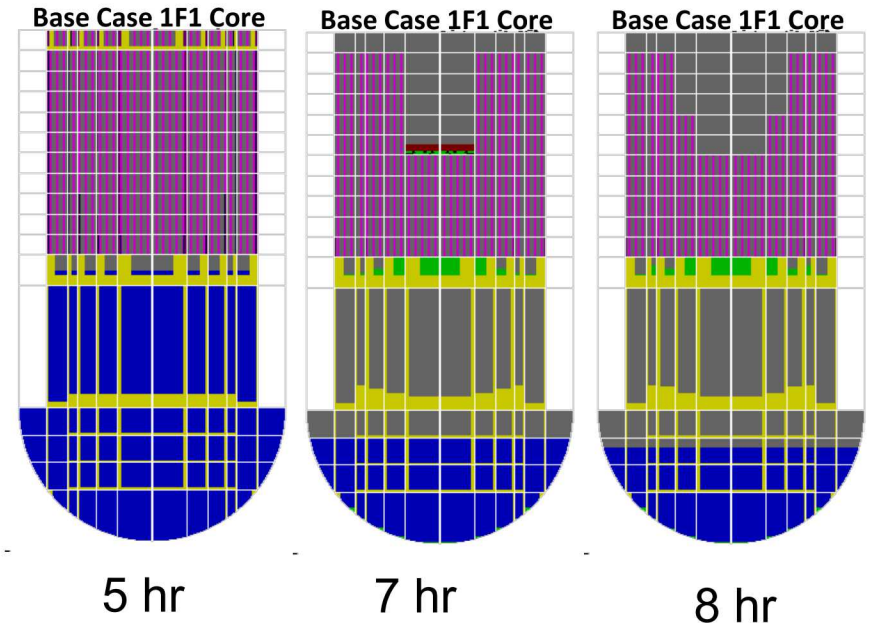
- *Unit 2 operated RCIC pump well beyond expected duration*

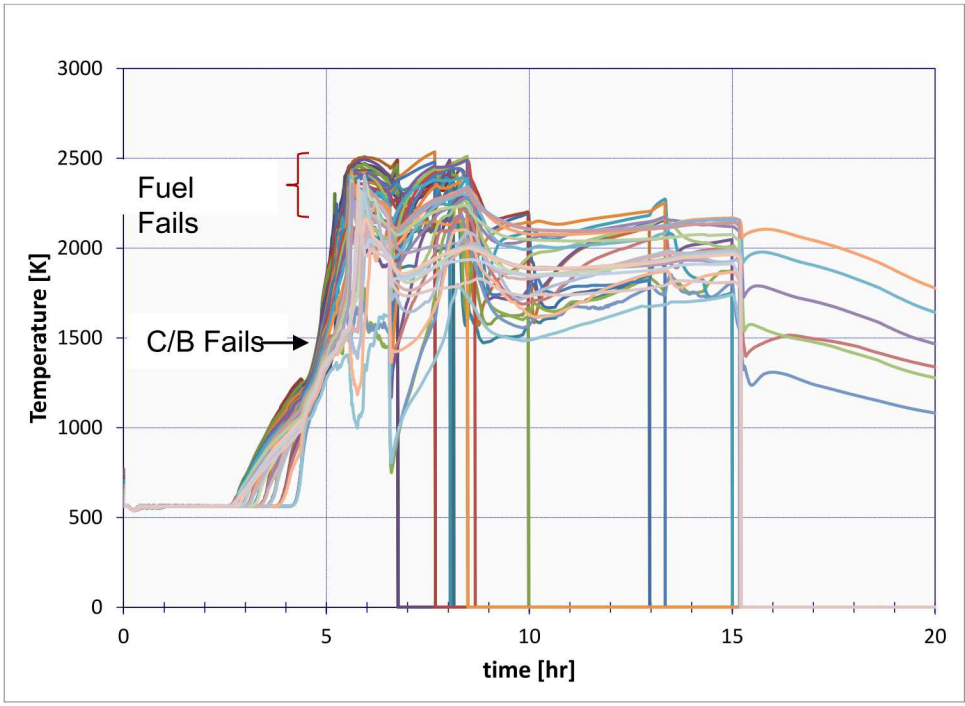
Vessel Water Boil-Down in Unit-1



- MELCOR Code predictions
  - Fuel uncovered at 3 hr
  - Core damage and H_2 generation by 4 hr
  - Steam line rupture at 6.5 hr
  - Reactor Vessel dry at 10 hr
  - Reactor Vessel melt-through between 12 and 14 hr

