SPECIAL ADDRESS: Fukushima Dai-Ichi Nuclear Power Station Update

D.R. Novog
Associate Professor
NSERC/UNENE Associate Research Chair – Nuclear Safety Analysis
McMaster University

Our thoughts and support have continuously been with the people of Japan as they struggle to deal with the massive destruction from the earthquake/tsunami – and the subsequent nuclear accidents at Fukushima Dai-Ichi.

~ 15000 deceased

~ 8000 missing

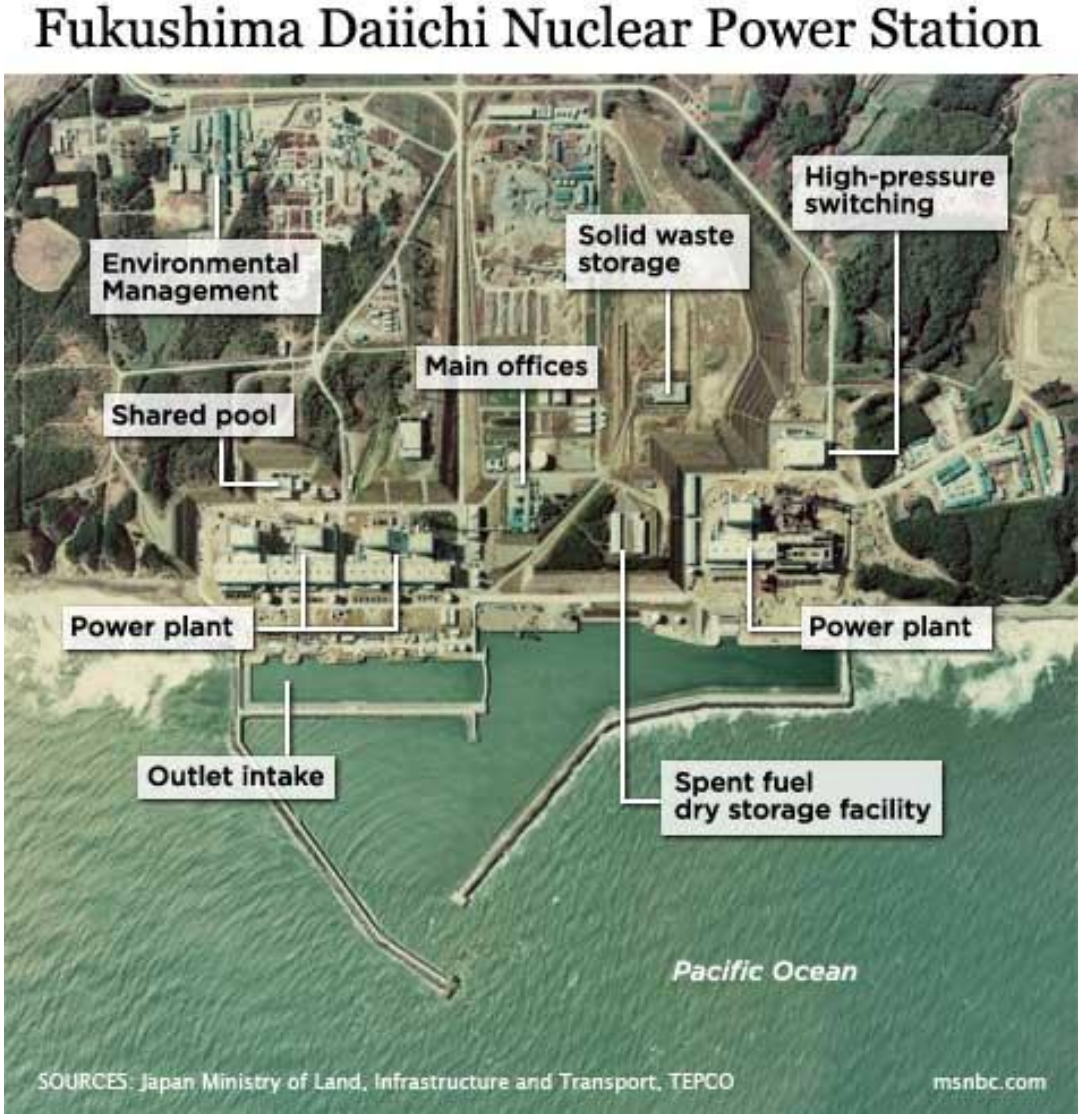
3 nuclear units with core damage + spent fuel pool issues.

