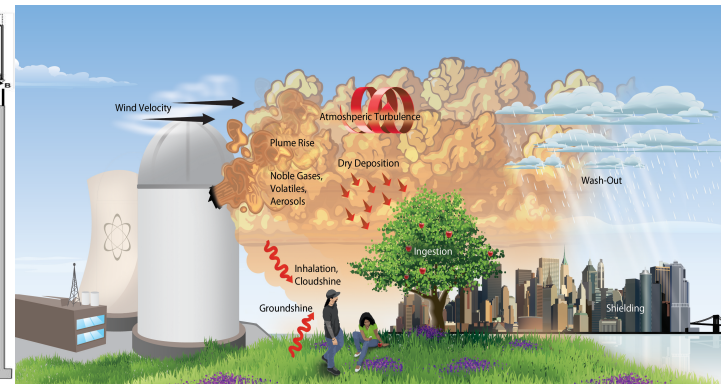
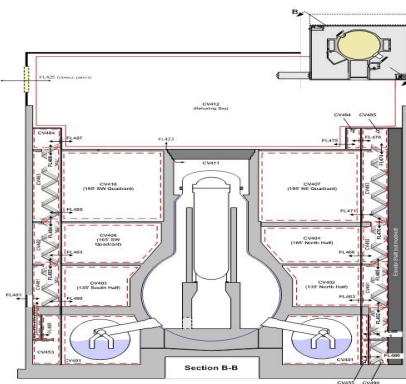


Exceptional service in the national interest



Benchmark Study of the Accident at Fukushima (BSAF) Overview

R.O. Gauntt

Severe Accident Analysis Department, Sandia National Laboratories

CSARP/MCAP Meeting, Bethesda MD



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WHAT STARTED IT ALL

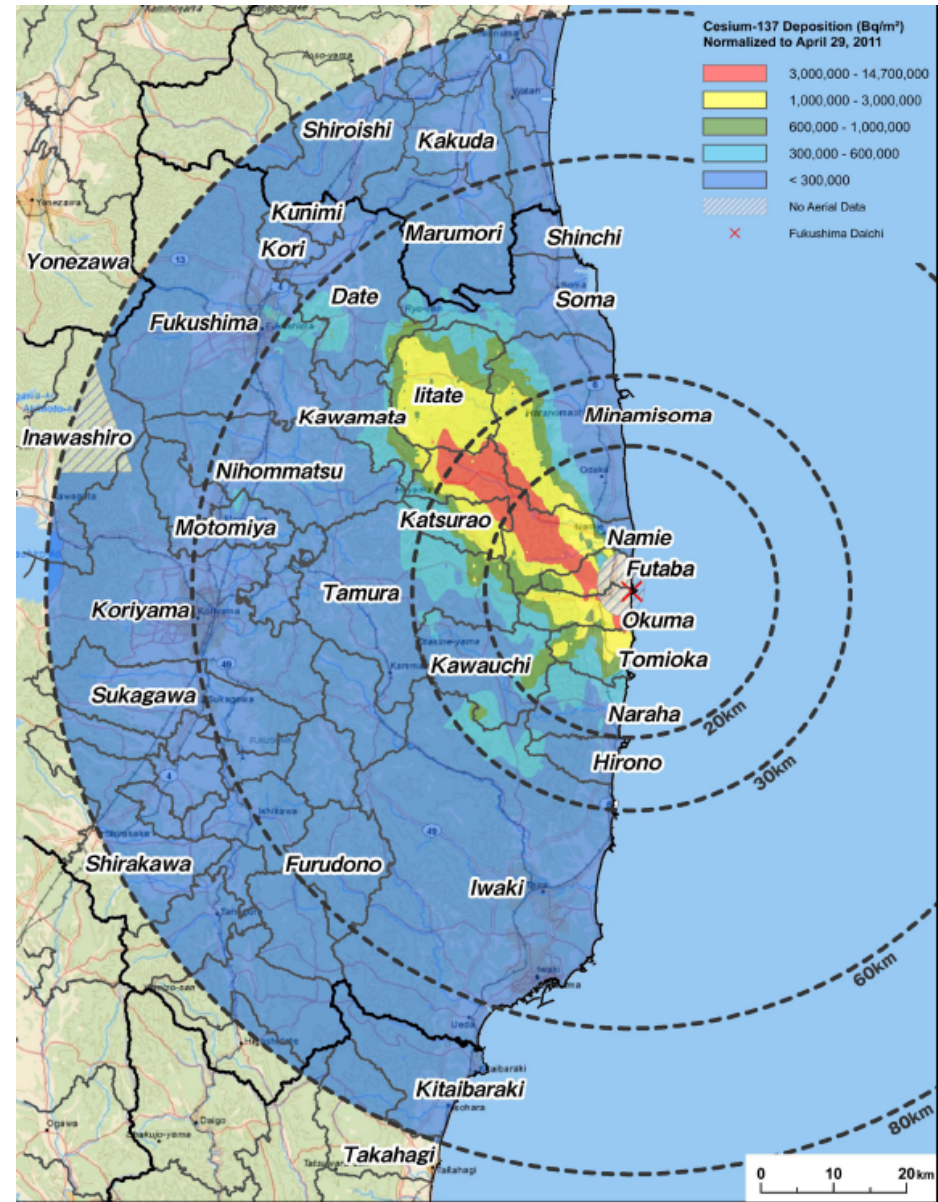


Naoto Kan
Japanese prime minister

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

- 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

Exceptional service in the national interest



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

The Accidents



U.S. DEPARTMENT OF
ENERGY



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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

