Japan’s Nuclear Tribulations
The Global Impact

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2011 Tohoku Earthquake

- On March 11,2011 at 14:45 PT, an earthquake with a magnitude of 9 took place off the coast of Japan.
- According to the US Geological Survey, the overall duration of the earth quake was close to 6 minutes. Over 15,000 people have died and around 18,0000 people are unaccounted for.

2011 Japan Earthquake

- It was the 5th biggest quake in the recorded history
- It is the most powerful earthquake in Japan, since recorded history of seismic activity from 1900
- Earthquakes of this magnitude like this hadn't happened in Japan for the last 1000 years
- It moved the Japanese mainland closer to US by 18 feet
- The destructive power was 1 million times the combined power of and Nagasaki

Effect on Earth

- Due to this quake, the whole earth axis shifted by 25 cm according to US Geological Survey
- The speed of the Earth's rotation increased due to redistribution of mass, shortening the day by 1.8 microseconds

Corresponding Tsunami

- Even though the magnitude and the duration of the earthquake was impressive, the corresponding tsunami was more devastative
- Just an hour after the earthquake, a tsunami with a peak of 3 to 9 meters at different locations. Tsunami reached as far as 10 km inland in Sendai



Damage to Japan

- Enough energy to power up Los Angeles for one year was released in the Tohoku Earthquake and Tsunami.
- The overall damage to Japan is the second highest after the atomic bombing of Japan in WW2. The overall energy release was twice the Great Indian Tsunami of 2004

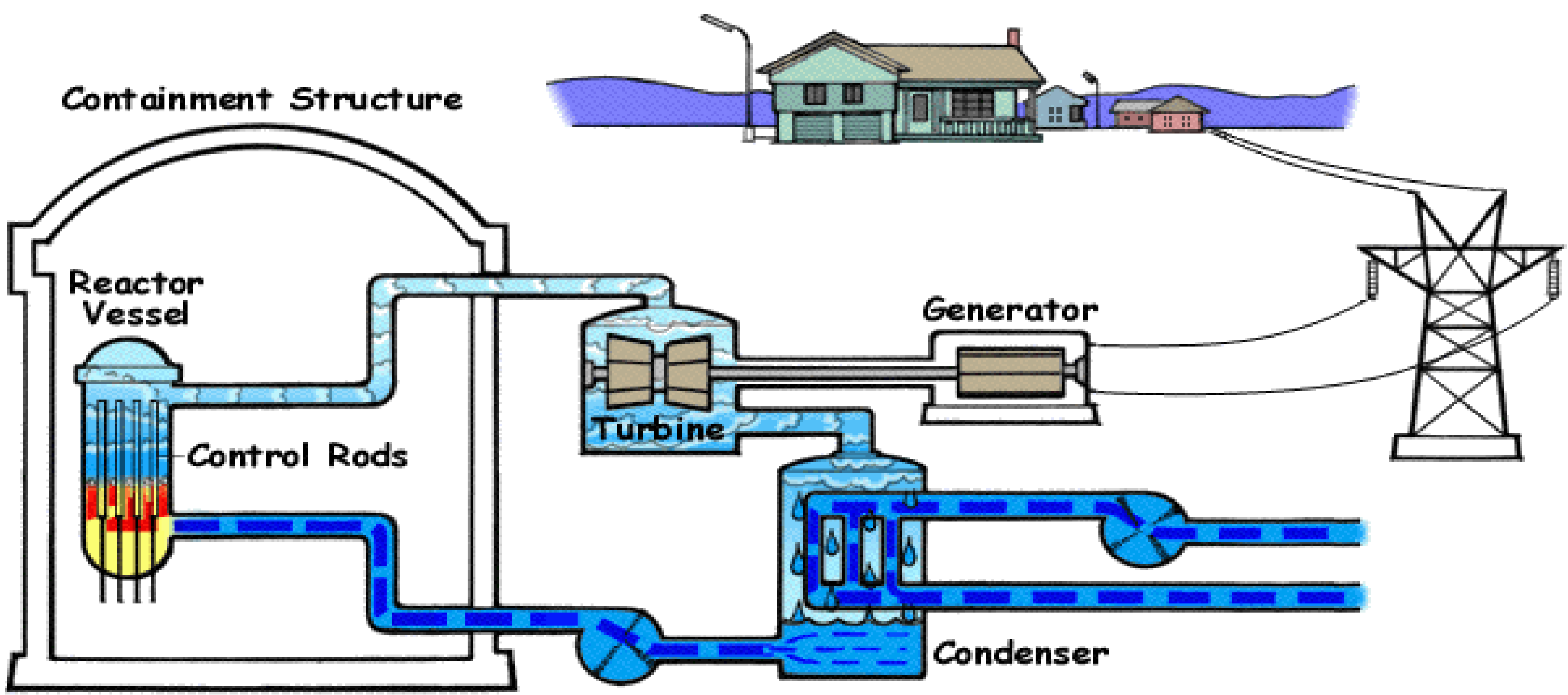
Damage to Japan

Fukushima Power Plant

- In this huge devastating loss due to Earthquake and the Tsunami, Fukushima Power Plant (as well as other nuclear and thermal power plants) were effected
- The emergency response protocols could not deal with the devastative effect of the Tohoku Earthquake.

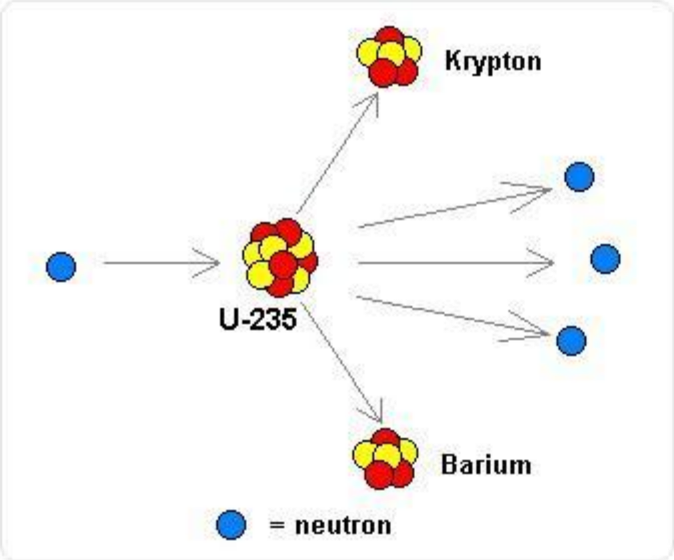
A Nuclear Power Plant Operates Converting Steam to Electricity

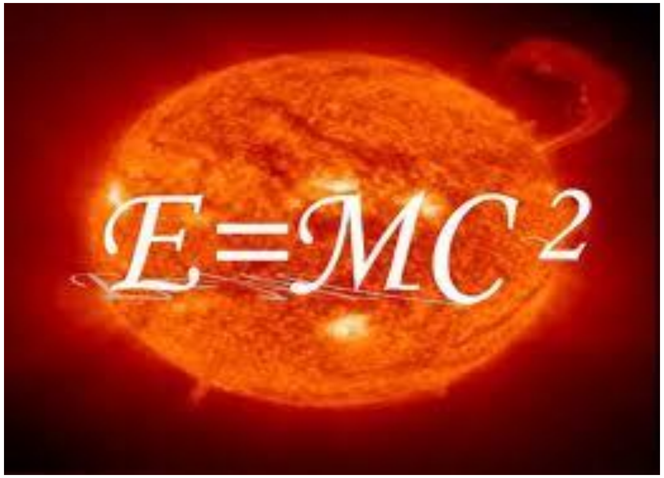
- A nuclear power plant is not really a special thing. Instead of using fossil fuels to generate heat, which in turn produces steam; nuclear reactors produce higher heat through a contained fission reaction.



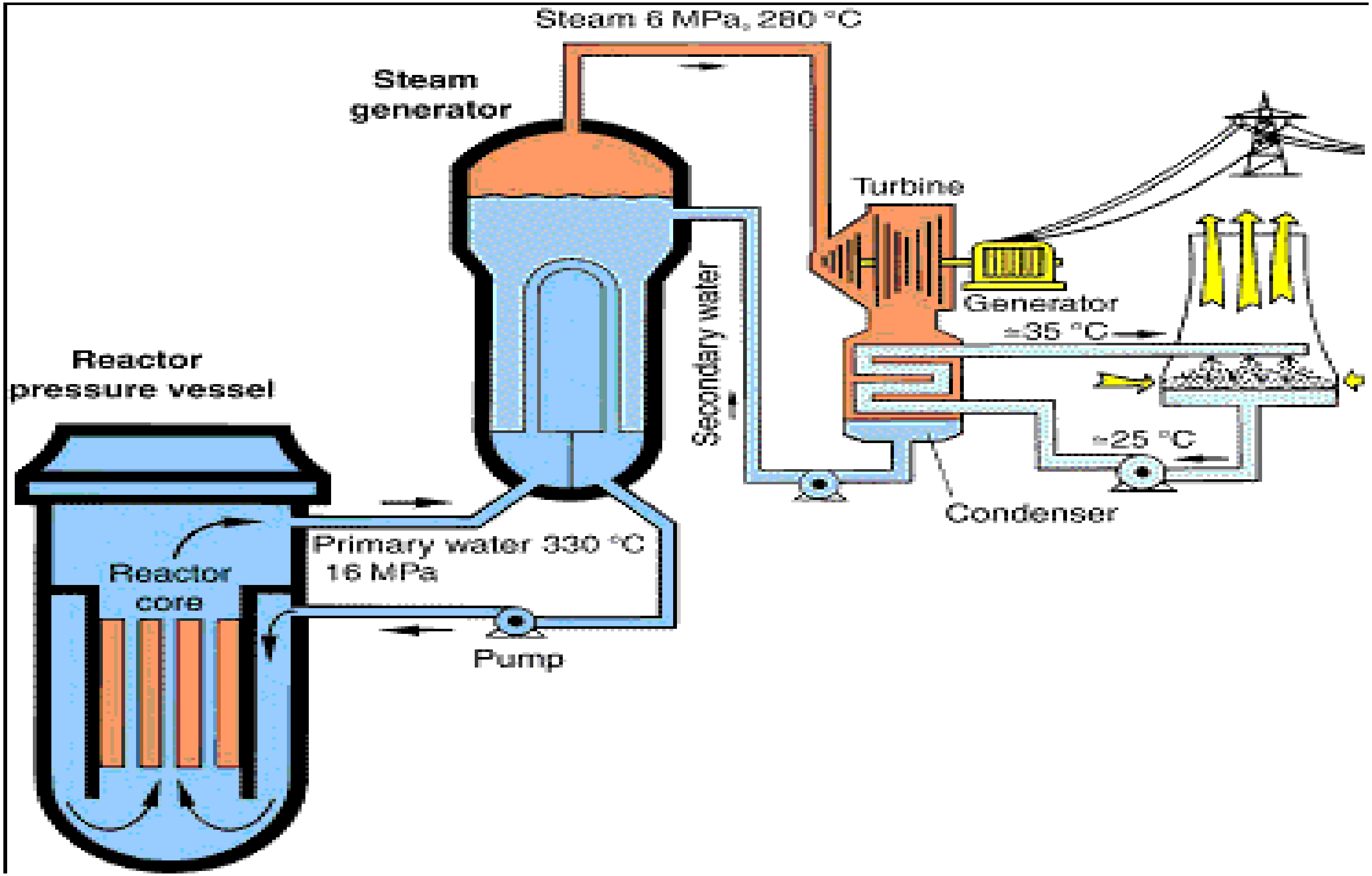
What is a Fission Reaction?

