

March 21, 2011

The Nuclear Crisis in Japan



Daniel Okimoto • Alan Hanson • Kate Marvel

The Fukushima Daiichi Incident

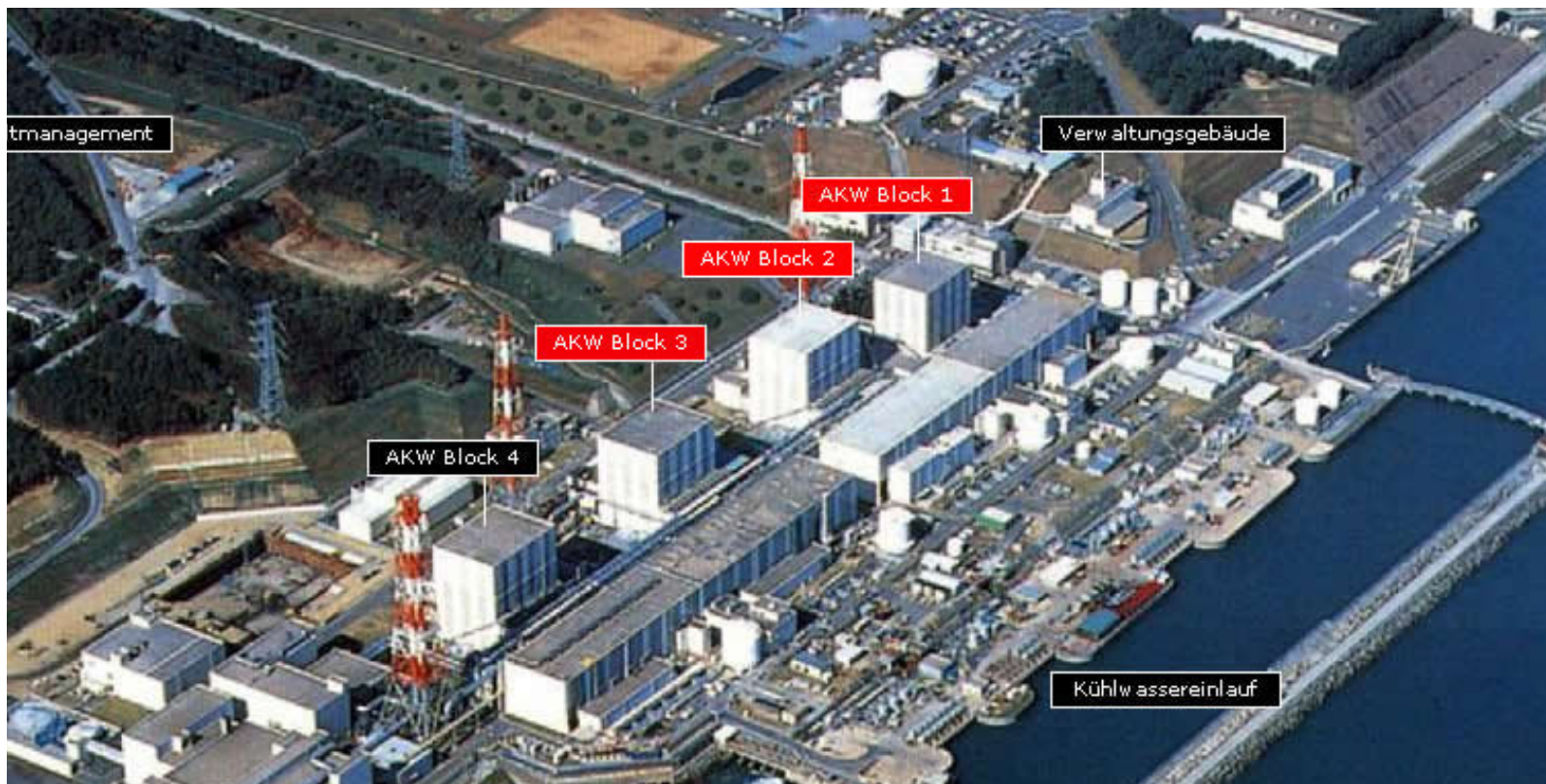
1. Plant Design
2. Accident Progression
3. Radiological releases
4. Spent fuel pools

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

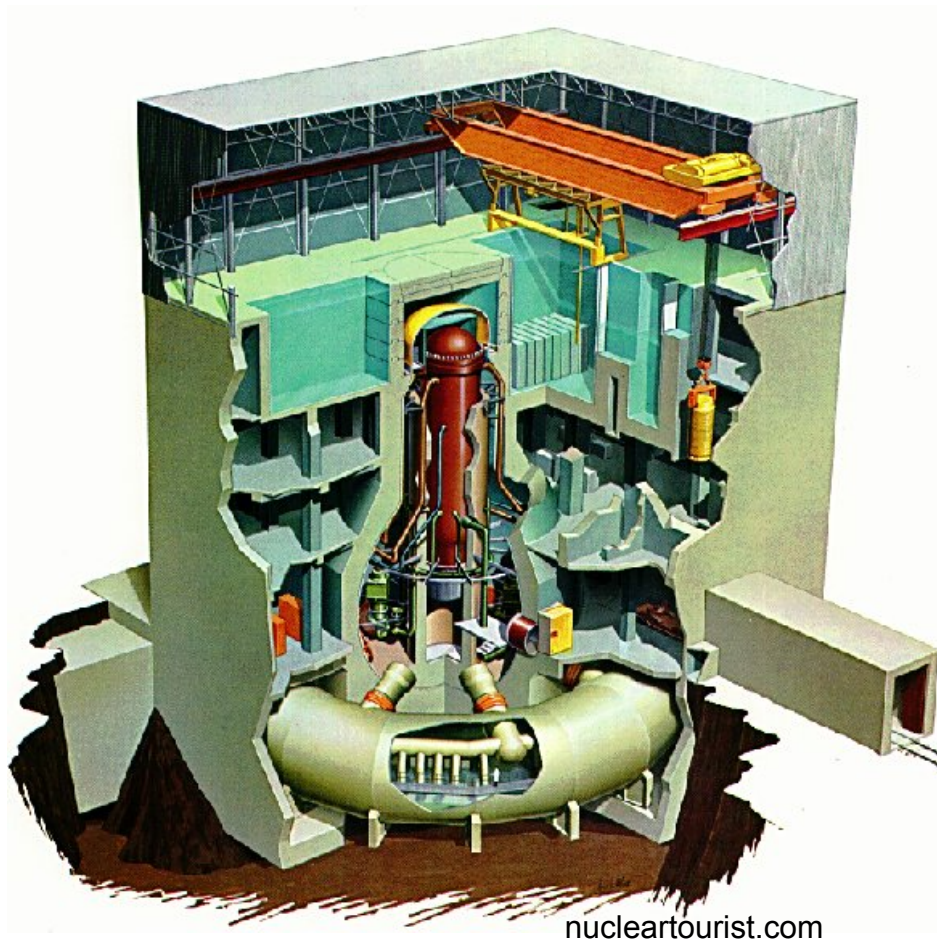


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1. Plant Design

► Building structure

- ◆ Concrete Building
- ◆ Steel-framed Service Floor



► 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

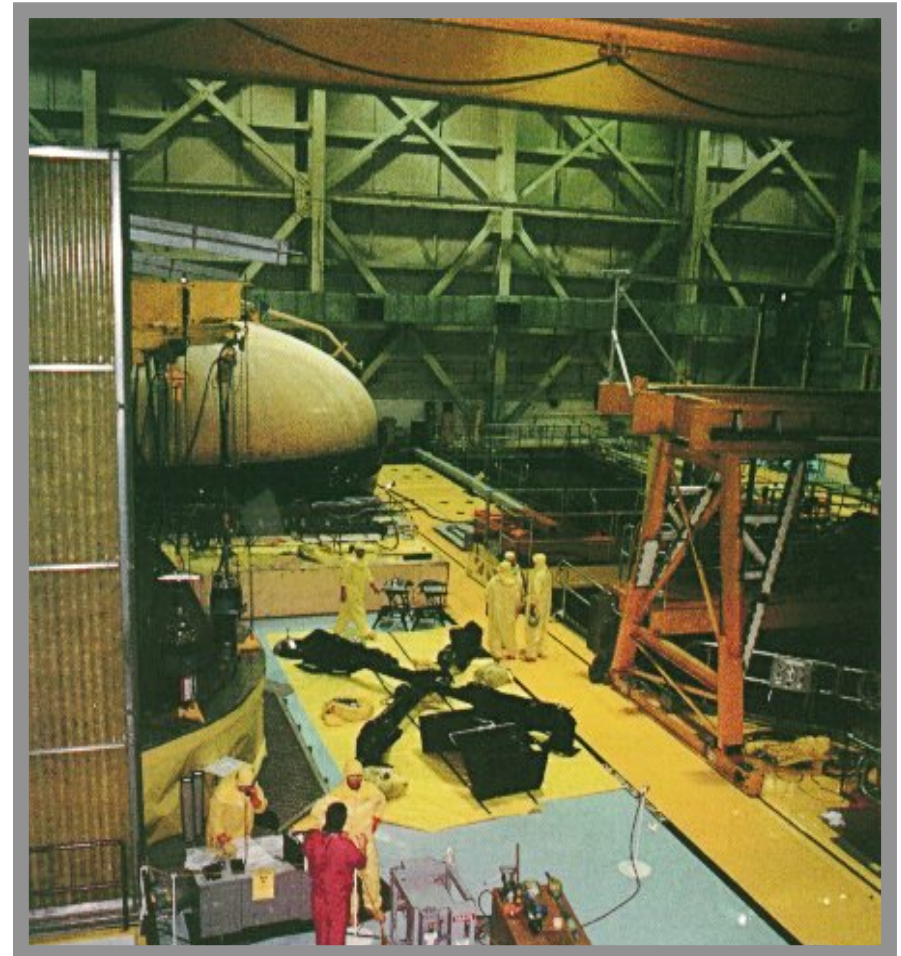


The Fukushima Daiichi Incident – March 21, 2011

The Fukushima Daiichi Incident

1. Plant Design

- ▶ Lifting the Containment closure head



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1. Plant Design

► Reactor Service Floor
(Steel Construction)

► Concrete Reactor Building
(secondary Containment)

