





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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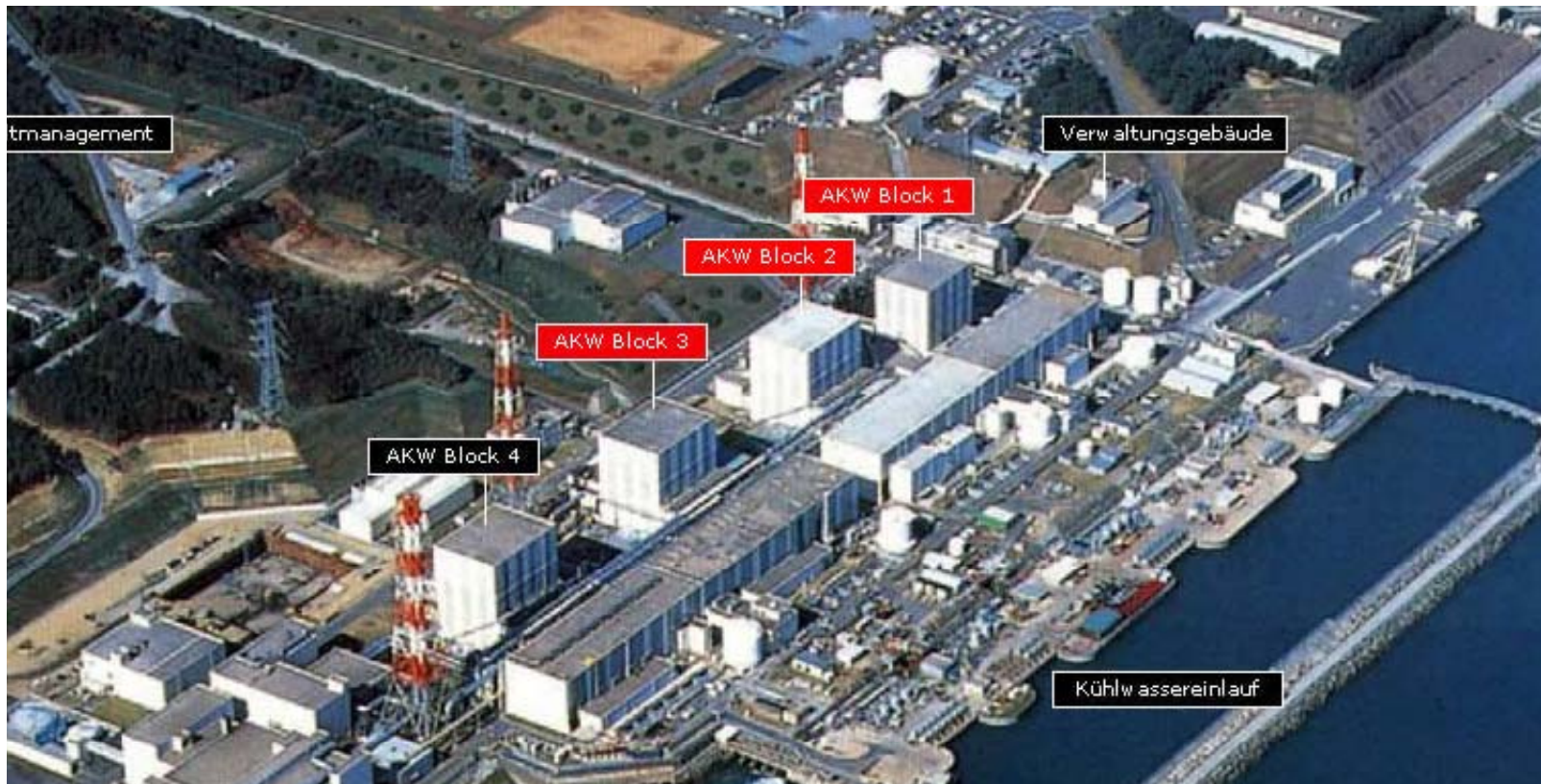
The Fukushima Daiichi Incident