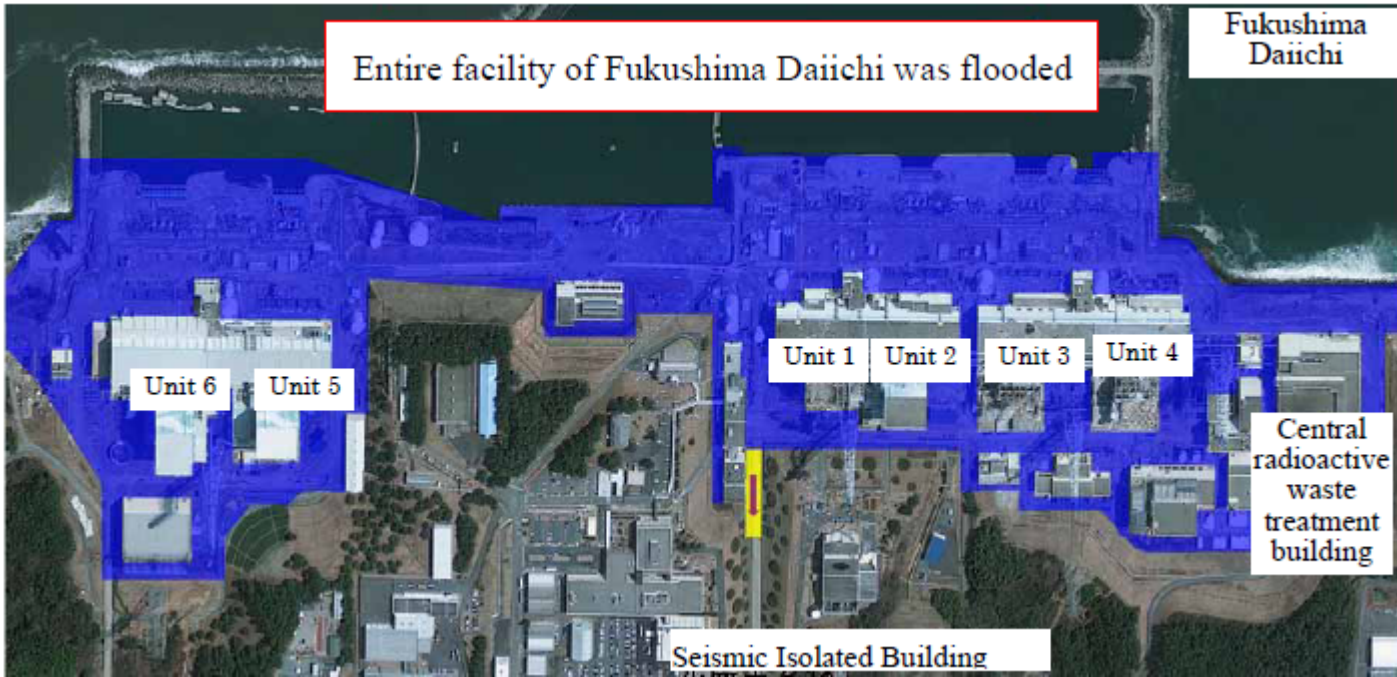


Collapsed tower





Daiichi Site was Inundated by Tsunami



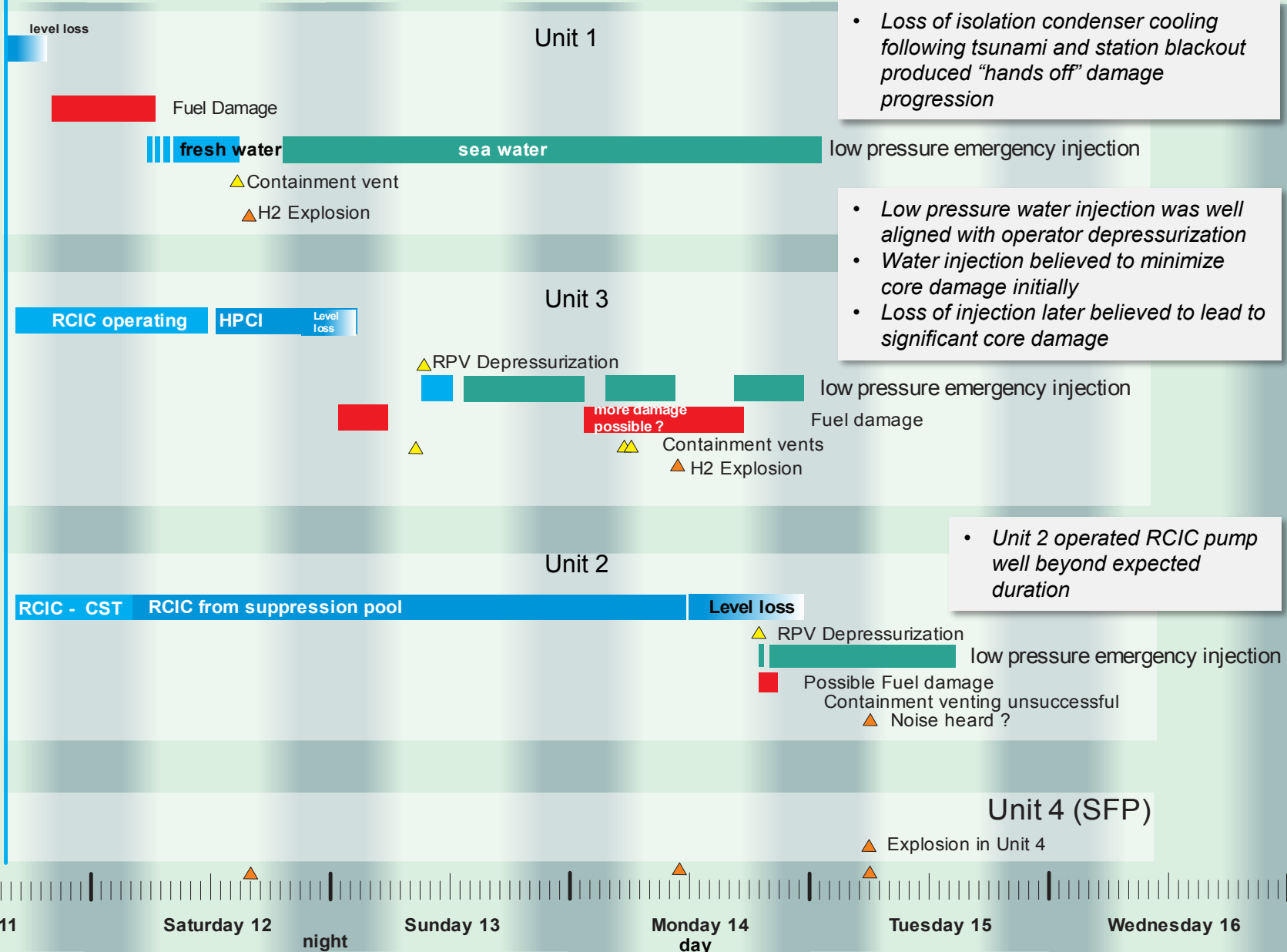
- Site flooding initiated “Station Blackout”
- Unit 1 and Unit 2 lost DC batteries
- Unit 2 maintained uncontrolled “Emergency Core Cooling System”
- Unit 3 retained some DC power and controlled ECCS
- ***All reactors isolated from ultimate heat sink (Ocean)***

