Seminar on
Nuclear Energy in Bangladesh

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Key Technical and Institutional Considerations for Rooppur: 3S, Grid, Waste, Economics, and HRD Challenges

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Brief Introduction about the Speaker

- Graduated from BUET in Mechanical Engineering in 1995, Completed Mater's and PhD in thermalhydraulic safety of a nuclear reactor from Saga University, Japan in 1997 and 2002 respectively.
- Working as a Professor, Dept. of Nuclear Engineering, University of Dhaka.
- Working as Point of Contact (PoC) since 2015, International Nuclear Security Education Network (INSEN), IAEA, Vienna, Austria.
- Awardee of a Senior Fulbright Visiting Scholar
- Worked as Visiting Professor, Nuclear Science and Engg., MIT, USA.
- Worked as Chairman (2017-2019), Dept. of Nuclear Engineering, University of Dhaka.
- Worked as Director at Bangladesh Atomic Energy Commission (BAEC).
- Worked as INSEN WG I chair, International Atomic Energy Agency (IAEA), Vienna, Austria
- Worked as an Expert Member of different national committees for the country's first under-construction Rooppur NPP project.
- Worked as an IAEA expert to deliver lectures on Nuclear Security Culture (NSC) in national workshops held in different countries organized by the IAEA.
- Worked as Chief Scientific Investigator (CSI) of the IAEA funded Coordinated Research Project (CRP) on Assessment of Nuclear Security Culture at a Public and a Private Medical Hospital of Bangladesh.
- Worked as National Counterpart under the Forum for Nuclear Cooperation for Asia Pacific (FNCA) Project on Nuclear Security and Safeguards from 2011 to Mid-August 2014.
- Worked on the GTRI (Global threat reduction initiatives) project funded by the DOE, USA.
- Published 2 Books, 1 Book Chapter, ≈55 Peer-reviewed Journal papers, 32 Int. conference papers, 3 Int. posters, 5 National conference papers in the field of nuclear safety, security, and energy.

Motivation of this presentation

The introduction of nuclear power marks a historic milestone for Bangladesh’s energy future. Understanding its technology, safety features, and long-term benefits is essential for building public confidence and ensuring the successful implementation of the national nuclear power program.

Presentation Outline

1. **Safety of the Gen-III+ VVER-1200 Reactor at Rooppur**

   (a) Reactor Technology

   (b) 3S Features
   - Safety Features
   - Security Features
   - Safeguards Features

   (c) Radiation Release
   - Severe Accident Conditions
   - Routine Operational Conditions

   (d) Grid Reliability

2. **Radioactive waste and spent fuel management**

3. **HRD challenges**

4. **Economic and Financial Implications**

5. **Conclusions and Recommendation**

19 infrastructure development issues

1(a) Reactor Technology

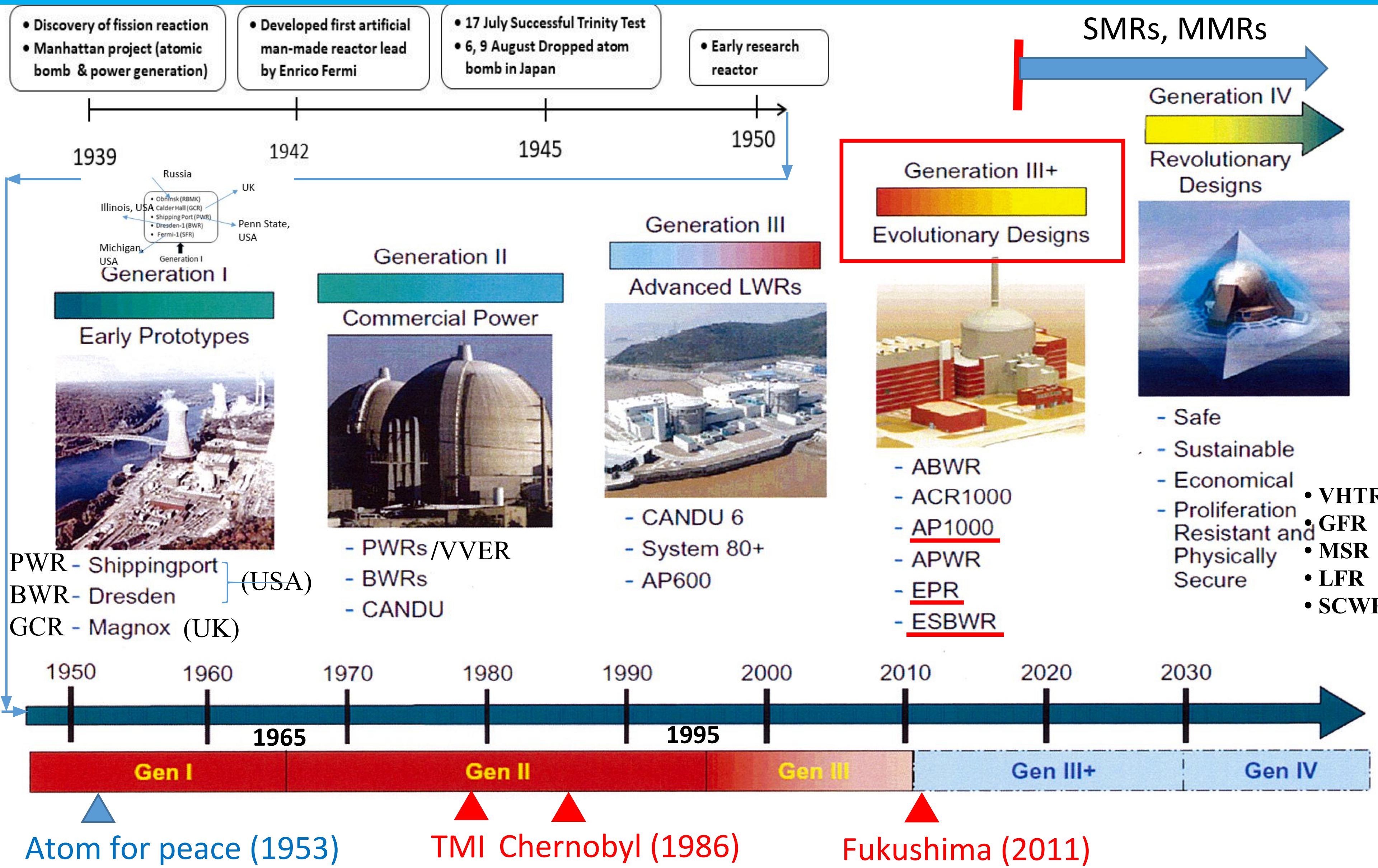


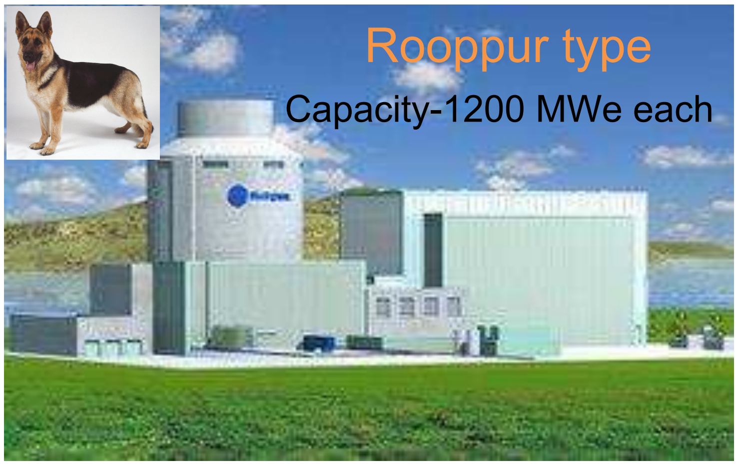
Fig.1: Evolution of Generation I-IV Reactors across the World

1(a) Reactor Technology…

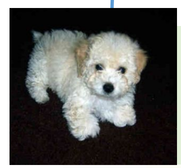
Generation II, III, and III+ reactors

Generation IV reactors

Large Reactors (LRs)



~1000-1600 MW_e
~\$3-10 Bn
5 -10 yrs

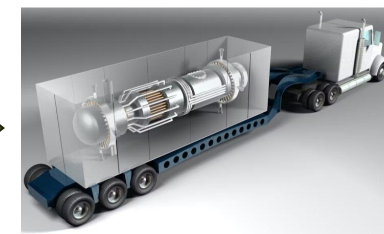


Small Modular Reactors (SMRs)

~70-300 MW_e
~\$1-3 Bn
3 - 5 yrs

Potential applications for replacing coal and gas-based plants

Micro Modular Reactors (MMRs)



~1-10 MW_e
<\$0.1Bn
<1 yr

Potential applications for data centers, military bases, coastal areas

Fig. 2: LRs, SMRs, MMRs.

1(a) Reactor Technology….

Gen IV multi purpose nuclear reactors

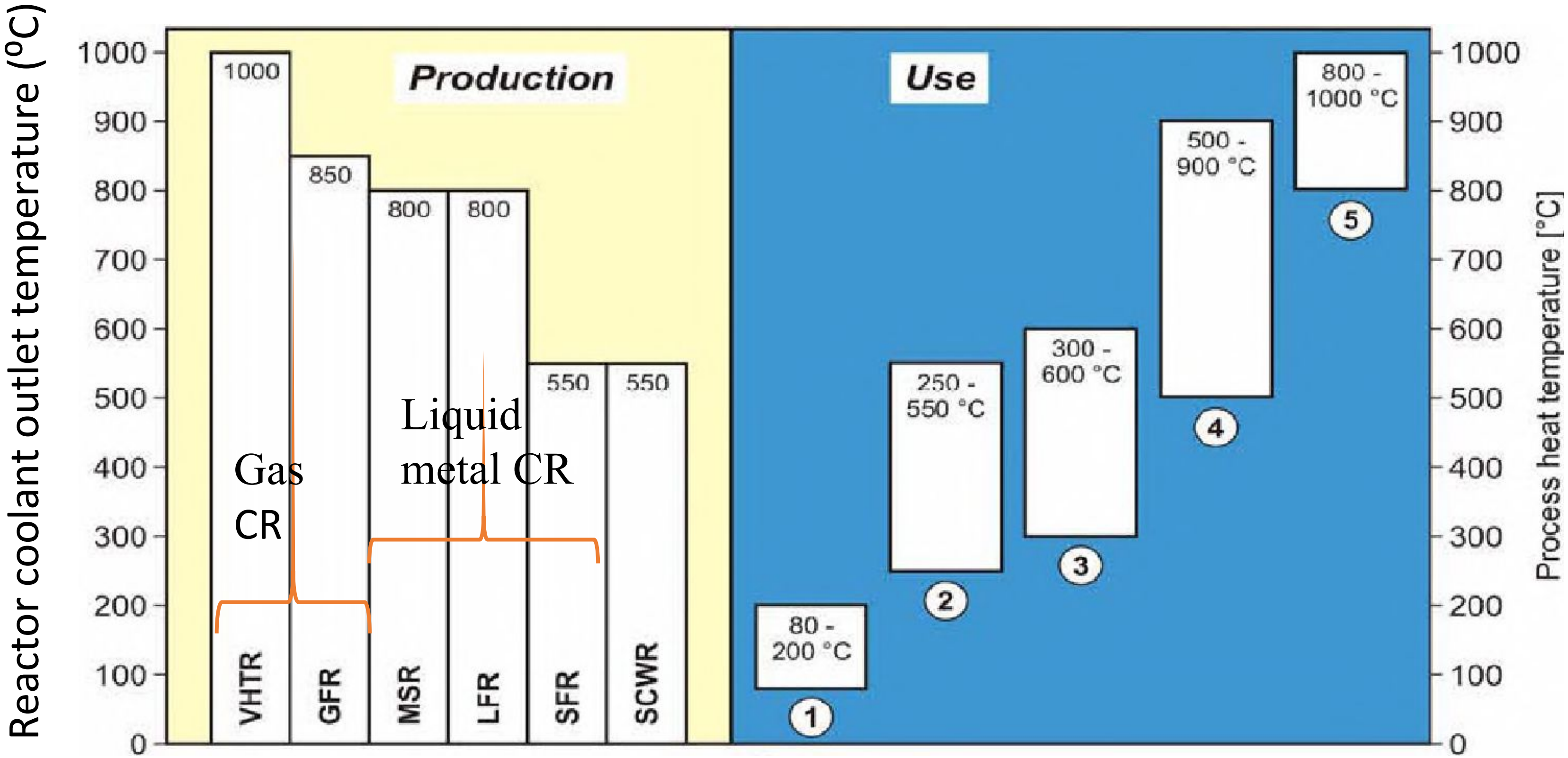


Fig.3: Gen IV reactors' outlet coolant temp.

Industrial process temperature range

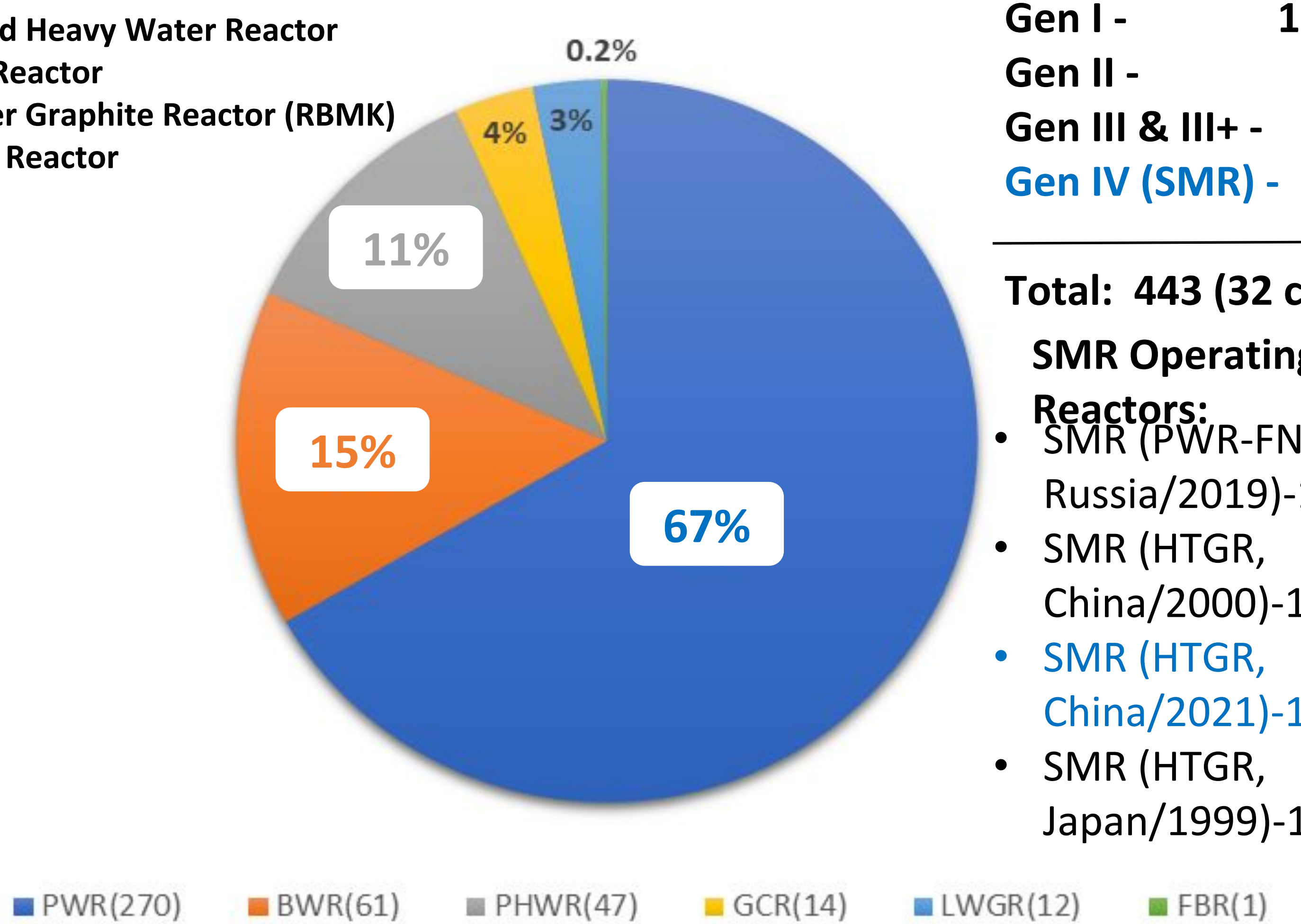
They can be used not only for electricity, but also for green hydrogen, drinking water, process heat, and process steam based on industry needs.

