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A Perspective Human Resource Development Model for the Nuclear Power Plant of Bangladesh

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ABSTRACT

The successful and peaceful use of nuclear power requires a competent, sustainable human resource plan. The International Atomic Energy Agency (IAEA) identifies Human Resource Development (HRD) as a critical milestone for countries embarking on nuclear power programs. As a newcomer to the nuclear industry, Bangladesh faces significant challenges in developing a skilled workforce to ensure the safe operation and long-term sustainability of nuclear power plants. Despite ongoing technical and infrastructural development, a structured and context-specific HRD framework for the nuclear sector remains insufficiently addressed. This study proposes a comprehensive human resource development model tailored to the needs of Bangladesh's nuclear power program. The model provides a strategic roadmap for capacity building by defining workforce requirements, identifying key stakeholder groups, outlining education and training pathways, addressing institutional and policy challenges, and incorporating national policies alongside international cooperation mechanisms. Particular emphasis is placed on aligning national initiatives with IAEA guidelines to ensure compliance with global safety and security standards. The proposed framework aims to support the development of a highly skilled and sustainable professional workforce capable of ensuring the safe, secure, and efficient operation of nuclear facilities in Bangladesh. By strengthening national capacity in nuclear human resources, the model contributes to long-term energy security, regulatory effectiveness, and sustainable socioeconomic development.

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1. INTRODUCTION

In recent years, the world has experienced a remarkable increase in energy demand, which has played a significant role in driving fluctuations in global climate conditions. Many factors influence rising energy demand, including population growth, urbanisation, and economic development. Electricity consumption has also increased globally due to changes in lifestyle and the spread of technologies, including electric vehicles and digital devices. Bangladesh faces significant challenges in meeting rising energy demand, driven by oil, coal, and other fossil fuels. (Islam et al., 2014). Currently, a major portion of the energy comes from natural gas. However, natural gas reserves are limited and are expected to be depleted within the next few years. Moreover, burning fossil fuel produces many other harmful gases, such as carbon monoxide, nitrogen oxides, and sulphur dioxide, which contribute to air pollution and pose serious health risks. To meet rising energy demand and mitigate health and environmental risks, many countries have designated nuclear power plants as a strategic priority. The utilisation of nuclear technology is well known today and expanded day by day to consider the technical, financial and environmental aspects. By considering these aspects, many developed and developing countries with dense populations and low energy resources also started using nuclear technology. (Karim et al., 2018). In Bangladesh, the introduction of nuclear technology represents a transformative step toward achieving energy security and reducing dependency on fossil fuels. As Bangladesh's population and industrial base expand, so does the demand for reliable electricity. Bangladesh has begun construction of the first nuclear power facility, the Rooppur Nuclear Power Plant (RNPP), a significant milestone in the energy landscape. By signing this significant milestone, Bangladesh has become the 33rd nuclear-armed nation. (Karim et al., 2018).

The peaceful application of nuclear technology in Bangladesh began in the 1960s under the Pakistan Atomic Energy Commission (PAEC) (Ashraf and Islam, 2018). After independence, Bangladesh joined the International Atomic Energy Agency (IAEA) in 1972 (Mollah, 2005). The Bangladesh Atomic Energy Commission (BAEC) was established in 1973 to apply nuclear technology and science to advance the country. (Mollah, 2005). The idea of constructing a Nuclear Power Plant (NPP) in Bangladesh was first proposed in 1961, with the Rooppur site chosen for the first NPP. (Siddiky, 2015). Considering resource constraints, Bangladesh developed the NPP through an Inter-Governmental Agreement (IGA) with the Russian Federation in 2011 (Bhuiyan et al., 2015). BAEC was designated as the client for the IGA, serving as the government's representative.**2.** A General Contract was signed between BAEC and JSC ASE, an engineering company of ROSATOM, to implement the agreement. This development emphasizes the government's willingness to embrace renewable energy solutions and the need for robust human resource development.

The nuclear energy industry demands a skilled and efficient workforce, including engineers, technicians, radiation safety specialists, regulatory compliance specialists, operational managers, and emergency preparedness specialists. Bangladesh, in its early stages of nuclear power program, faces challenges in developing a strong workforce. The country has a limited number of nuclear scientists and engineers due to recent inclusion in the national energy policy and a lack of industry-specific training and education programs. The global shortage of experienced nuclear sector experts exacerbates the problem. Although several studies have been conducted on RNPP, focusing on economic feasibility analysis, environmental impact, sedimentation in the Padma River, grid integration, and reactor technologies, several critical gaps remain in the structured HRD framework for Bangladesh's nuclear power plan. Currently, a limited number of research works have been published on the systematic assessment of workforce size, workforce distribution, and long-term staffing projections aligned with the different phases of nuclear power plants. To address this, Bangladesh must embrace innovative human resource development approaches, including capacity-building through education and training programs. The development of local expertise can be accelerated through collaborations with nations that have established nuclear power programs and partnerships with international organizations. Incorporating nuclear science and engineering into academic curricula at universities and technical institutes can also help develop a trained workforce. These activities must be supplemented with hands-on training, simulation-based learning, and internships at operational nuclear sites to provide practical experience. The objectives of this research are to develop a systematic, nationally specific HRD framework, along with mechanisms for institutional coordination, succession planning, and knowledge management, to support the long-term execution of Bangladesh's nuclear power program. In addition, the study seeks to examine the institutional coordination and knowledge management mechanisms required to ensure sustainable workforce development in Bangladesh's nuclear sector.

In the following sections, this paper will discuss the current study on human resource development in the embarking country and the infrastructure in Bangladesh for the peaceful use of nuclear technology within its territory. This research paper proposed a human resource development plan for nuclear energy based on a thorough examination of existing legislation and the exploration of best practices aligned with international standards. The success of Bangladesh's nuclear power program and its larger goals for energy sustainability and economic growth ultimately depend heavily on its human resources.

2. LITERATURE REVIEW

As Bangladesh embarks on its journey as a newcomer in the field of nuclear power, the establishment of the RNPP on the bank of the Padma River, featuring a 2400 MW VVER-1200 reactor, marks a significant milestone. (Alam, 2024). However, the country faces notable challenges, including technology, skilled workforce, and effective management. Researchers have approached these challenges from various perspectives to identify and address the limitations. Key areas of study include radiation measurement, its existence and management, water availability, river sedimentation in the Padma River, geological considerations, electrical systems, reactor technology, and nuclear materials. This section highlights research on the RNPP, summarising studies on human resource development (HRD), SWOT analyses, achievements to date, existing gaps, and ongoing internal research efforts.