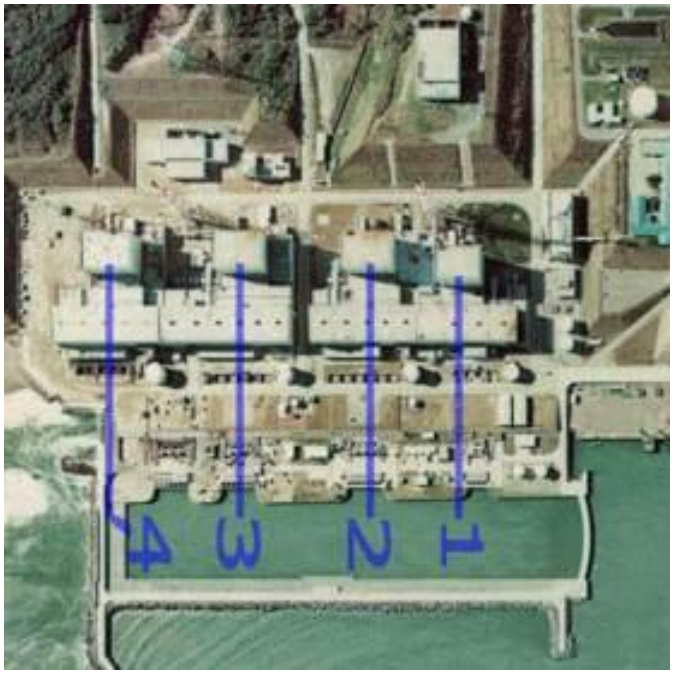
…when we see a crisis like the one in Japan, we have a responsibility to learn from this event, and to draw from those lessons to ensure the safety – Pres. Obama

Outline

- Brief overview of Fukushima #1 nuclear site, event and progression
- The recovery roadmap
- IAEA Fact Finding Mission important Preliminary Results
- Emerging themes for examination.

