Technical Seminar
on
Nuclear Safety and Protection

11 June 2011

Nuclear Engineering Safety

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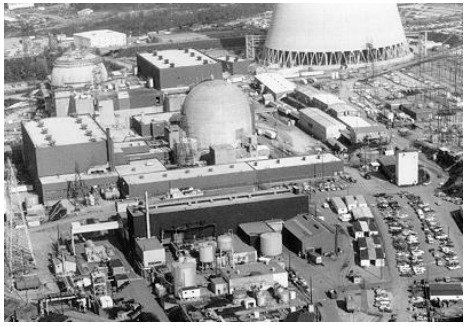
Evolution of Nuclear Power Systems

Generation I

Early Prototype Reactors



- Shippingport
- Dresden,Fermi-I
- Magnox

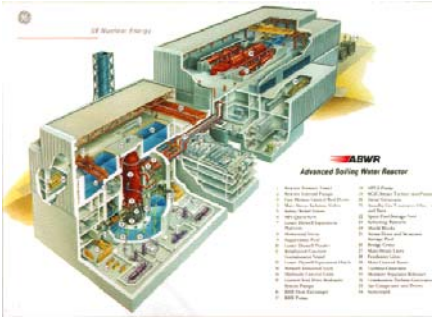
Generation II

Commercial Power Reactors

- LWR: PWR/BWR
- CANDU
- VVER/RBMK

Generation III

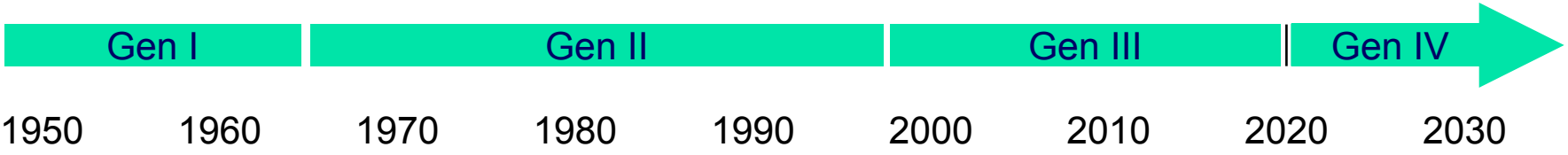
Advanced LWRs



- System 80+
- EPR
- AP1000
- ABWR

Generation IV

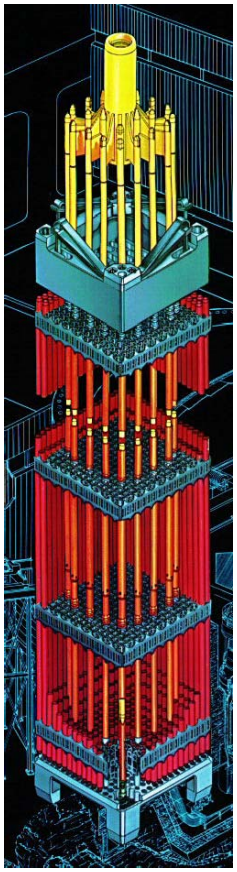
- **Enhanced Safety**
- **Improved Economics**
- **Minimized Wastes**
- **Proliferation Resistance**