(1) District heating, Seawater desalination
(2) Petroleum refining
(3) Oil shale and oil sand processing
(4) Steam reforming of natural gas
(5) Gasification of hard coal and lignite, HI electrolysis of steam, IS thermochemical cycle

Green H2

1(a) Reactor Technology….

PWR: Pressurized water reactor/VVER (Russian Designed)
BWR: Boiling Water Reactor
PHWR: Pressurized Heavy Water Reactor
GCR: Gas Cooled Reactor
LWGR: Light Water Graphite Reactor (RBMK)
FBR: Fast Breeder Reactor



Gen I -	**1**
Gen II -	**405**
Gen III & III+ -	**36**
Gen IV (SMR) -	**1**

Total: 443 (32 countries)

SMR Operating Reactors:

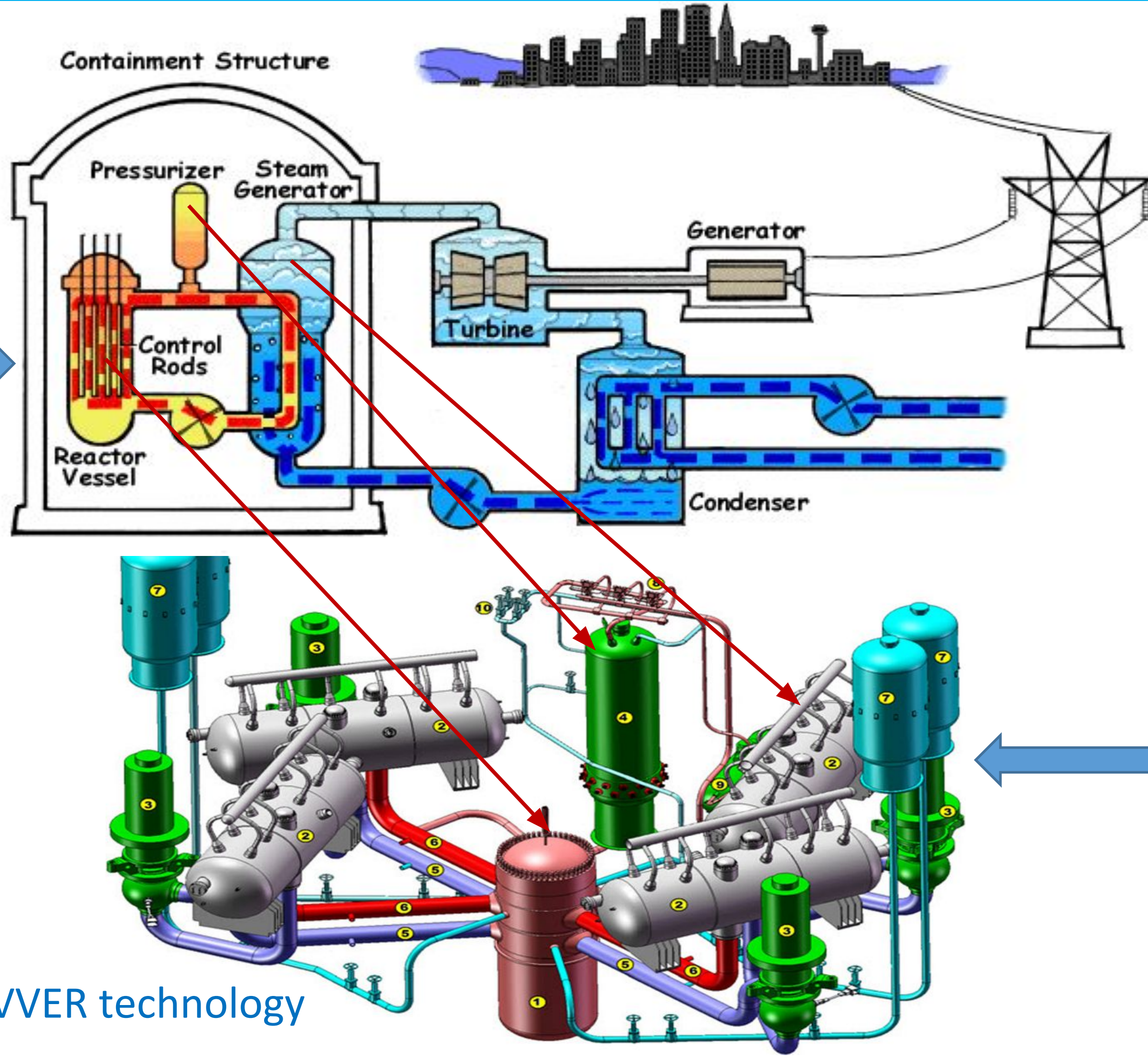
- SMR (PWR-FNPP, Russia/2019)-1(Gen-III+)
- SMR (HTGR, China/2000)-1(Gen-III+)
- SMR (HTGR, China/2021)-1(Gen-IV)
- SMR (HTGR, Japan/1999)-1(Gen-III)

Fig.4: Statistics of different generation operating reactors as of October 2021.

Source: IAEA PRIS, 2021

1(a) Reactor Technology….

Pressurized Water Reactor (PWR) (Western and Other country's brand)



Vodo-Vodyanoi Energetichesky Reaktor (VVER)-Russian brand, similar to PWR

Fig.5: PWR/VVER technology

Primary circuit of VVER-1200 plant; (1) Reactor, (2) Steam generator (SG), (3) Reactor main coolant pumps(4 Nos.), (4) Pressurizer, (5) Cold leg, (6) Hot leg, (7) ECCS Accumulator, (8) PRZ pulse safety device valve, (9) Relief tank, (10) Injection system

1(a) Reactor Technology….

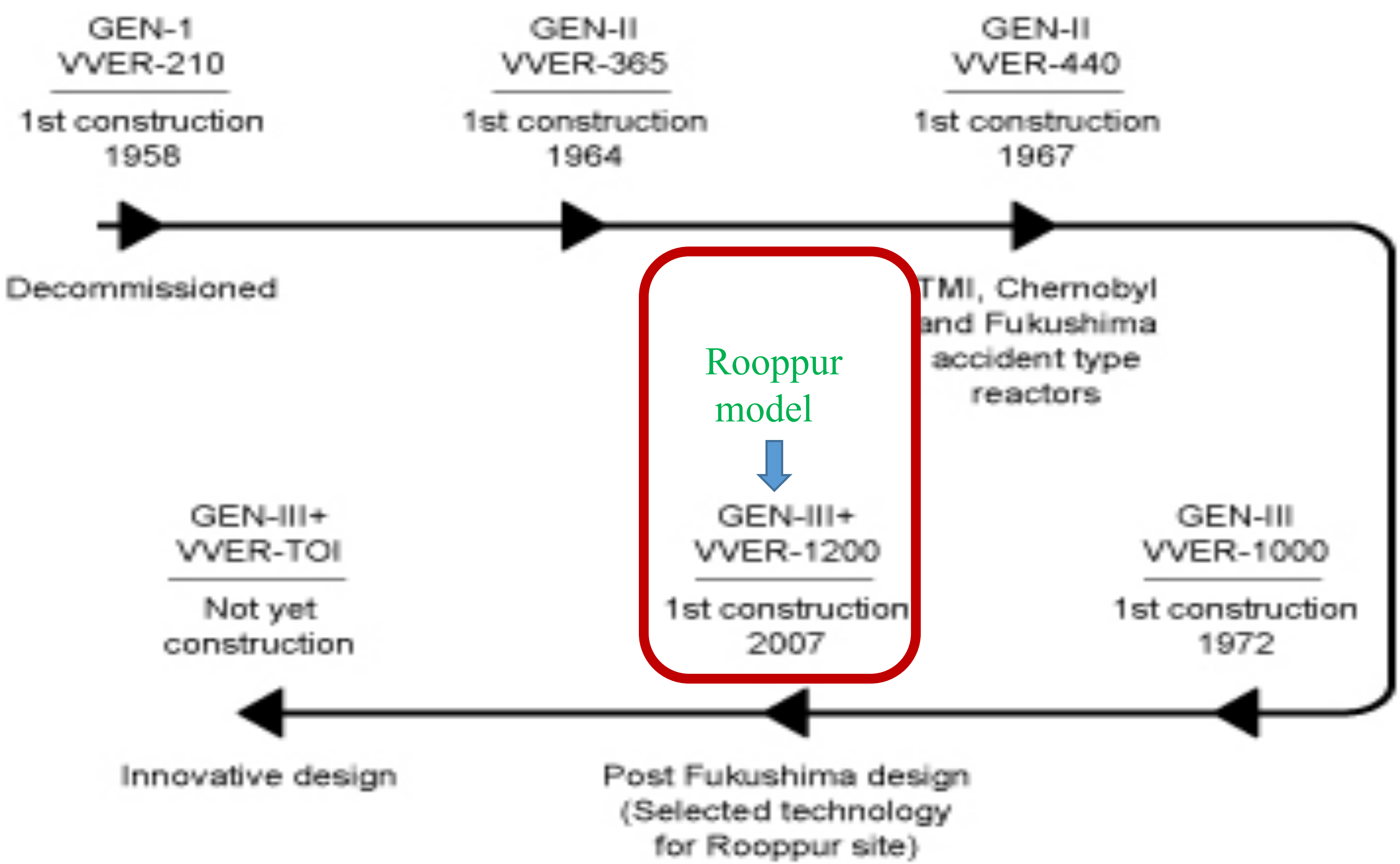


Fig.6: Evolution of Generation I-IV VVER Reactors in Russia

1(b) Safety Features

Table 1: Key Safety Enhancement Features from VVER-1000 to VVER-1300-TOI

Rooppur

Parameter	VVER-1000 (AES-91) (Gen III)	VVER-1200 (AES-2006) (Gen III+) (Rooppur Technology)	VVER-1300-TOI (Gen III+)
Design period	Started in 1970 and designed ended before Chernobyl accident (1986)	2000-2006	2009-2012
Certification	Rostechnadzor, *EUR	Rostechnadzor, *EUR	Rostechnadzor, *EUR
Electric power	1068 MW_e	1198 MW_e	1255 MW_e
Cost $/$kW_e$	1500-3000	4000	5000
Thermal Efficiency	35.6 %	36.4 %	37.9 %
Plant lifetime	40 -50 years	60 years	60 years
Capacity factor	0.8	0.9	0.93
Solid radioactive waste generation	53.30 m^3/yr	57 m^3/yr	44.50 m^3/yr
Earthquake resistance	0.12-0.25 g (6-7 **RS)	0.35 g (6-7 **RS)	0.4 g (7-8 RS)
Construction time	46 months	54 months	40-48 months
Grace period	< 24 hrs	24 hrs	72 hrs
Space requirement	High	Medium	Less
Fuel cycle	12 months	12-18 months	12-18 months
Period of fuel staying in the reactor core	4 yrs	4-5 yrs	4-5 yrs
Fuel type	UO_2	UO_2	UO_2 & MOX
Containment	Double	Double	Double
Core catcher (Corium)	Yes (new model)	Yes	Yes
CDF	3.0×10^{-7}	3.7×10^{-7}	7.0×10^{-7}
Cooling water requirements	High	Medium	Less
Radiation safety of population at emergencies	DBA:1.6 km BDBA (Severe accident): 16 km	DBA: 0.8 km BDBA: 3 km	DBA: 0.8 km BDBA: 3 km

1(b) Safety Features….