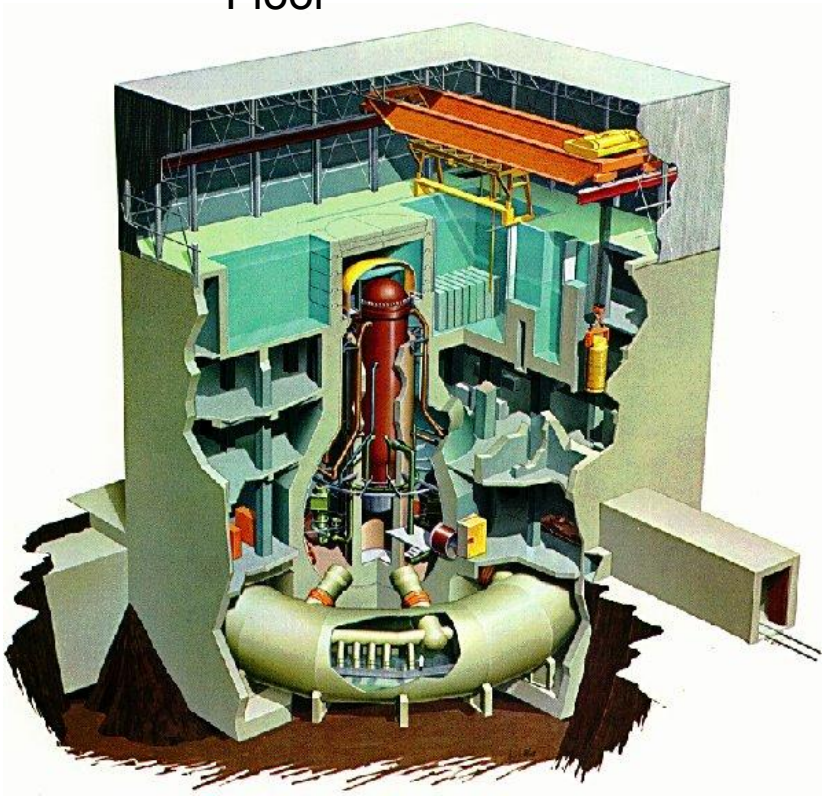
Fukushima #1 (Dai-Ichi) Layout





BWR Construction

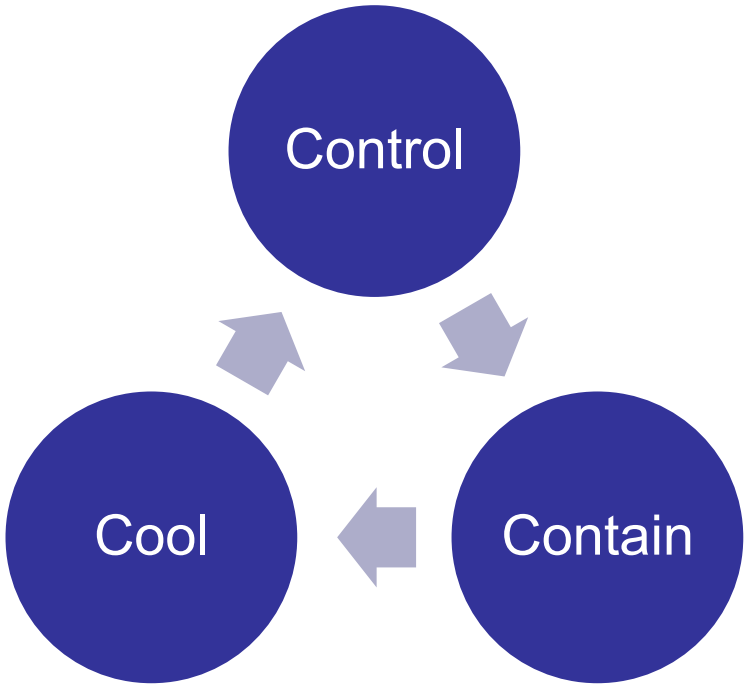
- Building structure
  - Concrete Building
  - Steel-framed Service Floor



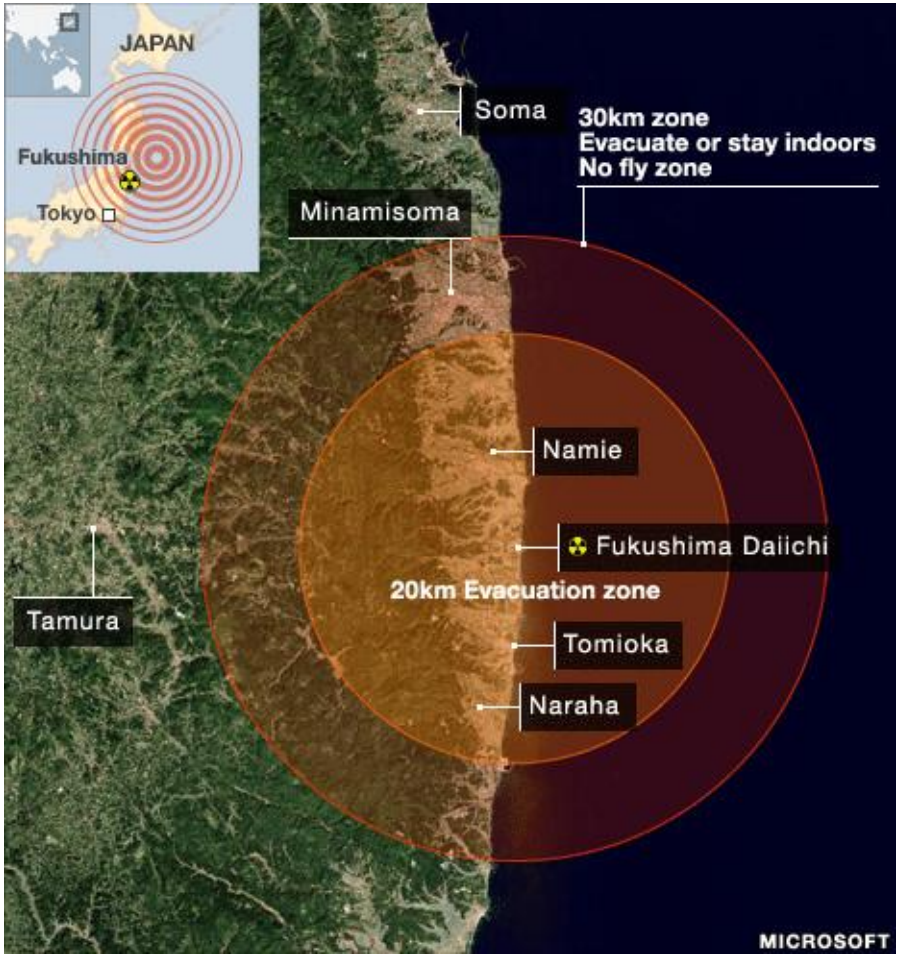
en.wikipedia.org/wiki/Browns_Ferry_Nuclear_Power_Plant