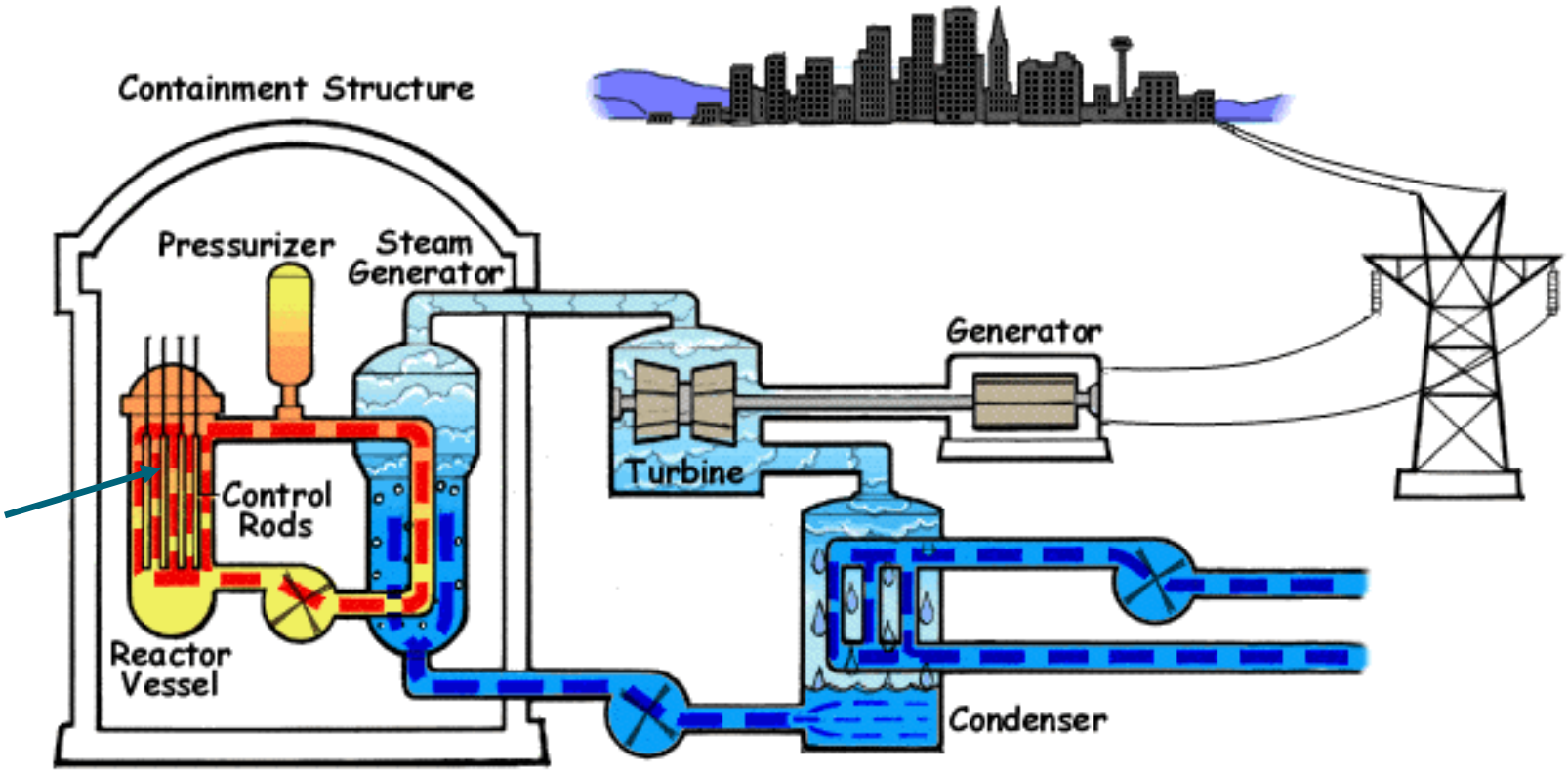


Nuclear Power Plant
Reactor Core and Containment

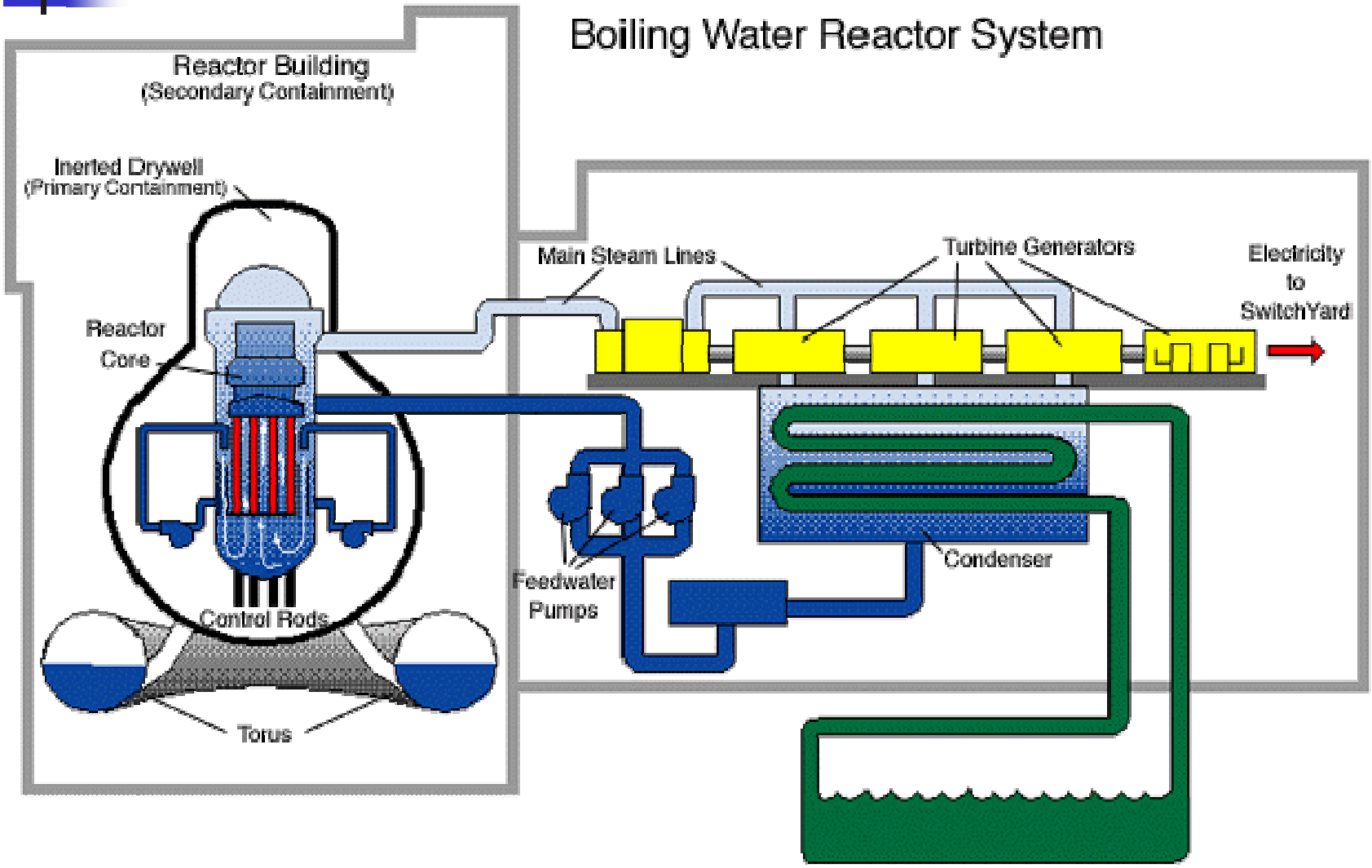
- Compressed water acts as moderator and coolant receives heat in a closed primary loop
- Heat is transferred to a non-radioactive secondary loop through steam generators

Fuel Rod Assembly





Boiling Water Reactor (BWR)