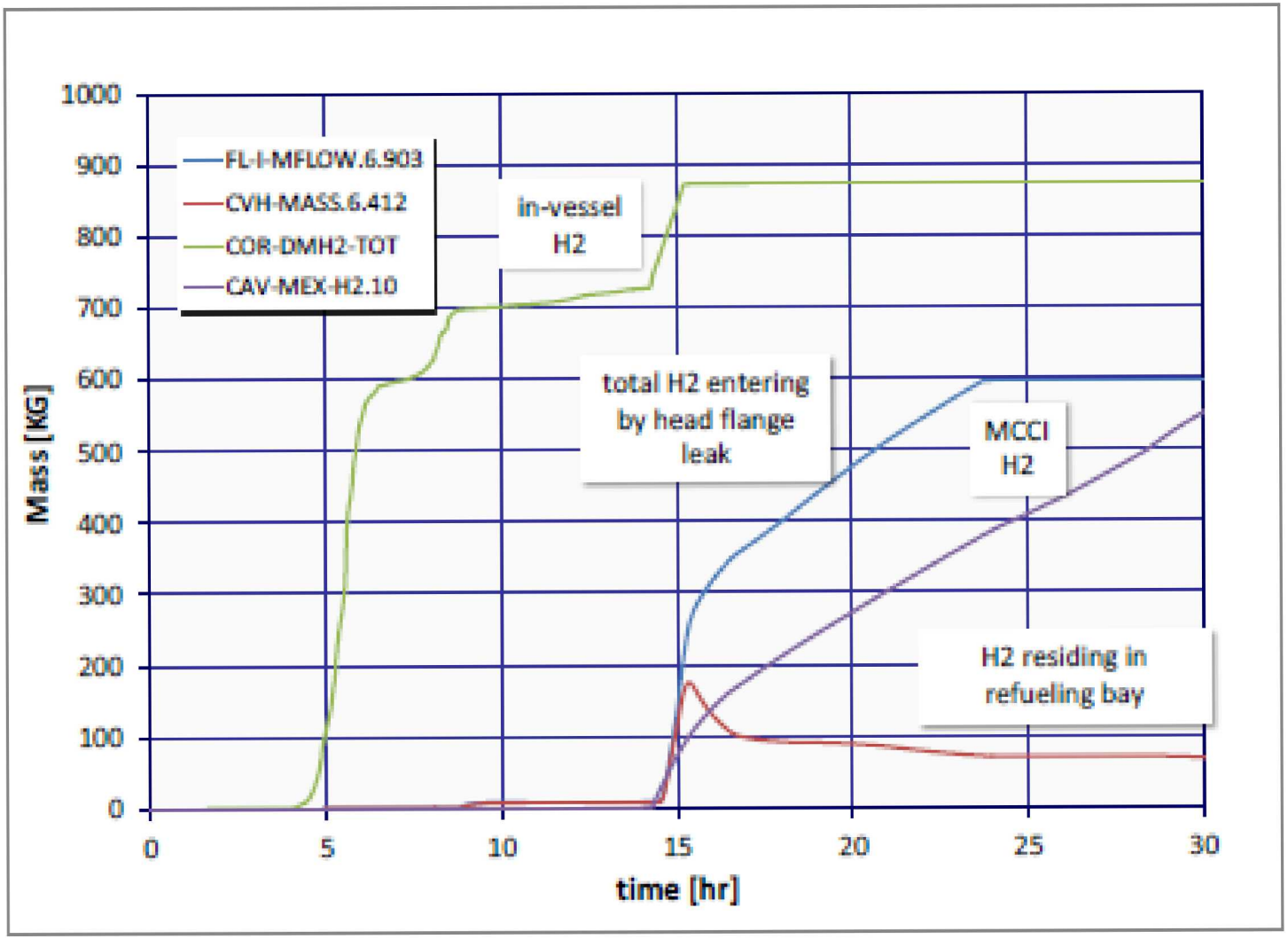
Predicted Degradation of Reactor Core



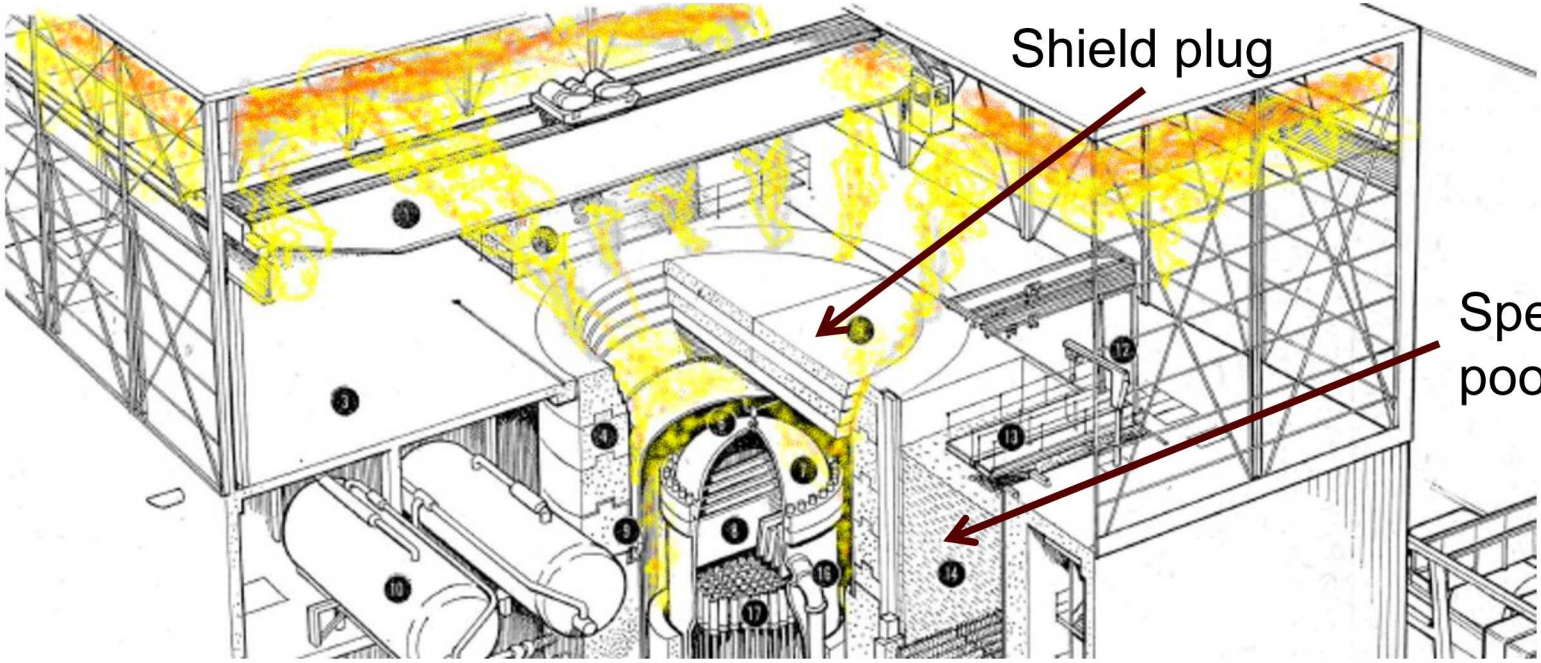


- Core damage starts at ~ 4 hours – Control Blade fails first
- Progressive fuel melting after 6 hours
- Core exit gas temperatures very high

Hydrogen in 1F1



Hydrogen Accumulation in 1F1



- 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