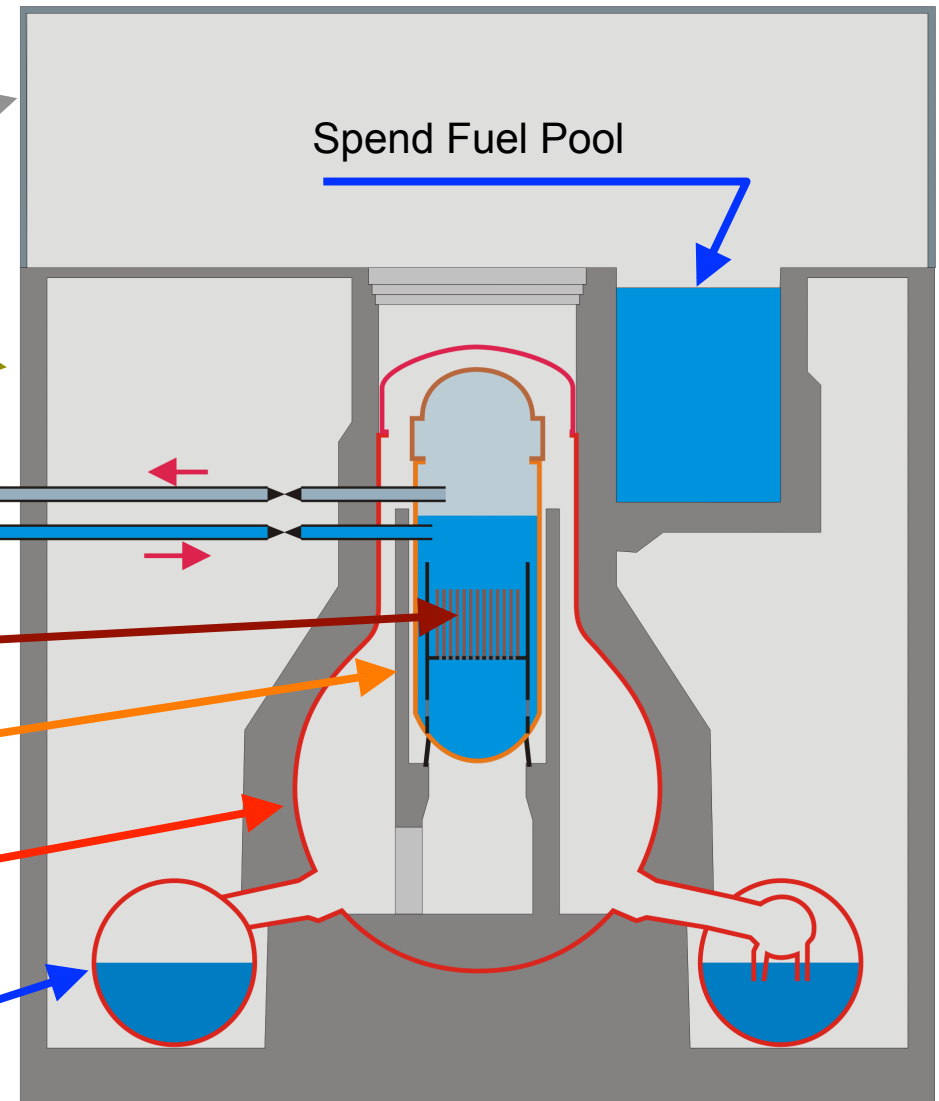
Fresh Steam line
Main Feedwater

► Reactor Core

► Reactor Pressure Vessel

► Containment (Dry well)

► Containment (Wet Well) /
Condensation Chamber



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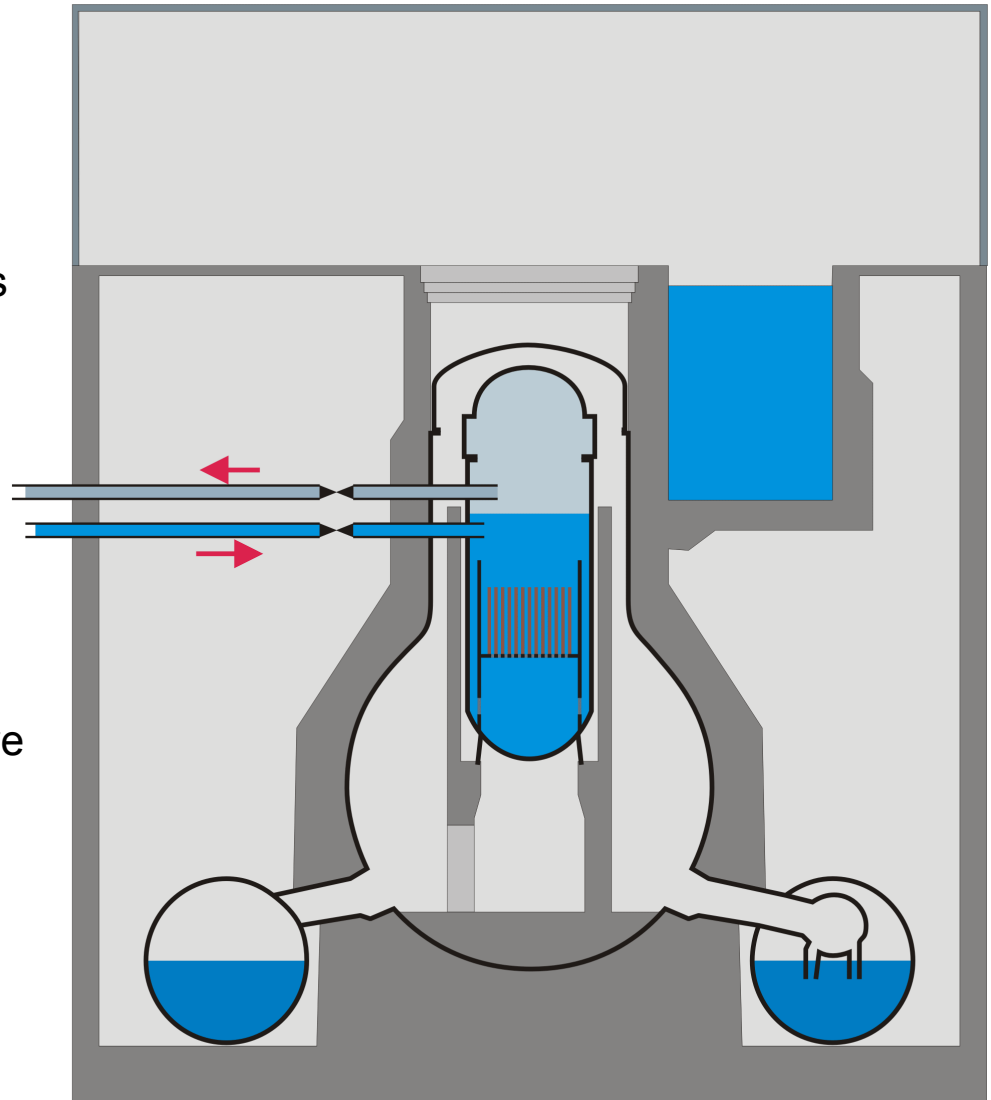
2. Accident progression

► 11.3.2011 14:46 - Earthquake

- ◆ Magnitude 9
- ◆ Power grid in northern Japan fails
- ◆ Reactors itself are mainly undamaged

► SCRAM

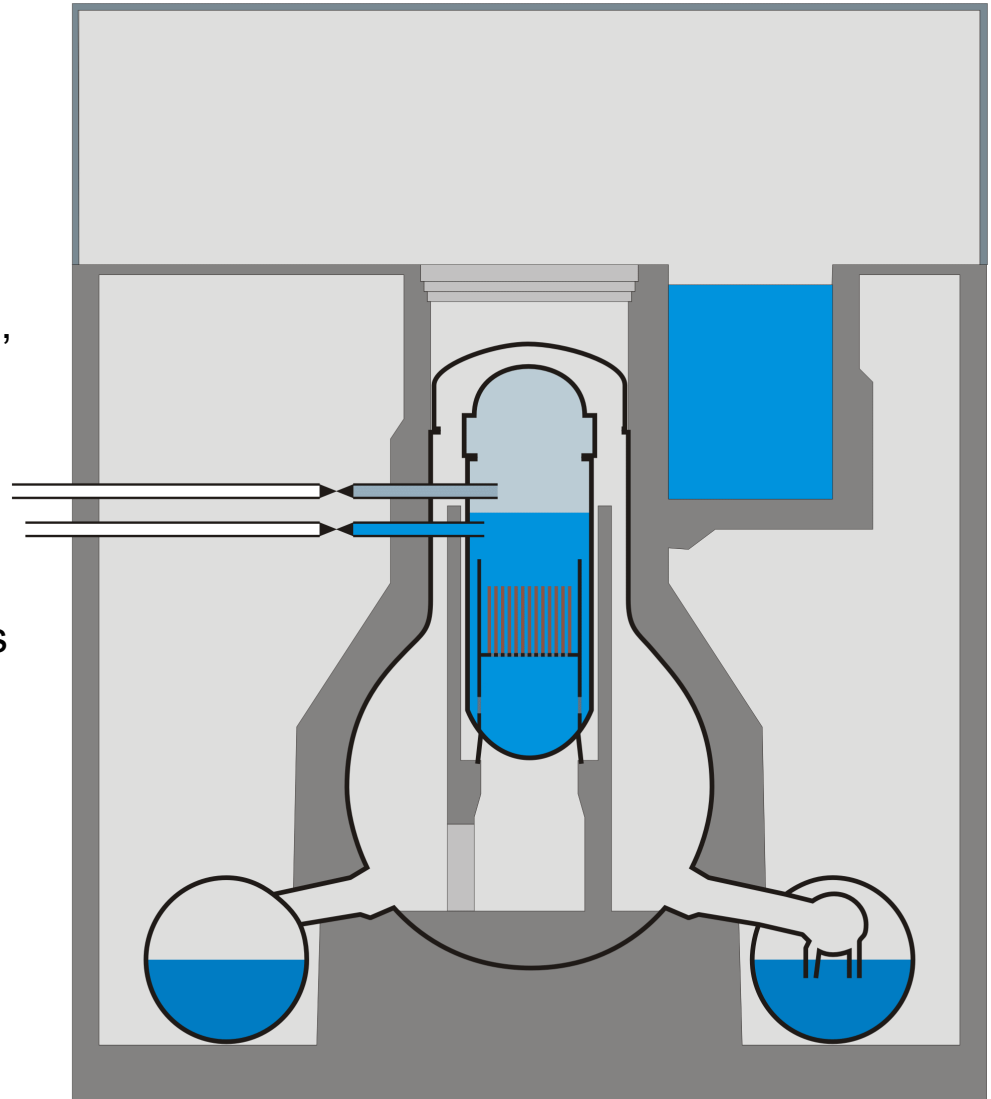
- ◆ Power generation due to Fission of Uranium stops
- ◆ Heat generation due to radioactive Decay of Fission Products
 - After Scram ~6%
 - After 1 Day ~1%
 - After 5 Days ~0.5%



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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



