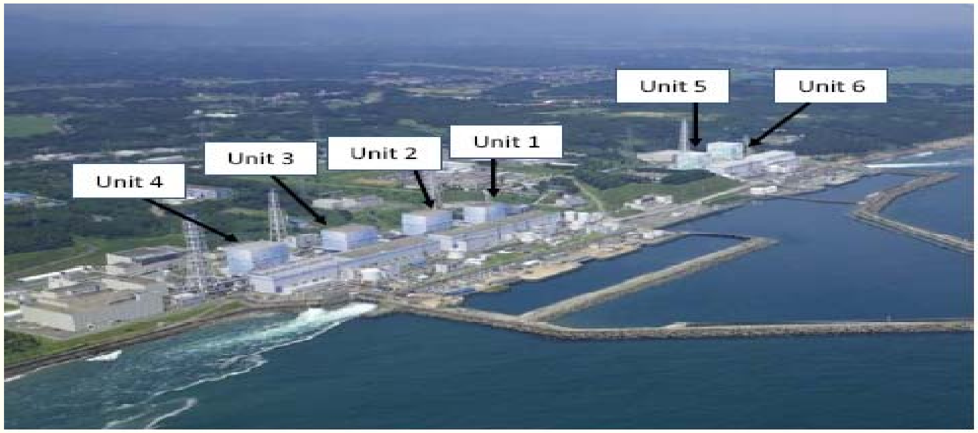
Lesson learned so far - Fukushima-I Nuclear Power Plants Accidents

