The Fukushima Daiichi Incident

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

nucleartourist.com
en.wikipedia.org/wiki/Browns_Ferry_Nuclear_Power_Plant
1. Plant Design

Service Floor
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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)
- Reactor Core
- Reactor Pressure Vessel
- Containment (Dry well)
- Containment (Wet Well) / Condensation Chamber
- Fresh Steam line
- Main Feedwater
- Spend Fuel Pool
**The Fukushima Daiichi Incident**

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%
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**
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 cant work infinitely
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
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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
  - Balooning / Breaking of the cladding
  - Release of fission products form 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
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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 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
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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 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 und 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
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 Units 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
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3. Radiological releases

The diagram illustrates the timeline and radiation levels during the Fukushima Daiichi Incident. It shows the radiation levels in microSieverts per hour (μSv/h) from March 12 to March 20, 2011. The graph includes various events such as explosions in Block 4, Block 2, and Block 3, as well as venting events in Blocks 1 and 3. The timeline is marked in Japanese local time (Ortszeit japanische Anlage).
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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

- ~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
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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
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

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