The Fukushima Daiichi Incident

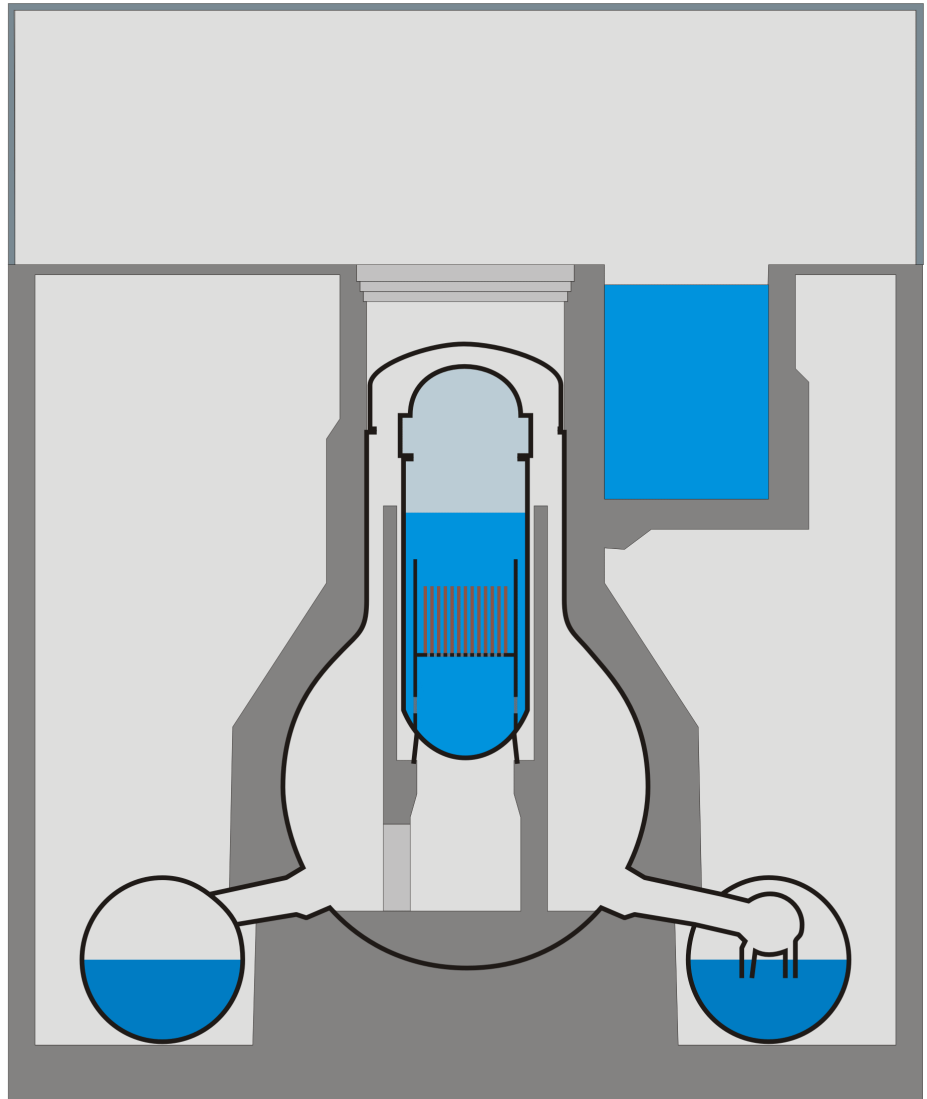
2. Accident progression

► 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

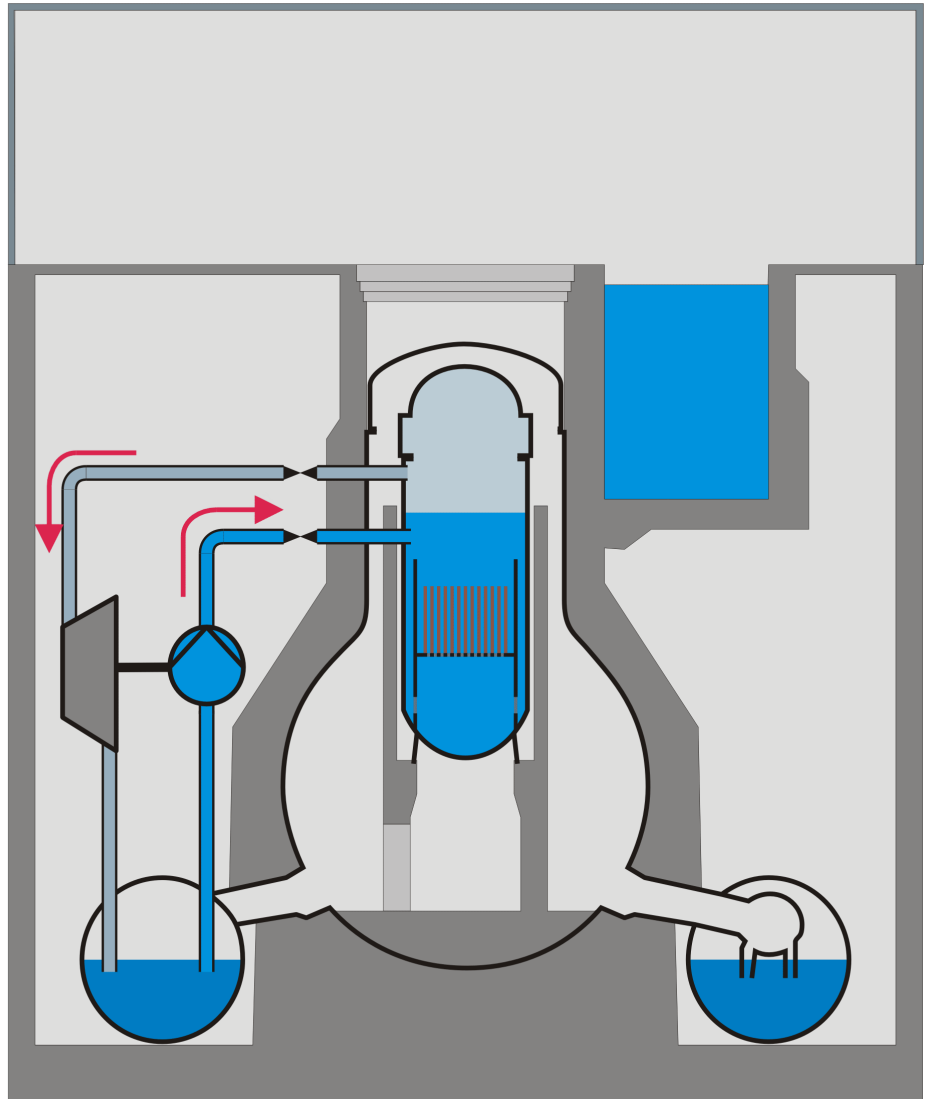
- ◆ Common cause failure of the power supply
- ◆ Only Batteries are still available
- ◆ Failure of all but one Emergency core cooling systems



The Fukushima Daiichi Incident

2. Accident progression

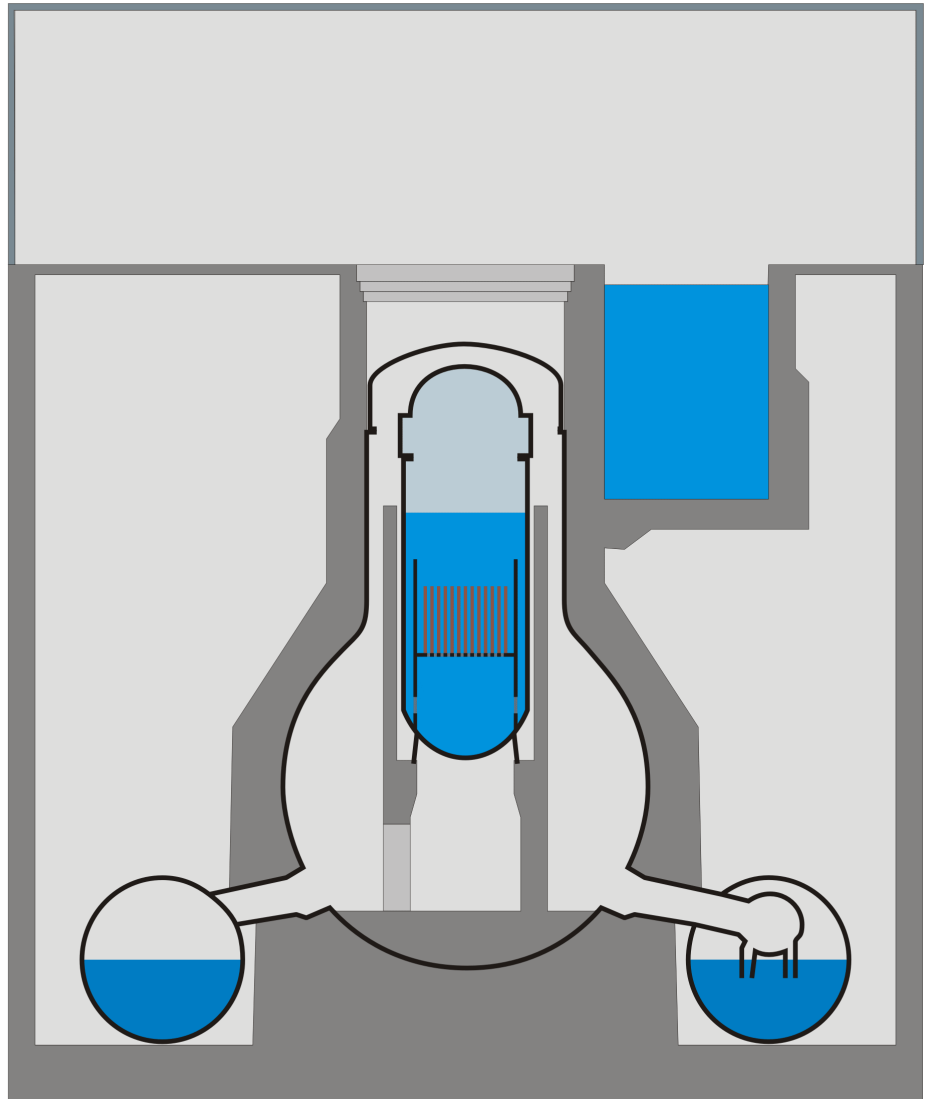
- ▶ Reactor Core Isolation Pump still available
 - ◆ Steam from the Reactor drives a Turbine
 - ◆ Steam gets condensed in the Wet-Well
 - ◆ Turbine drives a Pump
 - ◆ Water from the Wet-Well gets pumped in Reactor
 - ◆ Necessary:
 - Battery power
 - Temperature in the wet-well must be below 100°C
- ▶ As there is no heat removal from the building, the Core isolation pump cant work infinitely



The Fukushima Daiichi Incident

2. Accident progression

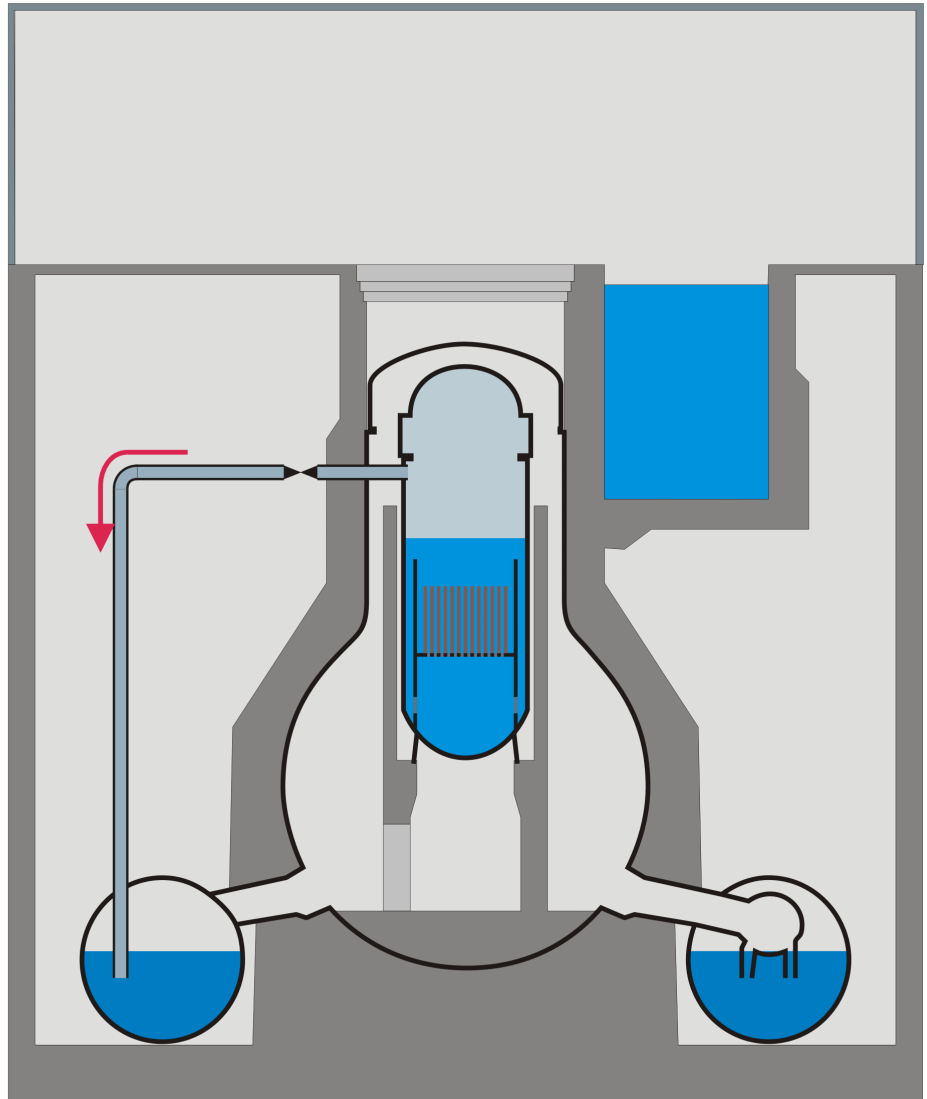
- ▶ Reactor Isolation pump stops
 - ◆ 11.3. 16:36 in Unit 1
(Batteries empty)
 - ◆ 14.3. 13:25 in Unit 2
(Pump failure)
 - ◆ 13.3. 2:44 in Unit 3
(Batteries empty)
- ▶ Decay Heat produces still steam in Reactor pressure Vessel
 - ◆ Pressure rising
- ▶ Opening the steam relieve valves
 - ◆ Discharge Steam into the Wet-Well
- ▶ Descending of the Liquid Level in the Reactor pressure vessel