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

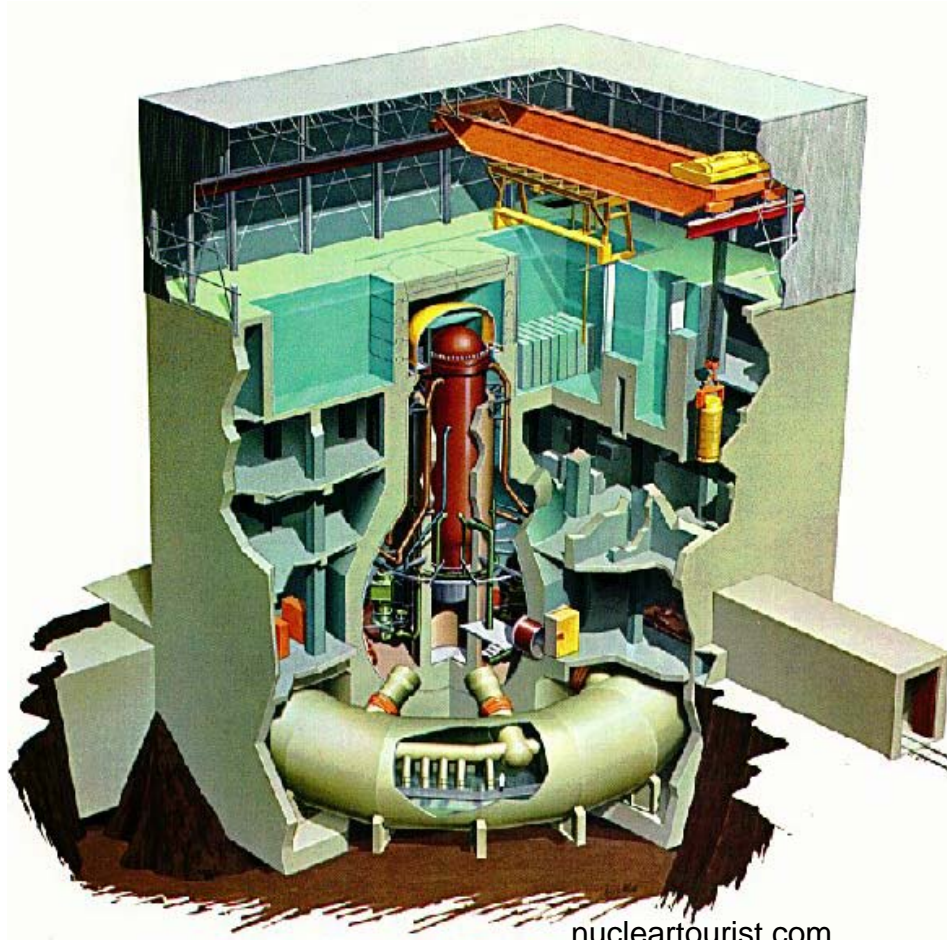


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1. Plant Design

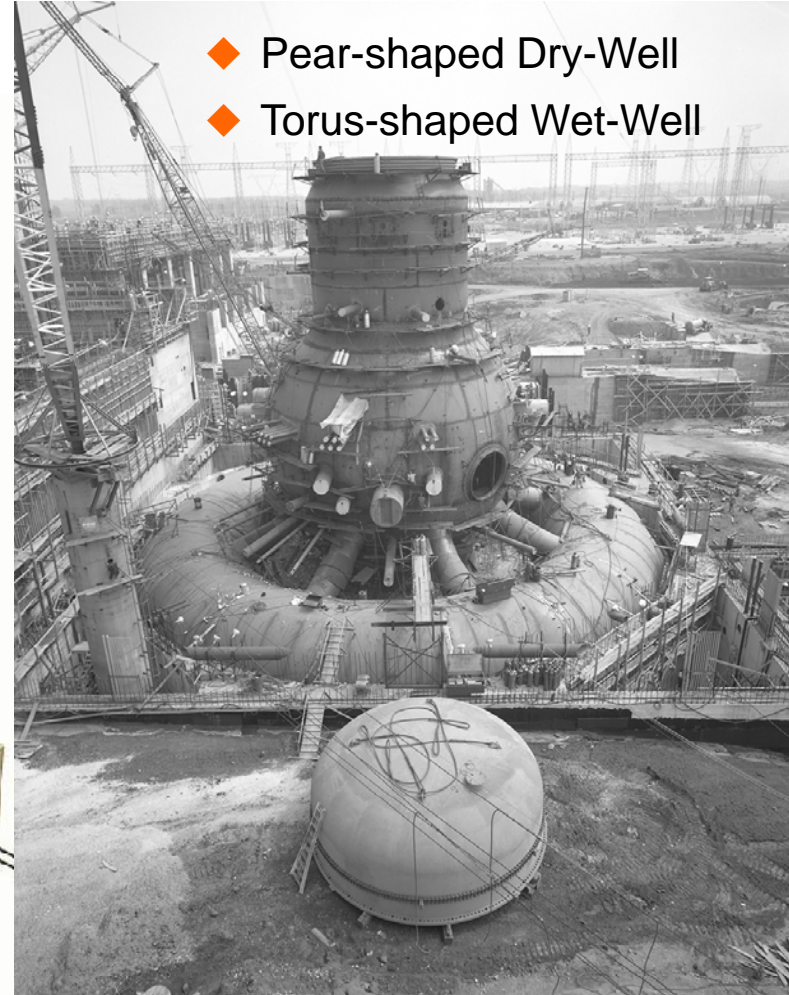
► Building structure

- ◆ Concrete Building
- ◆ Steel-framed Service Floor



► Containment

- ◆ Pear-shaped Dry-Well
- ◆ Torus-shaped Wet-Well



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1. Plant Design



► Service Floor



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1. Plant Design

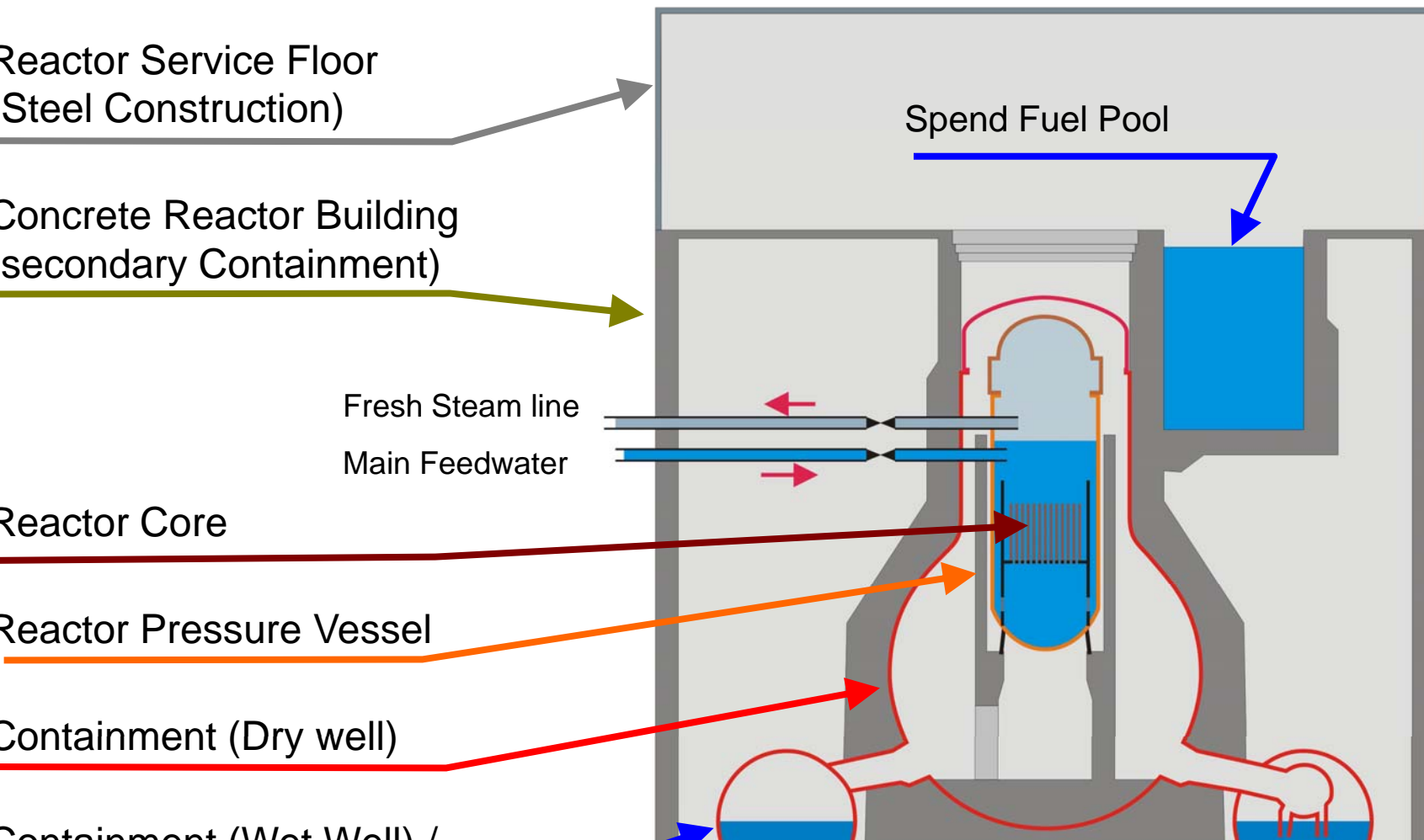


- ▶ Lifting the Containment closure head



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1. Plant Design



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2. Accident progression

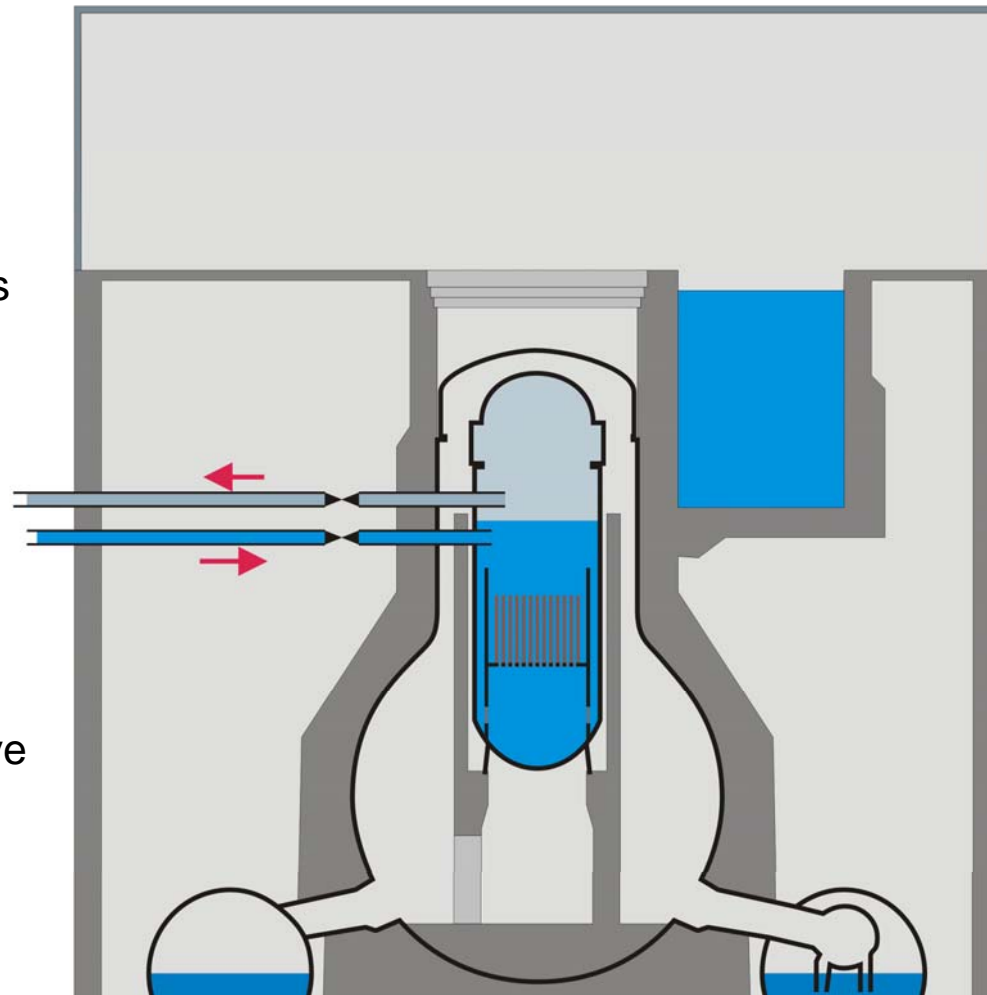


11.3.2011 14:46 - Earthquake