Rooppur NPP

Rooppur Reactor Model (Gen III+: VVER-1200, water cooled)

- Double containment
- Passive HAs
- PHRS from SG
- Core catcher
- H2 recombiners

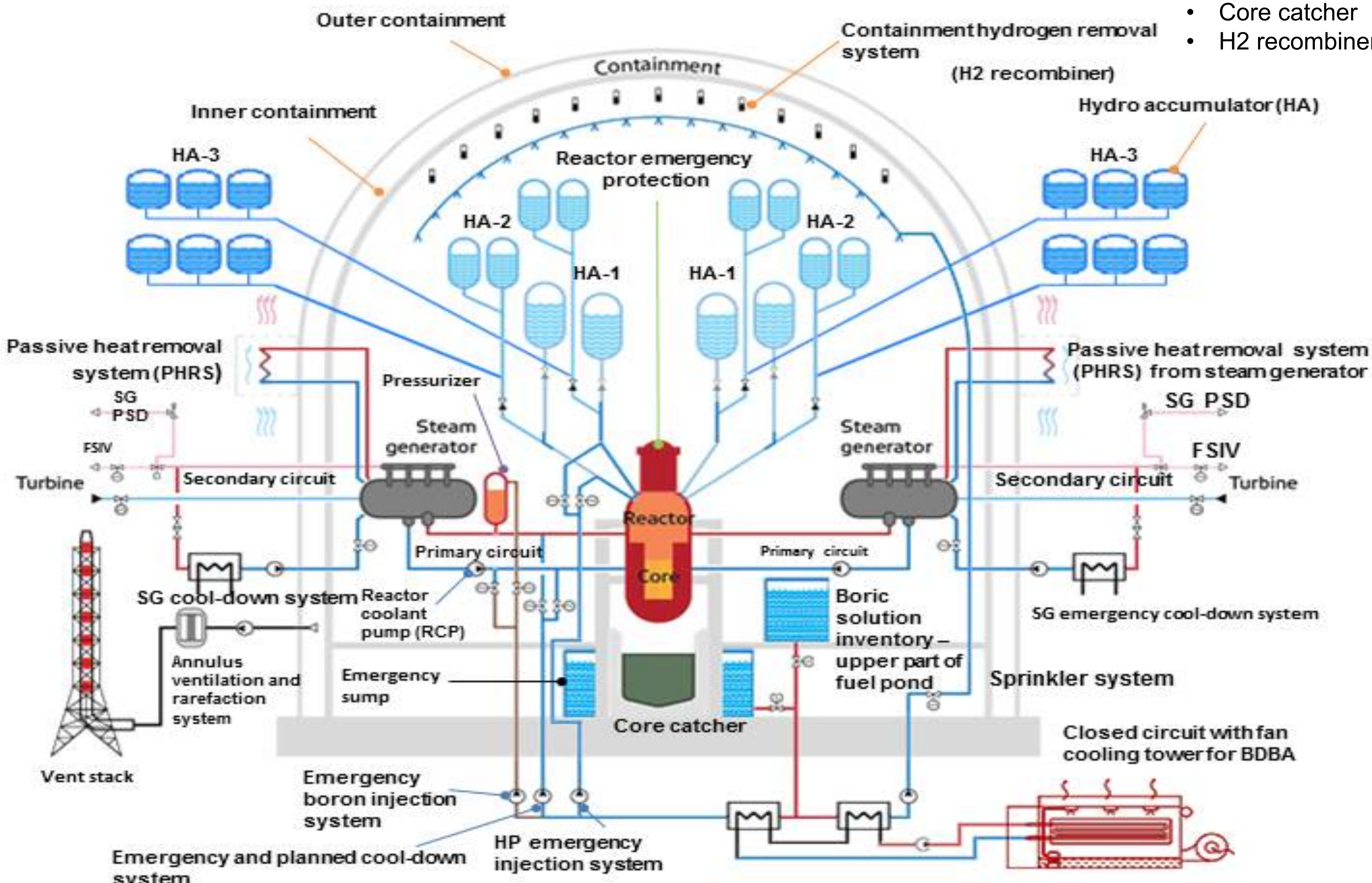


Fig.7: Advanced Safety features of Rooppur NPP.

1(b) Safety Features….

Rooppur NPP

Gen III+: VVER-1200, water cooled

Containment building is the single most important part of the Multiple Barriers provided against radioactive release

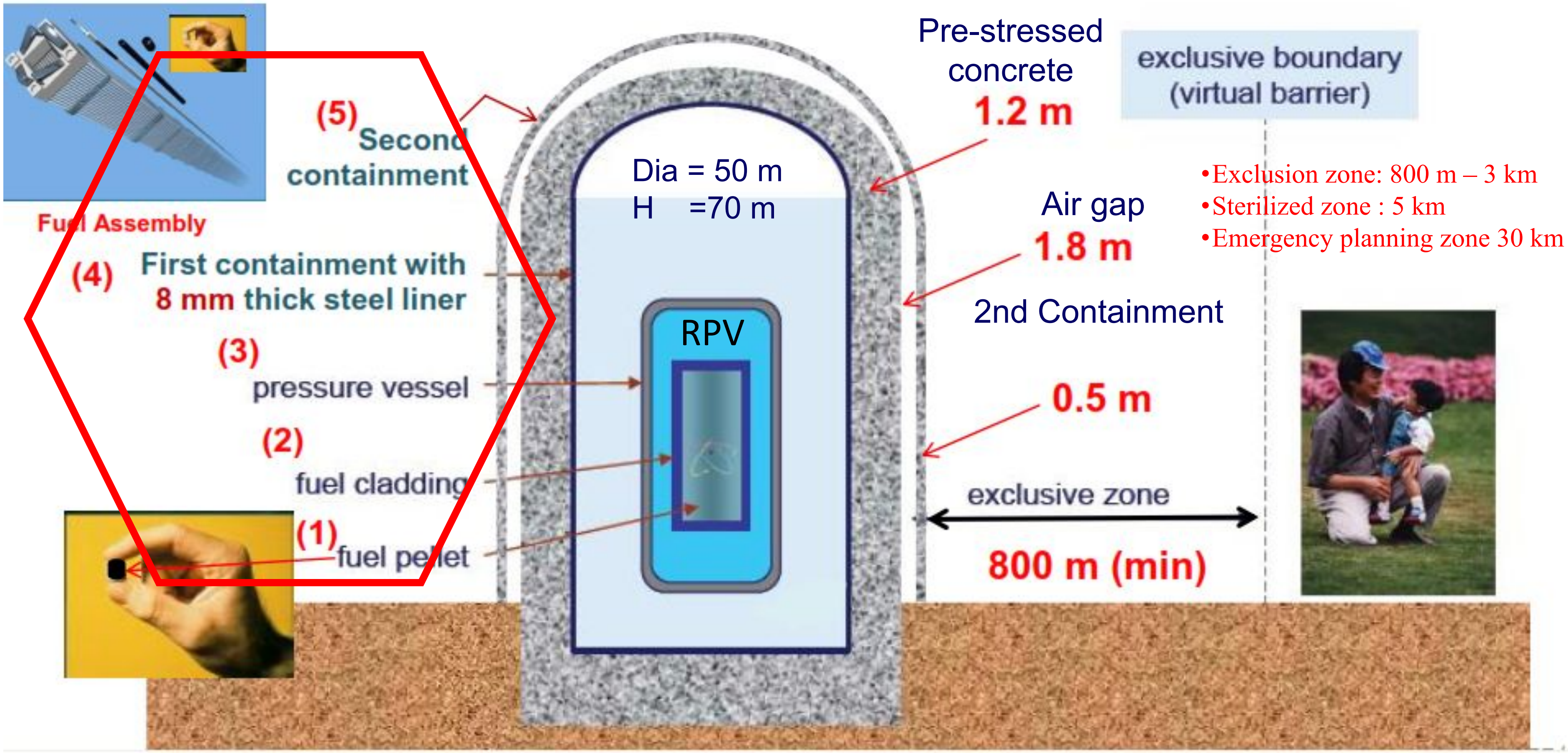
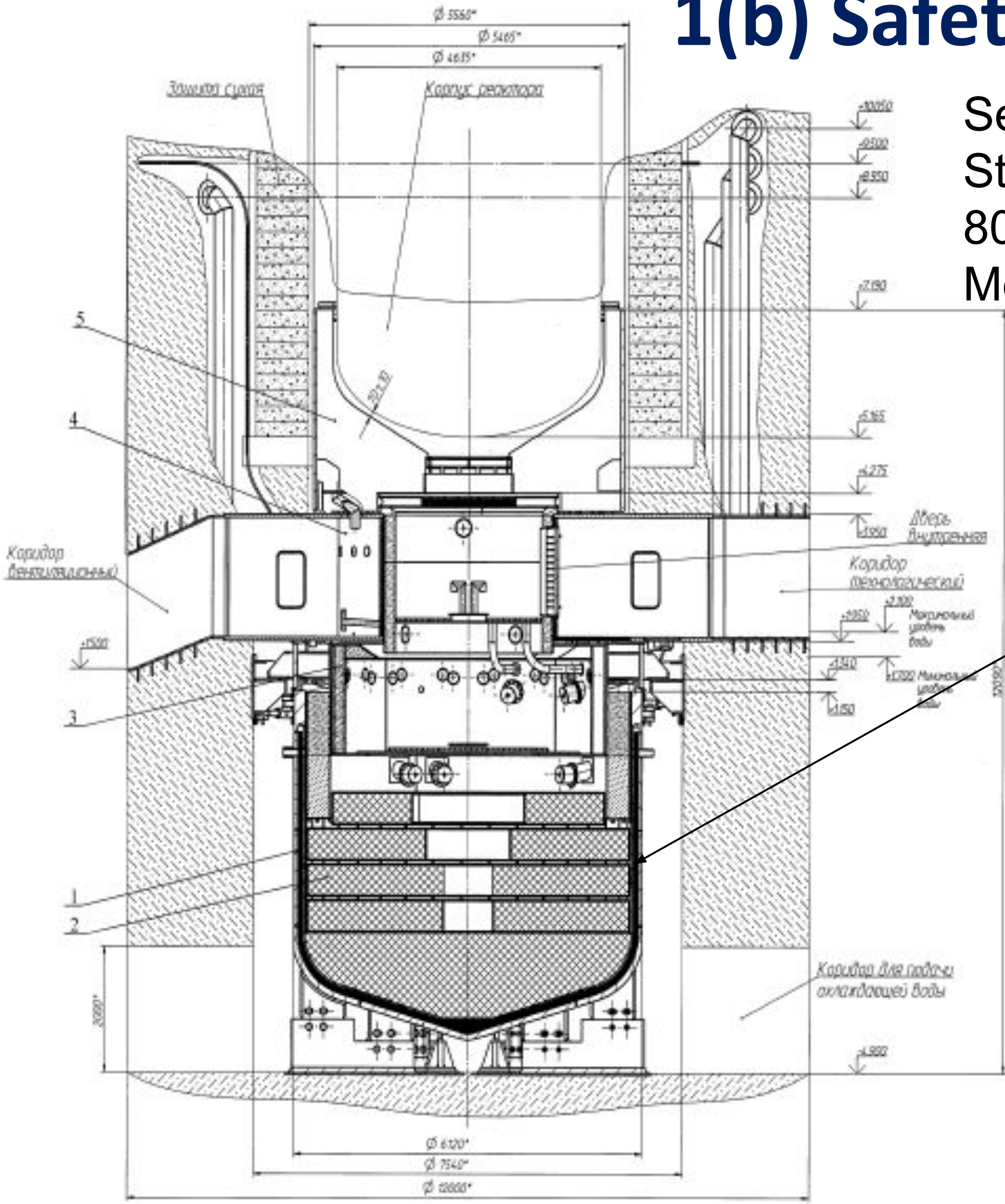


Fig. 8: Engineered safety system (5 barriers for radiation release protection)

1(b) Safety Features….



AES-2006 Core Catcher

1. Core catcher vessel
2. Sacrificial material
3. Thermal shield
4. Cantilever truss
5. Reactor cavity

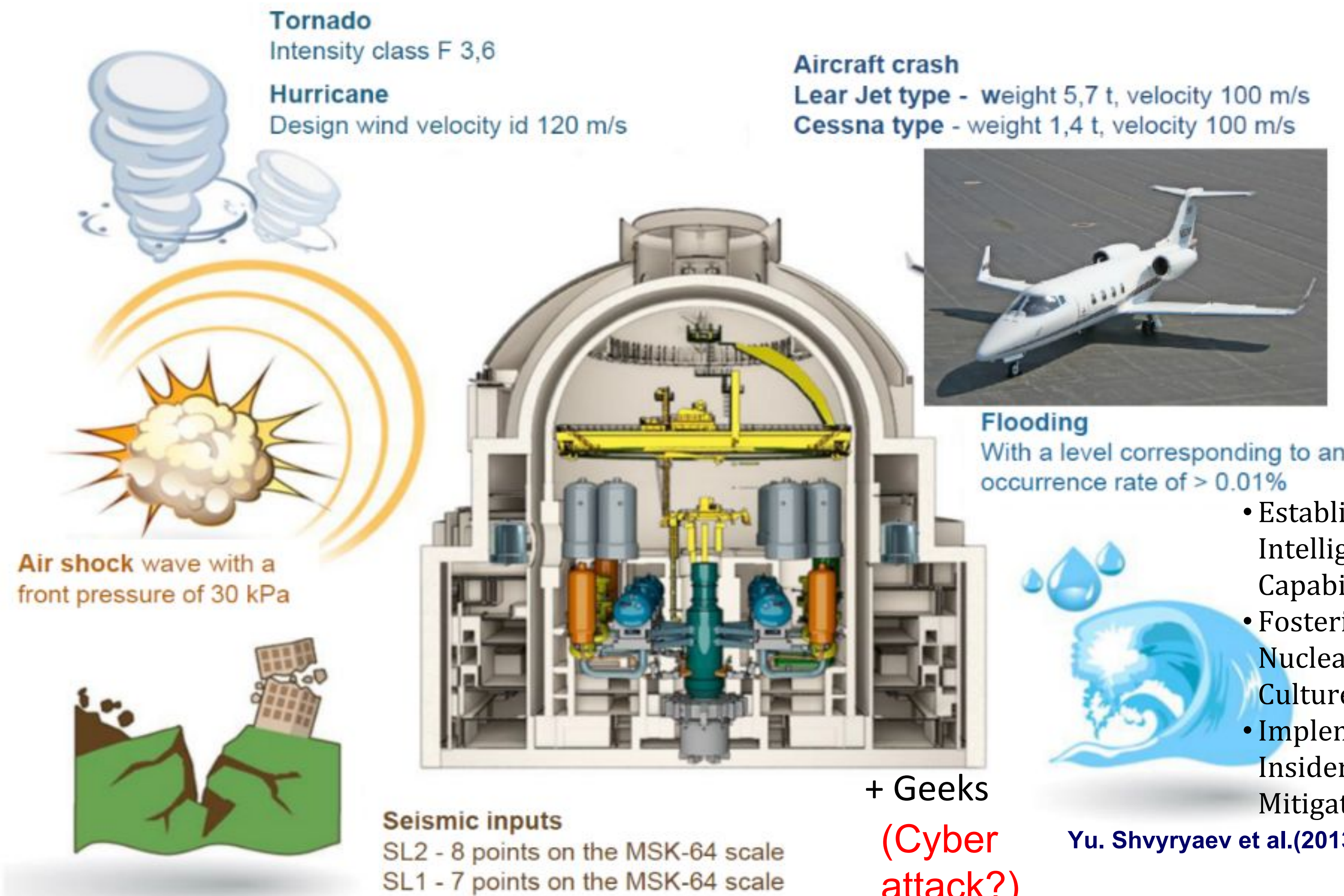
Self-weight ≈200 tons
Structural mass including self-wt: 800 tons
Molten material retain: 150 tons

under construction at Ostravets in Belarus (Image: AEM-Technology)

The molten core catcher is a unique safety device designed by Russian engineers. It is installed considering the site condition and safety requirements.

Fig.9: Core Catcher safety device for Rooppur NPP.

1(b) Safety & Security Features….



PPS: Guns, Gates, Guards(3Gs)

- Establishing Nuclea Intelligence Capability (NUCINT
- Fostering a Strong Nuclear Security Culture
- Implementing an Insider Threat Mitigation Program

+ Geeks (Cyber attack?)

