An Approach to the Design Elaboration and Construction of Rooppur NPP

1. Rooppur NPP Location

The Rooppur Nuclear Power Plant (Rooppur NPP) site is located in the village of Rooppur, adjoining Paskey union of Ishwardi Upazila of Pabna District, the People's Republic of Bangladesh. It is on the eastern (left) bank of the river Padma, 160 km north-west of the capital city of Dhaka, 21 km north-west of the town of Pabna, 8 km south of the center of Ishwardi Upazila, in the northwest of the country. It is the country's first nuclear power plant project site.

This Rooppur site was selected in 1962 by the then Site Selection Committee after evaluating twelve sites based on the applicable national and international siting criteria of seismic aspects, safe grade level, meteorological, etc. The site is in an area of the lowest seismic hazard zone of the country and the natural site elevation and location has ample margins of safety to avoid tsunami and flooding.

2. Nuclear Energy Programmatic Feasibility Study of Bangladesh

Bangladesh has a long history of its nuclear power programme. Based on several studies conducted so far, the nuclear energy had been identified to be a viable option as a component of the overall generation mix. Nuclear power programme had become a desirable option for power generation first in 1961. Before liberation several studies were conducted those justified the nuclear energy programme of the country. Rooppur NPP with capacity 70 MWe was first approved in 1963. During the period 1963-1969 several discussions were taken place with technology vendor countries for construction of a plant with capacity in the range of 140 – 200 MWe. But no real progress was realized.

Soon after the independence of Bangladesh in 1971, Bangabandhu Sheikh Mujibur Rahman, the Father of the Nation and the founding leader of Bangladesh had undertaken initiatives for implementation of Rooppur NPP project. Two separate feasibility studies for nuclear power in Bangladesh were conducted at the second half of 1970s and 1980s in association with the specialized foreign companies which confirmed and reconfirmed the feasibility of nuclear power that confirmed and reconfirmed the viability of 125 MWe and 300 MWe plant, respectively. But the project could not be implemented due to many constraints including funding. Introduction of nuclear power and implementation of Rooppur NPP project was always in consideration of the governments of Bangladesh, however no agreement was reached with the vendor countries.

The first National Energy Policy, 1996 identified nuclear energy as viable option for power generation. The policy recommended for early implementation of Rooppur NPP project. In 1997 the then government expressed its firm commitment to build nuclear plant and adopted and declared the Bangladesh Nuclear Power Action Plan (BNPAP) in 2000 to facilitate the implementation of the national nuclear power programme and Rooppur NPP. Preimplementation phase activities for two units of 600 MWe each were initiated. The site report of was prepared and the core manpower was developed.

The government of Bangladesh under the dynamic leadership of Honorble Prime Minister Sheikh Hasina adopted an ambitious, multifaceted development programme to transform the country into a middle-income country in 2021 and a developed country by 2041. Vastly increased electricity production, with the goal of connecting 2.7 million more homes to the grid by 2021, is a cornerstone of this push for development. Since 2009, Bangladesh has been working to diversify the energy supply sources to enhance national energy security, to reduce its dependence upon imported energy and over dependency on the limited indigenous sources such natural gas.

A fresh drive for implementing nuclear power programme had given in 2009. Since then Bangladesh took pragmatic measures to implement Roooppur NPP project. . The government policy documents, the Perspective Plan of Bangladesh, 2010-2021 and the Power System Master Plan, 2010 strongly recommended for implementation of Rooppur NPP project to diversify the energy supply sources to enhance national energy security. “In order to overcome the increasing power crisis in the country nuclear power plant shall be established immediately” - Resolution was passed unanimously by the National Parliament in November, 2010.

For embarking on nuclear power programme, a newcomer country needs to create appropriate nuclear power infrastructure. Like other countries which have begun to implement its nuclear programme and are new to it, Bangladesh had adopted a policy to creat national nuclear power infrastructure strictly following the international standards and the IAEA recommendations. Bangladesh made a strong commitment to the highest standards of operational transparency, safety, security and non-proliferation for its nuclear power programme. Nuclear infrastructure is multifaceted, containing governmental, legal, regulatory and managerial components, in addition to the physical infrastructure. The early activities of nuclear power programme included a detailed roadmap of nuclear infrastructure requirements. Bangladesh adopted the IAEA Milestones Approach, a methodology that provided guidance on working towards the establishment of nuclear power and followed the steps required for each of the 19 infrastructures. This approach consists of three phases, with a milestone to be reached at the end of each and focuses on pointing out gaps, if any, in countries’ progress towards the introduction of nuclear power. The Phase-1 involves considerations before the decision is taken to start a nuclear power programme and concludes with the official commitment. The Phase-2 entails preparatory work for the contracting and construction of a nuclear power plant, ending with the commencement of bids or contract negotiations for the construction. The Phase-3 (final phase) includes activities to implement the nuclear power plant, such as the final investment decision, contracting and construction. The duration of these phases varies by country, but they typically take between 10 and 15 years.

