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The Fukushima Daiichi Incident

1. Plant Design
2. Accident Progression
3. Radiological releases
4. Spent fuel pools
5. Sources of Information

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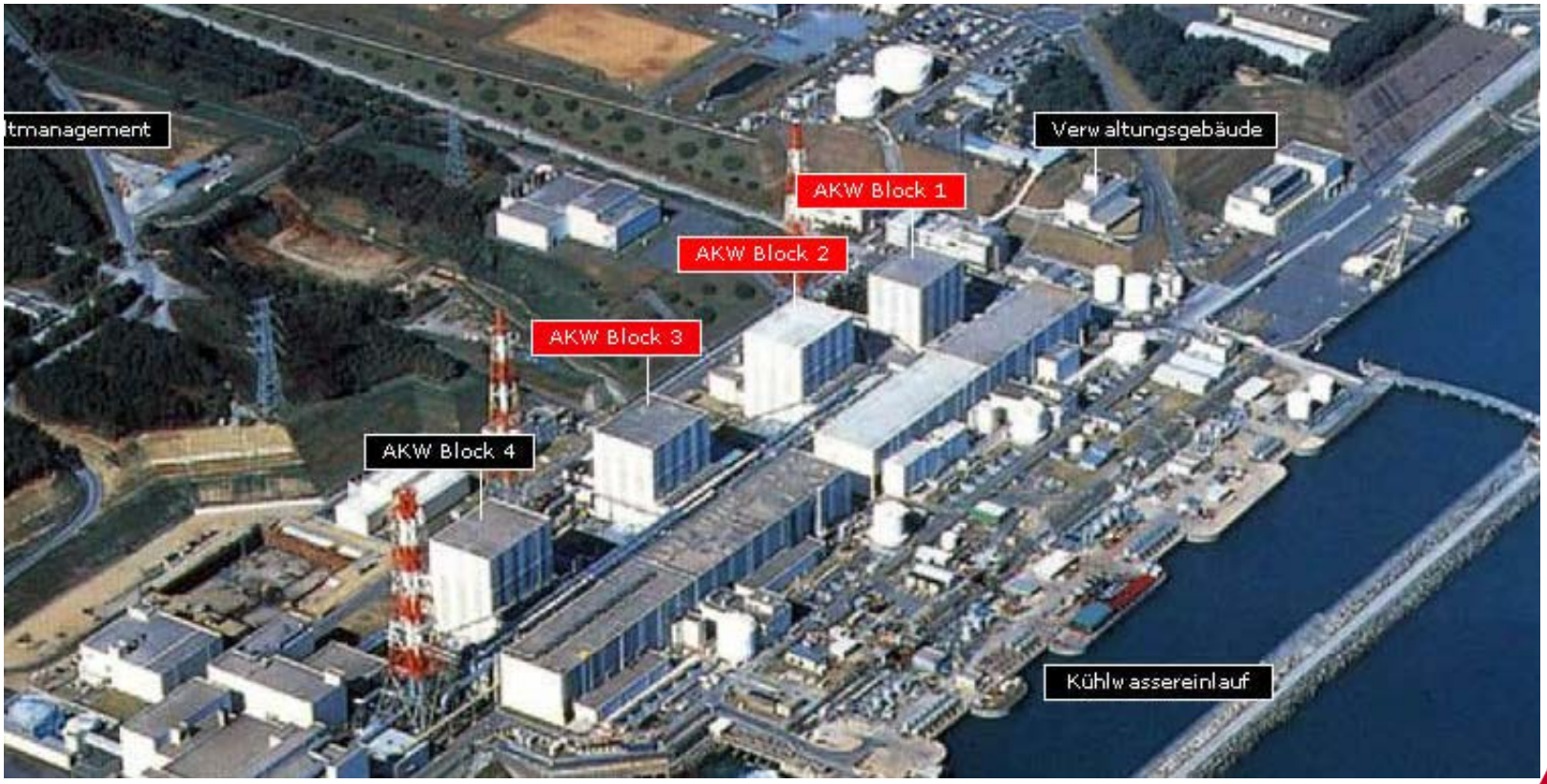
The Fukushima Daiichi Incident
1. Plant Design

- **Fukushima Daiichi (Plant I)**
  - **Unit I - GE Mark I BWR (439 MW), Operating since 1971**
  - **Unit II-IV - GE Mark I BWR (760 MW), Operating since 1974**



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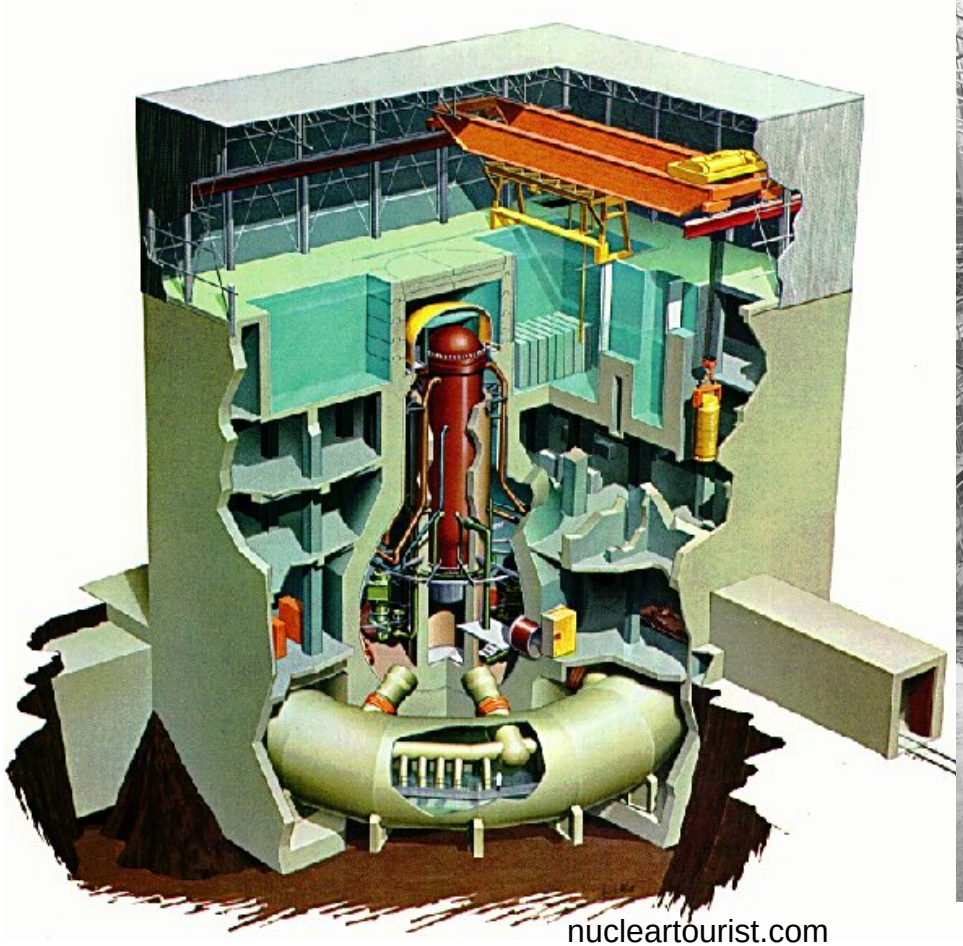
1. Plant Design

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



nucleartourist.com

- Containment
  - Pear-shaped Dry-Well
  - Torus-shaped Wet-Well

en.wikipedia.org/wiki/Browns_Ferry_Nuclear_Power_Plant

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1. Plant Design

- Service Floor

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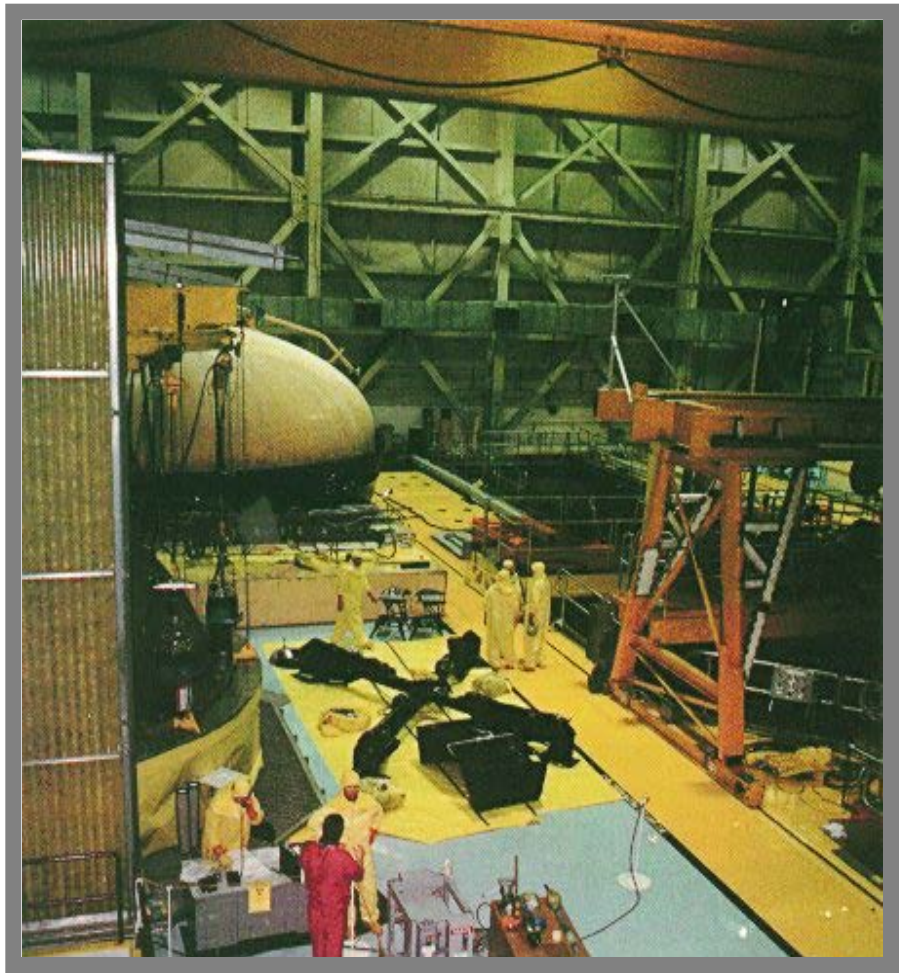
The Fukushima Daiichi Incident
1. Plant Design

- Lifting the Containment closure head



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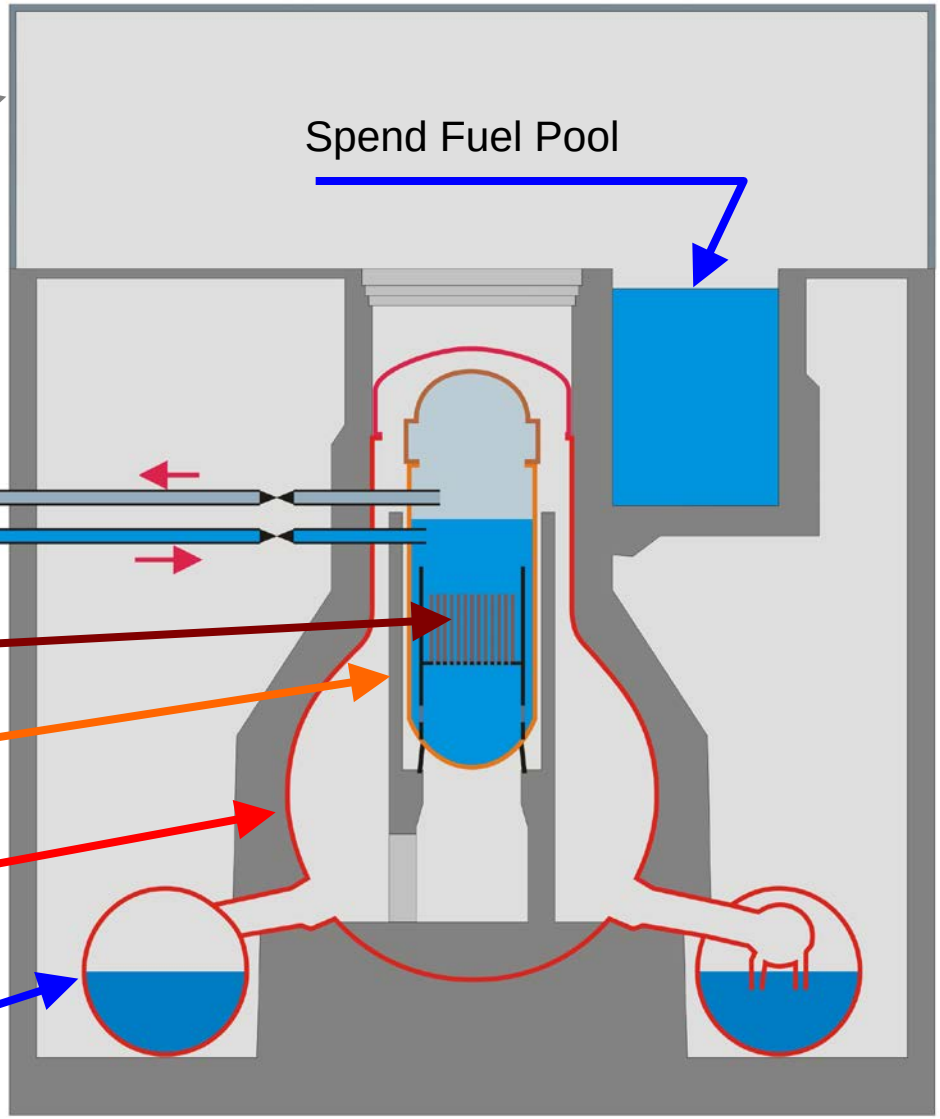
The Fukushima Daiichi Incident