Used by permission from TEPCO

Timeline of Major Fukushima Damage Events

Earthquake at 14:46: Loss of Offsite Power

Tsunami at 15:41: SBO

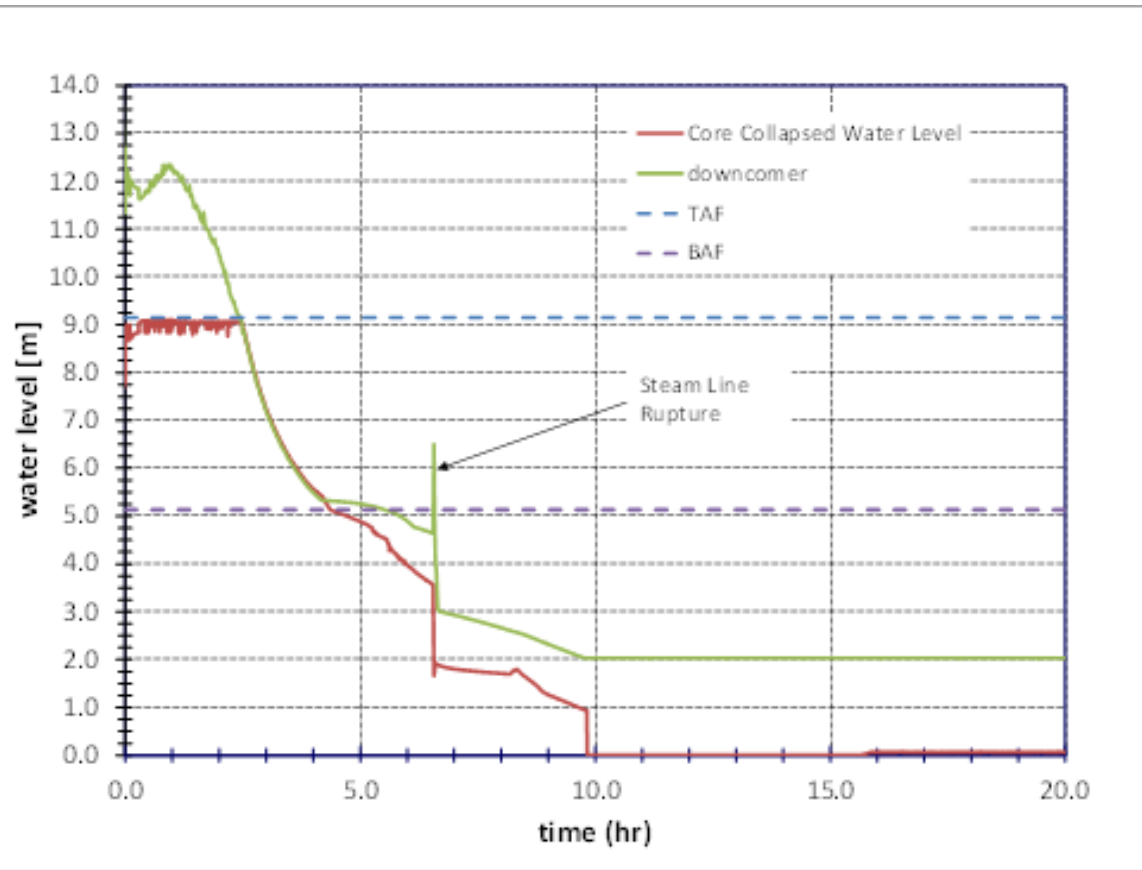


- Loss of isolation condenser cooling following tsunami and station blackout produced "hands off" damage progression

- 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

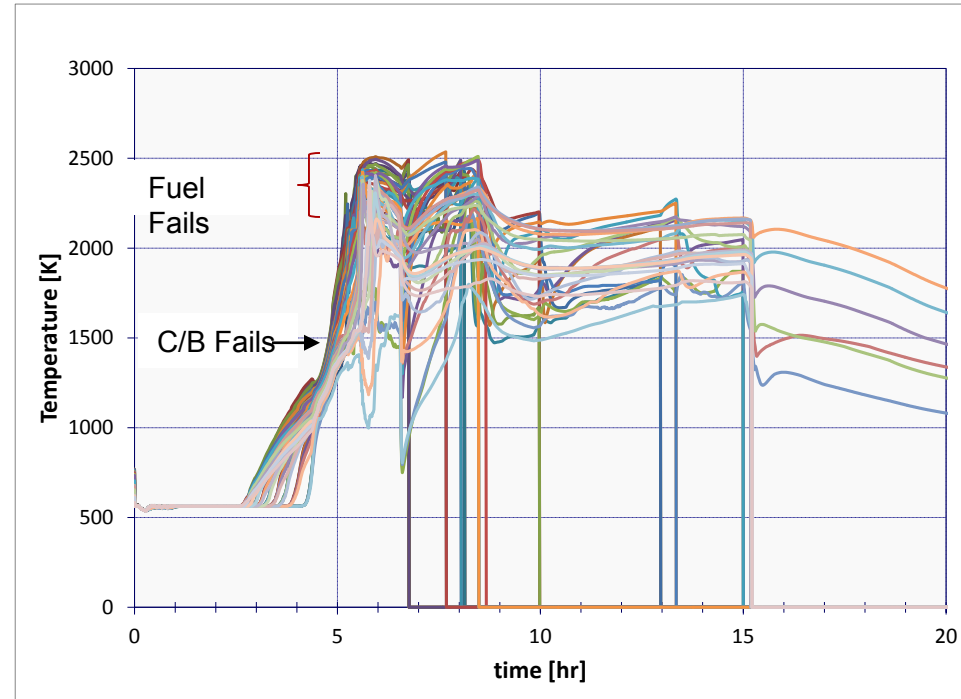
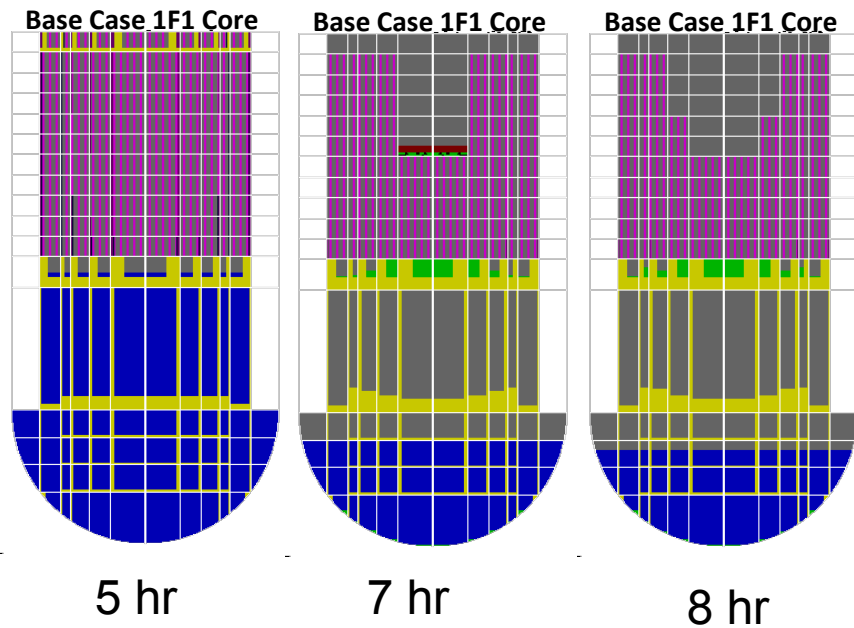
Vessel Water Boil-Down in Unit-1