Fig. 10 : Safety and Security Concerns

1(b) Safety, Security, and Safeguards Features

Table 2: Comparison among Safety, Security, and Safeguards (3S)

Attributes	Safety	Security	Safeguards
Definition	Achievement of proper operating conditions, prevention of accidents and mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards by following safety regulations, standards, codes, guidelines.	Prevention and detection of, and response to, theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear material, other radioactive materials or their associated facilities by introducing phy proc sys (PPS) and maintaining confidentiality.	Measures to verify that civil nuclear facilities are not being misused to pursue weapons and associated materials are properly accounted for and are not diverted to undeclared uses by doing nuclear mat. acc. & control (NMAC).
Cause / reason	•System failure •Human error •Natural disaster } Accident	•Sabotage •Malicious act •External attack •Insider, Cyber attack } Incident theft	Diversion / Misuse / Break out of nuclear mat.(NMs)
Focus	Technical and operational reliability based on redundancy, independency and diversity (Protect from accident)	Physical protection system (PPS), Insider threat and cyber threat (Protect from attacks)	NMs (Fissile- U, Pu) accounting, control, and verification (Protect from misuse of NMs)
Implications	Protection from accidental damage Foster safety culture	Protection from intentional damage or malicious acts Foster security culture	Protection from proliferation/undeclared use of NMs
Guiding Principles	IAEA Safety Standards	IAEA's & UN's legal instruments	IAEA's Legal Instruments
Responsibility	Operating facility, State	Operating facility, State	State, IAEA

1(b) The International Legal Framework for Nuclear Safety

IAEA-led

1. Convention on Early Notification of a Nuclear Accident.
2. Convention on Assistance in Case of a Nuclear Accident or Radiological Emergency.
3. Convention on Nuclear Safety
4. Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. [In the process to be a party of it ?]
5. Vienna Convention on Civil Liability for Nuclear Damage.
6. Protocol to Amend the 1963 Vienna Convention on Civil Liability for Nuclear Damage.

BD not party yet

7. Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (IMO-led).

The National Legal Framework for Nuclear Safety

Bangladesh Atomic Energy Regulatory Act (BAERA)-2012

Nuclear Safety and Radiation Control Rules (NSRC)-1997

1(b) The International Legal Framework for Nuclear Security

- **UN Security Council Resolutions (UNSCR)**
- ✔ UNSCR 1373 (2001);

  Prevention and suppression of terrorism to maintain international peace & security.

- ✔ UNSCR 1540 (2004);

  Dirty bombs (RDDs, REDs)

  Prevention of chemical, biological, radiological, nuclear (CBRN) threats posed by non-State actors.

- ✔ International Convention for the Suppression of Acts of Nuclear Terrorism (2005) (ICSANT) (2005)-in force

- **IAEA related Nuclear Security Conventions**
- Convention on Physical Protection of Nuclear Material (CPPNM) -1980 (in force)
- Amendments to the CPPNM (2005)-In force since 2016
- Regional Agreements and Nuclear Weapons Free Zone (NWFZ) treaties

1(b) The National Legal Framework for Nuclear Security

National laws concerning combating terrorism and financing of terrorism

- Bangladesh Atomic Energy Regulatory Act (BAERA)-2012
- The Chemical Weapons (Prohibition) Act - 2006
- The Anti-Terrorism Act-2009
- The Revised Anti-Terrorism Act-2012
- Anti-Terrorism Rules-2013
- Money Laundering Prevention Act-2012
- Money Laundering Prevention Rules-2013

1(b) The International Legal Framework for Nuclear Safeguards

1. Nuclear Non-Proliferation Treaty (NPT) [1968]

   (Effective: 31 August 1979-BGD)

2. Withdrawal and Non-Proliferation Obligations

   This refers mainly to Article X of the NPT

3. NPT related Comprehensive Safeguards Agreement (CSA) [1980]

   (Effective:11 June 1982-BGD);

4. Additional Protocol (AP) to the CSA [1997]

   (An extra layer of verification) (Effective: 30 March 2001-BGD)

5. Agreement on Improved Procedures for Designation of Safeguards Inspectors

6. Comprehensive Nuclear-Test-Ban Treaty (CTBT)

   Address nuclear test explosions

The National Legal Framework for Nuclear Safeguards

Bangladesh Atomic Energy Regulatory Act (BAERA)-2012

1(d) Grid Reliability

Why Power Evacuation from NPP is Critical

- **Large unit capacity**: Nuclear plants generate very large power (e.g., ~1200 MWe per unit at the Rooppur Nuclear Power Plant), requiring reliable transmission infrastructure to evacuate electricity to the national grid.

- **Grid stability**: Sudden loss or restriction of power evacuation can cause frequency and voltage instability in the national grid system of Bangladesh.

- **Nuclear safety**: Continuous off-site power supply is essential to operate cooling systems and safety equipment, even after reactor shutdown.

- **Economic efficiency**: Reliable evacuation ensures that the full generated electricity is delivered to consumers, protecting the economic viability of nuclear power projects.

1(d) Grid Reliability

<u>Rule of Thumb</u> in power systems for grid stability and frequency control

Many power grids calculate the required primary reserve as:

Normal fluctuations of demand (about 2–3% of total load) + possible loss of the largest generating unit.

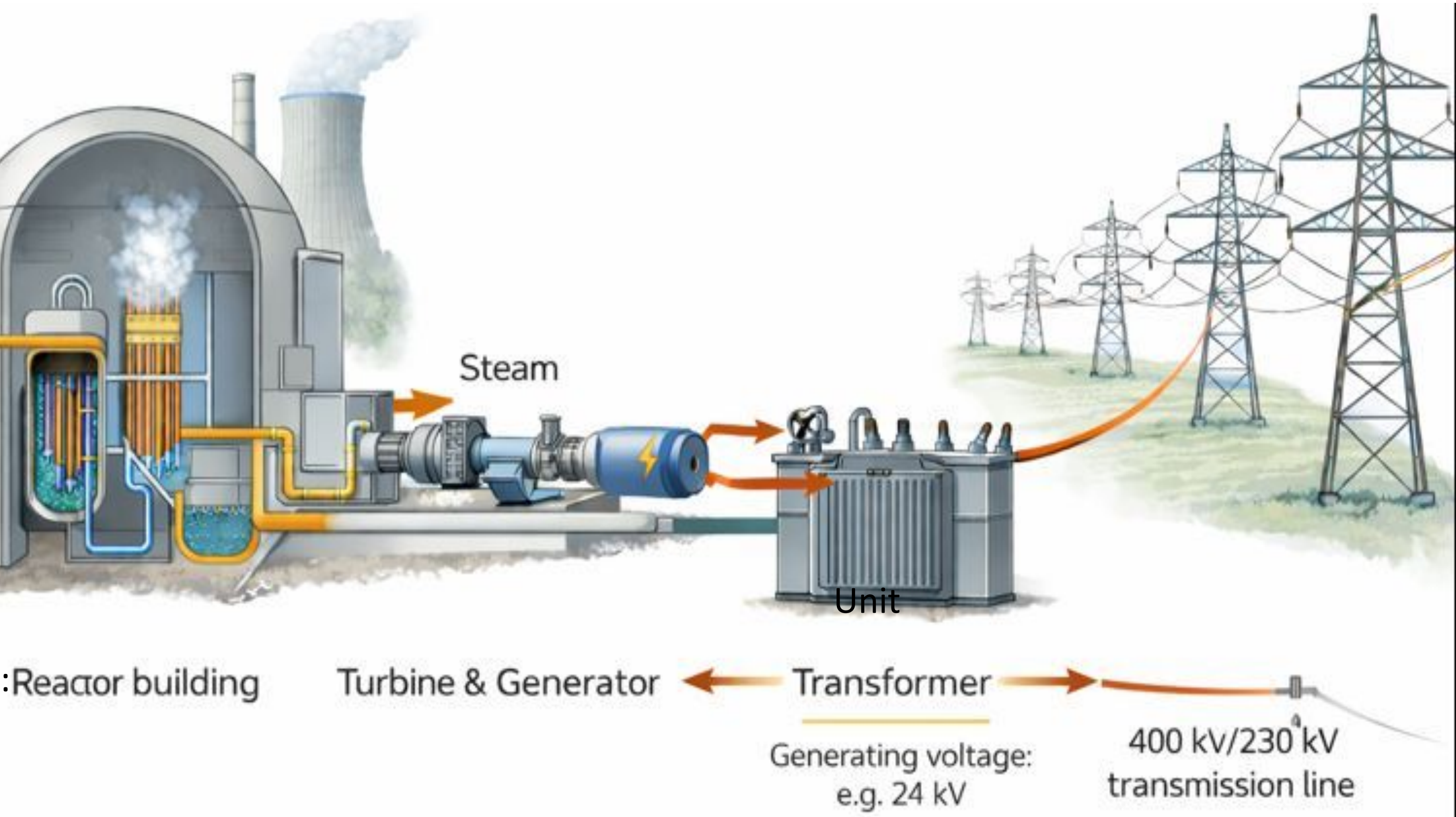


Fig.11:

1(d) Grid Reliability…

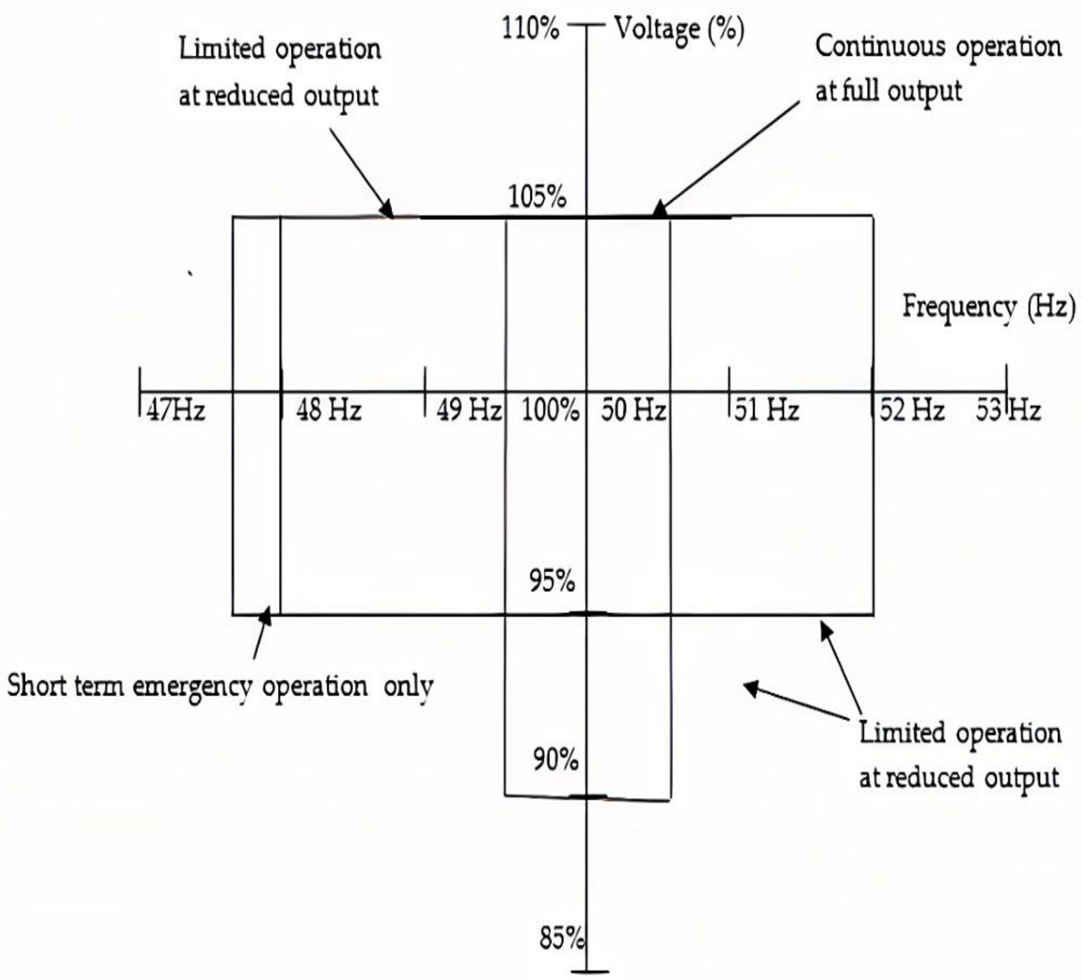


Fig.12: Required frequency and voltage range for NPPs operation according to IAEA.

Acceptance Criteria (Typical for VVER-1200 NPPs like Rooppur)

- **Normal Operation**: Frequency 50 ± 0.1–0.2 Hz, Voltage ±5% — Full power accepted, stable uniform heat distribution.
- **Acceptable Deviations (Continued Operation)**: Frequency 49–51 Hz (± 0.5 Hz) (short duration), Voltage ±10% — Minor thermal transients tolerated, no trip.
- **House Load Operation**: Frequency drop to ~47–49 Hz — Reactor power reduced to house load (~5-10%), acceptable for limited time.
- **Unacceptable (Automatic Trip/Scram)**: Frequency <47 Hz or >52 Hz, Voltage outside ±15% — Turbine/generator trip, reactor scram to prevent damage.

1(d) Grid Reliability…

Grid integration challenges, including spinning reserve requirements, frequency control, and system resilience, become more complex with large baseload nuclear units in the national grid.

From the real field study and information obtained from the National Load Dispatch Center (NLDC) PGCB, the frequency varies between 48.9 Hz to 51.2 Hz, with occasional drops as low as 48.7 Hz and peaks as high as 51.5 Hz under uncertain conditions.

Operating frequency requirements of VVER-1200 for Rooppur NPP as per Electricity Grid Code (EGC)-2019 of Bangladesh.

Table 2: Maximum Permissible Frequency and Voltage fluctuation as per Electricity Grid Code

Nominal frequency	Fluctuation range	Maximum permissible fluctuation range
50 Hz	49.0 – 50.5 Hz	47.5 to 52.0 Hz

1(d) Grid Reliability…

For Stable Grid System: Western Countries, Japan etc.

Usually, power transmission system designed for N-1 contingency; System remains stable after failure of any single component, e.g., one transmission line (230/400 kV) or transformer, including for nuclear power plants.

For Unstable Grid System: Energy hungry countries like BGD

Enhanced reliability through N-2 contingency planning (System stability maintained even after simultaneous failure of two critical components, e.g., transformer and transmission line) for secure and safe power evacuation.

1(d) Grid Reliability…

Grid Reliability Measures for Safe Nuclear Power Evacuation

Multiple redundant high-voltage transmission lines: Dedicated diverse paths, including four 400 kV and four 230 kV lines (e.g., Rooppur–Gopalganj 400 kV (Padma crossing), Rooppur–Bogura 400 kV, Rooppur–Baghabari 230 kV, and additional 400 kV lines to Dhaka over Jumana crossing, Rooppur to Damrai and Rooppur to Amin Bazar), each capable of handling significant power allowing full evacuation even after losing two lines.

Redundant transformers and switchyard configurations: Two unit transformers and two unit auxilary transformers and double busbar arrangements at the NPP switchyard with diversity to prevent single or double failures from isolating the generators.