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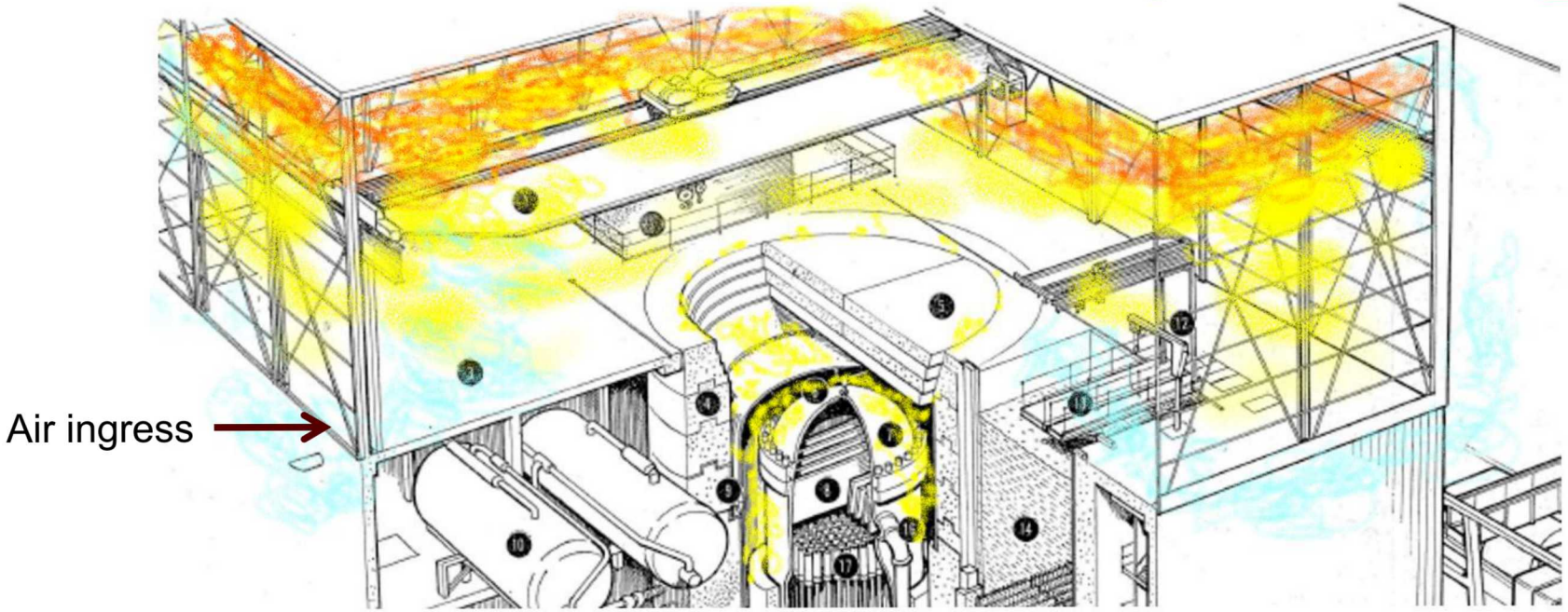

- At around ~23 hours, steam and hydrogen leakage from PCV greatly reduced
  - Water injection was stopped
  - PCV was depressurized by operator venting action
- Continuing condensation without steam source….
  - Reduces steam molar fraction to below 50% in refueling bay, and
  - Produces partial vacuum 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

