How a Boiling Water Reactor (BWR) Works

- Feedwater pump
- Circulating water pump
- Condenser
- Transformer
- Generator
- Reactor pressure vessel
- Fuel
- Control rods
- Recirculation pump
- Suppression pool
- Water
- Steam
- Power Transmission
- To tailrace
- Cooling water (seawater)
- Feedwater pump
- Circulating water pump
## Structural Features of Advanced Boiling Water Reactors (ABWR)

<table>
<thead>
<tr>
<th>Feature</th>
<th>BWR</th>
<th>ABWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>More compact containment vessel</td>
<td><img src="image1" alt="BWR Reactor" /></td>
<td><img src="image2" alt="ABWR Reactor" /></td>
</tr>
<tr>
<td>Simplified reactor systems</td>
<td>Reactor recirculation pump</td>
<td>Internal reactor recirculating pump</td>
</tr>
<tr>
<td>Diversification of control rod drive mechanisms</td>
<td><img src="image3" alt="BWR Control Rods" /></td>
<td><img src="image4" alt="ABWR Control Rods" /></td>
</tr>
<tr>
<td></td>
<td>Hydraulic drive</td>
<td>Electric drive + hydraulic drive</td>
</tr>
</tbody>
</table>

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Features of Advanced Boiling Water Reactors (ABWR)

Simplified reactor systems, more compact containment vessel and diversified core control drive mechanisms
Improved earthquake resistance and optimized emergency core cooling system

Greater Safety and Reliability

Reduced Radiation and Radioactive Waste Output
Easier to Operate and Maintain

More Economical

Reduced Construction Costs
Reduced building volume
Shorter construction period

Reduced Operating Costs
Improved operating ratio
Improved thermal efficiency
Reduced fuel costs
Shorter periodic inspection process
How a Pressurized Water Reactor (PWR) Works

- Containment vessel
  - Reactor pressure vessel
  - Control rods
  - Fuel
  - Coolant pump
  - Steam generator
  - Pressurizer

- Steam
  - Power Transmission
  - Transformer
  - Generator
  - Turbine
  - Condenser
  - Circulating water pump
  - Feedwater pump

- Water
  - To tailrace
  - Cooling water (seawater)
Cross-sections of Reactor Pressure Vessels

**Boiling Water Reactor (BWR)**
- Feedwater inlet (coolant inlet)
- Recirculating water inlet
- Steam
- Steam outlet
- Shroud
- Fuel
- Control rods
- Control rod drive mechanism

**Pressurized Water Reactor (PWR)**
- Coolant inlet (low temp)
- Coolant outlet (high temp)
- Control rod drive mechanism
- Fuel
- Control rods
Fuel Assembly Structures and Control Rods

Fuel Assembly of a Boiling Water Reactor (BWR)

- Handle
- External spring
- Fuel Rod
- Support lattice
- Channel box
- Tie plate
- Cross-section of A-A'

Fuel Rod
Pellets
Cladded fuel tube (zirconium alloy)

Approx. 4.5m
Approx. 14cm
Approx. 10mm

1 pellet = about 8.3 months-worth of a household's electricity

Fuel Assembly of a Pressurized Water Reactor (PWR)

- Control rod cluster
- Control rods
- Top nozzle
- Support lattice
- Bottom nozzle
- Cross-section of B-B'

Fuel Rod
Pellets
Cladded fuel tube (zirconium alloy)

Approx. 4.2m
Approx. 21cm
Approx. 10mm
Approx. 8mm

1 pellet = about 6 months-worth of a household's electricity
Natural Uranium & Enriched Uranium

Natural Uranium

Uranium 238 99.3%
Uranium 235 0.7%

Low-enriched Uranium

Uranium 238 95~97%
Uranium 235 3~5%
## Differences between Nuclear Power and Nuclear Bombs

<table>
<thead>
<tr>
<th>Ratio of Uranium-235 to Uranium-238 &amp; Chain Nuclear Reaction</th>
<th>Method of Controlling Fission Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>In a Nuclear Power Plant</strong></td>
<td></td>
</tr>
<tr>
<td>Uranium 235 (3~5%)</td>
<td>Many control rods are installed</td>
</tr>
<tr>
<td>Uranium 238 (95~97%)</td>
<td>and the reactions are self-</td>
</tr>
<tr>
<td></td>
<td>limiting, so the rate of fission</td>
</tr>
<tr>
<td></td>
<td>cannot increase rapidly.</td>
</tr>
<tr>
<td>The ratio of Uranium-235 is low, so fission is</td>
<td></td>
</tr>
<tr>
<td>sustained at a constant scale, for reasons such</td>
<td></td>
</tr>
<tr>
<td>as absorption of neutrons by Uranium-238.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>In a Nuclear Bomb</strong></td>
<td></td>
</tr>
<tr>
<td>Uranium 235 (Almost 100%)</td>
<td>No control rods are installed</td>
</tr>
<tr>
<td></td>
<td>and the reactions are not self-</td>
</tr>
<tr>
<td></td>
<td>limiting, so the rapid increase</td>
</tr>
<tr>
<td></td>
<td>in fission cannot be stopped.</td>
</tr>
<tr>
<td>The ratio of Uranium-235 is nearly 100% and at this high</td>
<td></td>
</tr>
<tr>
<td>level neutrons cannot be absorbed by anything else, so one</td>
<td></td>
</tr>
<tr>
<td>atom after another undergoes fission and the energy is</td>
<td></td>
</tr>
<tr>
<td>released instantly as an explosion.</td>
<td></td>
</tr>
</tbody>
</table>