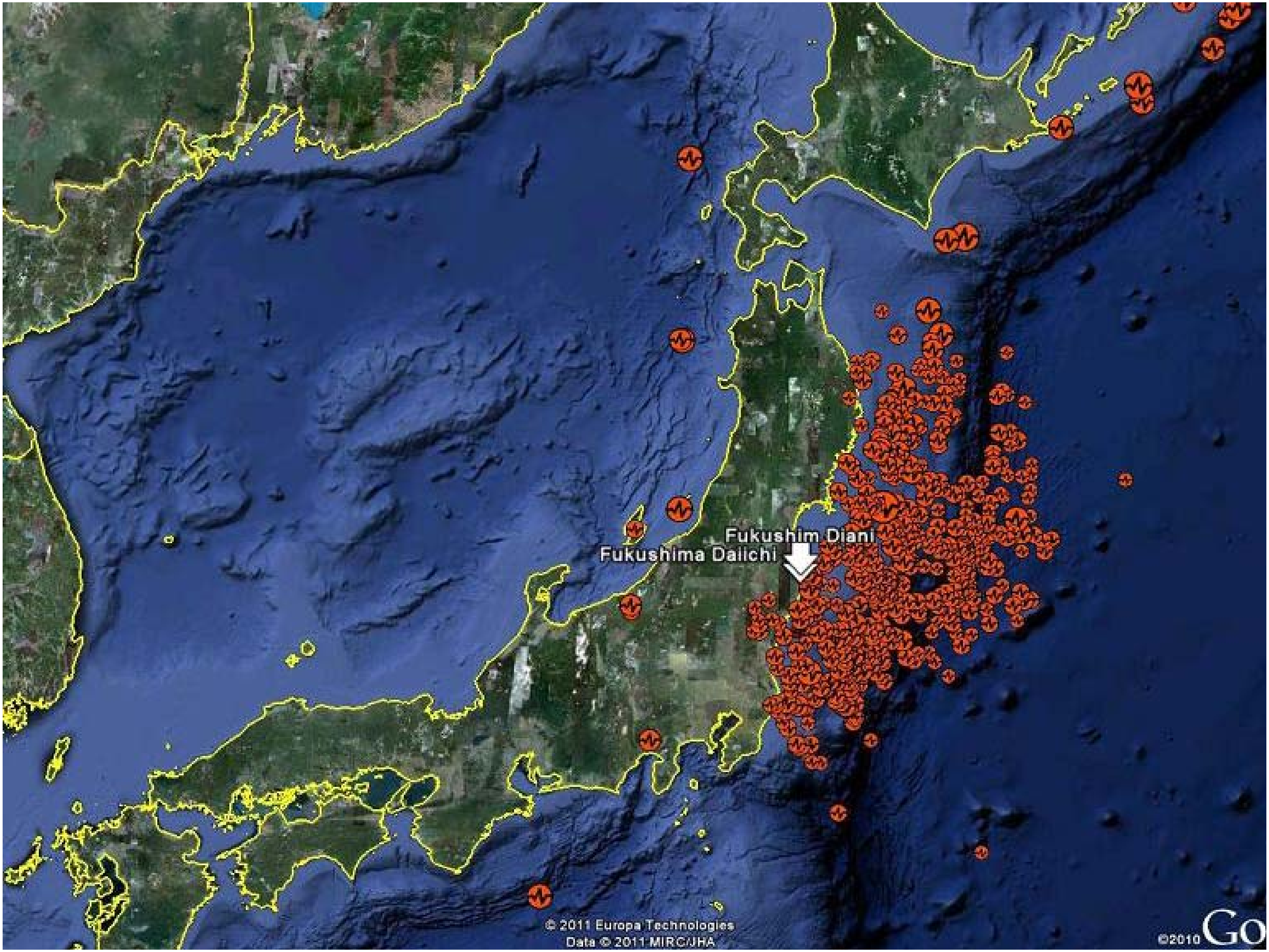


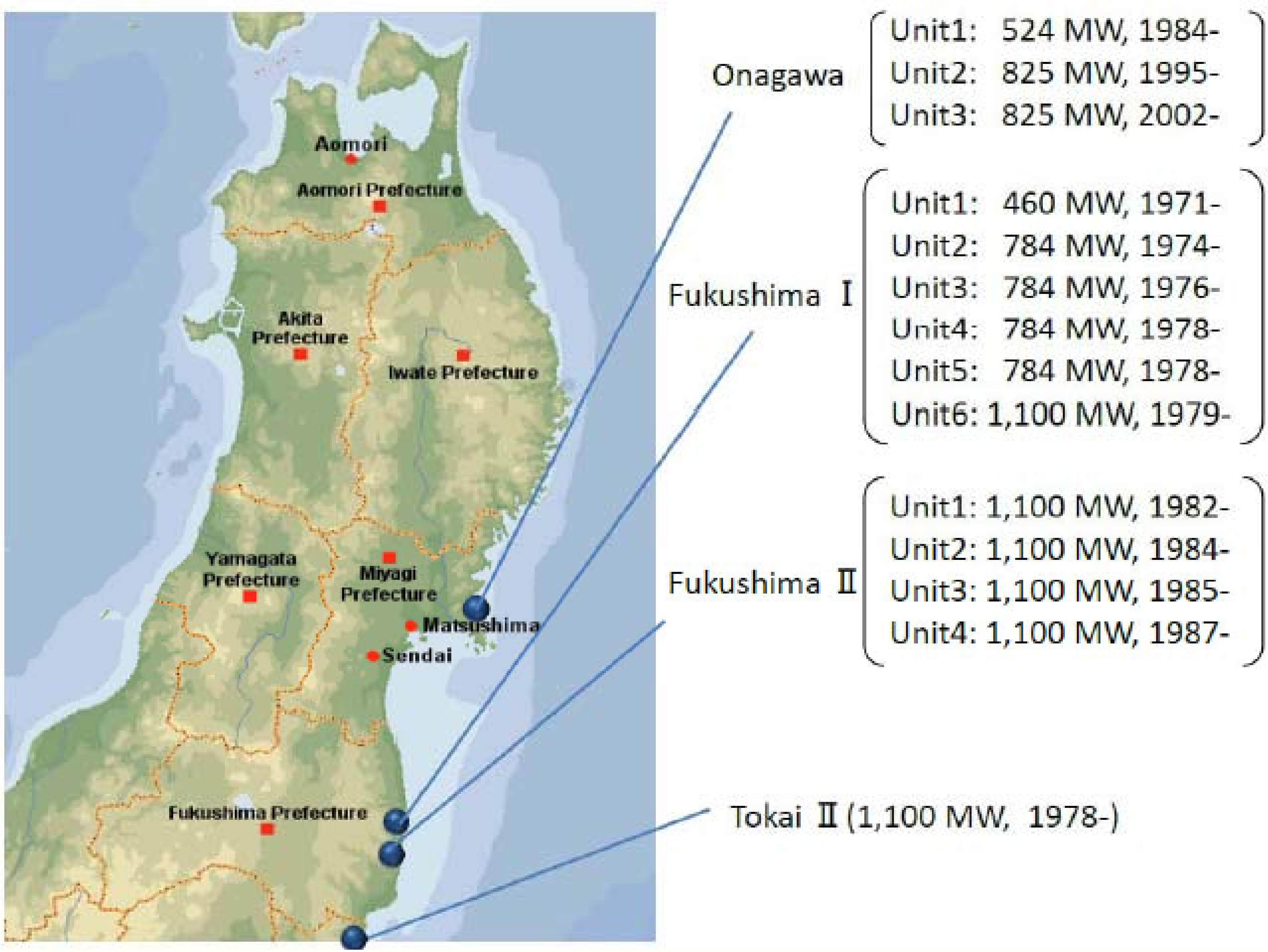
Presented by: Muhammad Ayub
Project Director
Pakistan Nuclear Regulatory Authority

INTERNATIONAL SEMINAR ON NUCLEAR SAFETY AND SECURITY CHALLENGES OF THE 21ST CENTURY
April 21 – 23, 2011

Earthquake Details

- March 11, 2011 at 05:46:23 AM UTC
- Magnitude of Earthquake - 9.0
- Predicted Earthquake – 7.5 to 8.0
- Depth of Earthquake – 32 Km
- Distance of Fukushima from epicenter – 177 Km
- Fault moved upward – 30 to 40 m and slipped over an area approximately 300 Km long and 150 Km wide


Fukushim Diani
Fukushima Daiichi
© 2011 Europa Technologies
Data © 2011 MIRC/JHA
©2010


Aomori
Aomori Prefecture
Akita Prefecture
Iwate Prefecture
Yamagata Prefecture
Miyagi Prefecture
Matsushima
Sendai
Fukushima Prefecture
Onagawa
Unit1: 524 MW, 1984-
Unit2: 825 MW, 1995-
Unit3: 825 MW, 2002-
Fukushima Ⅰ
Unit1: 460 MW, 1971-
Unit2: 784 MW, 1974-
Unit3: 784 MW, 1976-
Unit4: 784 MW, 1978-
Unit5: 784 MW, 1978-
Unit6: 1,100 MW, 1979-
Fukushima Ⅱ
Unit1: 1,100 MW, 1982-
Unit2: 1,100 MW, 1984-
Unit3: 1,100 MW, 1985-
Unit4: 1,100 MW, 1987-
Tokai Ⅱ (1,100 MW, 1978-)