The Fukushima Daiichi Incident

2. Accident progression

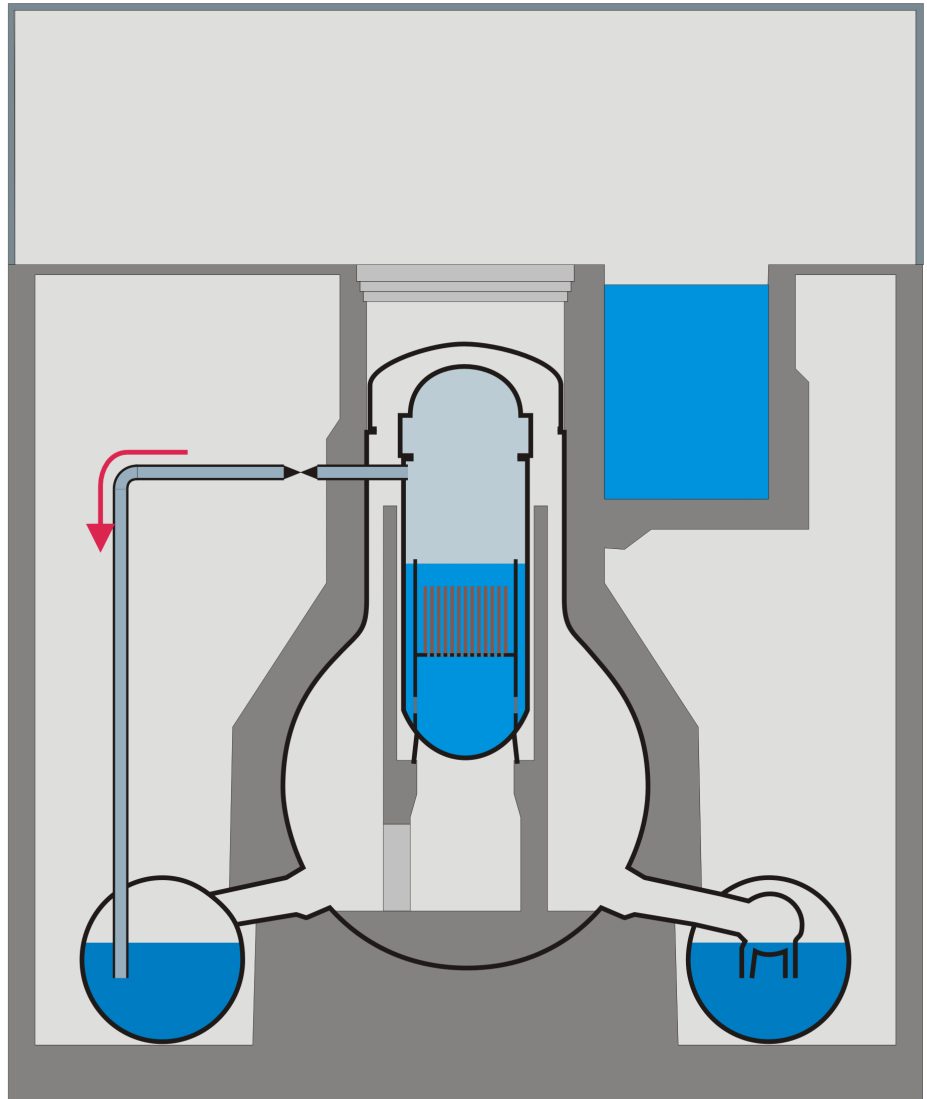
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The Fukushima Daiichi Incident

2. Accident progression

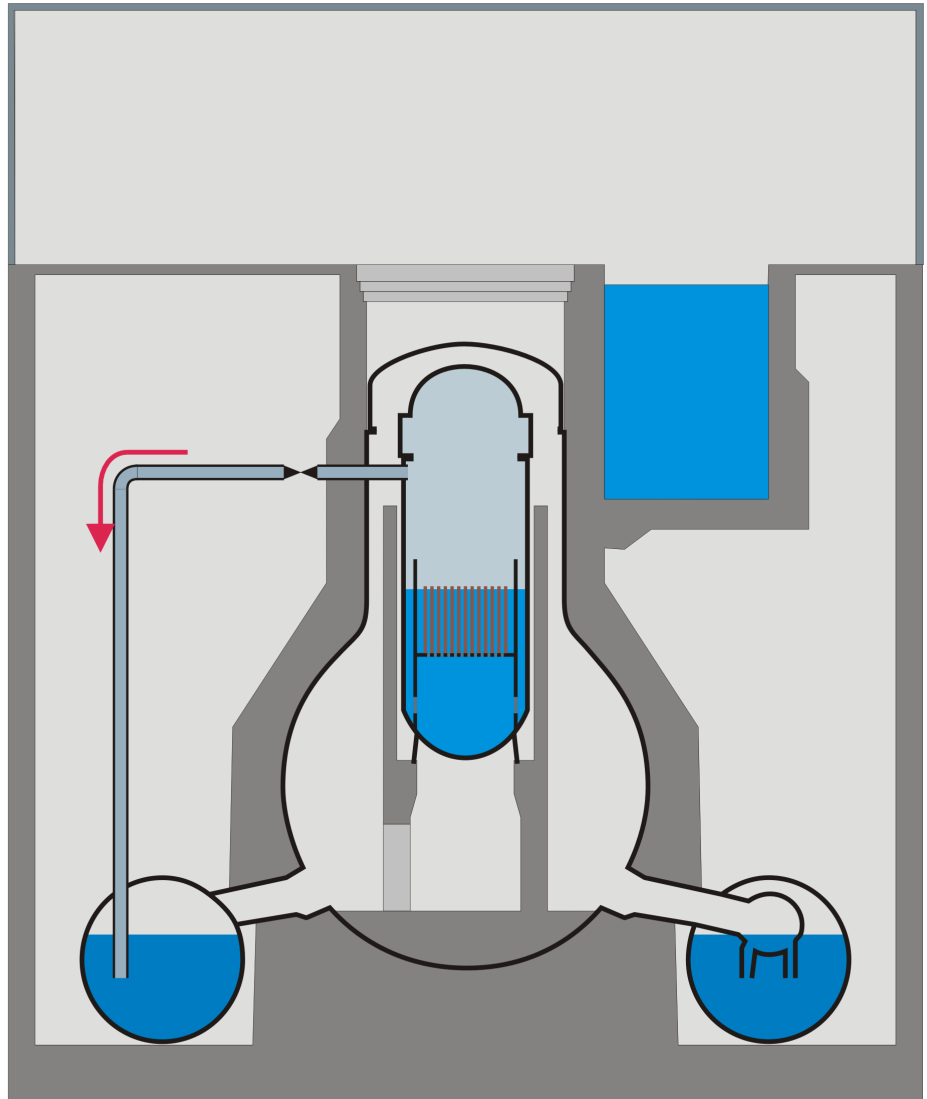
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The Fukushima Daiichi Incident

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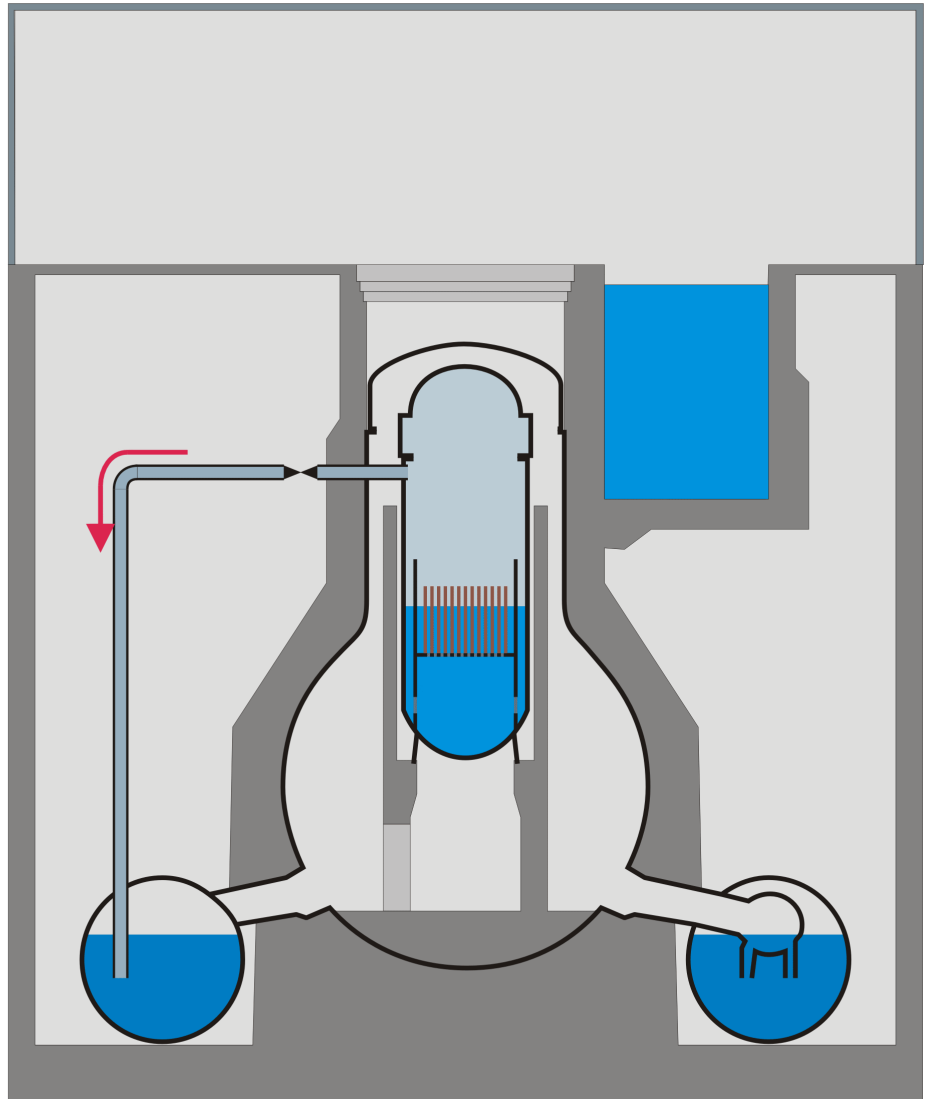
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The Fukushima Daiichi Incident