Economic assessments have also been conducted to evaluate the cost of electricity generation from RNPP relative to regional nuclear projects. For instance, Goswami, Rahman, and Chowdhury (2022) analysed the economic viability of nuclear power in Bangladesh and argued that, despite higher estimated generation costs compared to some neighbouring projects, nuclear energy remains a strategic option for ensuring long-term baseload electricity supply and low-carbon generation. While these studies contribute valuable insights into the techno-economic and environmental aspects of RNPP, they largely overlook the structured development of human resource capacity necessary for safe and sustainable plant operation. International literature consistently identifies human resource development (HRD) as a decisive factor in the success of nuclear power programs, particularly in newcomer countries. In a related perspective, Jafaru et al. (Egieya et al., 2022) investigated effective HRD programs for nuclear power plant (NPP) generation in Nigeria. The study concentrated on three major workforce groups: owners/operators, regulators, and construction workers. According to the data, roughly 9,045 individuals (73% construction employees, 24% owner/operators, and 3% regulators) must be effectively engaged in the NPP program by 2033; however, this number drops by 73% as the project proceeds and enters the operational phase.

Aram et al. (Gevorgyan & Marukhyan, 2011) examined Armenia's challenges in nuclear expansion. They highlighted the need to align national educational curricula with projected reactor deployment, identifying training capacity and

institutional preparedness as critical constraints—similarly, Gregor et al. Androjnažagar & Špiler (2008) investigated the HRD specifications for a new NPP in Slovenia, comparing the native scenario with global projects. The analysis identified a need for approximately 300 employees at the Slovenian NPP, with the retirement of current workers a significant obstacle. TVO drew comparisons to the Finnish Olkiluoto 3 reactor project, which began with 300 people in 2006 and has since expanded to over 3,000. To sustain nuclear power growth in Slovenia, the report underscored the risks posed by workforce ageing, retirements, and the lack of long-term succession planning. Namgung et al. (Namgung, 2013) focused on HRD initiatives for NPPs in Korea, where the nuclear sector faces a shortage of skilled engineers and operators. To solve this, Korea founded the KEPCO International Nuclear Graduate School (KINGS) as an autonomous school. Its curriculum focuses on hands-on training, bridging the gap between business and academia while addressing the technical competence shortage caused by an ageing workforce. KINGS also intends to share Korea's NPP development expertise and technology with developing nations by offering free programs for overseas students. While international HRD studies provide useful benchmarks, they cannot be directly applied to Bangladesh due to differences in institutional capacity, regulatory maturity, and educational infrastructure. Despite extensive research on the RNPP, no study has systematically assessed workforce requirements, identified competency gaps, evaluated training lead times, or aligned HR planning with the IAEA's Milestones in the Development of a National Infrastructure for Nuclear Power. This gap highlights the need for a structured, phased HRD framework. The present study addresses this by proposing a nationally tailored model that integrates workforce planning, competency development, institutional coordination, succession planning, and knowledge management to support sustainable nuclear power operations in Bangladesh.

3. NUCLEAR POWER INFRASTRUCTURE OF BANGLADESH

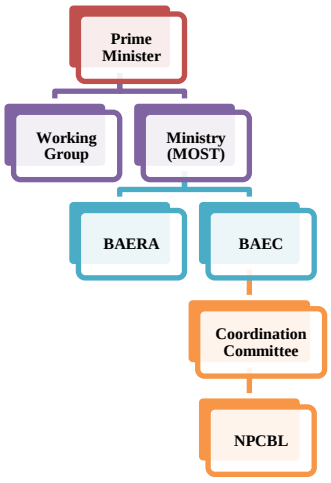

Figure 1: The structure of NEPIO of Bangladesh

The adoption of nuclear power raises critical safety considerations, necessitating robust nuclear infrastructure aligned with IAEA safety standards and guidelines. The government of Bangladesh formed the Nuclear Energy Program Implementing Organization (NEPIO) in 2010 as a high-level management authority to overlook the IAEA safety standards and guidelines (Islam et al., 2021).

The NEPIO of Bangladesh is responsible for overseeing the planning, development, strategic guidance, policy formulation, and coordination among stakeholders and implementation of nuclear projects, including the RNPP. The organization operates through key entities like BAEC, working groups and specialized Coordination Committee.

The RNPP's structure relies on multi-organisational cooperation, as depicted in Figure 2, which plays a critical role in promoting proper coordination and control. The Ministry of Science and Technology (MOST) is the main governing body and has been in control of BAEC, the owner of the NPP. To enable the project, BAEC cooperates with some major organizations, such as the Bangladesh Atomic Energy Regulatory Authority (BAERA), which guarantees the compliance with to the nuclear safety and regulatory requirements. The general designer and the contractor are Joint-Stock Company Atomstroyexport (ASE) which controls subcontractors of Bangladesh, Russia, and other countries to carry out construction and specialized tasks. The Ministry of Finance (MOF) will support the project financially and in regulatory terms, and the Department of Environment (DOE) will monitor environmental standards and proper environmental management throughout the project's life.

The most important construction and operator company, Nuclear Power Company of Bangladesh Limited (NPCBL) is the designated operating organization for RNPP, as outlined in the Nuclear Power Plant Act of 2015. During the operation and maintenance phase, RNPP will be managed under a comprehensive organizational structure that includes the RNPP Power Units Operation and Maintenance, the Emergency Management Department, the Security and Physical Protection System (PPS) Division, the Economics and Finance Division, HR Management Division, Administration Management Division, Inspection Division and Construction Division.

On June 19, 2012, the government enacted the "Bangladesh Atomic Energy Regulatory Act" (BAERA, 2012) (Islam & Islam, 2016), aiming to create an efficient independent Regulatory Body and to introduce Nuclear Law in the country. The key provisions of the BAER Act of 2012 address nuclear safety, security, and the safeguarding of nuclear and radioactive materials, as well as civil liability for damage caused by a nuclear accident. In accordance with this legislation, an independent regulatory body was constituted on 12th February, 2013 (Hossain et al.). The prime responsibility of BAERA is to supervise licensees' activities to ensure compliance with nuclear safety, security, liability and safeguards. For regulatory activities, several departments operate under the supervision of the Regulatory Authority's Chairman. A General Framework Contract (GFC) was signed between the Russian regulatory authority "TSO JSC "VO" Safety" and BAERA to assist with licensing at different stages of RNPP and in the development of nuclear regulatory infrastructure.