Fundamentals of Reactor Safety

- Control
  - Normal Control Systems
  - Safety Shutdown Systems
- Cool
  - Normal heat removal systems
  - Emergency Core Cooling System
  - Auxiliary Feedwater and Natural Circulation
  - Emergency Feedwater and Natural Circulation
- Contain
  - Physical barriers



March 11 Earthquake



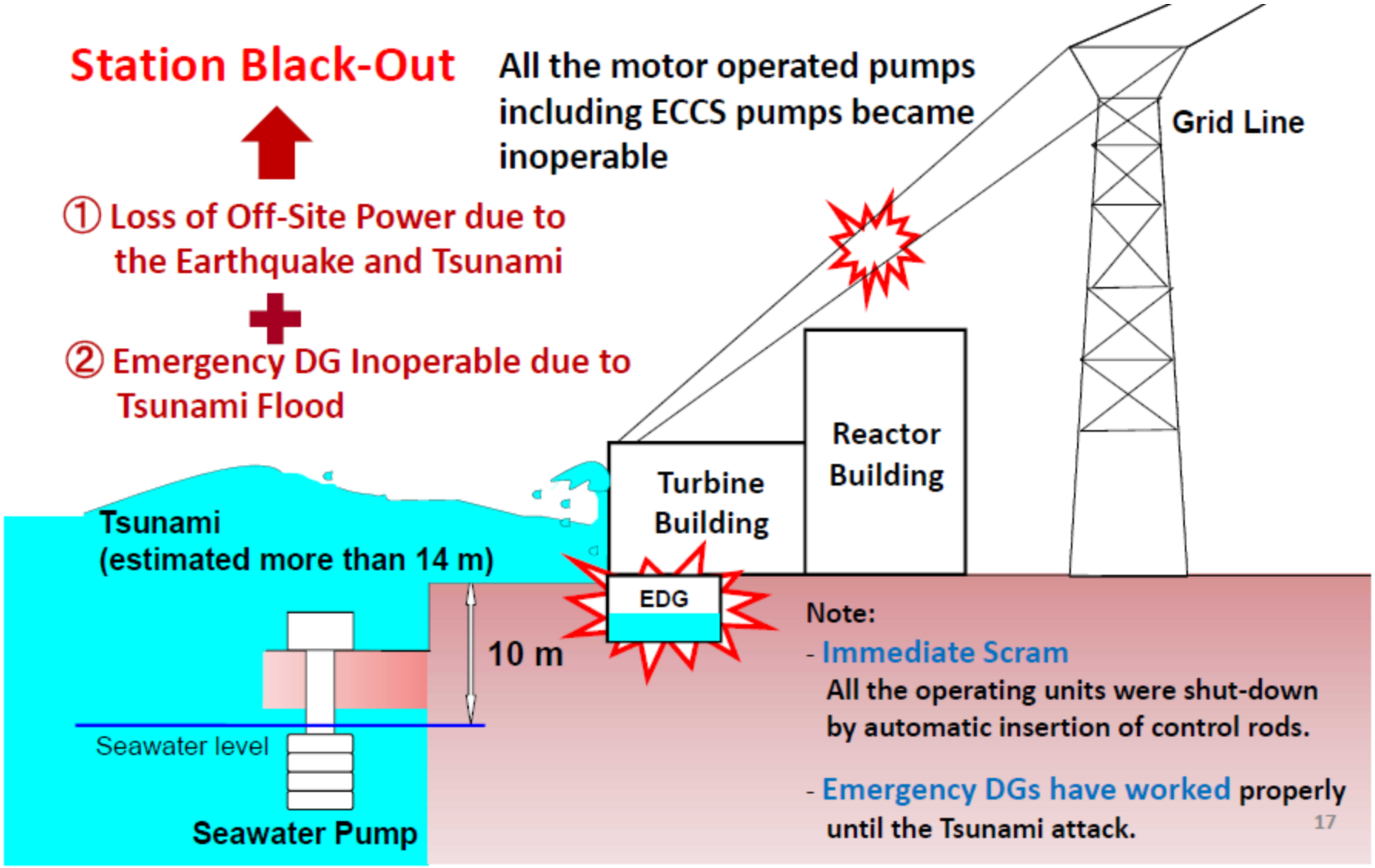