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Inherent Safety of Nuclear Reactors (Self-Limiting)

- Uranium-238 stops absorbing many neutrons
- Temperature effect of a moderator (density effect)
  As the density of the water drops, deceleration of neutrons ceases, which reduces the ratio of neutrons absorbed by U-235.
- Doppler effect on the fuel
  Uranium-238 absorbs a lot of neutrons

- Temperature drops
- Fission decreases
- Some output state
  Moves to one side if left alone (unstable)
  [Low output state] [High output state]

- Fission increases
- Temperature rises
- [Low output state] [High output state]

- Self-limiting
  Safe even if left alone (stable)

- Not Self-limiting
  [Low output state] [High output state]
Example of an Emergency Core Cooling System (BWR)

**Containment Vessel Spray System**
A donut-shaped spray tube is installed on the inner wall of the containment vessel and cools the inside of the vessel by showering it with cool water. This is a containment vessel spray system.

**Emergency Core Cooling System**
Water pipes in a donut shape are perforated, so if the water in the reactor core drops, it automatically sprays the fuel and cools it. This is a spray type of reactor core cooling system.
**Example of an Emergency Core Cooling System (PWR)**

**Containment Vessel Spray System**
If pressure rises inside the containment vessel, water is sprayed inside the vessel to restrain the rise in pressure.

**Emergency Core Cooling System (ECCS)**
The ECCS injects water into the reactor core via the corresponding system, according to conditions inside the pressure vessel.
Purposes of Periodic Inspections of Nuclear Power Plants

- **Check Soundness**
  - Confirm operational ability and performance of major equipment, plus settings functionality
  - Check soundness of equipment via disassembly inspections and leak tests

- **Maintenance of Functions**
  - Regular replacement of consumables
  - Measures to prevent deterioration
  - Early detection and correction of anomalies

- **Increase Reliability**
  - Inspect and address areas similar to where accidents or incidents occurred at other power plants
  - Replace equipment and facilities that introduce the latest technology

Safe and Stable Operation of the Plant
Methods for Evaluating the Soundness of Equipment

1: Safety standard includes a tolerance margin over actual failure limit
2: Minimum strength for equipment to withstand conditions without failing

- When first used
- Inspect Cracks & wear found
- Expected progress after certain period of time

- Design strength
- Cracks and wear (small)
- Cracks and wear (large)
- Safety standard
- Failure limit

- Reduced strength due to expected progression of wear/cracking
- Margin exists
  - Possible to continue
- Fails to meet safety standards, so repair or replacement required

*1: Safety standard includes a tolerance margin over actual failure limit
*2: Minimum strength for equipment to withstand conditions without failing
Changes in the Nuclear Safety Regulatory System

**[Former Regulatory System]**

- **Cabinet Office**
  - Atomic Energy Commission
  - Overall measures for protecting nuclear materials, etc.
- **Nuclear Safety Commission**
  - Double-checks safety reviews of nuclear reactors
- **METI**
  - Agency for Natural Resources and Energy
  - Nuclear and Industrial Safety Agency
  - Safety rules and regulations of nuclear power reactors
- **MEXT**
  - Safety regulations of experimental reactors
  - Safeguards *1
  - Monitoring of radiation and operation of SPEEDI (System for Prediction of Environmental Emergency Dose Information)
  - Regulations on the use of radioactive isotopes, etc.

Regulates via double-checking

- Power companies, etc.
- Research org., universities, etc.

**Promotional (Agency for Natural Resources and Energy) and regulatory agencies (Nuclear and Industrial Safety Agency) exist together within METI.**

**Decentralized to the Nuclear and Industrial Safety Agency, Nuclear Safety Commission & MEXT**

**Ensure Independence**

**Centralization of Regulatory Affairs**

**[New Regulatory System]**

- **Ministry of the Environment**
- **METI**
  - Agency for Natural Resources and Energy
- **Nuclear Regulation Authority**
  - Chair + 4 committee members (Diet-approved personnel)
  - The Secretariat of the Nuclear Regulation Agency
    - Regulates
    - Power co., research org., universities, etc.

- **Separated from METI and established the Nuclear Regulation Authority as an external bureau (Article 3 Committee *2)**

- **Decentralization of functions, including safeguards for non-proliferation*1 Monitoring of radiation and use of radioisotopes**

---

*1 Refers to verification measures to ensure that nuclear materials are only used for peaceful purposes and not diverted to military use, such as for weapons.
*2 Commissions of the so-called Article 3 (of the National Government Organization Law, Article 3, Paragraph 2, Establishment of Administrative Organs) are not under the command or supervision of top level organs (e.g. set up under the minister of a cabinet) and are independent, with exercise of their authority guaranteed by mechanisms of the Diet.

Source: Nuclear Regulation Authority pamphlet

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### New Regulatory Requirements for Nuclear Power Plants

#### Previous Regulatory Requirements

- **Design basis to prevent severe accidents**
  - Confirm that a single failure would not lead to core damage

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consideration of natural phenomena</td>
<td>Fire Protection</td>
</tr>
<tr>
<td>Reliability of power supply</td>
<td></td>
</tr>
<tr>
<td>Function of other SSCs*</td>
<td></td>
</tr>
<tr>
<td>Seismic/tsunami resistance</td>
<td></td>
</tr>
</tbody>
</table>

#### New Regulatory Requirements

- **Reinforcement of design criteria**
  - Expansion of consideration for external events