2. Accident progression

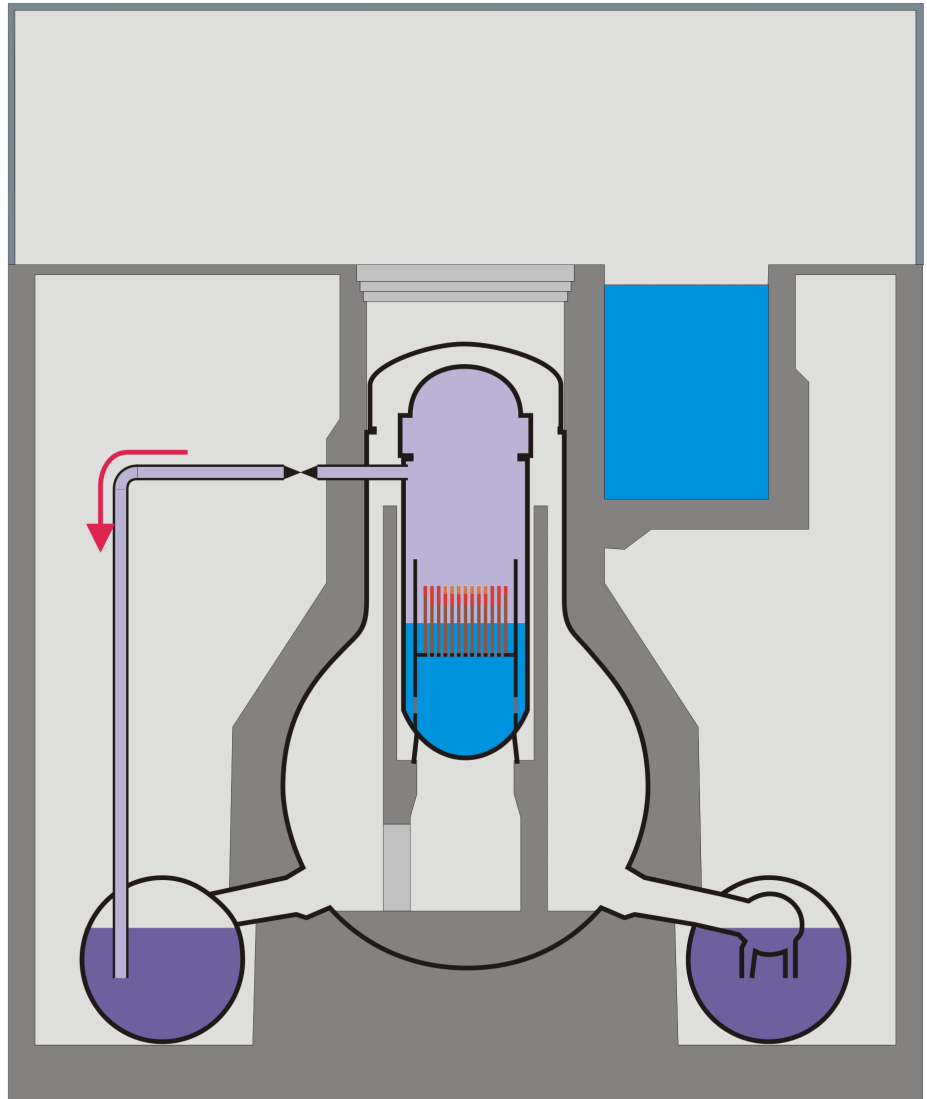
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The Fukushima Daiichi Incident

2. Accident progression

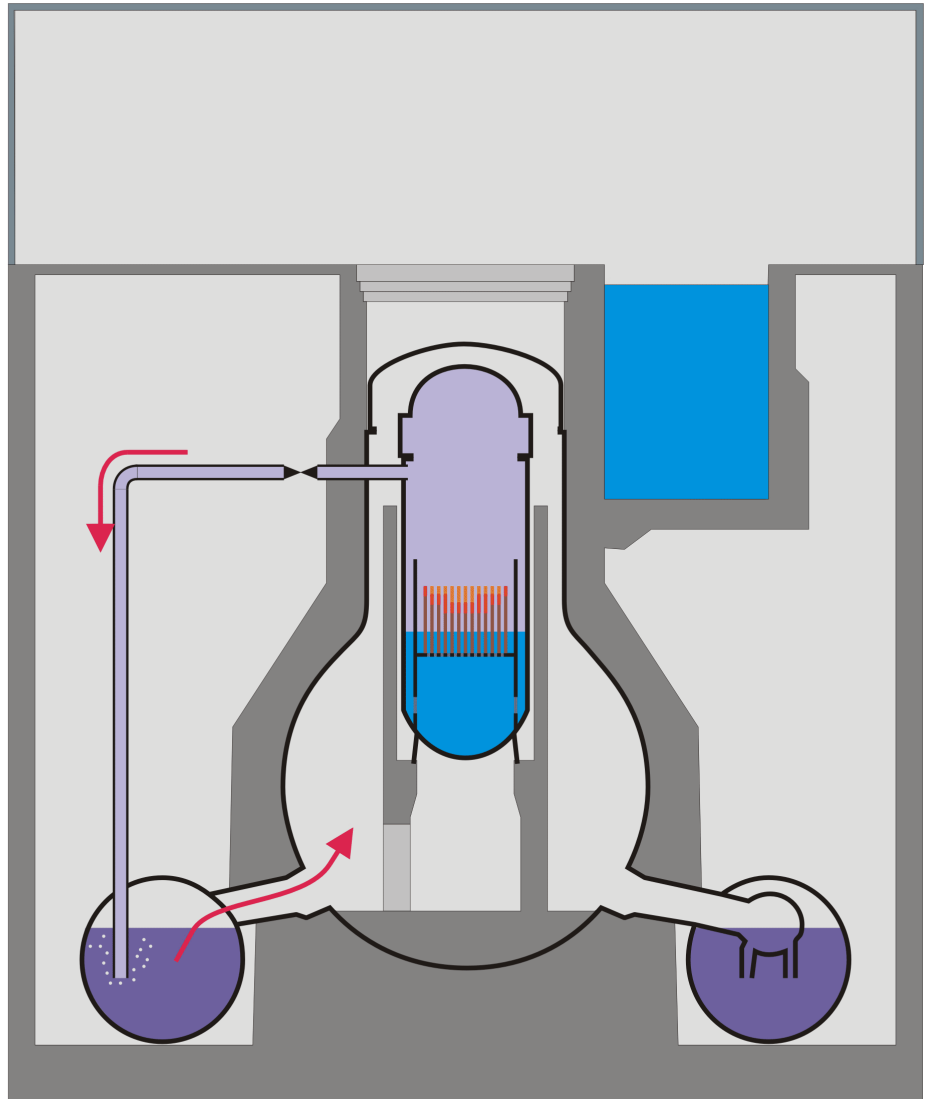
- ▶ Measured, and here referenced Liquid level is the collapsed level. The actual liquid level lies higher due to the steam bubbles in the liquid
- ▶ ~50% of the core exposed
 - ◆ Cladding temperatures rise, but still no significant core damage
- ▶ ~2/3 of the core exposed
 - ◆ Cladding temperature exceeds $\sim 900^{\circ}\text{C}$
 - ◆ Ballooning / Breaking of the cladding
 - ◆ Release of fission products from the fuel rod gaps



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2. Accident progression

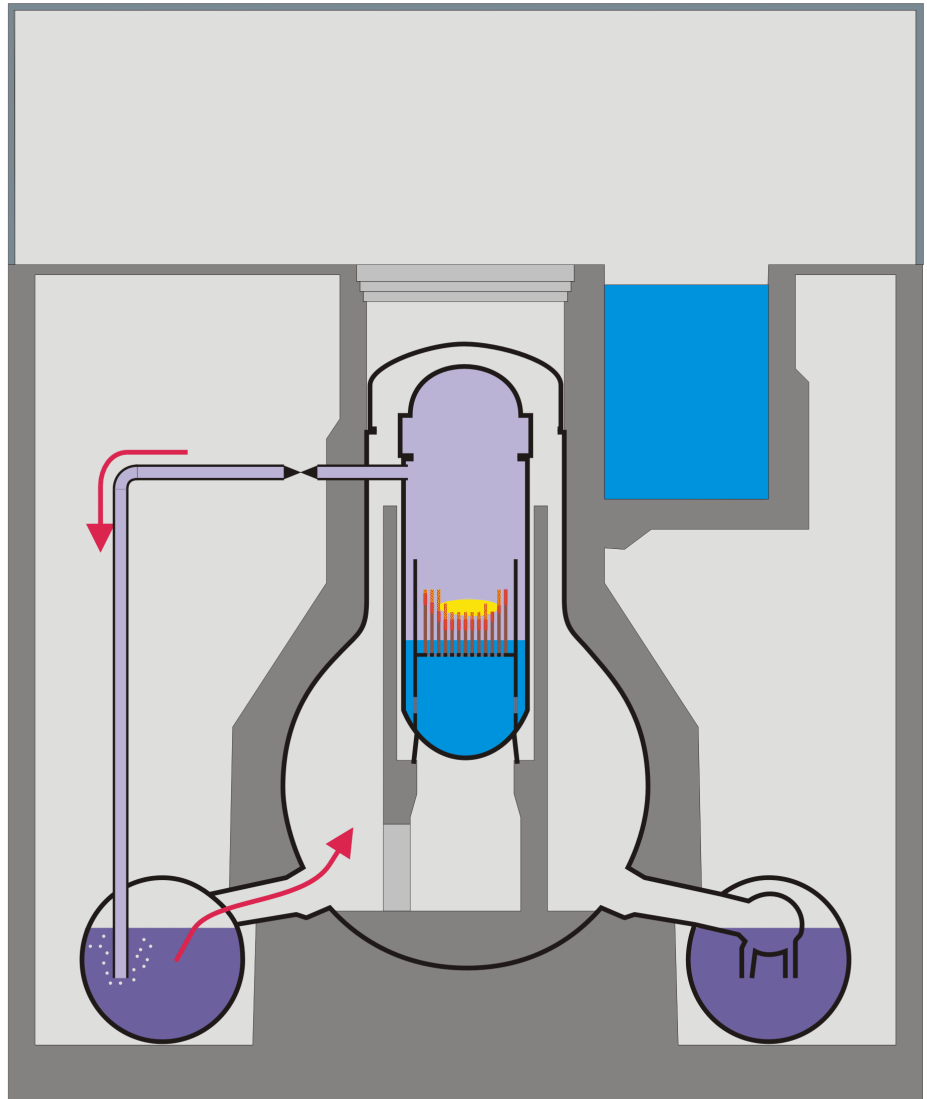
- ▶ ~3/4 of the core exposed
 - ◆ Cladding exceeds ~1200°C
 - ◆ Zirconium in the cladding starts to burn under Steam atmosphere
 - ◆ $\text{Zr} + 2\text{H}_2\text{O} \rightarrow \text{ZrO}_2 + 2\text{H}_2$
 - ◆ Exothermal reaction further heats the core
 - ◆ Generation of hydrogen
 - Unit 1: 300-600kg
 - Unit 2/3: 300-1000kg
 - ◆ Hydrogen gets pushed via the wet-well, the wet-well vacuum breakers into the dry-well