March 11 2011

Earthquake
- 14:46 JST magnitude ~9.0
- Shutdown of all operating units in the region.

Tsunami
- Series of waves starting at 15:27
- Largest wave (10m ~ 14m) at 15:46 → loss of EDG
- Decay power ~22-33 MW

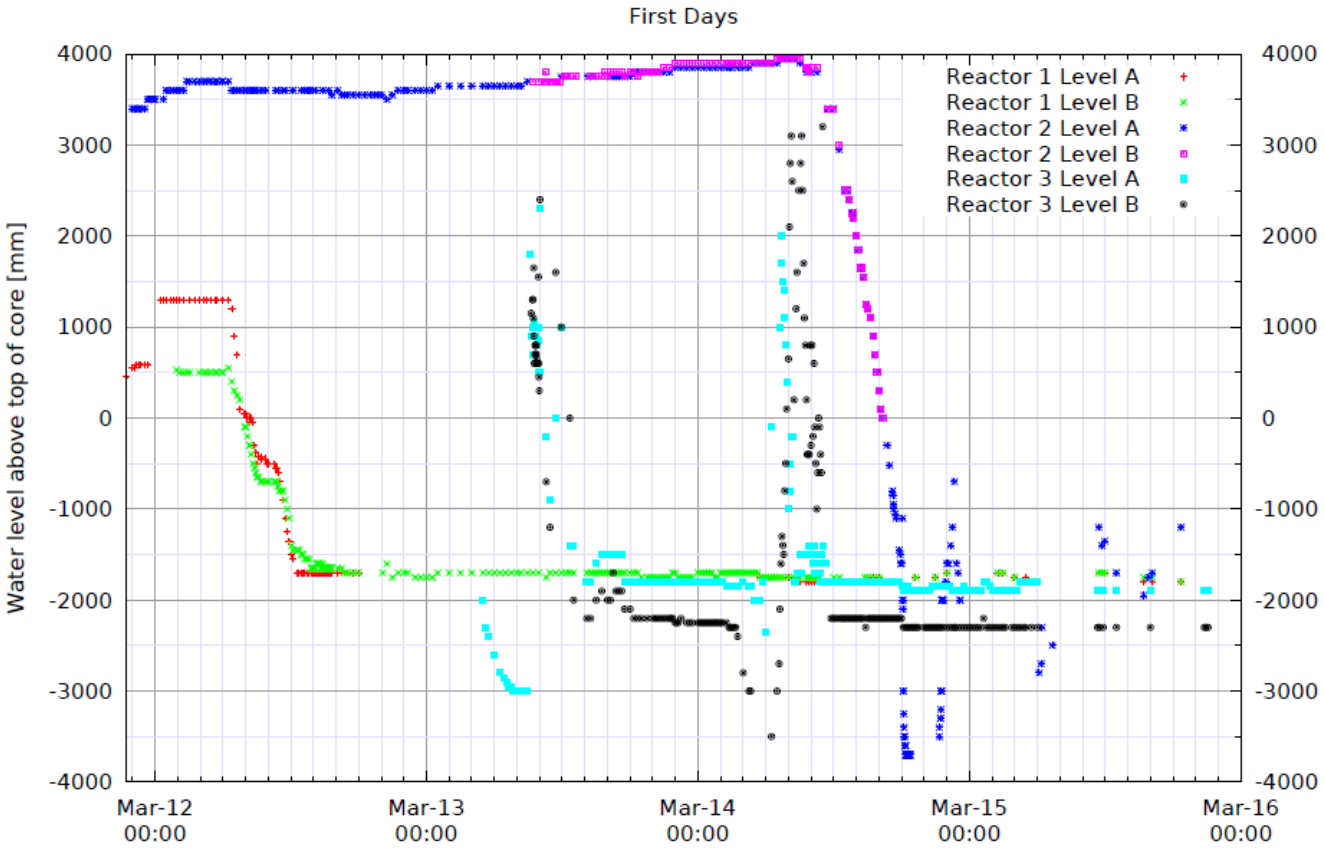
SBO
- 19:03 Government declares a Nuclear Emergency
- 19:30 Fuel in Unit 1 likely uncovered (provisional estimate)