■ MELCOR Code predictions

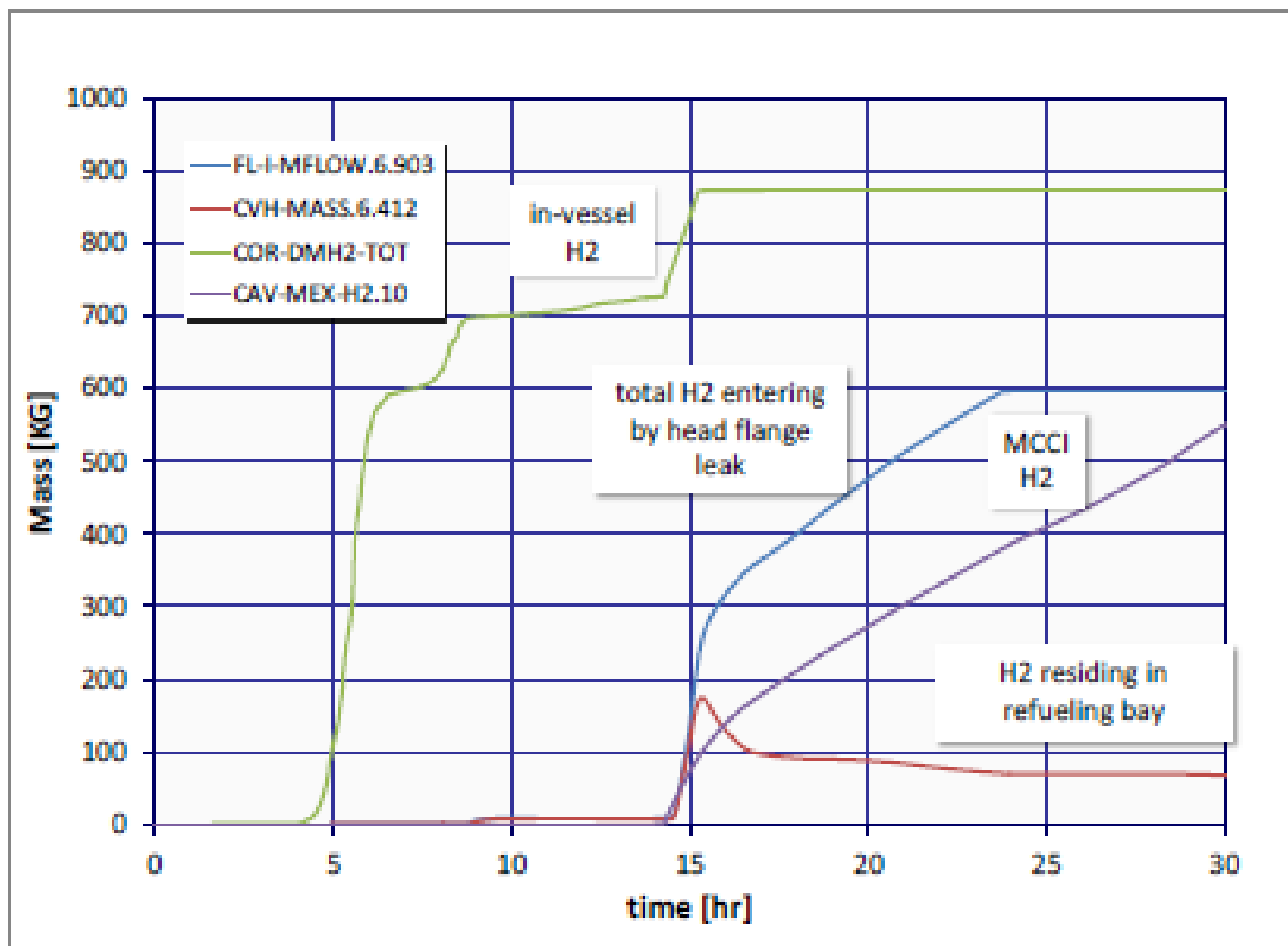
- Fuel uncovered at 3 hr
- Core damage and H_2 generation by 4 hr
- Steam line rupture at 6.5 hr
- Reactor Vessel dry at 10 hr
- Reactor Vessel melt-through between 12 and 14 hr

Predicted Degradation of Reactor Core

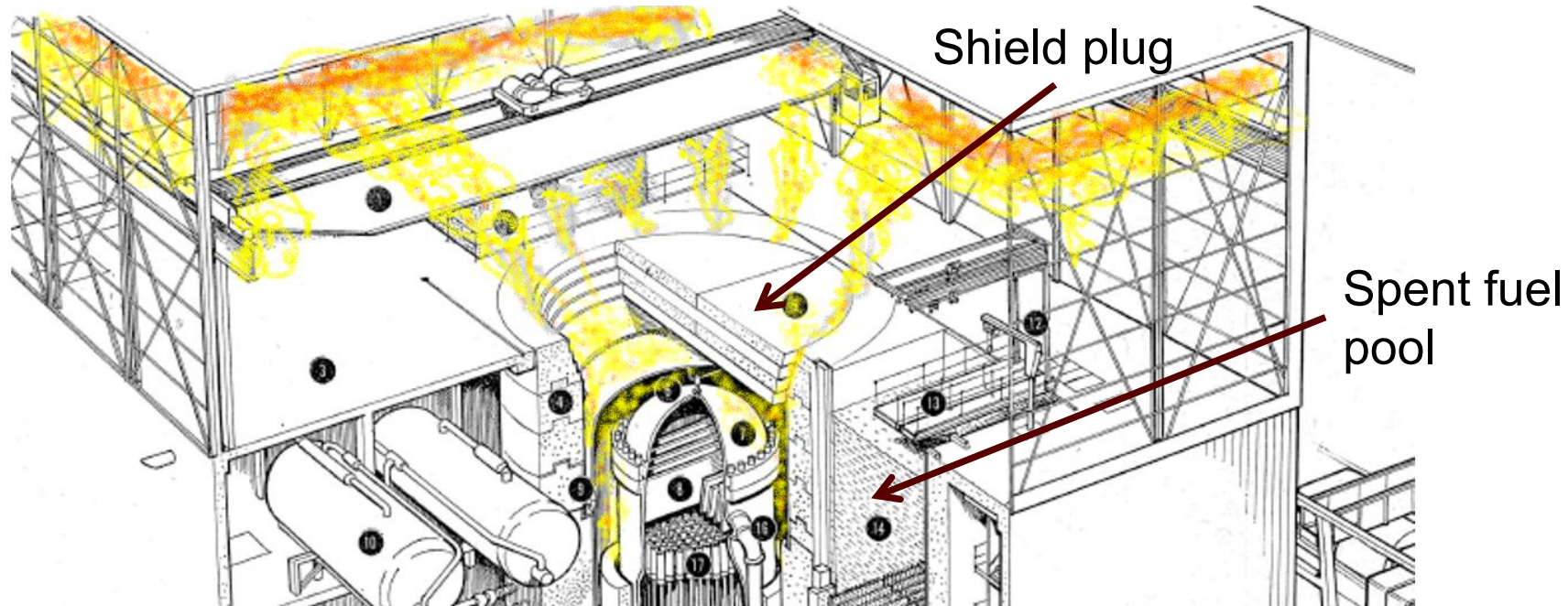


- Core damage starts at ~ 4 hours – Control Blade fails first
- Progressive fuel melting after 6 hours
- Core exit gas temperatures very high

