Chronological accident description until current situation and introduction to BWR theory

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1． introduction

- On March 11th 2011, the Great East Japan Earthquake and subsequent tsunami hit the north east area of Japan including the Fukushima Dai-ichi nuclear power station (NPS).
- After the earthquake, Fukushima Dai-ichi unit 1, 2, and 3 in normal operation are automatically shutdown by seismic SCRAM logic.
- However, due to subsequent tsunami of 15m height, plants lost electric power and safety equipment.
- In the end, three plants fell into severe accident, a massive amount of radioactive materials are released to environment.
- In this presentation, I will explain about the BWR theory with reference to basic safety functions for nuclear power plant (NPP), and I will show you the Fukushima Dai-ichi accident progression chronologically and current situation of the Fukushima Dai-ichi NPS.

1. Damage Caused by GEJE

Houses Swept Away by Tsunami in Iwate

Stranded Cruise Ship in Iwate

1. introduction

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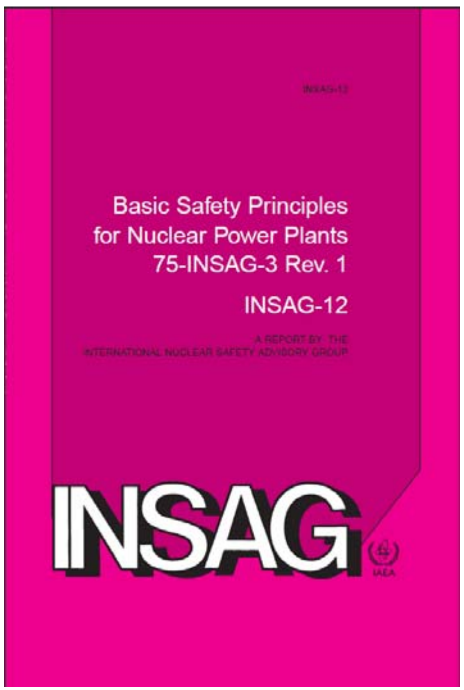
- However, due to subsequent tsunami of 15m height, plants lost electric power and function of safety equipment.
- In the end, three plants fell into severe accident, a massive amount of radioactive materials are released to environment.
- In this presentation, I will explain about the BWR theory with reference to basic safety functions for nuclear power plant (NPP), and I will show you the Fukushima Dai-ichi accident progression chronologically and current situation of the Fukushima Dai-ichi NPS.

2. Basic safety functions for NPP

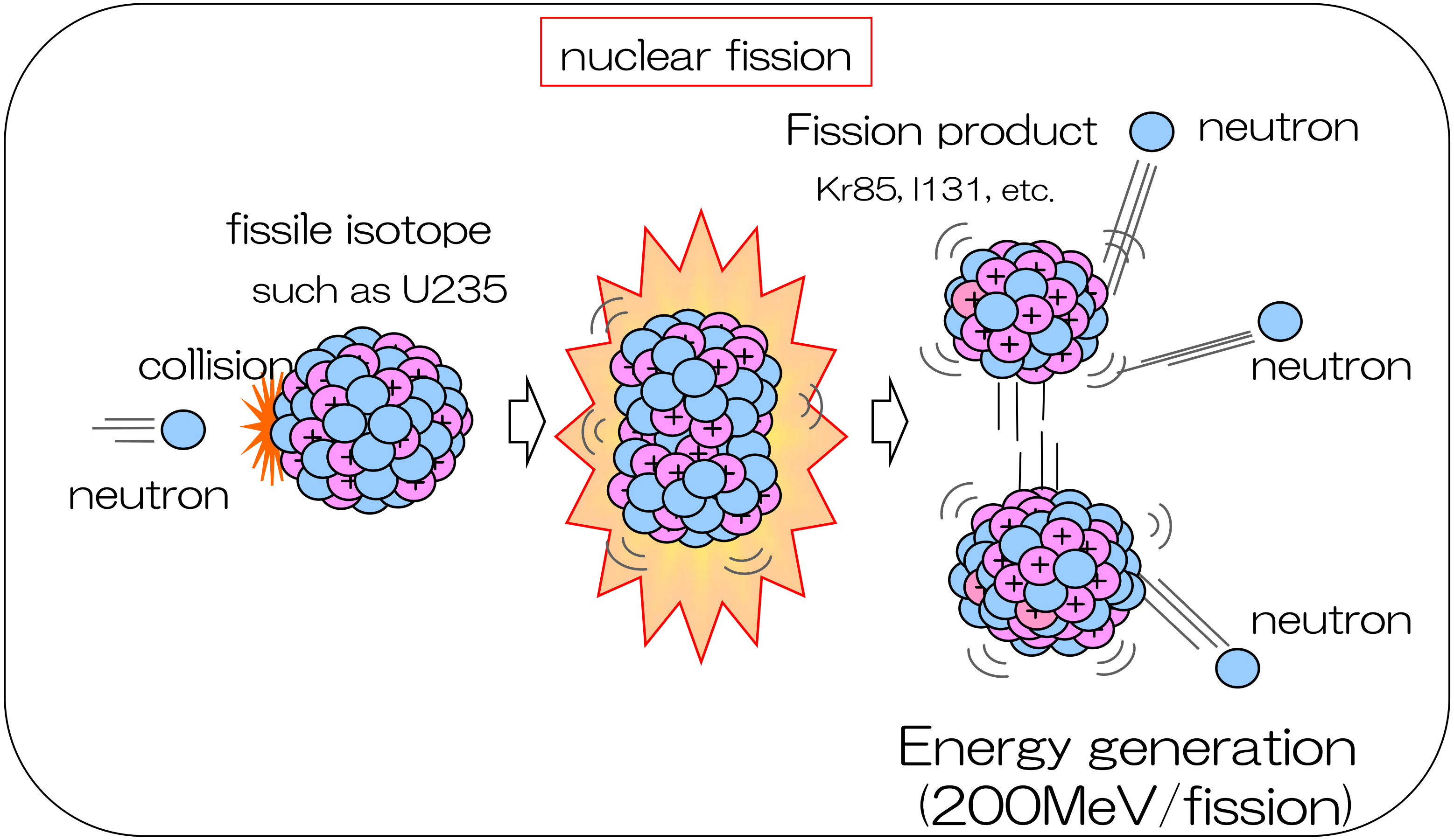
- controlling the power (shutdown)
- cooling the fuel (cooling)
- confining radioactive material (containment)



