CHERNOBYL AND BEYOND;

Nuclear Power Renaissance and Apprehensions

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SYNOPSIS

- INTRDOUCTION TO NUCLEAR REACTORS
- CHERNOBYL ACCIDENT
- TMI AND THE RESULTING ADVANCEMENTS IN REACTOR TECHNOLOGY
- FUKUSHIMA NUCLEAR DISASTER
- FUTURE OF NUCLEAR POWER IN PAKISTAN AND THE WORLD

NUCLEAR POWER REACTORS

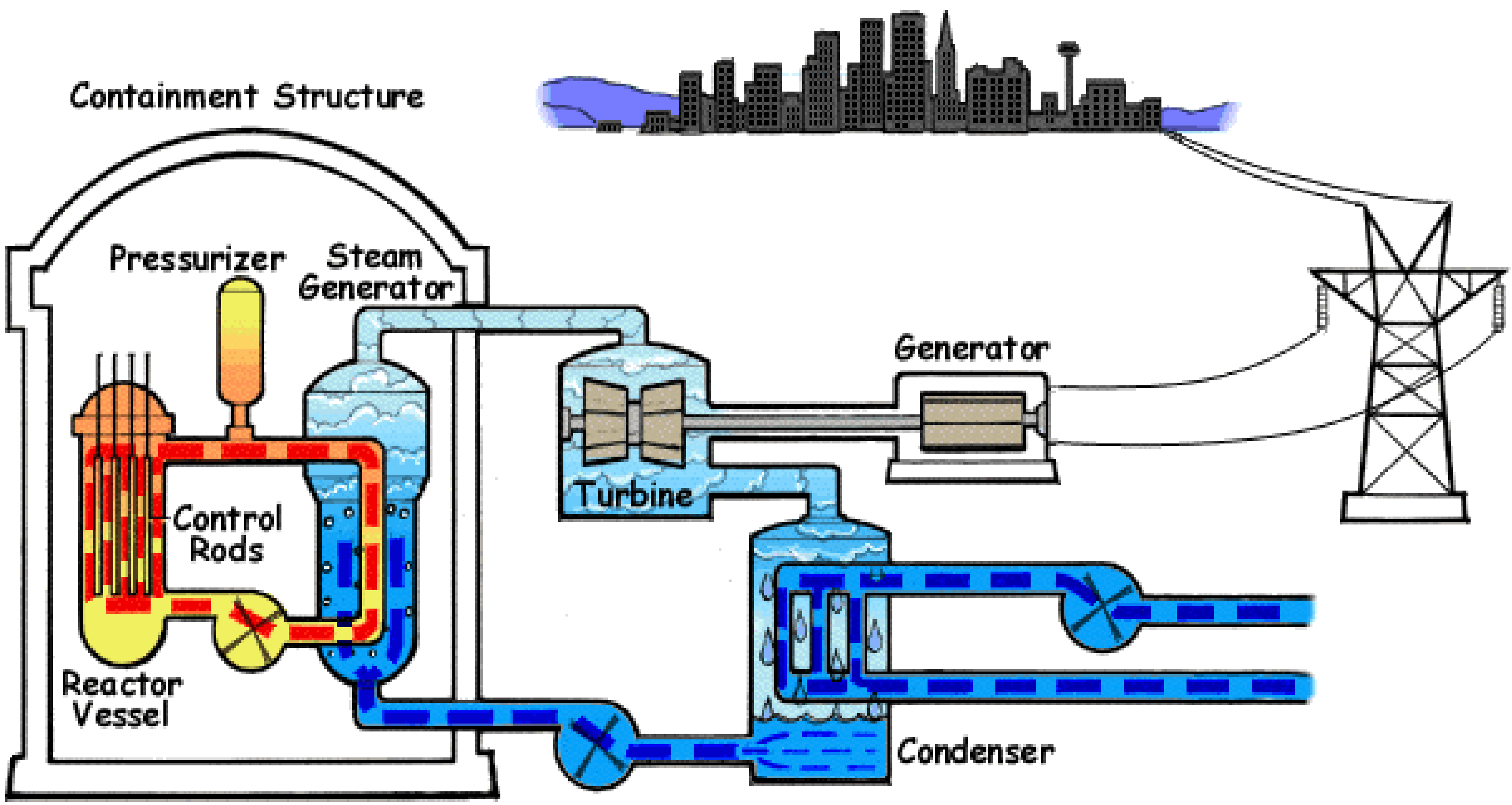
- UTILIZE FISSION PROCESS
- COMPRISES OF A CORE, MODERATOR, AND COOLANT
- MAJOR COMPONENTS INCLUDE:
  - REACTOR PRESSURE VESSEL (RPV)
  - PRESSURIZER
  - REACTOR COOLANT PUMPS
  - STEAM GENERATOR (PWR AND CANDU)
  - CONTAINMENT
- SAFETY IS BASED ON DEFENCE-IN-DEPTH CONCEPT