LOHS
- 20:50 Evacuation orders issued
- Beyond Design Basis (BDBA) – Common Mode Event



Source: Prof.Sekimura, presentation to National Academy of Sciences, USA, May 2011

Core Degradation



Subsequent Developments

March 12

- 8:00 U1 core melt & relocation (provisional estimate)
- 11:00 RCIC Fails in U3
- 15:36 H2 Explosion in U1
- 21:00 Seawater Injection U1

March 13

- 5:10 ECC exhausted in U3
- 9:00 U3 core damage and relocation.

March 14 – 15

- 11:01-14 U3 Explosion → debris & contamination
- RCIC in U2 fails → 20:00-14 U2 core damage begins
- 6:14-15 U2 explosion (not visible, believed to be in torus)

Source: World Nuclear Association, 2011.


Reactor No. 4
Reactor No. 3
Reactor No. 2
Reactor No. 1


Reactor No. 4
Reactor No. 3
Reactor No. 2
Reactor No. 1

Hydrogen Ignition

Prolonged Loss of Heat Sink

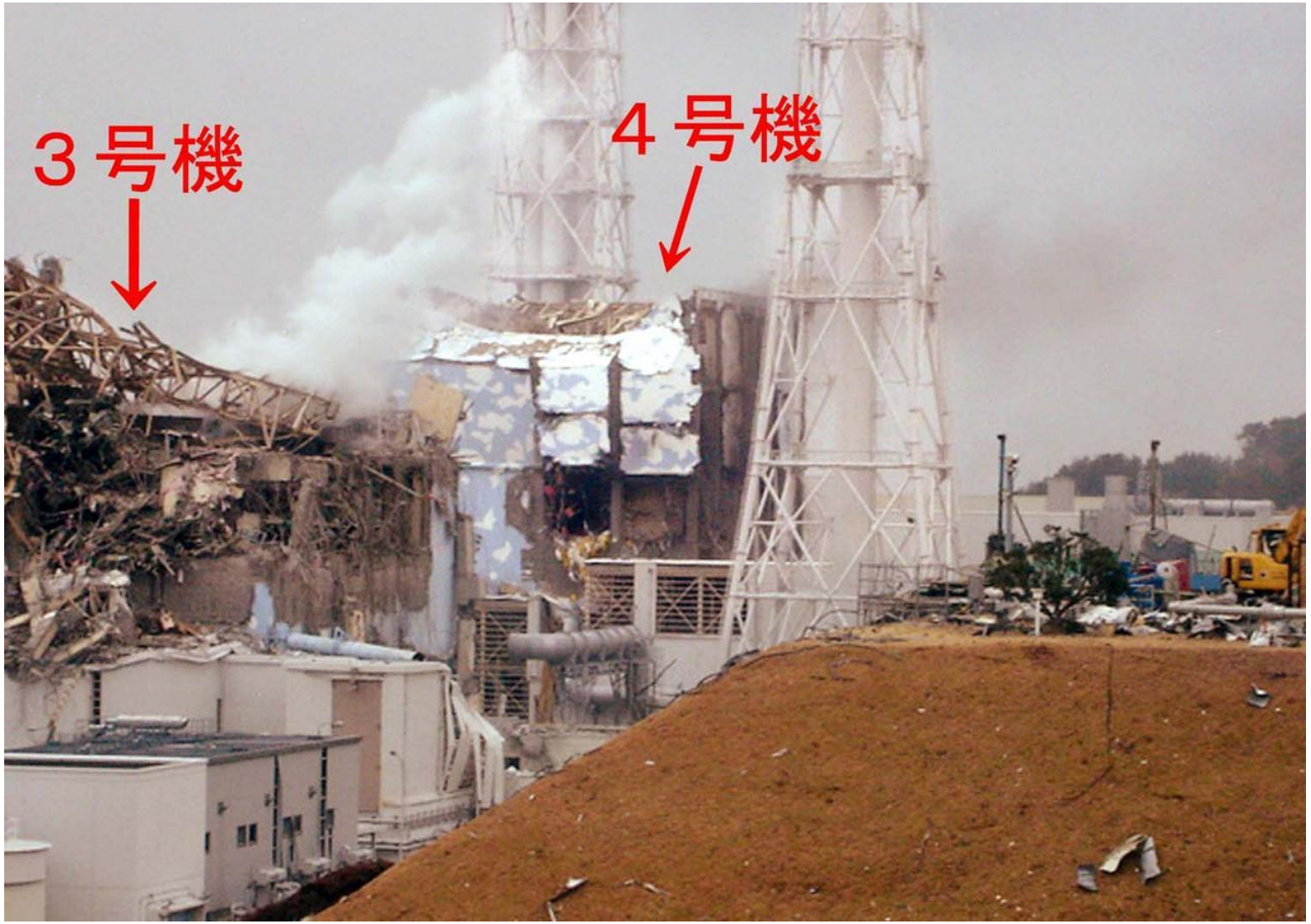
- Heat sink required at decay level powers
  - Pathway (E.g., water and forced circulation)
  - Sink (Heat exchangers, coolers, environment)
- SBO → LOHS event a dominant contributor to CDF in many power plant's risk assessment.
  - Blackout means "dark"
  - Instrumentation
  - Staffing and access/debris issues
- Simultaneous multi-unit event