Nuclear Safety
- keep core cooled, prevent core melt

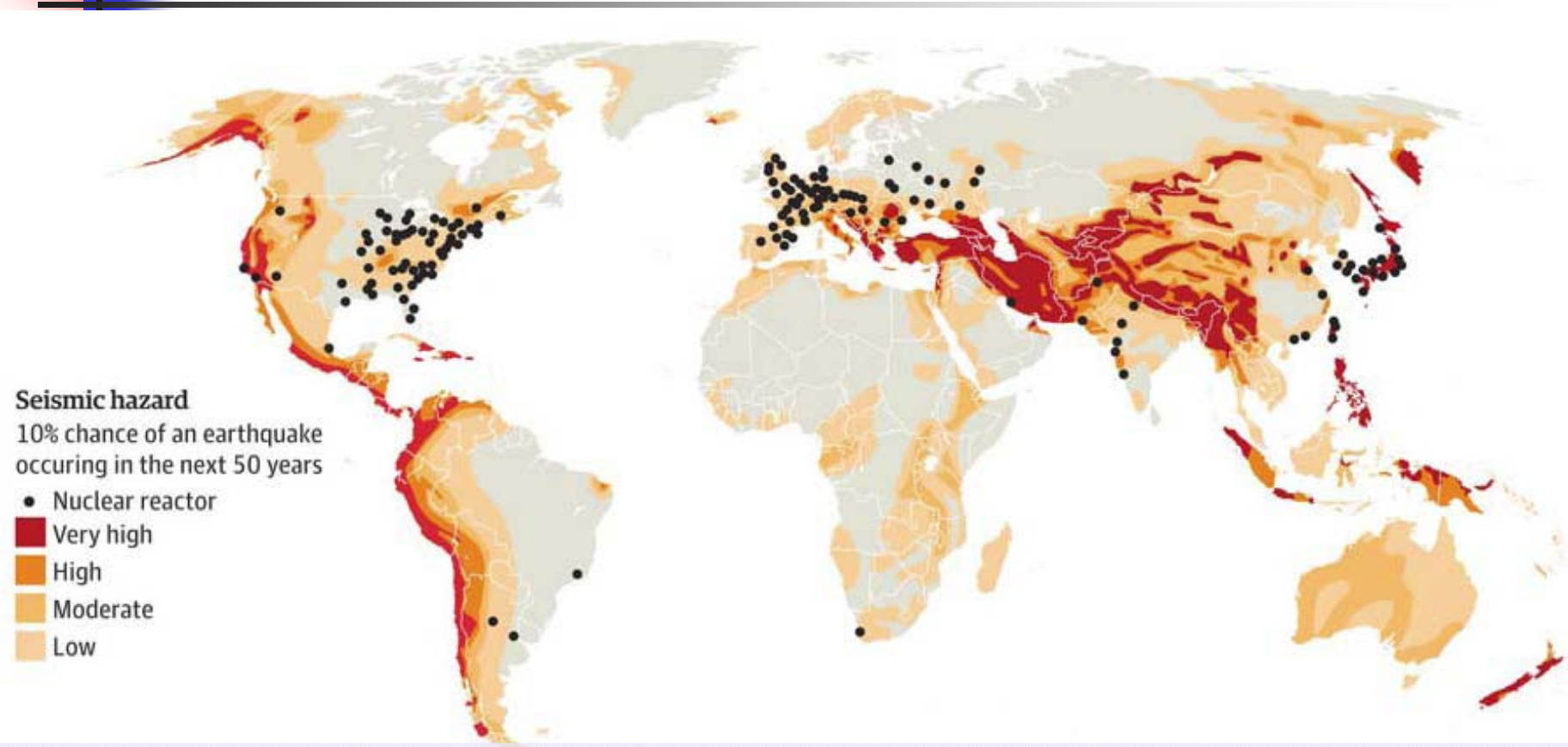
- Criticality Control
  - Reactor operates at "critical state" with generation of neutrons from fission balancing the loss of the neutrons within the reactor.
  - Control via insertion/removal of control rods made of neutron absorbers.
  - Special control rods and system provide very fast shutdown in the event of an unsafe condition ("scram").
- Emergency Core Cooling & Decay Heat Removal
  - When a reactor is shut down, fissions essentially cease, but energy is still being released from the decay of fission products.
- "Station Blackout"
  - Loss of electrical power

Time (from Shutdown)	Decay Heat (% of pre-shutdown)
Immediate	6.5%
1 hour	1.5%
7 day	0.2%

Defence in Depth - Safety in Design

- Multiple, redundant, and independent layers of safety systems in place to reduce the risk of a single, critical point of failure
- Multiple control on chain reaction
- Functionally redundant cooling systems with multiple power supplies (offsite, diesel generators, batteries)
- Physical safety barriers to contain radiation and provide emergency protection
- Materials management for reliable plant components
- Industry-wide personnel training program for safe plant operations
- Plant security to protect sabotage and assault