- Fission Reaction is a natural nuclear reaction that allows energy to be extracted from the conversion of matter to energy during the splitting of certain atoms.
- As Uranium and other fissile material are split, some of the mass is converted to energy



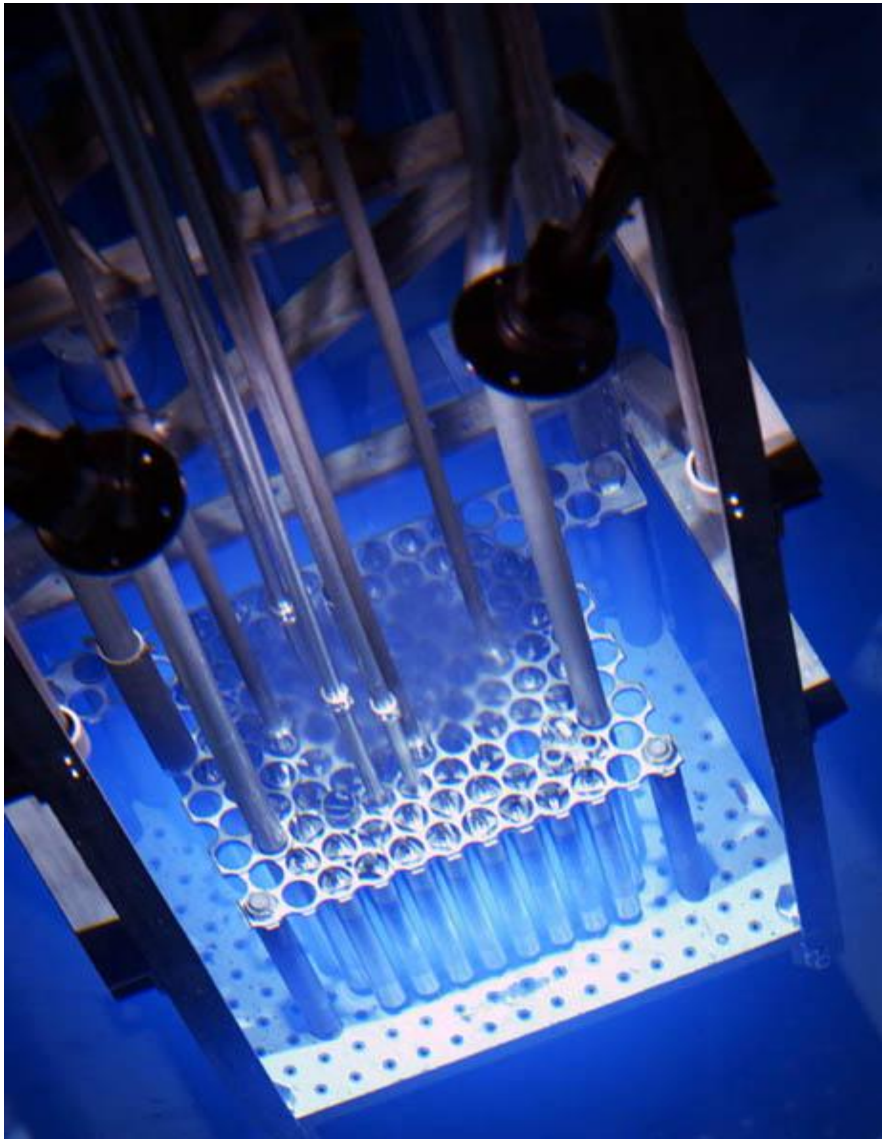


You Produce Steam More Easily as Compared to Coal Power Plants



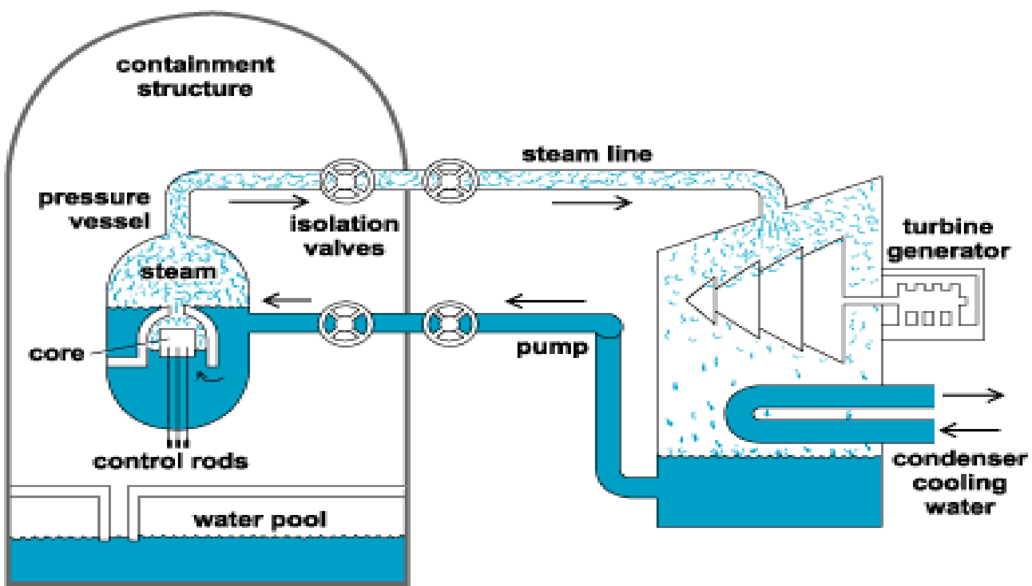
Nuclear Reactivity Control

- Nuclear reactivity (the rate of fission reaction) is controlled by **control rods** and **fuel rods**.
- These are the most important components in a nuclear reactor as they allow you to increase or decrease the rate of the reaction.



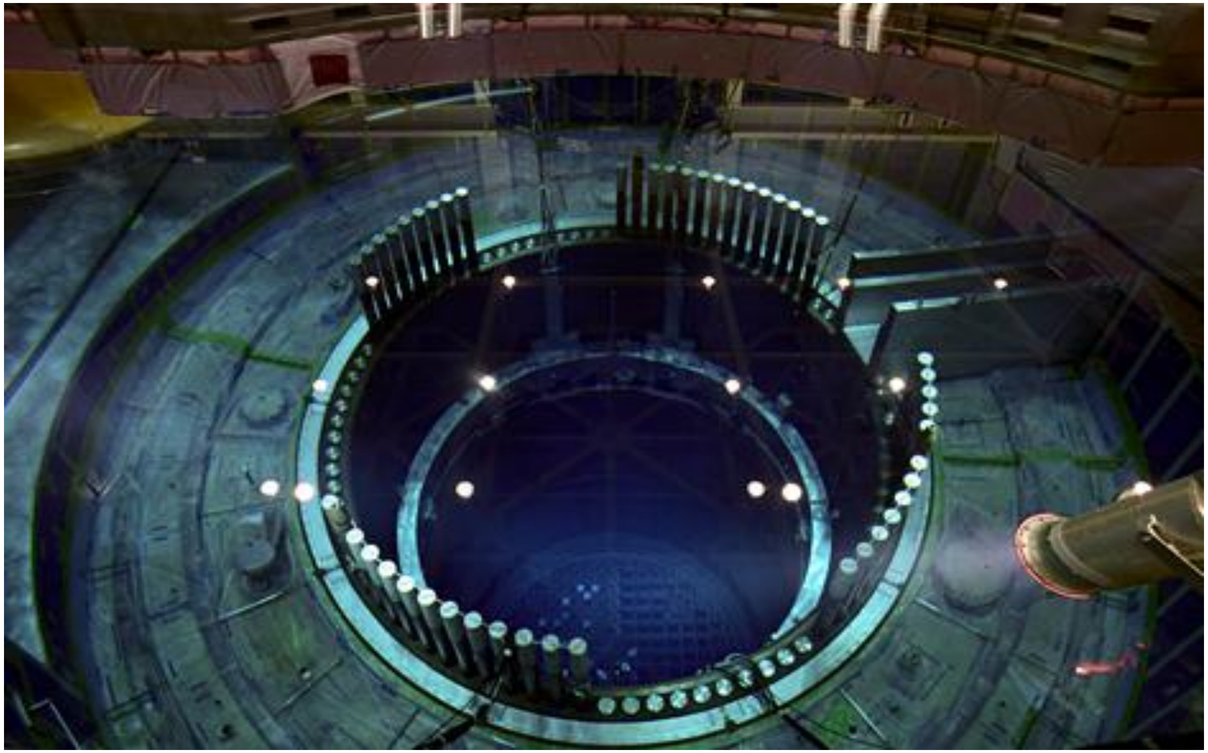
Steam Cycle

- In Fukushima, as well as in all other water cooled pressurized reactors, water cycles through the reactor core and the heat exchanger, so that part of the coolant turns into steam. The steam drives a turbine and then the coolant recycles from a water source (lake or sea) back to the reactor core. **<u>Instead of oil or coal, a nuclear reactor uses a fission reaction</u>**