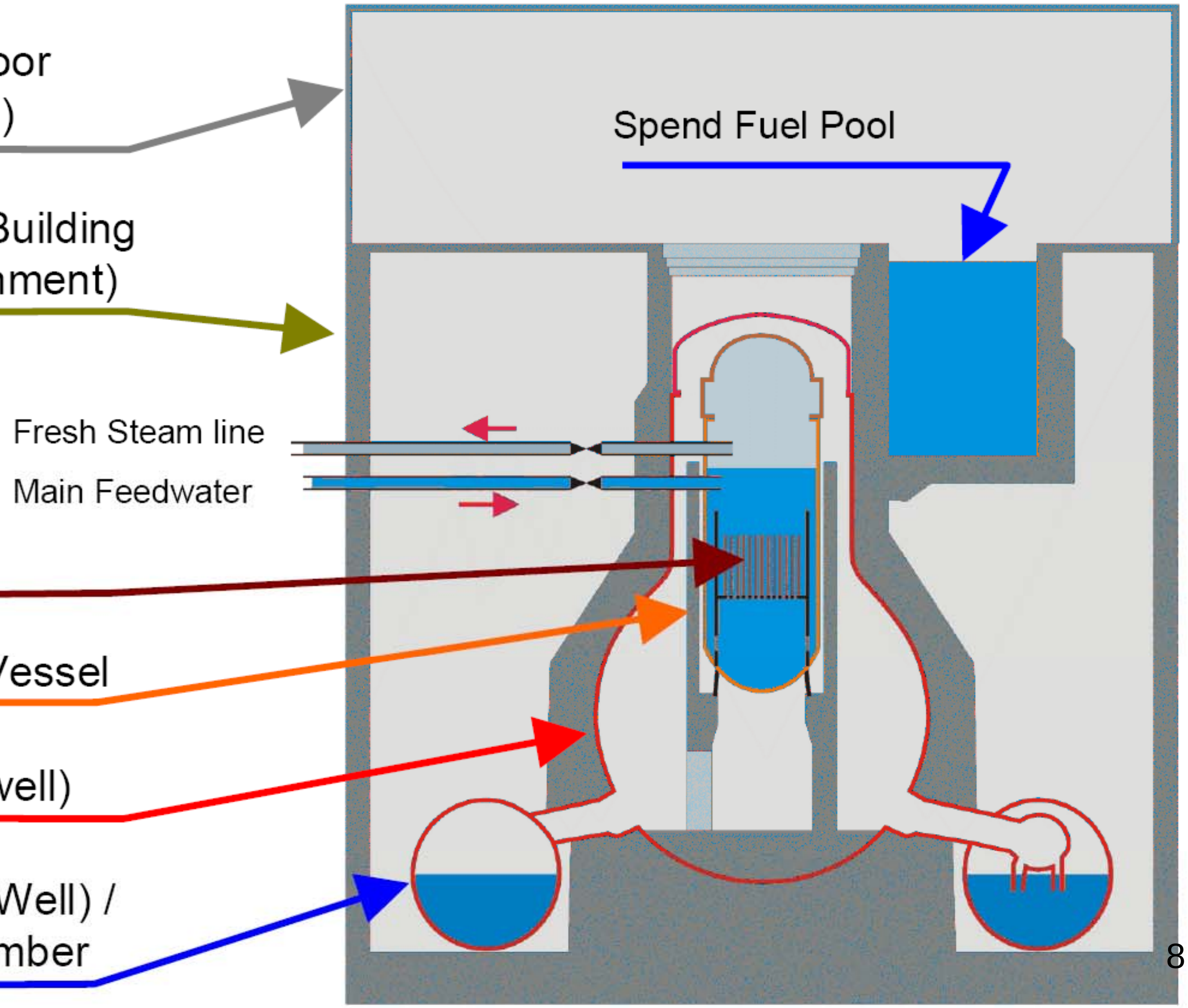
Tsunami Details

- Travel time - 55 min to Fukushima Unit 1
- Height of Tsunami wave
  - Fukushima –I 14m
  - Fukushima -II 12m
- Fukushima-I designed for tsunami of ~ 5.7m
- Fukushima- II designed for tsunami of ~ 5.2 m


MIYAKO

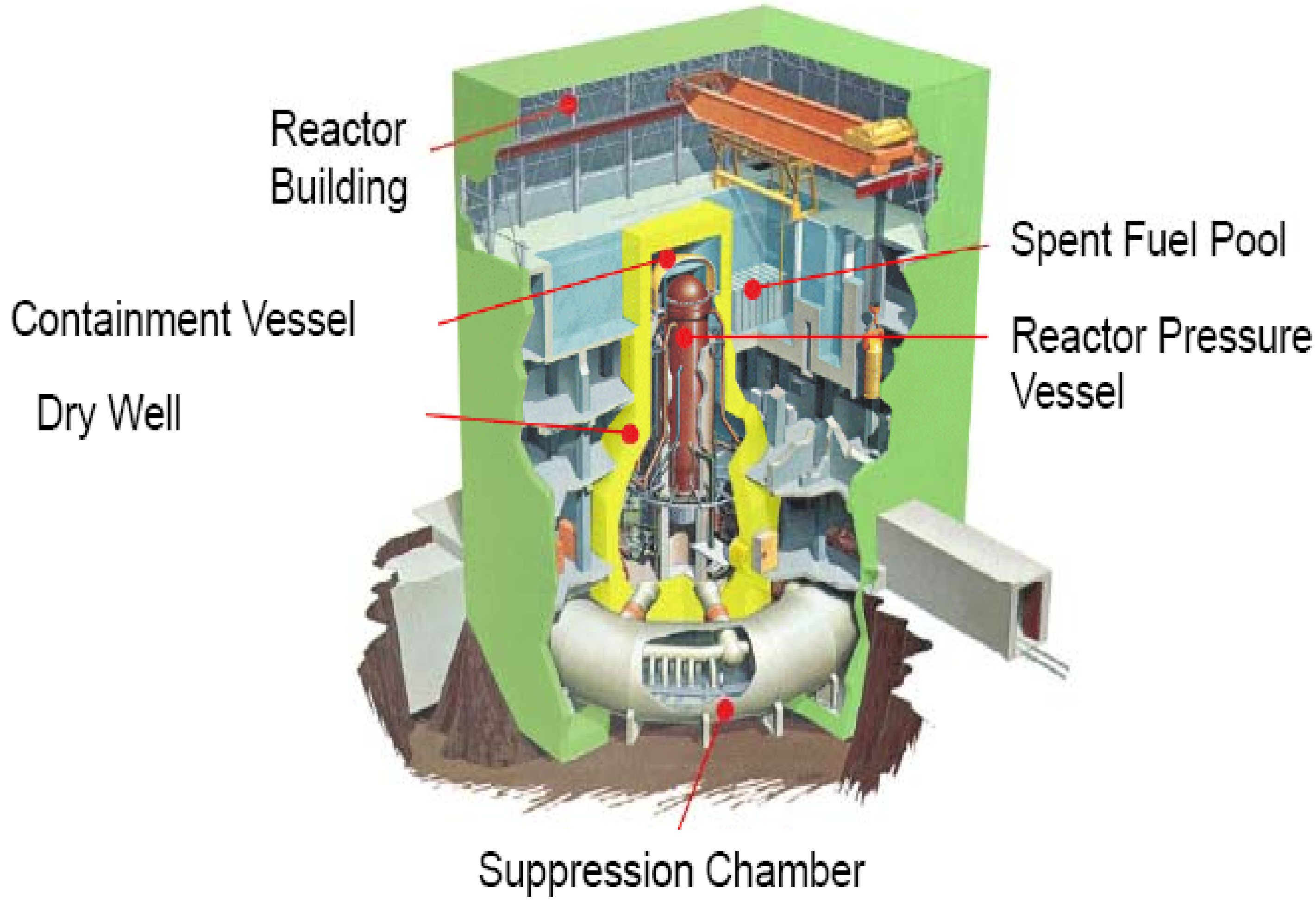
Fukushima BWR NPP

- Reactor Service Floor (Steel Construction)
- Concrete Reactor Building (secondary Containment)
- Reactor Core
- Reactor Pressure Vessel
- Containment (Dry well)
- Containment (Wet Well) / Condensation Chamber