Unit 1 Hydrogen Explosion

Unit 3 Hydrogen Explosion

Hydrogen Explosions

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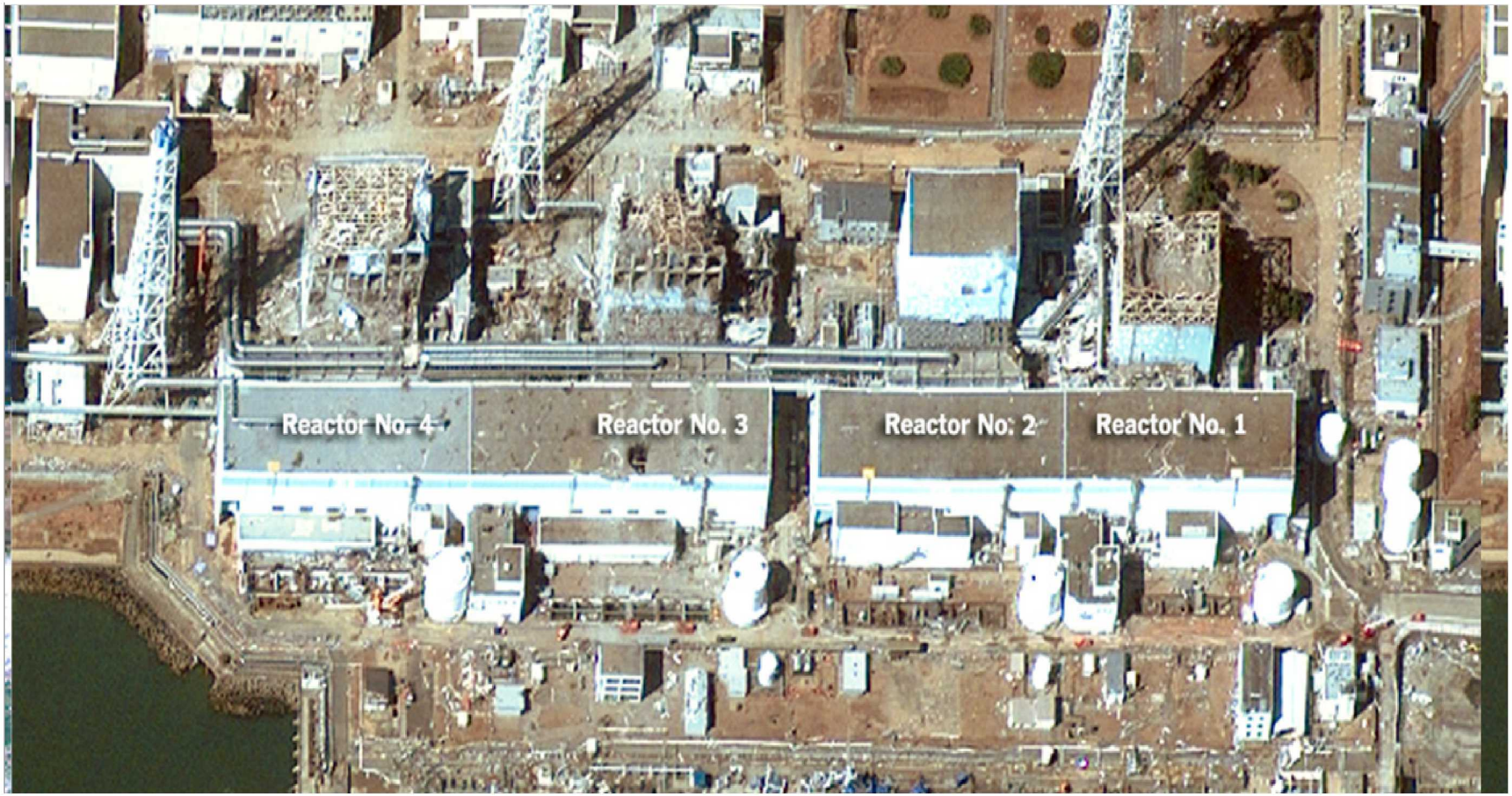

Containment Over-pressurization Led to Release of H2 into Buildings

BSAF

Summary BSAF Phase I report (published by NEA – Feb. 2016)