1. Plant Design

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



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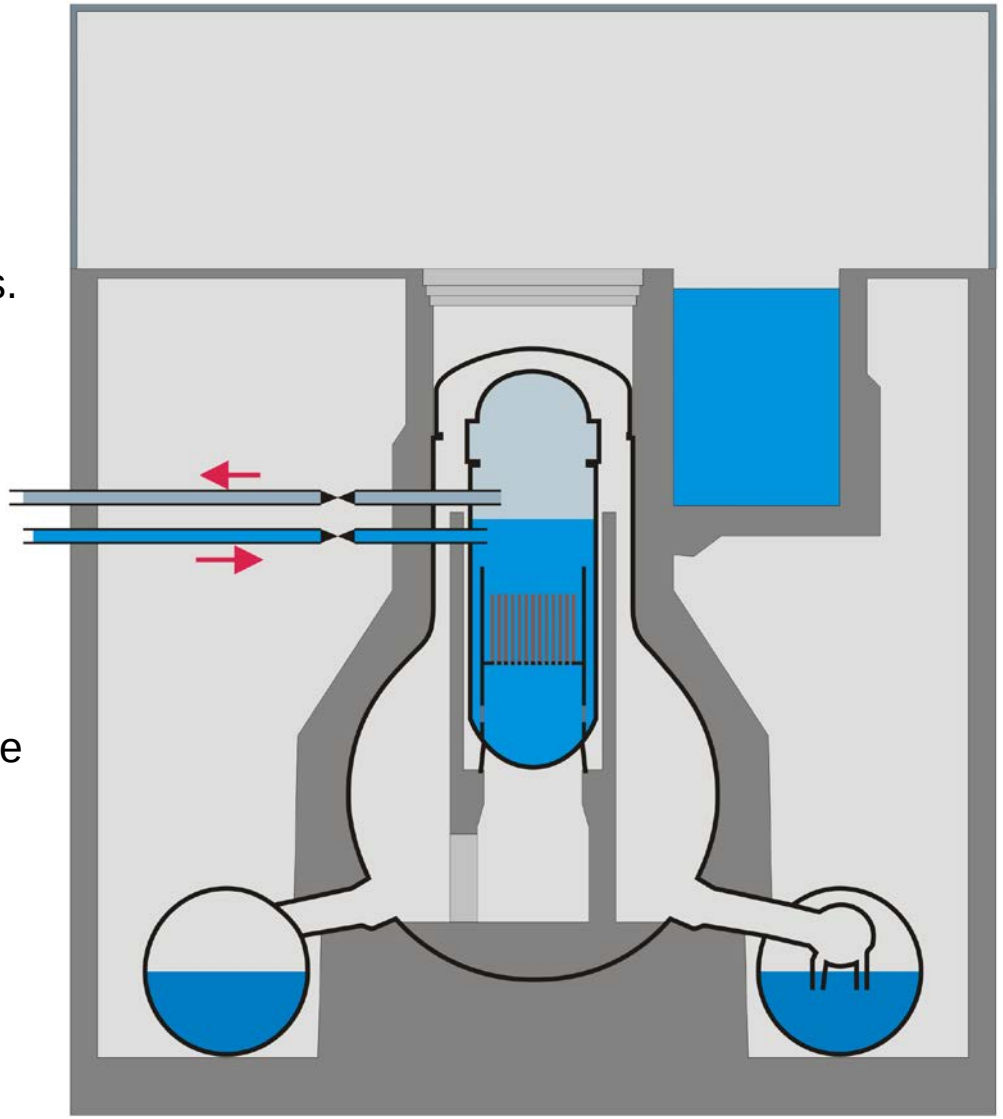
The Fukushima Daiichi Incident
2. Accident progression

- 11.3.2011 14:46 - Earthquake
  - Magnitude 9
  - Power grid in northern Japan fails.
  - Reactors themselves are mainly undamaged.

- SCRAM
  - Power generation due to fission of uranium stops
  - Heat generation due to radioactive decay of fission products
    - After Scram ~6%
    - After 1 Day ~1%
    - After 5 Days ~0.5%



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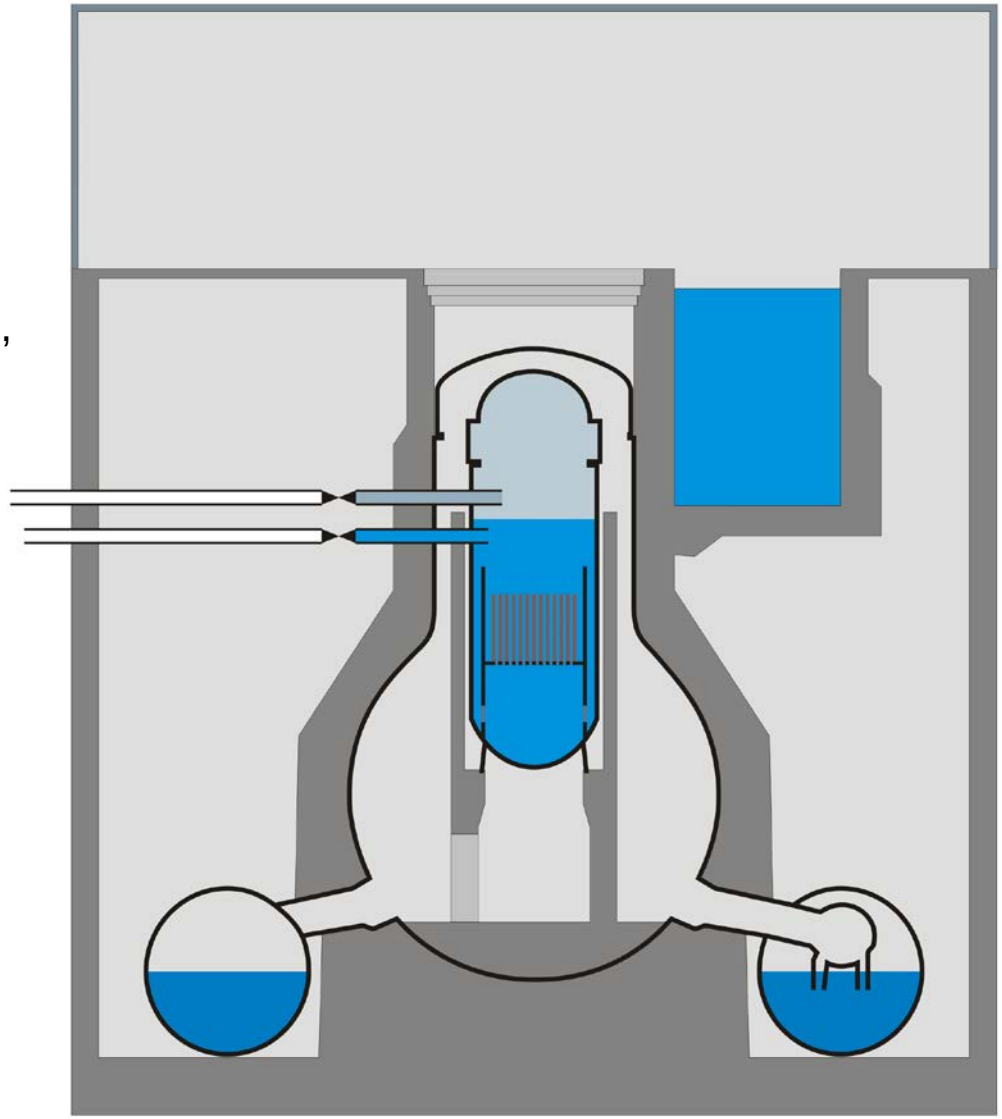
The Fukushima Daiichi Incident
2. Accident progression

- Containment Isolation
  - Closing of all non-safety related penetrations of the containment
  - Cuts off machine hall
  - If containment isolation succeeds, a large early release of fission products is highly unlikely.
- Diesel generators start
  - Emergency core cooling systems are supplied.
- Plant is in a stable save state.



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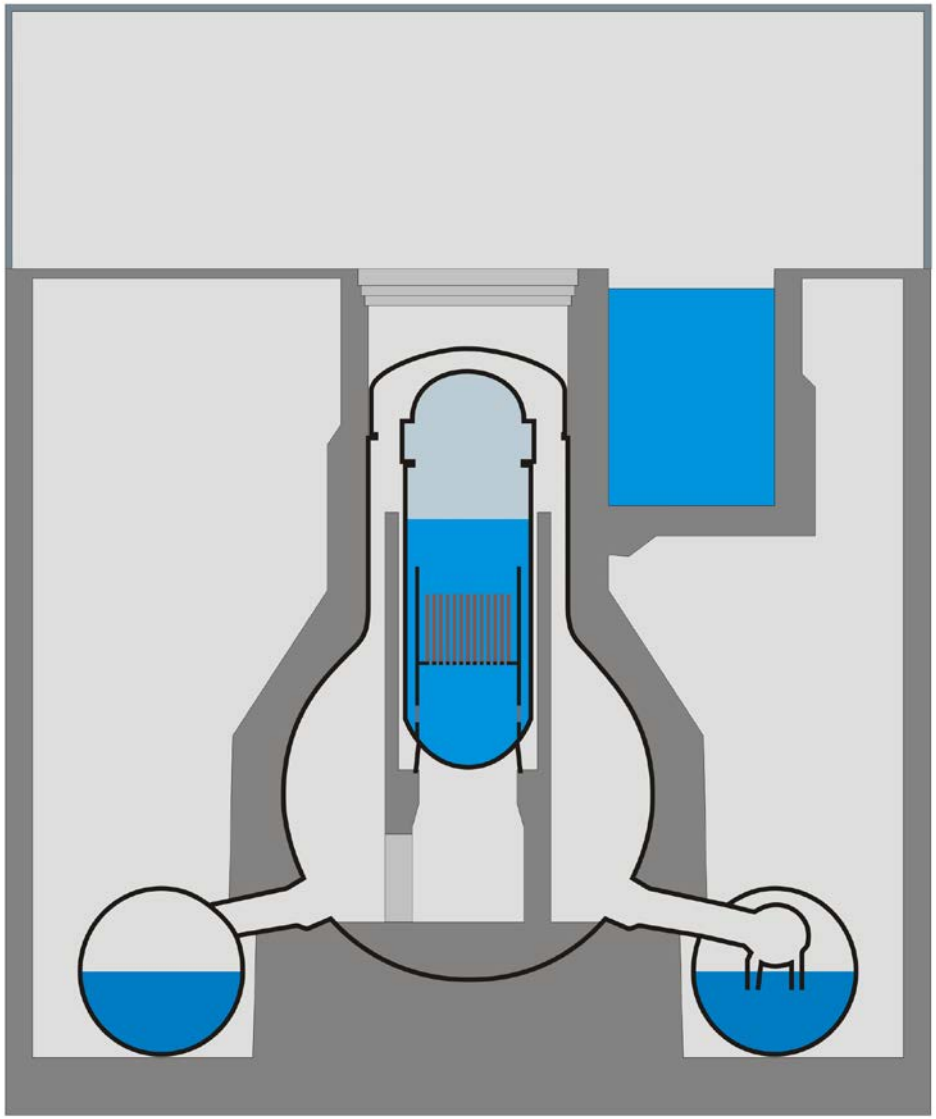
The Fukushima Daiichi Incident
2. Accident progression

- 11.3. 15:41 Tsunami hits the plant
  - Plant Design for Tsunami height of up to 6.5m.
  - Actual Tsunami height >7m
  - Flooding of
    - Diesel generators and/or
    - Essential service water building cooling the generators
- Station Blackout
  - Common cause failure of the power supply
  - Only batteries are still available
  - Failure of all but one emergency core cooling system.