National geographic, March 23, 2011

On-Site Activities

Source: TEPCO

Plant State March 20, 2011



Current Status – 31MAY2011 IEC Evaluation

Control

- Units 1-3
  - Achieved
  - No significant neutron flux
  - No short lived fission products (La-140)

Cool

- Units 1-3
  - Not achieved → Long term closed loop heat removal not in place.
  - Heat removal through
    - Feedwater system injection via grid powered pumps.
    - Backup diesel pumps available.
  - Cold shutdown state estimated in 6-9 months.

Current Status – 31MAY2011 IEC Evaluation

Contain

- Unit 1
  - RPV bottom assumed to be leaking
  - Containment breach suspected (ongoing N2 injection has not increased pressure)
- Unit 2
  - RPV or piping assumed to be leaking
  - Containment breach suspected (RPV and containment near atmospheric pressure).
- Unit 3
  - RPV leaking – unknown location
  - Containment breach suspected (near atmospheric pressure).

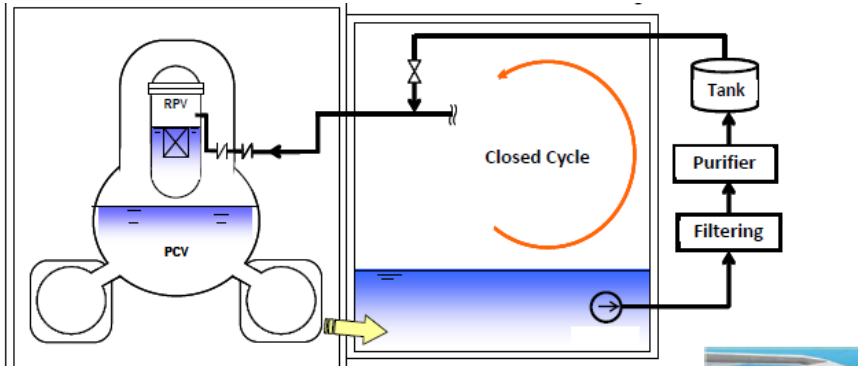
On-site Issues

- Water
  - 100k tonnes of contaminated water on site (rainy season) – June 3rd TEPCO report.
  - Risk related to rainy season
  - June 15 → 1.2ktonne treatment facility
- Structures
  - Worker dose
  - Used fuel pool support
  - Debris and contamination
  - Humidity and air quality issues

Dai-Ichi Roadmap Priorities

1. **Cooling reactors**
   Closed loop circulation to RPV
   Cold shutdown target in 6-9 months.