Bangladesh started to develop essential national infrastructure, including in establishing a legal and regulatory framework, developing core competency for NPP project management, determining national potion on funding and financing, etc. through the IAEA cooperation, dates back to 2009 when Bangladesh firmly decided to begin implementing its nuclear power project. The Integrated Nuclear Infrastructure Review (INIR) is a holistic peer review to assist Member States in assessing the status of their national infrastructure for introducing nuclear power. An Integrated Nuclear Infrastructure Review (INIR) mission was conducted by International Atomic Energy Agency (IAEA) during 9-15 November 2011 to review the infrastructure issues for the development of national infrastructure for nuclear power programme. The INIR mission concluded that Bangladesh reached Milestone 1, having "made a knowledgeable decision" regarding its nuclear power programme and the country has stepped into Phase 2, in the stage of preparation to negotiate the agreement(s)/contract(s) with the selected NPP vendor. The mission provided recommendations and suggestions on how to make further improvements. An Integrated Work Plan (IWP) for the period 2012-2015 was developed to close all existing gaps of national infrastructure, addressing possible activities & programmes and the responsible parties correspond to each recommendation and suggestion and each of the 19 infrastructure elements. The IWP of the has become a guiding document bringing all of the stakeholders in Bangladesh together to ensure the fulfilment of all safety, security, and safeguards requirements of the Rooppur NPP project. This IWP enabled Bangladesh to develop a holistic approach to implementing IAEA guidance as well as cooperating with national stakeholders and other bilateral partners towards the development of a national nuclear power programme.

Bangladesh formed its NEPIO (Nuclear Energy Programme Implementing Organization) in the form of high level committees based on the IAEA concept in 2010. The NEPIO has given mandate to monitor progress of nuclear power programme and Rooppur NPP project and coordinate all the required activities among the various implementing organizations/ministries involved in nuclear infrastructure development. At the top of the NEPIO, the National Committee chaired by the Prime Minister has been providing necessary directives and oversees the development of national nuclear infrastructure; establishment of the ownership pattern, project execution approach, selection of reactor technology, funding mechanism and HRD for Rooppur NPP project; capacity building in NPP owner/operating organization, strengthening nuclear regulatory and legislative issues and creation of nuclear security infrastructure. Besides, the National Committee, a Technical Committee headed by the Minister, Ministry of Science and Technology (MOST) and a Working Group and eight Sub-Groups headed by Secretary, MOST were formed to initiate and coordinate activities among various relevant organizations and stakeholders, namely regulatory authority, NPP owner-operator, grid operator, transport authority, power development board, relevant law enforcement agencies, academic, research and educational institutions. Bangladesh Atomic Energy Commission (BAEC) appointed as the owner organization of Rooppur NPP project.

As a part Phase-1 of national nuclear power programme, BAEC initiated pre-project activities of Rooppur NPP during 2009 -2012 under an annual development project entitled "Accomplishment of Essential Activities to Implement Rooppur Nuclear Power Plant Project". The site resource investigations were carried through involvement of national installations: Bangladesh University of Engineering and Technology, Dhaka University, Bangladesh Water Development Board, Bangladesh Meteorological Department, Survey of Bangladesh, Geological Survey of Bangladesh, Institute of Water Modeling, etc. based on the IAEA guidelines. The site related data and information derived from that study justified the suitability and economic reasonability of Rooppur NPP project. A comprehensive Site Report had developed that included a description of site, transportation conditions, earthquake, geology, hydrology, site land and topography of the site, electric power outgoing condition and environmental impact for introduction of the Rooppur NPP project site to the vendor country and the IAEA. The IAEA Preparatory Mission for Site Evaluation conducted during the period 10-14 July 2011 which reviewed the site report and provided recommendations for detailed site safety assessment of the site following the IAEA guidelines. The government of the People's Republic of Bangladesh and the government of the Russian Federation signed a Framework Agreement on Cooperation in the Sphere of the Use of Atomic Energy for Peaceful Purposes on 21 May 2010.

As a part of Phase-2 activities, Bangladesh created Bangladesh Atomic Energy Regulatory Authority (BAERA) for regulating overseeing the activities of nuclear project. Bangladesh has started building nuclear security infrastructure for Rooppur NPP considering 100 years of plausible threats. Bangladesh developed a joint action plan, adopted a Strategy for Promoting Communication in Bangladesh Nuclear Power with Russian party for 2015–2021. The country established core competency for NPP project and NPP programme management.

In May 2016, a follow-up INIR mission was conducted, which noted the progress that country had made for nuclear construction — Bangladesh had established a nuclear regulatory body, had chosen a site for its first nuclear power plant and had completed site characterization and environmental impact assessment, signed contracts for Rooppur NPP construction.