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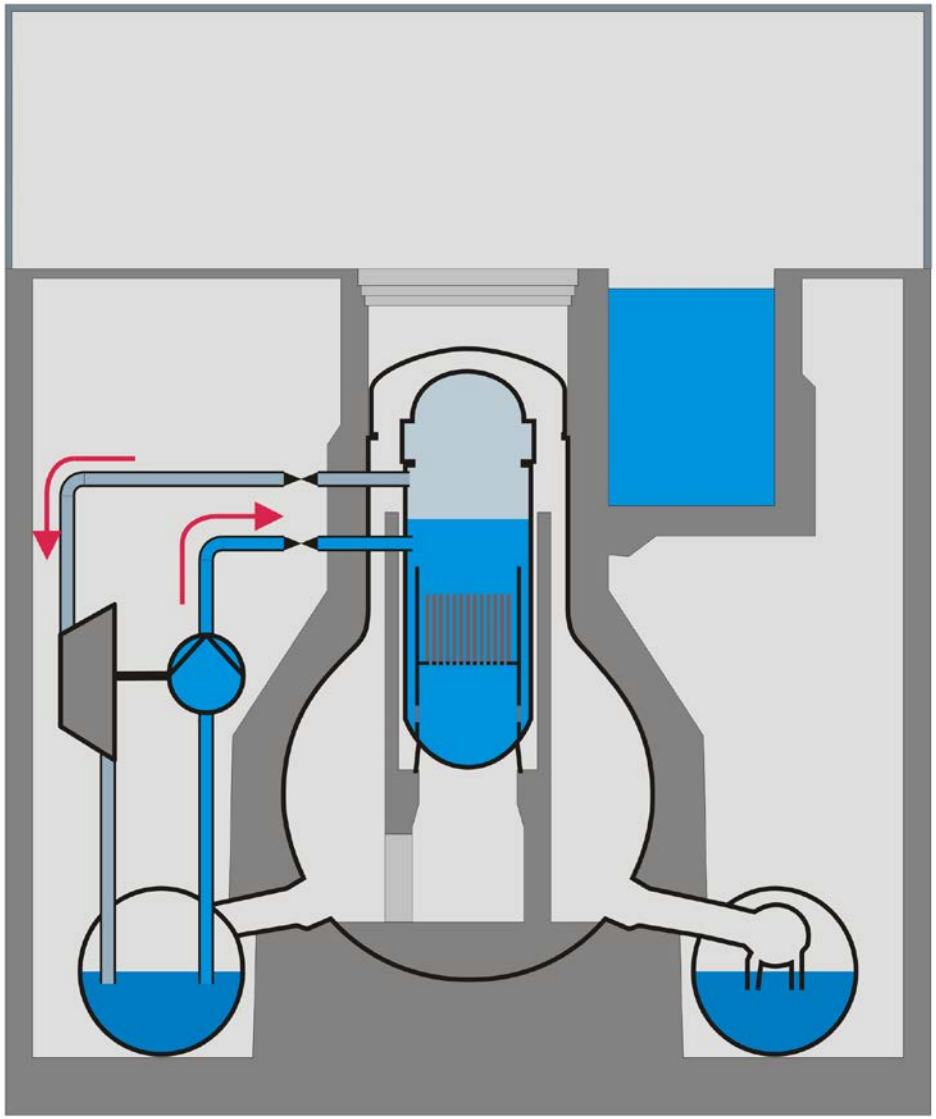
The Fukushima Daiichi Incident
2. Accident progression

- Reactor Core Isolation Pump still available
  - Steam from the reactor drives a Turbine.
  - Steam gets condensed in the wet-well
  - Turbine drives a pump
  - Water from the wet-well gets pumped in reactor
  - Necessary:
    - Battery power
    - Temperature in the wet-well must be below 100°C
- As there is no heat removal from the building, the core isolation pump cannot work infinitely.



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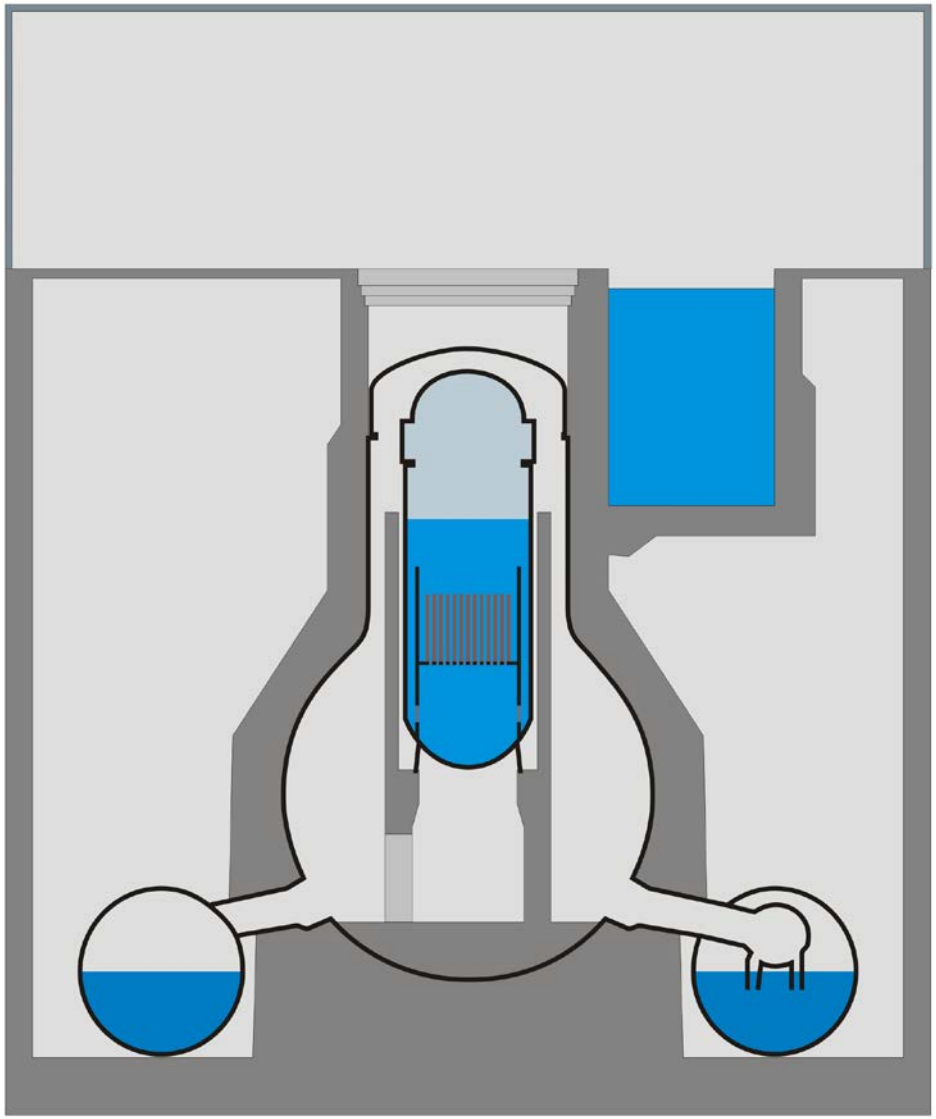
The Fukushima Daiichi Incident
2. Accident progression

- Reactor Isolation pump stops
  - 11.3. 16:36 in Unit 1 (Batteries depleted)
  - 14.3. 13:25 in Unit 2 (Pump failure)
  - 13.3. 2:44 in Unit 3 (Batteries depleted)
- Decay heat produces steam in reactor pressure Vessel
  - Pressure rising
- Opening the steam release valves
  - Discharge steam into the wet-well
- Descending liquid level in the reactor pressure vessel



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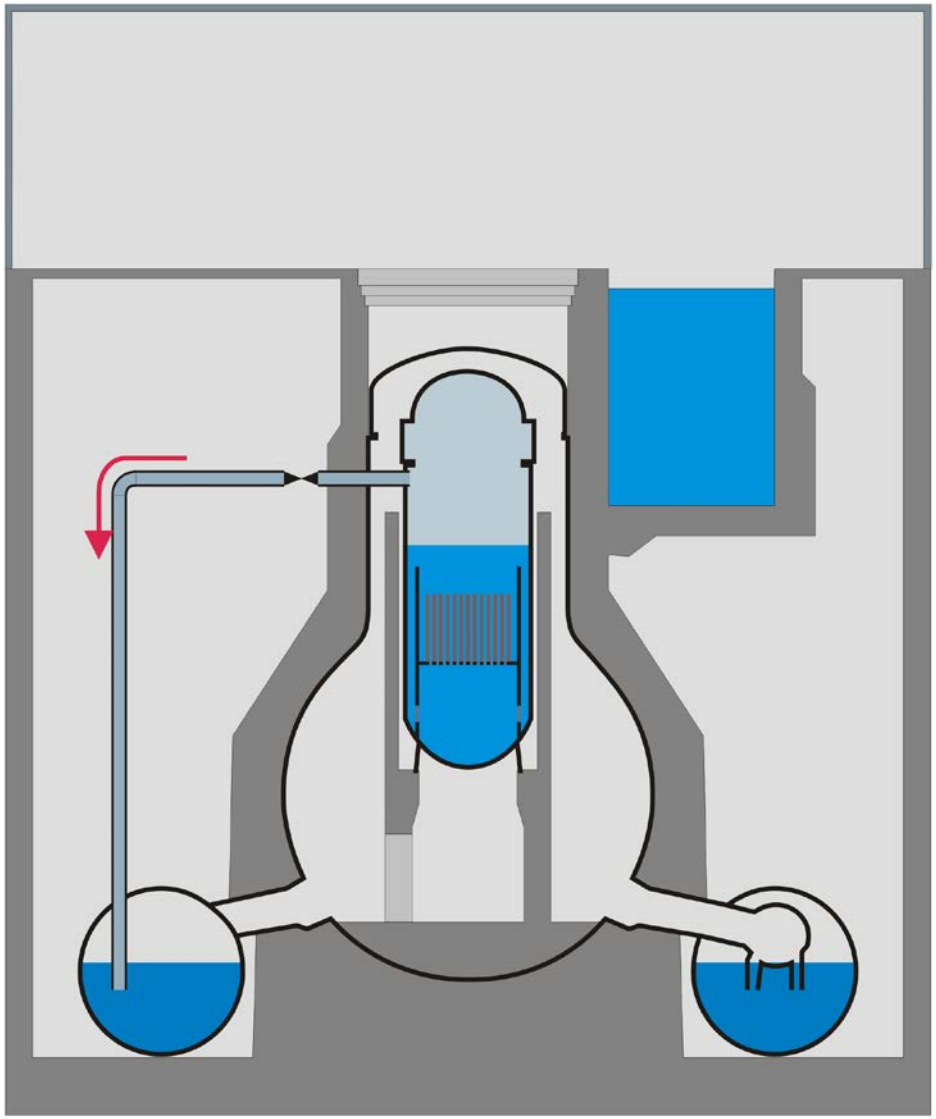