- ◆ 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



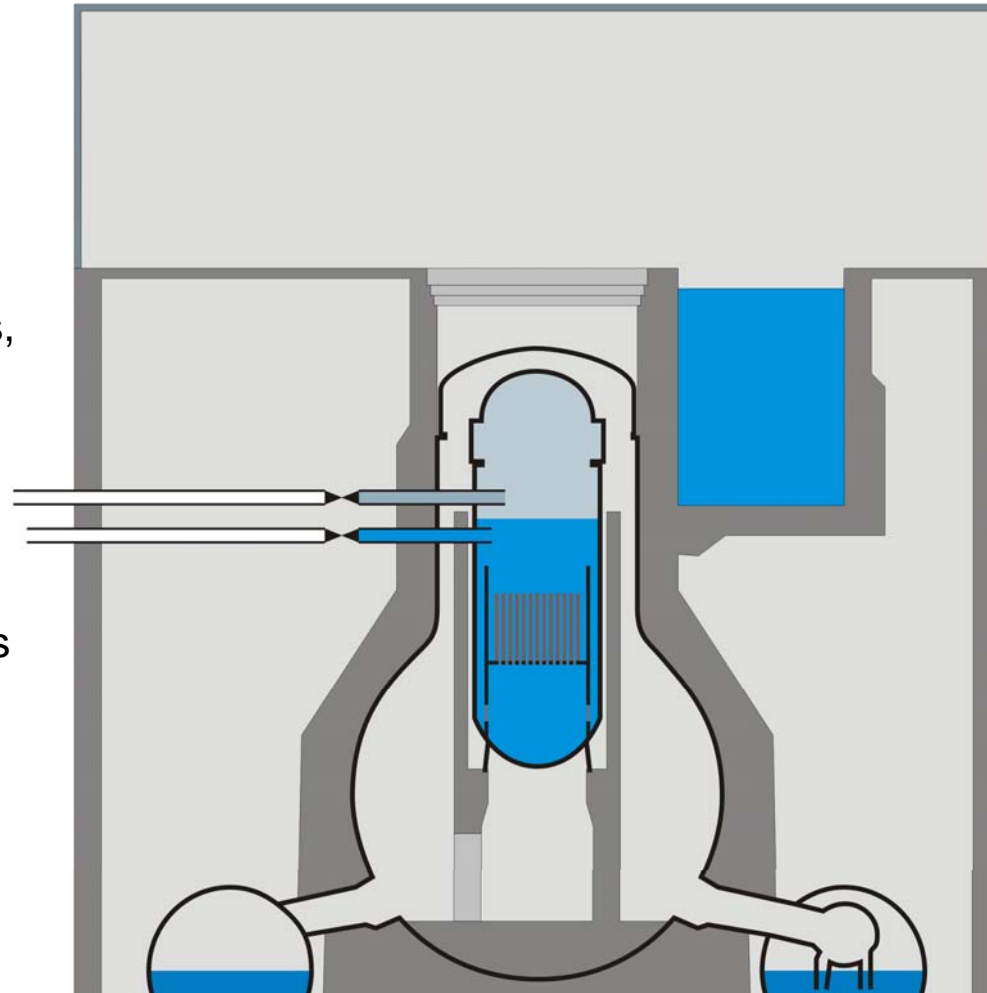
Containment Isolation

- ◆ 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



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2. Accident progression

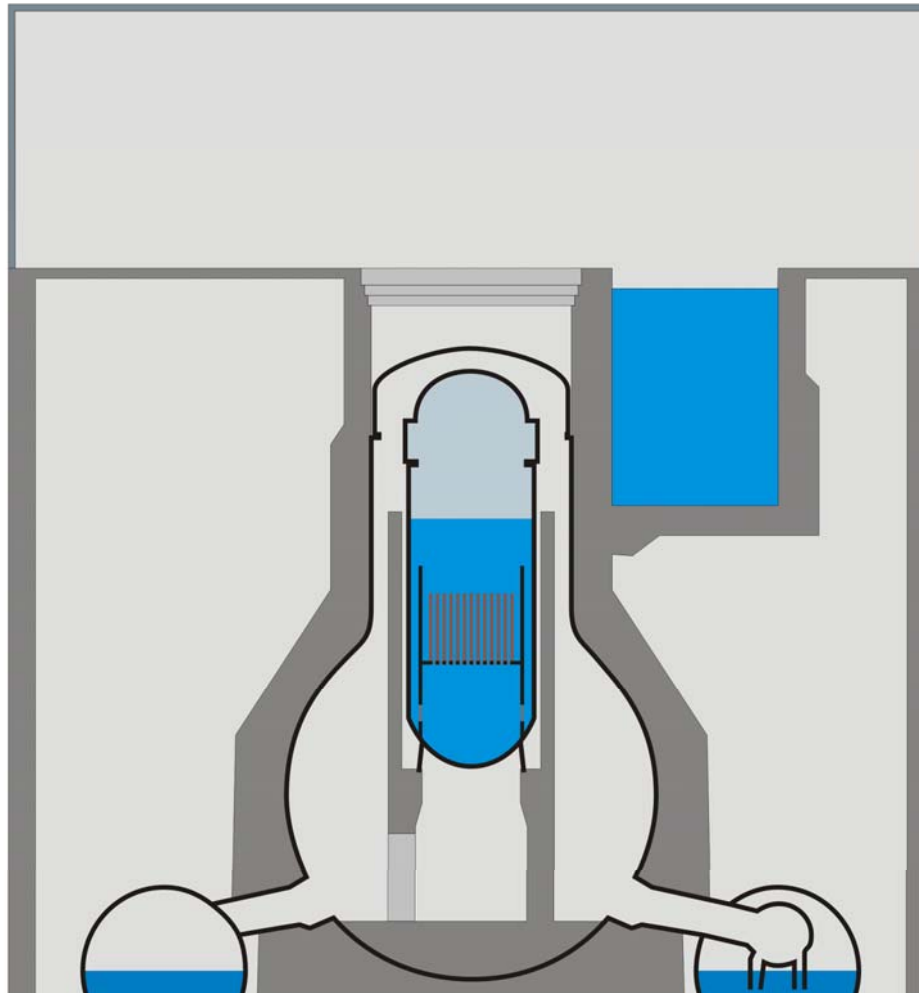


11.3. 15:41 Tsunami hits the plant

- ◆ 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



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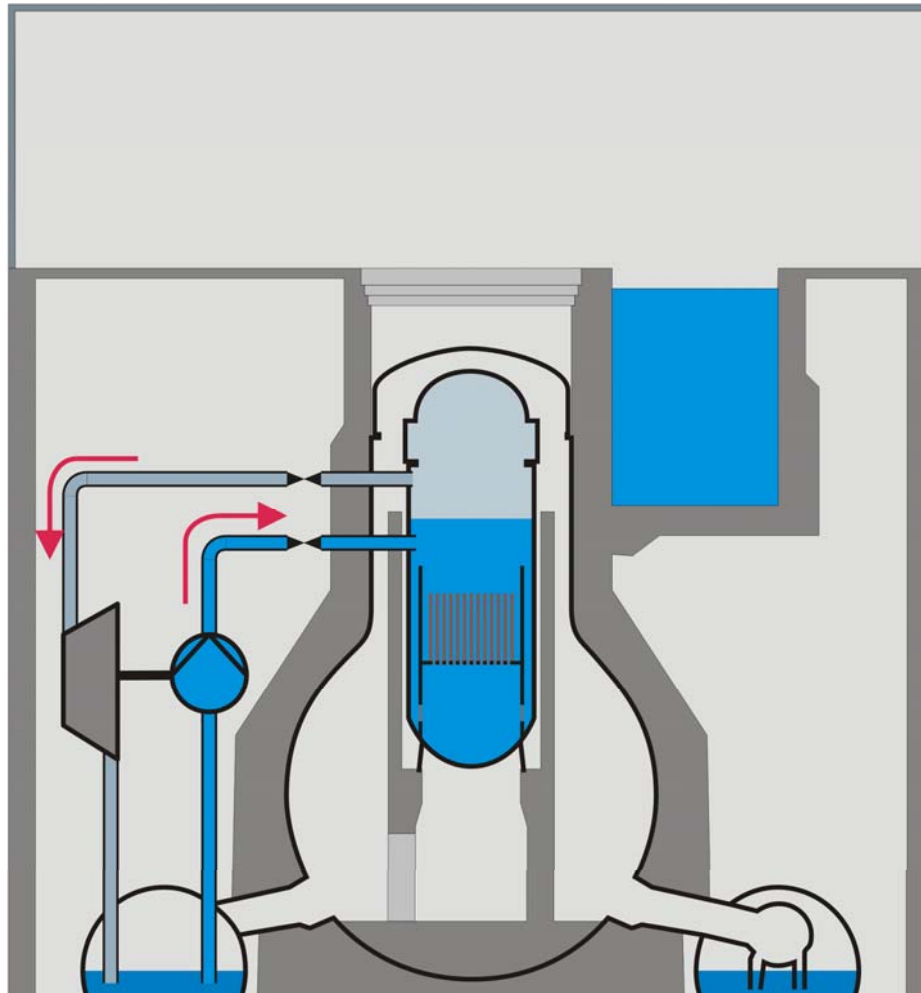
2. Accident progression



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 can't work infinitely



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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)

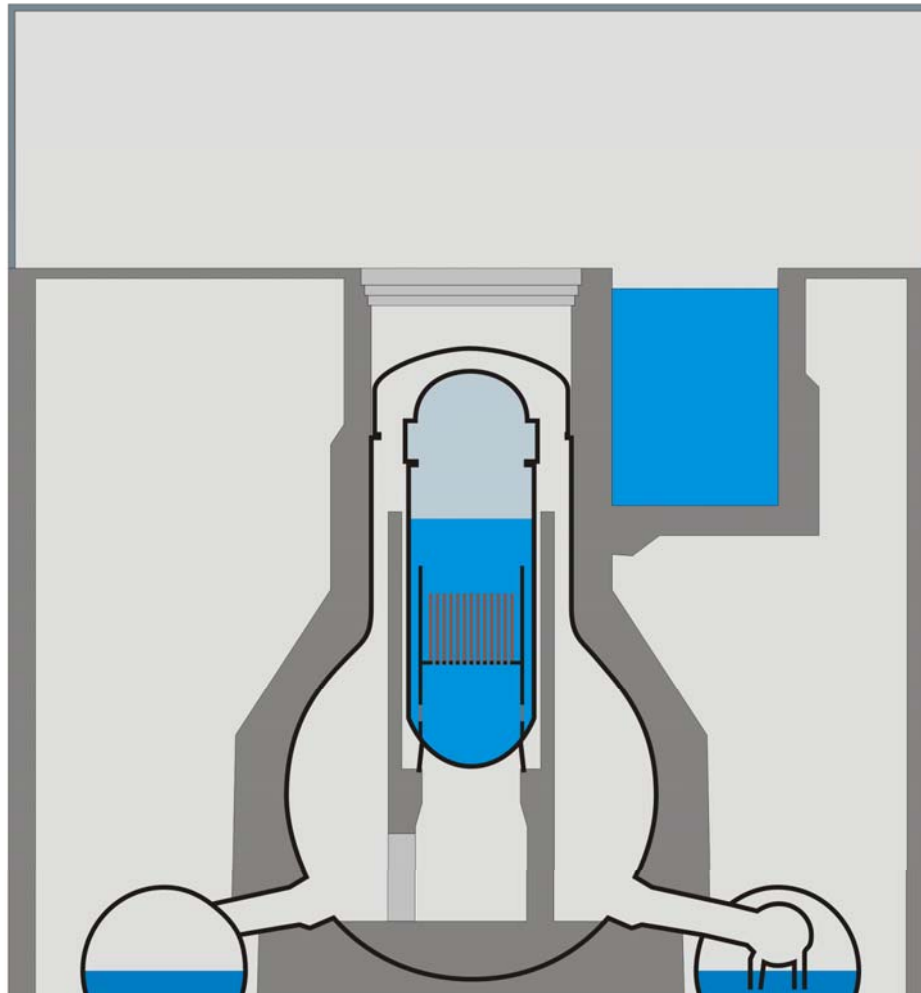
Decay Heat produces still steam in
Reactor pressure Vessel