Enhanced frequency and voltage control mechanisms: Strict frequency maintenance (e.g., within 49.0–50.5 Hz as required for VVER-1200 operation), including primary/secondary reserves exceeding the loss of the largest unit (1200 MW), free governor mode operation (FGMO) on generators, Automatic generation

1(d) Grid Reliability…

Grid Reliability Measures for Safe Nuclear Power Evacuation

- **Robust spinning and regulating reserves:** Sufficient online reserves (primary ~2–3% of load + max unit) to arrest frequency drops during power system disturbances without under-frequency load shedding.

- **Advanced protection and automation systems:** Fast-acting relays, special protection schemes (SPS), and wide-area monitoring, Substation automation system (SAS) to isolate faults quickly and prevent cascading outages.

- **Geographical and route diversity:** Transmission corridors on separate paths (e.g., avoiding common transmission towers, river crossings or cross border) to mitigate common-mode failures like natural disasters.

- **Grid reinforcements and substation upgrades:** Strengthened interconnected substations (e.g., Gopalganj, Bogura) with redundant bays and capacity for power flow distribution under N-2 scenarios.

- **Compliance with updated grid code provisions:** Specific amendments or

1(c) Radiation Release: Severe Accident Conditions

During SBO/LOCA

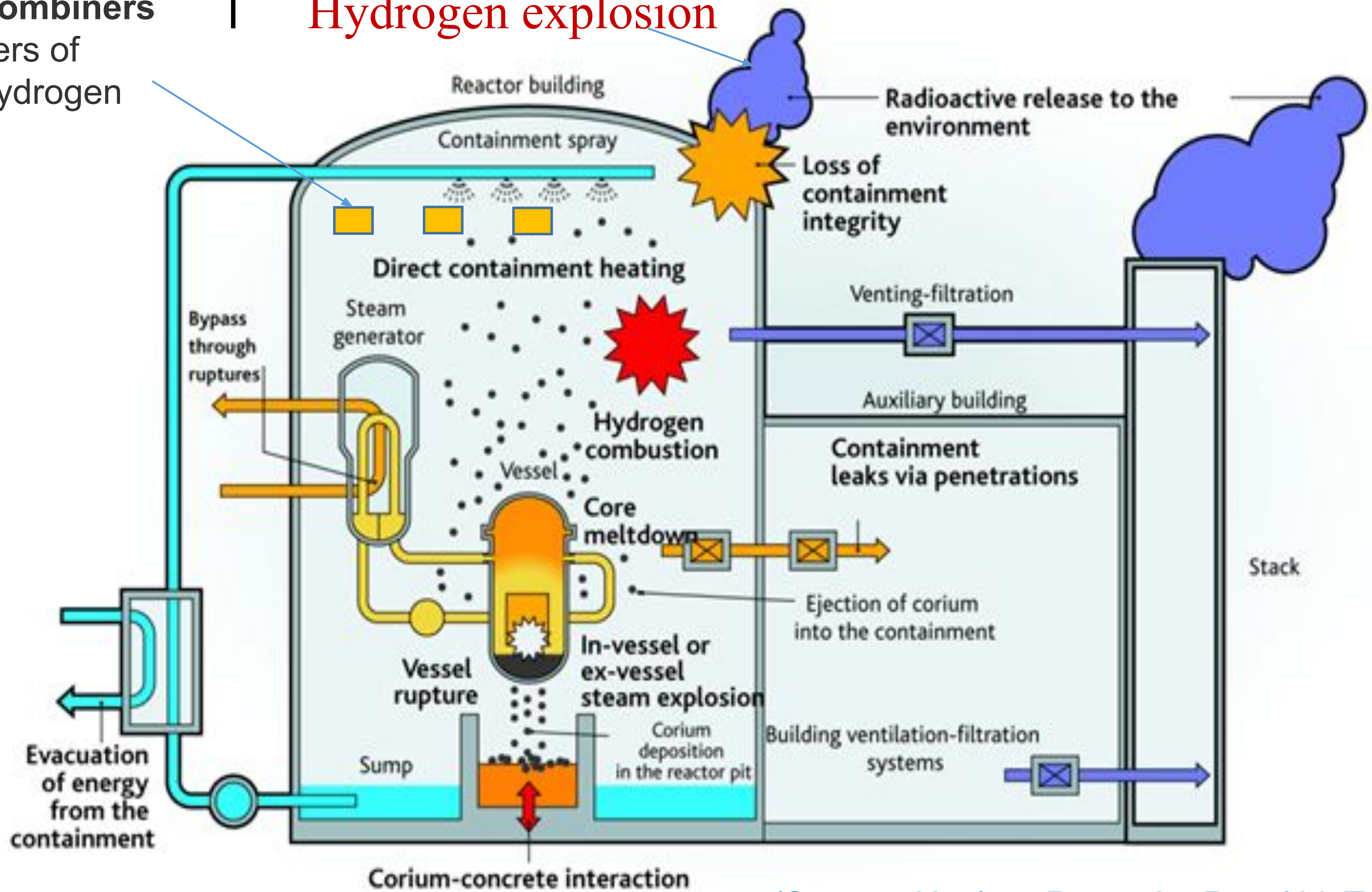
Rooppur NPP

$$2H_2 + O_2 \xrightarrow{\text{Catalyst (platinum or palladium)}} 2H_2O + \text{Heat}$$

(Fuel damage starts at ~1200°C & Full meltdown at 2850°C)

Hydrogen recombiners (A large numbers of autocatalytic hydrogen combiners)

Hydrogen explosion



(Source: Nuclear Power by Pavel V. Tsvetkov).

Fig.13: Severe accident phenomenon

1(c) Radiation Release: Severe Accident Conditions

Accident scenarios and Source term

Table 3 : Long-Term Station Blackout (LTSBO) Accident Scenarios

Accident Stage	Partial Core Melt (PCM) (42.85%)	Complete Core Melt (CCM) (100%)
Case ID	*PCM_7 level*	*CCM_7 level*
ECCS available	No	No
Reactor core uncovered for	3 hr	10 hr
Environment release start after reactor shutdown due to SBO	8 hr	8 hr
Sprays during release start	off	off
Sprays On after	3 hr	10 hr
Leak rate volume % per day	3.0	3.0
End of calculation at	24 hr	
Total I-131 equivalence activity (Bq)	2.20E+16	1.27E+17
Released radionuclides into environment	Noble gas -91% Iodine-5.2% Others (Cs, Te, …) 3.7%	Noble gas -66.8% Iodine-18.1% Others-15.1%
Noble gas to I-131 ratio	79:1	16:1

1(c) Radiation Release: Severe Accident Conditions

Table 4: Stability Classes

Description	Stability class	Expected weather condition
Strongly unstable	A	Sunny day
Moderately unstable	B	Sunny day
Slightly unstable	C	Sunny day
Neutral	D	Cloudy/Windy
Slightly stable	E	Night
Moderately stable	F	Clear night

TEDE = EDE (Ext.) + CEDE (Int.)

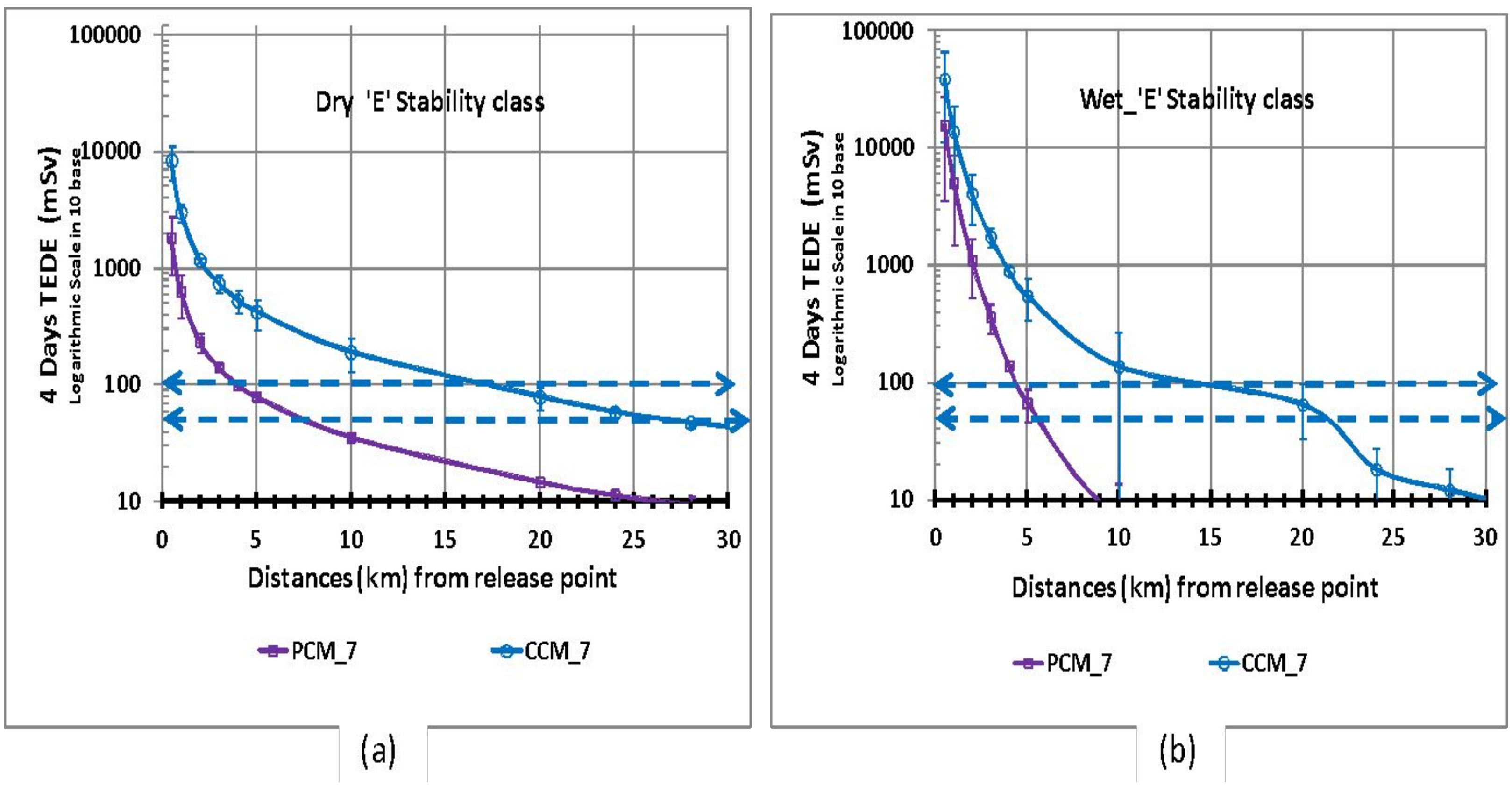


Fig. 14: Weather Effects for 4 days exposure; TEDE- PCM & CCM accident scenario .

1(c) Radiation Release: Severe Accident Conditions

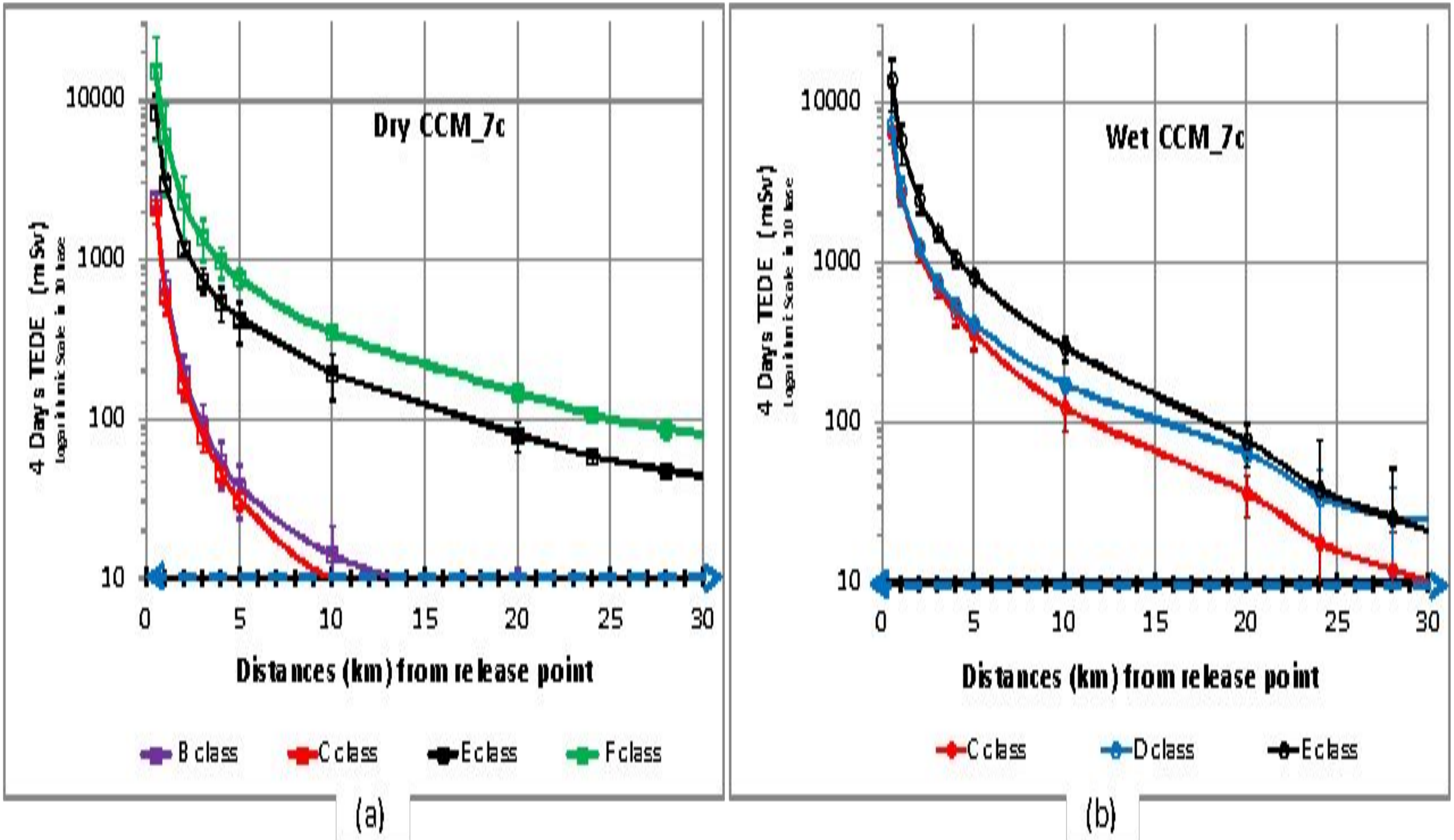
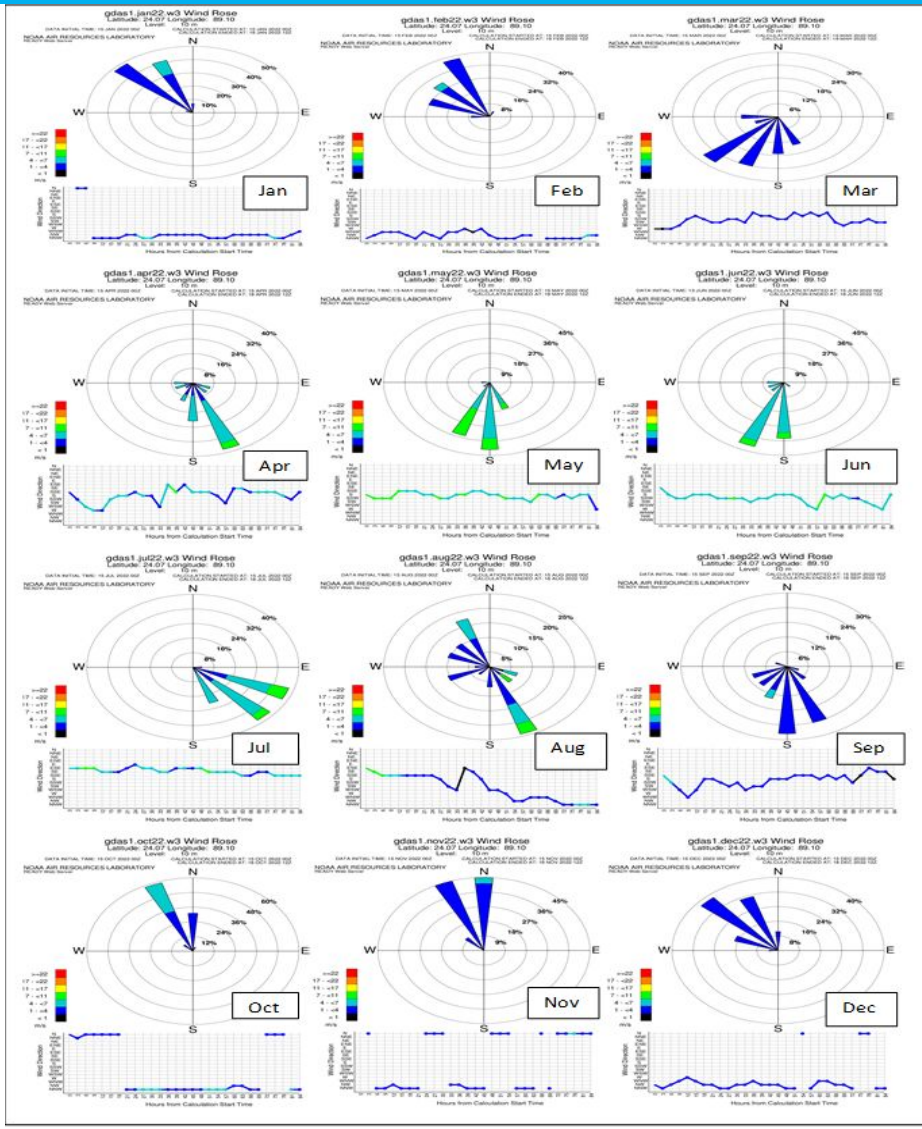