Hydrogen in 1F1

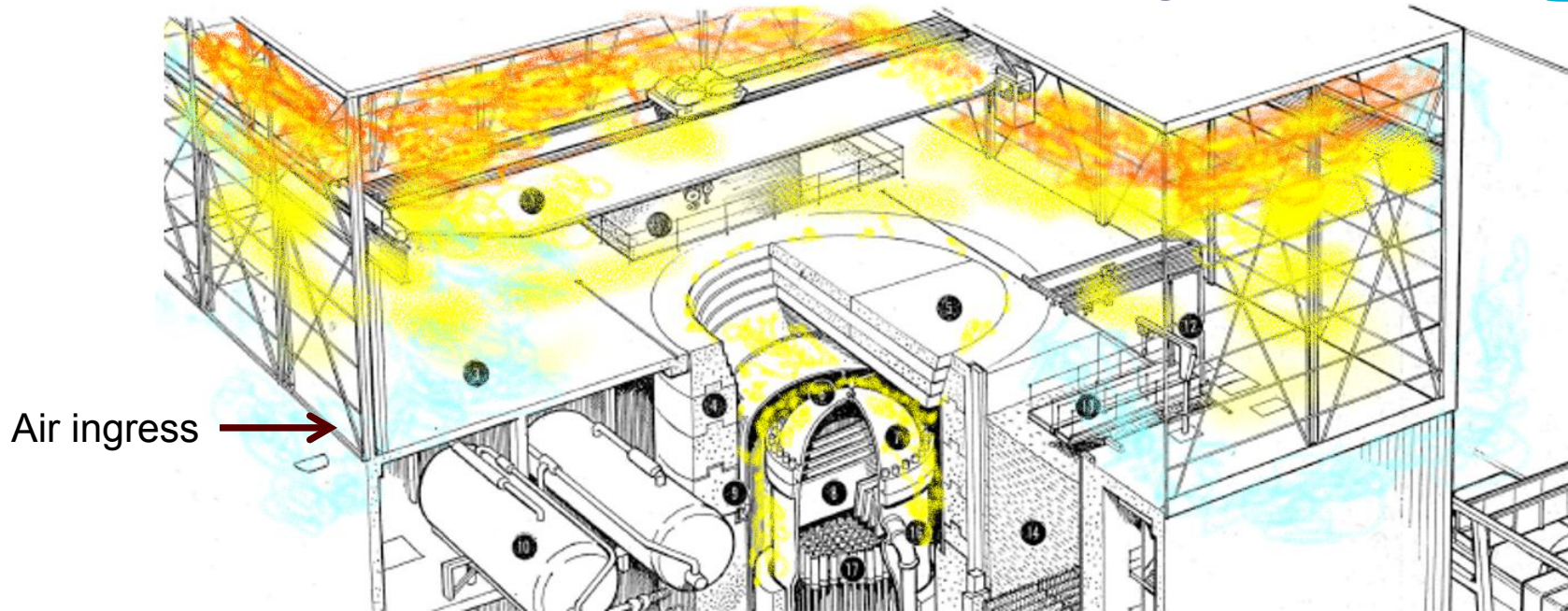


Hydrogen Accumulation in 1F1



- 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



- 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

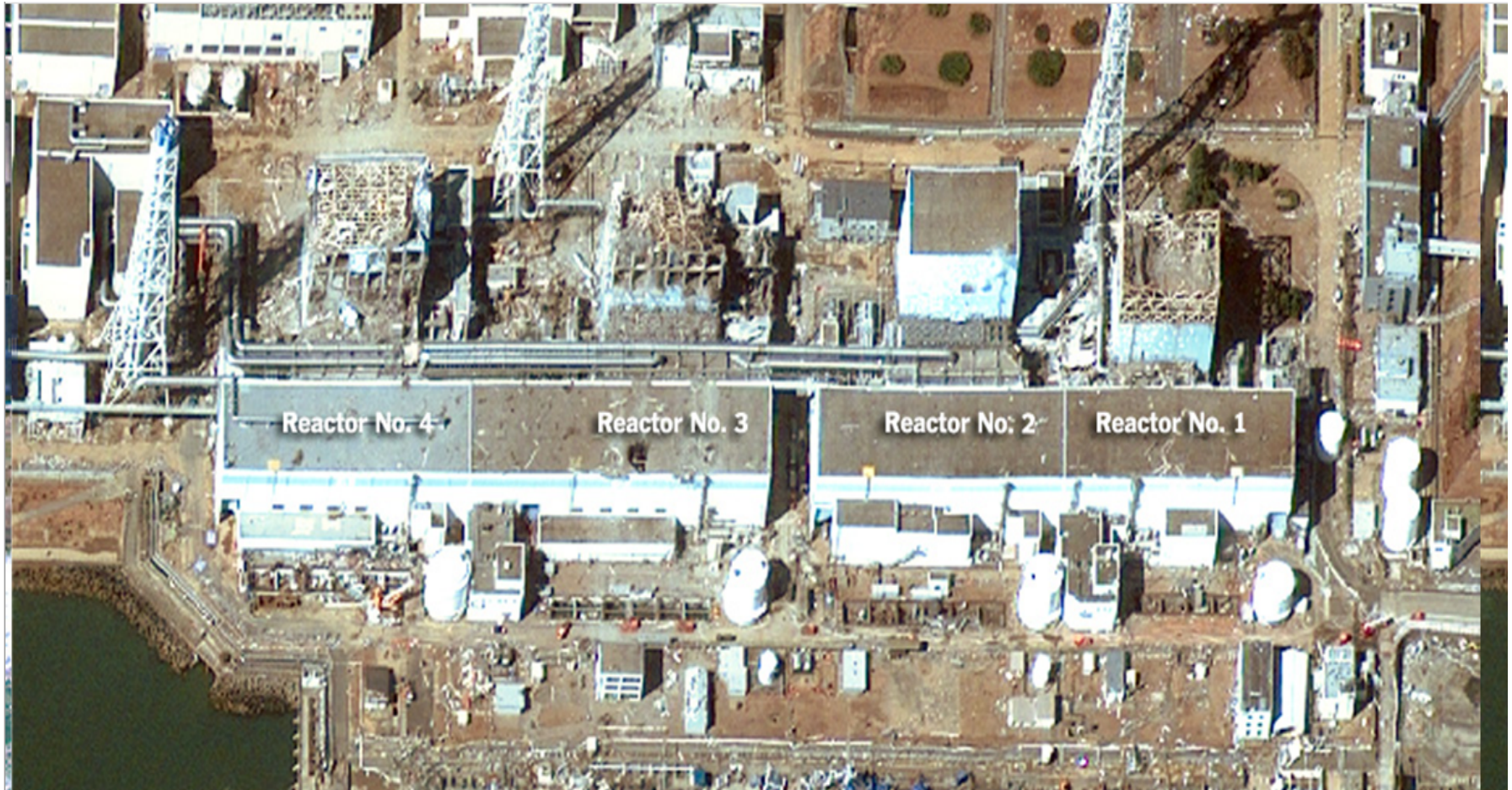


Unit 3 Hydrogen Explosion

oztvwatcher



Hydrogen Explosions



Containment Over-pressurization Led to Release of H₂ into Buildings

BSAF