The Fukushima Daiichi Incident

2. Accident progression

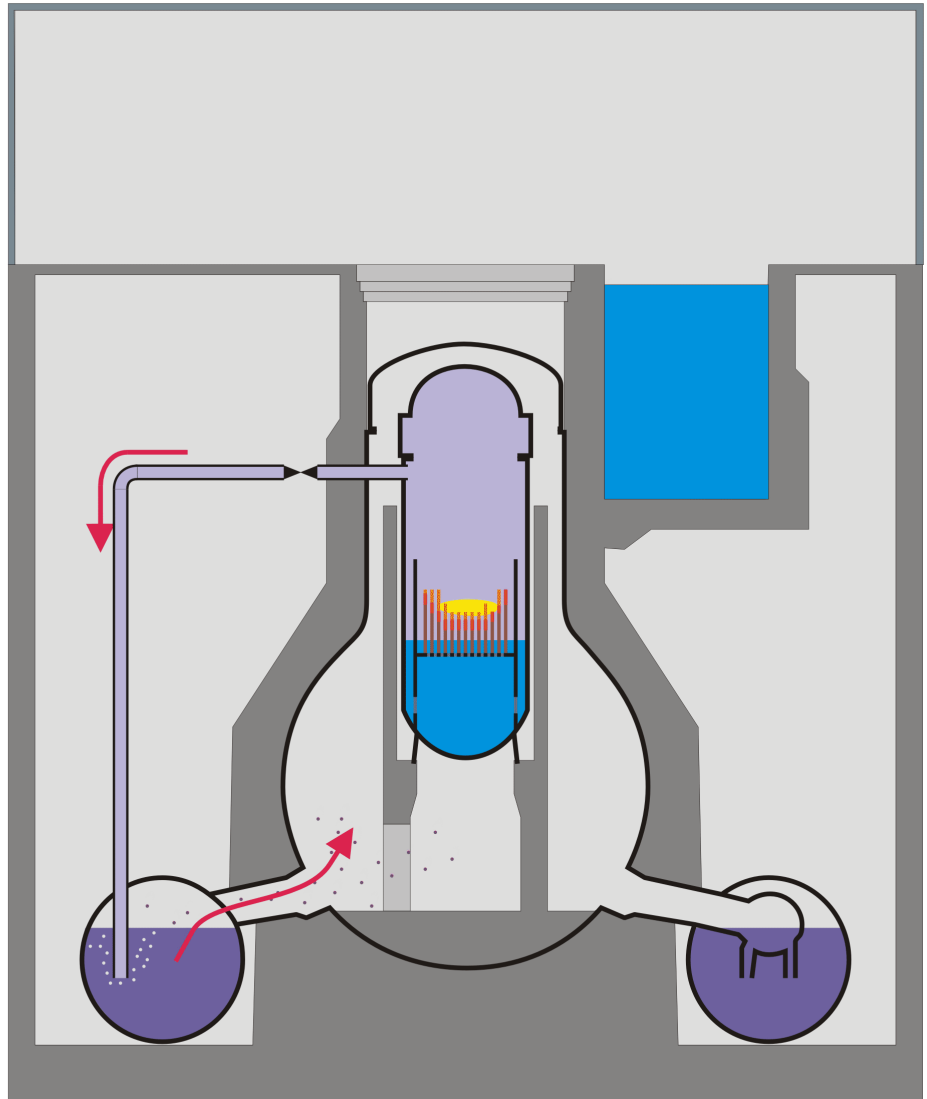
- ▶ at ~1800°C [Unit 1,2,3]
 - ◆ Melting of the Cladding
 - ◆ Melting of the steel structures
- ▶ at ~2500°C [Block 1,2]
 - ◆ Breaking of the fuel rods
 - ◆ debris bed inside the core
- ▶ at ~2700°C [Block 1]
 - ◆ Melting of Uranium-Zirconium eutectics
- ▶ Restoration of the water supply stops accident 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 condensate 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



2. Accident progression

► Containment

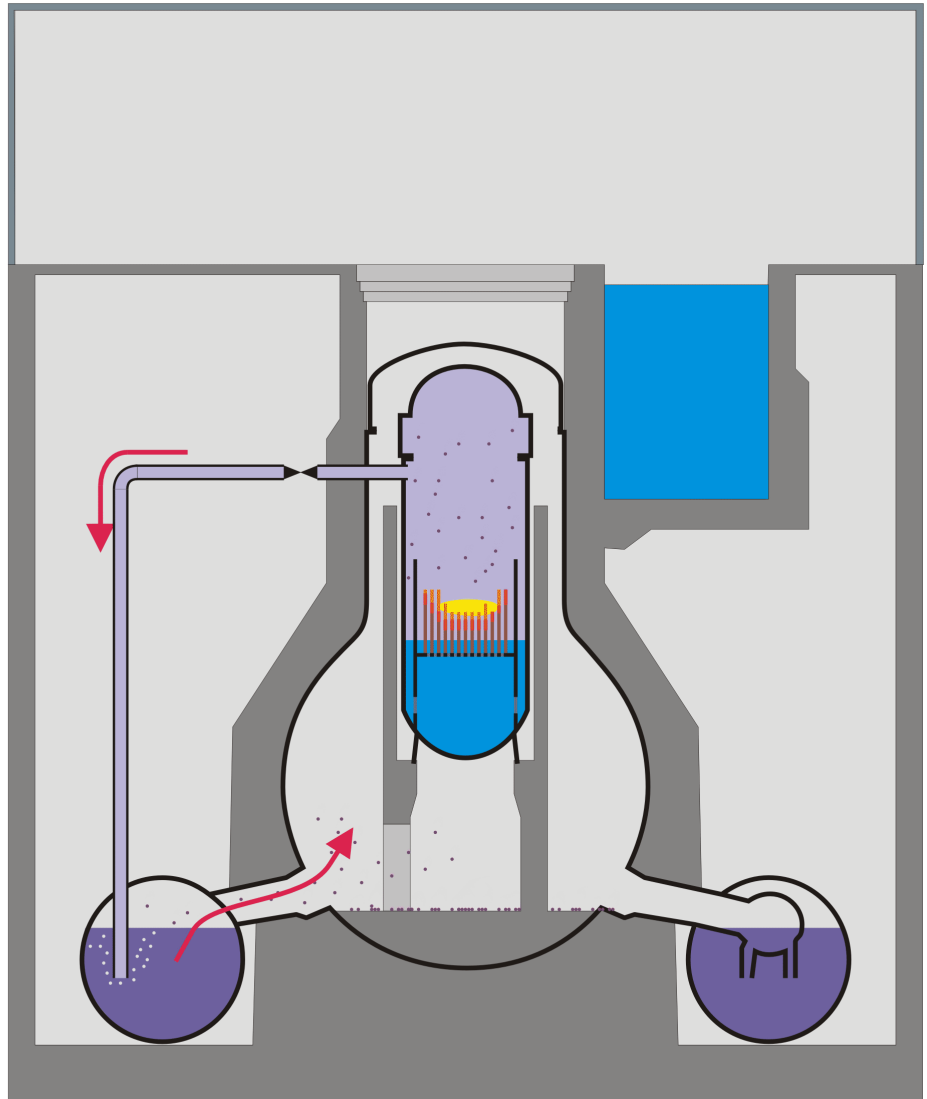
- ◆ Last barrier between Fission Products and Environment
- ◆ Wall thickness ~3cm
- ◆ Design Pressure 4-5bar

► 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

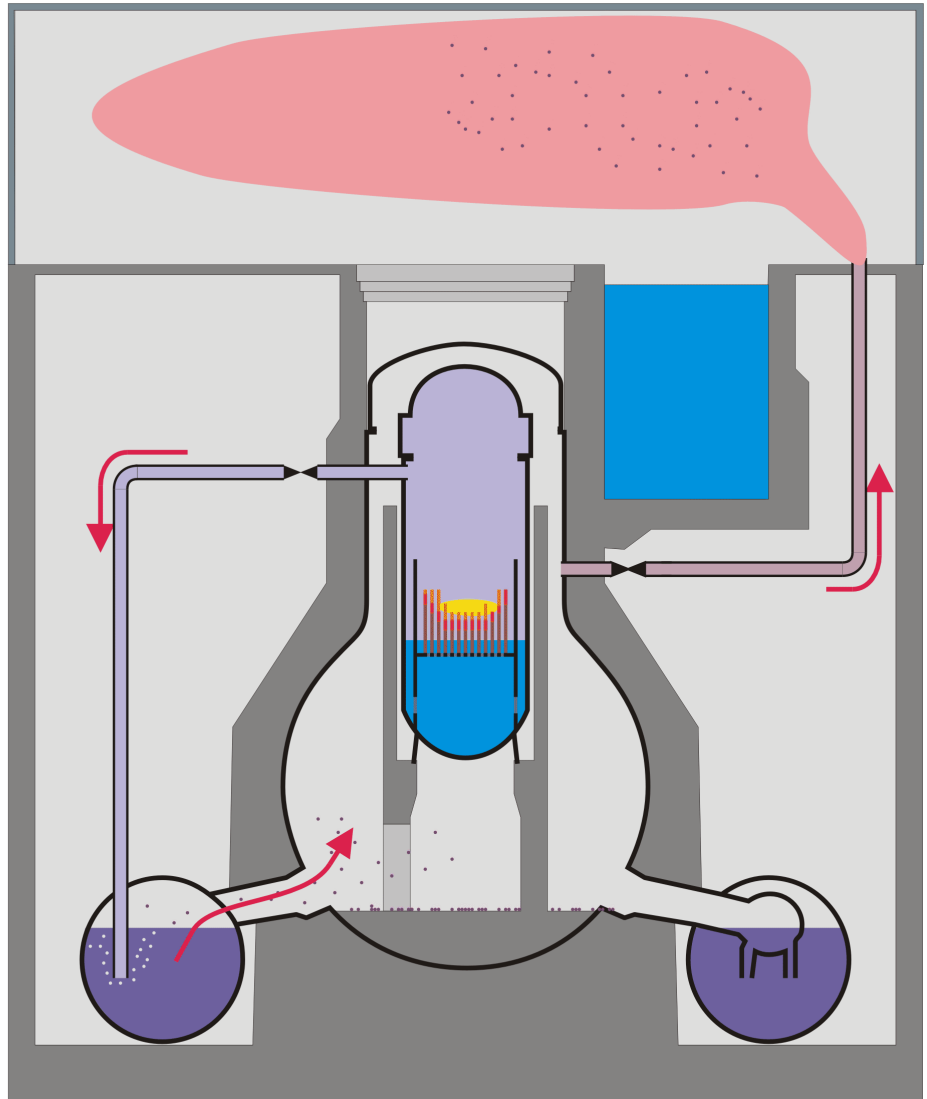
- ◆ Unit 1: 12.3. 4:00
- ◆ Unit 2: 13.3 00:00
- ◆ Unit 3: 13.3. 8.41



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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