Nuclear Reactors Around the World
Some in Earthquake Zones



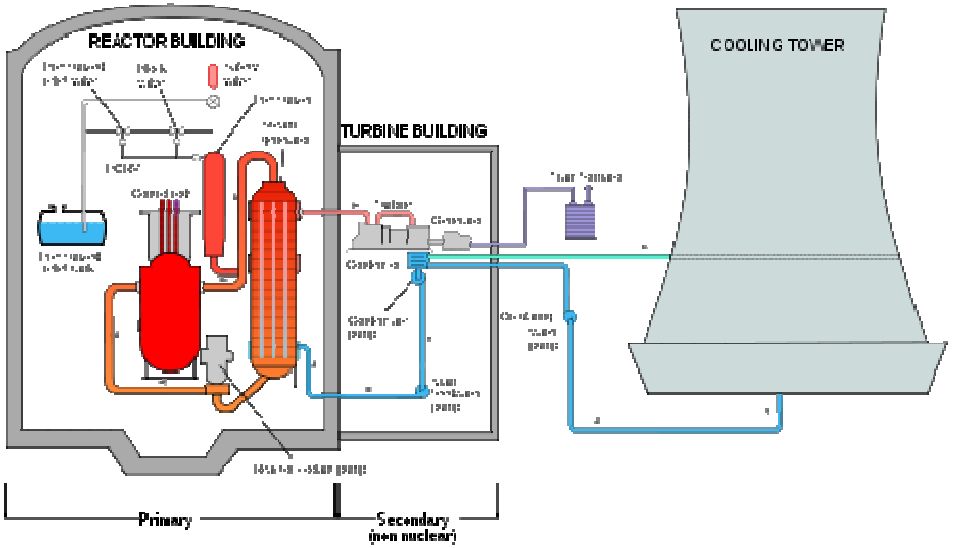
- In Japan, the nuclear power plants were unaffected by the 1995 Kobe-Osaka earthquake, and reactors shut down automatically in 2004, 2005, 2007, 2009 and 2011 earthquakes.
- In Taiwan, 3 reactors shut down automatically during the 1999 earthquake.

Three Mile Island Accident

- Occurred on 28 March 1979 at the Three Mile Island Nuclear Generating Station in the USA
- The only Pressurized Water Reactor (PWR) in the world has a major accident.

Causes:

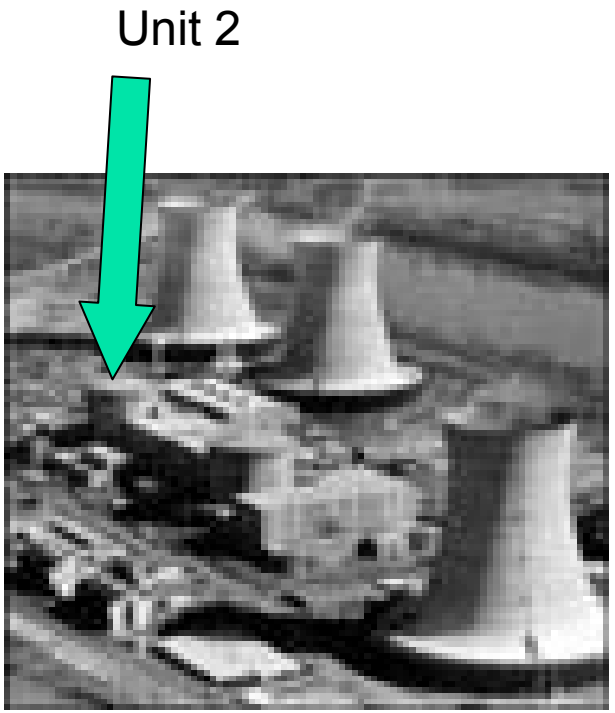
- Pumps failure
- A stuck-open pilot-operated relief valve (PORV)
- Poorly designed instrumentation causing operators confusion



Three Mile Island Accident

Results:

- Loss-Of-Coolant Accident (LOCA)
- Partial reactor core meltdown
- Most of the radioactive materials were retained with the containment building
- No significant radiation threat to the staff and general public
- 80,000 to 200,000 evacuated voluntarily
- 2000 lawsuits or claims were confirmed unsuccessful in 1996