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

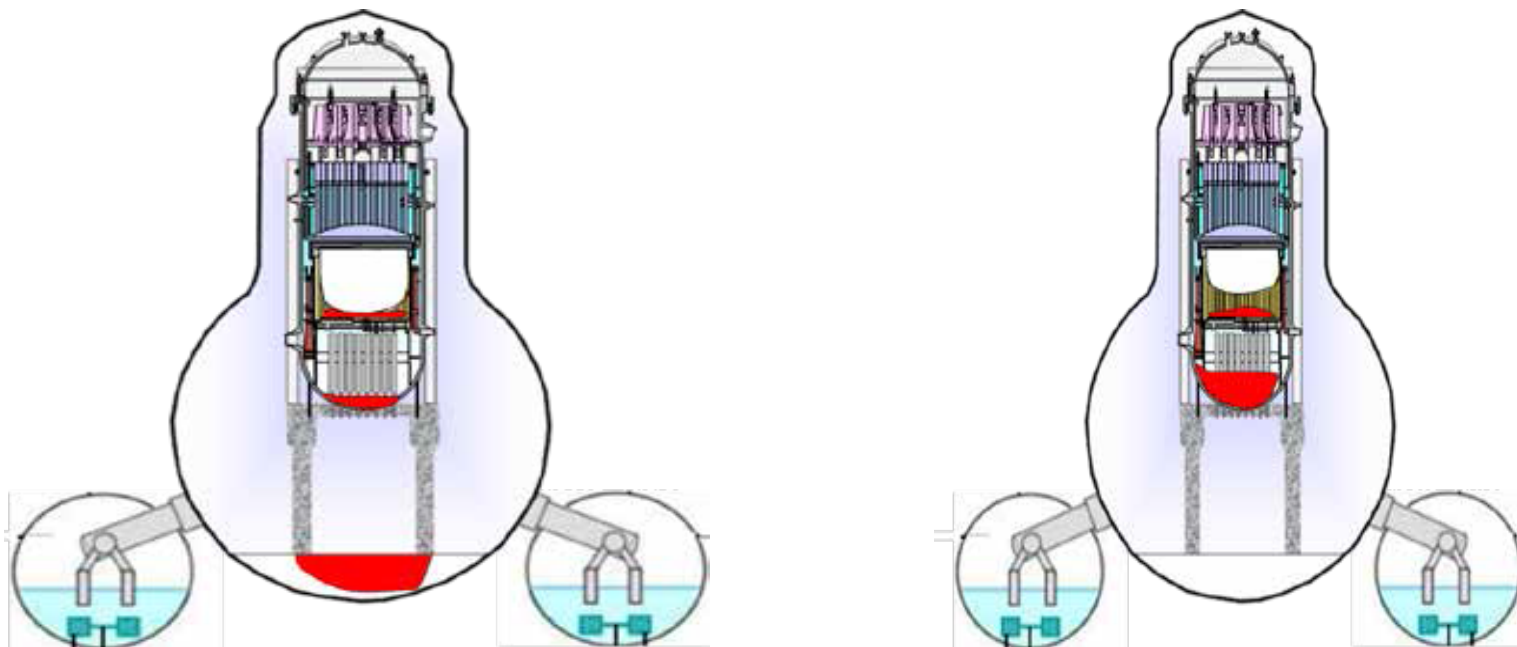


Figure 1: Qualitative description of the plausible status after comparison of the best estimate case analyses; a) Unit 1 RPV failure, b) Unit 2 no RPV failure.

BSAF

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

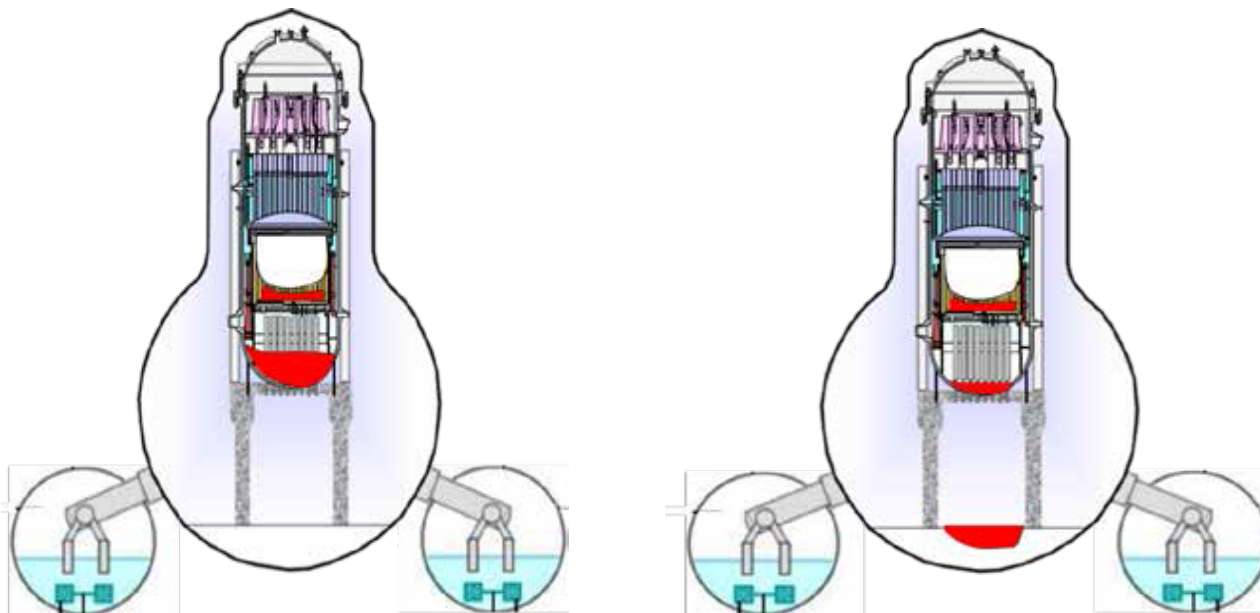
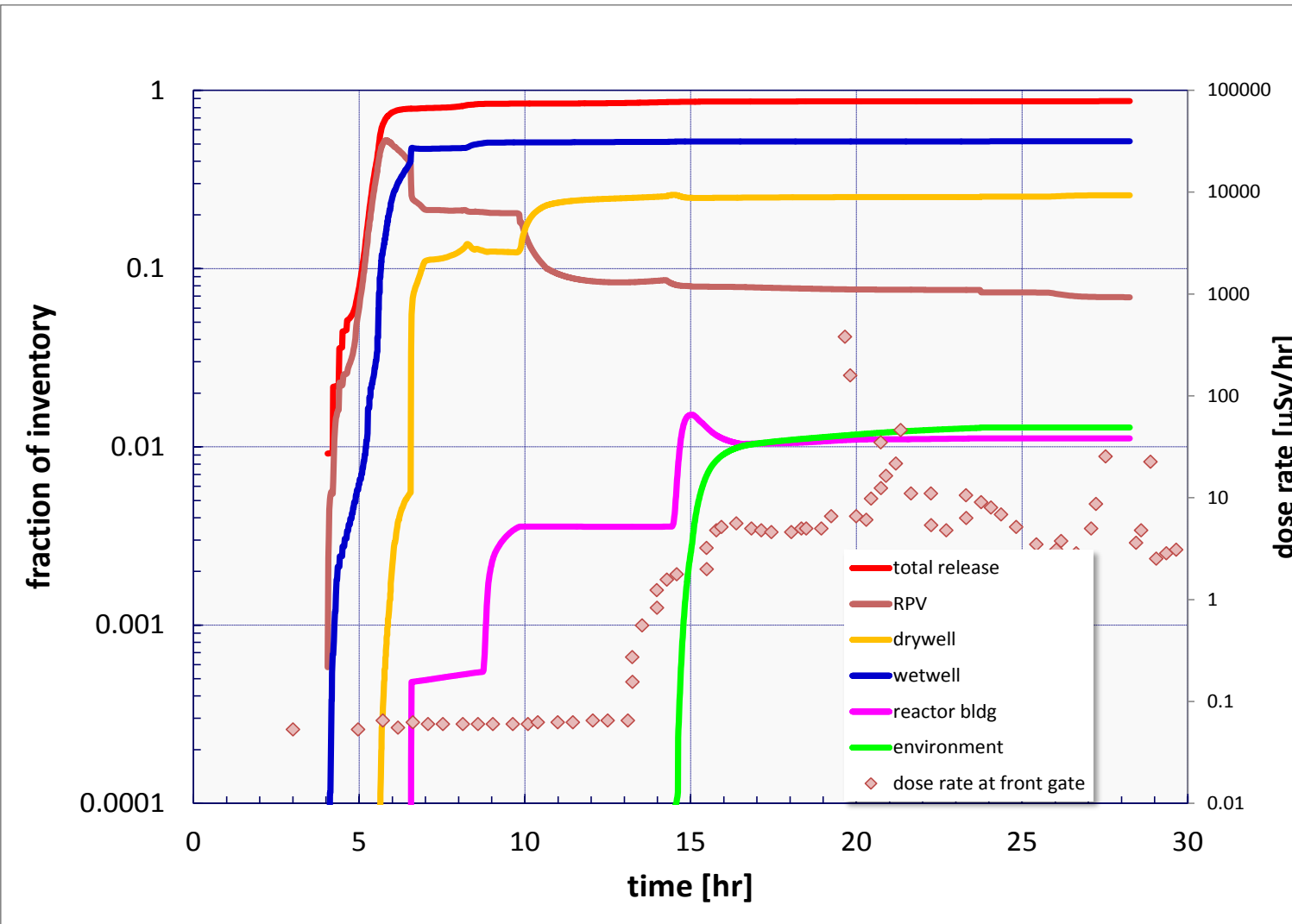