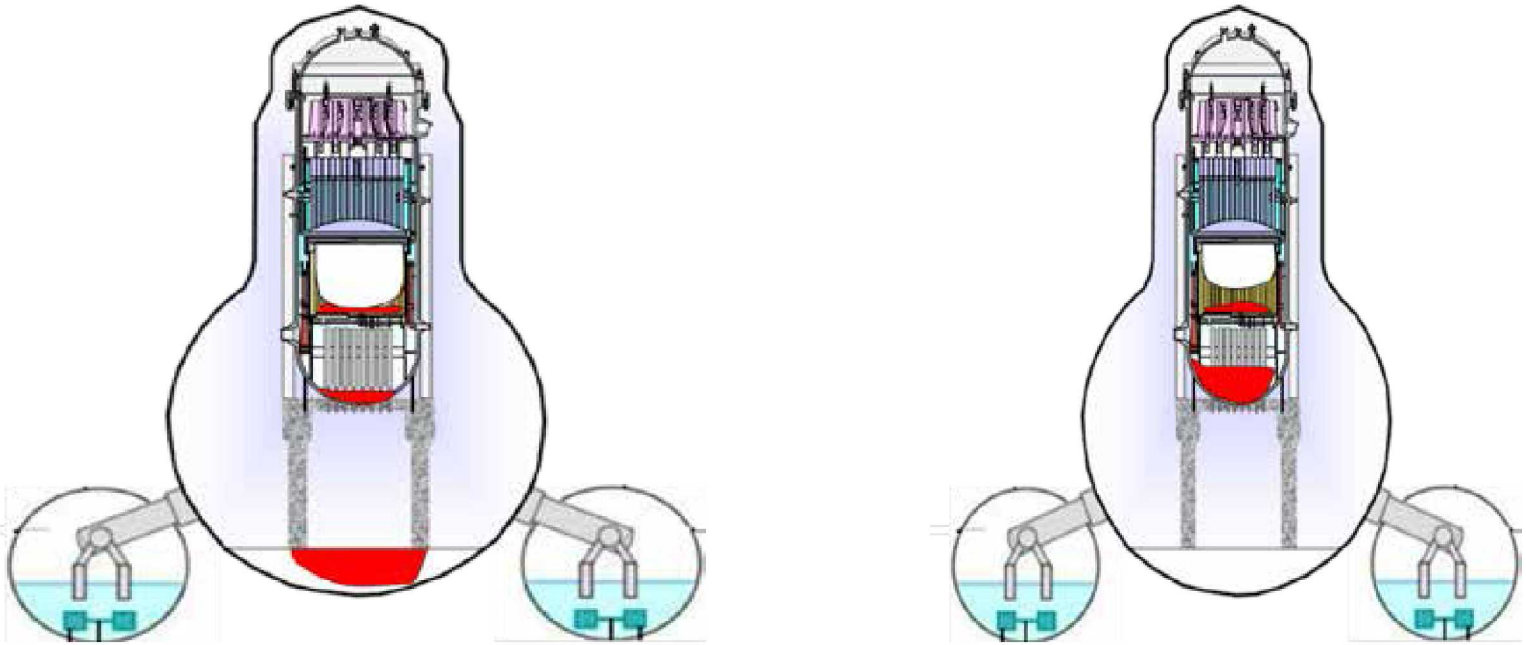

Figure 1: Qualitative description of the plausible status after comparison of the best estimate case analyses; a) Unit 1 RPV failure, b) Unit 2 no RPV failure.

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BSAF

Summary BSAF Phase I report (published by NEA – March 2016)

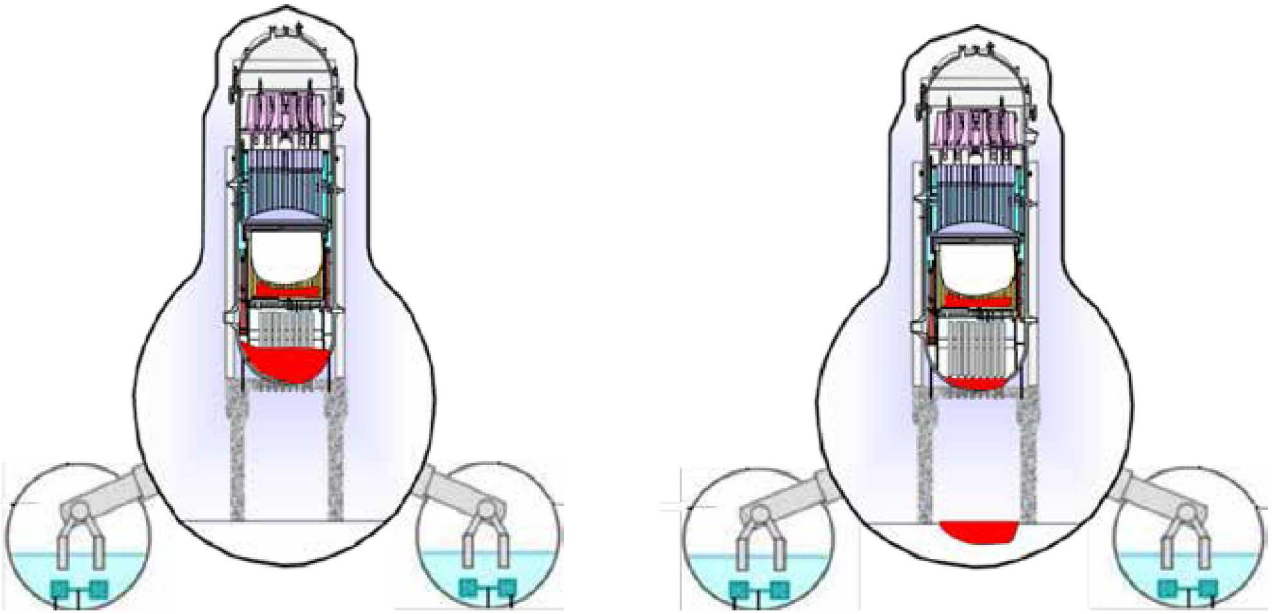

Figure 2. Unit 3: Qualitative description of the plausible status after comparison of the best estimate case analyses; a): no RPV failure, b): RPV failure and limited Melt-Concrete Interaction