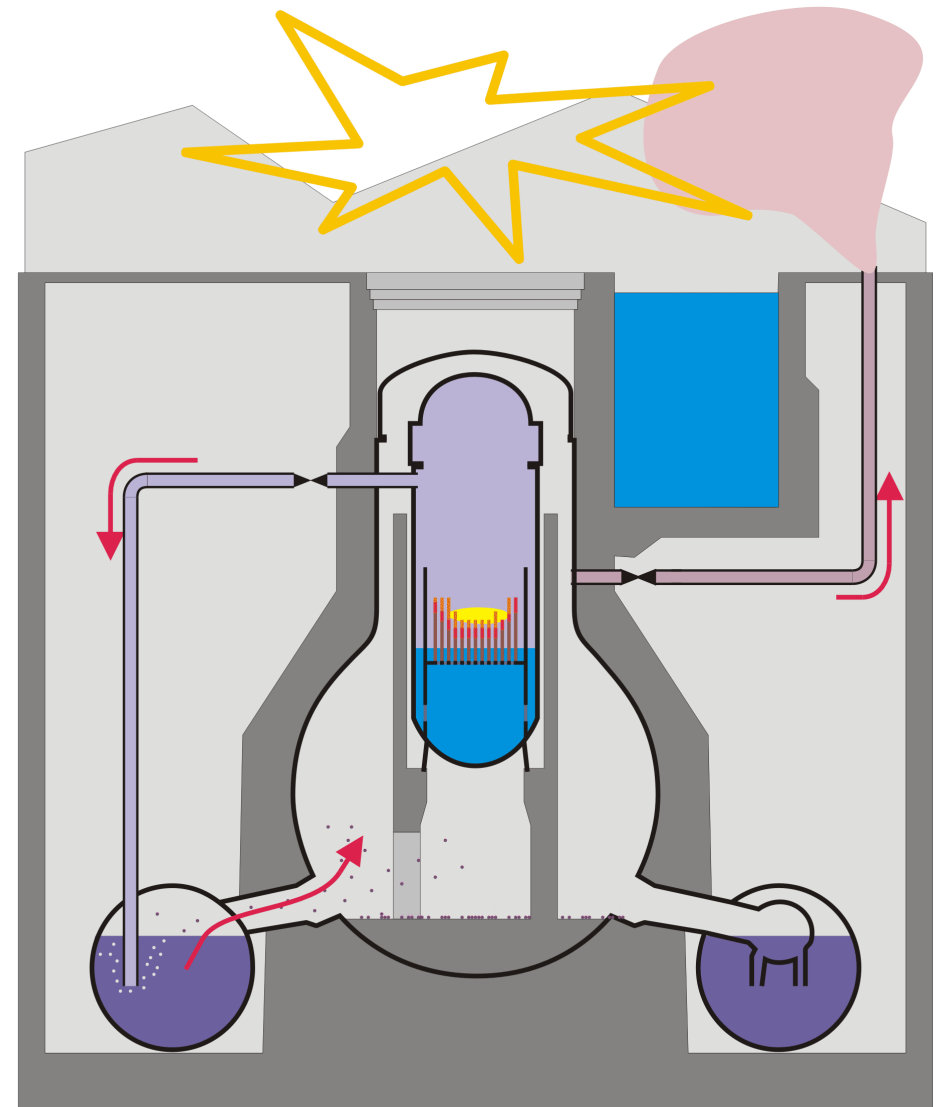


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2. Accident progression

► 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 relevant



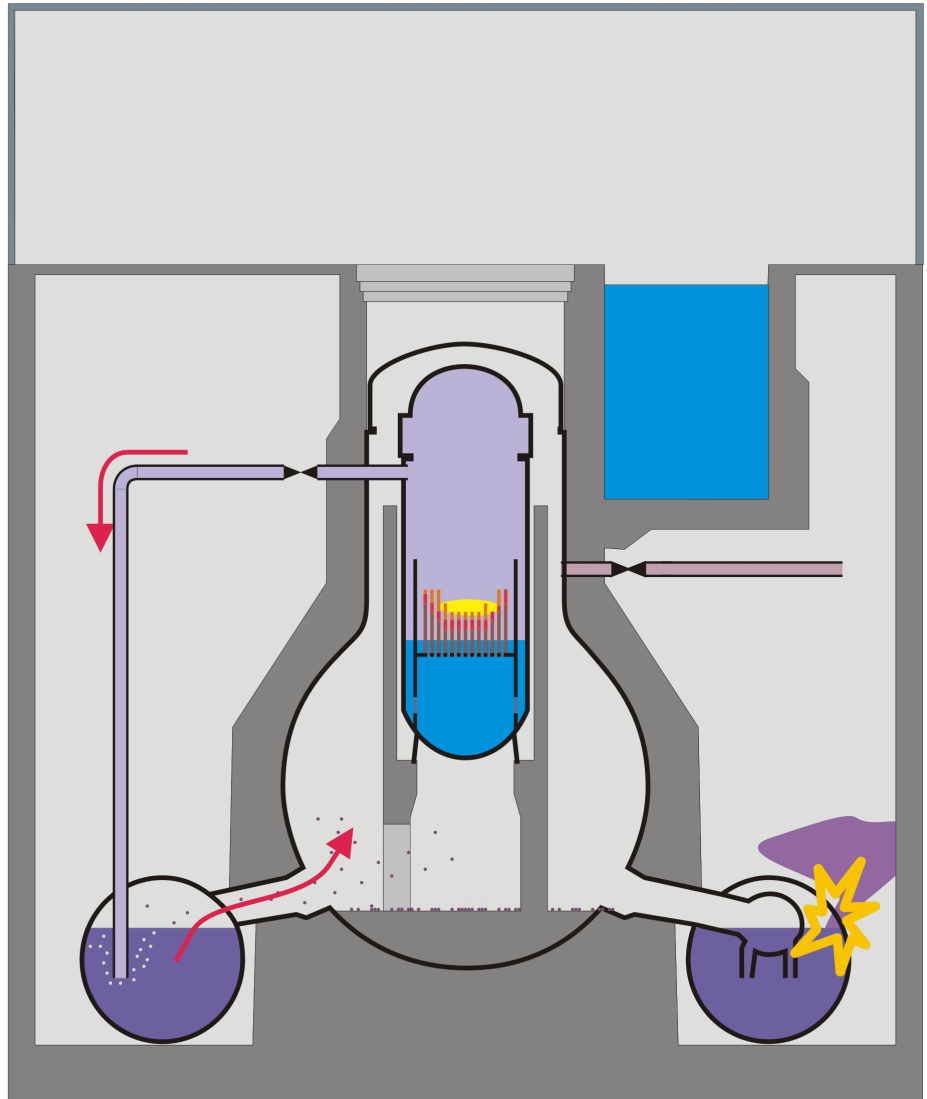
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2. Accident progression

► 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

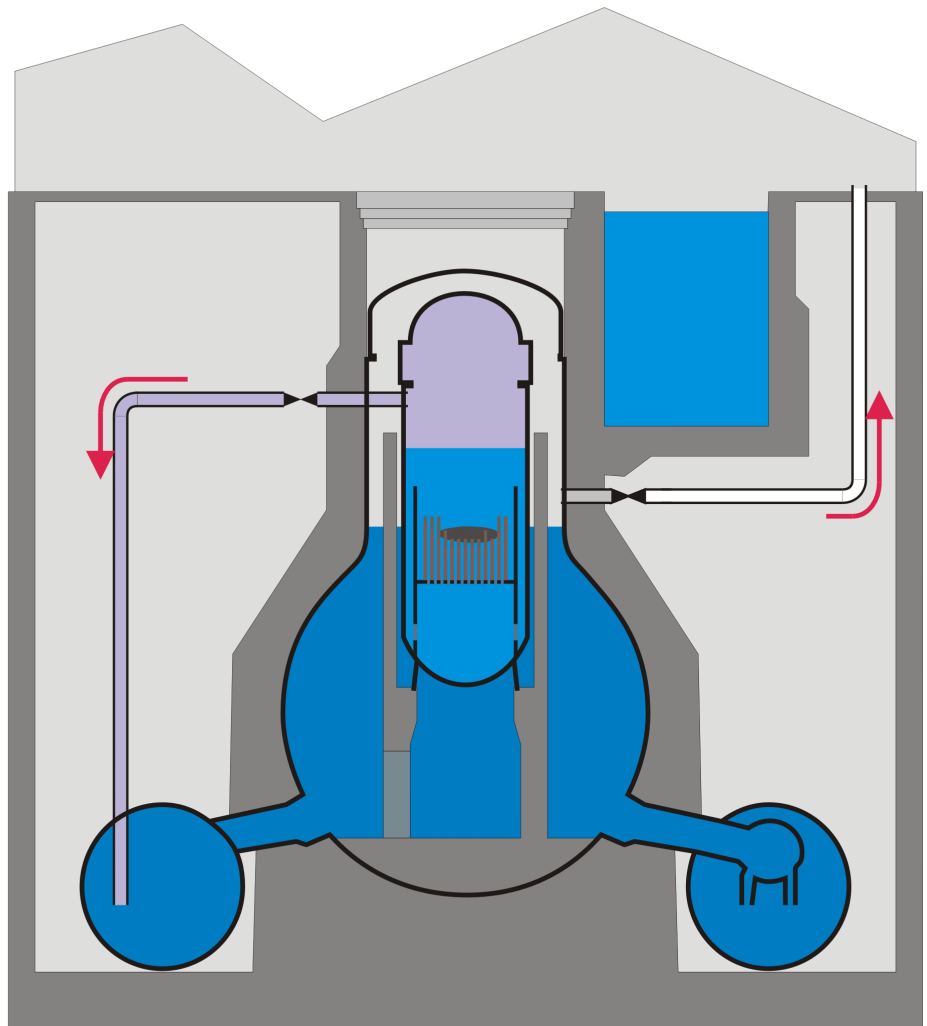
- ### ► No clear information's why Unit 2 behaved differently



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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 2mSv / h
- Mainly due to released radioactive noble gases
- Measuring posts on west side. Maybe too small values measured due to wind

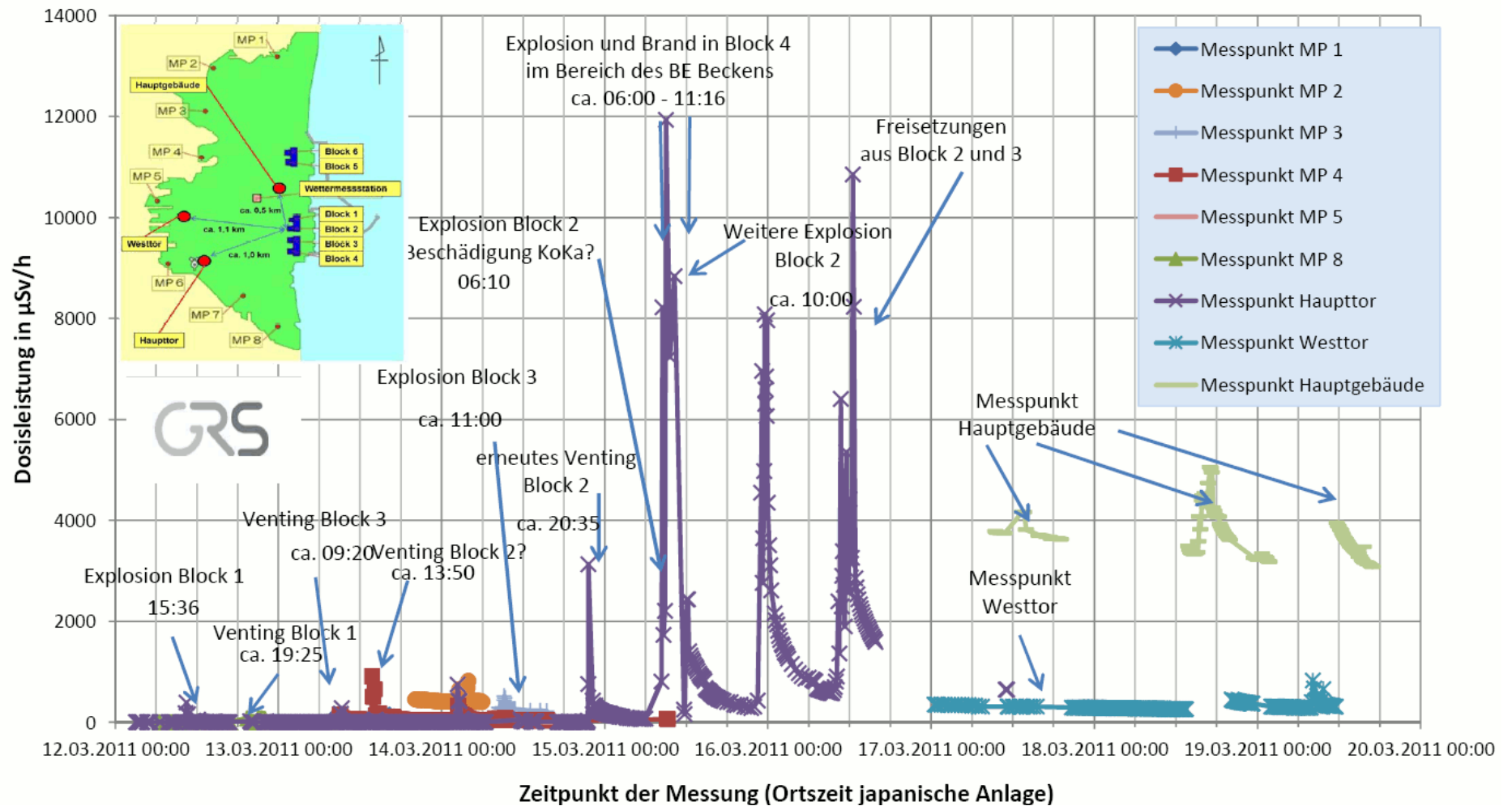
◆ After Explosion in Unit 2 (Damage of the Containment)

