World Nuclear Power Generation and Capacity

Lecture 26

June 4, 2012

Country	As of March 2012 Number of Nuclear Units	As of March 2012 Nuclear Capacity (MW)	2011 Nuclear Generation (BkWh)	2011 Nuclear Fuel Share (Percent)
Argentina	2	935	5.9	5.0
Armenia	1	375	2.4	33.2
Belgium	7	5,927	45.9	54.0
Brazil	2	1,884	15.6	3.2
Bulgaria	2	1,906	16.3	32.6
Canada	18	12,604	90.0	15.3
China	16	11,816	87.4	1.9
Czech RP	6	3,766	26.7	33.0
Finland	4	2,736	22.3	31.6
France	58	63,130	421.1	77.7
Germany	9	12,068	102.3	17.8
Hungary	4	1,889	14.7	43.3
India	20	4,391	28.9	3.7
Iran	1	915	0.1	0.0
Japan	50	44,215	156.2	18.1
Korea Rep.	23	20,671	147.7	34.6
Mexico	2	1,300	9.3	3.6
Netherlands	1	482	3.9	3.6
Pakistan	3	725	3.8	3.8
Romania	2	1,300	11.7	19.0
Russia	33	23,643	161.7	17.6
Slovakia	4	1,816	14.3	54.0
Slovenia	1	688	5.9	41.7
South Africa	2	1,830	12.9	5.2
Spain	8	7,567	55.1	19.5
Sweden	10	9,326	58.0	39.6
Switzerland	5	3,263	25.7	40.9
Taiwan, China	6	5,018	40.5	19.0
U.K.	17	9,703	56.4	15.7
U.S.*	104	101,465	790.2	19.3
Ukraine	15	13,107	84.8	47.2
Total	436	370,461	2,518.1	

* IAEA and EIA nuclear capacity figures vary slightly.

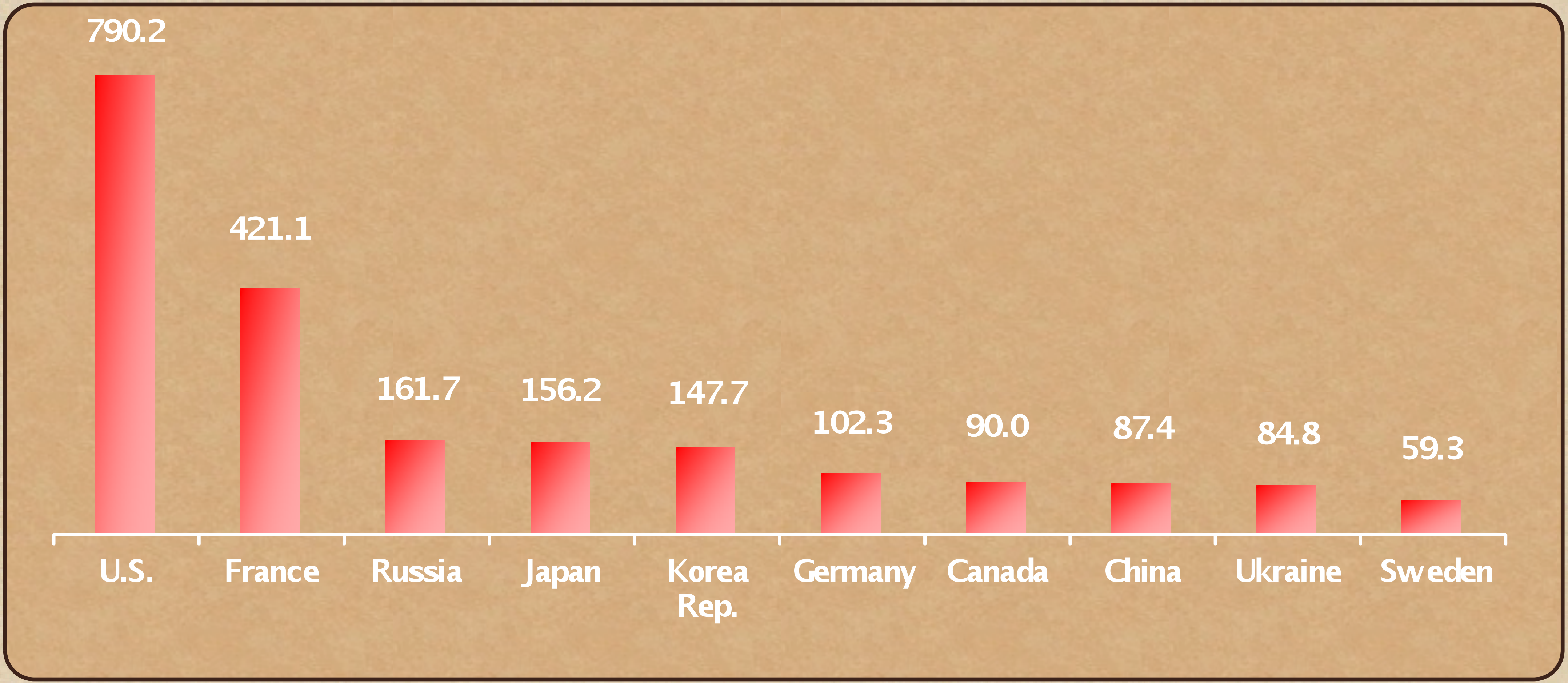
Source: International Atomic Energy Agency
http://www.iaea.org/programmes/a2/index.html