The implementation of management systems for the Operator, Regulator, and Technical Support Organizations (TSOs) in Bangladesh is guided by the Nuclear Power Plant Act of 2015 and the BAER Act of 2012. In a bid to adopt robust management systems, BAEC has established a Quality Management Division (QMD) to monitor these initiatives. Successful implementation of the Development Project Proposal (DPP) of the first stage of RNPP construction and the current implementation of DPP of the most crucial stage of the construction. This is an all-inclusive project management framework that ensures coordination, implementation, and oversight to support the successful construction of Bangladesh's first nuclear plant.

4. HUMAN RESOURCE DEVELOPMENT PLAN

Human Resource Development (HRD) is recognized as Issue No. 11 among the 19 infrastructure issues defined in the Milestones in the Development of a National Infrastructure for Nuclear Power. It constitutes a fundamental requirement for the safe, secure, and sustainable implementation of a nuclear power program. For newcomer countries such as Bangladesh, establishing a competent, adequately staffed workforce is essential to support all phases of nuclear power plant development, including construction, commissioning, operation, and regulatory oversight. In line with IAEA guidance, this section focuses exclusively on the HRD dimension and develops a structured, analytically grounded plan tailored to the national context. The analysis begins by identifying the targeted stakeholders involved in nuclear HRD, including the operating organization, regulatory authority, technical support organizations, academic and research institutions, and relevant government bodies. Understanding the roles and responsibilities of these stakeholders is essential for establishing clear accountability and coordination mechanisms in workforce planning. Subsequently, existing national policies and institutional arrangements related to nuclear education, training, recruitment, and competency development are systematically examined to assess their alignment with international recommendations. Therefore, building on this assessment, a structured HRD framework is proposed that integrates workforce planning, competency-based training, institutional capacity building, and knowledge management mechanisms. The framework is designed to follow a phased approach consistent with international best practices and to ensure progressive development of technical and regulatory competencies. To strengthen analytical rigor, the study further incorporates an estimation of workforce requirements based on international benchmarking and comparative staffing norms from operating nuclear power programs. Finally, the analysis evaluates the different categories of work functions within a nuclear power plant and examines the corresponding education, training, and certification lead times required to achieve operational readiness. Through this integrated and guideline-aligned approach, the proposed HRD model provides a systematic roadmap for developing sustainable nuclear human capital in Bangladesh while ensuring consistency with internationally recognized standards and practices.

4.1 Targeted Stakeholder

The human resource development plan for Bangladesh targets a wide range of entities to ensure the safety, security, and safeguarding of the nuclear facility. The targeted stakeholders typically include government authorities, Academic and research institutes, facility operators, and regulators. These stakeholders collaborate to address the technical, regulatory and social dimensions, ensuring the goals of secure and sustainable nuclear power development. MOST acts as the primary governmental authority overseeing nuclear activities in Bangladesh. This responsibility includes preparing and implementing policies that regulate and monitor nuclear activities nationwide, ensuring compliance with international safety standards and national priorities. To effectively manage these responsibilities, the MOST has established a dedicated Nuclear Power Wing that focuses exclusively on nuclear energy development and regulation. One of the MOST's core priorities is human resource development in nuclear science and technology. Academic and research institutions are identified as key stakeholders in achieving this goal. These institutions play a vital role in building a workforce equipped with the necessary skills and expertise to advance nuclear energy programs while ensuring safety and sustainability. Currently, four prominent universities in Bangladesh offer advanced degrees in nuclear science and engineering. These institutions include Military Institute of Science and Technology (MIST), University of Dhaka (DU), both of these institutions offers both secondary (B.Sc) - and tertiary-level (M.Sc) in nuclear engineering, Bangladesh University of Engineering and Technology (BUET) offers only NPCBL tertiary-level degree (M.Sc) in nuclear engineering, Chittagong University of Engineering and Technology (CUET) offers comprehensive academic programs spanning from undergraduate to doctoral levels. These universities offer specialized higher education programs that equip students with in-depth knowledge of nuclear science and engineering principles. The curriculum in these programs emphasizes nuclear safety, which is a cornerstone of sustainable and secure nuclear energy development. Through these academic offerings, the universities contribute to the creation of a skilled workforce capable of addressing the challenges of nuclear energy applications and ensuring adherence to stringent safety protocols. As the proprietor of the NPP, BAEC has established a framework to adequately train the workforce in both the technical and regulatory aspects of nuclear energy for peaceful purposes. NPCBL, an enterprise of BAEC, as an operator of RNPP, has an HRD plan that identifies a total of 2700 employees for NPCBL, while the total number of employees proposed for the operation and maintenance of Rooppur NPP is 2535. The necessary training for 1424 of this manpower has been ensured under the General Contract from 2017 to 2022, based on Job Position and Job Function at different times, with the contractor's assistance, in accordance with international

standards for each period. (Rooppur Nuclear Power Plant Construction Project, 2017) A skilled workforce is needed not only for support functions but also for the effective, long-term operation of NPPs. BAERA is responsible for overseeing the implementation of safety and security protocols to prevent accidents and mitigate the consequences of risk. In accordance with the Act, BAERA has formulated an HRD Plan, which is supported by the NuRid Project and assisted by a Technical Support Organization (TSO). [Bangladesh Atomic Energy Regulatory Authority, n.d.] The human resource development of the regulatory body is crucial because well-trained personnel of the regulatory body can monitor compliance effectively and take corrective actions as needed. The regulatory body's workforce needs to be competent to align with the international safety standards mandated by the IAEA. The targeted stakeholders work together to advance nuclear energy initiatives while maintaining the highest standards of sustainability, safety, and security, thereby meeting national HR demand through this concerted effort and international collaboration.