- ◆ Pressure rising

Opening the steam relieve valves

- ◆ Discharge Steam into the Wet-Well

Descending of the Liquid Level in



The Fukushima Daiichi Incident

2. Accident progression



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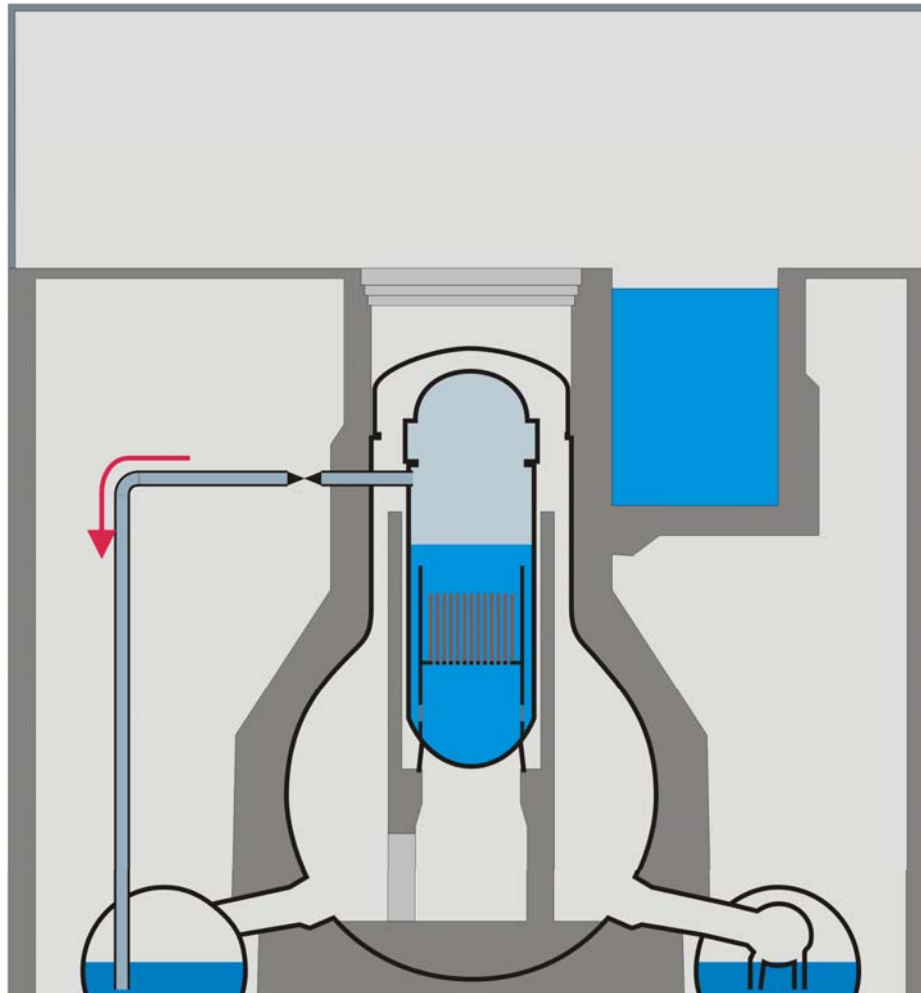
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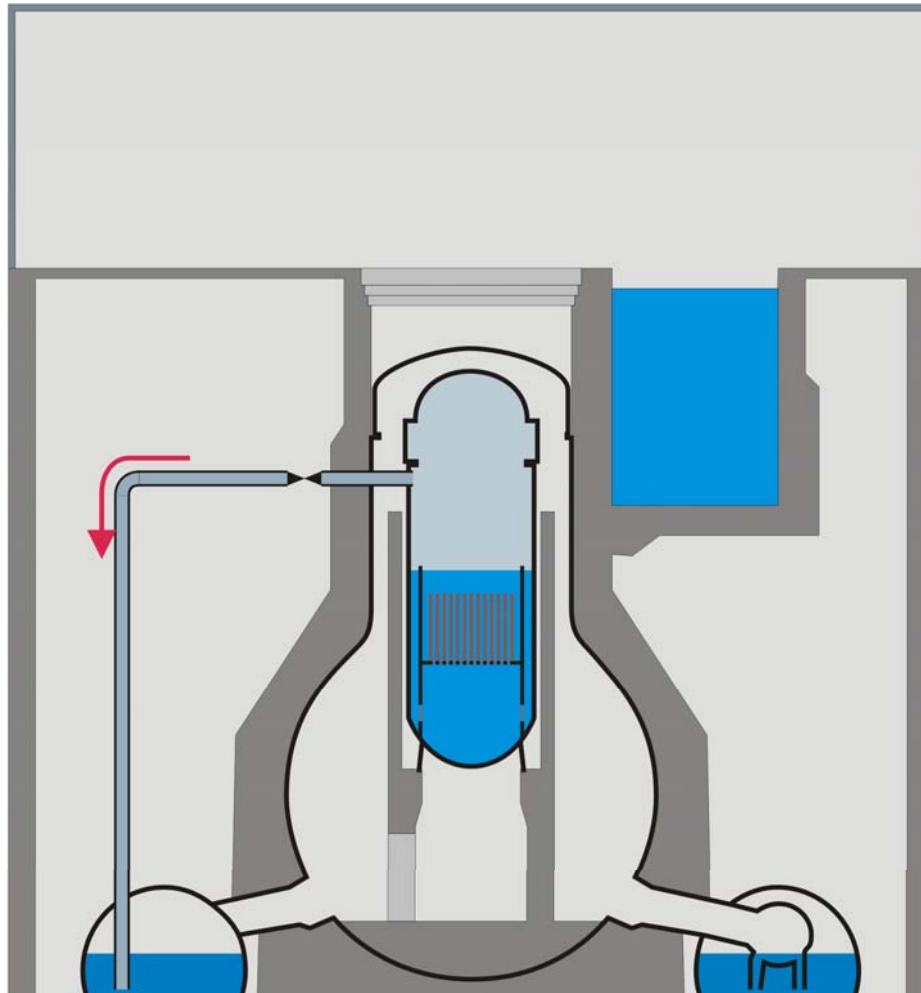
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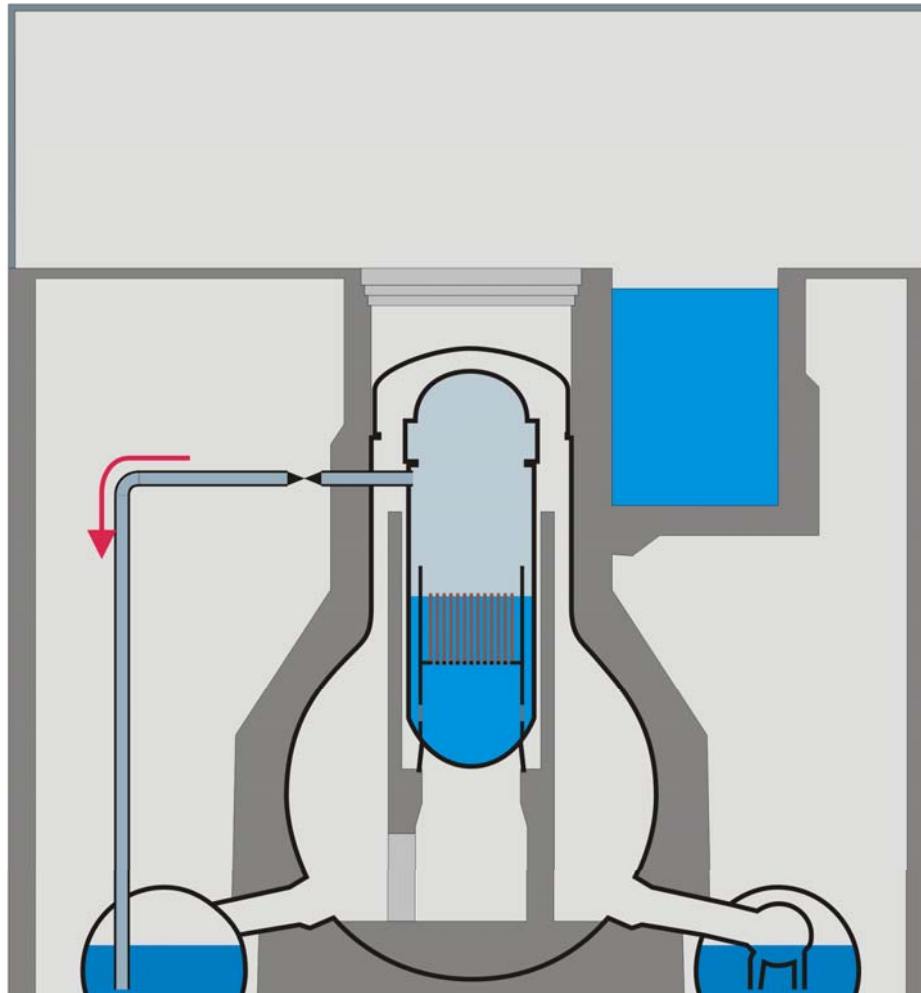
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2. Accident progression



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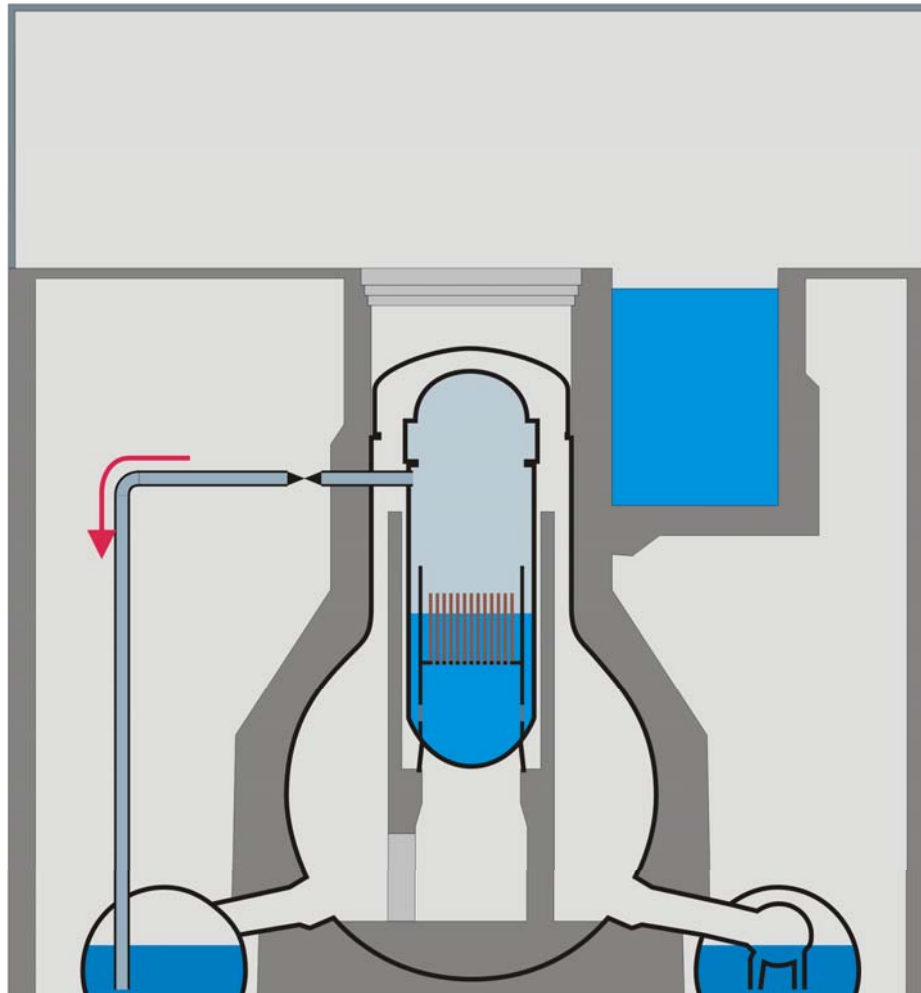
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2. Accident progression



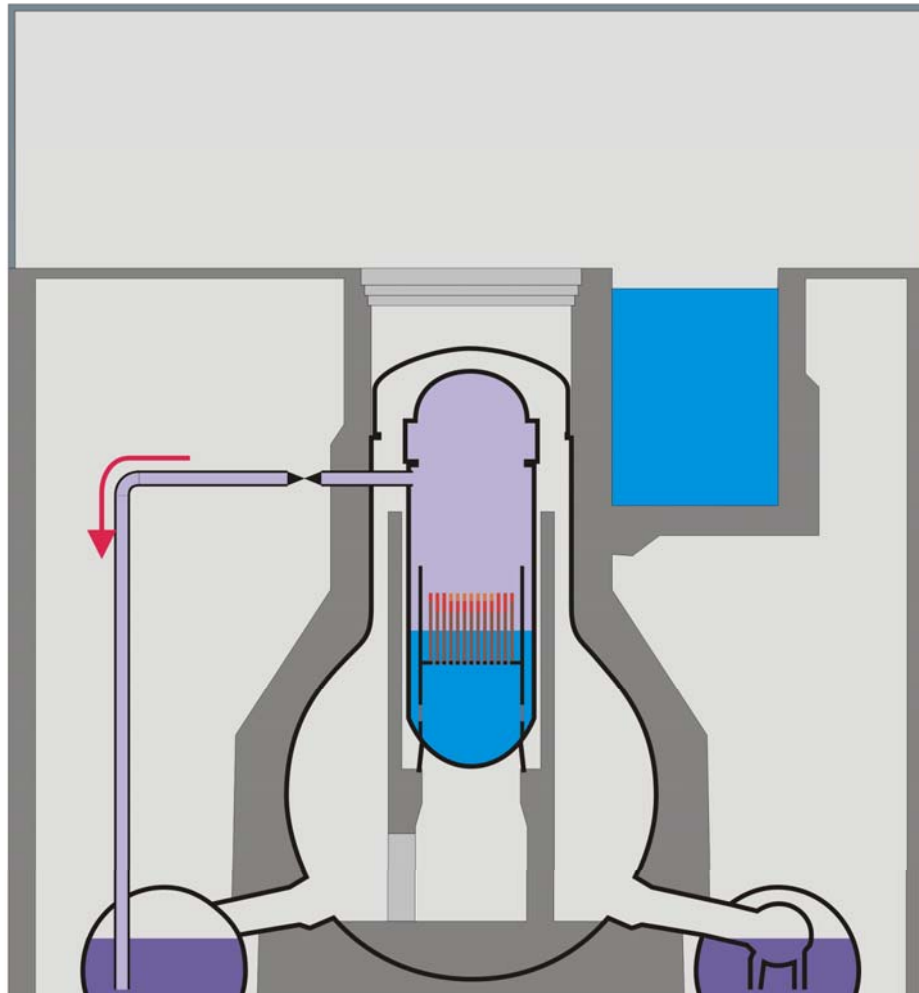
Measured, and here referenced
Liquid level is the collapsed level.
The actual liquid level lies higher
due to the steam bubbles in the
liquid