The NPP project feasibility study and site safety assessment is the Phase-2 activities of national nuclear power program. Bangladesh has recognized that safe and secure nuclear power generation can only be achieved by applying a comprehensive approach that allows consideration of all nuclear security issues in a systematic manner.

3. NPP Project Feasibility Study and NPP Site Safety Assessment and National Position for Rooppur NPP Build

The NPP project feasibility study is the evaluation and determination of whether a selected nuclear reactor project is an appropriate choice, given the project details, including the infrastructure, site, technology choices, economics and financial aspects. This study will assist in defining the envelope for NPP technology, deriving possible architectural and civil engineering solutions and emergency prevention measures in emergency situations and developing a set of documents and materials at pre-design stage for substantiating NPP project. The Site Safety Assessment of a nuclear project is engineering survey of the NPP site as per survey types: geological, seismic and seismo-tectonic, hydro-meteorological and geodetic survey and environmental studies and man-induced impact assessment studies. These studies are carried based on the IAEA guidelines and national and international normative requirements.

Taking into account the domestic legal and regulatory conditions to obtain licenses, industrial base, availability and competence of human resources for managing the construction project, national resources and economic and environmental condition to support NPP build, a Two-Stage Contracting Scheme has been adopted for Rooppur NPP: (1) The Preparatory Phase construction activities and (2) the Main Phase construction activities. The NPP Project Feasibility Study and Site Safety Assessment are the early commercial decision for implementation of nuclear project and component of the preparatory phase construction activities.

Construction of Rooppur NPP is implemented in accordance with an Intergovernmental Agreement (IGA) between the government of Russian Federation and Bangladesh, the Russian Federation on Cooperation in Construction of the Nuclear Power Plant signed on November 2, 2011. Under the provision of the IGA, the Russian Federation will provide ready nuclear fuel for Rooppur NPP for its entire life. Russian Federation is also signed a separate IGA to send back the spent nuclear fuel for its management in Russian Federation. An Agreement on Extension of the Credit for the Preparatory Period of Rooppur NPP Construction was signed on January 15, 2013 within the framework of the visit of the Prime-minister Sheikh Hasina to Russian Federation. Bangladesh has also signed an IGA with Russia to return the spent nuclear fuel from Rooppur nuclear power plant.

Bangladesh Atomic Energy Commission, the owner organization of Rooppur NPP concluded necessary contracts with JSC Atomstroyexport, a subsidiary of the Russian state nuclear corporation for the preparatory phase construction activities during 2013-2016 and signed a General Contract on December 25, 2015 for the construction and commissioning of Rooppur nuclear power plant. A state credit of 11.38 billion US$ was extended by the Russian Federation for financing the Construction of Rooppur NPP (Main Stage) and an Intergovernmental Credit Agreement (IGCA) was signed on July 26, 2016. The project is being implemented under a Turnkey approach.

4. Preparatory Phase of Rooppur NPP Construction (2013-2017)

The construction of a NPP requires huge preparation and years of preparatory work. One of the biggest challenges is completion of the site development and priority civil construction and erection works. Another challenge is to meet the requirements of the licensing obligations for the *Siting Licence* and the *Design and Construction Licence.* The support of the experienced contractor or vendor was inevitable for both the cases for the newcomer country to NPP build. Bangladesh assigned the General Contractor, JSC Atomstroyexport to perform preparatory phase construction activities that covered the siting activities, feasibility evaluation, engineering surveys and environmental studies, development of design documentation and technical assignment for elaboration of design documentation of Rooppur NPP Unit-1 and Unit-2, preparation of documentation packages of the design and licensing activities, development of construction site, civil construction and erection works at Pioneer Base and Construction Assembly Base and execution of first-priority works at industrial Site.

The General Contractor JSC Atomstroyexport and ROSATOM of Russian Federation has been working since 2013 for the preparatory construction activities. On October 2, 2013, the Prime Minister, Sheikh Hasina laid the corner stone into the foundation of the Rooppur NPP. The major preparatory phase activities are discussed below:

4.1 Feasibility Evaluation, Site Safety Assessment and Environmental Impact Assessment of Rooppur NPP

Systematic investigations of the project siting region, studied the library and archive data and performed a comprehensive site engineering survey and environmental studies, Feasibility Evaluation and Environmental Impact Assessment of Rooppur NPP were carried out by engaging the JSC Atomstroyexport in 2013. Based on the studies, five documentation packages with sixty books were developed. Rooppur NPP project office submitted the necessary documents as per requirements of siting license to Bangladesh Atomic Energy Regulatory Authority (BAERA). After proper revision of the documents, the BAERA granted the **Siting Licence of the Rooppur Nuclear Power Plant** [BAERA-RNPP-01-F-51-0001] on 21 June 2016 to the project authority through proper evaluation of results, reports and documentations developed based on the siting studies of the preparatory stage.