NUCLEAR POWER REACTORS

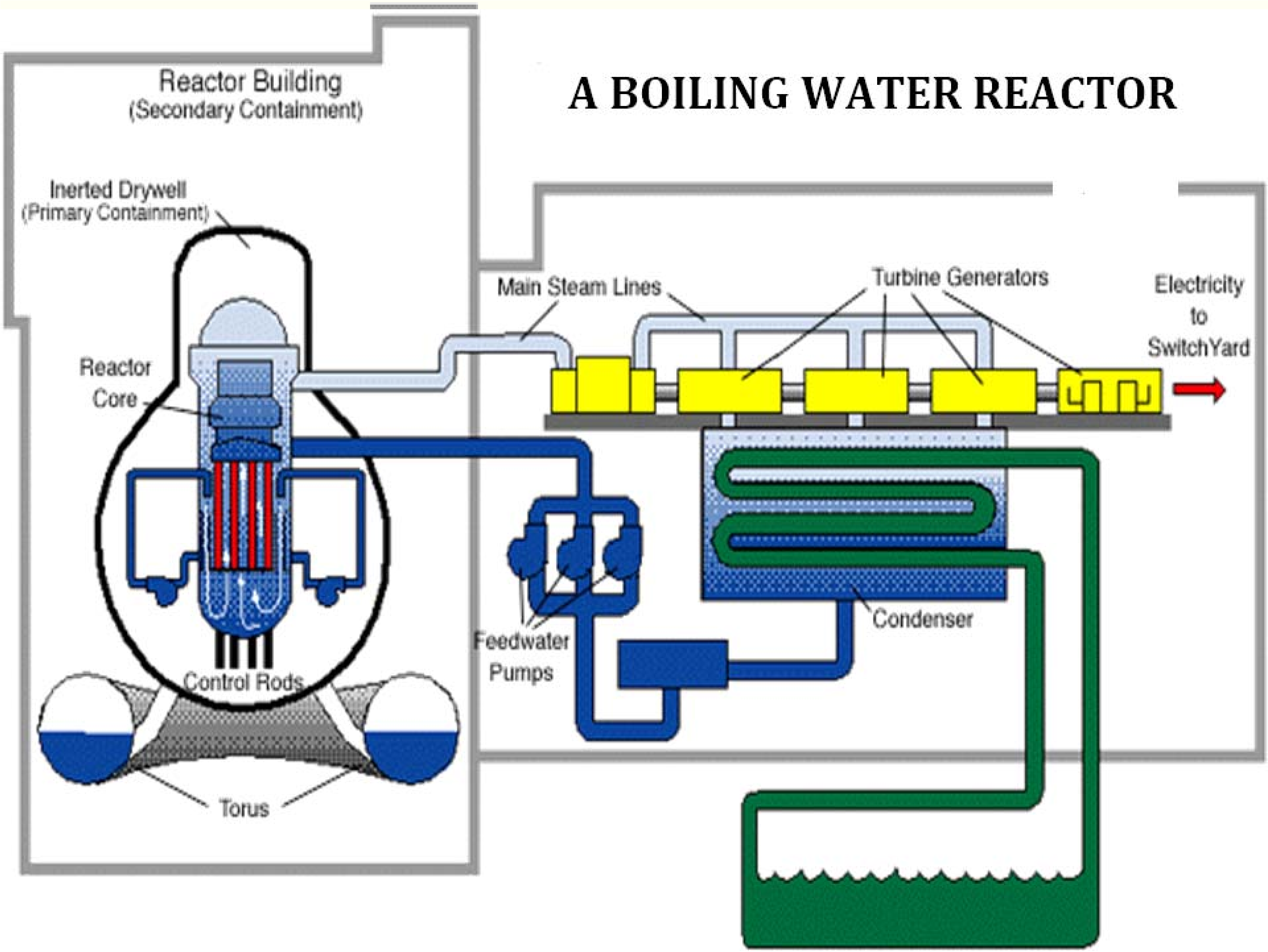
440 NPPs OERATING IN THE WORLD

- PRESSURIZED WATER REACTORS (265- *Majority operate in US, France , RF, China and Korea*)
- BOILING WATER REACTORS (94- *mainly operated in US, Japan and Sweden*)
- CANDU REACTORS (44- *Canada, India and Korea*)