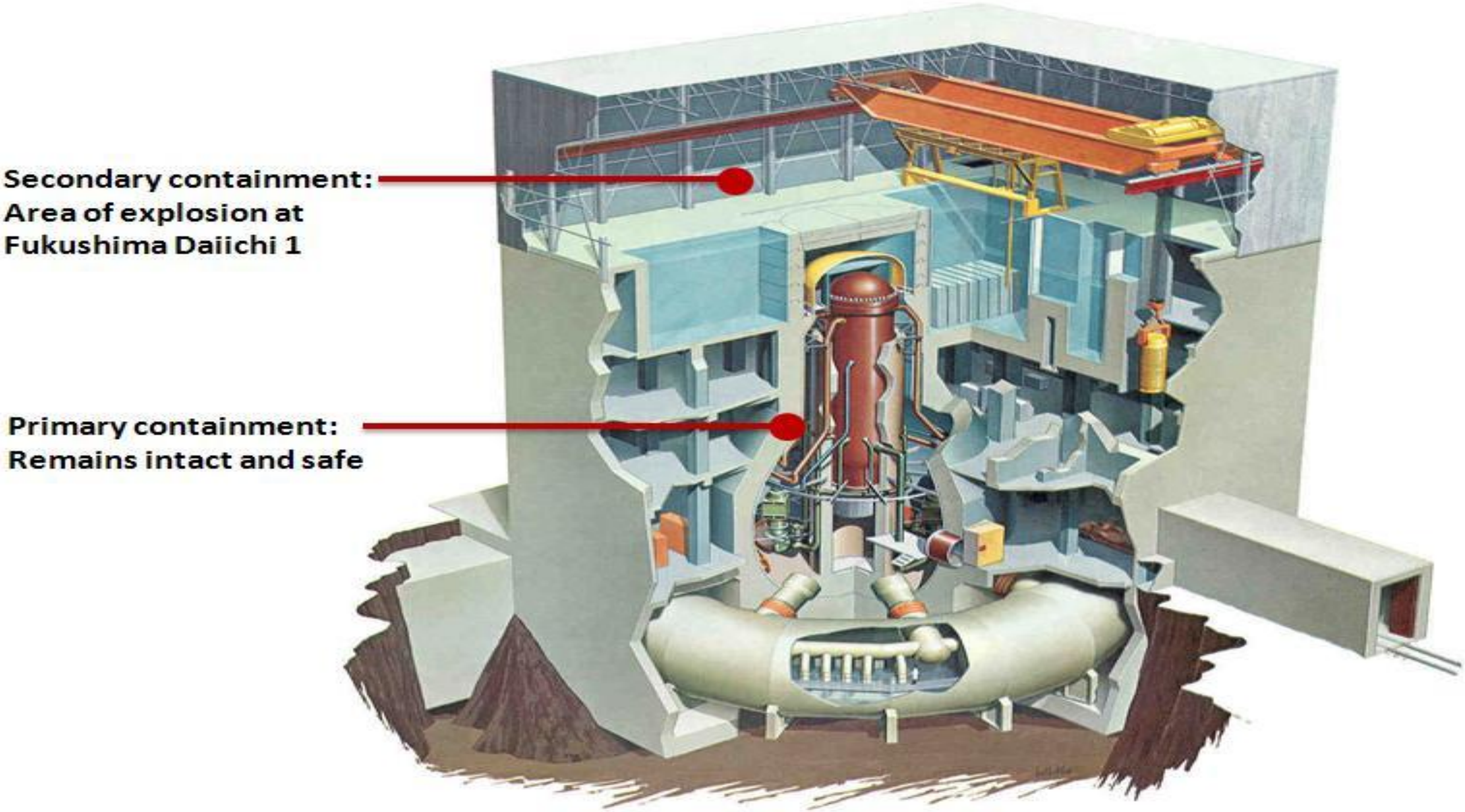
Cooling System

- Cooling system will help absorb the excess heat, so that it is transferred to a secondary system for power production through steam
- Cooling system will also keep the reactor temperature under control, but coolant must circulate at all times.