Moreover, systematic investigations at the design stage for derivation of the site-specific design were completed to evaluate the site-specific seismic design basis parameters and other site-specific parameters, particularly, relating to floods, temperatures, winds and other meteorological parameters as well as man-induced hazards for developing design documentation, technical documentations, namely PSAR, PSA documents and QA Programme and the first-priority working documentations of Rooppur NPP.

A systematic engineering-geological study completed at the project site; more than 400 explorations drilled (11 965 м) and more than 6700 samples studied in laboratory. Necessary equipment was installed and aero-meteorological models was developed and the engineering-hydro-meteorological studies performed. The topographic survey of the site region completed and engineering-geodetical studies were performed. For engineering-ecological survey and assessment of man-induced off-site impacts, necessary site monitoring established and the required studied performed.

The results of the geological engineering survey/study of the Rooppur NPP project site indicated that the site soils have weak bearing capacity. Therefore, soil improvement has become inevitable for construction of NPP and other complex engineering facilities of industrial and civil purposes. Based on comparative analyses, the Soil Stabilization Method by deep soil mixing technology has been adopted improvement of soil below excavation pit for buildings and structures of Rooppur NPP to ensure safe operation during the entire lifetime of the plant. The technique of soil stabilization with cement slurry (boring and mixing technology) has proven references of construction of complex engineering facilities of industrial facilities. The estimated the best possible volumetric amount of cement content is in the range of 240 – 250 kg/m3. However, in case of Rooppur NPP a conservative is made, the volumetric content of cement equal to 275 kg/m3 is using to ensure predetermined positive results of all the strength and deformation indicators. According to the study, the possible depth of liquefaction is minus 5.9m, i.e. it is mainly limited to the upper part of soil mass and the liquefaction study has confirmed that soil below 20m of Rooppur site will not liquefy. A technical and regulatory decision was made on consolidation under the base of Rooppur NPP and other complex structures and by means of cement-bound curtain cutoff to the depth of about 20m (meter) below excavation pits (it is predicted that the liquefiable zone below 20 m is absent), with deformation module under the long-term loading at least 100 MPa, angle of internal fraction of 35 degree and strength in uniaxial compression of 2 MPa. The BAERA granted **Approval on the Soil Stabilization Works under the buildings of Units Nos. 1 and 2 of the Rooppur NPP construction site** under the conditions of the Siting Licence No. BAERA-RNPP-01-F-51-0001 of 21 June for Units 1 and 2.

The seismic and geotectonic studies have been conducted. The study of seismic hazard assessment provided the seismic design parameters: Average Safe shutdown earthquake (SSE) intensity 8 points on MSK-64 scale (peak acceleration 0,33g) and average design basis earthquake (DBE) intensity 7 points on MSK-64 scale (peak acceleration 0.17g).

Based on a comprehensive hydrological, hydraulic and morphological studies of the site, the scenario of the maximum probable flood (MPF) formation has been determined. In prediction of the MPF scenario, the combination of all possible hydrological events were taken into consideration with probability of 0.01% (with frequency once per 10,000 years): (1) simultaneous flood peak occurrence including precipitation on all major river basins, (2) Bay of Bengal water fluctuation impact, (3) additional precipitation and sea level rise due to global climate change (global warming scenario) and (4) a failure of the Farakka dam located higher up the river Ganges (Padma). Based on the analyses, the design values of the MPF level is found 18.44m in the PWD (Public Works Department) system of elevations, or 17.981 elevation mark in the MSL (Mean Sea Level) system. According to relevant international guidelines, the general layouts of industrial enterprises shall be at least 0.5 m higher than the design MPF level. For Rooppur NPP, a 19.00 MSL site grade, more than 1.00 m above the design MPF level was considered to ensure site protection against flooding. The mark 19.15m MSL is accepted as a relative mark 0.00 of power units to guarantee that the plant will remain non-flooding under maximum levels of water rising. A technical and regulatory decision was made to backfill from top of the soil-concrete reinforced basement to the 19.00 m MSL grade to protect the territory against groundwater level rise consequences. Moreover, through analyzing the site under-flooding due to ground waters, it was ensured that the extreme level of ground waters would at elevation 15.50 m MSL. To protect all buildings and structures of the 1st category against the ground waters, the Rooppur NPP design has provided reliable waterproofing of the underground parts of the buildings and structures up to the grade. Thus, the engineering protection of Rooppur NPP against all possible flooding and under-flooding is provided by the design. In addition, the catch drains are designed for removal of surface and overflow waters from the lower relief areas of the territories adjacent to the NPP site to ensure normal operation of the constructions related to I-III safety categories. The design solution of Rooppur NPP site protection from the river Padma has also been made.
The Rooppur NPP site has tropical climate. The detailed engineering survey on extreme wind loads including a tornado and extreme temperatures were performed. The observed air

temperature: max: +44°C and min: +3.5°C. Based on the detailed study of the climatic conditions, the design parameters of the Rooppur NPP ventilation systems, plant cooling capacity, fluid coolant consumption parameter, supply pipelines diameters, air conditioning systems, architectural and planning concepts of the rooms have been designed. With due consideration of the quality and physio-chemical properties of the water of the Padma River as well as water level, the chemically demineralized water preparation system, structure of the cooling system of the main equipment (two cooling towers per unit), auxiliary power supply system, etc. has been designed.