http://www-pub.iaea.org/MTCD/publications/PDF/P082_scr.pdf

2. Energy generation by nuclear fission

When fissile isotope, such as U235, collides with neutron and captures it, nuclear fission occurs. Fissile isotope split into two small isotopes, such as Kr85, I131, etc., and two or three neutrons. Isotopes generated after fission event are called fission product (FP). These fission events release about two hundred million eV (200 MeV) of energy for each fission event.



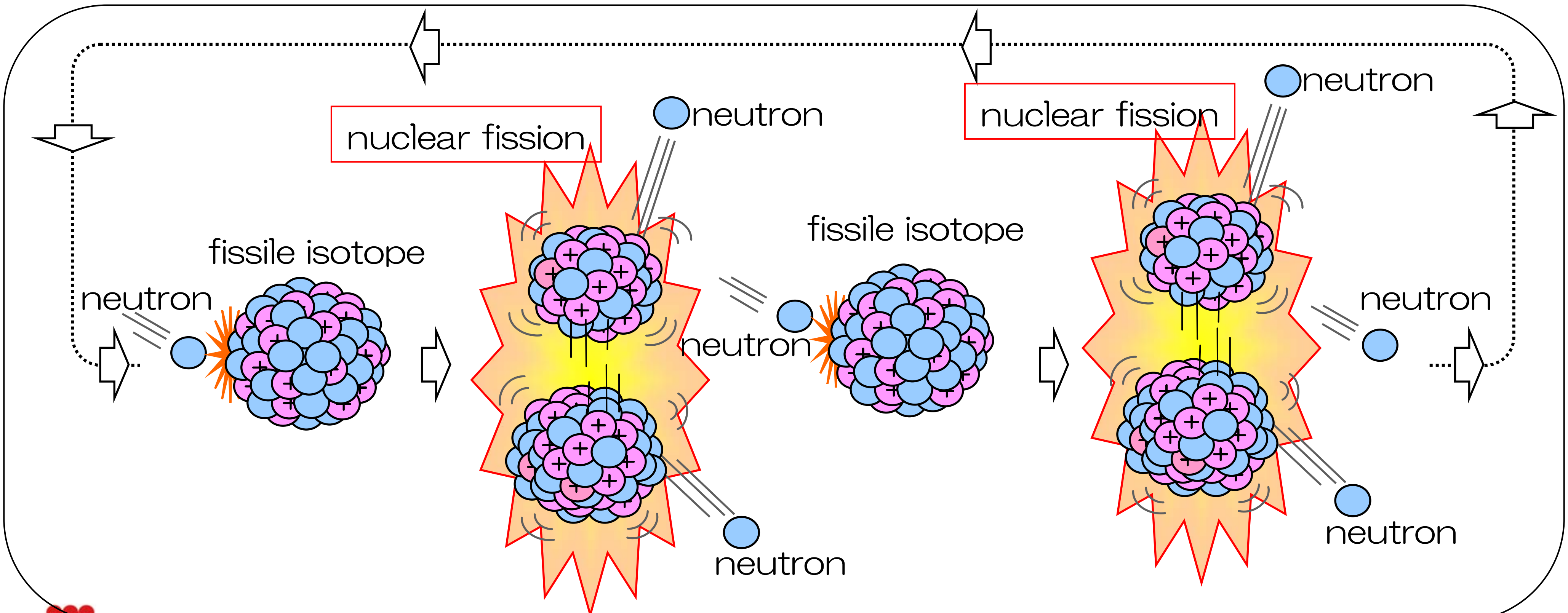
2. Nuclear chain reaction and criticality

Nuclear chain reaction

The state that nuclear fission continuously occurs by the neutrons generated previous fission events.