- Temporal peak values 12mSv / h
- (Origin not entirely clear)
- Local peak values on site up to 400mSv /h (wreckage / fragments?)
- Currently stable dose on site at 5mSv /h
- Inside the buildings a lot more

◆ Limiting time of exposure of the workers necessary

The Fukushima Daiichi Incident

3. Radiological releases



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3. Radiological releases

► Outside the Plant site

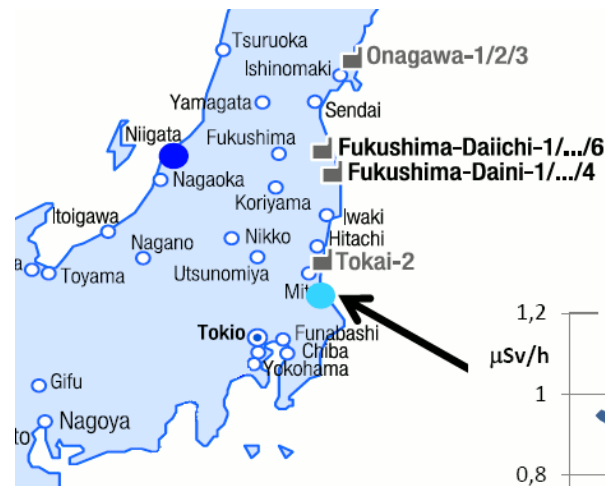
- ◆ As reactor building mostly intact
=> reduced release of Aerosols (not Chernobyl-like)
- ◆ Fission product release in steam
=> fast Aerosol grows, large fraction falls down in the proximity of the plant
- ◆ Main contribution to the radioactive dose outside plant are the radioactive noble gases
- ◆ Carried / distributed by the wind, decreasing dose with time
- ◆ No „Fall-out“ of the noble gases, so no local high contamination of soil

► ~20km around the plant

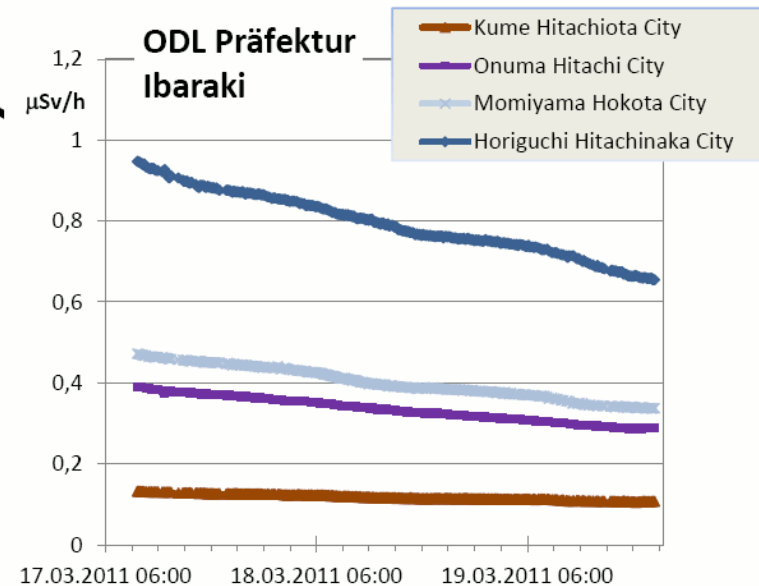
- ◆ Evacuations were adequate
- ◆ Measured dose up to 0.3mSv/h for short times
- ◆ Maybe destruction of crops / dairy products this year
- ◆ Probably no permanent evacuation of land necessary

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3. Radiological releases



GRS.de

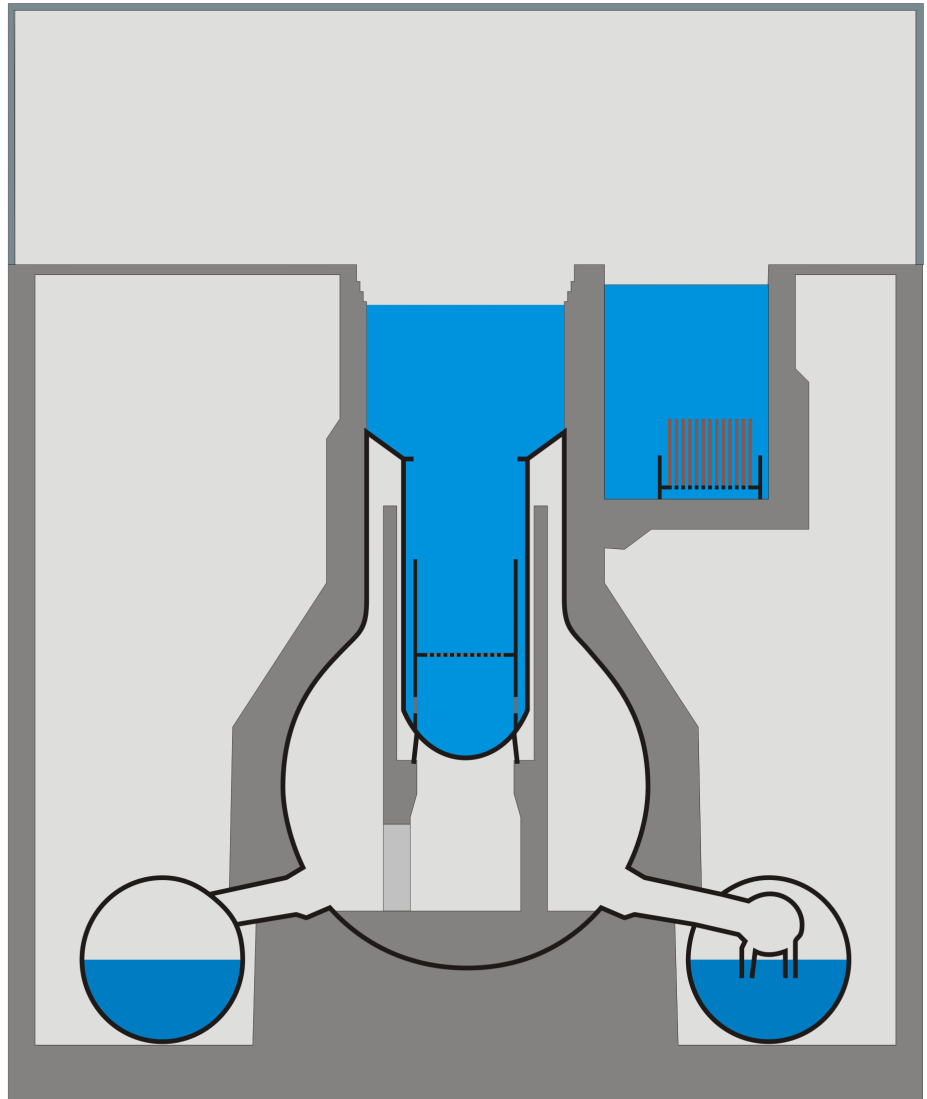


- ~50km around the plant
- ◆ Control of Crop / Dairy products
- ◆ Usage of Iodine pills
(Caution, pills can interfere with heart medicine)

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4. Spend fuel pools

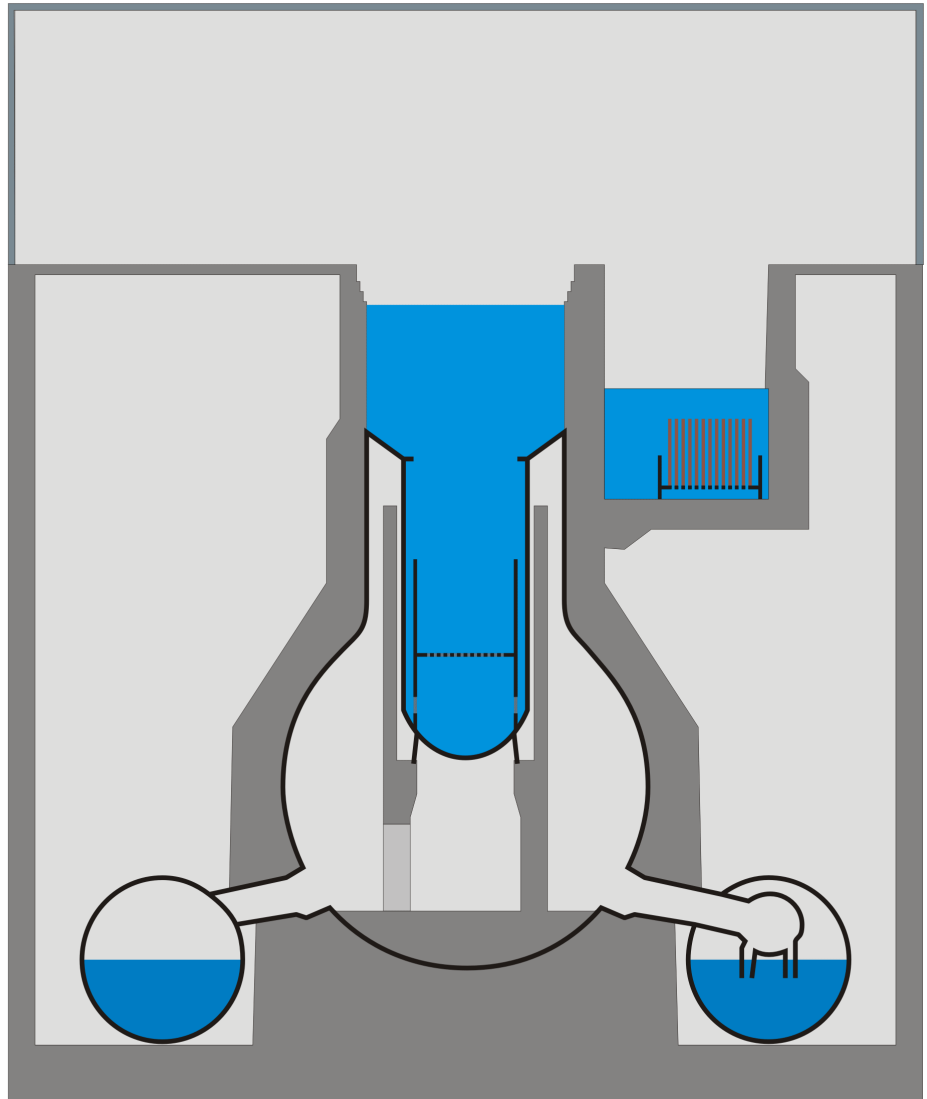
- ▶ Spend fuel stored in Pool on Reactor service floor
 - ◆ Due to maintenance in Unit 4 entire core stored in Fuel pool
 - ◆ Dry-out of the pools
 - Unit 4: in 10 days
 - Unit 1-3,5,6 in few weeks
 - ◆ **Leakage of the pools due to Earthquake?**
- ▶ Consequences
 - ◆ Core melt „on fresh air “
 - ◆ Nearly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



The Fukushima Daiichi Incident

4. Spend fuel pools

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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
- ▶ **It is currently unclear if release from fuel pool already happened**