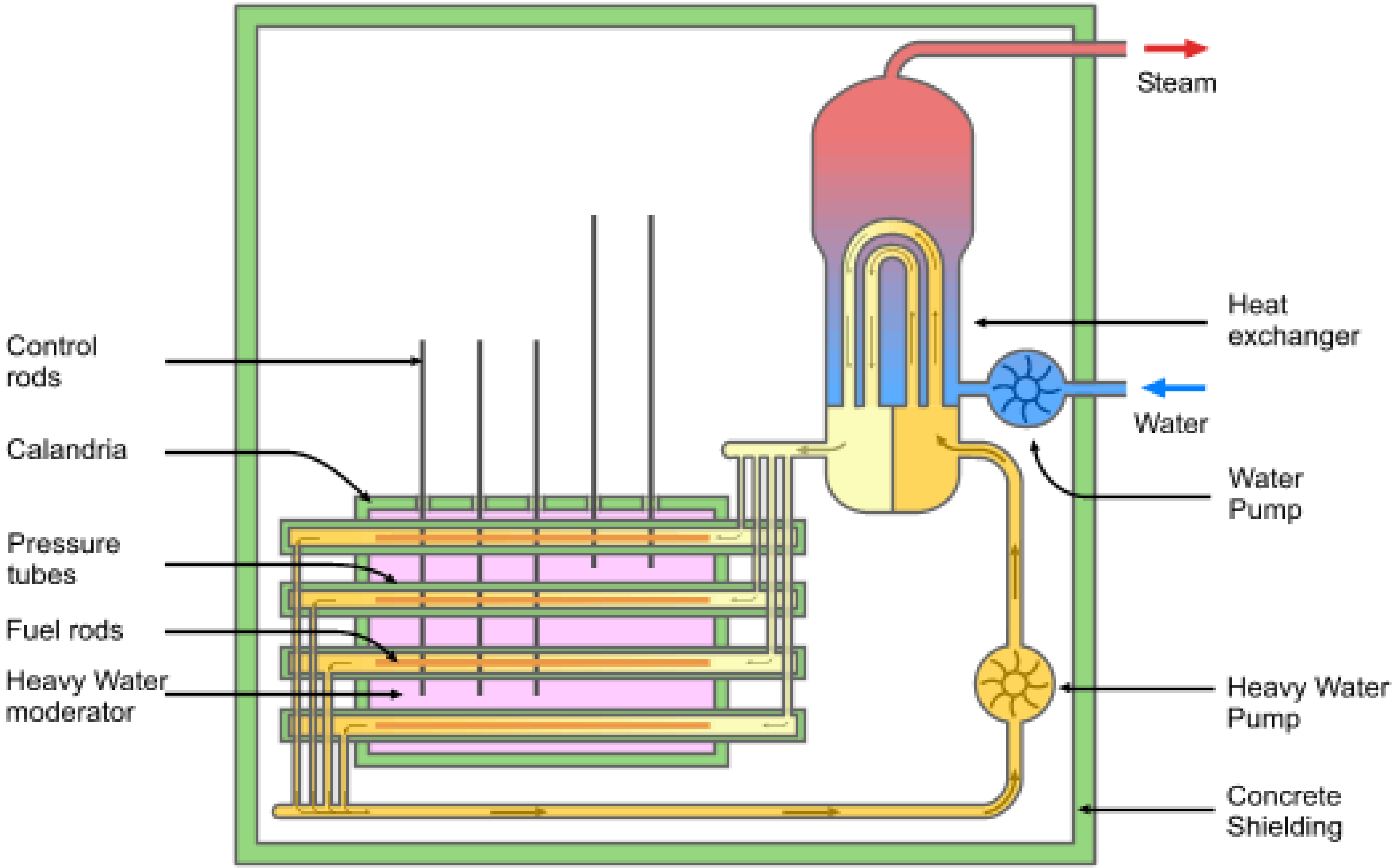
PRESSURIZED WATER REACTOR



A BOILING WATER REACTOR



CANDU REACTOR



A NUCLEAR POWER COMPLEX

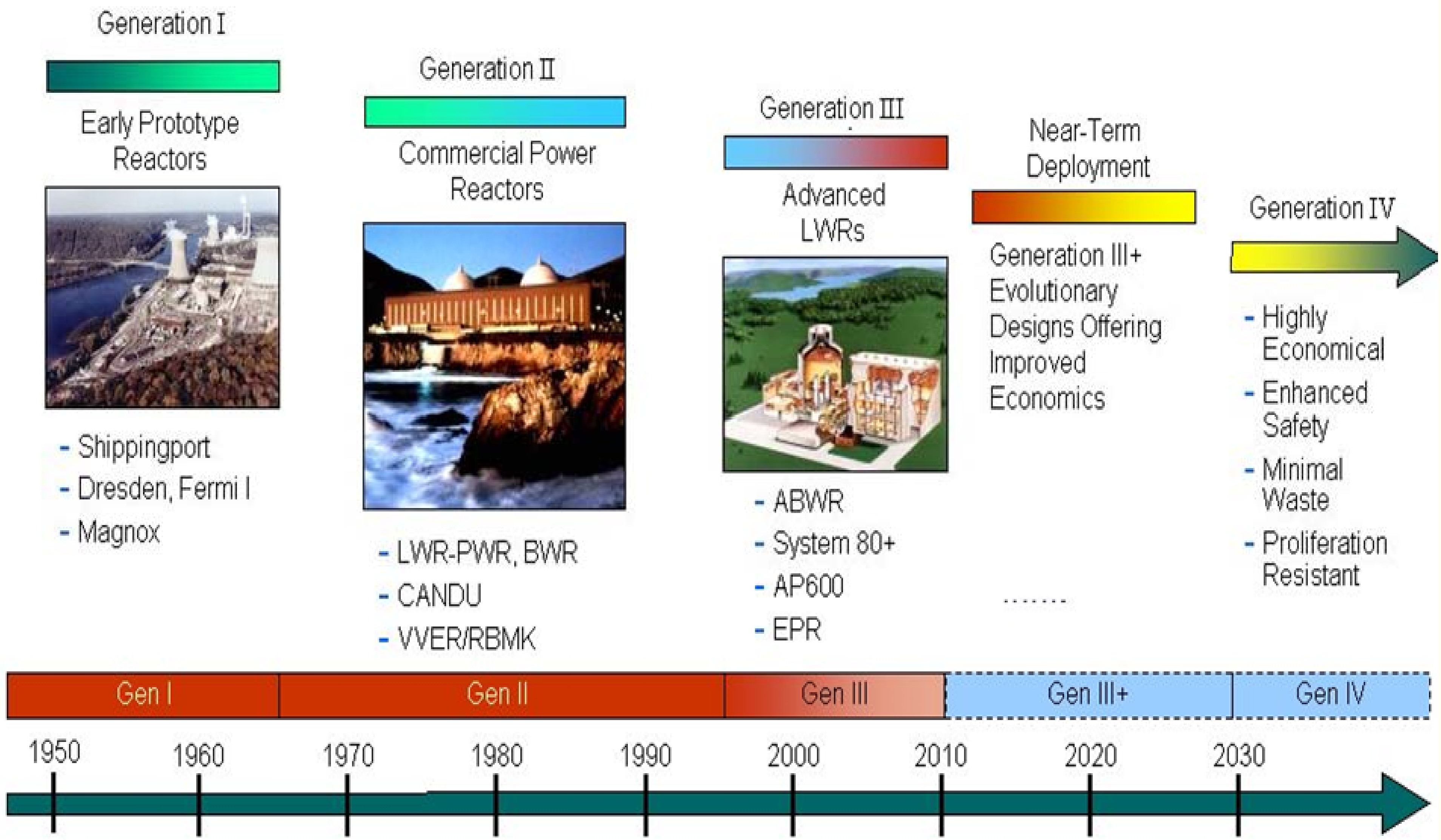
ADVANCED REACTORS

MAIN FEATURES:

- IMPROVED FUEL TECHNOLOGY
- SUPERIOR THERMAL EFFICIENCY
- USE OF PASSIVE SAFETY SYSTEMS
- STANDARDIZED DESIGN
- IMPROVED AUTOMATION
- LONGER DESIGN LIFE

e.g. APR, ABWR, AP-1000, ACR, VVER-1200, EPR etc.

ADVANCEMENT IN TECHNOLOGY



CHERNOBYL DISASTER
(April, 1986)

SEQUENCE OF EVENTS

- The RBMK-1000 is a Soviet-designed graphite moderated light water cooled pressure tube type reactor
- Accident occurred during simulation of a loss of power test
- A series of operator actions caused a dramatic power surge
- Interaction of very hot fuel with coolant led to fuel fragmentation and rapid steam production
- Intense steam generation caused a steam explosion releasing fission products to the atmosphere.