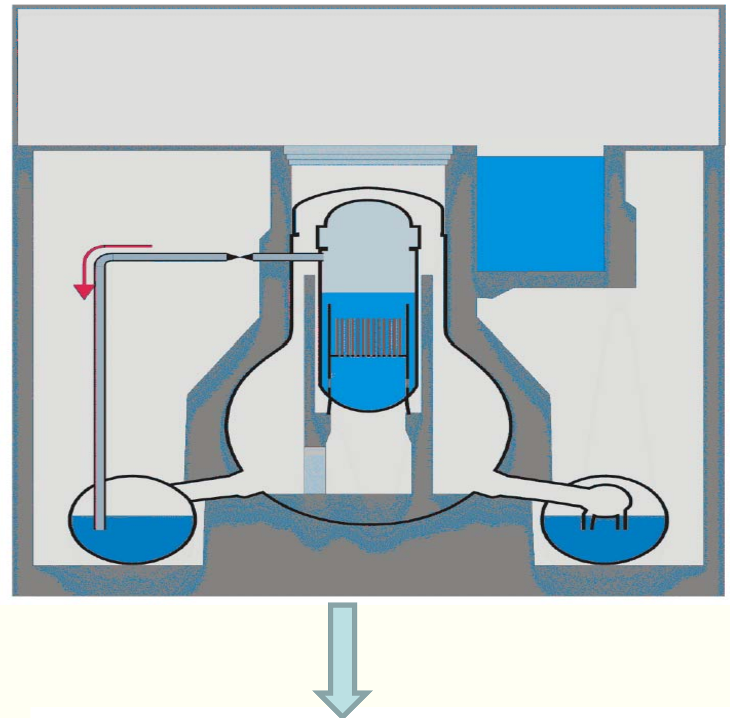


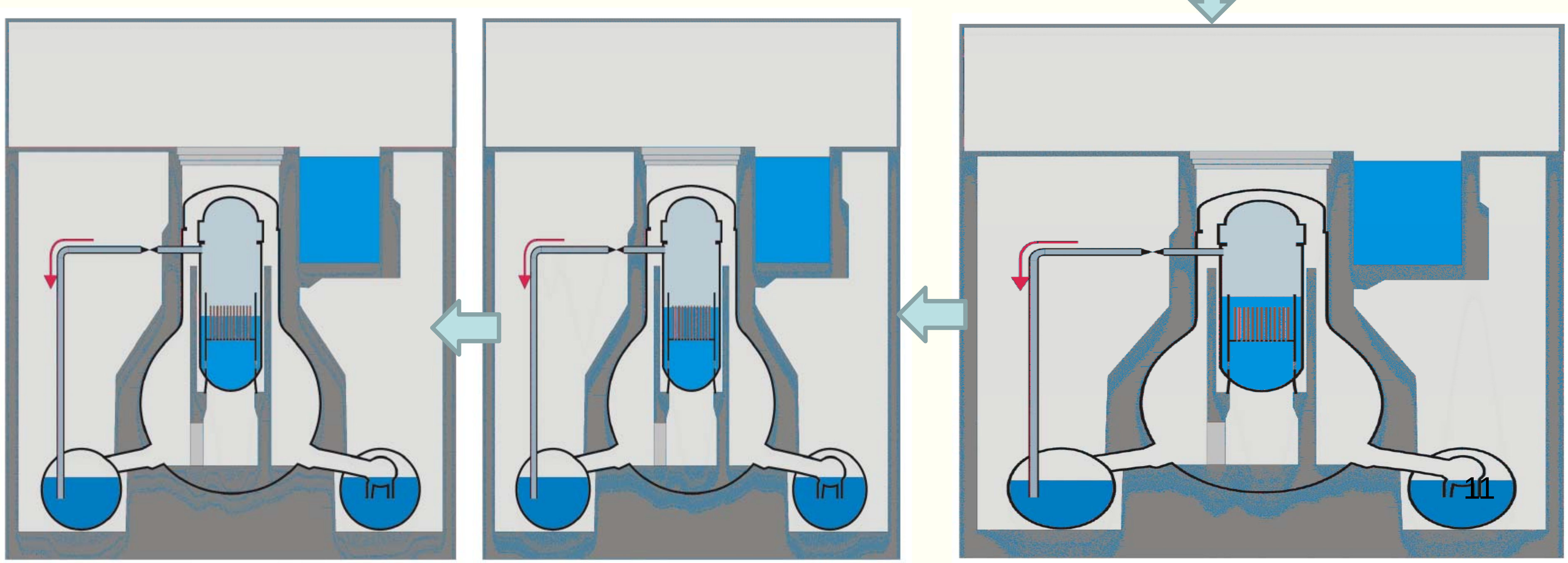
Service Floor (Reactor Building)

Overview of Mark-1 Type BWR (Unit 1,2,3 and 4)