-50% of the core exposed

- ◆ Cladding temperatures rise, but still no significant core damage

-2/3 of the core exposed

- ◆ Cladding temperature exceeds $\sim 900^{\circ}\text{C}$
- ◆ Ballooning / Breaking of the cladding



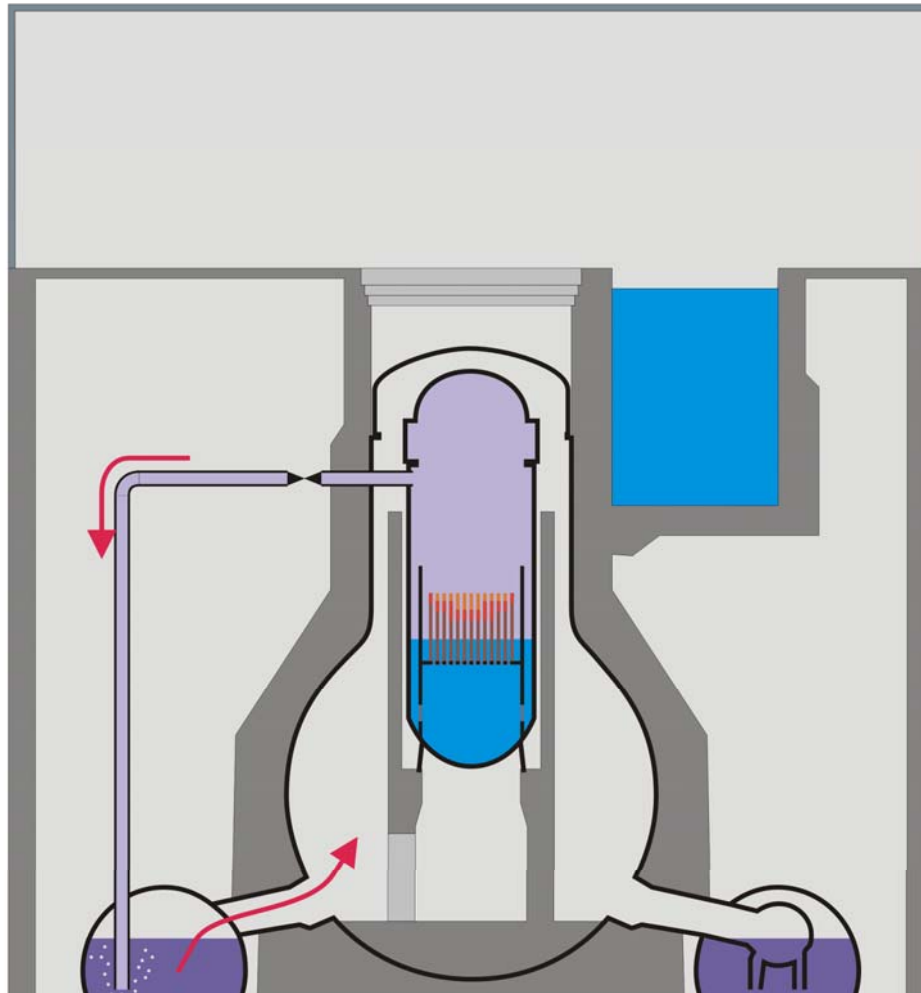
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2. Accident progression



-3/4 of the core exposed

- ◆ Cladding exceeds $\sim 1200^{\circ}\text{C}$
- ◆ 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



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2. Accident progression



t ~1800°C [Unit 1,2,3]

- ◆ Melting of the Cladding
- ◆ Melting of the steel structures

t ~2500°C [Block 1,2]

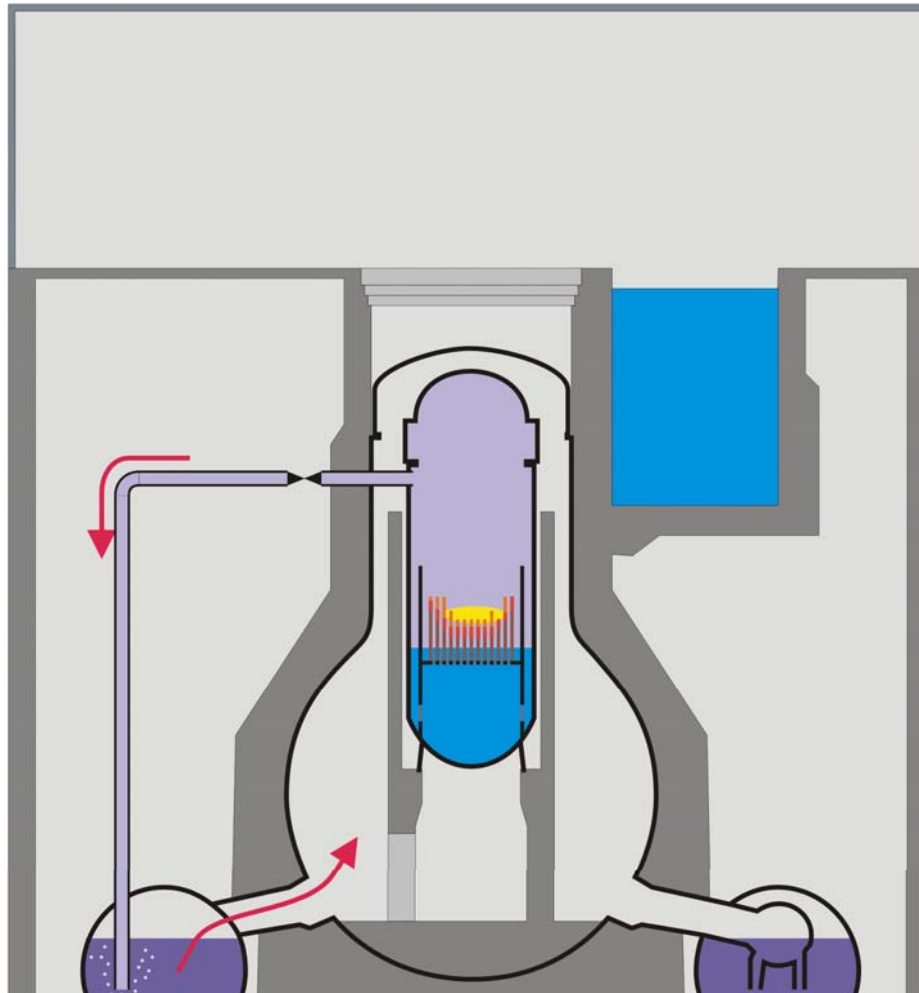
- ◆ Breaking of the fuel rods
- ◆ debris bed inside the core

t ~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)



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2. Accident progression



Release of fission products during
melt down

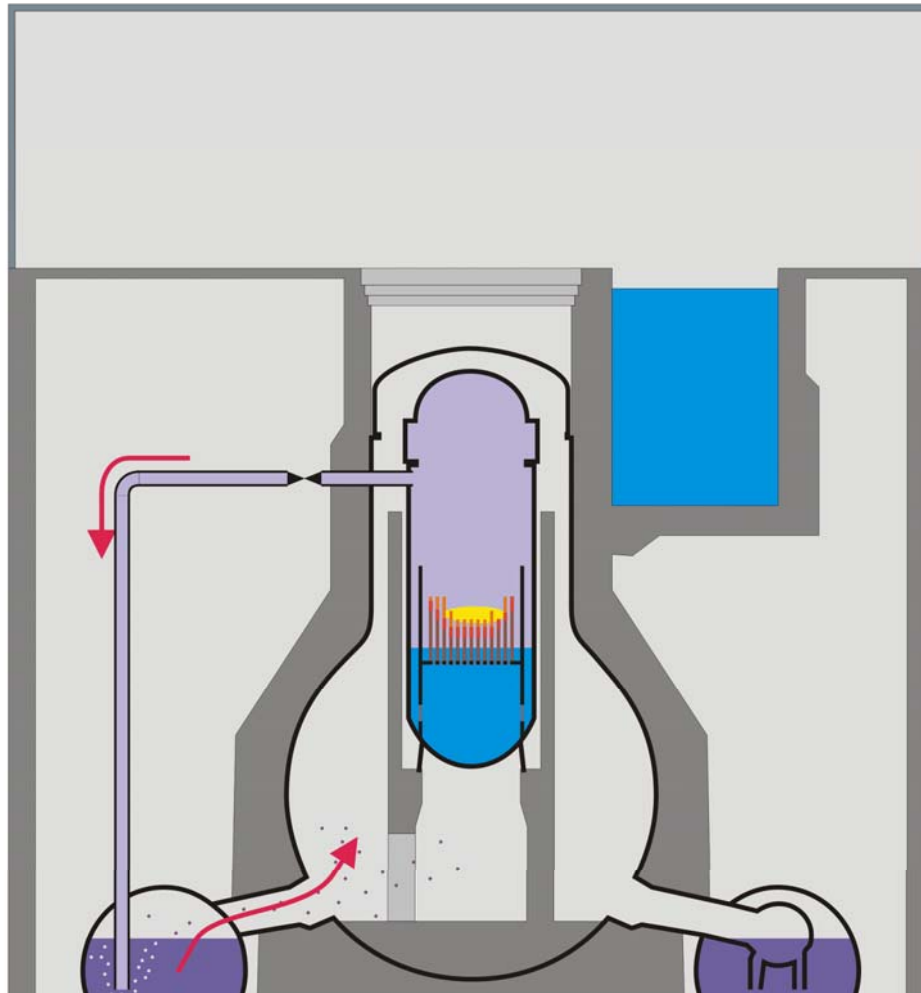
- ◆ Xenon, Cesium, Iodine,...
- ◆ Uranium/Plutonium remain in core
- ◆ Fission products condensate to airborne Aerosols