Fukushima Power Plant

Fukushima Nuclear Reactor



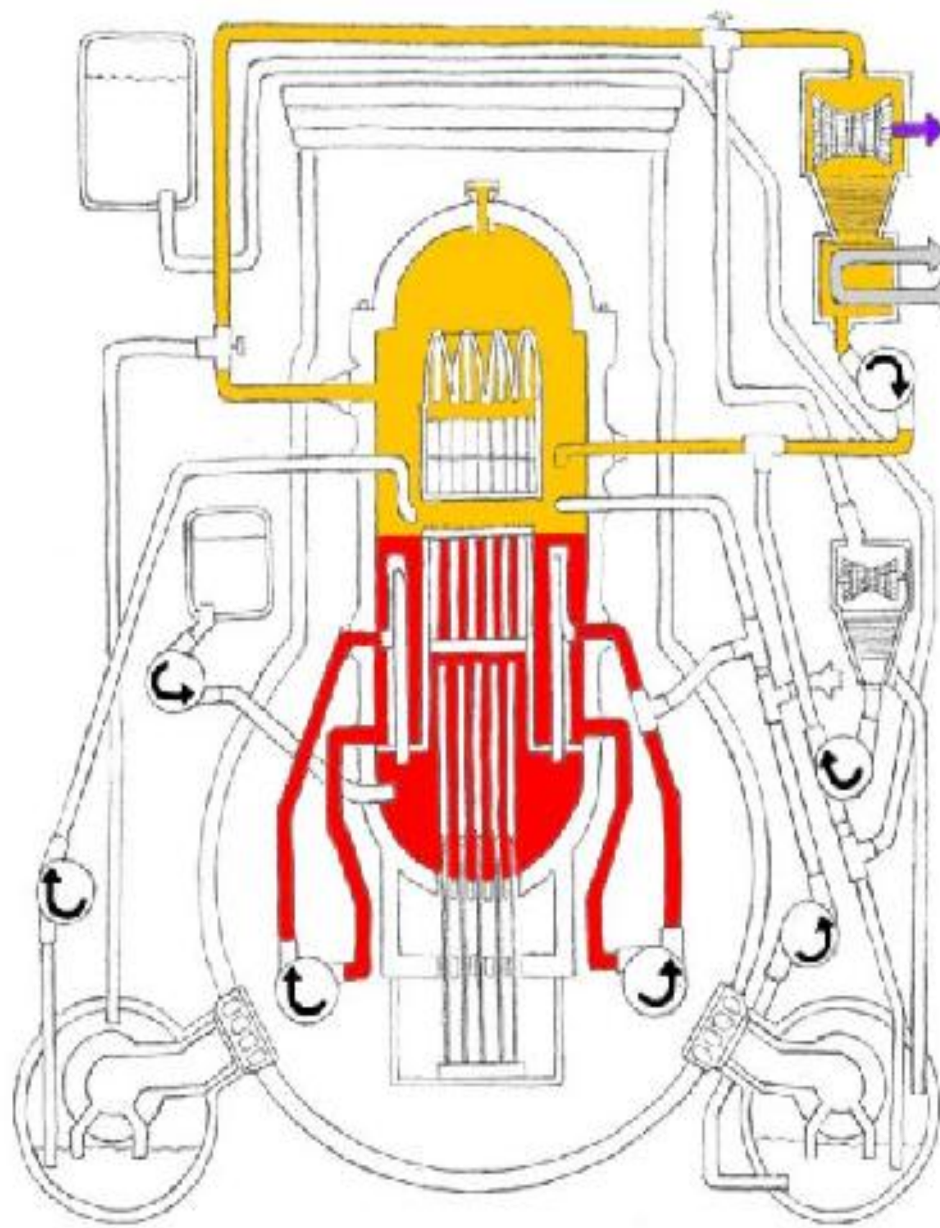
Boiling Water Reactor Design

Fukushima Nuclear Reactor Core

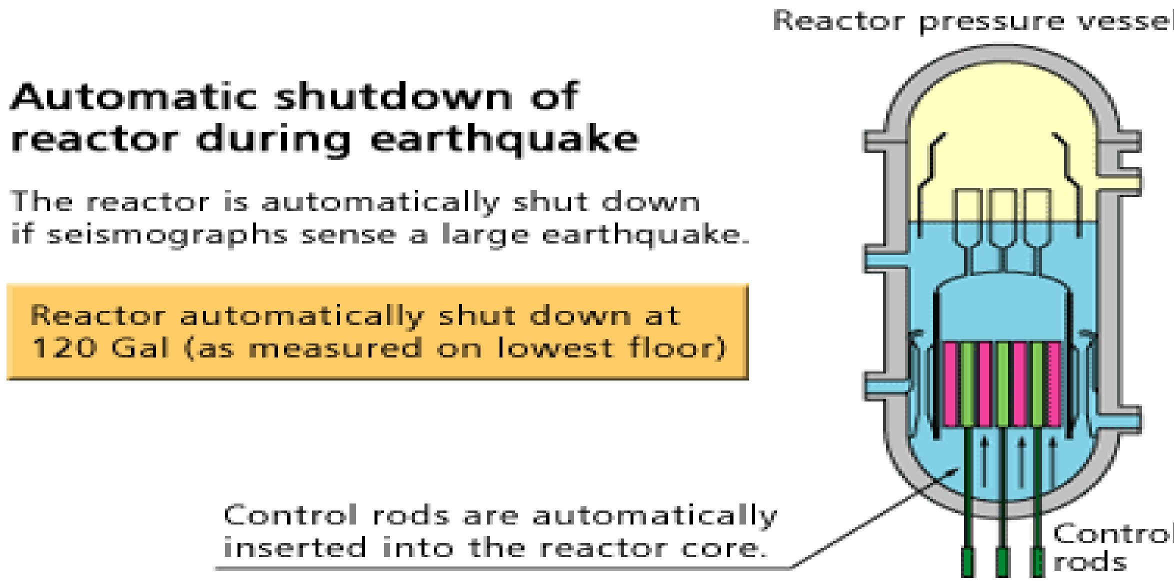
- The reactor is 800MWeach total 4.7GW
- It is a GE Lightbulb BWR
- The nuclear fuel is uranium oxide which is a ceramic with a very high melting point of about 1200 °C. The fuel is in the form of 1 cm pellets lined up inside a zirconium rod.
- These fuel rods are then put together to form assemblies, of which several hundred make up the reactor core.
- The first barrier for retaining radioactive products is the fuel pellet. The second barrier is the fuel rod. The general temperature in the core is 270 °C
- The pressure vessel is the third barrier to radioactive material release. The pressure vessel is a thick steel vessel that operates at a pressure of about 7 MPa (~1000 psi), and is designed to withstand the high pressures

Before the Quake

- Fukushima power plant was working without any problems before the quake. Throughout its history, it had no serious incidents. It was a tested nuclear model, although it was an old system
- The energy was being produced and the coolant was being circulated non stop.



Events Leading to Nuclear Incident

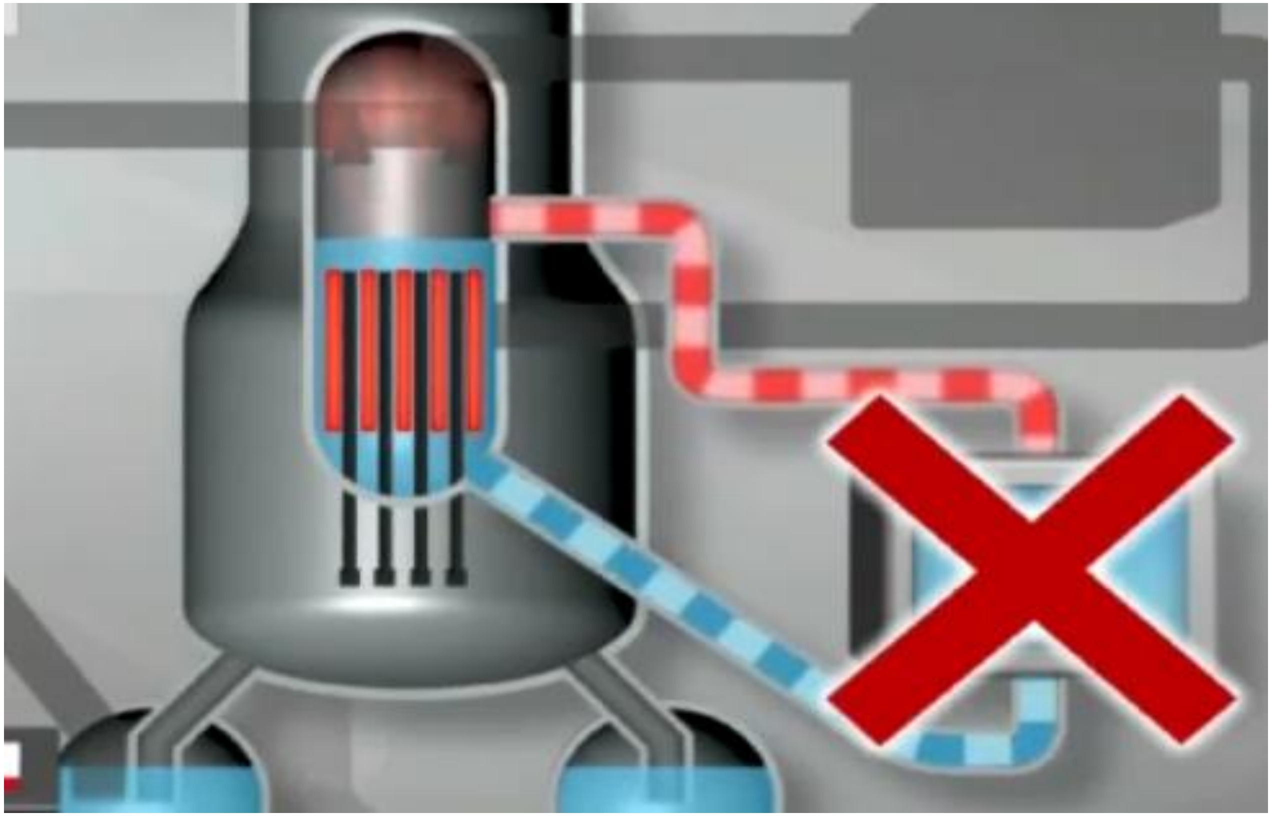


1) When the earthquake hit the seismometers detected it and the nuclear reactors shut down immediately
2) Within seconds after the earthquake started, the control rods had been inserted into the core and the nuclear chain reaction stopped instantly.
3) Even though reaction was finished, residual heat began to build up in the react

Residual Heat

- Even after the reactor stops, 85 % of the heat produced would be present right after scram
- After some time (depending on reaction dynamics), the heat residue drops to 7 percent and then to 0.35 % after 10 days
- Some un-sustained fission and decay heat from radioactive by products will generate heat
- After one year, typical spent nuclear fuel generates about 10 kW of decay heat per ton, decreasing to about 1 kW/t after ten years
- Residual heat is the reason why magma is hot due to uranium, thorium and potassium decaying radioactively

Loss of Primary Cooling

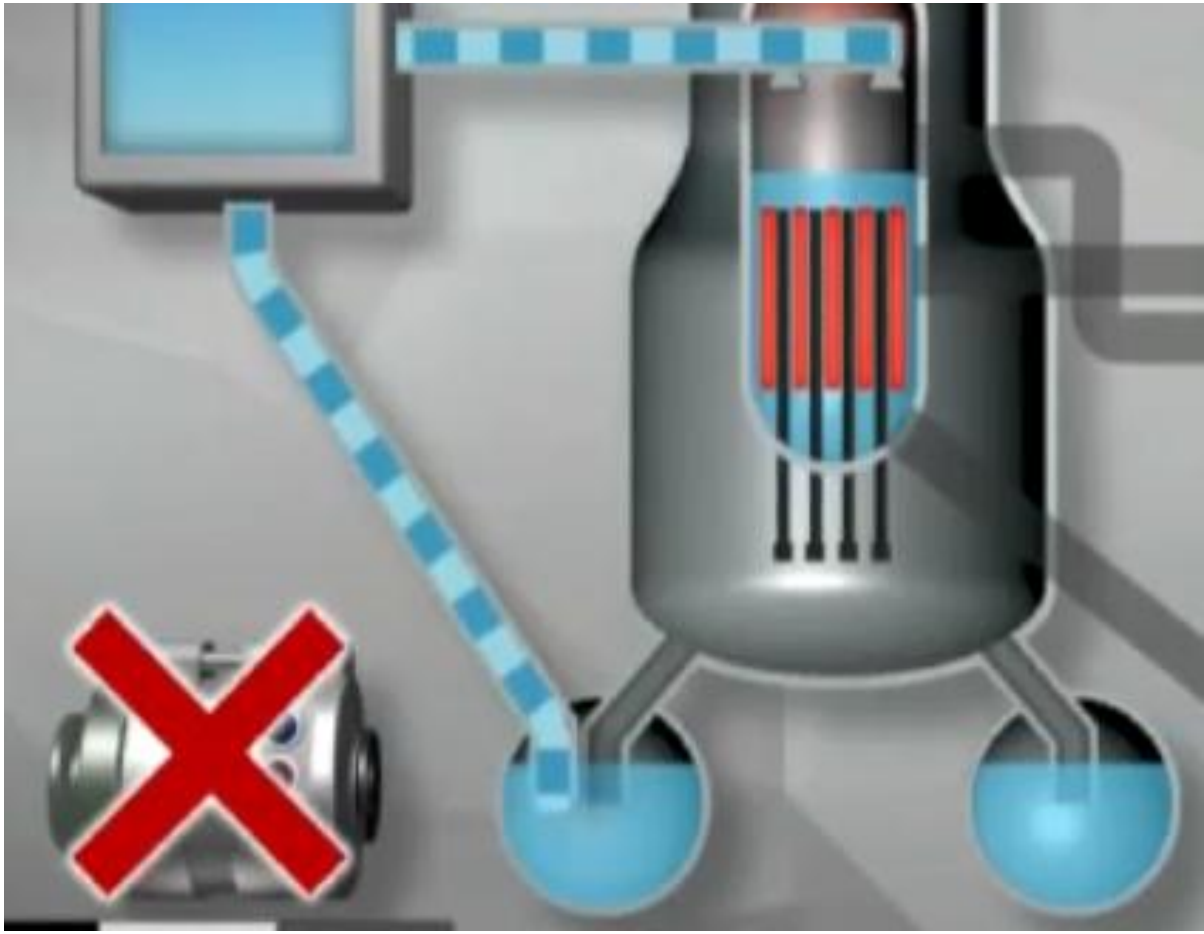


- Due to power outage, the main cooling system stopped working. Nuclear reactor uses external electricity as well as nuclear produced electricity to power the main cooling. Naturally both systems stopped after earthquake