The feasibility evaluation, site engineering survey and environmental studies and environmental impact assessment of Rooppur NPP justified the techno-economic feasibility of the construction project and substantiate the site for nuclear power plant construction. The outcomes of these studies are: (1) substantiation of Rooppur NPP construction site location and its site protection from natural and anthropogenic adverse effect (protection engineering); (2) decision on the principal space planning and design solutions for the most complicated and safety related buildings and structures and their protection engineering; (3) Rooppur NPP layout plans (situation plan and general layout); (4) elaboration of documentation packages for obtaining licenses required for NPP construction and (5) enveloping the VVER technology of AES-2006 design (VVER-1200).

All the of the above studies were carried out to receive materials for confirmation of the NPP technology and construction site in terms of nuclear safety and obtaining the right for design and construction of Rooppur NPP. Twelve documentation packages containing total 3436 books have been prepared. These documentation packages include NPP Design Documentations (total books no. 316), PSAR 18 Chapters 2 Appendices (total books no.44), PSA Level-1 (total books no. 11), EIA Reports (total books no.4), first-priority design documentation (total books no.1301) and first-priority working documentation (total books no. 1770). In addition, the Technical Assignment for Design of Rooppur NPP Unit-1 and Unit-2 was also developed. After proper revision of the documents, the authority, BAERA granted the **Design and Construction Licence for Rooppur Nuclear Power Plant Unit 1** on 2nd November 2017. This licence granted rights to BAEC (licensee) for design and construction of Unit 1 of Rooppur NPP with VVER-1200 (AES-2006) technology. In addition, after comprehensive review, the EIA Reports of Rooppur NPP was approved by the Department of Environment on 26 November 2017.

4.2 Site development and first priority civil construction and erection works

By the beginning of 2014, the civil and erection works for construction of the pioneer base and first-priority facilities of the construction and erection base at Rooppur NPP site were performed. The physical works includes land development, civil and erection works such as workshop, cement warehouse, chemical additive warehouse, construction laboratory, health center, general contractor building, amenity building, indoor warehouse, storage area for equipment and materials, development of pit for Unit 1 and Unit 2 for soil stabilization works.

Based on the safety evaluation report on safety status report of test field soil mass stabilization by deep soil mixing, BAERA granted approval for soil stabilization works at Rooppur NPP site on 9 July 2017 and the soil stabilization works under the buildings of Rooppur NPP Unit

1 had begun. The physical and mechanical characteristics of the stabilized soil mass has confirmed the design requirements and regulatory requirements. The soil stabilization works under Rooppur NPP Unit-1 had been completed and development of foundation of Unit-1 was made ready for First Concrete Pouring.

The first concrete pouring date is termed as FCD (First Concrete Date), which is the starting of construction of nuclear power plant. The inaugural ceremony the FCD, the first nuclear safety-related concrete at “Rooppur NPP” by the Hon’ble Prime Minister, Sheikh Hasina on 30 November 2017 has the beginning of construction at Bangladesh’s first nuclear power reactor. This ceremony has marked a significant milestone in the decade-long process to bring the benefits of nuclear energy to the world’s eighth most populous country.

4.3 Rooppur NPP Design Selection and Design Elaboration

The criteria of the selection of the design of NPP technology is basically focused on the projected demand for nuclear power generation, size, life-time, availability and capacity factor of the plant, provenness, licensability, simplicity and standardization of the design, operability and maintainability of the plant, etc. The design of Rooppur NPP is selected due consideration of these key features of NPP technology assessment suggested by the IAEA guiding documents as well as economics of construction and operation of NPP and techno-normative basis of licensibility, constructability and operability of the plant.

The Rooppur design is elaborated on the basis of the size and stability of the national electricity grid, project site characteristics (i.e. seismicity of the selected site, climatic condition, maximum probable flood scenario, soil condition, availability of water resources for ultimate cooling, the accessibility to water ways or other appropriate transportation routes for the transportation of large components or modules) are important factors in selection of the design. the design-basis of radiation protection, Environmental Impact Assessment, Emergency Preparedness, nuclear safety, security and safeguards aspects are also addressed into the design. With due consideration of project site suitability, techno-economic viability and regulatory and safety requirements, the latest addition to Russian VVER series i.e. AES-2006 (VVER-1200) design technology has been selected. The word VVER in Russian is Vodo-Vodyanoi Energetichesky Reaktor and in English it is Water-Water Energy Reactor, which is a Pressurized water reactor where water is used as both coolant and Moderator.