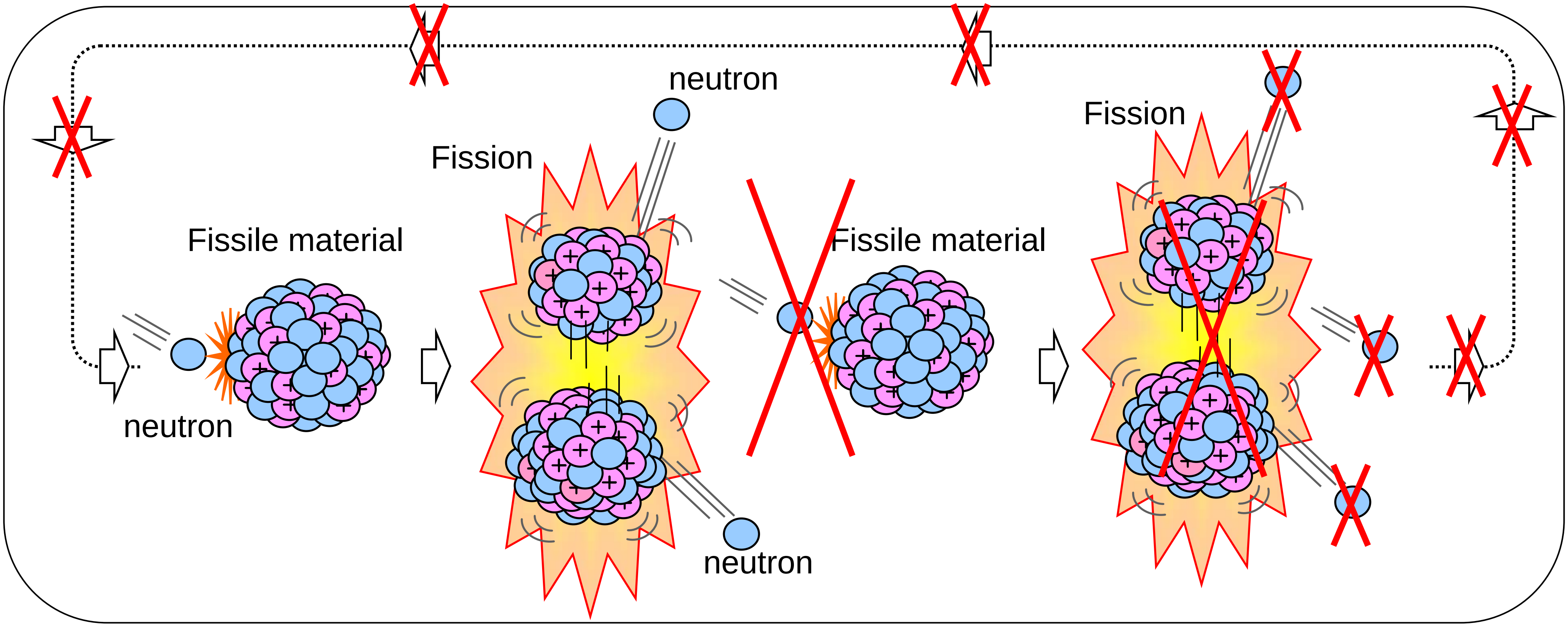
Criticality

When a nuclear chain reaction of fissile material is self-sustaining, the state is said to be in a criticality, in which there is no increase or decrease in power, temperature, or neutron population.



2. "Controlling the power" (shutdown)

- Controlling the power means "terminating the chain reaction."



- After "terminating the chain reaction",
  there is no energy generation by nuclear fission.
- What is the heat required to be hemoved after shutdown ?

2. Decay heat : energy generated after shutdown

Decay heat

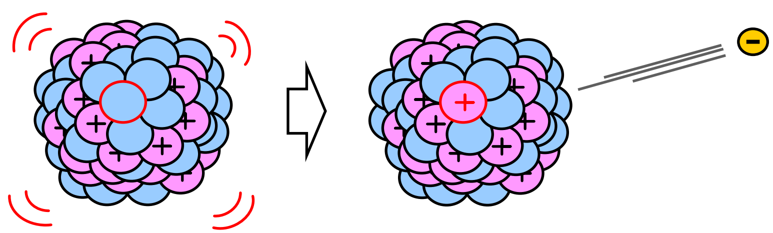
Fissile nucleus with large atomic number contains many neutrons. For example, atomic number of uranium two three five is ninety two, but number of neutrons is one hundred and forty three. This is why fission products have many neutrons compared to stable isotopes and are relatively unstable. Therefore, fission products decay to stable isotopes with releasing some energy. This energy discharged from FP is called decay heat.