BSAF Phase 2

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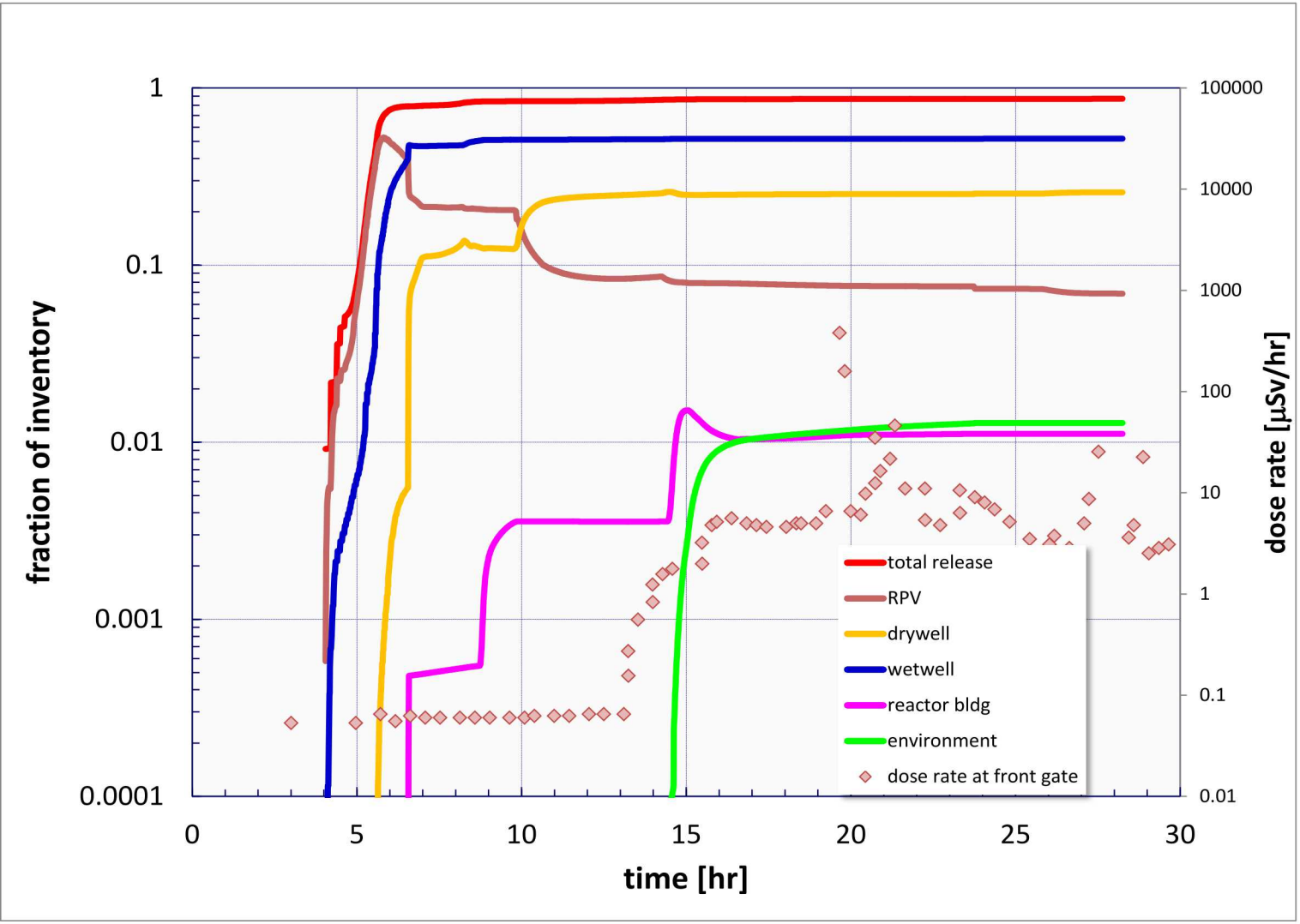
- Phase 2 focus is on fission product release
  - Airborne release to atmosphere
  - Aqueous release to groundwater
- Time duration is from initiation to 21 days
- Reactor damage
- Core concrete interactions
- Atmospheric transport
- Characterization of depositions in containment, reactor building and water-filled rooms