2. **Cooling and removing spent fuel**
   Cooling system and HX
   Physical supports.
   Removal of spent fuel to central storage



3. **Managing contaminated water**
   Storage and treatment

4. **Countermeasures against aftershocks and further tsunamis**
   Tidal barriers
   DG moved

5. **Minimising release of radioactive materials to atmosphere**
   Dust-suppressing polymer resin
   Mitigate leak pathways
   Temporary covering

External Assessment

1. Review of appropriateness of DBAs
2. Robustness of BDBA Response
   - Procedures for accident management, H2, and spent fuel pool
   - Multi-unit response
   - Information/instrumentation
3. Environment and situation for post accident recovery
   - High radiation
   - Debris
   - Aftershocks and complications
4. Emergency Response and Preparedness
   - Access and stagging
   - Communication
   - Monitoring
   - Evacuation zones

Source: Prof.Sekimura, presentation to National Academy of Sciences, USA, May 2011

Preliminary Summary

IAEA International Fact Finding Expert Mission – Preliminary Summary issued June 1, 2011.

- *The response of expert and dedicated staff in extreme conditions resulted in the best possible response given the exceptional circumstances.*
  - Professional backup support has provided great assistance.
  - In particular in J-Village → worker safety.
- *The Japanese Governments response to protect the public including evacuation has been impressive and extremely well organized.*
- *The hazard for several sites has been underestimated.*
  - Nuclear designers and operators should appropriately evaluate and provide protection against the risks of all natural hazards
  - periodically update these assessments.

IAEA Preliminary Summary

- ***Defence in depth, physical separation, diversity and redundancy*** *requirements should be applied for extreme external events*
  - common mode implications
  - Severe … events should be adequately covered in design, operations, resourcing and emergency arrangements.
- *… value of hardened on-site Emergency Response Centres with adequate provisions for communications, essential plant parameters, control and resources.*
  - They should be provided for all major nuclear facilities with severe accident potential.
  - Additionally, simple effective robust equipment should be available to restore essential safety functions in a timely way.
  - Consider environment and local implications and weather.

Emerging Themes and Examples

- Containment and Hydrogen
  - Venting → “The inspectors identified an apparent (beyond design and licensing basis) vulnerability, in that, if AC power is not available… air flow in the ventilation systems may be lost and … could result in hydrogen accumulation in the reactor building`. (Oyster Creek)
  - Hydrogen mitigation during SBO (James Fitzpatrick)
- Access to equipment during external event.
  - “the Unit 1 fire main isolation valve would need to be operated to pressurize the fire main to mitigate a fire in Unit 1, but the valve would be under water (inaccessible) following a design basis flood event” (Nine Mile Point)
  - Preventative maintenance of needed equipment (Nine Mile Point, Beaver Valley)
  - Flood mitigation sumps not seismically rugged (Nine Mile Point)
  - Winter readiness issues (Vermont Yankee)

Important Observations

<u>Fukushima has impacted our view of risk and consequences for external events at a fundamental level.</u>

1. Irrespective of the hazard we have to ensure that mitigation options remain available and can be deployed in a severe environment.
2. Irrespective of the hazard information must be available to diagnose and implement mitigating functions.
3. External hazard may preclude some options → need for robust yet simple options.
4. Trained, staged, tested and redundant features.

Final Notes

- We need to act to assure the public that the design and highly skilled operators are capable of mitigating all potential sequences.
  - It would limit our ability to learn lessons if we simply say that tsunamis do not occur here.
  - Good design, excellent operations and a vigilant regulator = success.
- We need to assess how we interface with the media, as clearly the information and context did not aid the public good.
  - The good → examples such as the CNSC role and information center.
  - The bad → mass media and news agencies with inadequate resources and knowledge during the early stages.

Thank you.