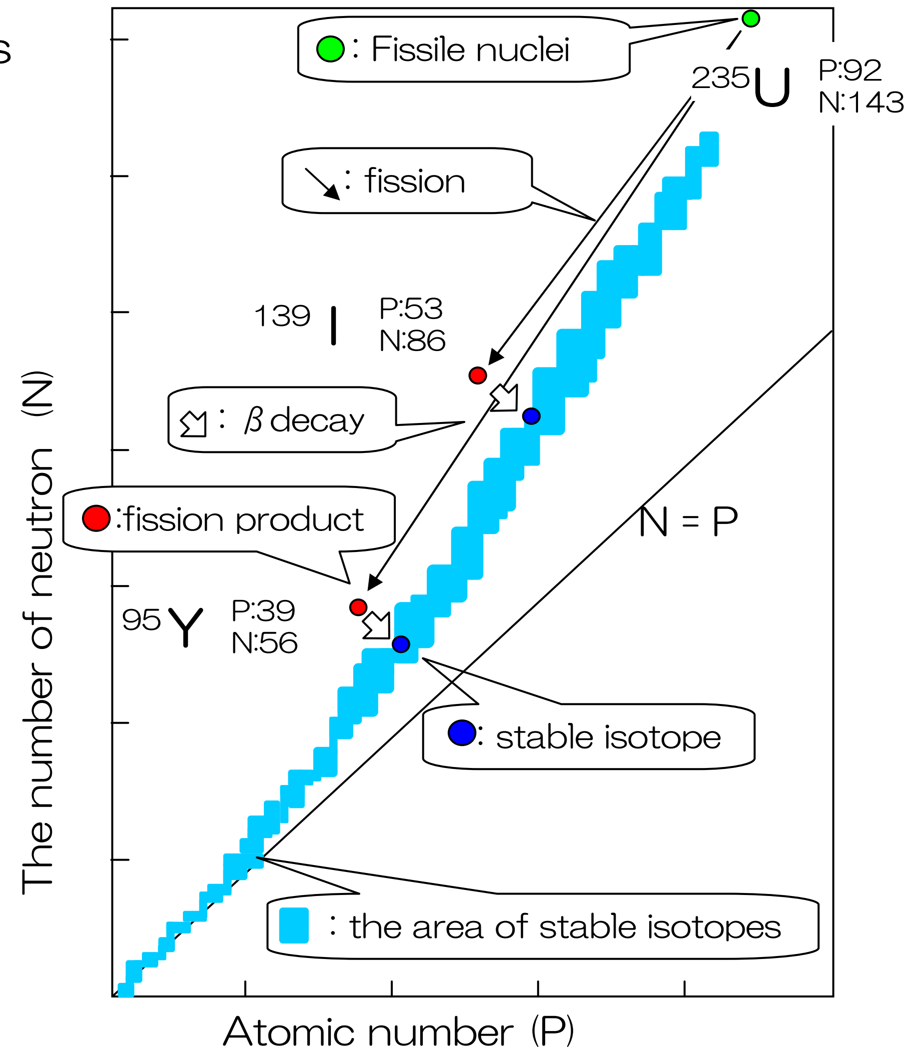
→Continuous removal of the decay heat is required after shutdown.

Example of decay (beta decay)

A neutron transform into positron and electron.

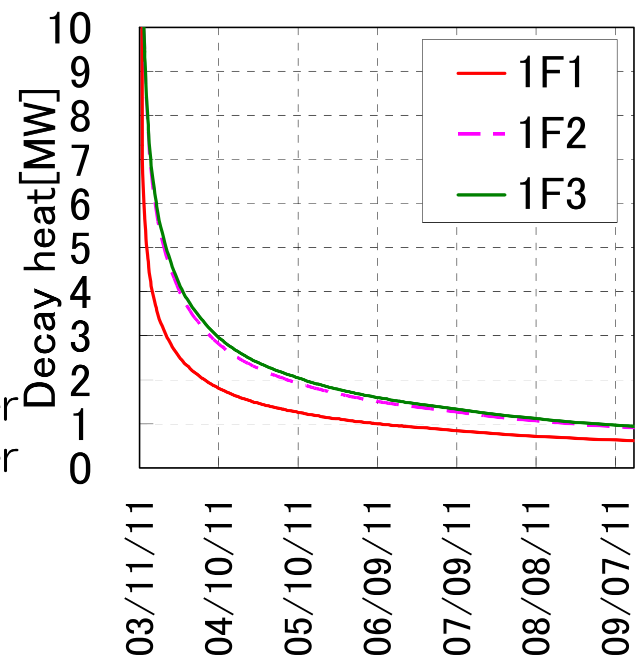
→Nuclei comes closer position to the light blue area.





2. "Cooling the fuel" (cooling)

- Cooling the fuel means "removal of the decay heat."
- Decay heat is decreasing monotonically;
  - 0 second after shutdown : about 5.5% of core power
  - 1 minute after shutdown : about 3.4% of core power
  - 1 hour after shutdown : about 1.3% of core power
  - 1 day after shutdown : about 0.5% of core power
  - 1 year after shutdown : about 0.03% of core power
  - 2 years after shutdown : about 0.01% of core power



- In Fukushima Dai-ichi BWR plants, there are many equipments for "cooling the fuel";

<u>Operable under high pressure condition</u>

  - IC (unit 1) : Isolation Condenser (passive cooling system)
  - RCIC (unit 2,3) : Reactor Core Isolation Cooling system (turbine driven)
  - HPCI : High Pressure Coolant Injection system (turbine driven)

<u>Operable under only low pressure condition</u>

  - LPCI : Low Pressure Coolant Injection system (motor driven)
  - CS : Core Spray system (motor driven)