Figure 2. Unit 3: Qualitative description of the plausible status after comparison of the best estimate case analyses; a): no RPV failure, b): RPV failure and limited Melt-Concrete Interaction

BSAF Phase 2

- 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

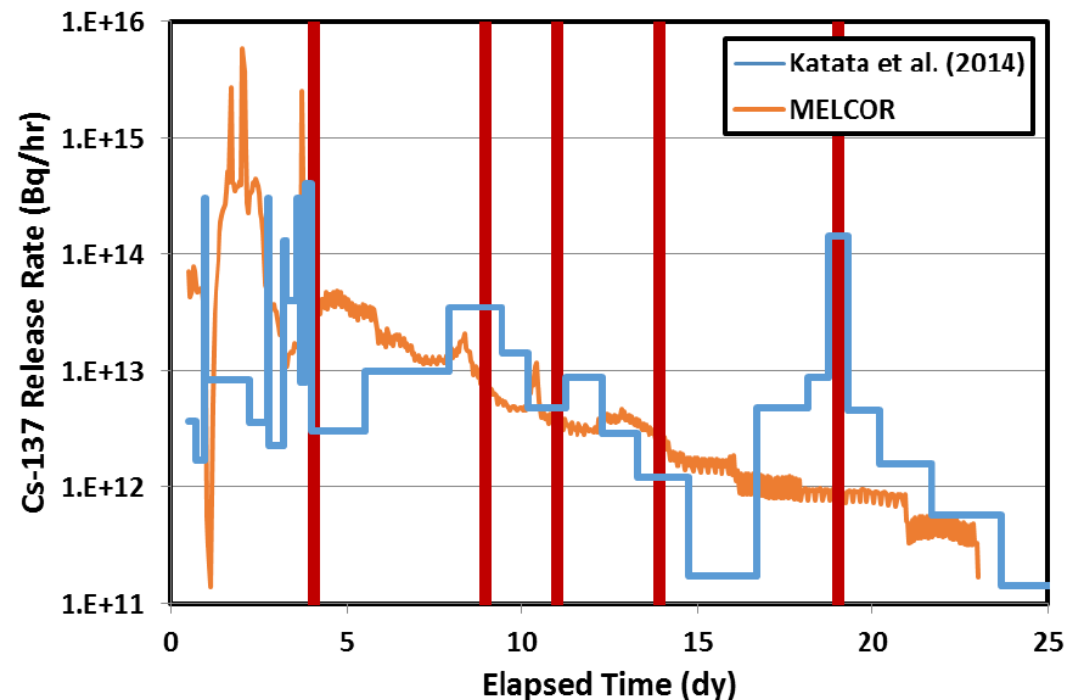
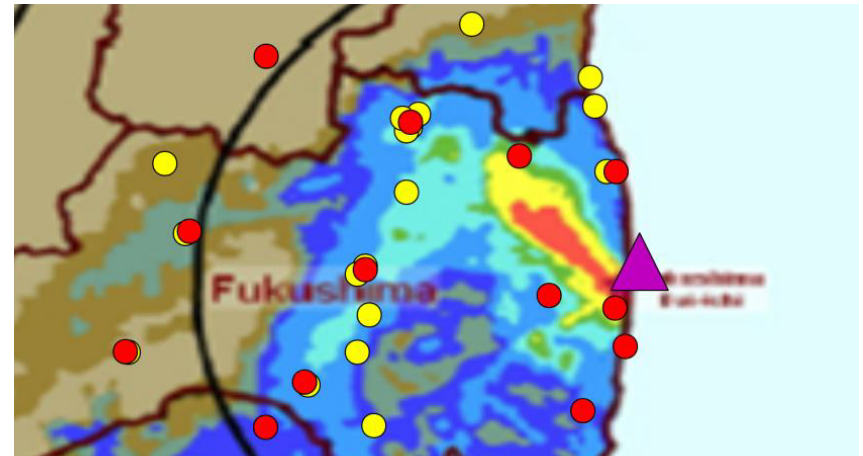