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response to international aircraft crashes</td>
<td>Newly introduced (measures against terrorism)</td>
</tr>
<tr>
<td>Measures to suppress radioactive materials dispersion</td>
<td>Newly introduced (measures against severe accidents)</td>
</tr>
<tr>
<td>Measures to prevent containment vessel failure</td>
<td></td>
</tr>
<tr>
<td>Measures to prevent core damage (Postulate multiple failures)</td>
<td>Reinforced or newly introduced</td>
</tr>
<tr>
<td>Consideration of internal flooding (newly introduced)</td>
<td></td>
</tr>
<tr>
<td>Consideration of natural phenomena in addition to earthquakes and tsunamis-volcanic eruptions, tornadoes and forest fires</td>
<td></td>
</tr>
<tr>
<td>Fire Protection (Use of flame retardant cable. other)</td>
<td>Reinforced or newly introduced</td>
</tr>
<tr>
<td>Reliability of power supply (Secure two independent lines. other)</td>
<td></td>
</tr>
<tr>
<td>Function of other SSCs (Enhance communication facilities. other)</td>
<td></td>
</tr>
<tr>
<td>Seismic/tsunami resistance (Setting of lake bank. other)</td>
<td>Reinforced or newly introduced</td>
</tr>
</tbody>
</table>

*SSC: Structure, Systems and Components
Periodic Safety Review of Nuclear Power Plant and Measures for Aging Management

- Periodic Operator’s Inspection (every 13 months)
- Periodic Safety Review (every 10 years)
- Periodic Safety Management Review
- Operational Safety Inspection

30 years in operation

- Periodic Operator’s Inspection (every 13 months)
- Periodic Safety Review (every 10 years)
- Periodic Safety Management Review
- Operational Safety Inspection

40 years in operation

- Periodic Operator’s Inspection (every 13 months)
- Periodic Safety Review (every 10 years)
- Periodic Safety Management Review
- Operational Safety Inspection

Aging Management Technical Assessment (AMTA)

To develop a Long-term Maintenance Management Policy

Additional Maintenance based on a Long-term Maintenance Management Policy

Regular Maintenance Management

Our Knowledge About Earthquakes

◎ Earthquake Mechanisms
There are four tectonic plates in the area around the Japanese archipelago and each plate moves slightly over the course of many years. When they do, a great deal of pressure is brought to bear both at plate boundaries and within the plate; when plates are displaced, it generates an earthquake.

◎ Scale of Earthquakes

<table>
<thead>
<tr>
<th>Magnitude</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnitude (earthquake size) is a measure of the amount of energy released by the earthquake.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gal is a unit of measure that expresses the strength of the shaking of an earthquake numerically in terms of acceleration (cm/sec). In general, the greater the Gal number, the greater the seismic intensity.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shindo</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shindo is the Japanese measure of the strength of shaking of the earthquake at an observation point on a decimal scale from 0 to 7. There are some 4,200 observation points across Japan monitored by the Japan Meteorological Agency.</td>
<td></td>
</tr>
</tbody>
</table>

◎ Active Faults
This refers to a fault that has been active repeatedly in recent geological history and may be active again in the future.

Sources: Former Nuclear and Industrial Safety Agency, The Seismic Safety of Nuclear Power Plants, and Japan Meteorological Agency homepage
Differences in Vibrations between a Nuclear Power Plant and a Normal Building

How vibrations are transmitted from a nuclear power plant built on solid ground (bedrock) and a normal building

A. Acceleration amplified by subsurface layers
B. Acceleration of hard ground (bedrock)

(Note) The seismic waveform is a schematic diagram.

Vibration of hard ground (bedrock) is 1/3 to 1/2 that of subsurface layers.

Maximum accelerations observed around Wakasa Bay during the 1995 Great Hanshin Earthquake

<table>
<thead>
<tr>
<th>Location</th>
<th>Maximum Acceleration (Gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maizuru Marine Observatory</td>
<td>16</td>
</tr>
<tr>
<td>Mihama Nuclear Power Plant (KEPCO)</td>
<td>13</td>
</tr>
<tr>
<td>Ōi Nuclear Power Plant (KEPCO)</td>
<td>22</td>
</tr>
<tr>
<td>Takahama Nuclear Power Plant</td>
<td>11</td>
</tr>
<tr>
<td>Tsuruga Nuclear Power Plant</td>
<td>16</td>
</tr>
<tr>
<td>Monju (Japan Atomic Energy Agency)</td>
<td>67</td>
</tr>
</tbody>
</table>

Sources: Former Nuclear and Industrial Safety Agency, New Seismic Design Review Guideline, and Agency for Natural Resources and Energy pamphlet
Appointment of Operations Manager

External Adjudicating Organization
Judges whether the requirements of the institutional regulatory standards for the management of an operator are fulfilled (in addition to a practical operations test, training and an oral exam (part can be written), judgment is made after confirming the person's background, etc.)

Appointed from among managers of operations who meet the standards stipulated by Nuclear Safety Regulation Authority as per the Safety Regulations.

Standards for Operations Manager (National Standards)
- Experience of operating nuclear reactors for five years or longer
- Experience of operating the same type of reactor for more than 6 months in past 1 year.
- Management supervisor rank
- Knowledge/skills related to nuclear reactors

Electricity Utility
- Management (Procurement)
- Judgment
- Report

Director of Operator (Installer of nuclear reactor)
- Operations managers/qualified persons
- Appointed

Operations managers (shift supervisors)
- Appointed from among managers of operations who meet the standards stipulated by Nuclear Safety Regulation Authority as per the Safety Regulations.