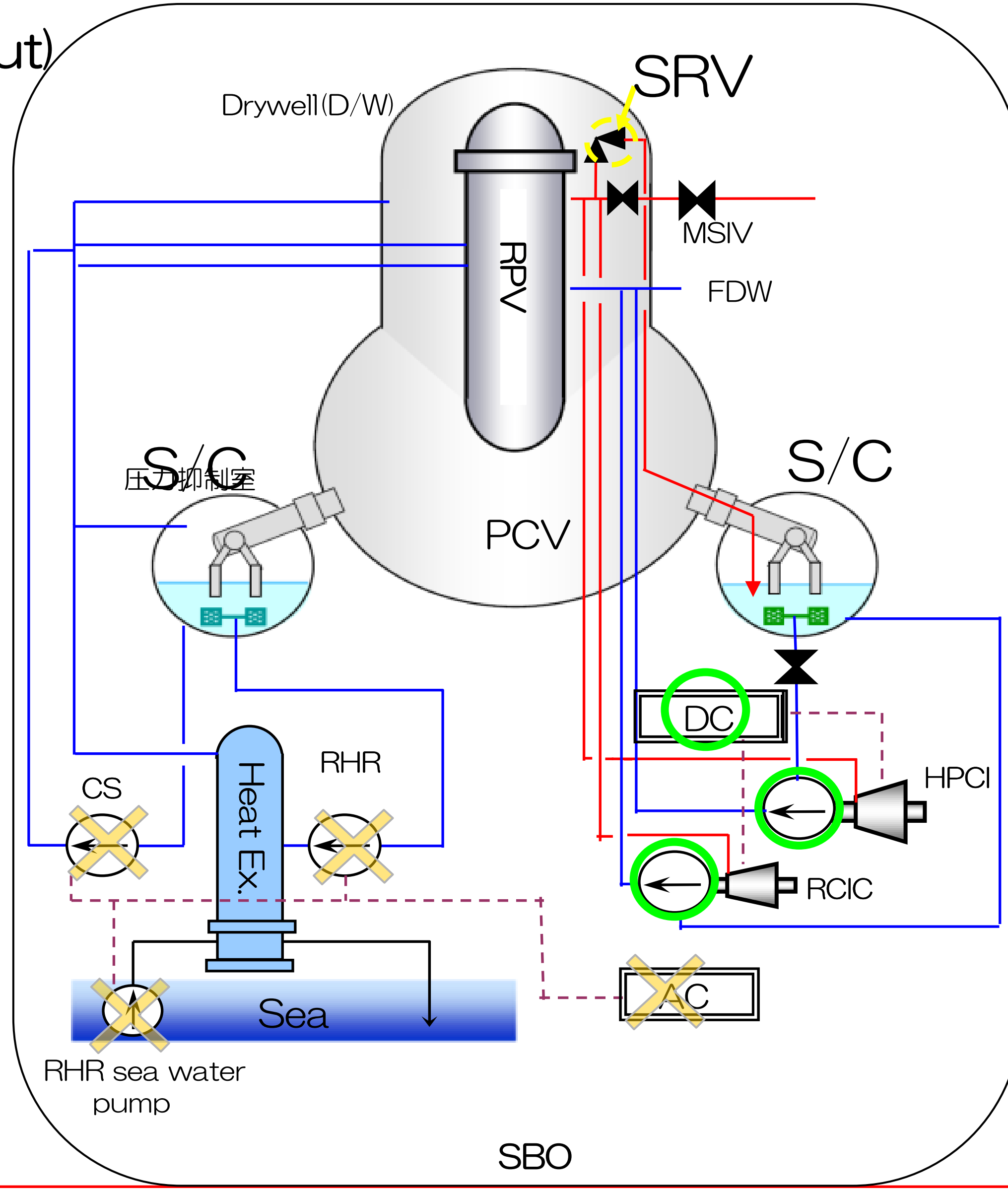
3. Impact of Loss of AC or DC power

Loss of AC power：SBO(Station Black Out)

・SBO is the condition that both loss of offsite power and function failure of D/G occurred at the same time. Only DC power is available.
・Motor driven pumps were NOT operable.
・DC power is used to control the turbine driven pumps, valve operation, and measurement instrument.
→RCIC, HPCI, IC are operable under SBO

Loss of AC and DC power：Total SBO

・Total SBO is the condition that both AC and DC power are NOT available.
・All RPV injection systems became out of control or never start up.
・Measurement systems are NOT operable.
→Operator can NOT operate any system and can NOT know plant condition until restoring AC or DC power.