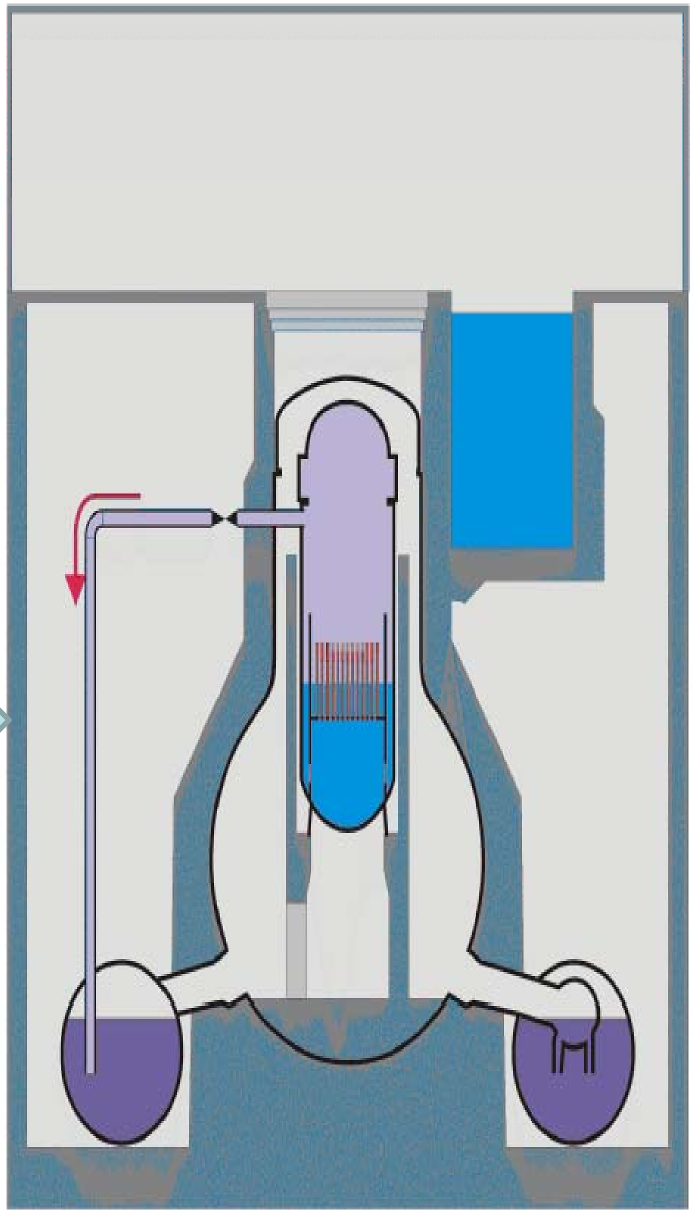


- ❖ **Decay Heat produces still steam in**
- ❖ **Reactor pressure Vessel (RPV)-**
- ❖ **Pressure rising in RPV**
- ❖ **Opening the steam relieve valves**
- ❖ **Discharge Steam into the Wet-Well**
- ❖ **Descending of the Liquid Level in the Reactor pressure vessel**

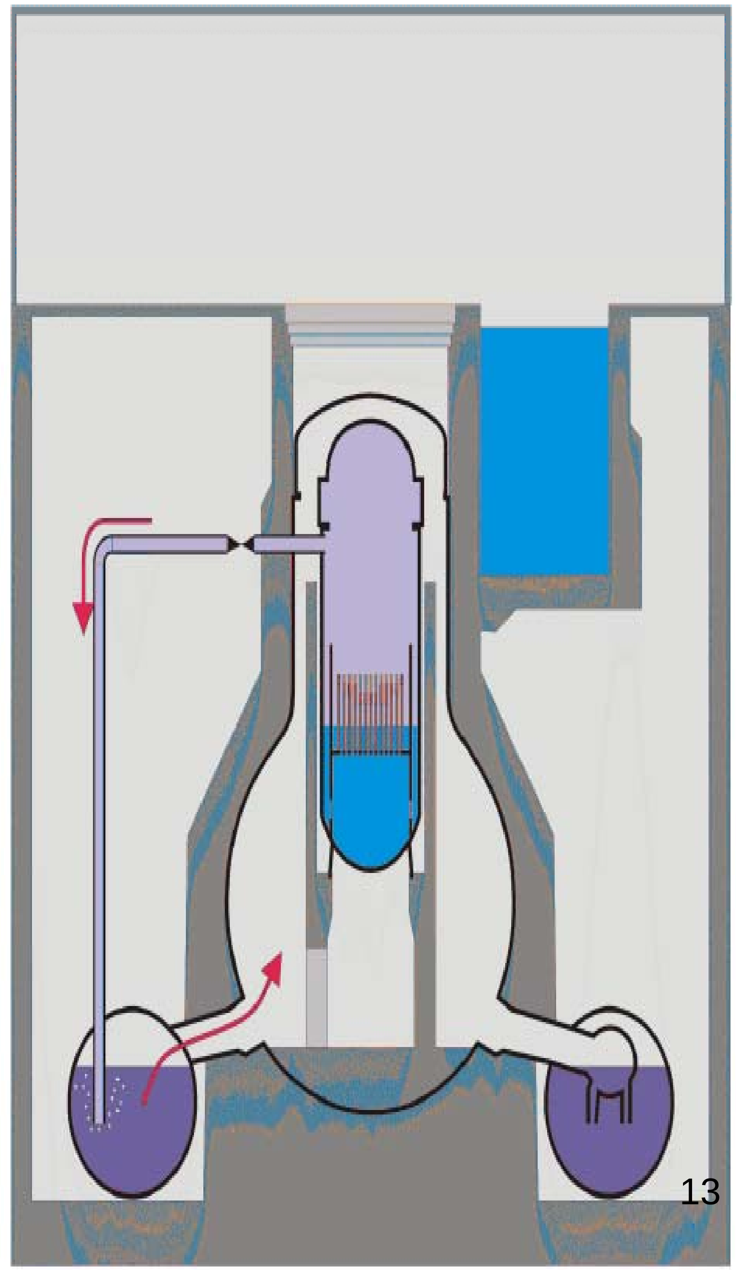




- Core exposed and Cladding temperatures rise, but still no significant core damage
- ~2/3 of the core exposed Cladding temperature exceeds ~900°C
- Balooning / Breaking of the cladding
- Release of fission products from the fuel rod gaps



- Release of fission products Xenon, Cesium, Iodine,…during melt down. Uranium/Plutonium remain in core
- Airborne Aerosols Discharge through valves into water of the condensation chamber
- Pool scrubbing binds a fraction of Aerosols in the water
- Xenon and remaining aerosols enter the Dry-Well. Design Pressure 4-5 bar
- Actual pressure up to 8 bars
- Normal inert gas filling (Nitrogen)
- Hydrogen from core oxidation
- Boiling condensation chamber (like a pressure cooker)
- Depressurization of the containment
- Unit 1: 12.3. 4:00
- Unit 2: 13.3 00:00
- Unit 3: 13.3. 8.41