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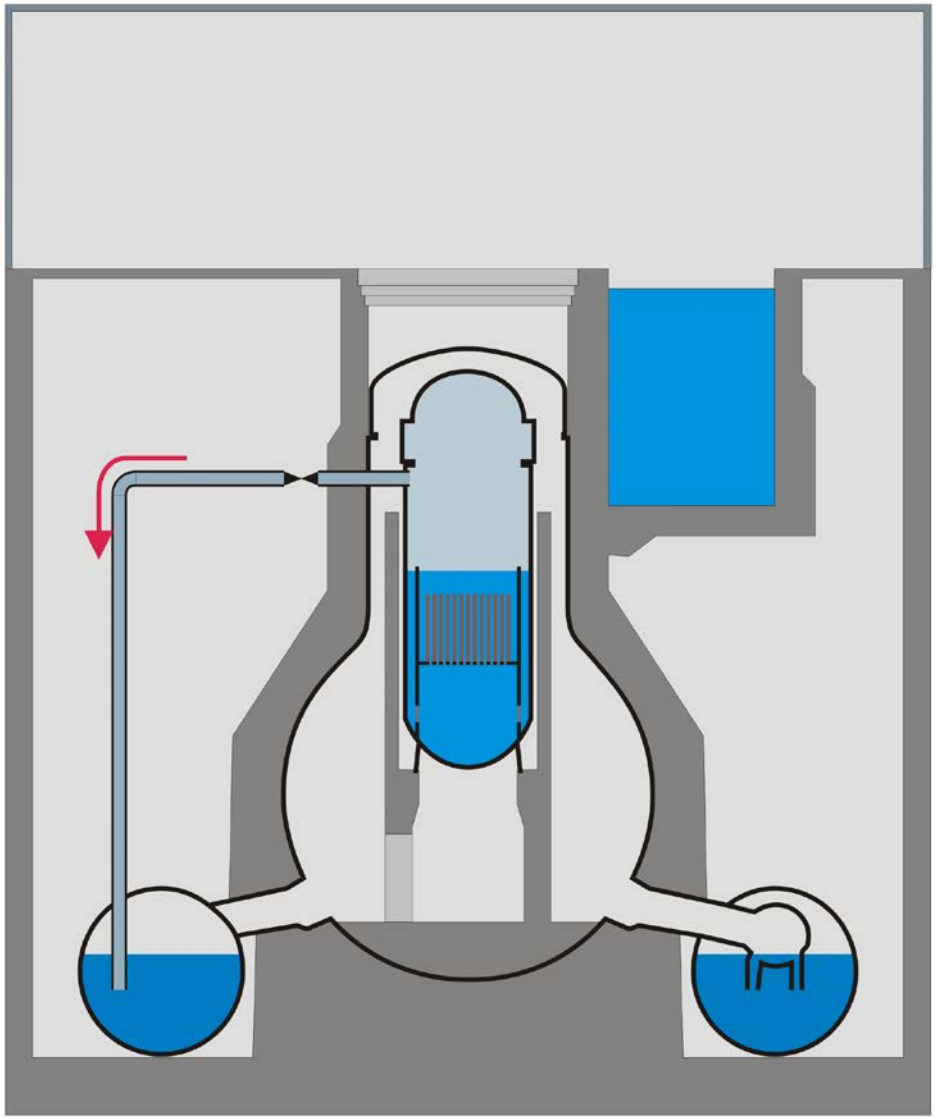

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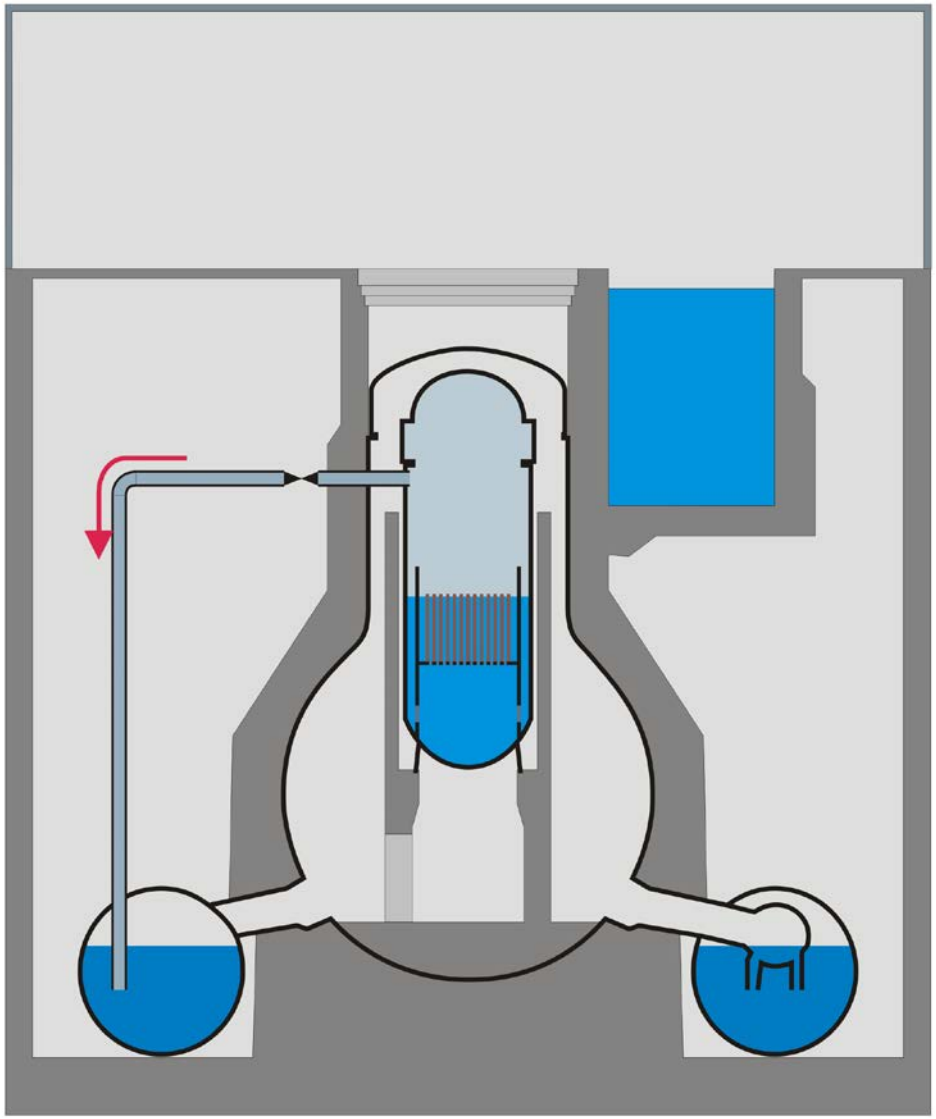

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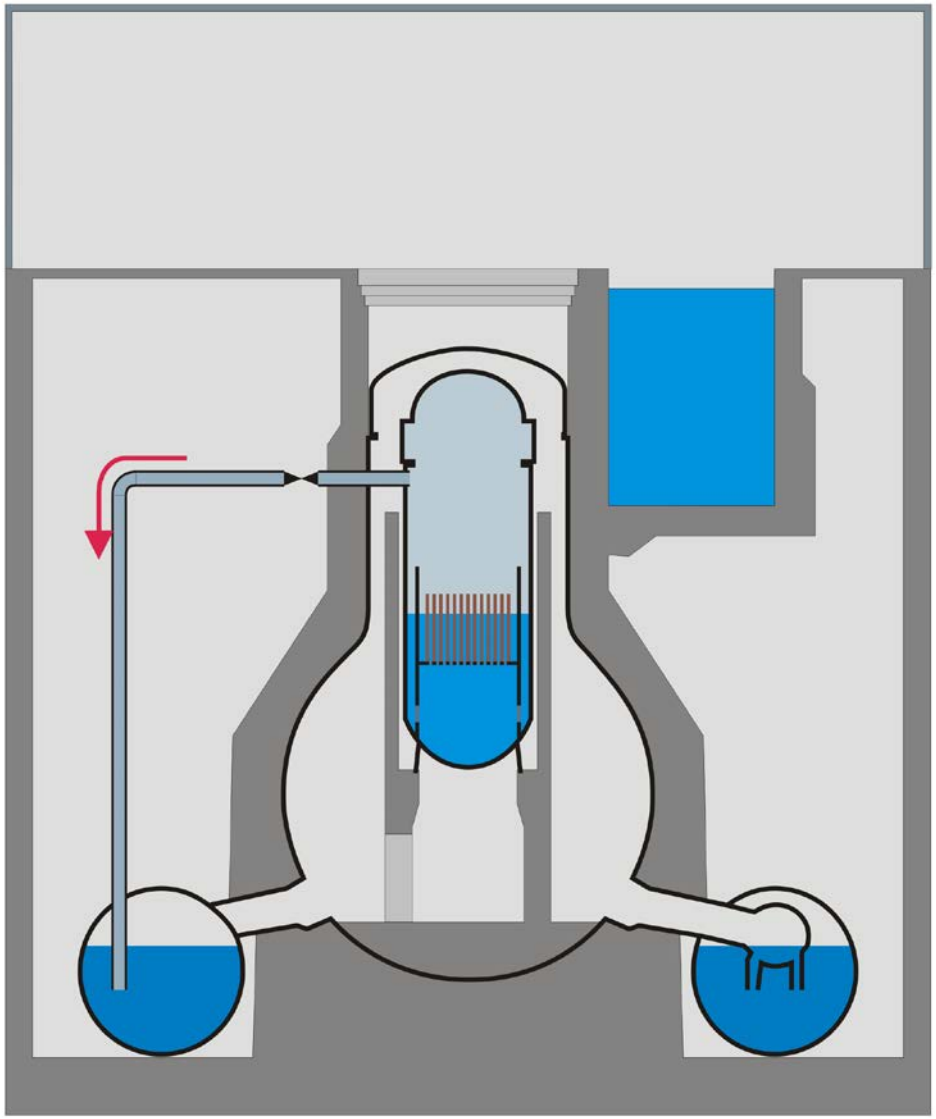

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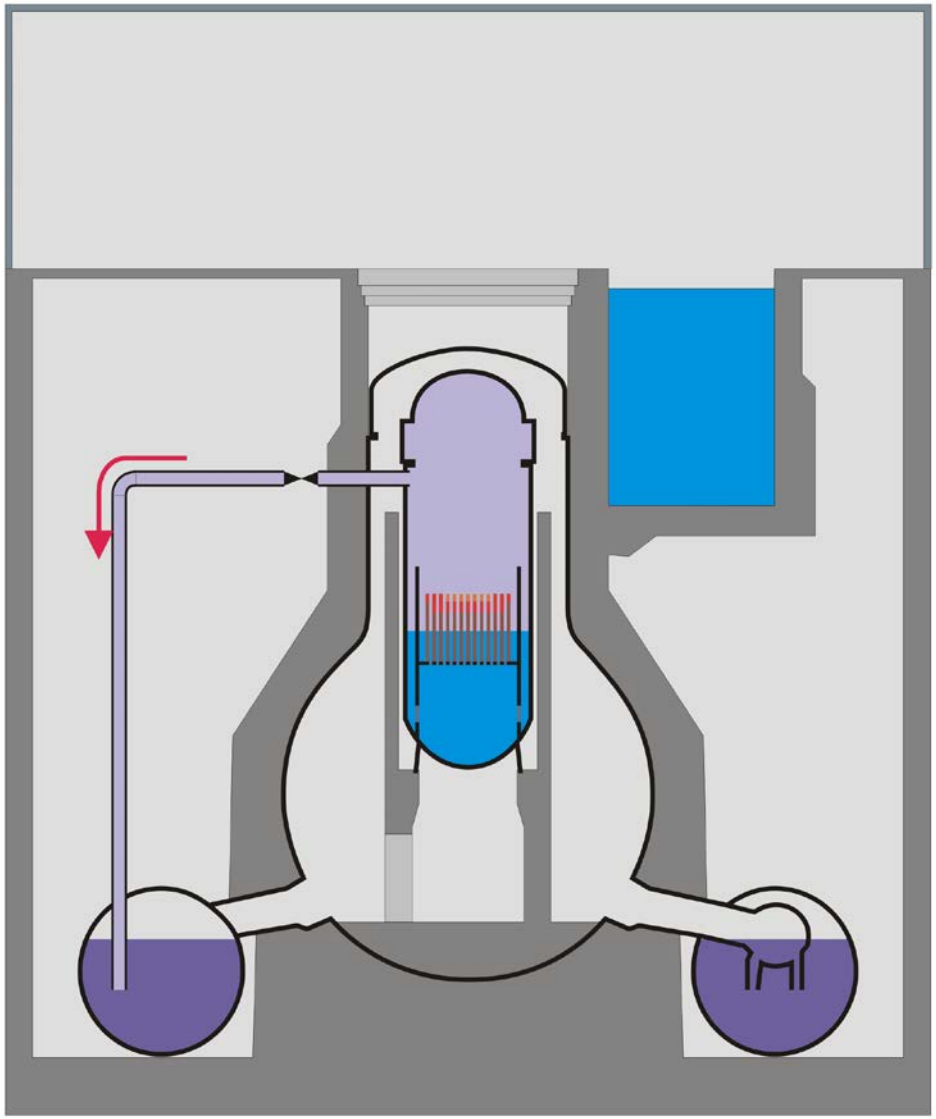
2. Accident progression