3. Turbine driven RPV water injection system

High pressure steam generated by decay heat will be provided to turbine

Reactor Core Isolation Cooling system : RCIC

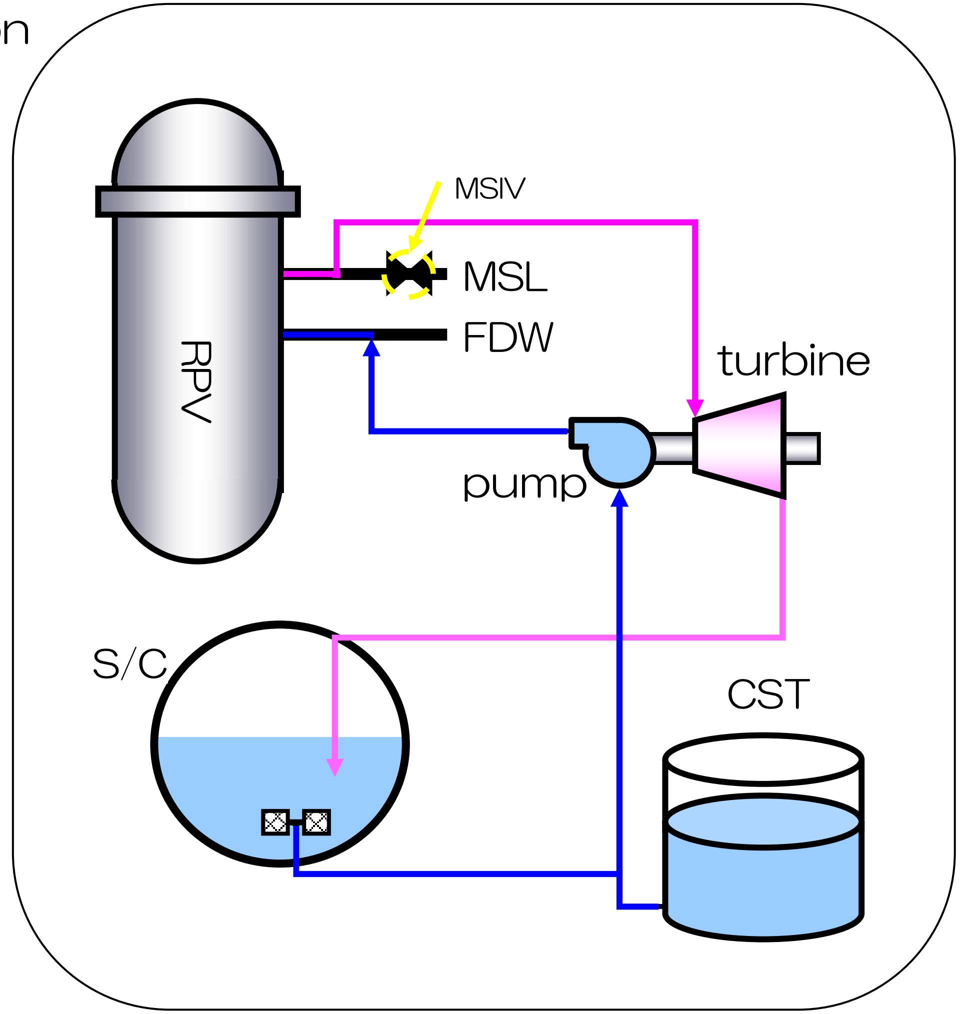
- Designed to be used during reactor core isolation (Isolation means main steam isolation valve is close position.)
- Operable in DC only condition
- Designed to remove the decay heat 15 minutes after SCRAM.

→If the decay heat decrease less than decay heat 15 minutes after SCRAM, RPV water level increase.

High Pressure Coolant Injection system : HPCI

- Designed to be used in medium and small break LOCA
- Operable in DC only condition
- Injection ability is ten times larger than RCIC, because HPCI have to makeup more water in LOCA condition.

→More steam was consumed to drive turbine. It is difficult to control the RPV water level and RPV pressure not in LOCA condition.