The Novovoronezh NPP-2 is the reference plant for the Rooppur NPP. The reactor plant is assigned with index B-523, while the Novovoronezh NPP-2 is assigned with index B-392M. The Rooppur NPP (reactor plant B-523) is an evolutionary development of the VVER reactor plants which meets all the safety features of a modern PWR as per the current Russian, Western, and IAEA standards and profitability requirements. It is a Gen-III+ VVER reactor. The Rooppur NPP is developed based on calculations and experimental justification of VVER-1000 and VVER-1200 designs with elaboration of designing, equipment manufacturing, construction and commissioning experience of Novovoronezh NPP-II and experiences in operation of the most recent VVER reactors in Russia and abroad.

Each reactor unit (Unit-1 and Unit-2) of the Rooppur NPP consists of the reactor plant (RP) with water-cooled power reactor with pressurized water and a turbine unit. The thermal diagramme is double circuit. The primary circuit is radioactive and comprises mainly RP (heterogeneous reactor including reactor vessel, reactor internals, upper unit with control rod drives, core, in-core detector assemblies, main connector leaks control device, surveillance-specimens, compression unit); heating parts of four steam generators (under elevated conditions with increased diameter of vessel including supports and fasteners, leveling vessels, hydraulic shock absorbers); four main circulating pumps (MCPs) with supports and fasteners; a steam pressurizer (including pressurizer with support, fasteners and TEH units, pipelines, PRZ PSD, valves, bubbler tank with supports) and auxiliary equipment. The RP also includes passive part of the ECCS (including four ECCS tanks, ECCS pipelines with valves and fasteners, ECCS PSD); passive core flooding system (including eight tanks HA:2);passive hydrogen recombiners, emergency gas removal system; equipment of the reactor concrete pit, Inner and outer Containment etc. The secondary circuit is non-radioactive and comprises steam generating part of the steam generators, main steam lines, a turbo generator set with a turbine installation and a turbine generator, a condensate pump, a system of low pressure regenerative heaters, a condensate system, deaerators, a feed water system including feed water pumps, and a system of high pressure regenerative heaters.

The fuel is low-enriched uranium dioxide with maximum enrichment to 5,00 % in ^{235}U ((4,95 ± 0,05) %). Gadolinium in the form of gadolinium oxide (Gd_20_3) with natural content of isotopes is used as the integrated burnable absorber. A nuclear reaction with thermal neutrons generating thermal energy takes place in the reactor core. Upon passing the reactor core, heated primary circuit coolant goes to steam generators where it gives away heat to the secondary coolant water through the walls of pipe system. The coolant goes through the main coolant pipe from the steam generator back to the reactor to be reheated. The four MCPs ensure circulation in the primary circuit.

Electrical systems of each Unit of Rooppur NPP consists of systems for the generation of power and its integration with the national grid. The system also includes the auxiliary power supply system for the startup and operation of the plant itself. The power generation system includes the generator with capacity of 1,200 MW with a voltage rating of 24KV and unit transformers with a capacity of 3x533 MVA.; The auxiliary power supply system contains sources of operating, backup and emergency power supply. Auxiliary emergency power supply is ensured by diesel generators and storage batteries. On the electrical systems, the Rooppur NPP has more powerful Emergency Power Supply System (EPSS) diesel generators and a common-unit diesel generator (DG capacity is 10,500 kW where the reference NPP has 6,070 kW of the DG. Moreover, the plant design provides for two storage batteries, which is designed to bring the NPP units into the controlled conditions and to actuate some of the safety systems during accident and post-accident (if occur, which is very unlikely to happen).

It is worthily mentioning that the Rooppur NPP meets the requirements of all four important dimensions of nuclear safety: structural integrity safety, thermal hydraulic safety, radiation safety and neutronic safety. The plant design also envisages safety systems based on different action principles: (1) inherent safety features, (2) active/engineered safety features/ and (3) passive safety features. The operating time of active systems of this NPP is not limited if power supply is available. The passive safety systems do not rely on any electric power supply for their functioning. These safety systems are those safety systems that use natural forces like gravity, natural circulation, pressure of compressed gas, etc. for ensuring safety of the reactors. The operating time and efficiency of the passive system ensure the performance of safety functions for at least 24 hours including the operation under blackout conditions.