Secondary Cooling System

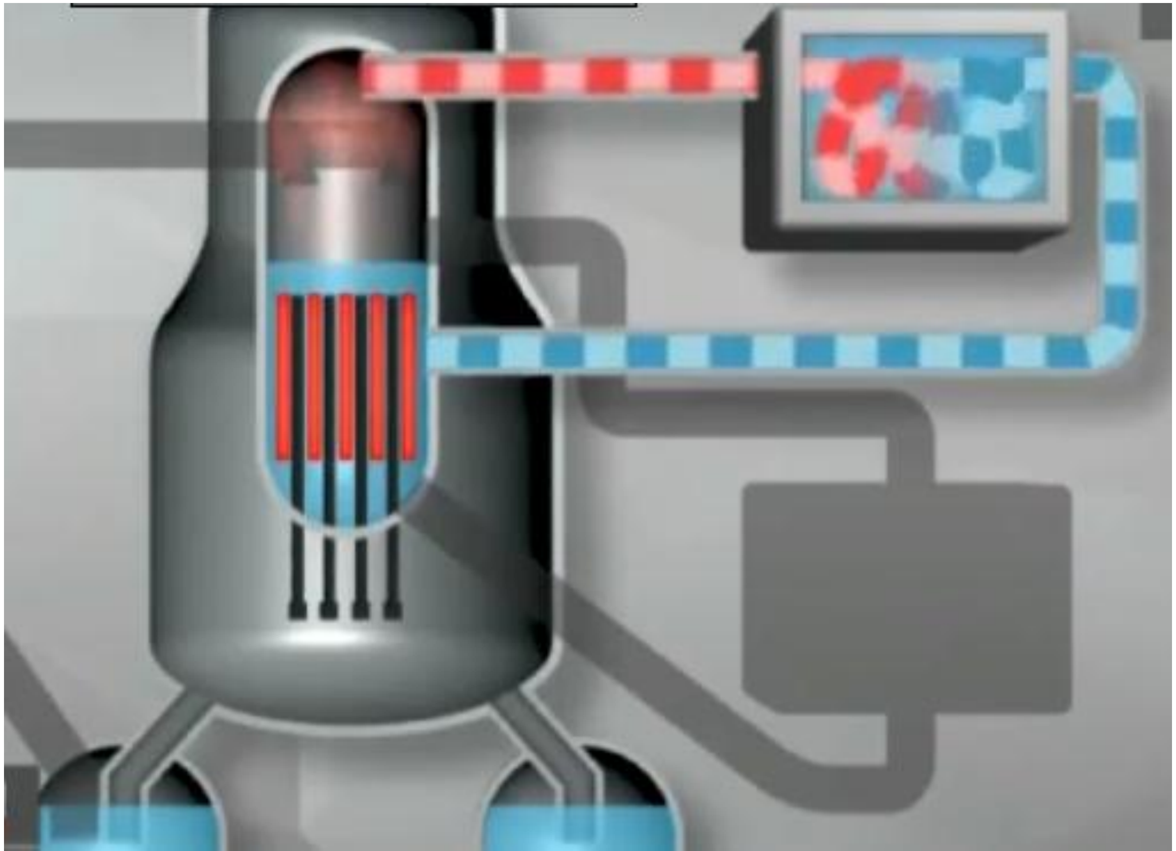
For the first hour, the first set of multiple emergency diesel power generators started and provided the electricity that was needed. The cooling process immediately lowered the temperature to manageable levels.

However, **the first set of generators also failed due to unknown reasons**.

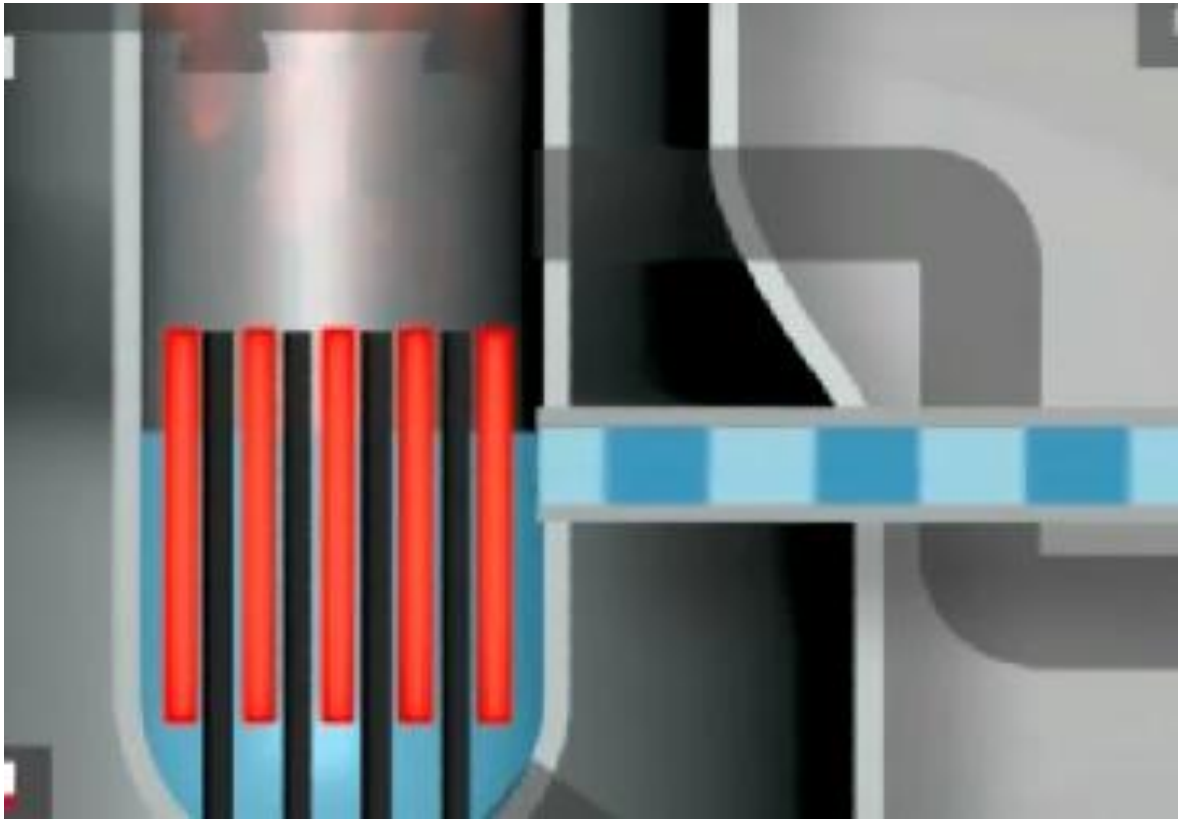


Third Cooling System

- As soon as secondary cooling system failed, third cooling system kicked in as the second set of generators started immediately to circulate water in the core



Tsunami Effect on Fukushima



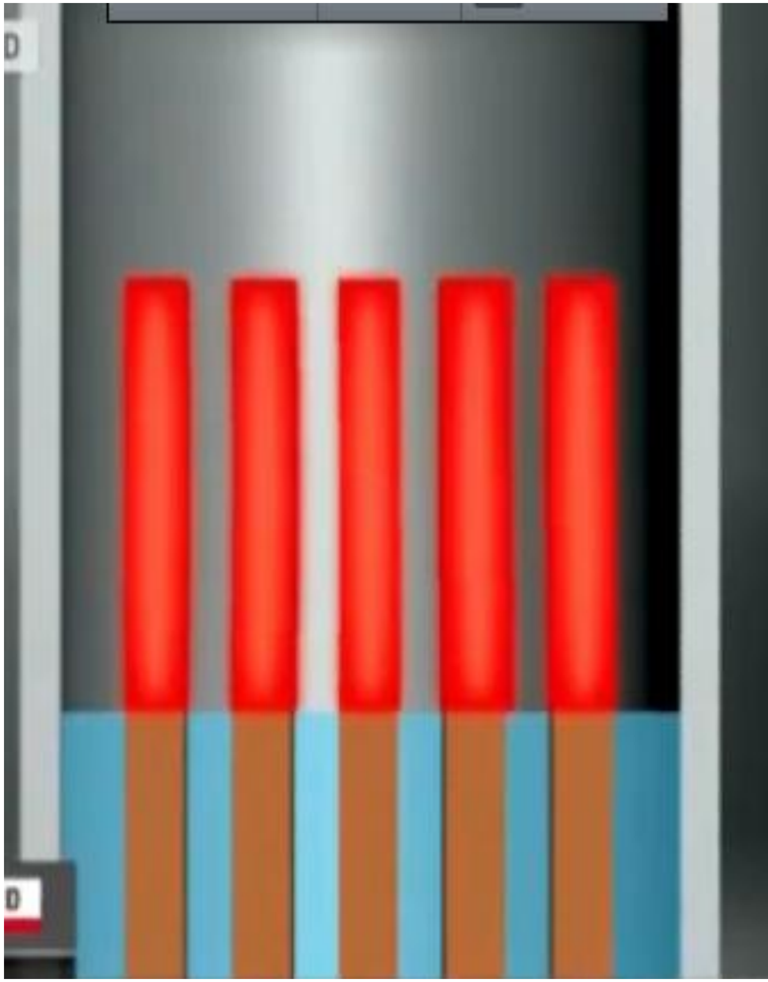
- Then, the tsunami came and devastated the power plant. All of the diesel generators were under water . This caused loss of efficiency as the 3rd generators also failed and coolant was lessened in the core

Emergency Battery Power Kicked in

- When the diesel generators failed after the tsunami, the reactor operators switched to emergency battery power. The batteries were designed as one of the backup systems to provide power for cooling the core for 8 hours
- However, **<u>After 8 hours, the batteries ran out</u>**, and the residual heat could not be carried away any more