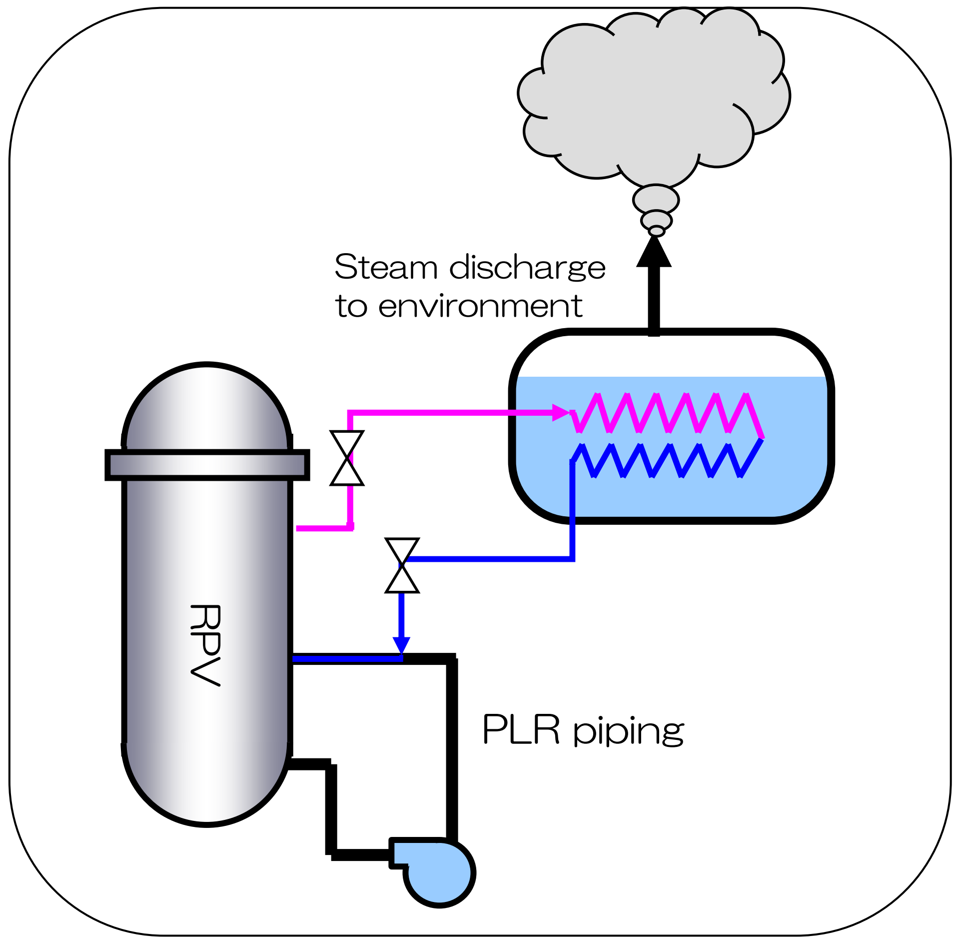


3. Passive Cooling system operable in unit 1

Isolation Condenser : IC

- Designed to use during reactor core isolation (Isolation means main steam isolation valve is close position.)
- Operable in DC only condition
- High pressure steam will be condensed in the heat exchanger, then condensate water go back to RPV.
- Steam generated in shell side is discharged to environment.
- Operable for 8 hours
- Designed to remove the decay heat 5 minutes after SCRAM.

→If the decay heat decrease to less than decay heat 5 minutes after SCRAM, RPV pressure decrease due to overcooling.
operator controlled the RPV pressure by opening/closing operation in unit 1.

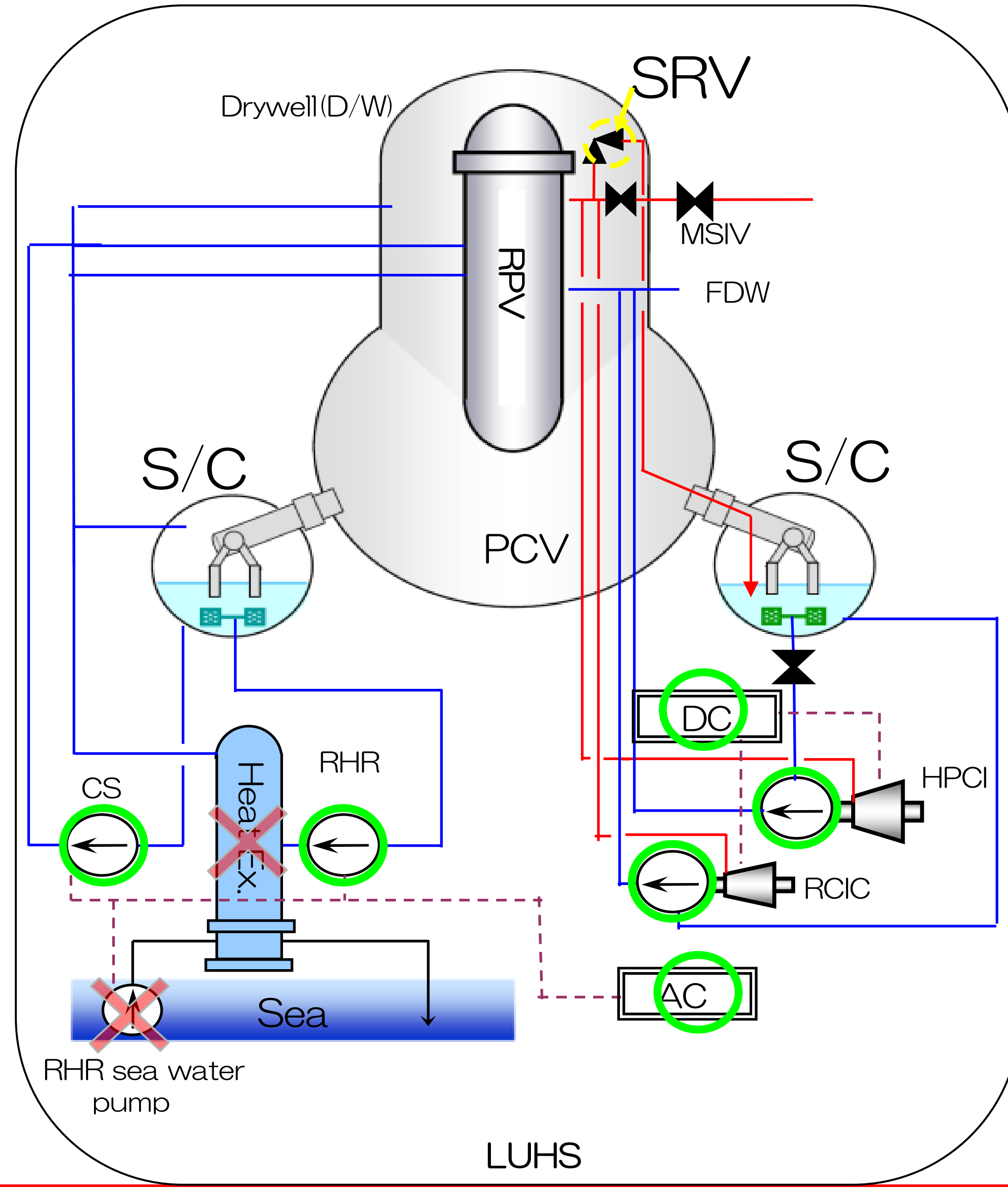


3. Loss of Ultimate Heat Sink：LUHS

- Decay heat removed from RPV will be transported to Suppression Chamber(S/C) through Safety Relief Valve(SRV).
- Energy stored in the S/C will be released to the sea by means of heat exchanger in RHR (Residual Heat Removal system).