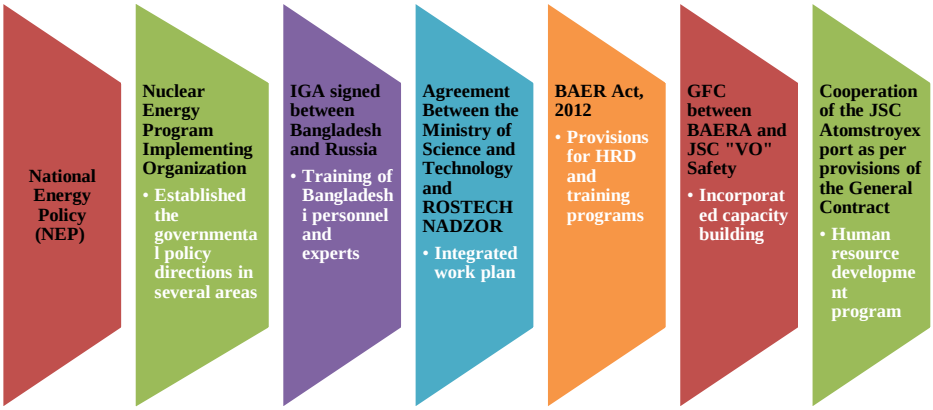

Figure 2: Pictorial view of HRD policies in Bangladesh perspective

4.2 Analysis of Existing Policies

The expansion of the nuclear industry demands a comprehensive policy framework for human resource development. This framework ensures an adequate number of competent workers to meet the sector's operational, safety, and innovation requirements while complying with international standards. Given the complexities of nuclear technologies and their vital social applications, human resource development (HRD) is critical to the global sustainability of nuclear initiatives. The strategy for implementing nuclear power requires several stages. These involve formulating nuclear laws and legislation, conducting feasibility analyses, conducting technological assessments, preparing proposals, and evaluating or negotiating contracts for funding, supplies, construction, commissioning, operation, and decommissioning. Nuclear power plants' success requires extensive planning, readiness, funding, human resources, and the prompt formulation of nuclear infrastructure.

In 1996, the Ministry of Power, Energy, and Mineral Resources of Bangladesh developed the very first National Energy Policy (NEP) (Hossain & Tamim, 2005). It highlighted nuclear technology as a power-generation technology. The government's policy must support the NPP project throughout its life cycle. A newcomer's government often establishes an administrative provision or coordination structure based on the IAEA's perception of a Nuclear Energy Program Implementing Organization (NEPIO) (Ibrahim, 2020). The government designated a ministry as a core ministry or administrative ministry to oversee the nuclear energy program. To accomplish the construction of country's nuclear power facility in a suitable, phased, synchronized, and extensive manner, Bangladesh formed NEPIO as a group of high-degree Government Committees (National Committee, Technical Committee, and Working Committee) that determines overall administrative provision for coordinating efforts on 19 infrastructure related queries as well as formulating relevant strategy and policies on RNPP project development and offering advice and directions essential for the project's proper implementation (Islam et al., 2021). The National Committee's terms of reference encompass offering essential guidelines and directives on nuclear infrastructure policy; determining ownership patterns and project implementation approaches; identifying financing mechanisms; planned collaboration and contract negotiations for RNPP; building capacity and technical proficiency; nuclear safety and regulatory infrastructure development, etc. The decisions of the National Committee have established the governmental policy directions in several areas. Establishing and maintaining the human resources required to oversee the program is one of them (Islam et al., 2021). Back in 2010, the Intergovernmental Agreement (IGA) signed by Bangladesh and Russia laid the foundation for training Bangladeshi personnel and experts to facilitate the construction and operation of the RNPP (Islam & Khan, 2017). In addition, the agreement between MOST and ROSTECHNADZOR, signed on February 27, 2012, and including a comprehensive work strategy, includes provisions for training personnel in the nuclear industry (Bhuiyan et al., 2015). To supervise nuclear and radioactive materials within the country, an independent nuclear regulatory authority, BAERA, was established. Section 11(30) of the BAER Act, 2012, prescribes HRD and training programs for regulatory body personnel, as does Section 23(m), which mandates that the authorization holder

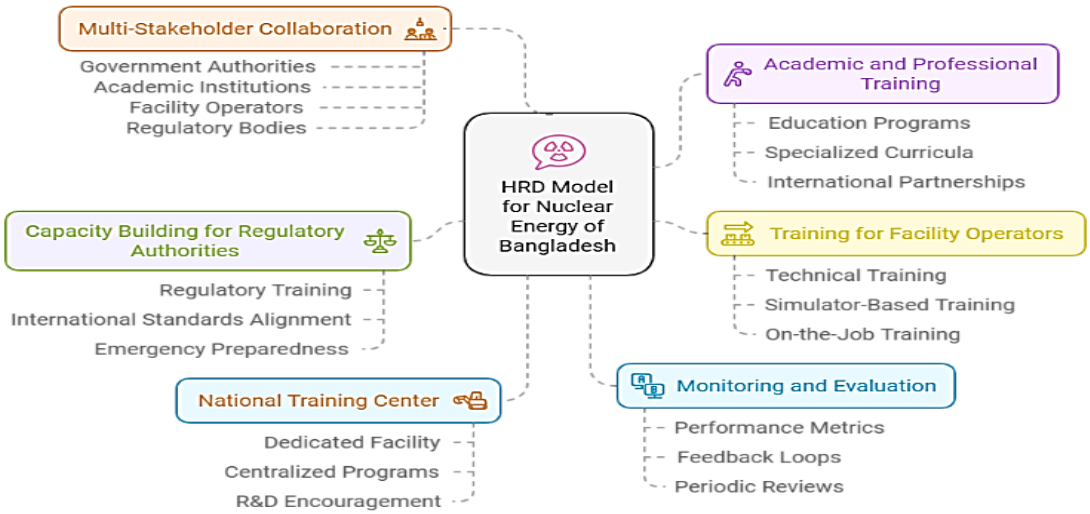

Figure 3: HRD Model for the use of nuclear energy of Bangladesh

be responsible for formulating and sustaining a human resources development program with sufficient funding.

In 2016, a General Framework Contract (GFC) was signed between BAERA and JSC VO Safety, covering 2016 to 2026 and incorporating capacity-building for BAERA personnel. Under this GFC, as mentioned earlier, discussions with JSC "VO "Safety" were conducted regarding assistance to BAERA HRD in 2021 and also in the year 2024 (Kapralov & Demeshko, 2021). However, a full-scope HRD contract is likely to be signed soon under the GFC; afterwards, TSO will cooperate with implementing the HRD plan for the BAERA personnel. NPCBL has been formulating and executing a well-organized, clearly articulated workforce and human resource development program for Units 1 and 2 of the RNPP, in collaboration with JSC Atomstroyexport, in accordance with the provisions of the General Contract for the CRNPP Project (Ashraf & Islam, 2018). The training program for these employees is developed in accordance with the RNPP construction schedule.