- a second explosion possibly due to hydrogen from zirconium-steam reaction threw out fragments from the fuel channels and hot graphite.

ACCIDENT CONSEQUENCES

- The accident caused the largest uncontrolled radioactive release into the environment ever recorded
- 30 operators and firemen killed within three months and several further deaths later due to acute radiation dose.
- 4000 cases of thyroid cancer in children (nine were fatal)
- About 130,000 people received significant radiation doses
- Widespread contamination which extended to several neighboring countries e.g. Sweden and Finland
- The accident was rated at level-7, on the IAEA International Nuclear Event Scale (INES)

LESSONS LEARNED

- Main causes of Chernobyl :
  - *No robust containment*
  - *a very high positive void coefficient*
  - *violation of operating procedures and poor safety culture*
  - *Inadequate operator training*
- The accident lead to a large scale improvements in the safety of Soviet designed reactors especially RBMK
  - *Improved control rod design and increase in number of absorbers*
  - *Reduction in positive void coefficient*
  - *Reduction in control rod drop time*

FOLLOW UP OF CHERNOBYL

- ADOPTION OF IAEA CONVENTIONS ON:
  - EARLY NOTIFICATION OF NUCLEAR ACCIDENT
    - to facilitate prompt assistance and requires States to notify the IAEA of their available experts, equipment, and other materials
  - CONVENTION ON ASSISTANCE IN THE CASE OF A NUCLEAR ACCIDENT OR RADIOLOGICAL EMERGENCY
    - establishes a formal notification system for nuclear accidents and requires States to report the accident's time, location, radiation releases, and other data essential for assessing the situation.