The combination of active and passive safety systems of Rooppur NPP ensures that all three safety functions of a nuclear reactor: to control reactivity, to remove core heat and to contain radioactive substances will be fully functional during normal operating conditions as well as unusual situation or accidental conditions. For example, to *control reactivity*, the Unit-1 and Unit-2 of Rooppur NPP have adequate active safety systems: emergency boron injection system, high-pressure emergency boron injection system and spray system and a passive safety: reactor emergency protection system. There are several active safety systems and passive safety systems for *remove decay heat* from the RP. The active safety systems are as follows: steam generator emergency cool-down system, high-pressure emergency boron injection system, emergency and planned cool-down system, essential loads cooling water system, component cooling system for essential loads of the reactor compartment, ventilation and air-conditioning support system. The passive safety systems specified by the design for *remove decay heat* include 1st stage hydro-accumulator ((passive part of the emergency core cooling system), low pressure second stage hydro accumulators and passive heat removal from steam generators with air heat. To ensure to *confine radioactivity*, the active safety systems include containment sprinkler system and annulus ventilation and rarefaction system while the passive safety systems include double containment; emergency containment hydrogen removal system; containment hydrogen concentration monitoring system; annulus passive filtration system; leak-tight enclosure system and molten core catcher.

The other features of Rooppur NPP as simple and rugged designs are, higher service life of main equipment (50 to 60 years, which can be increased significantly) without necessity of replacement, a long "grace periods" requiring no active intervention for the first 24 hours during a design basis loss of coolant accident (LOCA) and station blackout (SBO) and the higher "burn up" to reduce the fuel and the amount of radioactive waste, etc.

Moreover, necessary measures were implemented in the Rooppur NPP design to protect the plant against the extreme external natural impacts: seismic effects, extreme level of ground waters (NPP site under-flooding), extreme wind loads including a tornado, extreme temperatures, external air shock wave, lightning strokes, external fires, airplane crash, etc. and man-induced impacts. The double containment provides protection against external events and the containment building is the single most important part of the multiple barriers provided against radioactive release to the environment. The building and facility structures, process pipelines and other communication lines and structures are designed based on the following seismic impacts: Safe shutdown earthquake (SSE): 0.333g, (intensity VIII according to MSK-64 scale); design basis earthquake (OBE):0.172g (intensity VII according to MSK-64 scale). The Rooppur NPP components of Seismic Category I (structural units of buildings and structures, equipment, process and other service lines) are being additionally tested for resistance to earthquake with intensity 1.4 SSE. The seismic impact as above is accounted as a beyond design basis impact. The NPP design approaches has been taken to ensure fire protection including fires caused by a seismic impact.

A release of radioactive material to environment is not permissible in case of 1.4 SSE seismic impact. The calculations have demonstrated that the stability of main equipment and building structures is ensured in case of increased seismic impacts. Radiation safety is organized and implemented to prevent inadmissible effect of ionizing radiation sources on personnel, population and environment in the Rooppur NPP location area. The Rooppur NPP is designed in such a way that it will fulfill the fundamental principles and radiation safety norms, as well as to limit radiation impact on environment so as not to exceed the limits established by national and international organizations.

During normal operation, the exposure doses absorbed by the personnel and population, and the release of radioactive substances into the environment shall be kept below the established limits at reasonably achievable and socially and economically justified low level. The radiation consequences of design basis accident in the worst case would be limited within 300 meters at the border of sanitary protection zone maintaining the dose limits as per the regulatory documents. Reliable five layers of barriers prevent the radiation exposure to people and environment even in the worst-case scenario as shown in Figure-1.

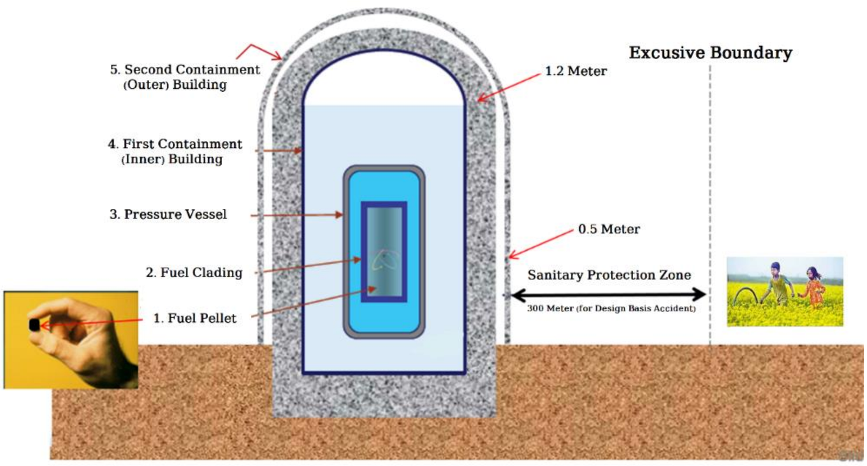

Figure 1: Five layers of barriers against the radiation exposure to people and environment

The safety system of Rooppur NPP is based on active safety systems with both normal and emergency power supply. To prevent severe accidents or mitigate their consequences, passive safety systems are envisaged which function without the involvement of the NPP personnel and do not require any power supply. In case of a severe accident with extreme power loss due to grid failure (like Fukushima NPP accident) the Rooppur NPP will remain safely shut-down for at-least 72 hours without the involvement of external assistance and off-site power supply.