Nuclear Regulation Authority
- Application
- Notification
- Safety regulations approval
- Safety inspection

- Must be nominated
- Confirmation, such as judgment process (ordinance, notice, internal rules)
- Confirmation, such as standard conforming judgment process
# Regulatory Flow for Commercial Nuclear Power Plant

## Planning Stage
- **Electricity Utility**
  - Nuclear Power Plant Reactor Construction Permit Application [Article 43-3-5]

## Construction Phase
- **Electricity Utility**
  - Construction Plan Permit Application
  - Welding Company Inspection [Article 43-3-13]
  - Safety Regulations Approval Application
  - Notification and Publication of Evaluation for Improving Safety [Article 43-3-29]

## Operation Phase
- **Electricity Utility**
  - Safety Regulations Compliance Obligations
  - Periodic Operator Inspection [Article 43-3-16]
  - Duty to Maintain Conformity with Technical Standards [Article 43-3-14]

## Decommissioning Phase
- **Electricity Utility**
  - Application for Approval of Decommissioning Plan
  - Safety Regulations Approval Application
  - Application to Confirm Completion of Decommissioning

## Approval Phase
- **Nuclear Regulation Authority**
  - Safety Review
  - Approval of Plan for Construction Work [Article 43-3-9]
  - Approval of Construction Plan Permit Application [Article 43-3-5]
  - Pre-operational Inspection [Article 43-3-11]

## Assurance of Facility Security
- **Electricity Utility**
  - Approval for Decommissioning Plan [Article 43-3-33]

## Security Assurance & Physical Protections of Nuclear Materials
- **Electricity Utility**
  - Approval of Safety Regulations [Article 43-3-24] / Physical Protection Regulations [Article 43-27]
Historical Trends in Reported Incidents and Failures at NPPs in Japan

Source: Nuclear Regulation Authority

Commercial NPPs in Japan

(notification based reports

Reports per unit

Source: Nuclear Regulation Authority

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Troubleshooting

Initial response
- Operator: Safety checks and emergency measures
- Government: Grasp situation

Investigation/study
- Operator: Calls, notices
- Local government: Content check
- Government: Announcement to news media (hold press conference, INES provisional assessment)

Recurrence prevention measure
- Operator: Investigate cause of the problem and deliberate on countermeasures
- Local government: Status check
- Government: Receive problem report

Roll out on same level
- Operator: Submit problem report
- Local government: Disclosure of reports
- Government: Announcement to news media (hold press conference on cause and countermeasures)

Communication and coordination
- Problem occurs
- Operators and government communicate through calls, notices, and press conferences
- Status checks and updates are shared with the media and nuclear power plant libraries.
Equipment Utilization Rate of Nuclear Power Plant

Sources: OPERATIONAL STATUS of NUCLEAR FACILITIES in JAPAN (until FY 2013), and Japan Atomic Industrial Forum Inc., Operational results of nuclear power plants in Japan (from FY 2014)
Control room: There is a switch for turning off the safety system.

There is no containment vessel.

Control rods

Pressure pipe

Cooling water

Main circulation pump

Steam-water separator

Mixture of steam & water

Steam

Turbine

Generator

Condenser

Cooling water

Coolant: water

Fuel

Self-Limiting Function

Japanese Reactor

Yes

Chernobyl Reactor

May cease to work

Coolant

Water

Water

Neutron moderator

Water

Graphite

Safety Equipment

Interlock prevents dangerous operations

Easily defeated

Robust containment vessel covering the reactor core

Yes

No
Ran special tests while operating at low-power

(April 25-dawn 26, 1986)

Reactor in an unstable state

Voids (bubbles) increased

Output rose

Runaway output

Many pressure lines rupture
Series of hydrogen explosions

(1:23 AM)

(Continues for 2 weeks)

Graphite in core catches fire

Turbine building fire

(Extinguished)

Radioactive materials in the reactor released

Reduced cooling water due to slowing of the reactor coolant pump

Characteristics specific to the reactor and deficiencies in the emergency shutdown system

Steam generated rapidly

Hydrogen generated rapidly

(from 1/2 day to 1 day later)
Causes of the Accident at Chernobyl Nuclear Power Plant

Lack of Safety Culture

Design Defects
- No containment vessel
- Designed to easily turn off safety equipment
- Positive void coefficient; during low power operation, the more voids (froths) in cooling water, the more output, etc.

Operator Regulation Violation
- Withdrew control rods more than regulated
- Operated with Emergency Core Cooling System (ECCS) turned off
- Conducted a special test at lower power than planned
  Continuous operation was prohibited due to instability at low power range (less than 20% of total output), etc.

Operational Mismanagement
- Managed by a non-reactor-specialist
- A special test was conducted without due processes or approval throughout the power plant
- Inadequate examinations on safety measures, etc.
Overview of the Three Mile Island Nuclear Accident

- **Main Events in the accident**
  On March 28, 1979, the main feedwater pump stopped in reactor 2 of the Three Mile Island (TMI) nuclear power plant in Pennsylvania in the United States. Although the auxiliary feedwater pump started up automatically, the secondary cooling water failed to circulate due to a closed pump outlet valve; in addition, an operator misunderstood the Emergency Core Cooling System (ECCS) and manually stopped it. The result of equipment failure and operator error caused a partial meltdown of structures inside the reactor.

- **Impact on the environment**
  The dose of radiation received by the public in the area was a maximum of 1 mSv and an average of 0.01 mSv, which is an extremely low level in terms of impact to health.
Overview of Accident at Mihama Nuclear Power Plant, Unit 2

Overview of the accident
On February 9th, 1991, one heat-transfer tube on Unit 2 of Kansai Electric Power's Mihama Nuclear Power Plant ruptured, initiating automatic shutdown of the reactor and activating the Emergency Core Cooling System (ECCS). The results of the ensuing investigation showed that a fixture designed to suppress vibration to the heat-transfer tube had not been inserted as far it was designed to be, resulting in abnormal vibrations of the tube. As a result, it was found that this high cycle fatigue (force repeated over 100,000 times) led to the material not being able to withstand the force, and the pipe rupturing.