- Measured, and here referenced, liquid level is the collapsed level. The actual liquid level lies higher due to the steam bubbles in the liquid

- ~50% of the core exposed
  - Cladding temperatures rise, but still no significant core damage

- ~2/3 of the core exposed
  - Cladding temperature exceeds ~900°C
  - Ballooning / Breaking of the cladding
  - Release of fission products from the fuel rod gaps



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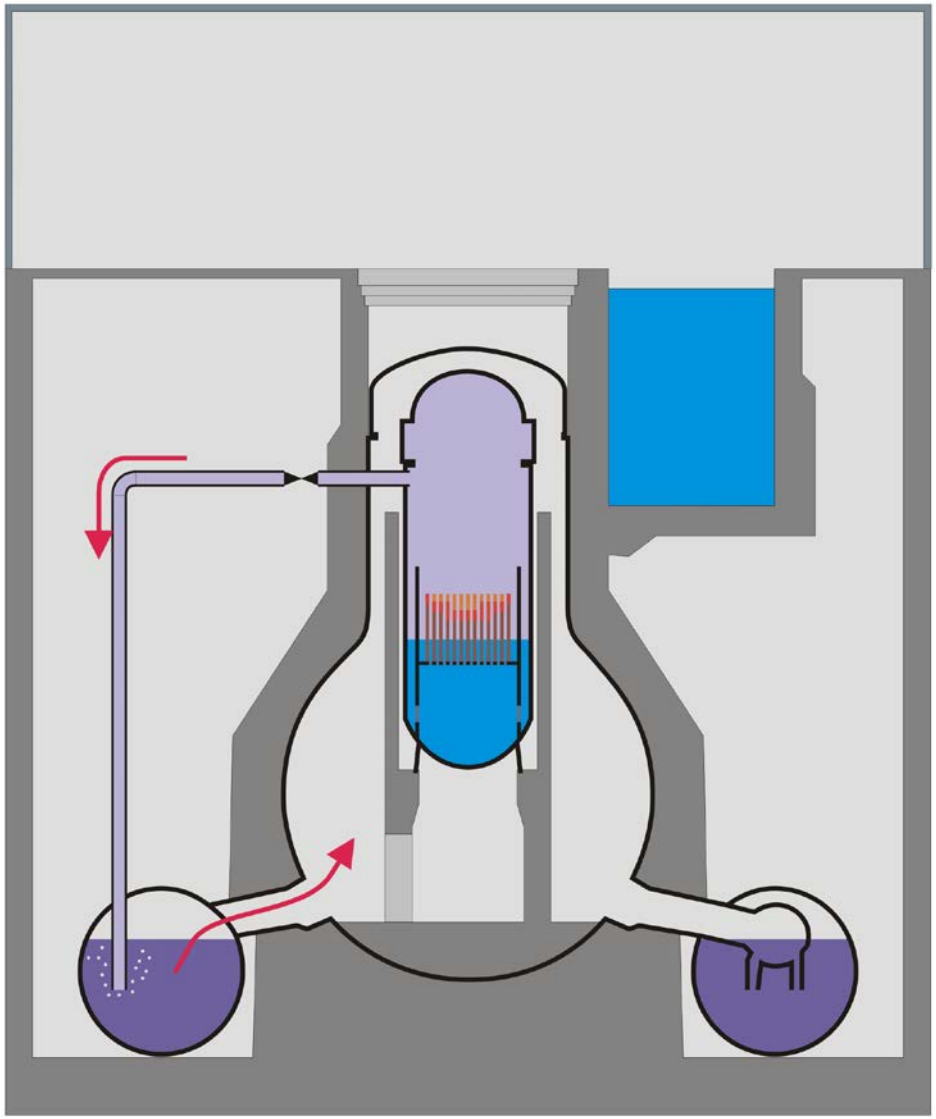
2. Accident progression

- ~3/4 of the core exposed
  - Cladding exceeds ~1200°C
  - Zirconium in the cladding starts to burn under steam atmosphere

    $Zr + 2H_20 \rightarrow ZrO_2 + 2H_2$
  - Exothermal reaction further heats the core
  - Generation of hydrogen
    - Unit 1: 300-600kg
    - Unit 2/3: 300-1000kg
  - Hydrogen gets pushed via wet-well vacuum breakers into the dry-well



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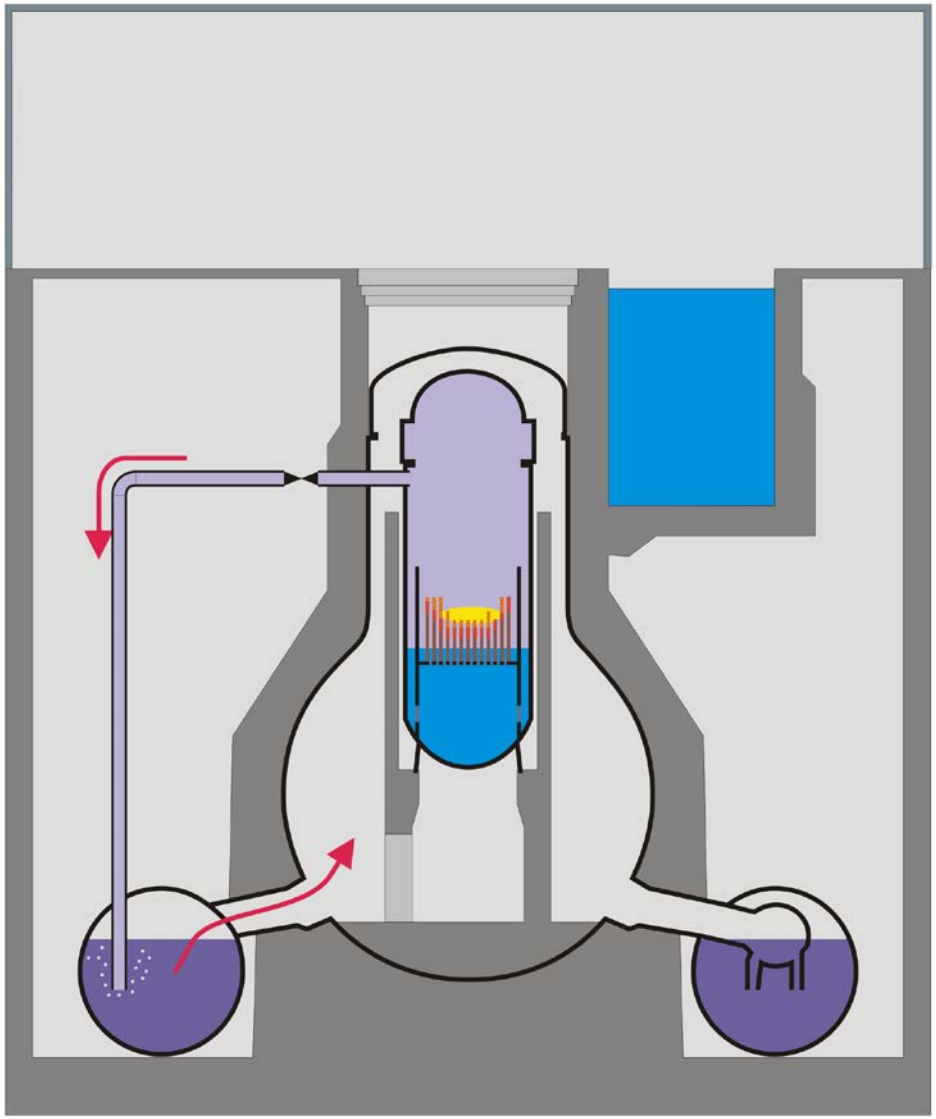
2. Accident progression

- at ~1800°C [Unit 1,2,3]
  - Melting of the cladding
  - Melting of the steel structures
- at ~2500°C [Block 1,2]
  - Breaking of the fuel rods
  - Debris bed inside the core
- at ~2700°C [Block 1]
  - Melting of Uranium-Zirconium eutectics
- Restoration of the water supply stops accident in all 3 Units
  - Unit 1: 12.3. 20:20 (27h w.o. water)
  - Unit 2: 14.3. 20:33 (7h w.o. water)
  - Unit 3: 13.3. 9:38 (7h w.o. water)



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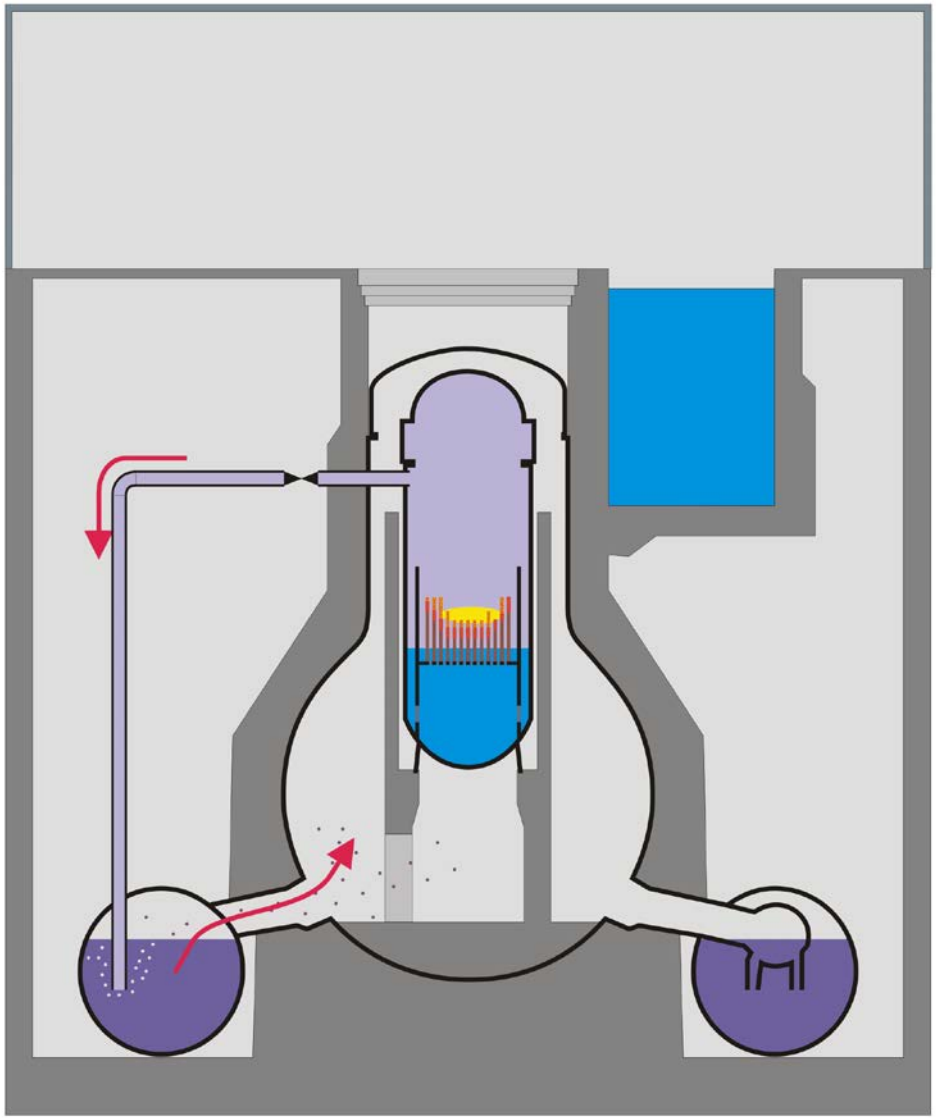
2. Accident progression

- Release of fission products during melt down
  - Xenon, cesium, iodine,…
  - Uranium/plutonium remain in core
  - Fission products condense to 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
  - Deposition of aerosols on surfaces further decontaminates air