5. Construction of Rooppur NPP – the First NPP of Bangladesh

The Rooppur NPP is the largest infrastructure project in Bangladesh. The Rooppur NPP is being constructed under that the General Contract includes detailed engineering design, civil construction, procurement, supply of equipment and materials and transportation them to the site, inspection, installation, testing, commissioning, comprehensive demonstration test of equipment and related works, training of the Rooppur NPP personnel for management, operation & maintenance and handover of the plant to the customer. Civil construction activities of different nuclear and non-nuclear facilities and supply of equipment and materials are progressing according to the schedule.

The Rooppur NPP have two units, each with power generation capacity of 1,200 MWe. The pouring of the first nuclear safety-related concrete at Rooppur NPP Unit-1 was on 30 November 2017. The first concrete pouring to the basement of the first unit was the begining of the nuclear construction activities. Under the provisions of the Design and Construction Licence of Unit-1, BAEC completed soil stabilization works and other civil construction works under the Reactor building Unit-1 and prepared the safety status report for consideration of BAERQ. **BAERA granted approval for concreting pouring on the foundation of plate of Reactor Building including transport Portal of Unit-1** on 18 February.

The concreting pouring works for the foundation plate of Unit-1 has been completed with due compliances of the design requirements, licensing conditions of Design and Construction Licence of Unit-1 and all other regulatory requirements of BAERA. Based on the final safety status report of the concreting works and all justification documents on civil engineering structures of the reactor building and Chapter 3 of the PSAR for Rooppur NPP, the **BAERA granted approval of continuation of the activities at the Reactor Building of Rooppur NPP Unit 1 up to the ceiling level of 0.000 as per the design on June 10, 2018**. Presently, the civil and construction works for development of the containment walls, outer walls, inner walls, reactor pit walls, core catcher placement foundation and core catcher walls are being performed. The First Unit of Rooppur NPP will be producing electricity on experimental basis at the beginning of 2023, provisional take over and final takeover at the end of 2023 and 2024, respectively.

Figure 2: Construction activities at the Unit-1 of Rooppur NPP up to the ceiling level of 0.000

Figure 3: Completion of Reinforcementat works ready for First Concrete Pouring Unit-2 of Rooppur NPP

The soiling stabilization works under Rooppur NPP Unit-2 have been commenced and the final safety status report of the Reactor Building of Unit-2 (20UJA) prepared and submitted to BAERA for granting Design and Construction License for Rooppur Nuclear Power Plant Unit-2. The Authority granted the **Design and Construction Licence for Rooppur Nuclear Power Plant Unit-2 on July8, 2018. All necessary works including reinforcement works have been completed and this unit is ready for celebrating the** FCD ceremony of the Unit-2 of Rooppur NPP on 14 July 2018 in presence of Hon'ble Prime Minister of Bangladesh.

The fuel loading/commissioning of this unit will in October 2023 and the provisional and final takeover will be October 2024 and October 2025, respectively.

6. Conclusion

Construction of Rooppur NPP is the biggest project in the country's history. It is the biggest development initiative not only for its project cost, but also because its construction is the evidence that we do have the courage and conviction that are necessary for undertaking such modern, scientific, safety and security related highly technological intensive such as nuclear technology for production of electricity. The source of our courage and conviction is the dream of the Father of our nation Bangabandhu Sheikh Mujibur Rahman.

The Roopppur NPP consists of two VVER type (AES-2006) reactors each with a 1200 MW(e) gross electricity generation capacity. The referential project for Rooppur NPP is Novovoronezh II NPP in Russia, which is a unique new Generation 3+ power unit with two VVER-1200 reactor units. Bangladesh started preparatory construction activities in 2013 with technical and financial assistance of Russian Federation. Honorable Prime Minister Sheikh Hasina launched the nuclear power construction of the country's first nuclear plant on 30 November, 2017 by pouring concrete at the construction site of the Unit-1 of Rooppur NPP. For 60 years, Bangladesh has had a dream of building its own NPP. The first concrete pouring of Rooppur NPP on 30 November 2017 was a milestone in the national development programme, it was a step to forward to realize of the dream. Bangladesh has becoming a proud member of the socalled elite “Nuclear Club” through this event. The Prime Minister will also inaugurate the first concrete pouring ceremony of the Unit-2 of Rooppur NPP on 14 July 2018. The two units generating 2,400 MWe will be operational in 2023 and 2024. For 60 years, Bangladesh has had a dream of building its own nuclear power plant.

The Rooppur Nuclear Power Plant will provide not only low cost electricity, it will provide clean, reliable electricity that will be delivered 24/7, so that people can meet their needs and aspirations without harming the environment. It will also enhance our knowledge and allow us to increase our economic efficiency and security awareness.