- LUHS means the condition in which the decay heat could not be removed from S/C.
- In case of LUHS, even if we could continue cooling the core, decay heat remains inside the PCV boundary.

→Temperature and pressure of the PCV increase gradually.



4. “Confining radioactive material” (containment)

- Radioactive material would be released after loss of “cooling the fuel.”
- As a consequence, loss of “cooling the fuel” causes fuel overheating and break of the physical barrier and release of radioactive material.

- From next slide, I will show you how we lost the function of equipments for “cooling the fuel.”

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4. Chronological accident description for unit 1

- 3/11 14:46
  - Earthquake : Reactor was automatically shutdown.
    Decay heat was continuously generated.
  - Loss of off-site power : However, DG was automatically started.
    Therefore, AC and DC power were available in this period.
- 14:52 – 15:34
  - IC cooling : Reactor was cooled by IC with start-stop operation so that RPV cooling down rate did not exceed 55 degree-C/hr. Unit 1 was operated to achieve cold shutdown.
- 15:37
  - Tsunami hit : AC and DC were lost. **IC was not in operation at this time.**
- After tsunami hit
  - RPV water inventory decrease due to boiling.
- Around 18:10 (from MAAP calculation)
  - Core uncovery : Starting fuel heat up
- Around 18:50 (from MAAP calculation)
  - Reactor core damage : Peak clad temperature became above 1200 degree-C
- Around 3/12 01:50(from MAAP calculation)
  - RPV bottom damage : Corium (melted fuel) slumping to PCV pedestal
- After core damage
  - Radioactive materials were released to environment

4. Chronological accident description for unit 2

- 3/11 14:46
  - Earthquake : Reactor was automatically shutdown.
    Decay heat was continuously generated.
  - Loss of off-site power : However, DG was automatically started.
    Therefore, AC and DC power were available in this period.
- 14:50 – 15:41
  - RCIC injection : Reactor was cooled by RCIC, even though RCIC was tripped several times due to RPV water level too high.
- 15:37
  - Tsunami hit : AC and DC were lost. **RCIC had been in operation since 2 minutes before loss of power.** RCIC continued injecting the water to RPV with no controlling.
- Around 3/14 9:00
  - RCIC operation was terminated due to some reason
- After termination of RCIC
  - RPV water inventory decreased due to boiling.
- Around 17:00 (from MAAP calculation)
  - Core uncovery : Starting fuel heat up
- Around 19:20 (from MAAP calculation)
  - Reactor core damage : Peak clad temperature became above 1200 degree-C
- After core damage (can NOT specify from MAAP calculation)
  - RPV bottom damage : Corium (melted fuel) slumping to PCV pedestal
  - Radioactive materials were released to environment

4. Chronological accident description for unit 3 (1/2)

- 3/11 14:46
  - Earthquake : Reactor was automatically shutdown. Decay heat was continuously generated.
  - Loss of off-site power : However, DG was automatically started. Therefore, AC and DC power were available in this period.
- 14:50 – 15:37
  - RCIC injection : Reactor was cooled by RCIC, even though RCIC was tripped several times due to RPV water level too high.
- 15:37
  - Tsunami hit : AC power was lost but DC power was available. RCIC was kept in operation with operator's control.
- 3/12 11:36
  - RCIC operation was terminated due to some reason
- 3/12 12:35
  - HPCI was automatically started due to RPV water level too low. RPV pressure decreased because HPCI consumed much steam.
- XX:XX
  - HPCI could not inject enough water due to lack of RPV pressure to drive turbine.
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4. Chronological accident description for unit 3 (2/2)

- After degradation of HPCI RPV injection
  - RPV water inventory decreased due to boiling.
- 3/13 02:42
  - HPCI was terminated manually by operator.
- Around 09:10 (from MAAP calculation*)
  - Core uncovery : Starting fuel heat up
- Around 10:40 (from MAAP calculation*)
  - Reactor core damage : Peak clad temperature became above 1200 degree-C
- After core damage (can NOT specify from MAAP calculation)
  - RPV bottom damage : Corium (melted fuel) slumping to PCV pedestal
  - Radioactive materials were released to environment

*: Note that we did NOT employ analysis condition in this MAAP analysis that RPV water injection by HPCI was degraded before HPCI manual termination.

5. Summary

- In this presentation, the BWR theory with reference to basic safety functions for nuclear power plant (NPP) was shown
- The Fukushima Dai-ichi accident progression was explained chronologically.

- You can see the current situation of Fukushima Dai-ichi NPP at the following URL.
http://www.tepco.co.jp/en/nu/fukushima-np/index-e.html

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