Furthermore, the IAEA is helping member nations meet this requirement by developing a milestone-based approach (Ha-Duong, 2024). This approach has been globally acknowledged for executing nuclear power projects, and the strategy divides the nuclear power projects into three stages that operates as a comprehensive guide to assist member states in recognizing the necessities for the peaceful, safe, and secure use of nuclear energy.

4.3 Proposed Framework

The proposed framework for human resource development in Bangladesh for the peaceful use of nuclear energy includes government authorities, the facility operator, and a national education and training institute. A country's nuclear program requires building national expertise and competence. A country may initially depend on foreign skills to introduce nuclear technology. However, it is essential to reduce this dependency over time by developing human resources to sustain the nuclear facility. Different specialized personnel are required in various stages including construction, operation, maintenance and decommissioning of the facility.

The success rate of a nuclear project depends heavily on the presence of skilled and qualified professionals across all disciplines. The HRD model of nuclear energy in Bangladesh includes six key components that focus on collaboration, Training, capacity building, and continuous evaluation to build a highly skilled workforce for the safe and efficient operation of nuclear facilities. Multi-stakeholder collaboration involves cooperation among different government authorities, academic and research institutes, nuclear facility operators, and the regulatory body. The collaboration among these government authorities helps develop a comprehensive approach to national policy-making, capacity building, training, and regulatory compliance. Academic and professional training is essential for developing national-level expertise in the nuclear industry through educational programs with specialised curricula and international partnerships. This process helps to align Bangladesh's nuclear sector with international standards. Training for facility operators is important to guarantee the safety and efficiency of the nuclear power plant. The training for facility operators involves technical training, simulation-based training, and on-the-job training. A well-structured training program can be developed for the facility operator, with assistance from an international expert, by defining the training objectives and target audience. The training program covers theoretical instruction in nuclear physics, reactor operation, radiation safety, cybersecurity, and emergency procedures. Simulation-based training helps the facility operator gain hands-on experience with various nuclear power plant scenarios and ensures they can make quick decisions under pressure. On-the-job training provides nuclear personnel with practical exposure to plant maintenance procedures and troubleshooting techniques. These phases also familiarize the operating personnel with the real-world nuclear safety protocols. The regulatory body plays a crucial role in ensuring the safety, security, and environmentally responsible operation of nuclear power plants. The core

regulatory function involves the authorization, formulation of regulations and guides, regulatory oversight of nuclear material accounting and control, enforcement and communication with interested parties. To enforce safety regulations, conduct inspections, and identify risks in nuclear power plants, a well-trained regulatory workforce is important. Skilled regulatory body personnel impose various national and international safety standards on the operator to reduce the risk of accidents and radiation hazards. The regulatory body's training program should cover key areas, including the formulation of effective policies and regulations; reactor technology and operations; radiation protection and environmental safety; emergency preparedness and response; security and safeguards; inspection techniques; advanced nuclear energy technology; and continuous learning in risk assessment. A dedicated national training facility can be established to provide a standardised training program, hands-on experience, and

According to the International Atomic Energy Agency (IAEA) guidelines (Alam et al., 2019), countries with no prior nuclear experience require at least 15 years to fully develop the necessary infrastructure and expertise for a nuclear power program. This preparatory timeline is divided into four key phases, ranging from the initial decision-making stage to the complete commissioning and operation of a nuclear power plant. Across these stages, at least 2,200 experts are required to build and sustain the program. The distribution of expertise among stakeholders is critical to maintaining a balanced, functional system. As illustrated in Figure 5, the majority of required personnel are concentrated in the operator's organization (68%), as they are directly responsible for the design, construction, operation, and safety of the nuclear power plant. The owner's organization constitutes 18% of the required workforce, reflecting the need for management, financing, and long-term oversight. The regulatory body requires 9%

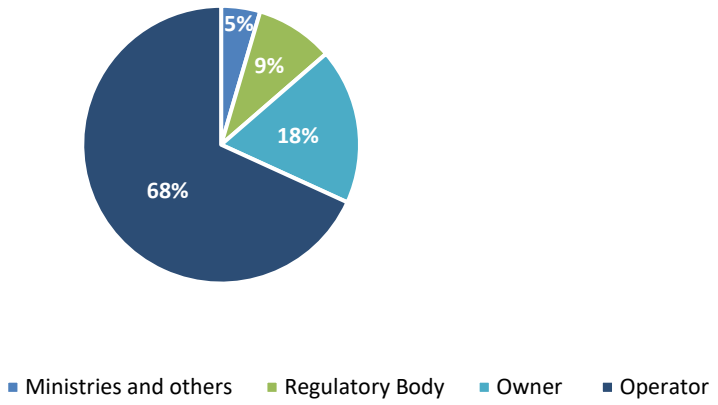

Figure 4: IAEA Requirement to Nuclear Infrastructure development

continued professional development to enhance nuclear safety, security, and regulatory compliance. This training facility can be used as a nuclear training centre, offering centralized program and encouraging research and development. Additionally, this dedicated centre keeps the workforce updated on advancements in nuclear technology and evolving global safety standards. Lastly, the HRD model's performance can be assessed through performance metrics, periodic reviews, and feedback loops. This process helps to refine the training program and regulatory process to meet the nuclear industry's demands. Dependence on a foreign country and the development of a highly skilled workforce can ensure the safe, secure, and sustainable operation of the nuclear power plant in Bangladesh.

4.4 Analysis of Estimated Workforce Requirement: International Best Practice

The safe, secure, and sustainable operation of nuclear power plants can be ensured by highly qualified personnel. For nuclear power plants to be implemented and operated successfully, human resource management is essential. The need for human resources must also comply with national regulations, IAEA guidelines, and nuclear country best practices.

of the personnel, emphasizing its role in independent supervision, licensing, and ensuring compliance with safety and security standards. Lastly, ministries and other stakeholders account for 5% and contribute to national policy, legal frameworks, and inter-agency coordination. This distribution clearly shows that, while all stakeholders are indispensable to nuclear infrastructure, the operator bears the greatest share of responsibility.

The heavy concentration of expertise within the operator's organization reflects the operational challenges and technical complexities of running an NPP. Meanwhile, the regulatory body and ministries ensure oversight, governance, and adherence to international obligations, thus creating a balanced system of accountability and performance.