Impact on the environment
Although this was the first time in Japan that an emergency core cooling system (ECCS) had been activated due to spillage of primary coolant, the amount of radioactive materials released in the event was negligible and no impacts on the environment were observed.
Overview of Accident in Secondary Piping at Mihama Nuclear Power Plant, Unit 3

**Overview of the accident**
On August 9th, 2004, an accident occurred in Unit 3 of the Mihama Nuclear Power Plant owned by Kansai Electric Power Co., in which pipes in the secondary system ruptured.

At the time of the accident, contracted workers were inside the building that housed the turbines of the Mihama 3 reactor preparing for the 21st periodic inspection that was scheduled to start from the 14th of August.

With the workers inside, a condensate pipe ruptured near the ceiling on the 2nd floor inside the building housing the turbine, causing hot water at 140°C and 9 atmospheres of pressure to blast out as steam.

Operators who were in the building for inspections immediately found victims who had passed out in front of the elevator on the 2nd floor of the turbine building.

Although the 11 victims of the contracted company were transported to a hospital, 5 died and the other 6 were seriously injured.

However, the accident in the secondary and main cooling systems did not affect the public or nearby workers with radioactive materials.

**Cause of the accident**
A large rupture was found downstream of an orifice (flowmeter) for measuring condensate pipe water flow.

The investigation found that turbulence was likely to occur at points downstream of the orifice and an internal inspection of the part that ruptured found that the so-called erosion-corrosion process had gradually reduced the thickness of the pipe, thus weakening it to the extent that it ruptured due to the load during operation at the time.

Management guidelines were established in 1990 for the wear of secondary piping in PWR, and from that time parts of pipes that were anticipated to be corroded had been measured according to plan. However, the part of the pipe that ruptured (A line) was from the very beginning supposed to be measured, but it had been missed and the thickness of the pipe had never been measured at the time of the accident.
Overview of the accident
During a manual inspection at 5:02pm on November 7, 2001 of the high-pressure injections system of reactor 1 at the Chubu Electric Power Co., Inc., Hamaoka Nuclear Power Plant, a condensed steam pipe in the residual heat removal system ruptured.

Cause of the accident
1. Steam condenses in the upper part of the pipe. A high concentration of hydrogen and oxygen accumulated at a point about 7m from the surface of the water.
2. During the manual inspection of the high-pressure injection system, the change in pressure caused super-hot steam to flow into the layer of hydrogen and oxygen, igniting it. Precious metals may have acted as a catalyst.
3. Once ignited, the flame spread into the layer of hydrogen and oxygen (combustion state: deflagration → detonation)
4. The pressure inside the pipe rose precipitously, rupturing an elbow near the surface of the water (about 3,000 atmospheres of pressure). Other parts of the pipe were deformed.
Overview of the Sodium Leak Accident at the Prototype Fast Breeder Reactor

Overview of the accident
On December 8, 1995, while bringing the Monju Prototype Fast Breeder Reactor of the former Power Reactor and Nuclear Fuel Development Corporation (PNC) (now Japan Atomic Energy Agency) into operation, an accident occurred, resulting in a sodium leak. The ensuing investigation found that sodium had leaked from a temperature gauge in the sodium line and the sodium reacted with oxygen in the air, resulting in a sodium fire.

Impact of the accident
However, the accident in the secondary main cooling system did not affect the public or nearby workers with radioactive materials. The nuclear reactor also shut down safely and the reactor core was unaffected. However, sodium did leak and the sodium fire did in fact broaden the impact. And because the operator, PNC at the time, clearly mishandled informing the public, it made many people, especially those living in the region, worry and mistrustful.
Overview of Modifications to the Monju Prototype Fast Breeder Reactor

**Purposes of Modifications**
1. Prevent any sodium leaks
2. If a leak occurs, detect it promptly and prevent spread of problems

**Temperature Gauge Replaced**
- Prevent vibration of the temperature gauge (prevent damage)
- Prevent sodium leaks from temperature gauge

**Sodium Leak Countermeasures**
- Promptly detect any sodium leaks
- If a leak is detected, immediately withdraw sodium in the lines to the tank (using larger lines and redundancy of motor-driven valves)
- If a sodium leak occurs, inject nitrogen gas into the chamber (extinguish by smothering)

**Make Evaporator Safer**
- Reliable detection of water leaks
- If a problem occurs, promptly discharge water/steam in heat transfer lines (Quickly stop reaction between sodium and water)
Overview of the Criticality Accident at the JCO Uranium Processing Plant

Overview of the accident
On September 30, 1999, while equalizing a solution of enriched uranium at the JCO uranium processing plant, workers poured a solution containing uranium into a settling tank not designed for that purpose beyond its critical mass, initiating a criticality accident. They were acting in accordance with an illegal company manual. The critical state continued for some 20 hours and resulted in the 2 workers dying.

Impact on residents
In addition to the radiation emitted to the environs during the criticality period, a small amount of radioactive gas was also released into the air and some 319 people were estimated to have received a dose of radiation exceeding 1 mSV, the annual effective dose limit for the general public; those exposed include workers, disaster responders and the residents of the surrounding area (130 residents).