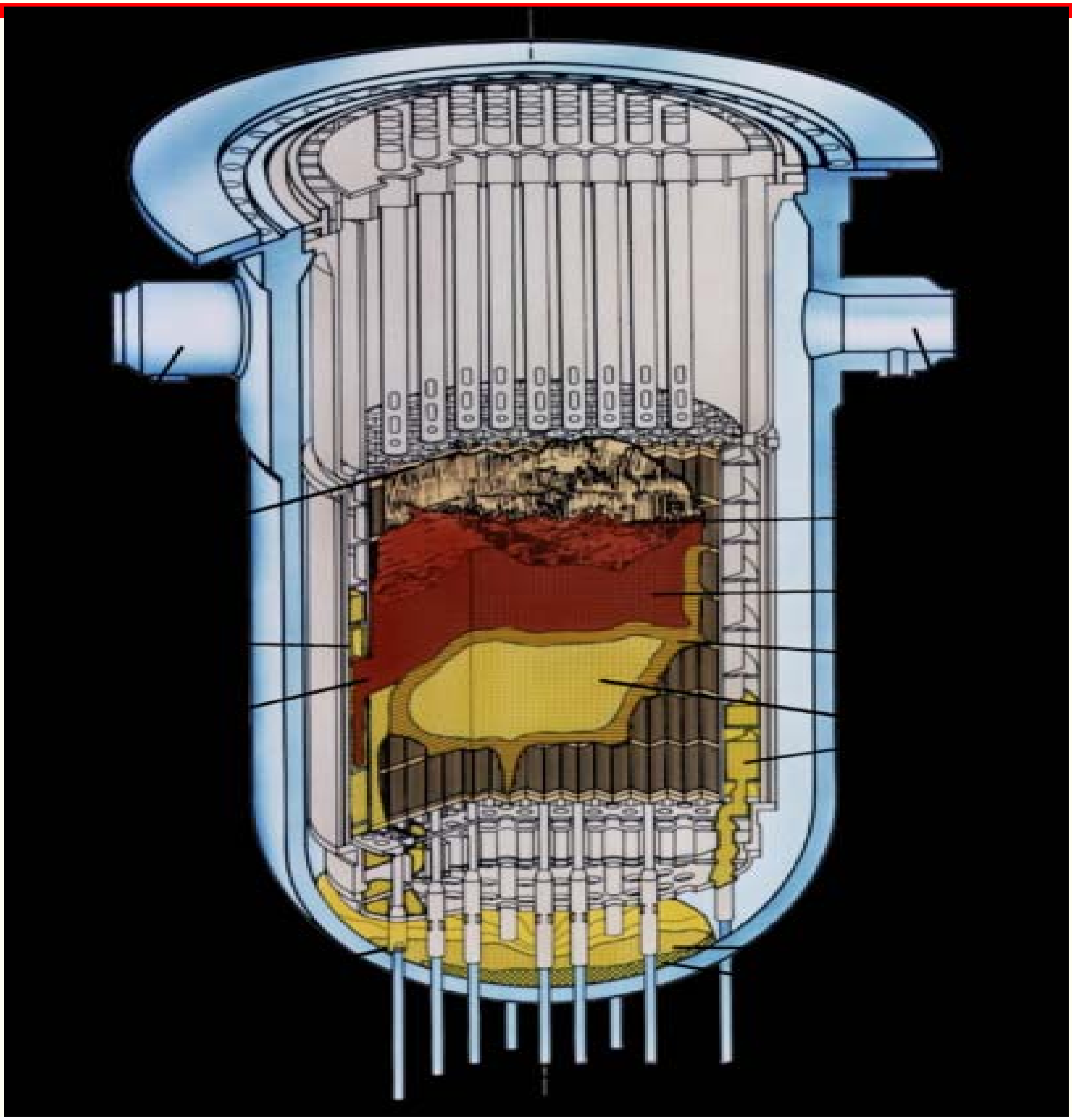
TMI (1979) SEQUENCE OF EVENTS

- 800 MWe PWR designed by Babcock and Wilcox of USA
- Plants of this type and design had a proven safety record
- Loss of feedwater followed by reactor shutdown
- Inadequate decay heat removal due to coincident failure of auxiliary feedwater
- Stuck open relief valve which remained unnoticed causing a loss of coolant accident
- No dedicated instrument to measure core water level
- Operator misjudged the Pressurizer water level