Fig. 15: (a & b) Average calculated 4 days TEDE vs. distances for various upper bound stability classes (with uncertainty), Blue arrows indicate EPA sheltering-in-place, or evacuation threshold; for worst CCM state LTSBO accident case.

Weather Effects….4-day Exposure TEDE- Different stability classes

1(c) Radiation Release: Severe Accident Conditions



Wind roses constructed using **84-hour wind speed and direction data** period starts on the **15th of each month**

<u>Seasonal Wind Characteristics</u>

- **Dry season (September–March): [Wind speed: 1 to <4 m/s]**

Predominant wind direction from the **northwest to southwest**

- **Wet season (April–August): [Wind speed: 4 to <7 m/s]**

Dominant wind direction from the **southeast to northwest**

Fig. 16: Monthly wind rose diagrams covers year 2022 based on GDAS1 meteorological datasets (NOAA ARL READY Location: Rooppur site, 24.07° N, 89.1° E).

Early Protective Measures for the Public

Thyroid gland protection case

1. Take Iodine Tablets

Protect thyroid gland

KI advised if thyroid dose >50 mSv from radioiodine.

Whole body protection case

2. Sheltering indoors

- Stay inside buildings
- Close doors & windows
- Follow official instructions

3. Evacuation

(TEDE >10–50 mSv)

- Carefully planned routes
- Support for children and elderly people

Table 5: Nat. & Int. Guidelines for Radiation Protection

Protective Actions	Intervention Levels		
	NNREPRP (BGD)	IAEA GSR part-7	U.S. EPA
Stable Iodine Administration / Iodine thyroid blocking (ITB)	**50 mSv** (Equivalent dose to the thyroid due to exposure from radioiodine in first 7 days) ~ Thyroid committed dose equivalent	**50 mSv** (Equivalent dose to the thyroid due to exposure from radioiodine in first 7 days) ~ Thyroid committed dose equivalent	**50 mSv** (Child thyroid dose from exposure to radioiodine)~ Child Thyroid committed dose equivalent
Sheltering-in-place or, Evacuation	**100 mSv** (TEDE/whole body dose in first 7 days)	**100 mSv** (TEDE/whole body dose in first 7 days)	**10 - 50 mSv** (TEDE/whole body in first 4 days)

TEDE = EDE (External) + CEDE (Internal-Inhalation)

NNREPRP & GSR-7: Base actions on **7-days TEDE**.

- **Thyroid gland protection**
  KI advised if thyroid dose **>50 mSv** from radioiodine.
- **Evacuation**
  If **TEDE >10–50 mSv** (Evacuation typically start at 10 mSv).
- **Shelter preferred**
  For vulnerable groups (old /hospitalized people (up to 50 mSv)

1(c) Routine Operational Release Case

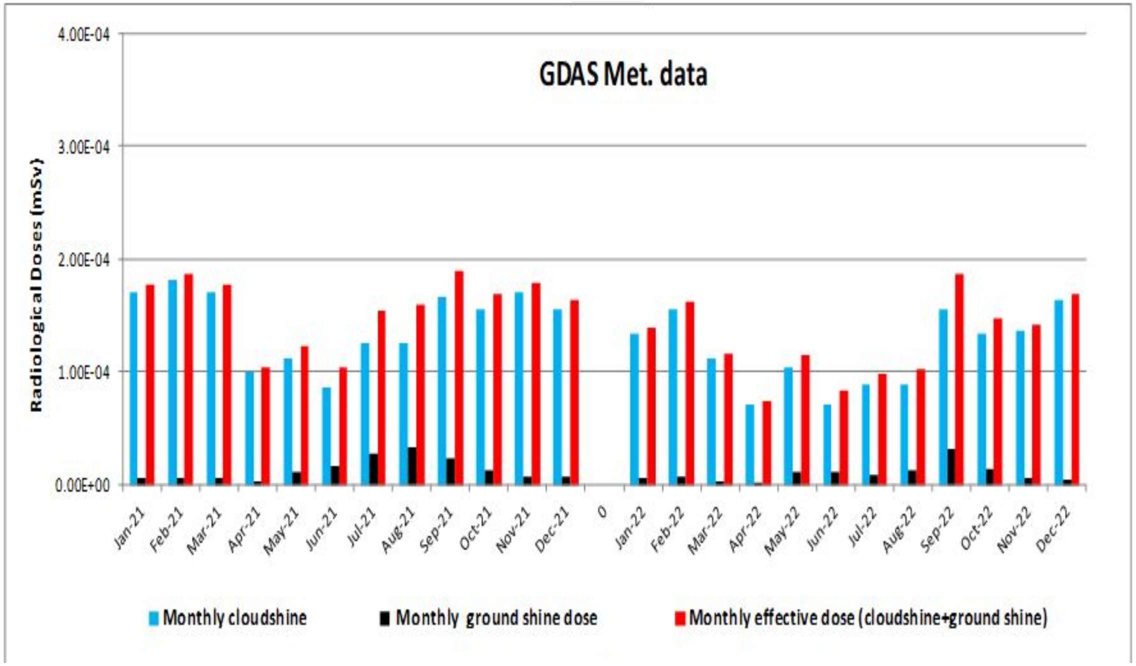


Fig. 17: Month-wise cloud shine dose, ground shine dose and effective dose from Routine Operation

Table 6: Annual effective dose from Routine Operations

NPP	Rooppur NPP 1
Reactor type	VVER-1200
Using Code	HYSPLIT
Annual Effective dose (mSv)	2.41E-03
(%) of Annual Dose limit (1 mSv)	0.24

- Highest **monthly cloud shine doses** occur during the **dry season (September–March)**
- **Ground shine doses** are higher in the **wet season (April–August)** Mainly due to **wet deposition** enhancing ground contamination
- **Effective dose values** are comparatively higher during the **dry season (September–March)**
- Approximately 90% of the radiological dose is contributed by the cloud shine dose.
- Annual dose is approximately **0.3% of the public dose limit (1 mSv/year).**
- Indicates **negligible exposure** from routine operations at **Rooppur NPP.**
- Dose is **well below regulatory limits** Also significantly lower than **natural background radiation** near the site Reported as **0.96 mSv/year.**

2. Radioactive Waste and SNF Management

Tab. 7: Nuclear Waste Management System **Rooppur NPP**

Type of nuclear waste generation	Volume	Radioactivity
HLW (Vitrified Spent fuels) [Np, Am, Cm]/SNFs Russia?	3%	95%
ILW (Fuel cladding, pipes, filters, resigns)	7%	4%
LLW (Gloves, towels, shoes, clothes, tools, papers, aprons, shoe covers) and nuclear medicine wastes	90%	1%
	Local management	

Global Practice for Spent Fuel Storage and Management:

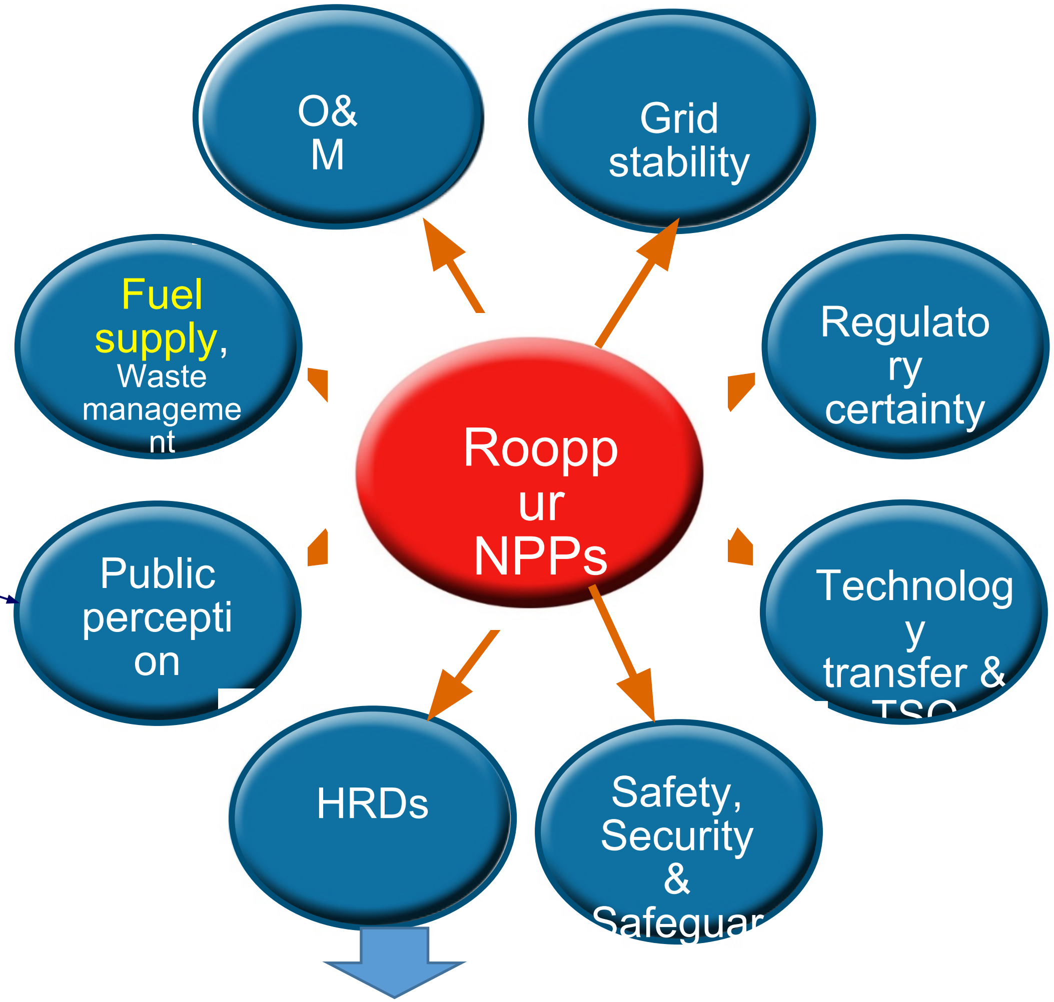
- **Initial storage**
  Spent nuclear fuel is first stored in spent fuel pools for cooling and radiation shielding (Typical depth ~10–12 m) and it is kept there for short- to medium-term **(≈5–10 years)**
- **Long-term interim storage**
  Most countries transfer spent fuel to dry cask storage for several decades.
- **National Reprocessing strategy**
  France, Russia, India, and China reprocess a significant portion of their spent fuel; Japan maintains a reprocessing-oriented policy with evolving implementation.
- **Direct disposal strategy**
  The U.S., Canada, Finland, and Sweden have opted for direct disposal.
  Finland and Sweden leading in permanent geological repository development **(Below 400-500 m)**.
- **Global status**
  Many countries have not yet made a final decision and currently rely on wet pool and dry cask storage while monitoring technological and policy developments.

The spent nuclear fuel (SNF) from the Rooppur NPP is supposed to be sent back to the Russian Federation as per the 2017 agreement between Bangladesh and Russia.

3. HRD Challenges

Nuclear fuel security?