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



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2. Accident progression



Containment

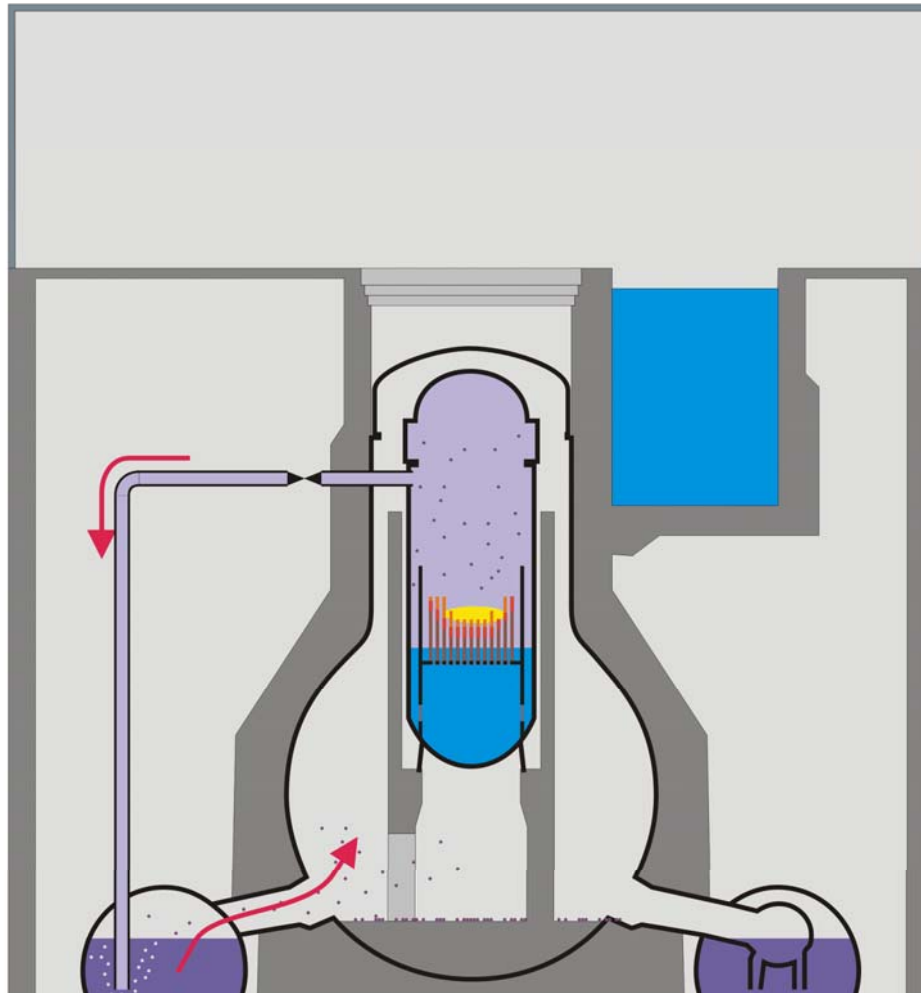
- ◆ Last barrier between Fission Products and Environment
- ◆ Wall thickness ~3cm
- ◆ Design Pressure 4-5bar