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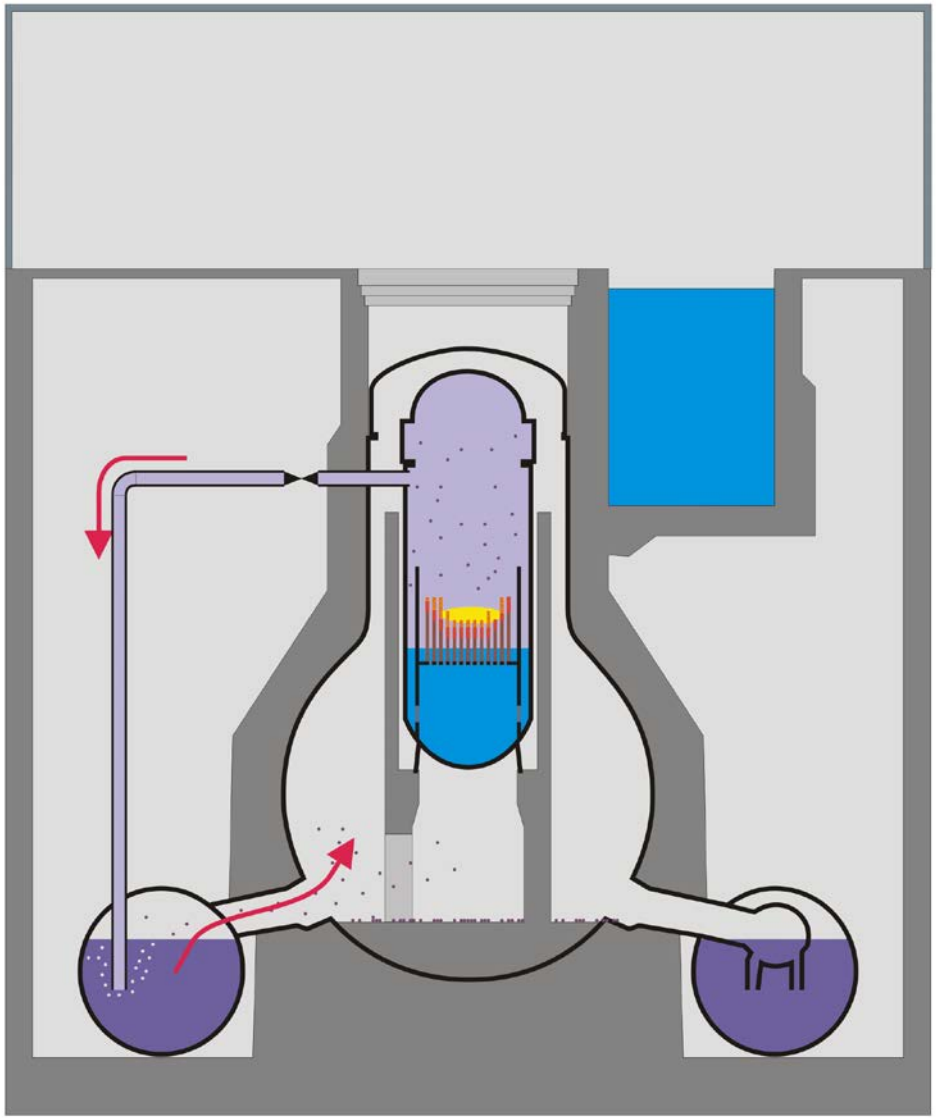
The Fukushima Daiichi Incident
2. Accident progression

- Containment
  - Last barrier between fission products and environment
  - Wall thickness ~3cm
  - Design pressure 4-5 bar
- Actual pressure up to 8 bars
  - Normal inert gas filled (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



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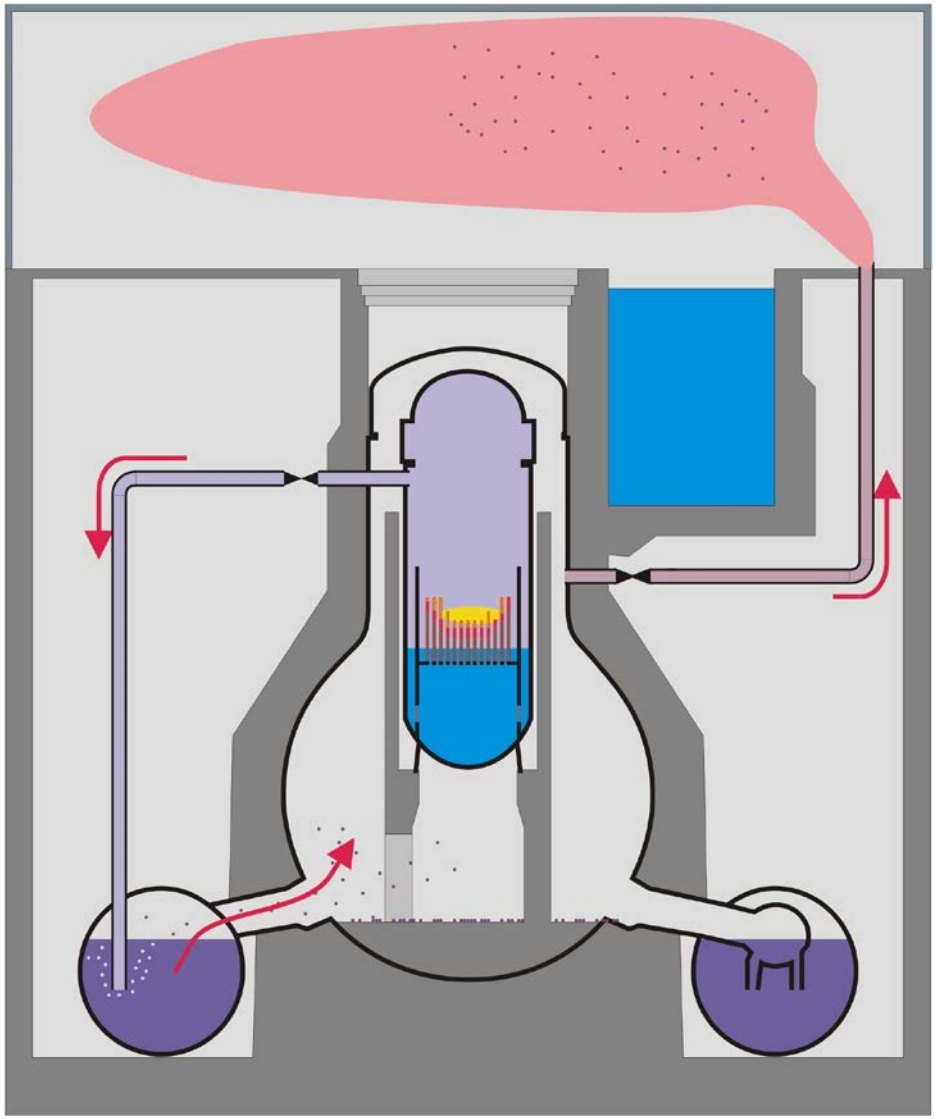
The Fukushima Daiichi Incident
2. Accident progression

- Positive and negative aspects of depressurizing the containment
  - Removes energy from the reactor building (only way left)
  - Reducing the pressure to ~4 bar
  - Release of small amounts of aerosols (Iodine, Cesium ~0.1%)
  - Release of all noble gases
  - Release of hydrogen
- Gas is released into the reactor service floor
  - Hydrogen is flammable



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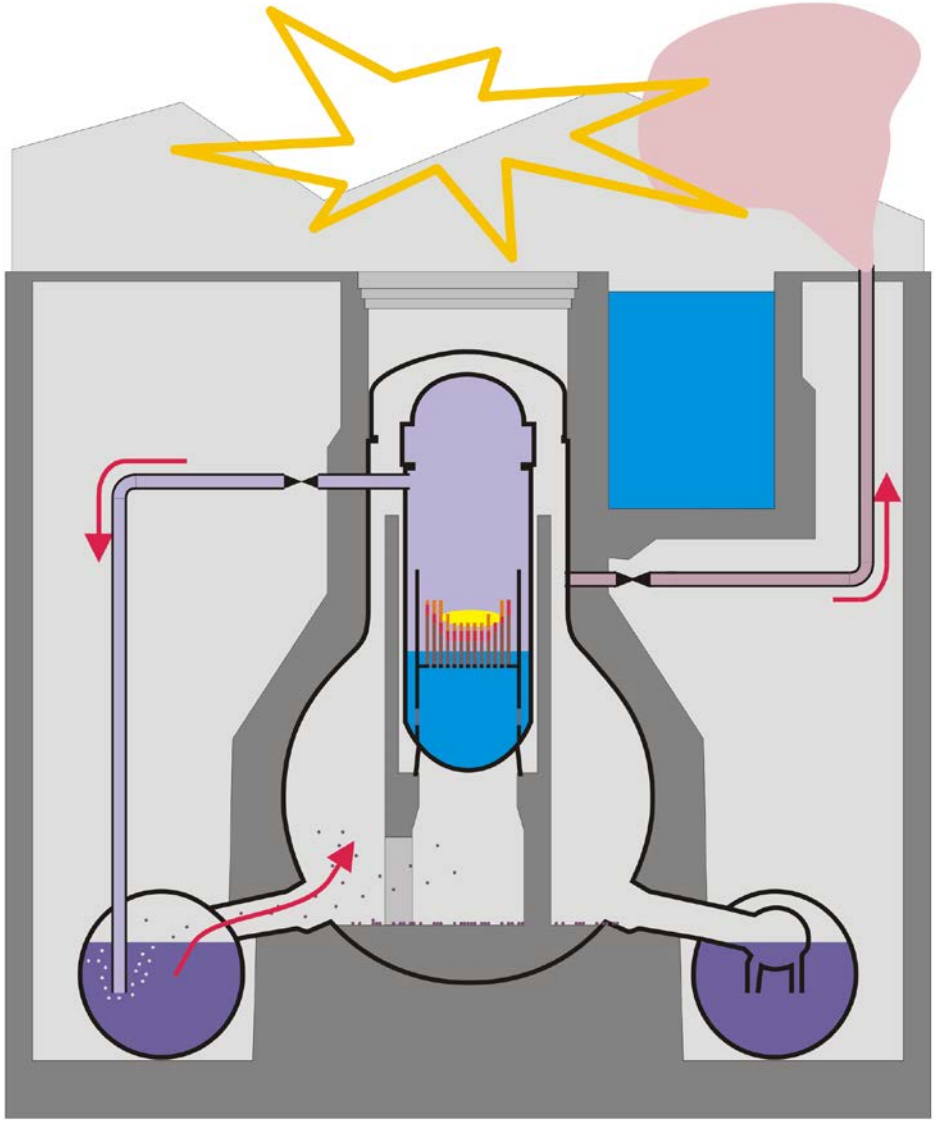
The Fukushima Daiichi Incident
2. Accident progression

- Unit 1 und 3
  - Hydrogen burn inside the reactor service floor
  - Destruction of the steel-frame roof
  - Reinforced concrete reactor building seems undamaged
  - Spectacular but minor safety relevance



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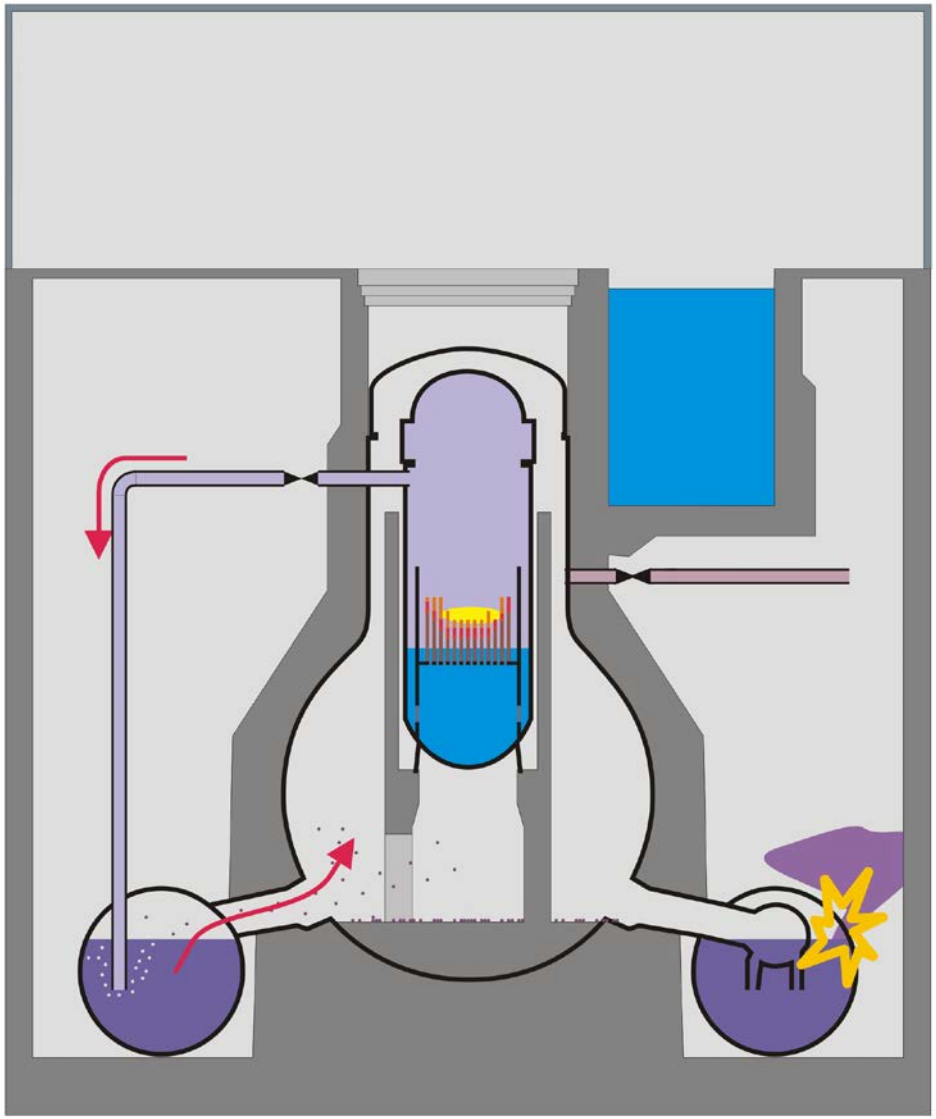
The Fukushima Daiichi Incident
2. Accident progression