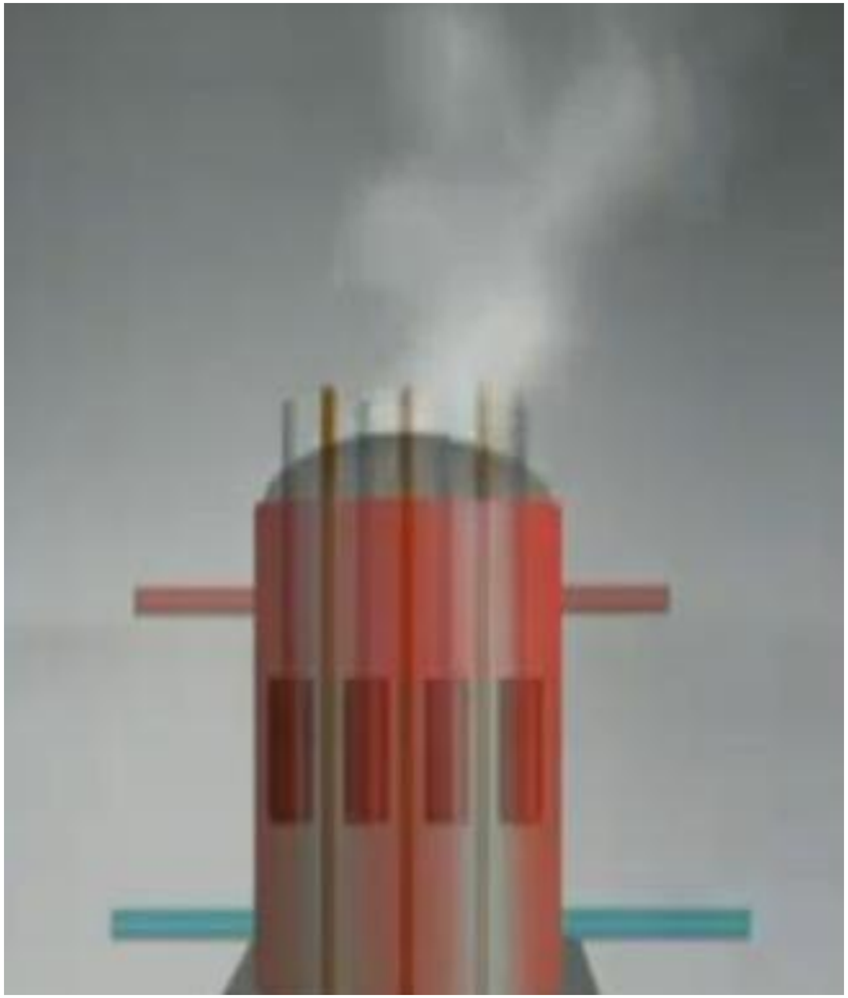
Loss of Coolant Capacity

- Hence, all 4 systems had been lost and coolant circulation systems stopped completely
- No electricity to restart the coolant systems were forthcoming
- Some heat had dissipated, but still close to 1000 degrees of temperature were found in some areas of the core
- Due to the tsunami, mechanical standby cooling system for emergencies also failed (such as converting steam to water to re-circulate)



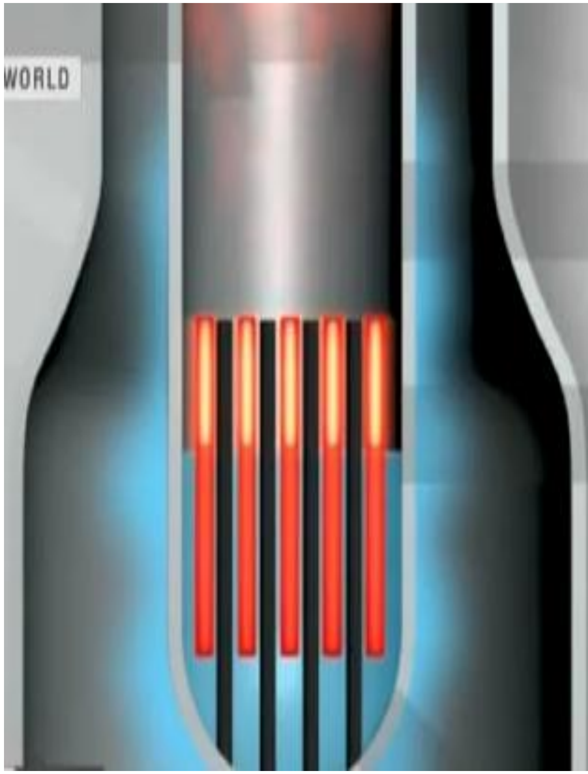
Venting Steam to Lower Pressure

- The priority now was to maintain the integrity of the fuel rods by keeping the temperature below 1200°C (temp at fuel rods melt), as well as keeping the pressure at a manageable level
- To protect the integrity of the vessel and containment, **<u>the operators started venting steam from time to time to control the pressure</u>**



Events Leading to Nuclear Incident

- Mobile generators were placed at the site, but total temperature exceeded 1200 C
- More water was boiling off and being vented than was being added to the reactor, thus decreasing the cooling ability of the remaining cooling systems
- The temperature of some of the fuel rod cladding exceeded 1200 °C, initiating a reaction between the Zirconium fuel rods and water which produced hydrogen gas