France	77.7
Slovakia	54
Belgium	54
Ukraine	47.2
Hungary	43.3
Slovenia	41.7
Switzerland	40.9
Sweden	39.6
Korean Rep	34.6
Armenia	33.2
Czech Rep	33
Bulgaria	32.6
Finland	31.6

Nuclear power plants provided 13.5 percent of the world's electricity production in 2010. In total, 13 countries relied on nuclear energy to supply at least one-quarter of their total electricity. Countries generating the largest percentage of their electricity in 2011 from nuclear energy were:

Top 10 Nuclear Generating Countries

2011, Billion kWh



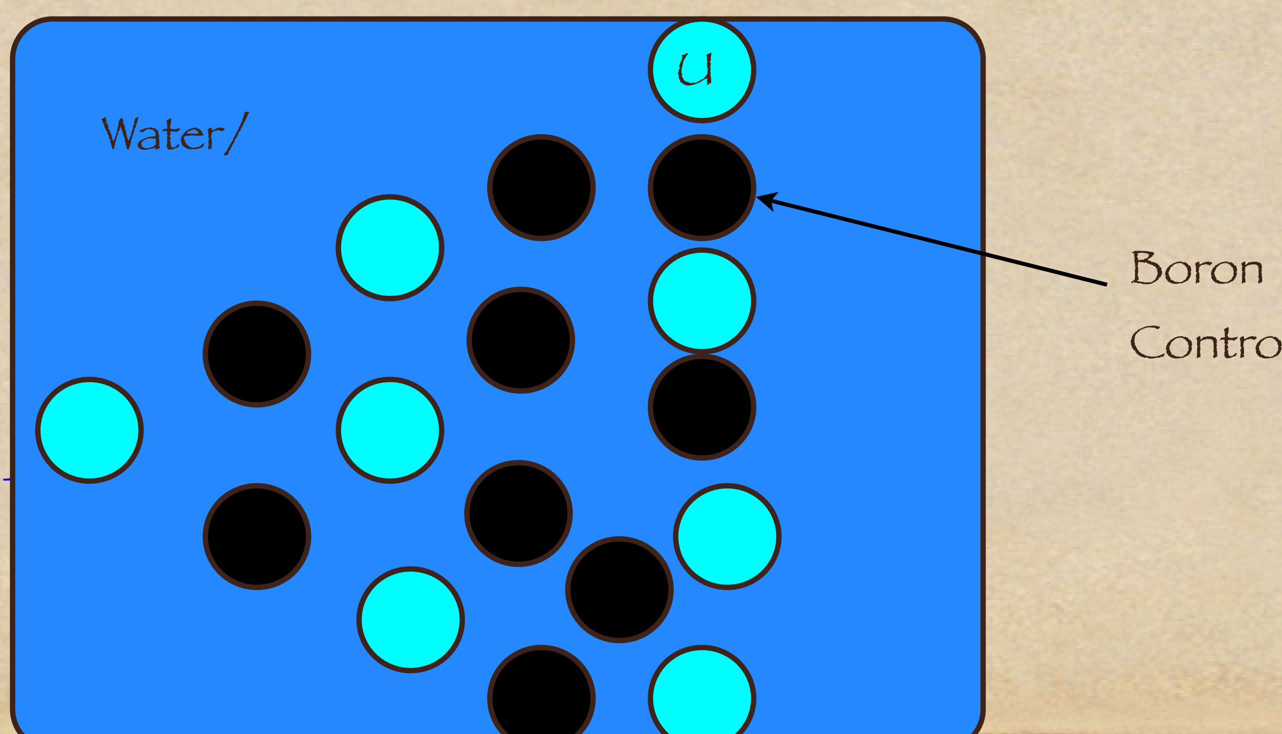
Criticality:

Need a certain amount of ^{235}U to sustain a chain reaction.

$$^{235}_{92}U + n \rightarrow ^{236}_{92} U$$

$$^{236}_{92}U \rightarrow ^{90}_{36} Kr + ^{143}_{56} Ba + 3n$$
$$+199\ Mev$$

$n + ^{239}_{94}$



In breeder tech reactors we also get into

$$n + ^{238} U \rightarrow ^{239} U$$

$$^{239}_{92}U + n \rightarrow ^{239}_{94} Pu + \text{stuff}$$

Boiling water reactor

BWR

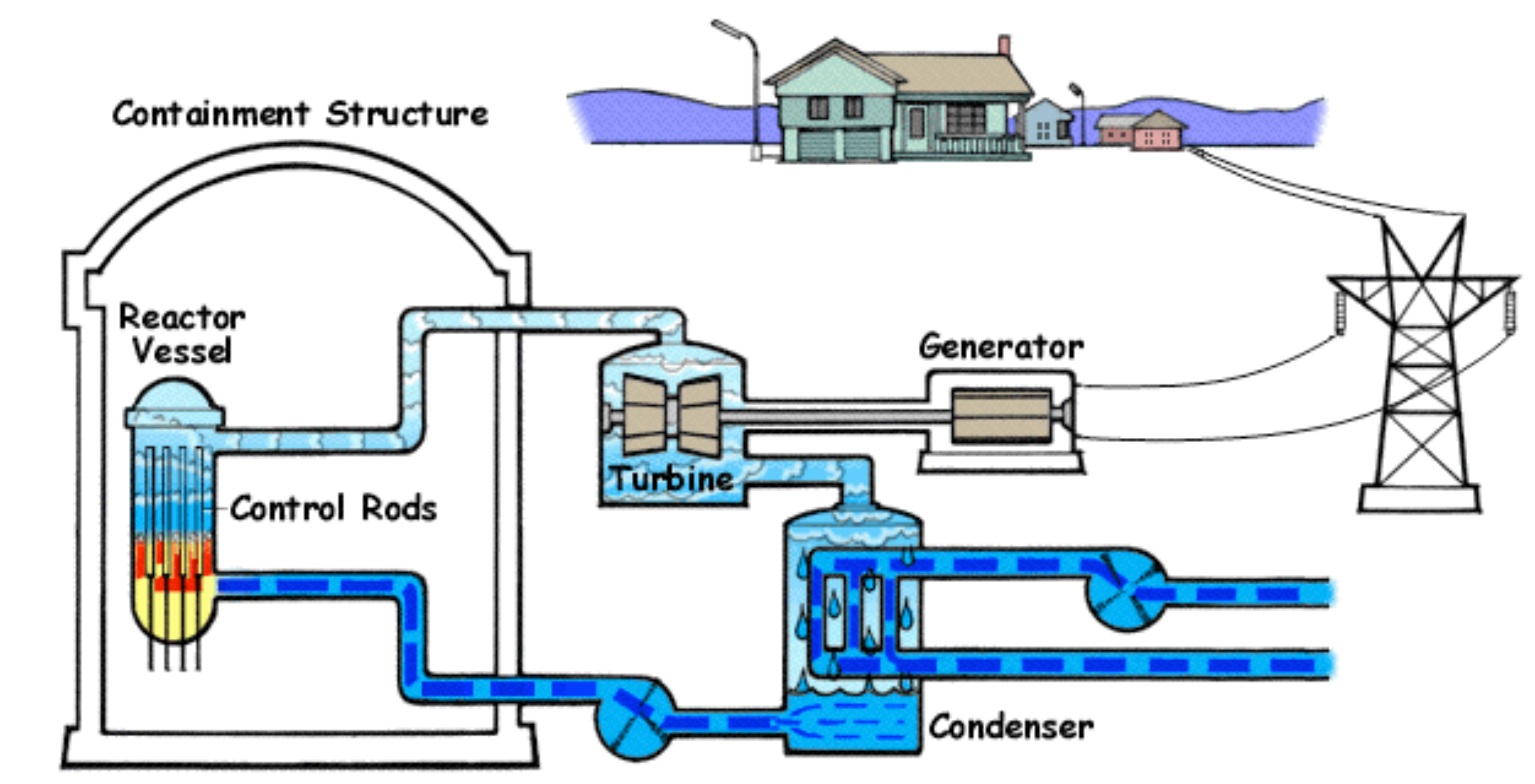
versus

Pressurized Water Reactor

PWR (submarines)

In PWR's water is pressurized to prevent it from boiling. Water gets superhot and outside the reactor, it heats up and boils unpressurized water. Pipes needed to carry this high pressure water around.