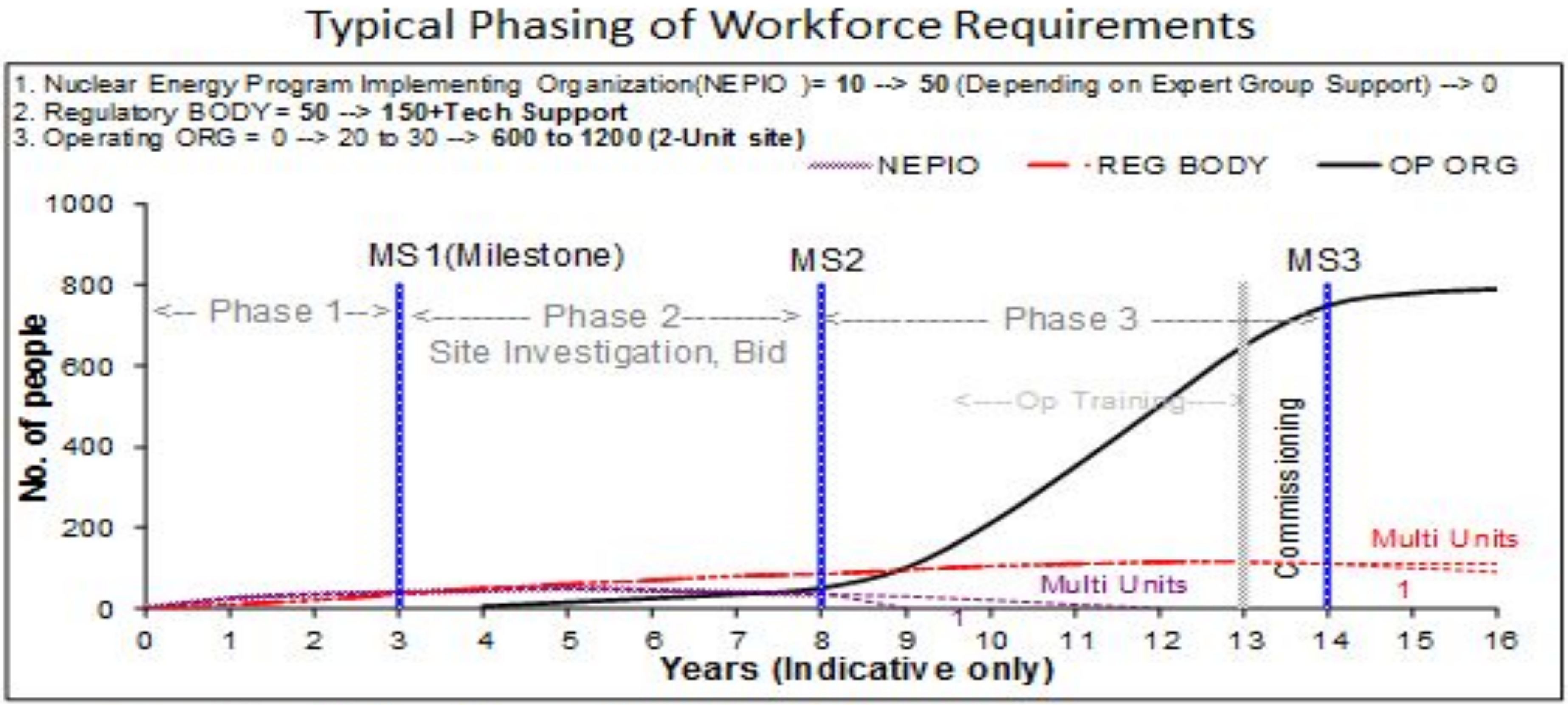
To remove the image of risk in the mindset of people



Fostering strong safety & Security cultures

80% of technological incidents and accidents occurred due to human errors, human failure, violation of rules, and lack of knowledge, skill and training.

3. HRD Challenges



- 300-400 Professionals for a single unit(1000MW NPP)
- 100-150 Professionals at Regulatory Body

Sources: (1) IAEA TRS-200, HRD, pp- 369 (2) IAEA NES No. NG-T-3.10, Workforce Planning for New Nuclea
Power Programmes

Fig.19: Workforce requirements for NPP constructions and Regulatory body establishment.

3. HRD Challenges….

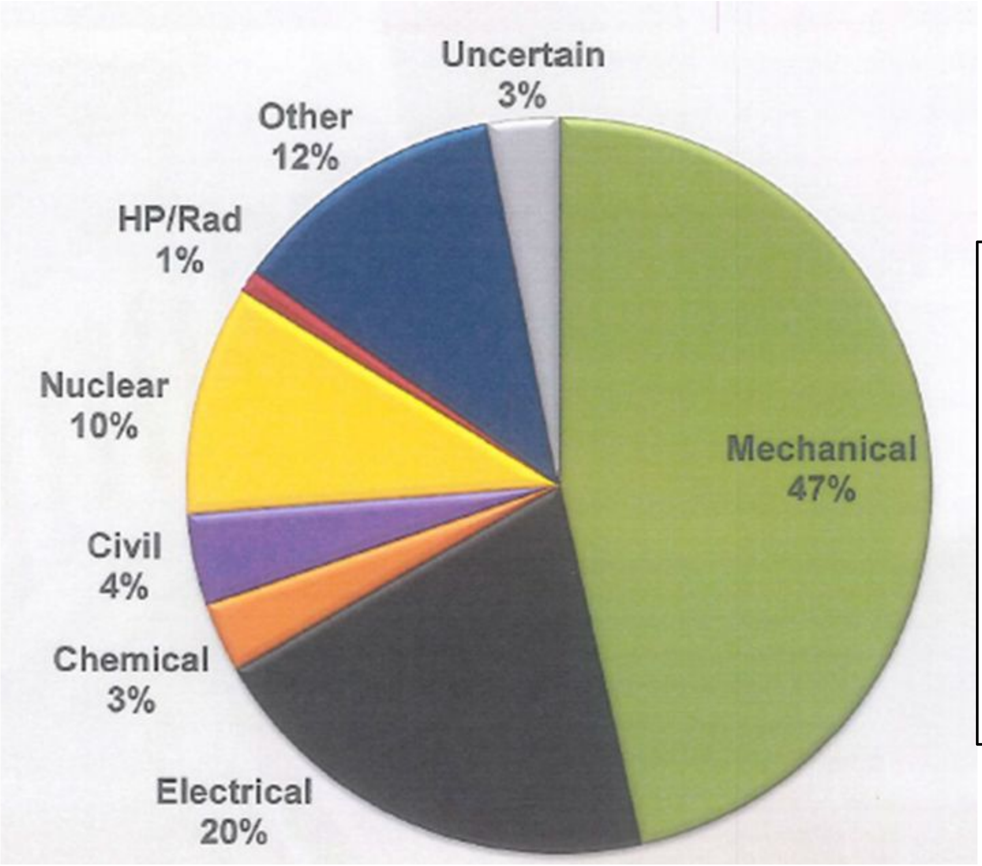


Fig. 20: Typical NPP Staffing Distribution

Source: Nuclear Energy Institute(NEI)

- Majority of permanent workforce is needed for the Operating Organization once NPP is commissioned.
- Around 65 - 80% of workforce are required at non-graduate level i.e. ‘Technicians’.
- Also need Business, Finance, Project Management, HR, etc.

3. HRD Challenges….

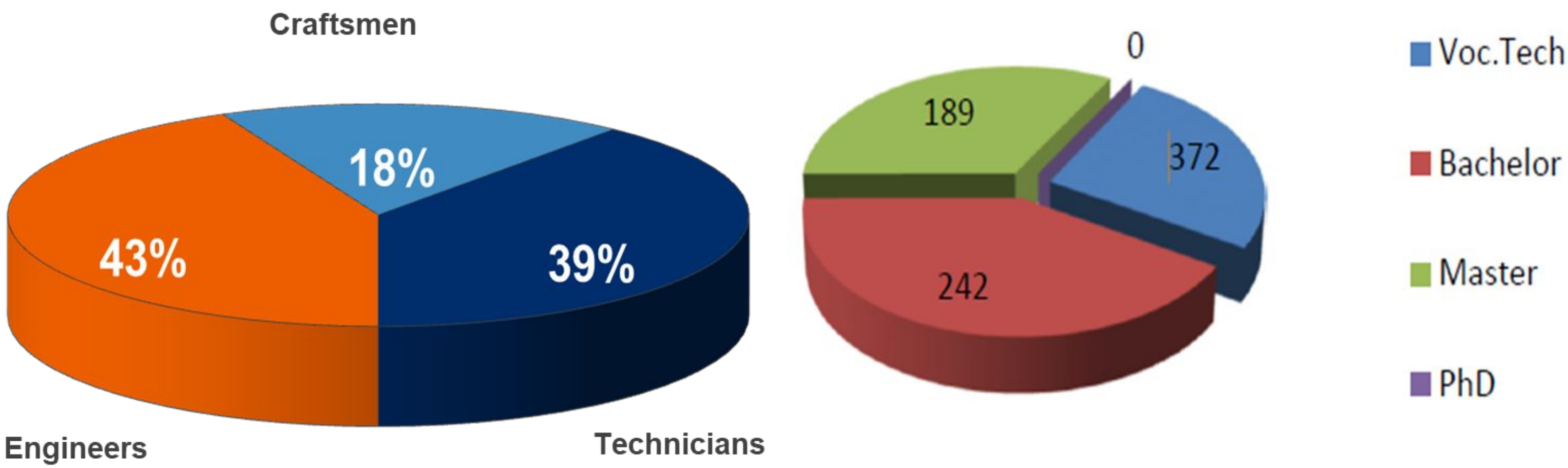


Fig. 21: Education level

- **Per year intake for B.Sc. in Nuclear Engineering at DU: 30**
- **Per year intake for B.Sc in Nuclear Engineering at MIST: 40**
- **Masters in NE program at BUET and CUET.**

Table 8: Current staff level at NPCBL, BAERA, and BAEC

NPCBL staff	BAERA staff	BAEC staff	Comment
1800	61 (Own) + 19 (Posted from BAEC) Engrs: Grad: 20 ; DIP:2 (CE) Scist: 34 Non-tech: 24	800	No NE Engrs. Recruited at BAEC as of now.

4. RNPP's Economic & Financial Implications

RNPP's Economic & Financial Evaluation

4. RNPP’s Economic & Financial Implications

Table 9: Typical commissioning schedule of VVER NPP.

Now (at A-4)

Stage A Pre-commissioning alignment activities					Stage B Physical startup		Stage C Power startup	Stage D Pilot commercial operation		Commercial operation
A-0	A-1	A-2	A-3	A-4	B-1	B-2	C	D-1	D-2	
Preparatory substage	Equipment inspection and testing	Contain ment test-ing	Reactor cold and hot tests	Inspection of the reactor installation main equipment	Loading of nuclear fuel	First Critica-lity	Reactor power raise up to connec-tion to the grid	Trial opera-tion at power up to 100%	Integrated testing	
39 months	9 months	1 month	3 months	3 months	2 months		1 month	10 months		

(1) Fuel Loading: 1-2 weeks (B1)	**(2) Maintaining equip. in operational mode:** B1+B2 : 1+1 = 2 months
(3) Pilot operation: D1+D2 : 10 months	**(4) Guarantee operation period:** 12 months
Total Time ≈ 80 months : Nearly 7 years	

4.RNPP's Economic & Financial Implications…

Key Input Parameters, Methodology, and Assumptions

Key Input Parameters

- Technical: Net capacity, capacity factor, plant lifetime, construction duration
- Financial: Total project cost, overnight capital cost, WACC, loan terms
- O&M and Fuel: Fixed O&M cost, fuel cost, decommissioning costs
- Inputs modeled using probabilistic distributions

Calculation Methods

- LCOE calculated using discounted cash flow methodology
- NPV and IRR and PBP used to assess investment viability
- Monte Carlo simulation to capture uncertainty
- Sobol global sensitivity analysis to identify key cost drivers
- Break-even tariff modeling

Key Assumptions

- 90% debt financing with long-term concessional Russian loan
- 60-year plant lifetime and baseline 6,8,12-year construction period
- Once-through fuel cycle with spent fuel returned to supplier country
- Construction delay risks explicitly modeled
- Learning effects and policy scenarios (carbon pricing, subsidies) included

4.RNPP's Economic & Financial Implications…

Table 10: Comparison of Worldwide Studies of O&M Costs and Fuel Costs

Name of the study	O&M cost ($/MWh)	Fuel Cost ($/MWh)
MIT(2003)	12.34	4.82
The Royal Academy of Engg. (2004)	14.58	11.22
The University of Chicago(2004)	8.98	4.49
Canadian Nuclear Association (2004)	7.86	4.49
OECD/NEA(2005)	11.22-29.23 (average=20.2)	4.49-19 (average=11.74)
UK Energy Review(2006)	12.9	6.51
Global high case(Paks II, 2015)	18.4	7.85
Global low case (Paks-II, 2015)	7.52	5.27
Global average (Paks-II, 2015)	12.79	6.28
Rooppur NPP project		
High case	14.5	11.2
Low case	7.82	4.5

4.RNPP's Economic & Financial Implications…

Table 11: Levelized Costs of Electricity (LCOE) vs Levelized Full System Costs of Electricity (LFSCOE)

$$LUEC = \frac{\sum_{t=tc}^{Lifetime} \frac{(Investment_t + O\&M_t + Fuel_t + Decommmissioning_t)}{(1+r)^t}}{\sum_{t=1}^{lifetime} \left(\frac{Electricity}{(1+r)^t}\right)}$$

Aspect	LCOE (Levelized Cost of Electricity)	LFSCOE (Levelized Full System Cost of Electricity)
Cost Scope	Plant-level costs only (CAPEX, O&M, fuel, financing)	Plant-level plus system-level costs
System Integration	Assumes no additional system costs	Includes grid integration, grid reinforcement, redundancy, and reserve capacity.
Power purchase agreement (PPA)	May underestimate true system costs	Reflects full economic impact on the power system
Policy Usefulness	Suitable for project-level comparison	Suitable for system planning and policy decisions