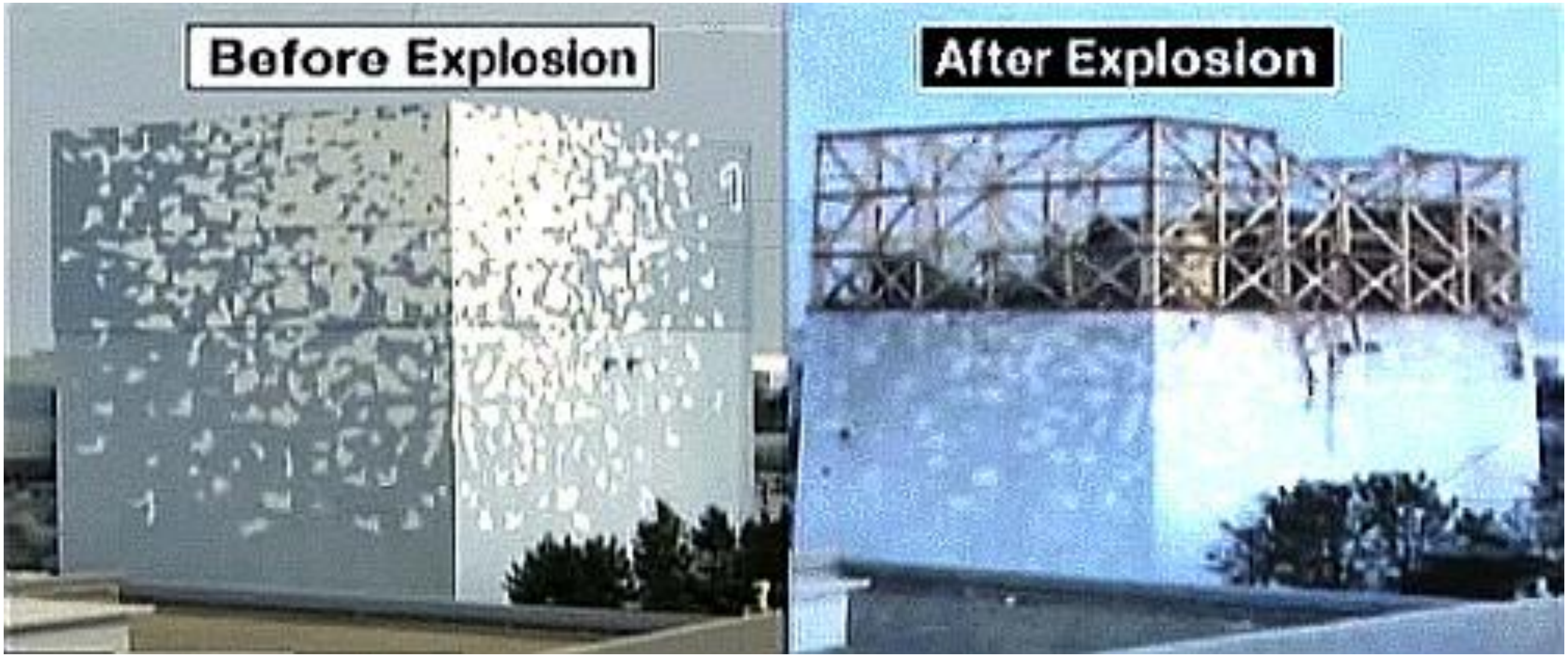


Explosion at Fukushima Plant

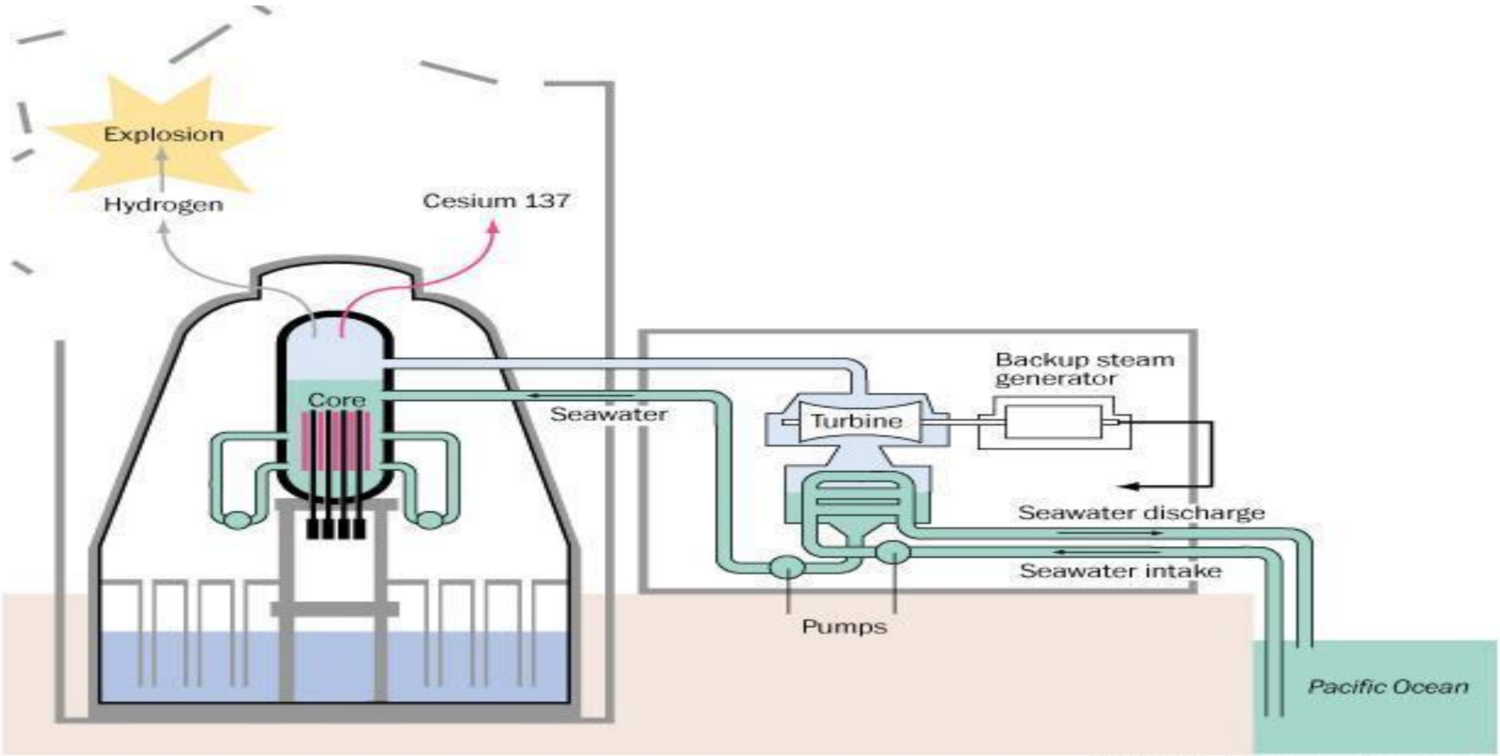
- Due to venting, some oxygen got mixed with hydrogen and this caused a hydrogen explosion which damaged the secondary containment

Containment Breach after Explosion

- The primary containment remained intact after the hydrogen explosion, but the second containment failed.



Radioactive Release



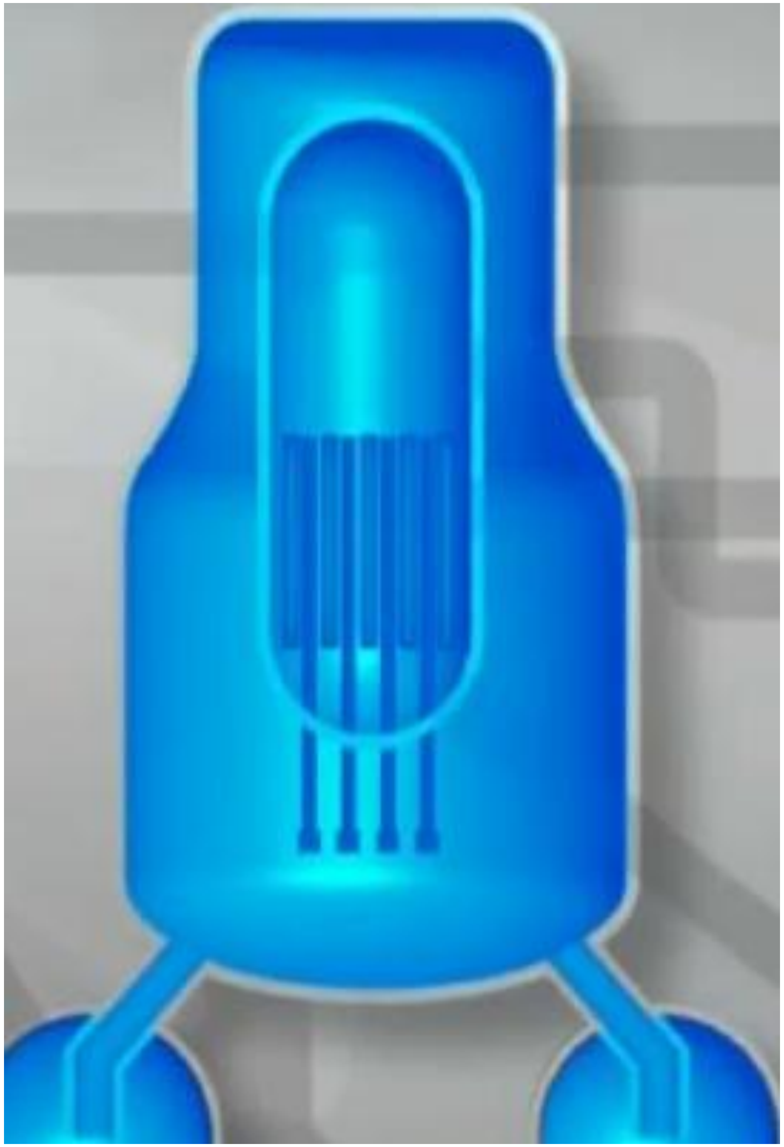
Sursa: The Washington Post

- Some of the radioactive fission products (cesium, iodine, etc.) started to mix with the water and steam, since the fuel rods were exposed to air due to loss of water in the main core.
- It was reported that a small amount of cesium and iodine was measured in the steam that was released into the atmosphere.

Sea Water Injection

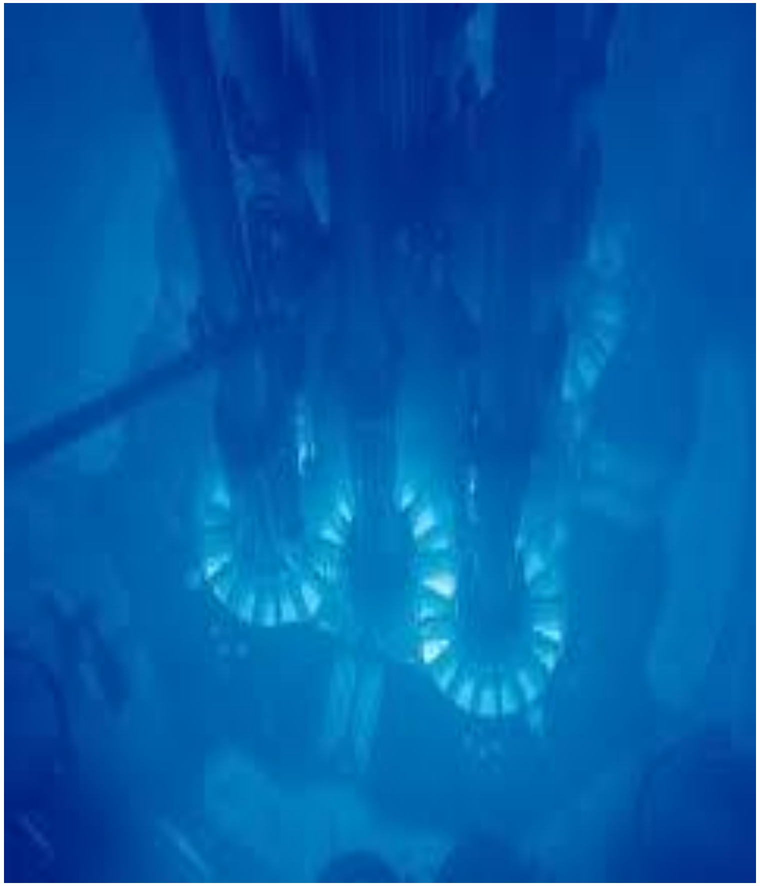
- Since water inventory in the reactor was decreasing, **engineers decided to inject sea water** (mixed with boric acid – a neutron absorber) to ensure the rods remain covered with water

- Injection of the sea water helped to solve the problem as the whole system was covered with water. Also no other option was left, as all 4 cooling systems had failed



Result

- This process decreased the temperature of the fuel rods to a non-damaging level. Because the reactor had been shut down a long time ago, the decay heat had decreased to a significantly lower level, so the pressure in the plant stabilized, and venting was no longer required.
- Only two people at the power plant died and due to tsunami