In the article "Human resource development in new nuclear energy states: Case studies from the Middle East," Banks et al. (2012) state that the International Atomic Energy Agency says specialized nuclear fields may take 5–10 years to train for. Their analysis also shows that only 20-35% of the workforce needed for a civil nuclear power program requires a college degree, and only 20% of that group needs a background in nuclear engineering. In 2009, the UAE

decided to buy four nuclear reactors from a Korean consortium headed by the Korean Electric Power Company (KEPCO). The agreement calls for the construction and commissioning of four APR1400 nuclear reactors with a combined power output of 5600 MW. (BanksMassy & Ebinger, 2012). According to an internal analysis, the Emirates Nuclear Energy Corporation (ENEC) estimates that it will require between 900 and 1,000 "preoperational" employees by 2016, 1,400 preoperational and operational employees between 2017 and 2020, when the UAE's first reactor is expected to come online, and approximately 2200 permanent operational employees by 2020 (BanksMassy & Ebinger, 2012)When will the four reactors in the country be

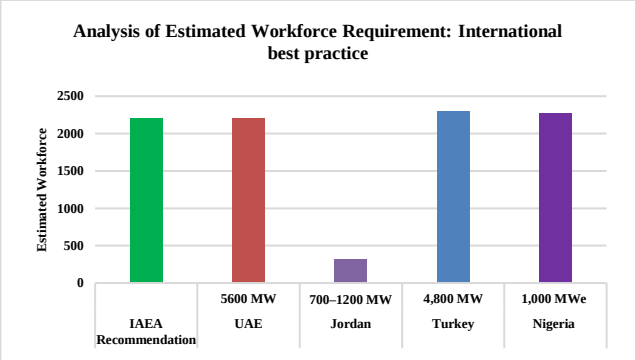

Figure 5: Analysis of estimated workforce requirement: international best practice

expected to be operational? Only a small percentage of the plant's employees need to be nuclear engineers, according to

ENEC's assessments. Additional experts will include technicians, computer scientists, mechanical, electrical, chemical, and power engineers.

By 2020, the Jordan Atomic Energy Commission (JAEC) plans to have a 700–1200 MW reactor operational. (BanksMassy and Ebinger, 2012), and by 2025, a second. JAEC concluded that the ATMEA-1 and AES 92 technologies are the best evaluated contenders on May 1, 2012. The primary problem of building the human resources capability necessary to manage the nuclear sector properly is acknowledged by the Jordan Nuclear Regulatory Commission (JNRC), the nation's nuclear regulatory authority. A thorough workforce planning exercise was carried out by the Commission, which called for 321 employees overall by 2014 (BanksMassy and Ebinger, 2012) Moreover, identified certain talents that would be added as the nuclear program developed.

Turkey's strategy for constructing commercial nuclear power plants stands out among the Middle East's emerging nuclear energy states. The country has signed an intergovernmental agreement (IGA) with the Russian Federation to develop and operate four VVER-1200 pressurized water-type nuclear power reactors with a combined generating capacity of 4,800MW. Turkey, unlike the UAE and Jordan, has not released a white paper detailing its nuclear policy. Hacettepe University, Turkey's foremost nuclear-related university, predicts that the four reactors at the Akkuyu site will require around 1500 workers to operate. The Turkish Atomic Energy Agency (TAEK) has a staff of 800, including around 50 technical professionals who assess licensing applications.

Nigeria aims to include 1,000 MWe pressurized water reactors into its energy mix by 2027-2037. The NPHR model projected workforce needs for a 1,000 MWe pressurized water reactor with the build-own-operate transfer model over 25 years (2015-2040). The NPHR tool estimated that implementing the NPP would need around 2,271 individuals, with a 10% standard deviation (Dahunsi, 2023).

Figure 6 depicts the human resource development breakdown for two Belarusian NPP units with a combined capacity of 2400 MW. In the case of Belarus, major organizing entities include NEPIO, the regulatory body, SSO/TSO, NPP staff, and foreign specialists. Human resources for NEPIO, Regulatory Body, SSO/TSO, and NPP staff are 20, 82, 70, and 2533, respectively, with only 7% of the required staff being foreign specialists (IAEA, 2022).

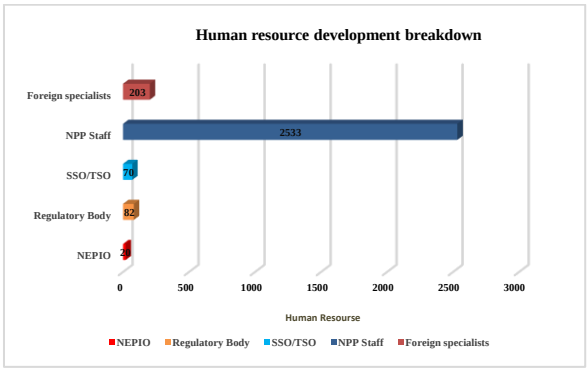

Figure 6: Human resource development breakdown for two Belarusian NPPs.

A developing nation like Bangladesh, with its twin-unit RNPP, requires more than 2,000 technically trained workers (Alam et al., 2019).

The preponderance of personnel required in the manufacturing of equipment and components phase is approximately 3000. In the plant construction phase, it is approximately 2000, for nuclear power plants ranging in size from 600 to 1300 MW(e), as per TRS 200. The Plant operation and maintenance phase will require approximately 220 personnel, while the Regulatory Body will require approximately 50 personnel for licensing and regulation purposes (Figure 7).

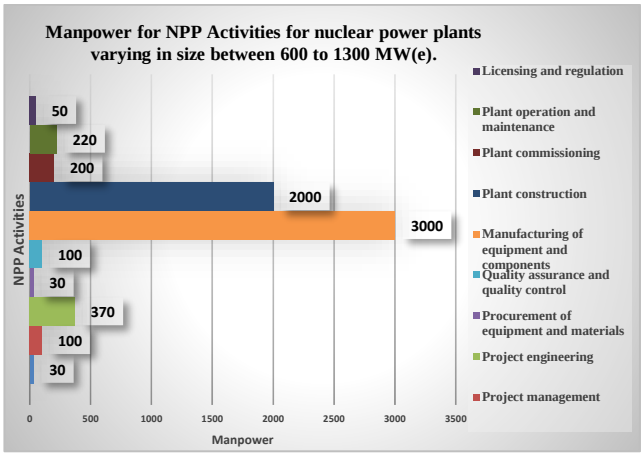

Figure 7: Manpower for NPP activities (IAEA, 1980)

A comparison of the present analysis with the workforce benchmarks provided in Nuclear Power Plant Personnel Training and Its Evaluation (TRS-200) indicates general consistency in the phase-wise distribution of personnel for a reference 1000 MWe nuclear power plant, while also clarifying discipline-specific competency requirements. In this study, TRS-200 is used as an international benchmark framework to evaluate the adequacy of the proposed human resource development (HRD) structure.