Authorized Procedure

Procedure Used in the Accident
# International Nuclear Event Scale (INES)

<table>
<thead>
<tr>
<th>Level</th>
<th>Standards</th>
<th>Reference cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 (Major Accident)</td>
<td>- Major release of radioactive material with widespread health and environmental effects.</td>
<td>- Chernobyl nuclear accident (1986) in former Soviet Union</td>
</tr>
<tr>
<td>6 (Serious Accident)</td>
<td>- Significant release of radioactive material</td>
<td>- Fukushima Daiichi nuclear accident resulting from the Tohoku earthquake (2011)</td>
</tr>
<tr>
<td>5 (Accident with Wider Consequences)</td>
<td>- Limited emission of radioactive material</td>
<td>- Three Mile Island nuclear accident, U.S. (1979)</td>
</tr>
<tr>
<td>4 (Accident with Local Consequences)</td>
<td>- Minor release of radioactive material</td>
<td>- JCO criticality accident (1999)</td>
</tr>
<tr>
<td>3 (Serious Incident)</td>
<td>- Exposure in excess of ten times the statutory annual limit for workers</td>
<td>- Near-accident at a nuclear power plant with no safety provisions remaining</td>
</tr>
<tr>
<td>2 (Incident)</td>
<td>- Exposure of a member of the public in excess of 10 mSv</td>
<td>- Mihama Power Plant, Unit 2 Steam generator heat-transfer tube rupture accident (1991)</td>
</tr>
<tr>
<td>1 (Anomaly)</td>
<td>- Overexposure of a member of the public in excess of statutory annual limits</td>
<td>- Monju sodium leak accident (1995)</td>
</tr>
<tr>
<td>0 (Deviations)</td>
<td>No safety significance</td>
<td>- Primary coolant leak at the Tsuruga Power Station Unit 2 (1999)</td>
</tr>
</tbody>
</table>

*Sievert (Sv): Unit representing the effect of radiation on the body. (1 mSv = 1/1,000 Sv)
WANO is a private organization comprised of members who are companies in the nuclear power industry. WANO aims to maximize the safety and reliability of nuclear power plants worldwide by working together to assess, benchmark and improve performance through mutual support, exchange of information and emulation of best practice (established May 1989).

Participants
32 Countries/Regions

- General Assembly
- Main Governing Body
- Coordinating Center (London)
  - Atlanta Center
  - Moscow Center
  - Paris Center
  - Tokyo Center

WANO Programs
- Exchange of information on operating experience
- Peer views (site evaluations)
- Holding workshops and seminars
- Technical support and exchange
  (Mission of best practices, operator exchanges, operation benchmarks and technical support)

- Federation of Nuclear Power Companies of Japan
- 9 Electricity Utilities, The Japan Atomic Power Company, Japan Nuclear Safety Institute, Japan Atomic Energy Agency, J-Power EPDC
- Korea Hydro & Nuclear Power Co., Ltd.
- Nuclear Power Corporation of India Limited
- Pakistan Atomic Energy Commission
- Taiwan Power Company
- China National Nuclear Corporation
As a precaution against emergencies, a new Nuclear Emergency Preparedness Commission (NEPC) will be permanently established under the Cabinet to promote nuclear emergency preparedness measures throughout the government during normal times.

<table>
<thead>
<tr>
<th>Ordinary times</th>
<th>Emergency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nuclear Emergency Preparedness Commission</strong></td>
<td><strong>Nuclear Emergency Response Headquaters</strong></td>
</tr>
<tr>
<td>Chairperson : Prime Minister</td>
<td>Director-general : Prime Minister</td>
</tr>
<tr>
<td>Vice-Chairperson : Chief Cabinet Secretary, NRA Chairman, Minister of State for Nuclear Emergency Preparedness</td>
<td>Deputy Director-generals: Chief Cabinet Secretary, Minister of State for Nuclear Emergency Preparedness, NRA Chairman</td>
</tr>
<tr>
<td>Commissioners : Minister of State, Deputy Chief Cabinet Secretary for Crisis Management, Vice Ministers, Parliamentary Secretaries, etc.</td>
<td>Members : Minister of State, Deputy Chief Cabinet Secretary for Crisis Management, Vice Ministers, Parliamentary Secretaries, etc.</td>
</tr>
<tr>
<td>Secretary General : Minister of the Environment</td>
<td>(Role) General coordination of nuclear emergency response measures and post accident measures.</td>
</tr>
<tr>
<td>(Role) Promoting policy enforcement, etc. based on the Nuclear Emergency Response Guidelines*1</td>
<td>(Role) Promoting the long-term comprehensive policy enforcement in the case of nuclear accident occurrence</td>
</tr>
</tbody>
</table>

**Relevant Ministries and Agencies**
- National Police Agency, MEXT, MHLW, MLIT, Japan Coast Guard, Ministry of the Environment, Ministry of Defense, etc.
- National Police Agency, MEXT, MHLW, MLIT, Japan Coast Guard, Ministry of the Environment, Ministry of Defense, etc.

* These are guidelines prepared by the Nuclear Regulation Authority for nuclear operators and local governments, etc. to ensure smooth implementation of nuclear emergency preparedness measures, emergency response measures, and measures for restoration from a nuclear emergency.

Source: Nuclear Regulatory Authority
Clarification of Nuclear Emergency Categories (3 Stages)

Operational Chart—From Alert to General Emergency

Alert
- Crisis Management Center
  - Regulatory Agency Deputy Director-general
  - ERC (Emergency Response Center)
    - Regulation Authority Chairman, Regulatory Agency Director, Etc.