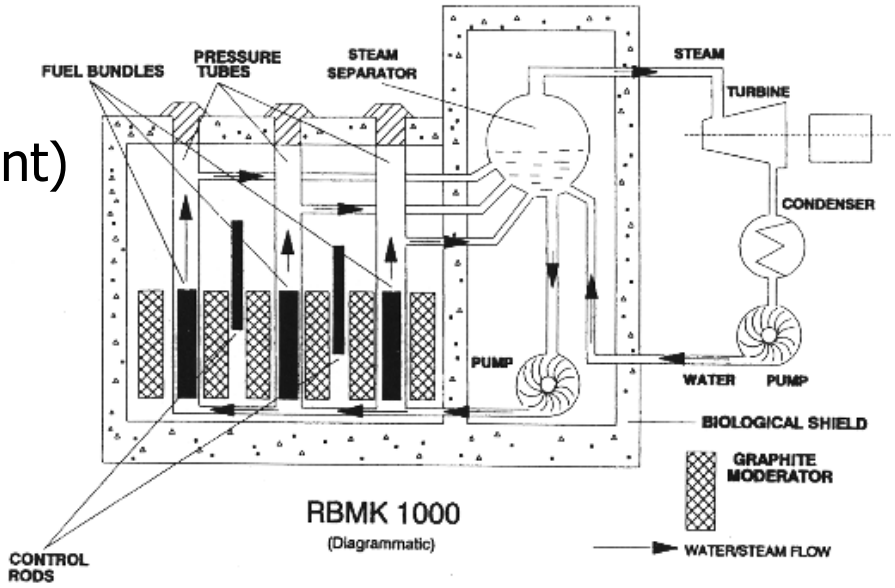


Chernobyl Disaster

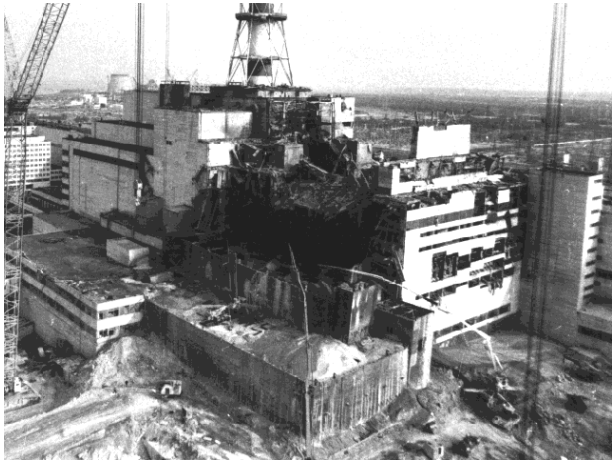
- Occurred on 26 April 1986 at the Chernobyl Nuclear Power Plant in the Ukrainian SSR.
- RBMK type of reactor, a type of BWR.

Causes:

- Flawed design (positive void coefficient)
- Violation of operating procedures, absence of a safety culture
- Reactor unstable at low power level
- Low speed control rods
- Flammable materials used in the reactor core
- No strong containment building.



Chernobyl Disaster



Results:

- Suffered a catastrophic power increase
- Causing (steam) explosions in its core
- Dispersed large quantities of radioactive fuel and core materials into the atmosphere
- Ignited the combustible graphite moderator
- 65 people killed; 31 of them died within weeks
- 200-300 staff and fire-fighters suffered from radiation sickness
- Around 130,000 received high dose of radiation
- Around 4000 cases of thyroid cancer
- Around 330,000 evacuated

Fukushima I Accident

Six BWR units at the Fukushima Nuclear Station:

- Unit 1: 460 MWe BWR, 1971 (operation prior to event)
- Unit 2: 784 MWe BWR, 1974 (operation prior to event)
- Unit 3: 784 MWe BWR, 1976 (operation prior to event)
- Unit 4: 784 MWe BWR, 1978 (outage prior to event)
- Unit 5: 784 MWe BWR, 1978 (outage prior to event)
- Unit 6: 1100 MWe BWR, 1979 (outage prior to event)

Fukushima I Accident

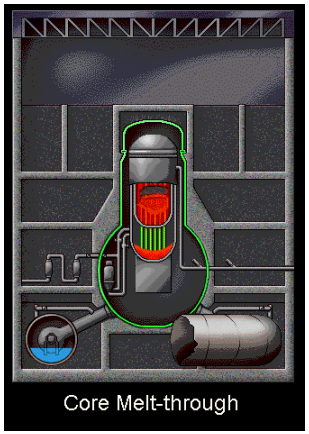
Causes:

- Richter Scale 9 earthquake on 11 March 2011.
- Followed by a huge tsunami.
- Nuclear reactors were shutdown automatically.
- Loss of offsite power
- Emergency diesel generators not working after the Tsunami

Core Damaged but retained in vessel

Results:

- Loss of effective cooling to the reactor and spent fuel.
- Hydrogen was produced which causes explosion.
- Reactor core was partially damaged.
- Release radioactive materials to the environment.