TRS-200 recommends that the pre-project phase be dominated by engineering graduates (approximately 57%), particularly from nuclear engineering (reactor physics and safety analysis), civil engineering (site evaluation and seismic qualification), mechanical engineering (thermal-hydraulic design and system configuration), electrical engineering (grid integration and power systems), chemical engineering (coolant chemistry and fuel cycle considerations), and environmental engineering. The present assessment aligns with this recommendation by identifying these core disciplines as essential for feasibility studies, licensing documentation, safety analysis reporting, and infrastructure planning.

During construction, TRS-200 emphasizes a workforce composed primarily of artisans (≈84%) and technicians (≈13%), supported by a limited number of engineers (≈3%) responsible for supervision, quality assurance, and nuclear safety compliance. Consistent with this guidance, the study highlights the critical roles of civil engineers (containment and structural works), mechanical engineers (reactor coolant systems and turbine installation), electrical engineers (switchyard and power distribution systems), and instrumentation and control (I&C) engineers (protection and control systems) in maintaining nuclear-grade construction standards.

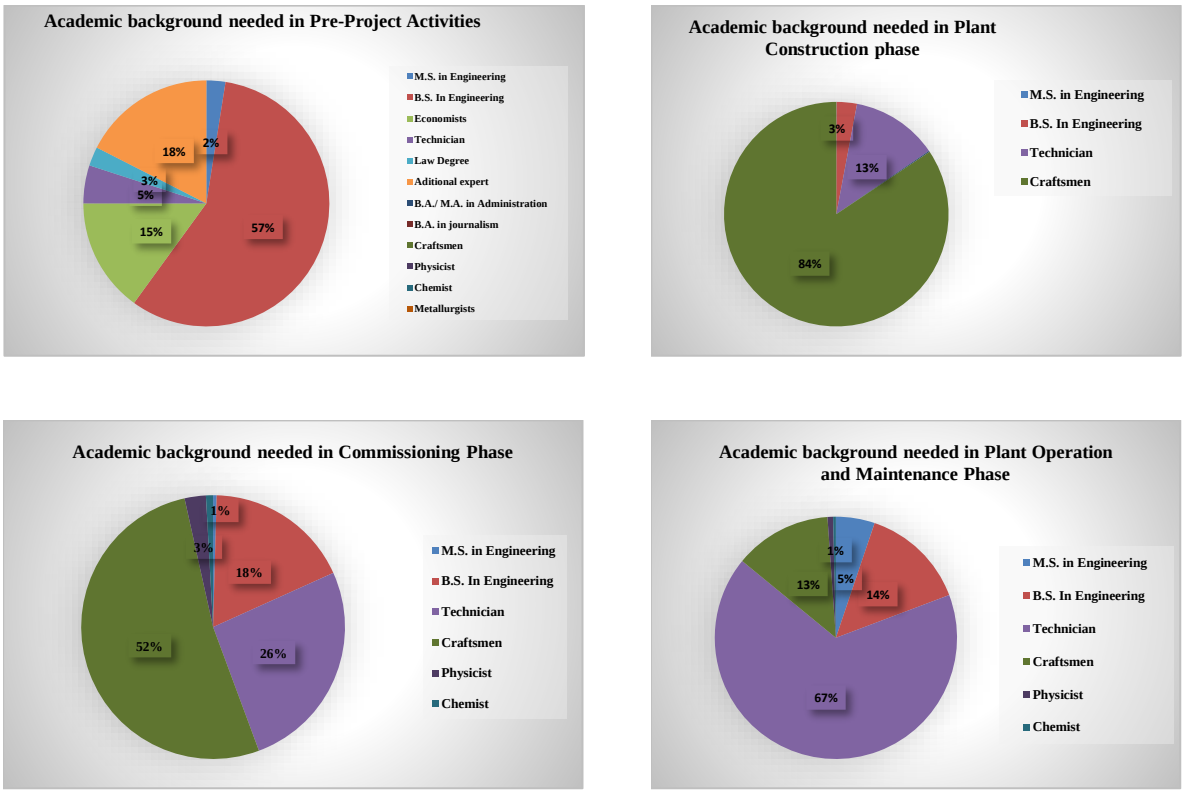

Figure 8: Academic background in four main phases (IAEA, 1980)

For commissioning, TRS-200 identifies an increased requirement for engineering graduates (≈18%), particularly nuclear, mechanical, electrical, and I&C engineers, as well as technically trained personnel for system testing and validation. The present analysis similarly emphasizes the roles of reactor physicists, system engineers, and I&C specialists in functional testing, safety system verification, and regulatory compliance confirmation.

In the operation and maintenance phase, TRS-200 recommends a balanced technical structure comprising

engineering graduates (≈14% with B.S. degrees and ≈5% with advanced degrees) and a majority of qualified technicians (≈67%). The analysis confirms that nuclear engineers (core management and safety analysis), mechanical engineers (maintenance and reliability engineering), electrical engineers (generator and grid systems), I&C engineers (digital safety and automation systems), chemical engineers (radiochemistry and coolant control), and radiation protection specialists are essential for sustained plant safety and performance.

In addition to the technical and regulatory requirements, the competency of NPP personnel is addressed in accordance with the IAEA Safety Standards Series No. SSG-75 establishes that all personnel performing activities that may affect nuclear safety shall possess and maintain competence commensurate with their responsibilities. Such competence encompasses appropriate educational background, professional training, practical experience, technical skills, and demonstrated safety culture attributes. The operating organization is required to implement a systematic approach to training (SAT), ensuring that training programs are developed based on job and task analysis and are subject to periodic evaluation and continuous improvement. The guidance further requires formal qualification and authorization processes for safety-critical positions, including initial licensing, simulator-based assessments, and periodic requalification of control room operators. Additionally, it emphasizes continuing professional development, leadership competence, and effective oversight of contractor personnel engaged in safety-related work. The integration of SSG-75 requirements into the proposed framework reinforces human performance reliability and strengthens the overall safety management system throughout the nuclear power plant's lifecycle (IAEA, SSG-75).