Boiling water reactor



Efficiency 34%
Power 1220 MW
342 tons /year
UO_2

The **Fukushima Daiichi nuclear disaster** is a series of fires, equipment failures and releases of radioactive materials at the Fukushima I Nuclear Power Plant, following the 9.0 magnitude Tōhoku earthquake and tsunami on 11 March 2011. The plant comprises six separate boiling water reactors maintained by the Tokyo Electric Power Company (TEPCO).

At the time of the quake, reactor 4 had been de-fueled while 5 and 6 were in cold shutdown for planned maintenance. The remaining reactors shut down automatically after the earthquake, with emergency generators starting up to run the control electronics and water pumps needed to cool reactors. The plant was protected by a seawall designed to withstand a 5.7 m (19 ft) tsunami but not the 14 m (46 ft) maximum wave which arrived 41–60 minutes after the earthquake. The entire plant was flooded, including low-lying generators and electrical switchgear in reactor basements and external pumps for supplying cooling seawater. The connection to the electrical grid was broken. All power for cooling was lost and reactors started to overheat, owing to natural decay of the fission products created before shutdown. The flooding and earthquake damage hindered external assistance.

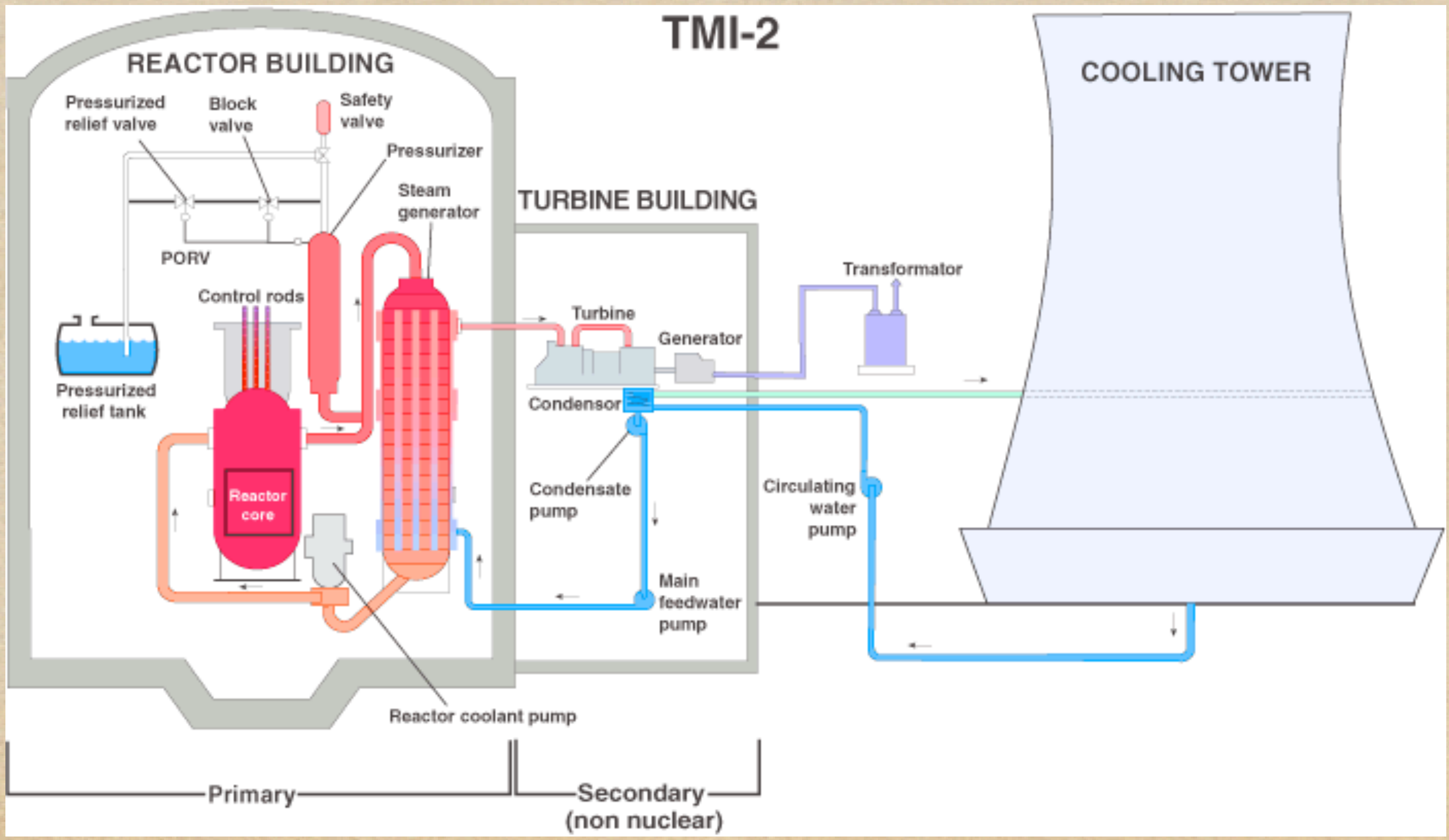
Evidence soon arose of partial core meltdown in reactors 1, 2, and 3; hydrogen explosions destroyed the upper cladding of the buildings housing reactors 1, 3, and 4; an explosion damaged the containment inside reactor 2; multiple fires broke out at reactor 4. Despite being initially shutdown, reactors 5 and 6 began to overheat. Fuel rods stored in pools in each reactor building began to overheat as water levels in the pools dropped. Fears of radiation leaks led to a 20 km (12 mi) radius evacuation around the plant while workers suffered radiation exposure and were temporarily evacuated at various times. One generator at unit 6 was restarted on 17 March allowing some cooling at units 5 and 6 which were least damaged. Grid power was restored to parts of the plant on 20 March, but machinery for reactors 1 through 4, damaged by floods, fires and explosions, remained inoperable. Flooding with radioactive water continues to prevent access to basement areas where repairs are needed. However, on 5 May, workers were able to enter reactor buildings for the first time since the accident.