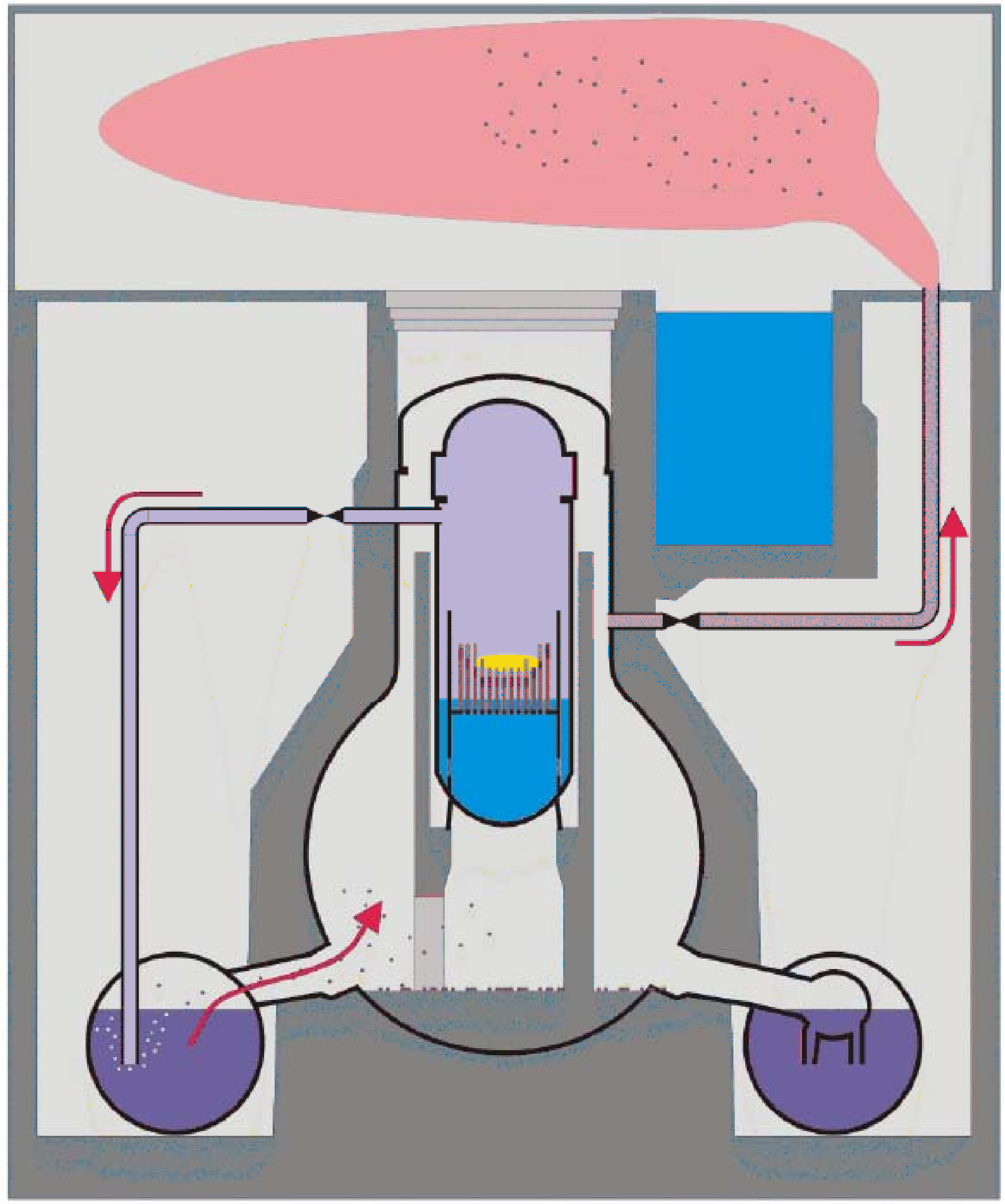


Positive and negative Aspects of depressurizing the containment

- ❑ Removes Energy from the Dry Well (only way left).
- ❑ Reducing the pressure to ~4 bar.
- ❑ Release of small amounts of Aerosols (Iodine, Cesium)
- ❑ Release of all noble gases.
- ❑ Release of Hydrogen.

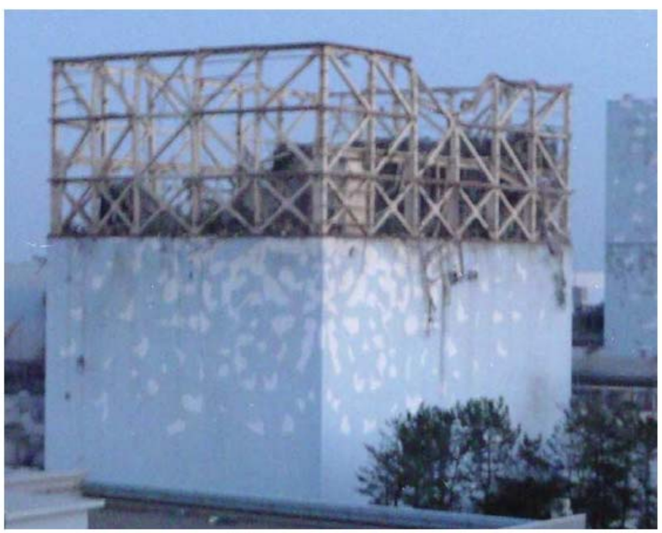
<u>Gas is released into the reactor building</u>