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



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2. Accident progression

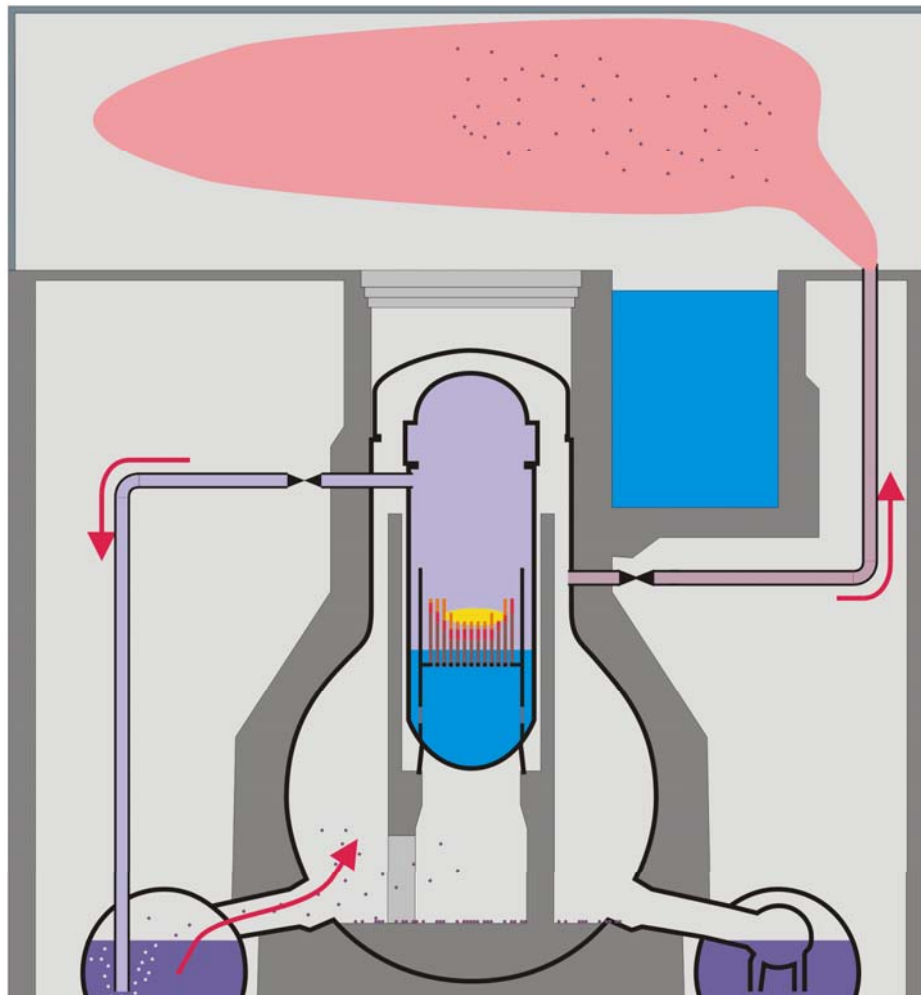


Positive and negative Aspects of depressurizing the containment

- ◆ 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

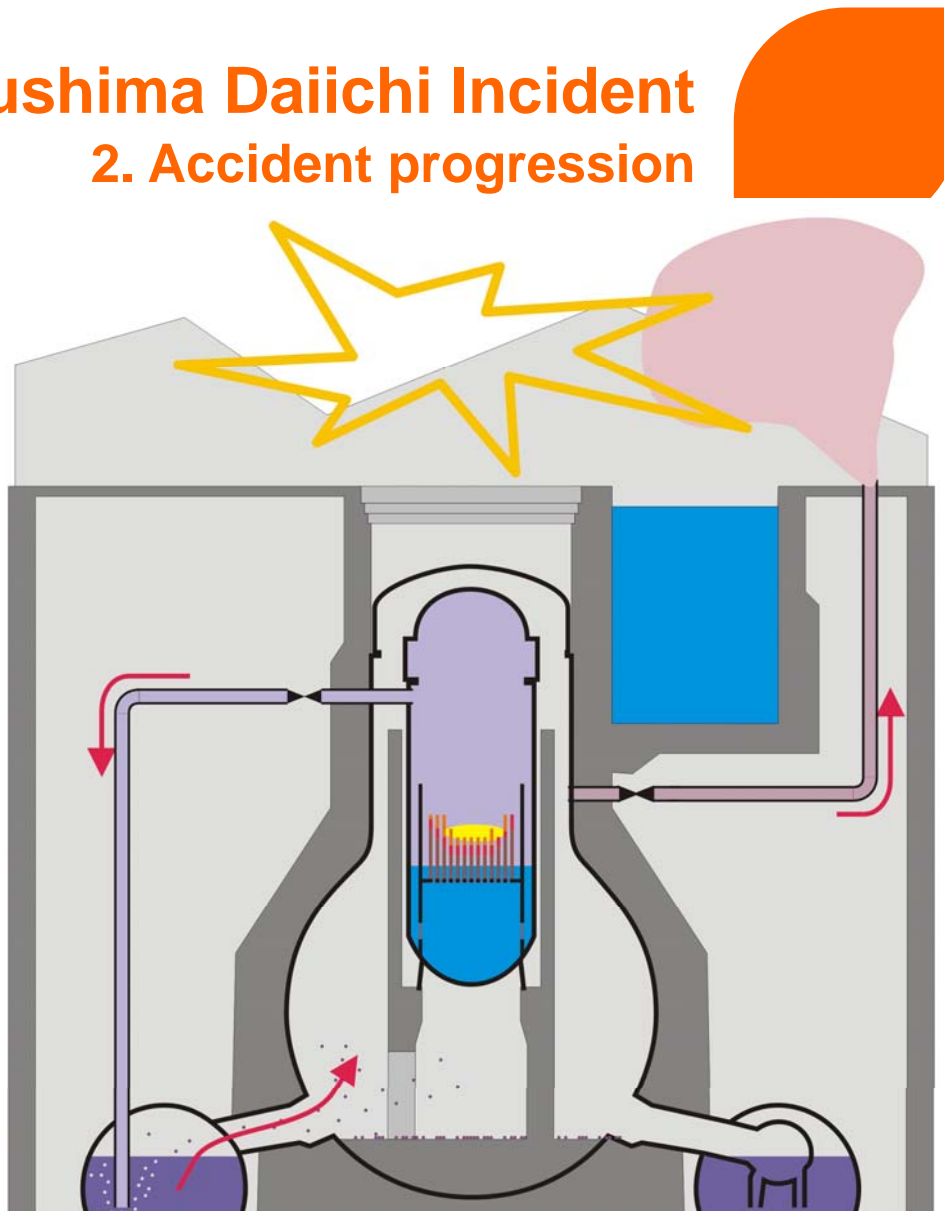


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2. Accident progression

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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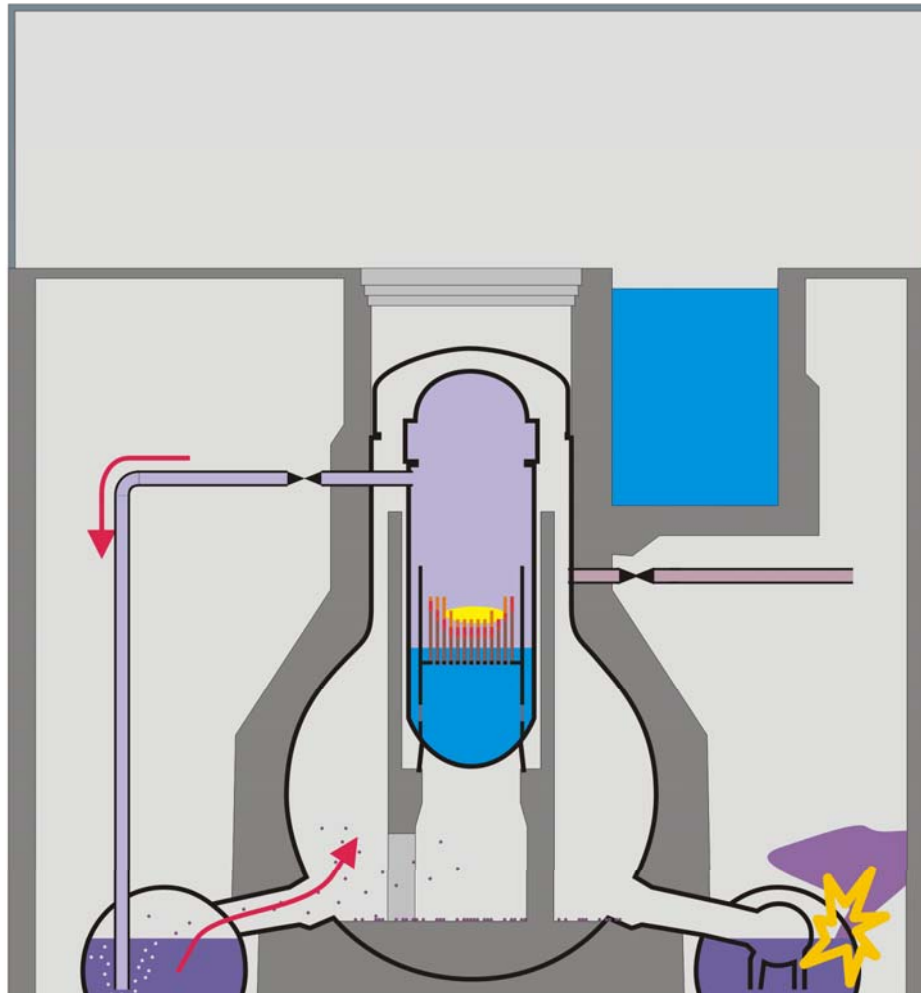
2. Accident progression



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

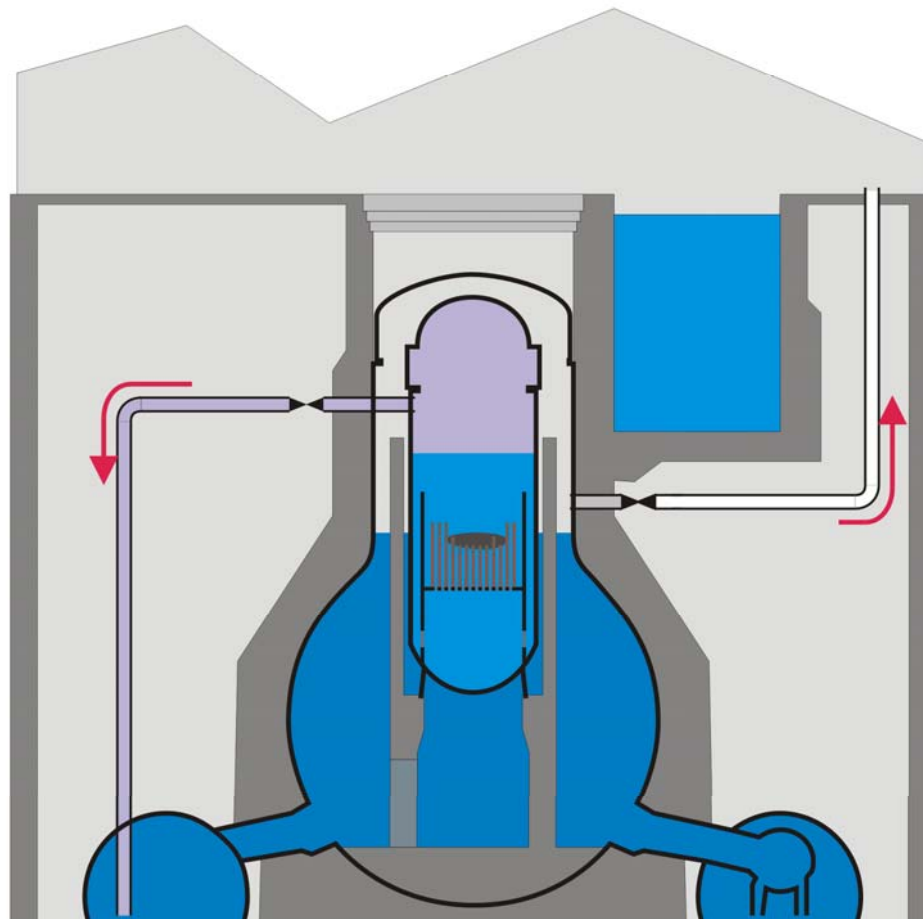


Current status of the Reactors

- ◆ 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

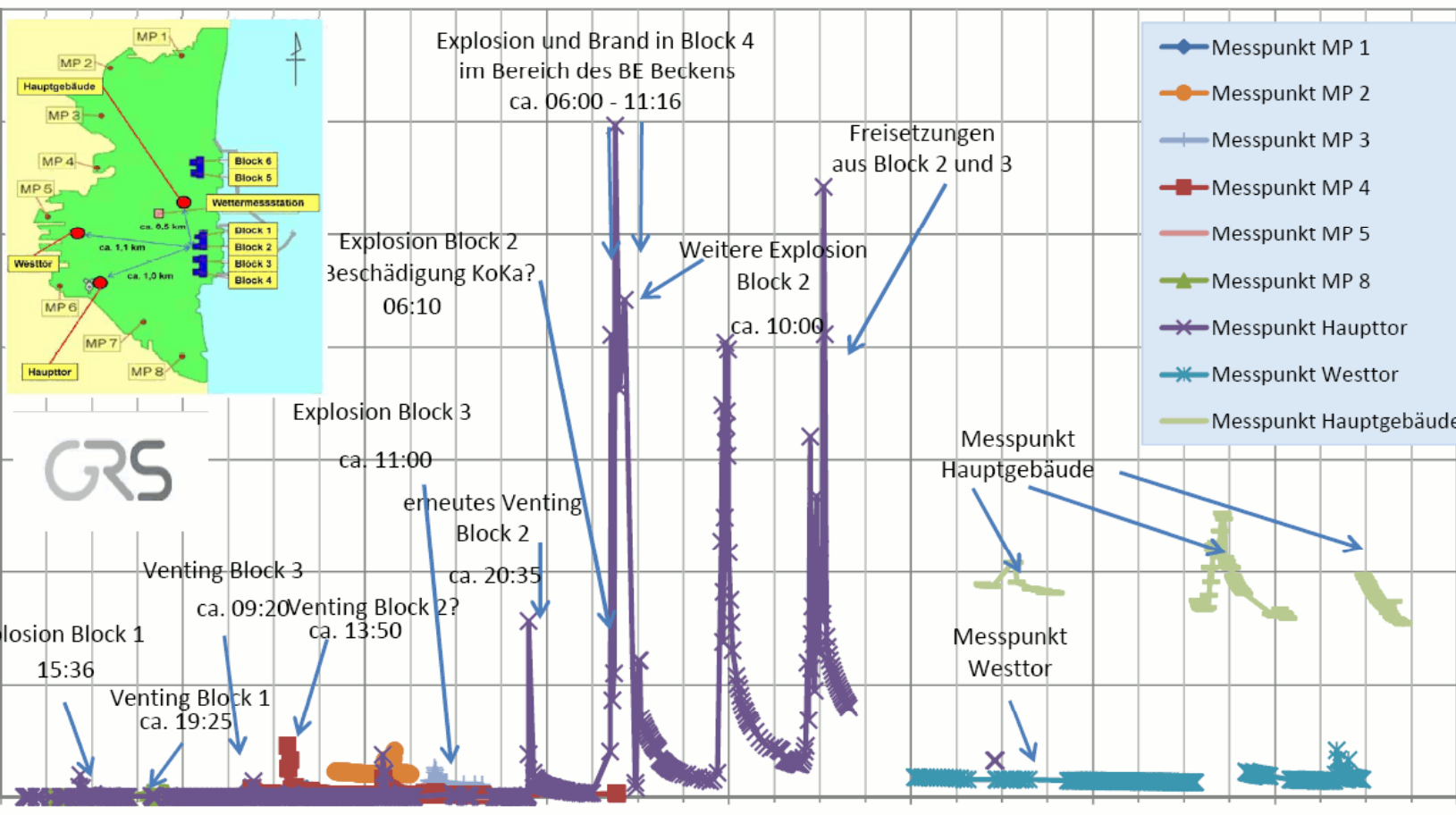
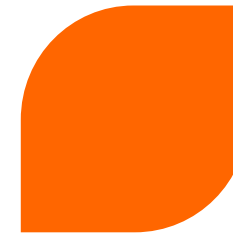
- ◆ Before Explosion in Unit Block 2
 - Below 2mSv / h
 - Mainly due to released radioactive noble gases
 - Measuring posts on west side. Maybe too small values measured due to wind

- ◆ 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

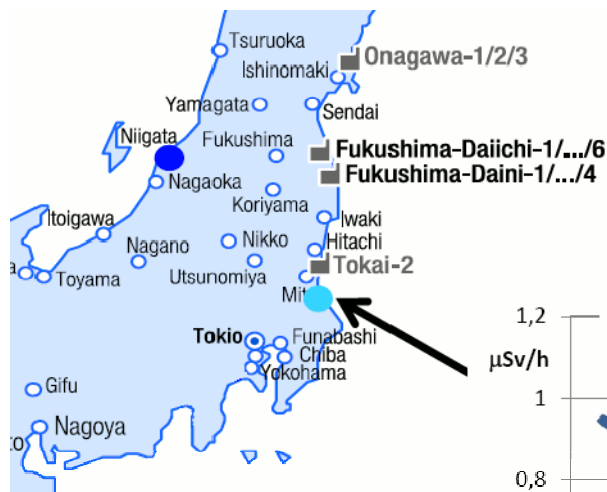
- ◆ As reactor building mostly intact
=> reduced release of Aerosols (not Chernobyl-like)
- ◆ Fission product release in steam
=> fast Aerosol grows, large fraction falls down in the proximity of the plant
- ◆ Main contribution to the radioactive dose outside plant are the radioactive noble gases
- ◆ 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