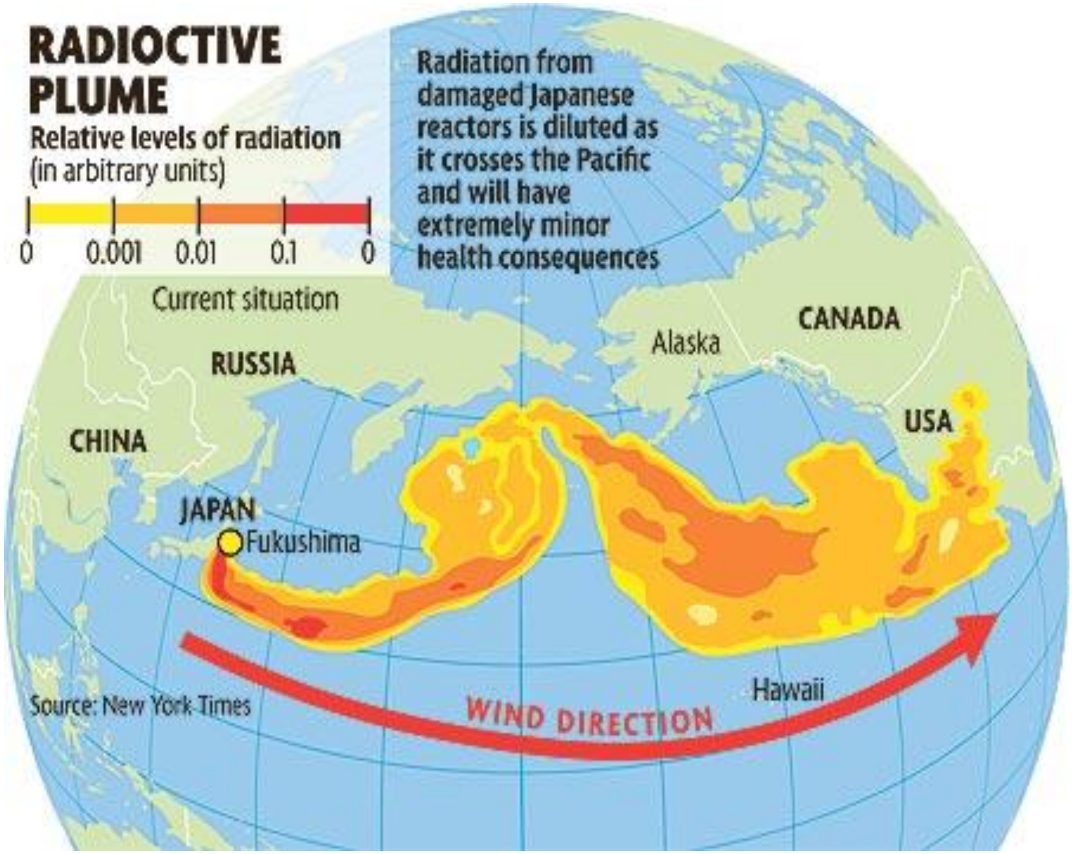


Analysis

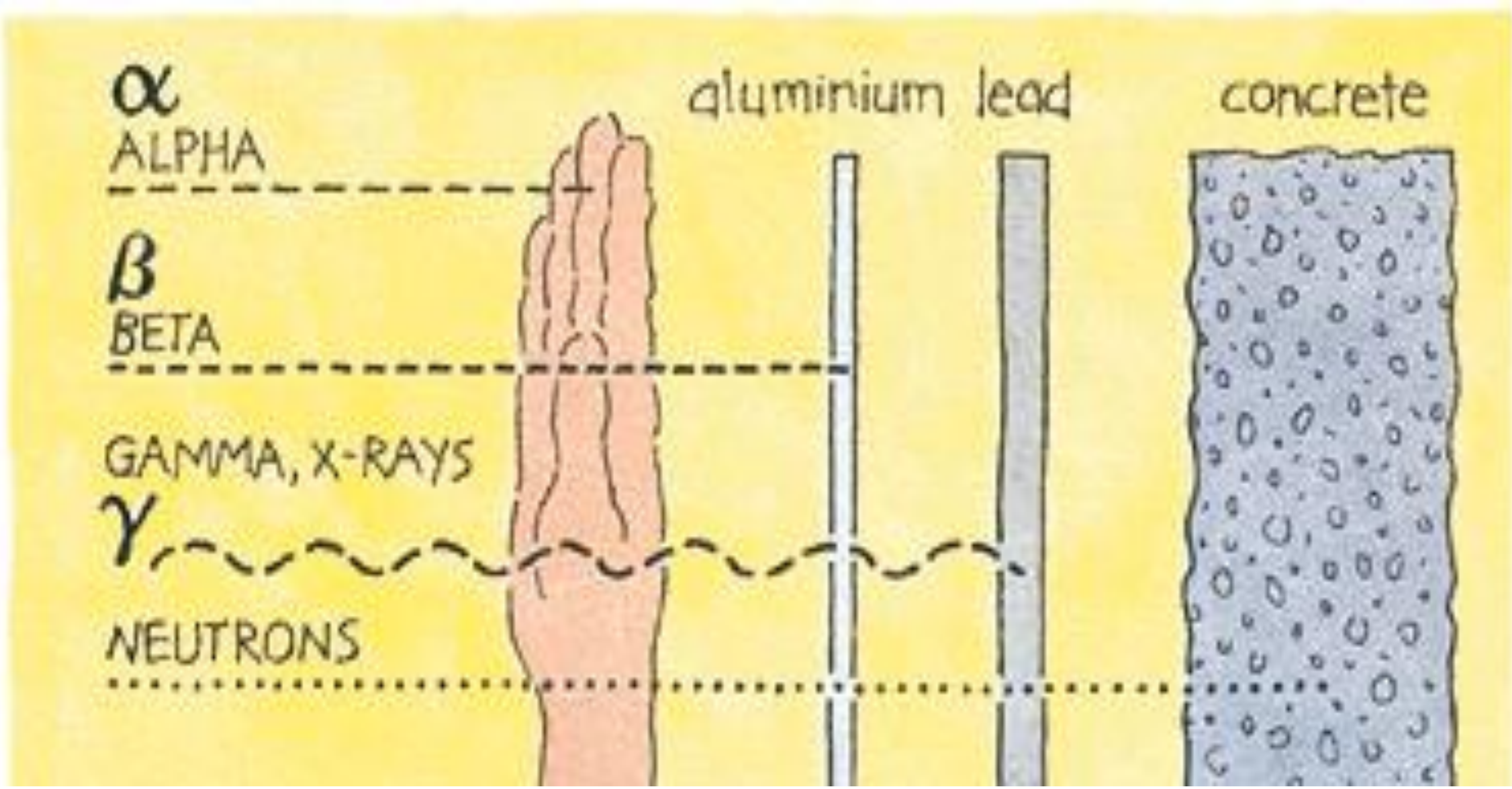
- Fukushima Nuclear Reactor was old technology of the end of 1960's and beginning of 70's of GE BWR reactors. It had enough redundant backups (total of 4), but it was too old to resist the chain of events that occurred
- The Nuclear Reactor was designed to withstand an earthquake or a tsunami. However, two devastating events coupled together exceeded the design parameters and the above said chain of events occurred.
- If seawater had been pumped earlier, the result would have been more favorable. However due to fear of fuel damage, they waited too long.

Nuclear Dispersion

- Some amount of radioactive byproducts were dispersed, but the amounts effecting after the 100 km radius are completely negligible.



Radiation Level Safety



Time, **D**istance, **S**hielding. If you reduce the time you are exposed to a radiation source, maximize the distance from the radiation source, and place some object or other form of shielding between you and the radiation source, you can reduce your radiation exposure

Standard Radiation Levels

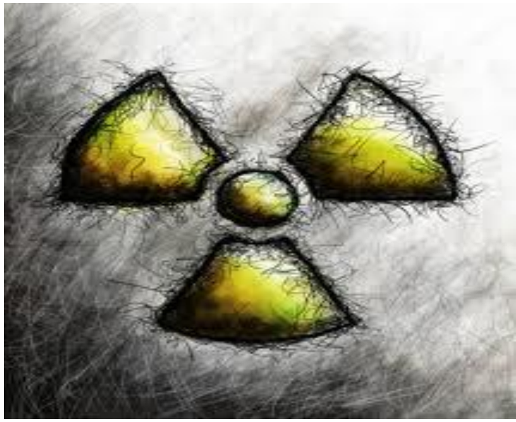
- A coal plant would emit three times the radiation of a nuclear power plant due to the presence of natural uranium in the coal
- Up to 5000 mRem per year can be taken safely A 40 year old can have a maximum of 200 Rem. Anything above 300 Rem increases chance of cancer by 10%
- Normal exposure is 300 mRem per year
- A person emits about 40 mRem of radiation due to natural Carbon 14 found in the body. Sitting next to two persons would double the exposure
- A person who smokes a pack of cigarettes gains 3 .5mRem of radiation corresponding to ¼ annual dose. A chain smoker has been exposed to more radiation overall as compared to those near nuclear plants

World Reactions

- Germany decided to shut down all nuclear reactors made before 1976.
- France stated that a similar scenario of earthquake/tsunami cannot occur in France
- Canada stated that CANDU reactors are free from these troubles due to heavy water.
- UK uses Gas Cooled Reactors, passively cooled systems
- USA conducted an inspection of all of its nuclear power plants and declared them safe
- China made a statement that her nuclear power plants use advanced technology and hence not prone to these types of incidents

How It Could Have Been Handled?

- Pumping seawater as soon as backup systems are offline
- Using nitrogen based cooling systems to cool down then temperature of the system
- Getting mobile generators up and running as soon as possible on the primary coolant
- Dispersion of nitro bromide hexa fluorine foam solution on the building constantly. (Expensive but effective) – prevents radioactive scattering
- Tarp on the secondary containment
- Possible artificial rain on the site to force scattering to come down



Problem with Old Reactors

- Most old reactors are based on American design of the 60's. They are high pressure water cooled reactors and most of these reactors still use analog pressure / temperature sensing systems and actuators
- None of them have advanced backup against Scale 10 catastrophes
- All of them are prone to human errors as automation is spars

Recommendation

- It is recommended that gravity based cooling systems with a reservoir of water on top of the reactors should be implemented with advanced nitrogen based emergency coolers. Also all analog systems should be changed to redundant digital systems
- New Generation IV reactors that uses gas cooling (helium or Carbon Dioxide) are the new design reactors. In fact, China, Korea and South Africa are investing heavily in these technologies
- Special Generation V reactors are being deployed in USA. These reactors are said to have zero chance of any incident occurring as reactivity will immediately die as the heat increases

Nuclear Reactors are Safe

- If properly implemented, nuclear reactors are very safe. However, right technology and correct procedures has to be used. Chances of a nuclear explosion is always zero and it is physically impossible
- All incidents have occurred due to human error.

THANK YOU

- Please contact me for further information about the safety aspects of Nuclear Reactors

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www.nuclearlectures.co.cc