Site Area Emergency
- Emergency Meeting Team
  - Deputy Chief Cabinet Secretary for Crisis Management
- Regulation Authority Accident Response Headquarters
  - Regulation Authority Chairman for Crisis Management

General Emergency
- Nuclear Emergency Response Headquarters
  - Director-general: Prime Minister
    - Deputy Director-general: Regulation Authority Chairman
  - Secretariat
    - Regulatory Agency Director

Top-Level Government
- Onsite Measures
  - Licensee Company
- Offsite Measures
  - Accident

Videoconferencing System
- Launch Situation Rapid Response Center
  - Nuclear Safety Inspector
    - Senior Specialist for Nuclear Emergency
- ERC (Emergency Response Center)
  - Call to Assembly
  - Other Ministries and Agencies, Self-Defense Forces, Etc.
  - Request for Assistance Call to Assembly
- Situation Rapid Response Center
  - Director General for Emergency Response
- Off-site Center
  - Director General for Emergency Response

ERC
- ERC
  - ERC
- ERC
- ERC

Nuclear Regulation Authority
- Natural Disaster

Central
- ERC
- ERC
- ERC

Onsite
- ERC
- ERC
- ERC

Offsite
- ERC
- ERC
- ERC

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Expansion of Nuclear Emergency Response Action Zone

**Approx. 5 km Radius**

**PAZ**
(Precautionary Action Zone)

Upon the declaration of a general emergency, residents within this zone should evacuate immediately and, as a general rule, should each administer stable iodine.

**Approx. 30 km Radius**

**UPZ**
(Urgent Protective Action Planning Zone)

As a general rule, residents should first take shelter indoors. Next, residents should prepare to evacuate or temporarily relocate and also to administer stable iodine according to the developing situation at the nuclear power plant.
# Radiation Protection for Residents

## Extent of Emergency

<table>
<thead>
<tr>
<th>PAZ (-5 km)</th>
<th>UPZ (5-30 km)</th>
<th>30+ km</th>
</tr>
</thead>
<tbody>
<tr>
<td>According to the situation at the facility, the nuclear power plant operator reports the emergency category to both the national government and local authorities.</td>
<td><strong>●</strong> Local authorities will prepare and implement necessary evacuations in response to instructions or orders from the national government.</td>
<td><strong>●</strong> Assistance with preparations for the evacuation of persons requiring support.</td>
</tr>
<tr>
<td><em><em>Alert (EAL1</em>)</em>* (Ex.) Occurrence of large tsunamis, earthquakes with seismic intensity of 6 or higher, etc.</td>
<td><strong>●</strong> Preparations for evacuation of persons requiring support. (those who are ill or injured, the elderly, physically challenged persons, infants, expectant and nursing mothers, etc.)</td>
<td><strong>●</strong> Reception of persons requiring support.</td>
</tr>
<tr>
<td><em><em>Site Area Emergency (EAL2</em>)</em>* (Ex.) Station Blackout over 30 minutes beyond, etc.</td>
<td><strong>●</strong> Evacuation of persons requiring support.</td>
<td><strong>●</strong> Reception of evacuees.</td>
</tr>
<tr>
<td><em><em>General Emergency (EAL3</em>)</em>* (Ex.) Station Blackout over 1 hour, etc.</td>
<td><strong>●</strong> Preparations for general evacuation.</td>
<td><strong>●</strong> Assistance with evacuation, etc.</td>
</tr>
<tr>
<td>Emission of Radioactive Materials Outside of the Facility</td>
<td><strong>●</strong> Preparations for administration of stable iodine.</td>
<td><strong>●</strong> Preparations for administration of stable iodine.</td>
</tr>
<tr>
<td><strong>Evacuation of residents to outside the PAZ following the instructions of the national government.</strong></td>
<td><strong>●</strong> Administration of stable iodine.</td>
<td><strong>●</strong> Indoor sheltering.</td>
</tr>
</tbody>
</table>

**Based on the results of emergency monitoring, the national government will implement necessary protective measures, such as evacuations, on the basis of air dose rates or other appropriate standards.**

### OIL

- **OIL*1**
  - Air dose rate of 500 microsieverts per hour.
- **OIL2**
  - Air dose rate of 20 microsieverts per hour.
- **OIL4**
  - Body surface beta radiation exposure of 40,000 cpm. (Dropping to 13,000 cpm after 1 month.)
- **OIL6, etc.**
  - Radioactive iodine in drinking water. 300 becquerels/kg, etc.

**OIL: Standard for determining the necessity and extent of measures to be implemented for the protection of residents when radioactive materials have been emitted, based on the results of monitoring, etc.**

---

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Sources: Nuclear Regulation Authority, Federation of Electric Power Companies
### Operational Intervention Level (OIL) and Protective Measures