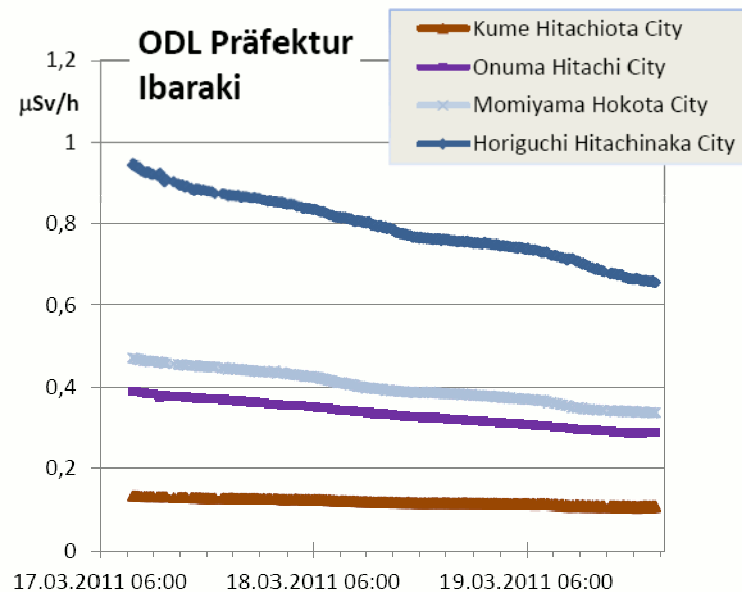
- ◆ Evacuations were adequate
- ◆ Measured dose up to 0.3mSv/h for short times
- ◆ Maybe destruction of crops / dairy products this year
- ◆ Probably no permanent evacuation of land necessary

The Fukushima Daiichi Incident

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. Spent fuel pools

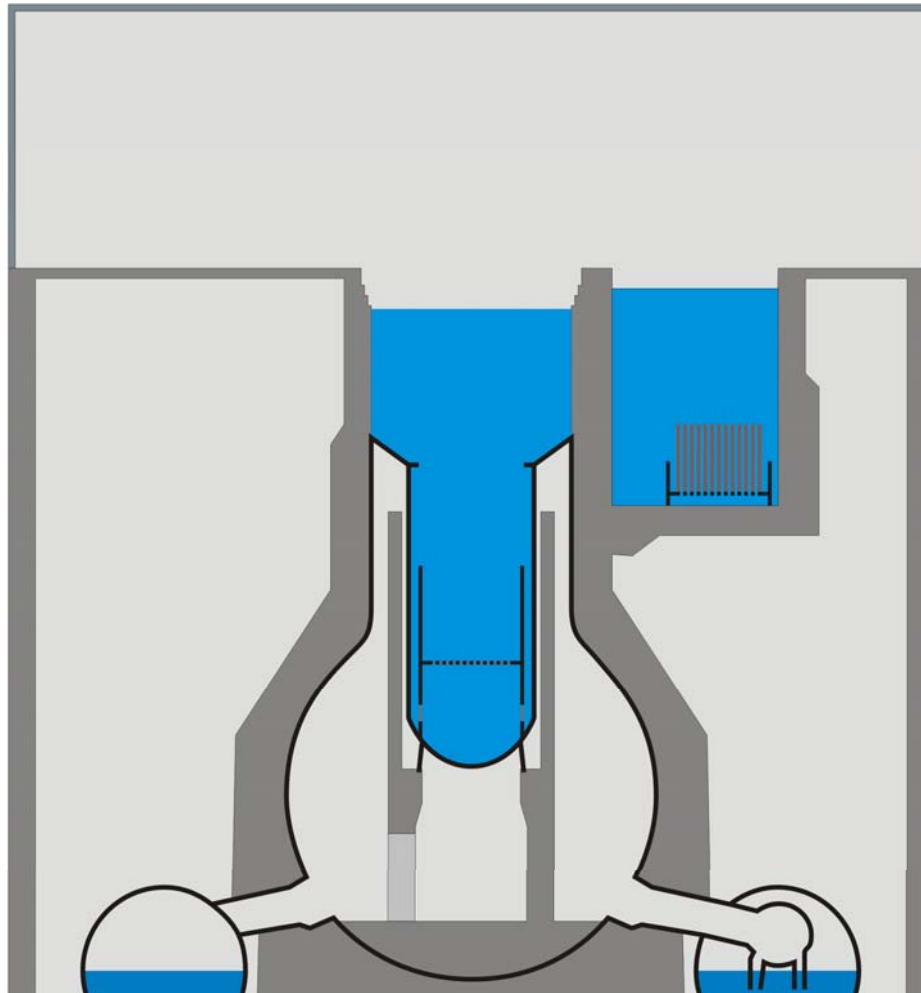


Spent fuel stored in Pool on
Reactor service floor

- ◆ 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



The Fukushima Daiichi Incident

4. Spent fuel pools

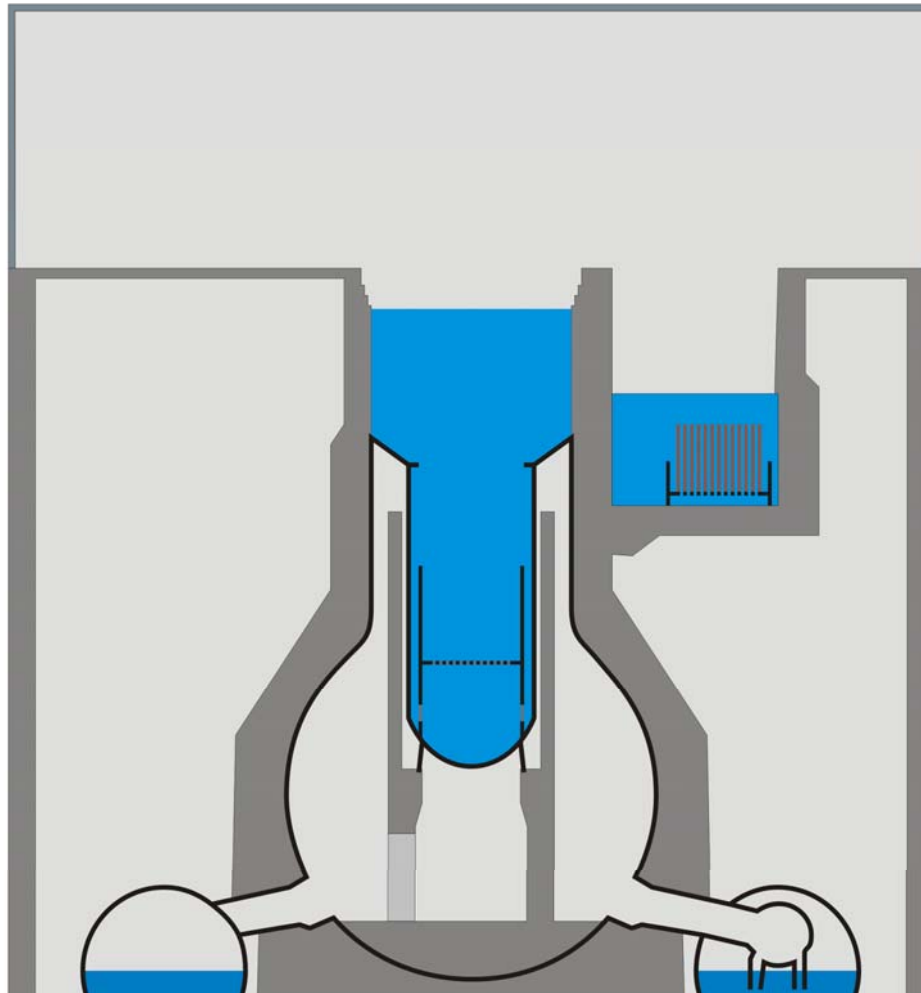


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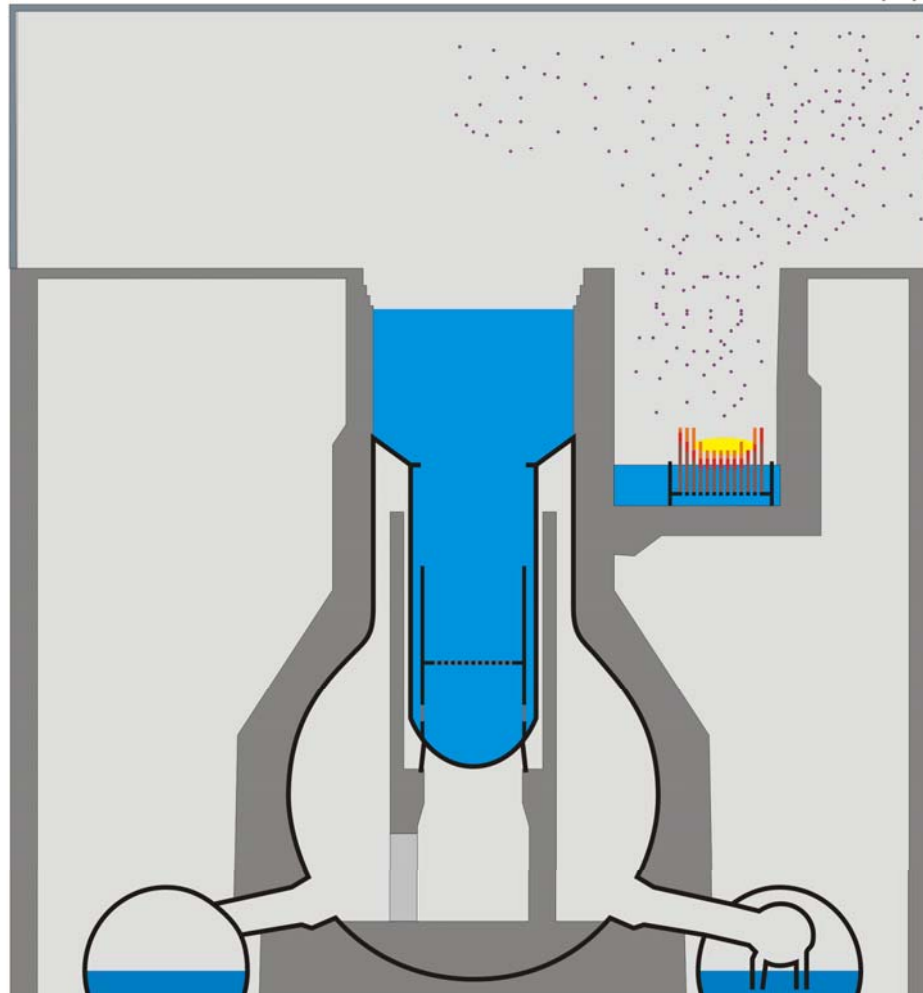


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5. Sources of Information



Good sources of Information

- ◆ Gesellschaft für Reaktorsicherheit [GRS.de]
 - Up to date
 - Radiological measurements published
 - German translation of japanese/englisch 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

Way too few information are released by TEPCO, the operator of the plant