SEQUENCE OF EVENTS

- Manual blocking of the ECCS actuation
- Loss of primary coolant flow due to pump cavitation
- Steam formation in the core inhibited natural circulation
- Boiling of water lead to core uncovery
- Zirconium (cladding) reacted with water to form hydrogen
- High core temperature lead to core meltdown
- Containment remained intact
- Radioactivity released into the environment due to release of primary coolant into auxiliary building

MOLTEN REACTOR CORE OF TMI



LESSONS LEARNED FROM TMI

- Accident rated at level-5 on the INES
- lesson learned resulted in provisions for:
  - vents at the top of reactor pressure vessel
  - dedicated core water level measurement
  - improvement in man-machine interface
  - improved operator training

AFTERMATH OF TMI

- Safety research initiated which resulted in development of new regulatory requirements
- Concept of Beyond DBAs including Severe Accidents
- Traditional deterministic approach is complemented by probabilistic approach
- Several safety features proposed to cope with severe accidents including:
  - passive autocatalytic recombiners
  - cavity flooding system
  - pilot operated relief valves
  - double containment in European reactors

FUKUSHIMA DISASTER (MARCH 11, 2011)

- Earthquake caused automatic reactor trip
- Loss of external power and startup of emergency diesel generators
- Failure of emergency diesel generators within 1hr due to tsunami flooding
- Complete loss of off-site and on-site electrical power (station blackout) rendering all the cooling sources unavailable
- Batteries remained available for 08 hrs
- Heat-up of core due to loss of cooling - system pressure increased

SEQUENCE OF EVENTS

- Core uncovered and heat-up of fuel and cladding
- Metal water reaction resulting in hydrogen production
- AC power temporarily restored by portable diesel generators
- pressure in the containment drywell rose as wet well became very hot
- Drywell containment was vented to surrounding reactor building
- Hydrogen explosions destroyed the reactor buildings of Unit 1 and 3
- Spent fuel pool of unit 2 caught fire and reactor building damaged

CONSQUENCES OF FUKUSHIMA

- 70 % of fuel in reactor core of Unit-1, 30 % of unit-ii and 25 % of unit-iii is suspected to be damaged
- Structural integrity of RPV in Units 1, 2 and 3 is still unknown
- Unit-3 primary containment integrity is suspected to be damaged
- Release of substantial amount of radioactivity into the environment
- INES rating initially fixed at level-4 was later enhanced to level-5
- Was further elevated to level-7 on April 12, 2011

FOLLOWUP OF FUKUSHIMA

- WENRA PROPOSED TO PERFORM RE-ASSESSMENTS OF THE FOLLOWING:
  - Extreme natural events exceeding the design basis such as earthquakes, flooding and other external conditions
  - Prolonged complete loss of electrical power and ultimate heat sink.
  - Accident management strategies to prevent and mitigate severe core damage and consequential hydrogen buildup.
  - Degraded conditions in the spent fuel storage.
  - Possibility of several units being affected at the same time.

FUTURE OF NUCLEAR POWER

- A number of countries are striving to develop nuclear power program, with Pakistan among them
- large scale development in existing infra structure in countries like India and China
- Several countries like UAE, Turkey, Egypt, and Vietnam have expressed a desire to embark on nuclear power generation.
- Pakistan's current electricity mix is dominated by natural gas, hydro, and oil/diesel generation
- Pakistan's current electricity generation capacity does not meet the demand creating significant shortfalls
- Government of Pakistan envisions increase in existing nuclear generation capacity upto 8,800 MW by 2030.

CONCLUSION

- Fukushima accident was an extraordinary event
- Event will certainly change the world's perception about nuclear power
- World is carbon constrained and energy hungry
- Nuclear power should continue to play a vital role as a safer and cleaner source of energy generation
- Thorough re-assessments of operating nuclear power plants is necessary to regain public confidence

THANK YOU FOR YOUR ATTENTION