Estimated Cs Release from Unit 1

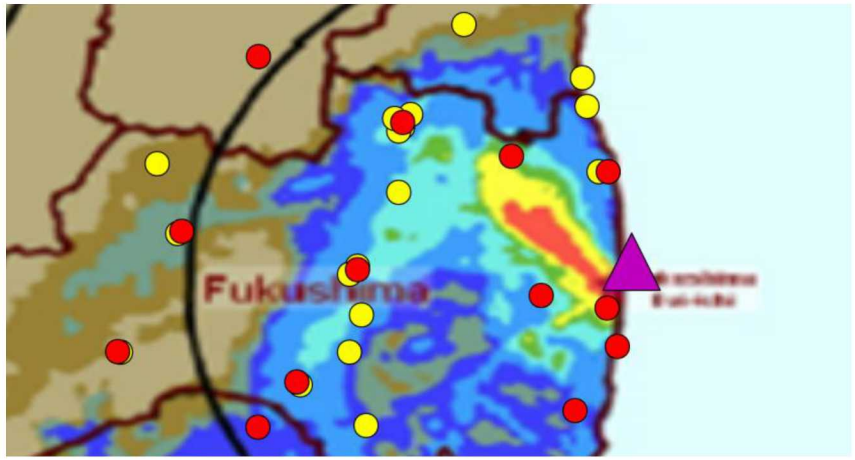


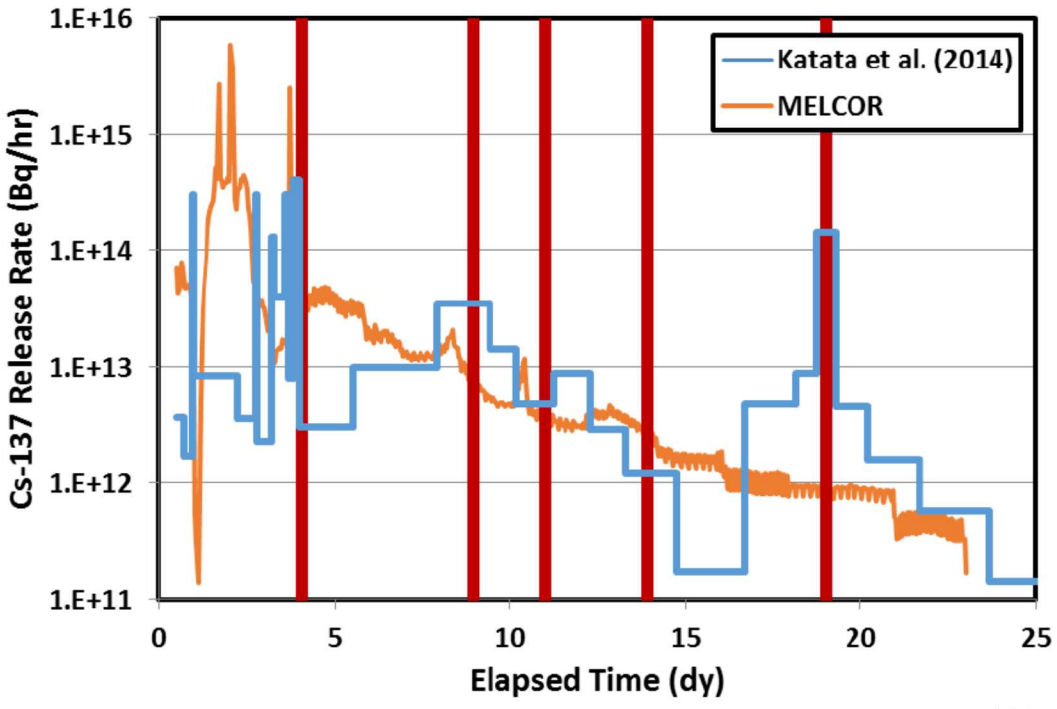
Radiation monitors at front gate jump at ~13 hr

Cs Env release estimated at about 400,000 Ci

Extending Calculations – Why 3 Weeks?

- Significant releases well past initial BSAF Phase I simulations
  - Phase I extended to 6 days
- Large predicted Unit 2 releases to the NW after day 9
- Key times when wind blows to NW (vertical redlines on plot)
  - 98 hours (4.1 dy), March 15
  - 215 hours (9 dy), March 20
  - 264 hours (11 dy), March 22
  - 334 hours (13.9 dy), March 24
  - 456 hours (19 dy), March 30