Overall, the comparison demonstrates structural alignment between the proposed HRD framework and the recommendations of the International Atomic Energy Agency Technical Reports Series No. 200 (TRS-200) regarding workforce distribution and discipline-specific competencies. In addition, the framework incorporates the competency-based requirements outlined in IAEA Safety Standards Series No. SSG-75, which emphasizes systematic training, formal qualification, authorization, and continuous professional development for personnel performing safety-related functions at nuclear power plants. While the evaluation confirms consistency with both workforce planning benchmarks and competency assurance principles, it also highlights the need to further strengthen national capacity in nuclear engineering, instrumentation and control (I&C) engineering, radiation protection, and specialized technician training. Enhancing these areas is essential to meet international benchmark requirements fully and to ensure a safe, secure, sustainable, and reliable 1000 MWe nuclear power program supported by a competent, safety-focused workforce.

4.5 Analysis of Types of Works and Training Lead Time Required at an NPP

For job duties including nuclear operations, reactor engineering, radiation safety, and training, the recruiting process may begin several years before the candidate is required for the role. Figure 9 depicts selected nuclear work functions in a nuclear power plant with extensive training

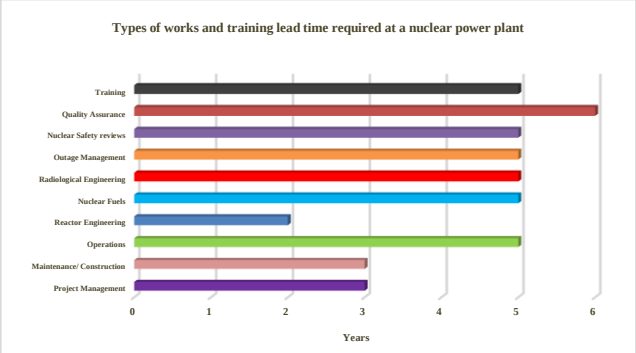

Figure 9: Types of nuclear work with extensive training time frames in a nuclear power plant

time frames (IAEA, Vienna 2007; IAEA, Vienna 2011). Based on Figure 9, the recruitment and training process for various nuclear power plant job functions requires significant lead time, often several years before personnel are ready for their roles. Positions such as Quality Assurance, Operations, Nuclear Safety Reviews, Outage Management, Radiological Engineering, and Nuclear Fuels demand approximately 5 years of preparation and training. In comparison, general training programs also extend up to 5 years. Other roles, including Project Management and Maintenance/Construction, require around 3 years, whereas Reactor Engineering has a shorter lead time of about 2 years. The variation in training duration reflects the criticality of each role and the stringent requirements imposed by national regulations, technical standards, vocational training needs, labour laws, and industry best practices to ensure competency and safety in nuclear operations.

5. MAJOR CHALLENGES

As Bangladesh is a newcomer to the nuclear industry, there are many challenges in implementing the human resource development plan. The lack of qualified professionals in reactor operations, radiation safety, cybersecurity, and regulatory oversight is a major challenge in Bangladesh. A limited number of qualified trainers can limit the development of skilled personnel. Initially, Bangladesh can rely on foreign experts for nuclear technology transfers, training and plant operation. There are also a limited number of dedicated training centre with advanced simulations-based training facility while a limited number of universities started nuclear focused curricula and research. A highly qualified regulatory body is necessary to ensure strict compliance with IAEA safety standards and principles; therefore, strengthening the regulatory framework is also a crucial challenge for Bangladesh. Lastly, there are still major challenges to public

understanding and acceptance of nuclear energy, as misinformation and safety concerns can undermine workforce motivation. Building trust in the nuclear industry requires effective public communication tactics. A multi-stakeholder approach is needed to address these issues, including government assistance, academic and professional cooperation, international cooperation, and ongoing professional development. Building a skilled and sustainable nuclear workforce in Bangladesh would require strengthening educational programs, establishing a specialized national training centre, and guaranteeing a strong financial and policy commitment.

6. CONCLUSION

As Bangladesh ranks 33rd among countries using nuclear energy for power generation, the establishment of the RNPP (Karim et al., 2018) underscores the need to develop a strategic human resource development plan. This research work highlights that a well-developed HRD framework is important not only for the safe and efficient operation of the facility but also for ensuring long-term sustainability and regulatory compliance. The HRD model includes collaborations among nuclear stakeholders, strengthening institutional capacity, capacity building for regulatory authorities, training facility operators, expanding education and training infrastructure, and monitoring and evaluating performance through international cooperation. Implementing the HRD framework in Bangladesh faces several challenges. There is a lack of sufficiently skilled professionals in nuclear science and engineering. Geopolitics also plays a significant role in shaping the HRD strategy, especially in a developing country like Bangladesh. Due to the delicate nature of nuclear technology and its strong connection to global security, diplomatic ties are frequently necessary to gain access to training, technology, and experience. For example, by working with nations such as China, Russia, and other member states, the IAEA can create opportunities for information sharing and technical training. However, access to these resources can be restricted by geopolitical conflicts, sanctions, or changes in international policy. Thus, the factor of geopolitical realities must be considered in the HRD plan to guarantee the long-term peaceful use of nuclear energy.

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DATA AVAILABILITY STATEMENT

Datasets generated during the current study are available from the corresponding author upon reasonable request.

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ETHICS APPROVAL

This study is an engineering experimental investigation. The MIJST Research Ethics Committee has confirmed that formal ethical approval was not required.

ETHICS, CONSENT TO PARTICIPATE, AND CONSENT TO PUBLISH

Not applicable.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization of the study, development of the human resource development model, methodology design, data analysis, and primary manuscript drafting.
Author 2: Literature review, framework refinement, validation of IAEA guidelines integration, and critical revision of the manuscript for important intellectual content.
Author 3: Overall guidance on nuclear sector applicability, policy alignment review, and final review of the manuscript for submission.

ARTIFICIAL INTELLIGENCE ASSISTANCE STATEMENT

Portions of this manuscript were assisted by an artificial intelligence language model (ChatGPT, OpenAI). The tool was used solely for language editing, text refinement, and improving clarity. All content, data interpretation, analysis, conclusions, and final decisions were produced, verified, and approved by the authors. The authors take full responsibility for the accuracy and integrity of the manuscript.

CONFLICT OF INTEREST DECLARATION

The authors declare that they have no conflicts of interest.

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