- Unit 2
  - Hydrogen burn inside the reactor building
  - Probably damage to the condensation chamber (highly contaminated water)
  - Uncontrolled release of gas from the containment
  - **Release of fission products**
  - Temporal evacuation of the plant
  - High local dose rates on the plant site due to wreckage hinder further recovery work

- No clear information's why Unit 2 behaved differently



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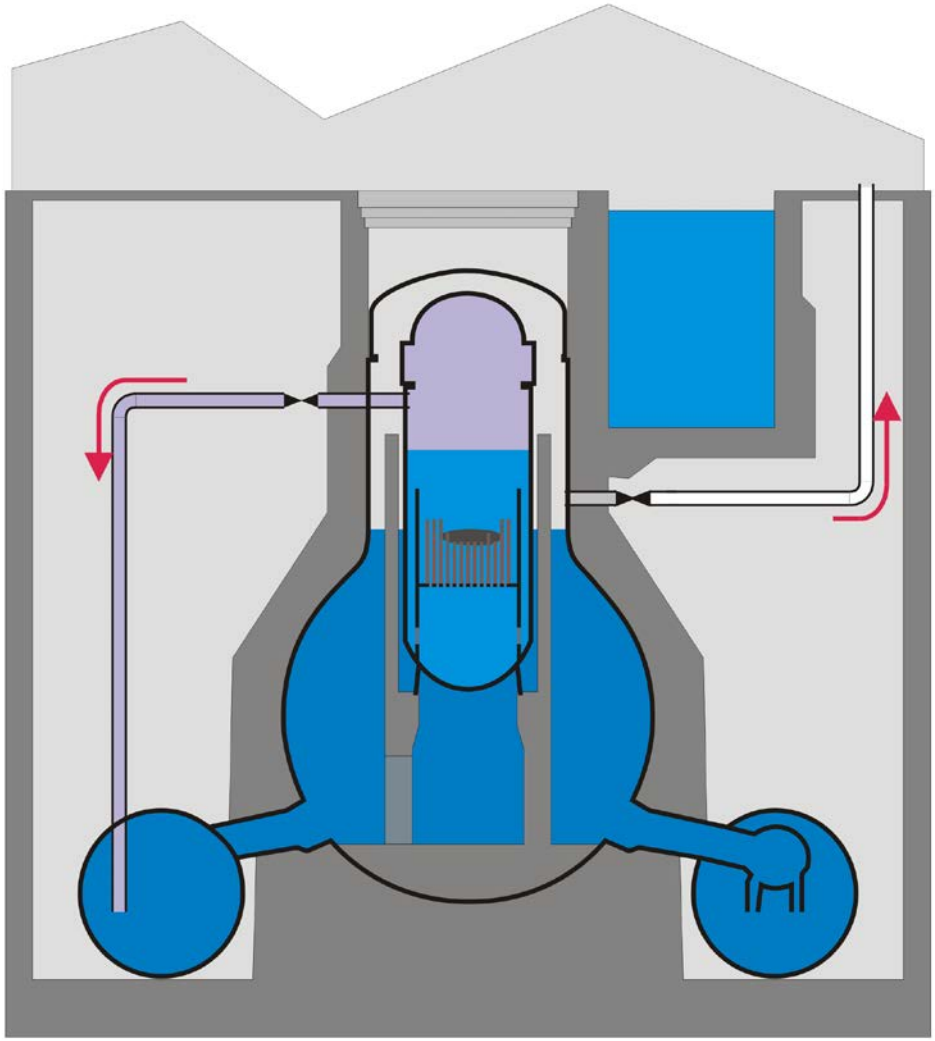
The Fukushima Daiichi Incident
2. Accident progression

- Current status of the Reactors
  - Core Damage in Unit 1,2, 3
  - Building damage due to various burns Unit 1-4
  - Reactor pressure vessels flooded in all Units with mobile pumps
  - At least containment in Unit 1 flooded
- Further cooling of the Reactors by releasing steam to the atmosphere
- Only small further releases of fission products can be expected



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3. Radiological releases

- Directly on the plant site
  - Before Explosion in Unit Block 2
    - Below 2 mSv/h
    - Mainly due to released radioactive noble gases
    - Measuring posts on west side. Maybe too small values measured due to wind
  - After Explosion in Unit 2 (Damage of the Containment)
    - Temporal peak values 12 mSv/h
    - (Origin not entirely clear)
    - Local peak values on site up to 400 mSv/h (wreckage / fragments?)
    - Currently stable dose on site at 5 mSv/h
    - Inside the buildings a lot more
  - Limiting time of exposure of the workers necessary

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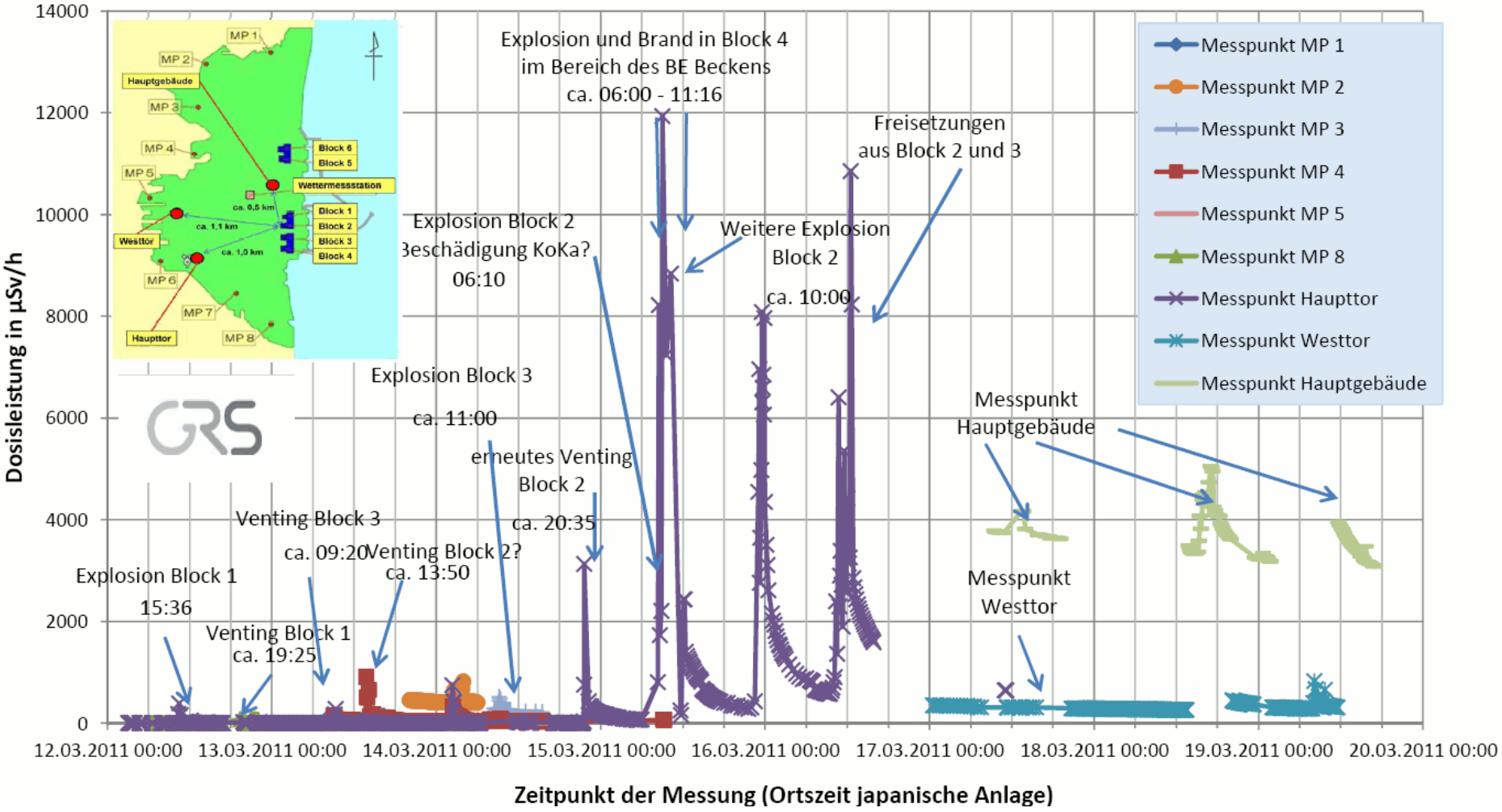
The Fukushima Daiichi Incident

3. Radiological releases



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The Fukushima Daiichi Incident
3. Radiological releases

- Outside the Plant site
  - As reactor building mostly intact
    => reduced release of aerosols (not Chernobyl-like)
  - Fission product release in steam
    => fast aerosol formation - large fraction deposited near the plant
  - Main contribution to the radioactive dose outside plant are the radioactive noble gases
  - Carried / distributed by the wind, decreasing dose with time
  - No “Fall-out“ of the noble gases, so no local high contamination of soil

- ~20 km around the plant
  - Evacuations were adequate
  - Measured dose up to 0.3mSv/h for short times
  - Maybe destruction of crops / dairy products this year
  - Probably no permanent evacuation of land necessary

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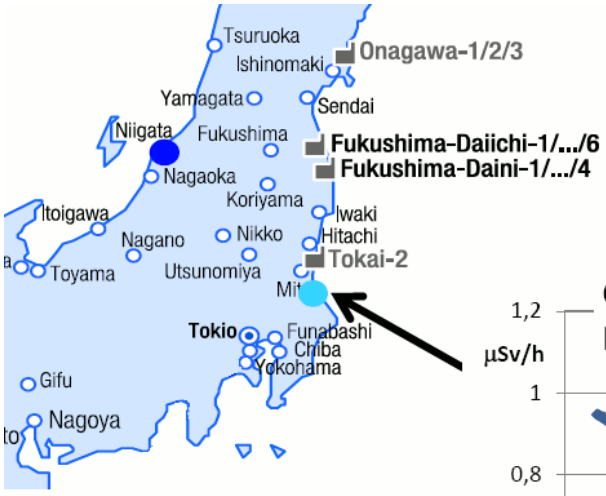
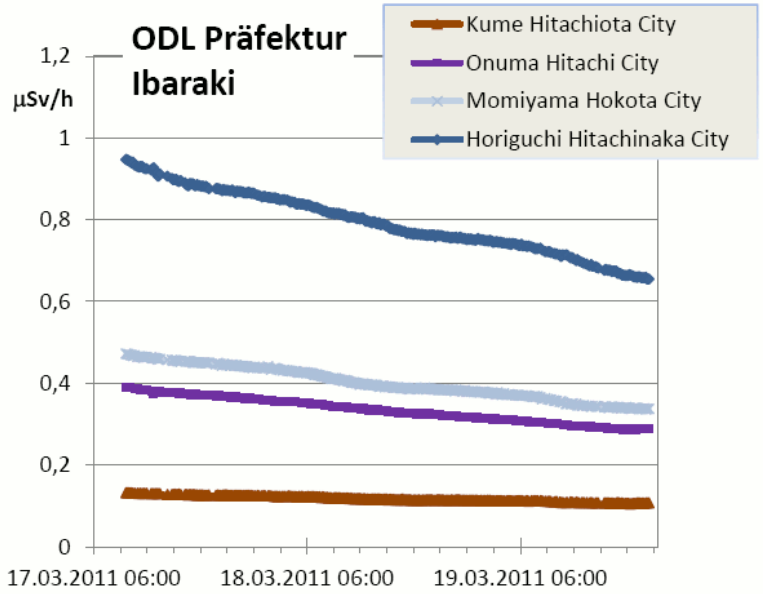
3. Radiological releases