Three Mile Island Accident

(*March 2001*, *minor update Jan 2012*)

- **In 1979 at Three Mile Island nuclear power plant in USA a cooling malfunction caused part of the core to melt in the # 2 reactor. The TMI-2 reactor was destroyed.**
- **Some radioactive gas was released a couple of days after the accident, but not enough to cause any dose above background levels to local residents.**
- **There were no injuries or adverse health effects from the Three Mile Island accident.**

The Three Mile Island power station is near Harrisburg, Pennsylvania in USA. It had two pressurized water reactors. One PWR was of 800 MWe (775 MWe net) and entered service in 1974. It remains one of the best-performing units in USA. Unit 2 was of 906 MWe (880 MWe net) and almost brand new.



The accident to unit 2 happened at 4 am on 28 March 1979 when the reactor was operating at 97% power. It involved a relatively minor malfunction in the secondary cooling circuit which caused the temperature in the primary coolant to rise. This in turn caused the reactor to shut down automatically. Shut down took about one second. At this point a relief valve failed to close, but instrumentation did not reveal the fact, and so much of the primary coolant drained away that the residual decay heat in the reactor core was not removed. The core suffered severe damage as a result.

The operators were unable to diagnose or respond properly to the unplanned automatic shutdown of the reactor. Deficient control room instrumentation and inadequate emergency response training proved to be root causes of the accident

What Happened:

- After shutting down the fission reaction, the TMI-2 reactor's fuel core became uncovered and more than one third of the fuel melted.
- Inadequate instrumentation and training programs at the time hampered operators' ability to respond to the accident.
- The accident was accompanied by communications problems that led to conflicting information available to the public, contributing to the public's fears
- A small amount of radiation was released from the plant. The releases were not serious and were not health hazards. This was confirmed by thousands of environmental and other samples and measurements taken during the accident.
- The containment building worked as designed. Despite melting of about one-third of the fuel core, the reactor vessel itself maintained its integrity and contained the damaged fuel.

Longer-Term Impacts:

- Applying the accident's lessons produced important, continuing improvement in the performance of all nuclear power plants.
- The accident fostered better understanding of fuel melting, including improbability of a "China Syndrome" meltdown breaching the reactor vessel and the containment structure.
- Public confidence in nuclear energy, particularly in USA, declined sharply following the Three Mile Island accident. It was a major cause of the decline in nuclear construction through the 1980s and 1990s.

Welcome
Professor David Dorfan
Ex Chair, Physics UCSC,
Was a Member of
the 3 mile island accident review committee (DOE)