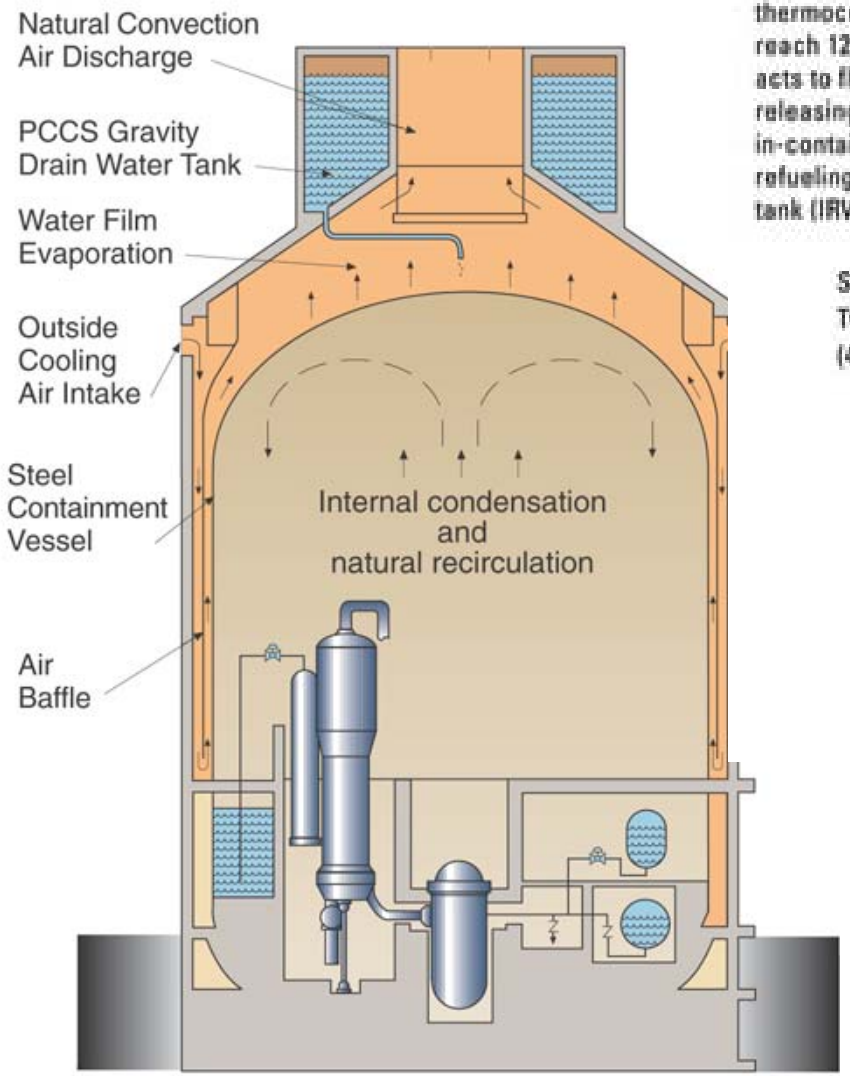


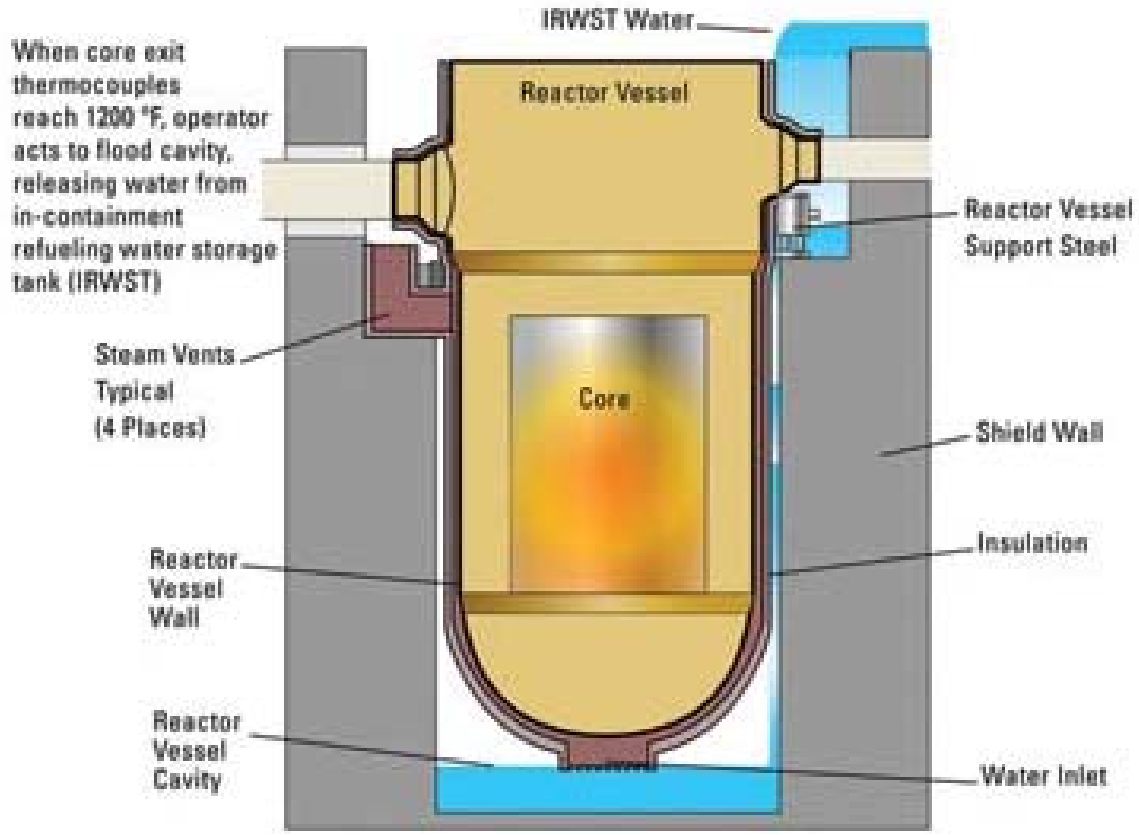
Some portions of core melt into lower RPV

Responses triggered by Fukushima

- On 6 May, 2011, Prime Minister Naoto Kan requested the Hamaoka Nuclear Power Plant (浜岡原子力発電所) be shut down
  - An earthquake of magnitude 8.0 or higher is estimated 87% likely to hit the area within the next 30 years.
  - The power station has 5 units of BWR and ABWR came on line between 1976 to 2005. (Unit 1 and 2 were permanently shutdown in 2009.)
- Germany will shutdown all of its nuclear power plants by 2022
  - 7 oldest reactors offline for safety review will not used again.
  - Another one plagued by technical problems will be shut down.
  - 6 others will go offline by 2021 at the latest
  - 3 newest will go offline by 2022
- China suspended all new nuclear plants, ordered safety review
- India ordered safety review of its 20 nuclear power reactors

Generation III
Advanced LWR: AP-1000





- Passive safety systems
- Redundancy
- Stronger containment

Can Nuclear Power Be Safe?

How can the industry regain public trust on nuclear reactor safety?

- Sufficient defence-in-depth is essential
  - Newer designs have advanced safety features
  - What about the aging reactors, particularly in a "Station Blackout" event?
- Safety culture is essential
  - Human error is often the cause of serious accident
- Not a local issue - International collaboration is essential
  - Stronger international effort is needed to ensure safety and compliance
  - International emergency recovery fund to support control and mitigation of nuclear accidents, including safety improvement
- Emergency preparedness
  - Efficient response system including proven emergency plans
- Effective information dissemination and communication
  - HKSAR expert to stay in the nuclear power stations in Mainland
  - Online access of radiation monitoring in Mainland

Sources / Related Links

- World Nuclear Association, http://www.world-nuclear.org/
- Nuclear Energy Institute, http://www.nei.org/
- U.S. Nuclear Regulatory Commission, http://www.nrc.gov/
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- World Health Organization 2006