Radiation monitors
at front gate jump
at ~13 hr

Cs Env release
estimated at about
400,000 Ci

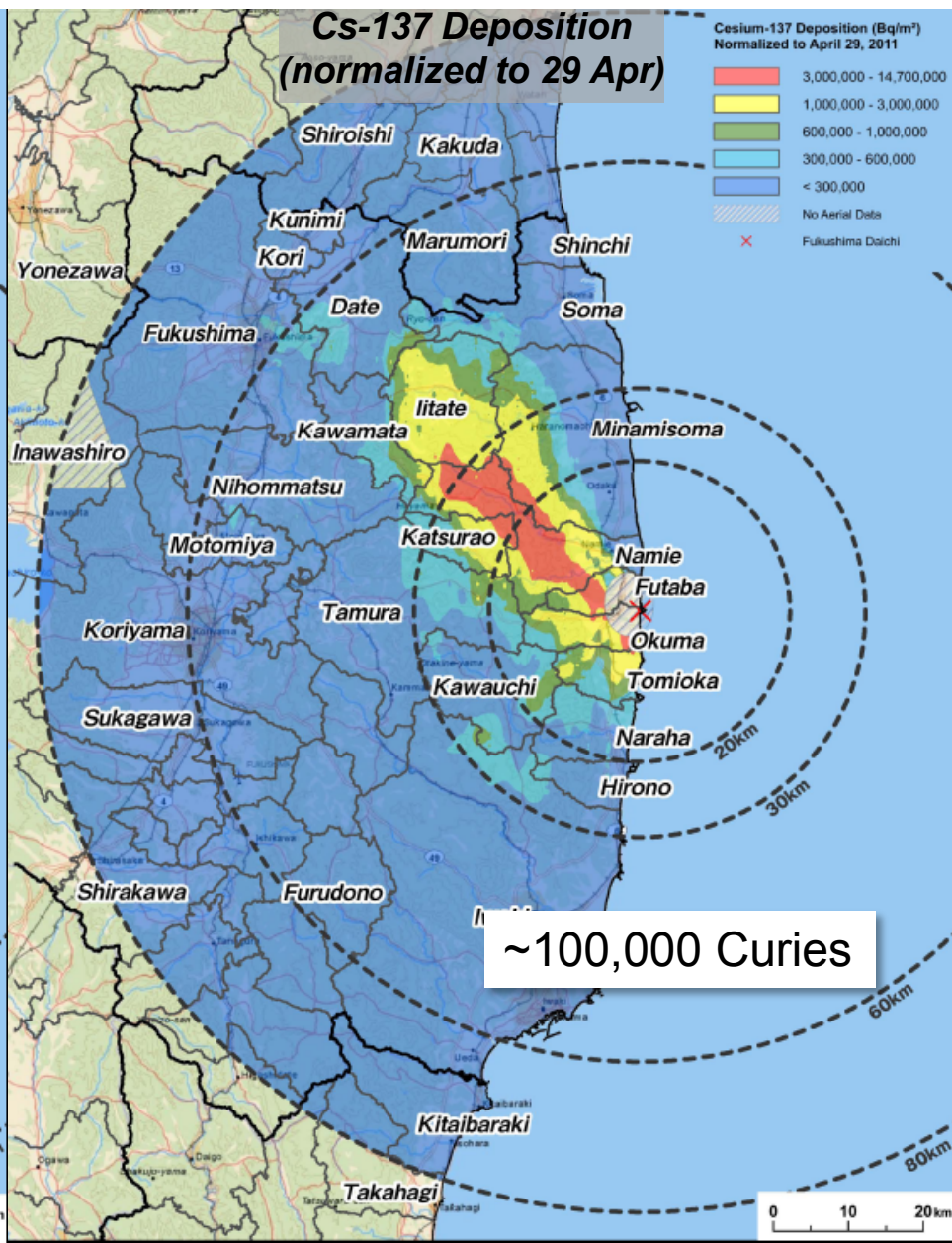
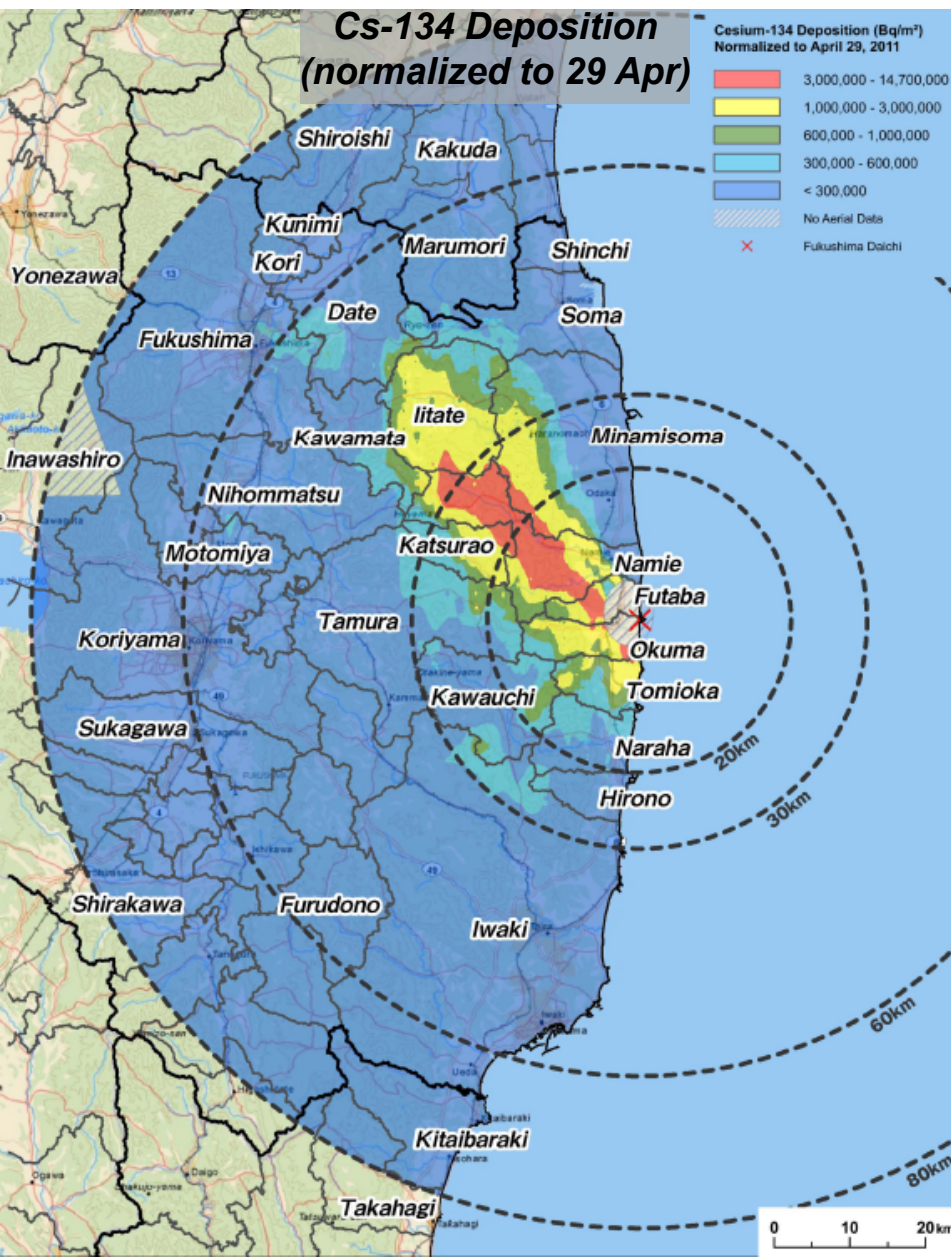
Extending Calculations – Why 3 Weeks?

- 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

FUKUSHIMA DAIICHI
JAPAN



Phase 2 BSAF

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