GRS.de



- ~50km around the plant
  - Control of Crop / Dairy products
  - Usage of Iodine pills (Caution, pills can interfere with heart medicine)

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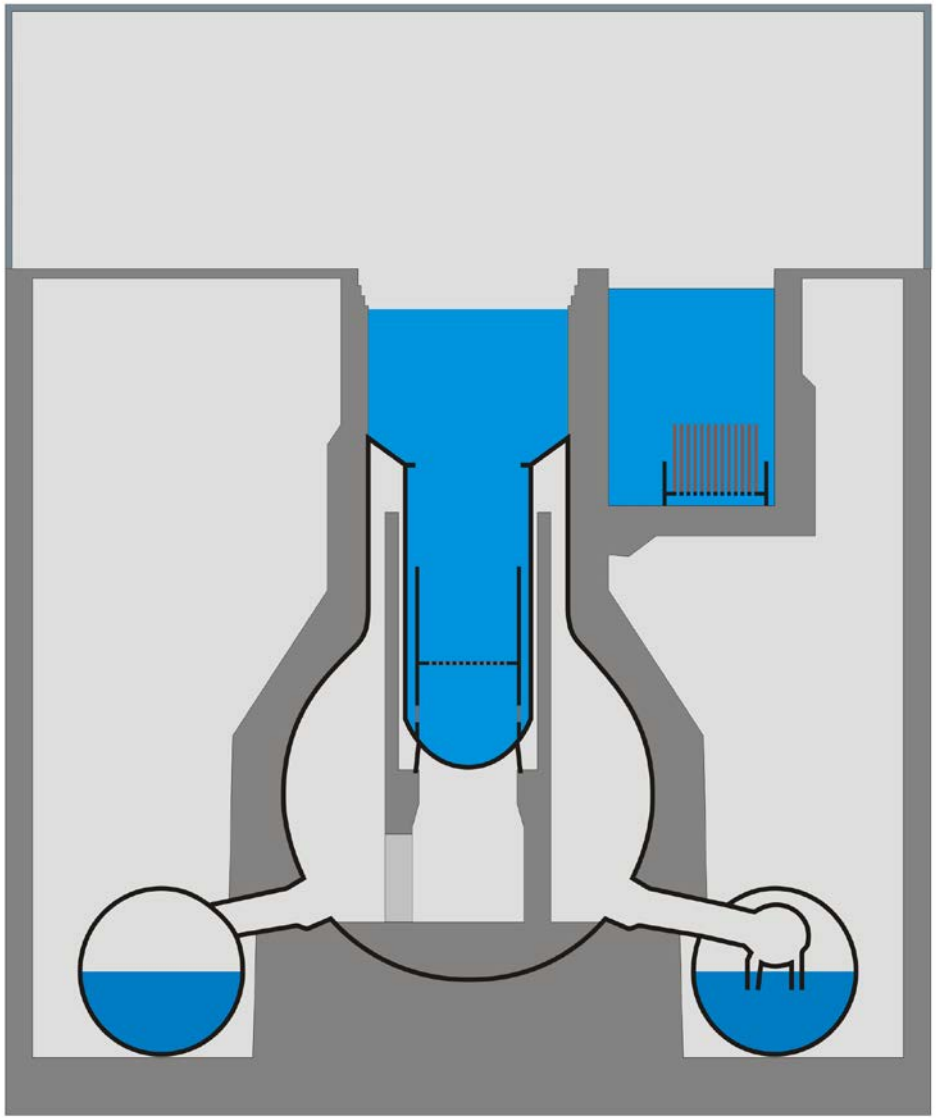
The Fukushima Daiichi Incident
4. Spent fuel pools

- Spent fuel stored in pool on reactor service floor
  - Due to maintenance in Unit 4 entire core stored in fuel pool
  - Dry-out of the pools
    - Unit 4: in 10 days
    - Unit 1-3,5,6 in few weeks
  - **Leakage of the pools due to Earthquake?**
- Consequences
  - Core melt “on fresh air”
  - Nearly no retention of fission products
  - Large release



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The Fukushima Daiichi Incident
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- Spent fuel stored in pool on reactor service floor
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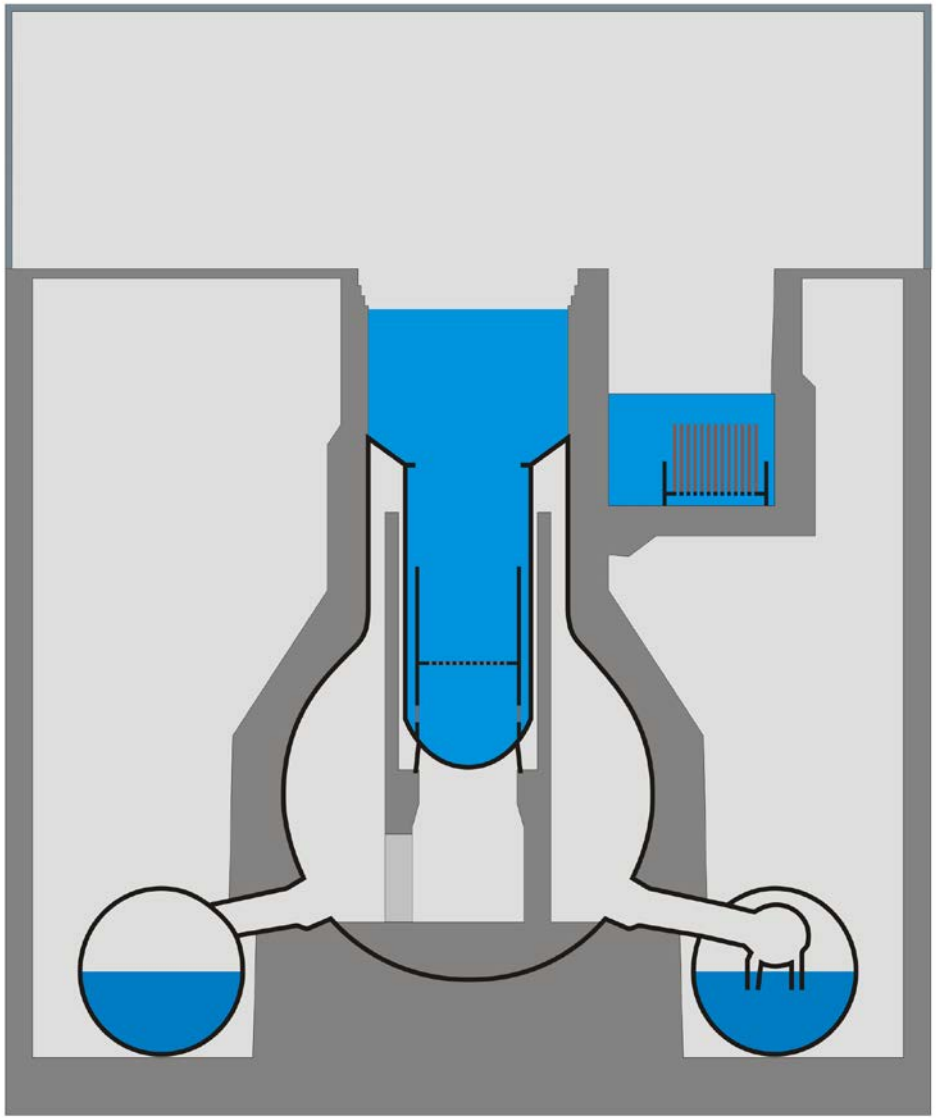

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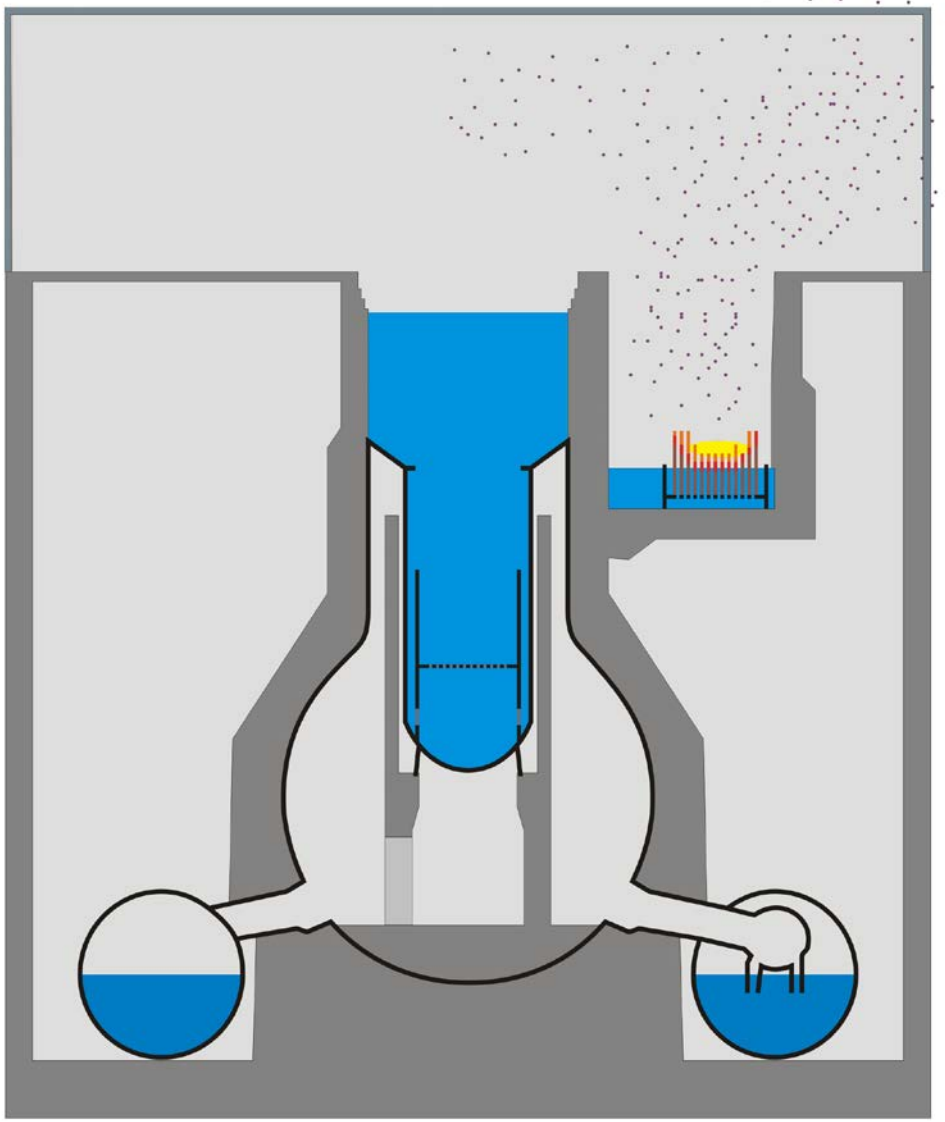
    - Unit 1-3,5,6 in few weeks
  - **Leakage of the pools due to Earthquake?**
- Consequences
  - Core melt “on fresh air”
  - Nearly no retention of fission products
  - Large release
- **It is currently unclear if release from fuel pool already happened**



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The Fukushima Daiichi Incident
5. Sources of Information

- Good sources of Information
  - Gesellschaft für Reaktorsicherheit [GRS.de]
    - Up to date
    - Radiological measurements published
    - German translation of Japanese/English web pages
  - Japan Atomic Industrial Forum [jaif.or.jp/english/]
    - Current Status of the plants
    - Measurement values of the reactors (pressure liquid level)
  - Tokyo Electric Power Company [Tepco.co.jp]
    - Status of the recovery work
    - Casualties
- Maybe too little information was released by TEPCO, the operator of the plant

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