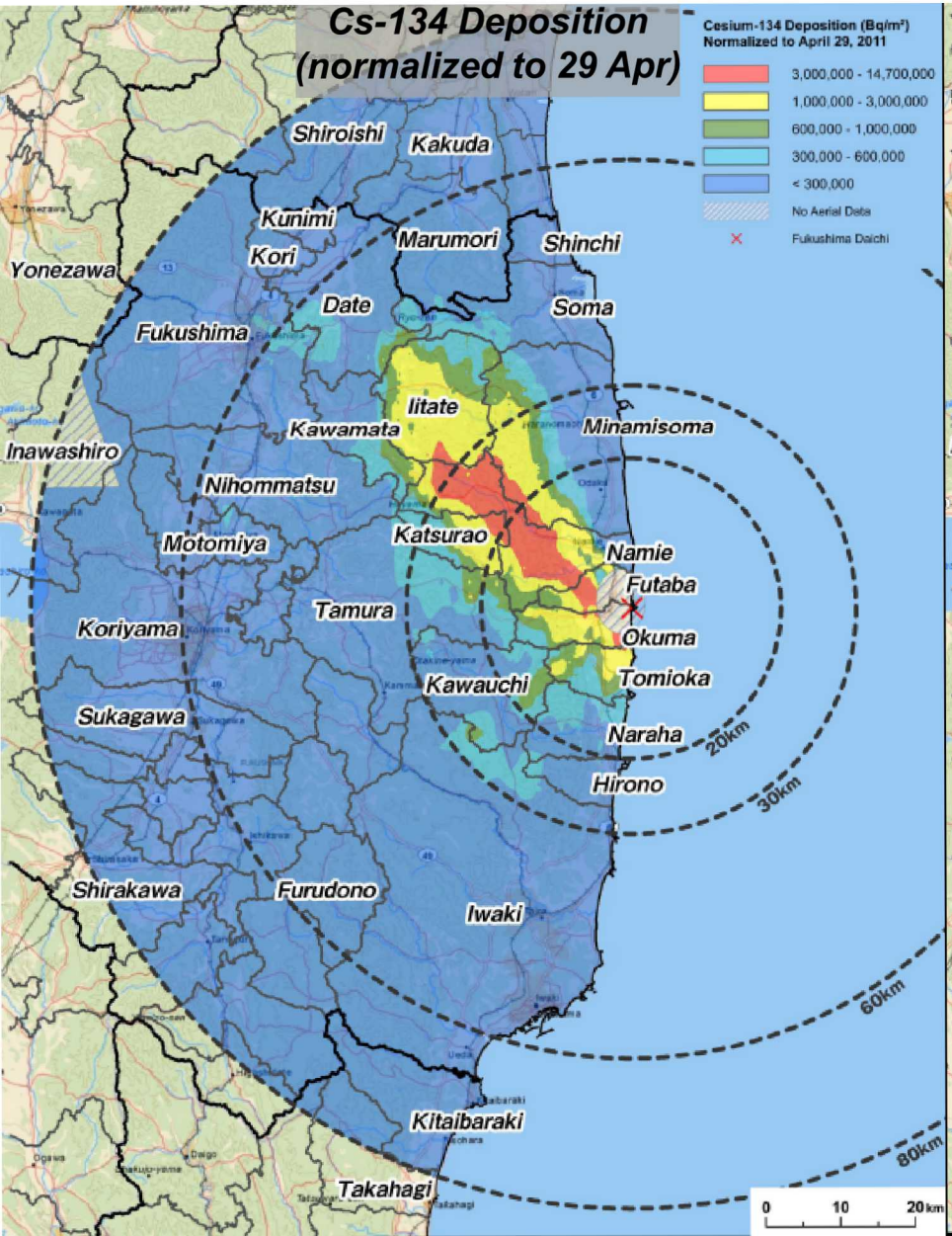


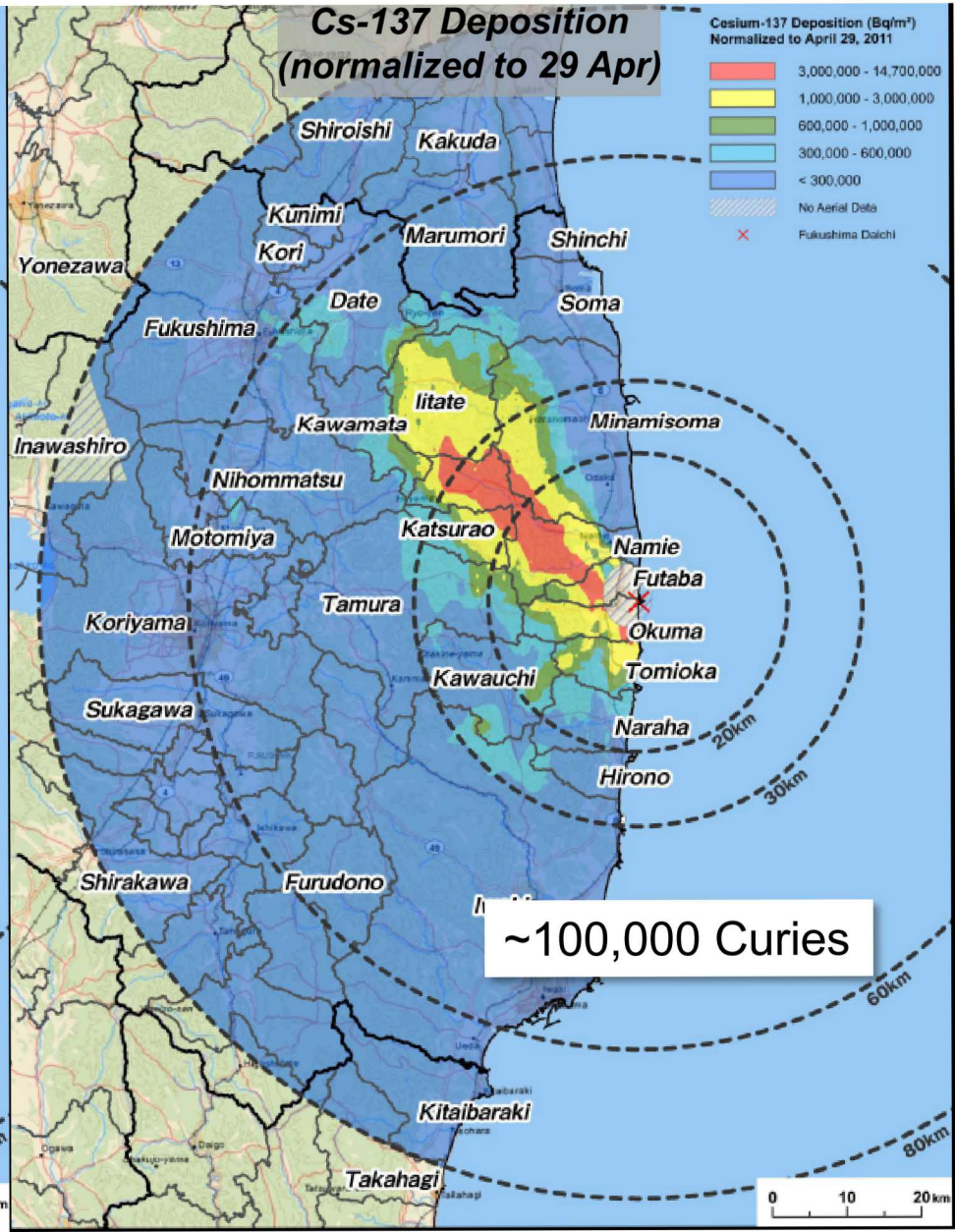


Aerial Measuring Results
Joint US/Japan Survey Data

National Nuclear Security Administration

FUKUSHIMA DAIICHI
JAPAN





Phase 2 BSAF

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- Work to continue through 2018
- Final report at end of project
- Real world validation of severe accident codes MELCOR ans MACCS