4.RNPP's Economic & Financial Implications…

Nuclear vs. Alternatives: 2020

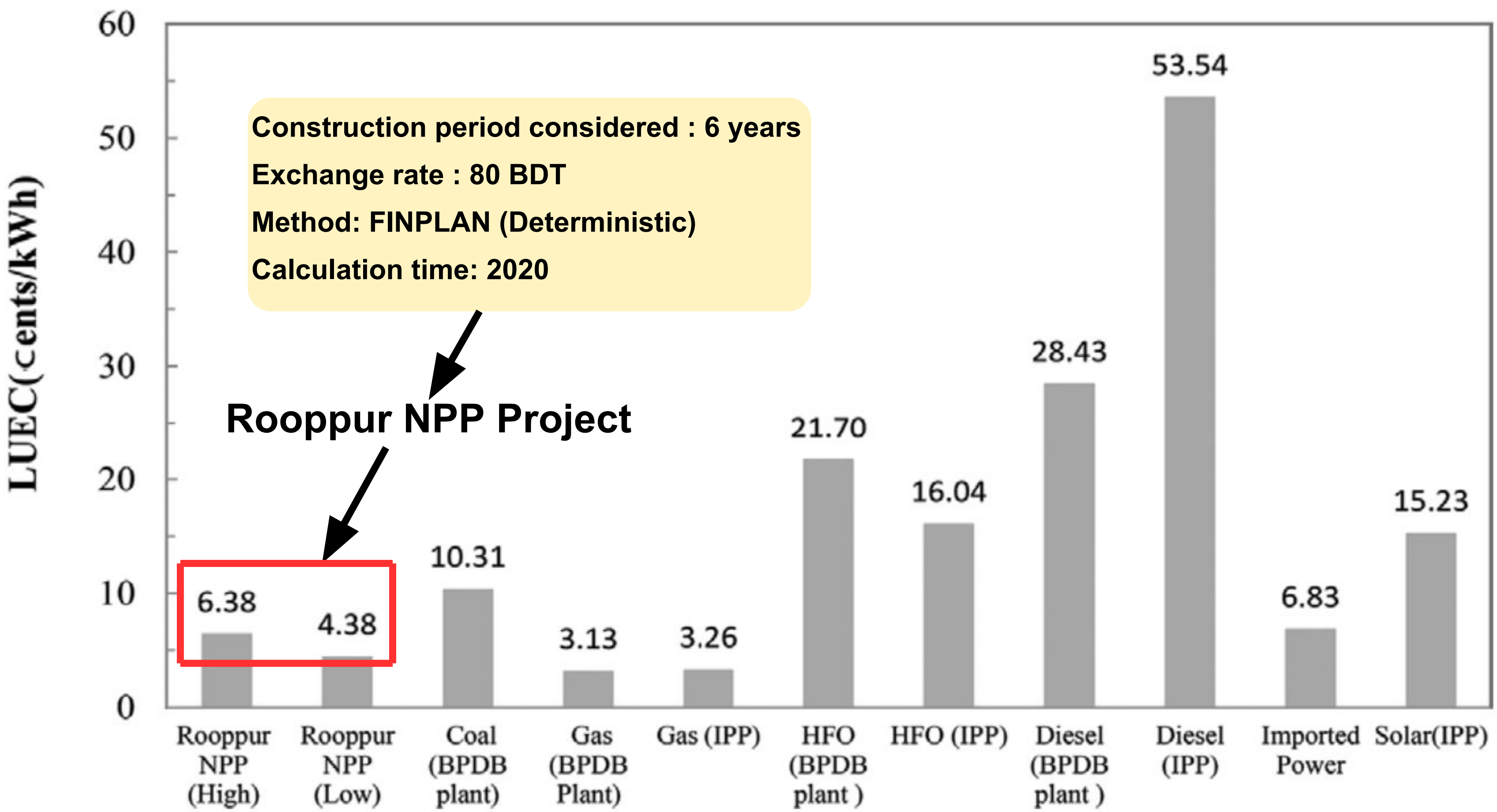


Fig.22. Comparison of LUEC with other power generating sources in Bangladesh. Source: BPDB (2018-2019)

4.RNPP's Economic & Financial Implications…

Nuclear vs. Alternatives: 2026

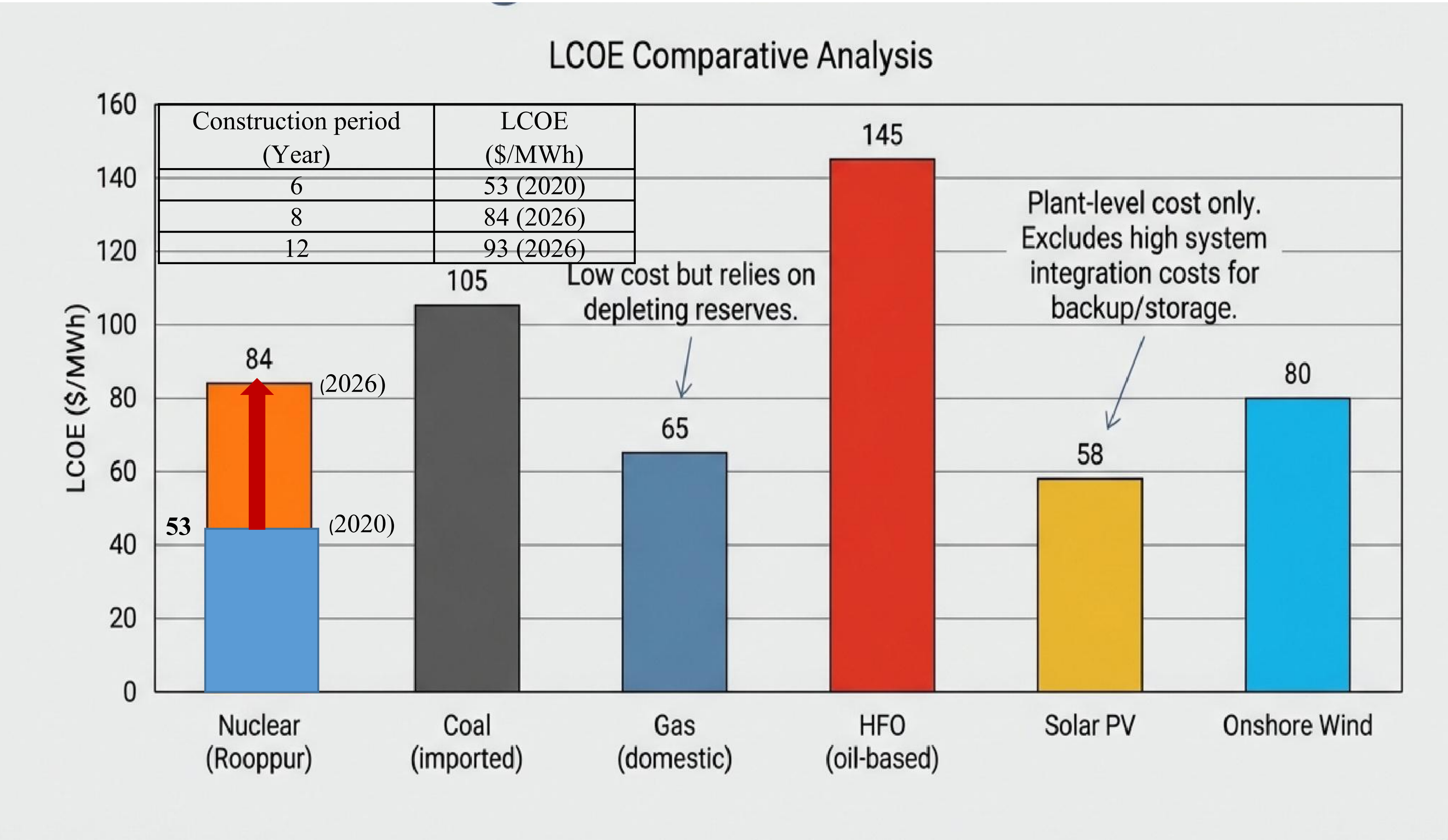
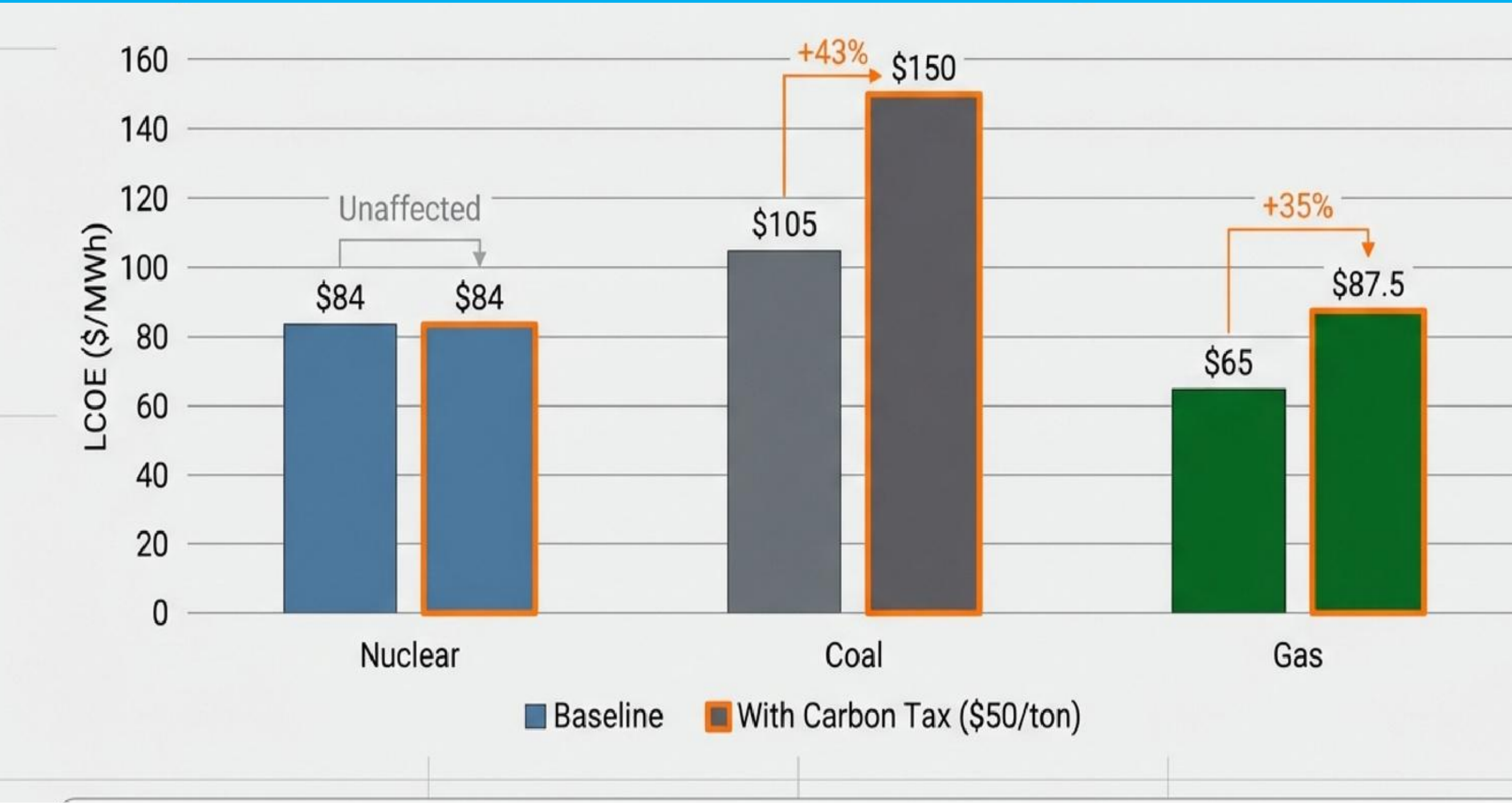


Fig.23. Comparison of LCOE with other power generating sources in Bangladesh.

4.RNPP's Economic & Financial Implications…



At $50 t/CO2, Nuclear becomes the cheapest baseload option, beating Gas

Fig. 24. Carbon pricing effects on power generation costs.

4.RNPP's Economic & Financial Implications…

Table 13: Power Purchase Agreements: Nuclear vs Conventional Plant

	Construction, operational & outages risks	**PPA term length**	**Financing structure**	**Cost**	**Operation**	**Liability insurance**
Nuclear	High	Very long (50-60 years)	Long-term: 25–30 year Export Credit Agency loans such as Rosatom financing	Fixed	Baseload	Complex & expensive (often mandated by international treaties or national laws)
Conventional	Low-Med	Short (25-30 years)	Shorter debt tenors	Variable	Flexible	General liability coverage

PPA: LFSCOE (Levelized Full System Cost of Electricity = LCOE + System integration costs??

5. Conclusions and Recommendations

IAEA & Int. Expectations vs. Bangladesh Status

Area	IAEA/Int. Expectations	Bangladesh-Status & Recommendations
Regulatory Body Independence	Fully independent, adequately resourced, competent regulatory body with long-term technical self-reliance	• Regulatory body is established and functional. • Institutional independence is limited as it operates under the same ministry as promotional and operating organizations. • Regulatory depth and long-term technical self-reliance are still under development.
Radioactive Waste Management	Clear national policy and implementation strategy covering LLW, ILW, and spent fuel end-state	• National policy exists • Not yet finalize the long-term disposal strategy for LLW/ILW • Spent fuel take-back arrangements rely on vendor agreements, with limited national end-state clarity.
Decommissioning Strategy & Funding	Legally secured decommissioning strategy and funding mechanism established early in plant life	• Decommissioning plan not yet finalized • Dedicated decommissioning fund and detailed national strategy are expected to be developed during operational phase.
Emergency Preparedness and Response (EPR)	Fully integrated on-site and off-site EPR system, regular large-scale exercises, strong public communication and cross-border coordination	• EPR framework and plans exist • Physical infrastructure, large-scale exercises, and local authority capacity are still evolving.
International Legal Commitments	Ratification and effective national implementation of applicable nuclear safety and security conventions	• Bangladesh is party to major international conventions • Practical implementation experience and enforcement mechanisms are still maturing.
Fuel cycle policy	Credible, long-term fuel supply assurance strategy with minimal geopolitical risk	• Fuel supply assured through vendor-based arrangements • Diversification mechanisms (e.g., multi-country leasing or backup options) remain limited • Domestic fuel rod capacity building plan yet to finalize

5. Conclusions and Recommendations

IAEA & Int. Expectations vs. Bangladesh Status

Area	IAEA/Int. Expectations	Bangladesh-Status & Recommendations
Grid Reliability & Nuclear Interface	Demonstrated long-term grid reliability (N-2 criterion) and resilience to extreme events	• Major grid reinforcements completed for RNPP • Sustained N-2 performance and operational resilience needs to be demonstrated for long-term operation.
Technical Support Organizations (TSOs)	Strong national TSOs capable of independent safety analysis, and maintenance issues	• Heavy reliance on vendor and international TSOs • Domestic analytical and independent review capability remains limited.
Nuclear Liability & Insurance	Fully operational nuclear liability regime with tested compensation and claims mechanisms	• Legal framework established • Insurance pool and claims-handling mechanisms remain untested in practice.
Human Resource Sustainability	Integrated national HRD strategy for operators, regulators, and technical experts	A fully integrated, long-term national HRD plan involving all stakeholders is not yet established.
Nuclear Intelligence	Effective nuclear intelligence capability to detect, assess, and respond to emerging nuclear security threats, including illicit trafficking, cyber threats, and insider risks through inter-organization coordination.	Nuclear security framework established under national regulations; however, a dedicated nuclear intelligence unit and integrated information-sharing mechanism among national security agencies are still evolving. Capacity building and specialized training are required.
Nuclear Diplomacy	Active engagement in international nuclear governance, participation in treaties, conventions, and technical cooperation programs to ensure safe, secure, and peaceful use of nuclear energy.	Establish international nuclear cooperation frameworks through the IAEA, UN. Bilateral cooperation with the Russian Federation for nuclear power development is ongoing; however, broader multilateral nuclear diplomacy and regional cooperation can be further strengthened.
Stakeholders Communication	Transparent communication strategy to inform and engage stakeholders including the public, policymakers, media, academia, and local communities to build trust in	Limited public awareness and outreach activities have been initiated by BAEC, NPCBL. However, a comprehensive national stakeholder engagement and risk communication strategy is still developing.

THANK YOU

Q &A