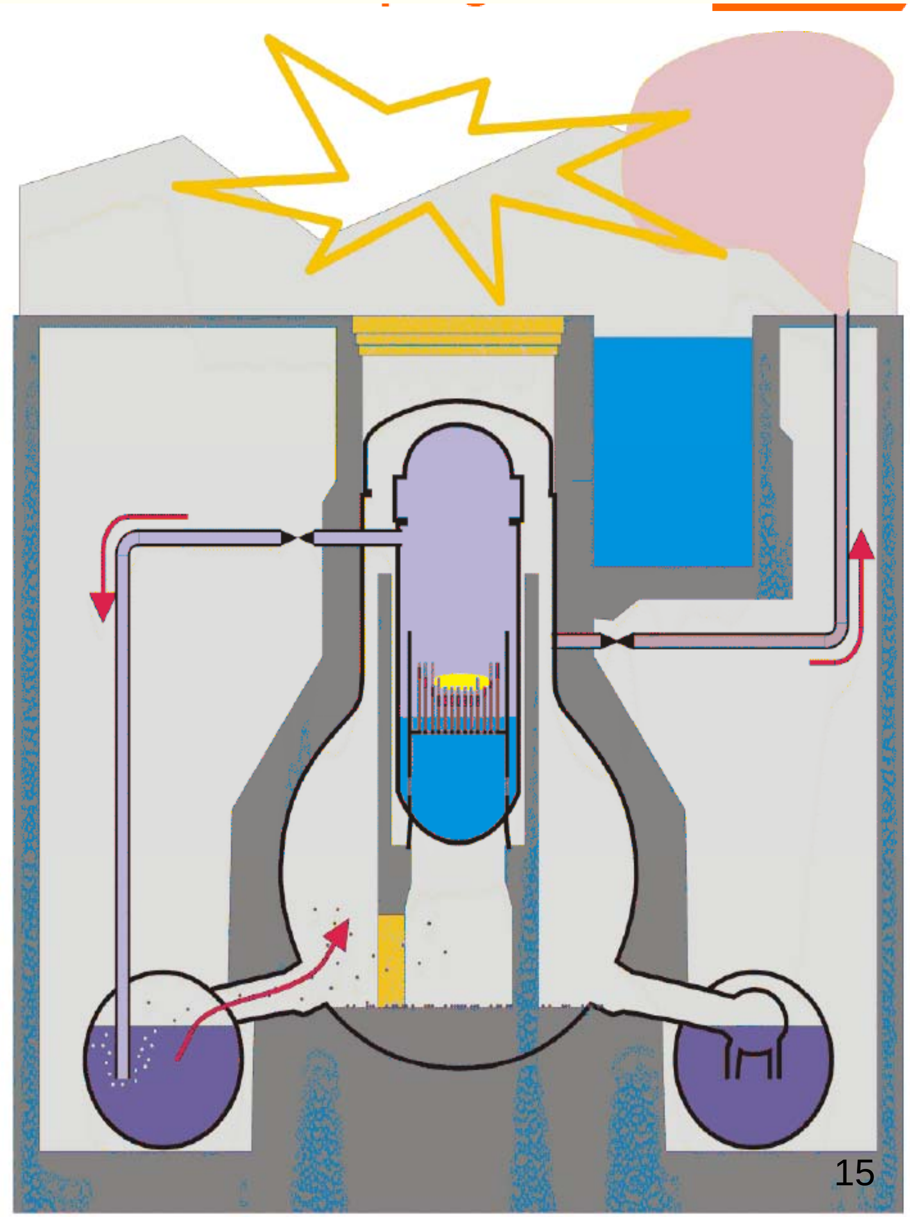
Hydrogen is flammable



Unit 1 und 3

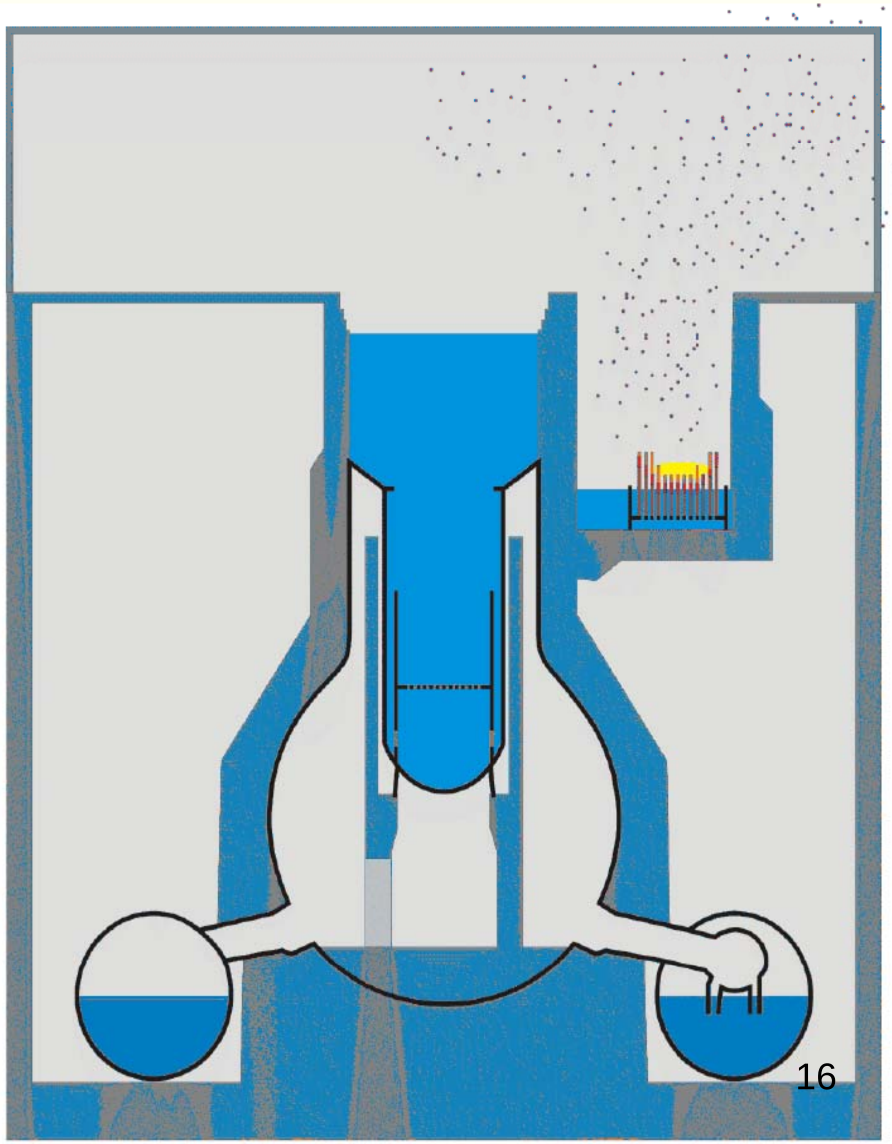
- ❖ **Hydrogen burn inside the reactor building. Destruction of the steel-frame roof**
- ❖ **Reinforced concrete reactor building seems undamaged.**





Fukushima Unit # 4

- Due to maintenance in Unit 4 entire core stored in Fuel pool
- Spend fuel stored in Pool on Reactor service floor
- Leakage of the pools due to Earthquake? Or loss of cooling. Dry-out of the pools
- Consequences - Core uncover – Oxidation of cladding –Generation of Hydrogen