<table>
<thead>
<tr>
<th>Type of Criteria</th>
<th>Overview of Criteria</th>
<th>Default Value *1</th>
<th>Overview of Protective Action</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Urgent protective action</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OIL1</td>
<td>Criteria whereby residents are told within a few hours to evacuate or stay indoors to prevent effects due to radiation from the ground, inhalation of airborne radioactive material or inadvertent ingestion.</td>
<td>500µSv/h (radiation dose rate measured at 1m above the ground)</td>
<td>Specify an area and conduct evacuation within a few hours. (Including persons with limited mobility to temporarily stay indoors)</td>
</tr>
<tr>
<td>OIL2</td>
<td>Decontamination criteria to take precautions to prevent external exposure from inadvertent ingestion and skin contamination.</td>
<td>Beta rays: 40,000 cpm (count rate from detector a few cm from the skin)</td>
<td>Based on the criteria of evacuation or temporary relocation, carry out inspection of evacuees at shelters, and quickly carry out simple decontamination if the criteria are exceeded.</td>
</tr>
<tr>
<td><strong>Early protective action</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OIL4</td>
<td>Criteria to restrict consumption of local products*2 and temporarily transfer residents within approximately 1 week to prevent effects due to radiation from the ground, inhalation of airborne radioactive material or inadvertent ingestion.</td>
<td>Beta rays: 13,000 cpm [Value after 1 month] (count rate from detector a few cm from the skin)</td>
<td>Specify the area within approximately 1 day, restrict the consumption of local products, and carry out temporary transfer within approximately 1 week.</td>
</tr>
<tr>
<td><strong>Restrict food and drink intake</strong></td>
<td>As criteria to determine restriction of food and drink consumption through OIL5, criteria used when specifying the area to carry out measurement of radionuclide concentrations in food and drink.</td>
<td>20 µSV/h (radiation dose rate measured at 1m above the ground)</td>
<td>Specify the area in which to measure radionuclide concentrations in food and drink within a few days.</td>
</tr>
<tr>
<td>OIL6</td>
<td>Criteria used for restricting consumption of food and drink to avoid effects due to radiation from ingestion.</td>
<td>0.5 µSV/h (radiation dose rate measured at 1m above the ground)</td>
<td>Measure and analyze radionuclide concentrations in food and drink within approximately one week, and swiftly implement restrictions on consumption of items that exceed the criteria.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Drinking water</th>
<th>Milk and dairy products</th>
<th>Vegetables, cereals, meat, eggs, fish, other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radioactive iodine</td>
<td>300Bq/kg</td>
<td>2,000Bq/kg*3</td>
<td></td>
</tr>
<tr>
<td>Radioactive cesium</td>
<td>200Bq/kg</td>
<td>500Bq/kg</td>
<td></td>
</tr>
<tr>
<td>Alpha nuclides of plutonium and transuranium elements</td>
<td>1Bq/kg</td>
<td>10Bq/kg</td>
<td></td>
</tr>
<tr>
<td>Uranium</td>
<td>20Bq/kg</td>
<td>100Bq/kg</td>
<td></td>
</tr>
</tbody>
</table>

*1: The “default value” is the OIL value used at the start of an emergency situation, and when the radionuclide composition deposited on the ground becomes clear, the default OIL value is revised if required.

*2: “Local products” are food products that were produced outdoors in areas directly contaminated by radioactive materials that are consumed within a few weeks (for example vegetables or milk from cows that ate grass in the area).

*3: Vegetables are included apart from root vegetables and types of potato.
Reinforcement of Network between Government and Nuclear Power Plant Operators

Operational Chart—Initial Response and Thereafter

- Nuclear Emergency Response Headquarters
- Nuclear Emergency Response Headquarters Secretariat
  - Top-Level Government Team
  - Regulation Authority Members
- Meetings of Related Agency Directors, Etc.
  - Chairperson: Regulatory Agency Director
- Related Ministries and Agencies
- Local Government
- Communications Satellite
- Videoconferencing System
- Off-site Center (OFC)
- Joint Council for Nuclear Emergency Response
- Nuclear Power Facility Situation Rapid Response Center
  (Head Office of Nuclear Power Plant Operator)
- Nuclear Emergency Response Support Organizations
- Logistical Support Base
- Emergency Response Base (within Site)
- Offsite Disaster Victim Support
- Coordination
- Onsite Crisis Management Support
- Supervision, Instructions, Orders
- Onsite Crisis Management Support

Central Onsite
System for Prediction of Environmental Emergency Dose Information (SPEEDI)

Overview of SPEEDI

- **Government**
  - Nuclear Emergency Response Headquarters
  - Meteorological & radiation observation data
  - Central Data Processing Computers
  - Nuclear Safety Technology Center
- **Local Government**
  - Disaster Response Headquarters
  - Weather Monitoring Equipment
  - Monitoring Stations, etc.
- **Emergency Response Base Facilities (Off-site Center)**
  - Relay Device II
  - Local Nuclear Emergency Response Headquarters
- **Weather Information Providers**
  - Japan Weather Association
  - Wind direction and speed, cloud cover, rainfall, temperature, etc.
- **GPV & AMeDAS Data**
- **Emission Source Info**
  - Nuclear Reactor Facility
  - Nuclear Fuel Facility, etc.
- **Calculations**
  - Meteorological & radiation observation data
  - Effective Dose from External Exposure (Noble Gas)

SPEEDI Map Information

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Nuclear Damage Compensation System

- **Nuclear Damage Liability Facilitation Fund**: JPY 120 billion for compensation measures (including amount stipulated by government decree)
- **Minister of Education, Culture, Sports, Science and Technology**: Approval of compensation measures, Appointment
- **Dispute Reconciliation Committee for Nuclear Damage Compensation**: Guidelines for determining scope of nuclear damage, Mediated settlement (ADR)
- **Compensation amount**: Losses and Damage Assumed by Nuclear Operator (Unlimited Liability) + Government assistance when recognized as necessary
- **Private Insurance Contract**: (Liability Insurance Contract for Nuclear Damage Compensation)
- **Government Compensation Contract**: (Contract for Indemnification of Nuclear Damage Compensation)
- **Measures required for supporting claimants and preventing widespread damage**

- **General accident**
- **Earthquake, volcanic eruption, tsunami**
- **Social unrest and unusually severe natural disasters**
- **Government**
- **Nuclear Operator** (no-fault liability, channeled liability)
- **Operator exemption from liability**

- **Claimants**

Source: Ministry of Education, Culture, Sports, Science and Technology

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