General sequence of events

- Earthquake caused automatic reactor trip
- Loss of external power and Startup of Emergency Diesel Generators
- Failure of Emergency Diesel Generators within 1hr due to tsunami flooding
- Complete loss of off-site and on-site electrical power (Station Blackout) rendering all the cooling sources unavailable
- Batteries remained available for only 08 hrs
- Heat-up of core due to loss of cooling - system pressure increased

General sequence of events

- Loss of reactor core water from safety/relief valves to suppression pools
- Core uncovered and heat-up of fuel and cladding
- Metal water reaction resulting in hydrogen production
- Pressure in the containment drywell rose as wet well became very hot
- The Drywell containment was vented to reactor building
- Hydrogen accumulated at the top of reactor building
- Igniters failed as electricity was not available
- Hydrogen explosion in reactor building of units 1 & 3 occurred on 12 and 14 March respectively.
- Explosion occurred on15 March in unit- 2, possibly damaging the pressure suppression system

General sequence of events

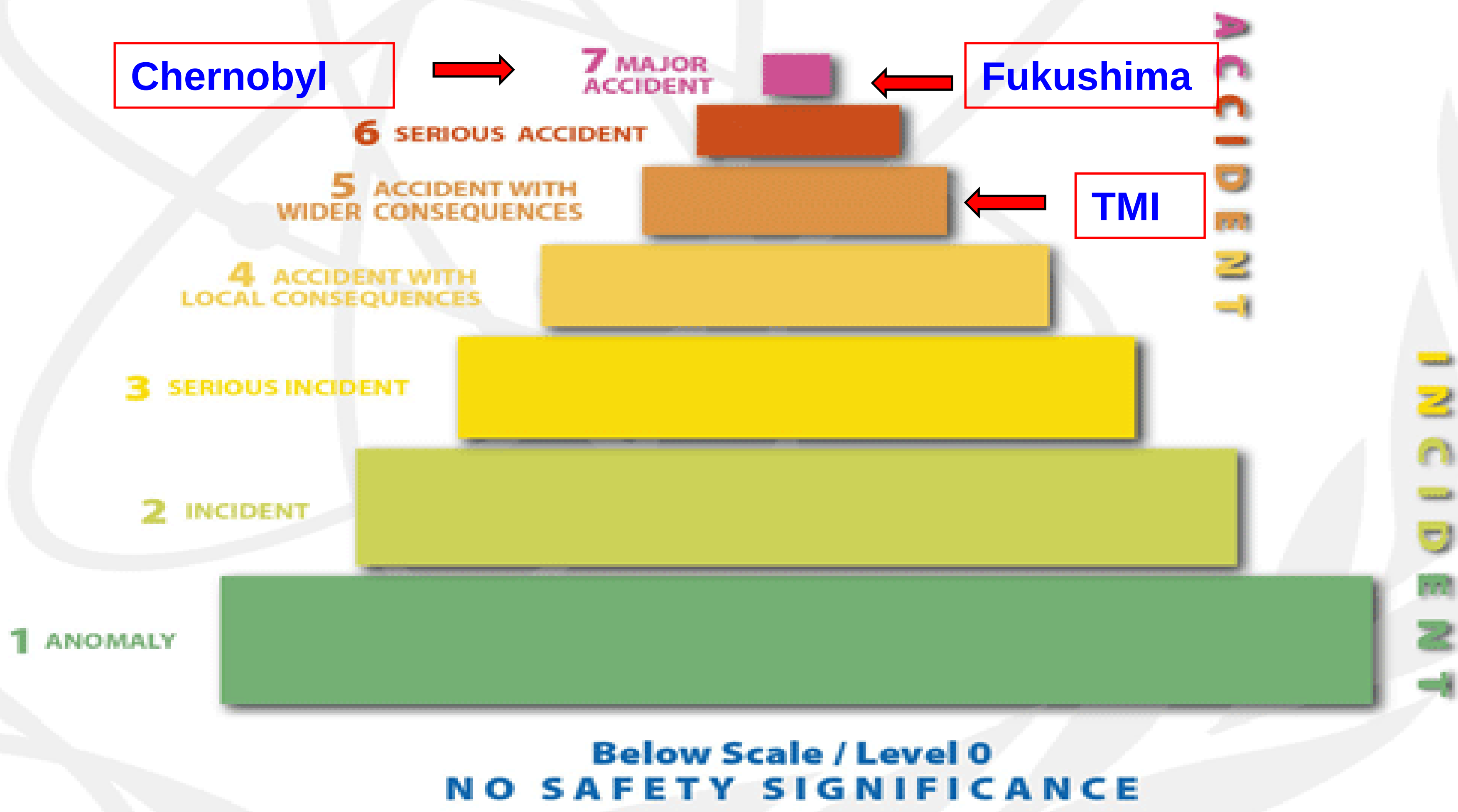
SEQUENCE OF EVENTS AT UNIT- 4

- The reactor core was de-fuelled in November so it was empty and all the fuel was in the spent fuel pool
- This fuel still had appreciable decay heat
- Water in the spent fuel pool boiled-off and metal water reaction started generating hydrogen gas
- Fire in spent fuel pool due to high temperature
- An explosion caused by hydrogen accumulating near the spent fuel pool damaged the rooftop area

Radioactivity released into the environment from reactor building of unit 1, 3 and 4.


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

International Nuclear Event Scale (INES)



MAJOR LESSONS LEARNED

Major Lessons Learned so Far

- **The details of the accident are still not available – it is too early to draw all lessons learned – major lessons listed**
  - The concept of design basis for natural events needs to be revised in view of the geological and climatic changes
  - Re-analyze design features of NPP against SBO
  - Current regulatory requirements needs to be expanded and strengthened
- Re-evaluation of plants to withstand extreme man-made events also
- Re-evaluation of design features for controlling and removing hydrogen in the reactor and fuel buildings

MAJOR LESSONS LEARNED SO FAR

- Disaster planning should be for multiple emergencies
- Emergency plan and physical security arrangements
- Accident management strategies should be based on failure of multiple units – deal with common cause failures
- Civil liability regime should be re-assessed with regards to multiple units failure
- Layout of the plants to be revised for better handling of emergencies
- Long Term Operation (Life extension) to older Nuclear power plants- Need to be reassessed and upgraded – before allowing further operation