Assessment of Nuclear Safety and Security Regime of Pakistan

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Abstract

As global interest in nuclear energy grows, particularly for low-carbon power generation, medical innovation, and agricultural resilience, establishing a robust nuclear safety and security regime is essential for ensuring the peaceful and responsible use of nuclear technology. This paper offers a comprehensive assessment of Pakistan's nuclear safety and security regime within the broader context of its peaceful nuclear program. A founding member of the International Atomic Energy Agency (IAEA) and an early supporter of the "Atoms for Peace" initiative, Pakistan has consistently demonstrated its commitment to the peaceful use of nuclear technology by developing a dual-focused regulatory framework that separately addresses nuclear safety and nuclear security. This study analyzes the evolution, legal foundations, institutional mechanisms, and regulatory infrastructure of Pakistan's national regime, highlighting its adherence to IAEA safety standards, international legal instruments, and voluntary codes of conduct. Drawing from Pakistan's practical experience, the paper examines the peaceful applications of nuclear technology across five key sectors: energy, healthcare, research and education, agriculture, and industry. It further explores the role of the Pakistan Nuclear Regulatory Authority (PNRA), the structure and enforcement of licensing and oversight mechanisms, and the integration of safety and security culture. Special attention is given to human capacity building, radioactive waste management, transport safety, emergency preparedness, and international cooperation— a

key dimension that shape Pakistan's proactive engagement with global nuclear governance. The analysis concludes by positioning Pakistan's nuclear safety and security regime as a responsible, transparent, and internationally aligned framework that contributes not only to national development but also to the strengthening of global nuclear norms.

Keywords: Nuclear Safety, Nuclear Security, Pakistan, IAEA, PNRA, PAEC.

Introduction

The peaceful application of nuclear technology is an important contributor to the modern global challenges such as sustainable energy production, improved healthcare, food security and scientific progress. Since Pakistan had realized the potential of nuclear energy in enhancing the socioeconomic development of the country, it applied the peaceful use of nuclear energy in a well-developed legal, institutional and regulatory framework. As one of the initial supporters of the "Atoms for Peace program"[1] and the signatory of the IAEA in 1957, Pakistan has been showing compliance to the international norms and safety standards.

Pakistan's nuclear program has developed into a complex system which has applications in various sectors including energy, medicine, agriculture, industry and environmental management. The global events in the aftermath of 9/11 led to a fundamental change in the nuclear governance, which was caused by the rapidly changing dynamics of the global processes. This development separated the wider nuclear safety concept into two distinct areas of "nuclear safety" and "nuclear security." Nuclear safety encompasses measures, practices and regulations that are aimed at guaranteeing safe functioning of nuclear facilities, and protecting the environment and population against the adverse impact of ionizing

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[1] Rubio Varas, "D.3.6 Validated Short Country Reports," *Unavarra.es*, 2019, https://academica-e.unavarra.es/entities/publication/09b9eb69-3d58-432d-afd0-2f4f7a3cf435

radiations, particularly in the event of accidents or malfunctions.[2] Conversely, Nuclear Security is the application of measures that prevent, detect, and mitigate acts of theft, sabotage, unauthorized access, or unauthorized movement of nuclear or radioactive material and the facilities related to them.[3]

Pakistan emerged as a proactive actor through its advanced nuclear security infrastructure, complemented by its long-standing adherence to nuclear safety. Moreover, Pakistan implemented a dual-focus regulatory framework to prevent accidents (nuclear safety) and counter intentional threats (nuclear security). This progress was reflected in Pakistan's adherence to several legally binding and non-binding commitments, and voluntary measures. All these efforts have created a strong and two-pronged nuclear regulatory regime in Pakistan which continues to evolve in compliance with the international standards.

Pakistan has steadily advanced its commitment to utilizing nuclear technology for peaceful purposes, while maintaining compliance with nuclear safety and security frameworks. This adherence has led to the establishment of a well-coordinated national system that focuses on both aspects - nuclear safety and nuclear security. This article discusses the basic structure of nuclear safety and security regime in Pakistan, its evolution, structure, and operational dynamics. It discusses the regulatory role of the PNRA, implementation of the IAEA-based nuclear safety and security standards and institutionalization of a national safety and security culture. Furthermore, it covers the peaceful applications of nuclear technology in five core sectors. These include healthcare, power generation, research and education, agriculture, and industry. Alongside, it highlights Pakistan's contributions to the international nuclear governance in terms of cooperation, capacity-building and adherence to international instruments.

[2] International Atomic Energy Agency (IAEA), IAEA Nuclear Safety and Security Glossary (Vienna: IAEA, 2022), https://www-pub.iaea.org/MTCD/Publications/PDF/IAEA-NSS-GLOweb.pdf
[3] IAEA, Nuclear Safety and Security Glossary.

Moreover, the paper highlights the national framework in Pakistan that has been developed in accordance with the international best practice and is comprised of five main pillars: Independent Nuclear Regulatory Authority, Comprehensive Legal and Regulatory Infrastructure, Robust Nuclear Security Architecture, Strong International Engagement, and Deep-Rooted Safety and Security Culture. This article is organized into three parts. The first part describes nuclear technology's applications in different sectors of Pakistan. The second part briefly discusses the history of international nuclear safety and security regime. Whereas the last part offers a thorough examination of the national regime in Pakistan which encompasses the five main pillars of Pakistan's national framework. This paper aims at evaluating Pakistan's role as a responsible nuclear state and its contribution to the international nuclear safety and security by analyzing the effectiveness, flexibility and international alignment of its regulatory infrastructure.

Peaceful Applications of Nuclear Technology in Pakistan

Pakistan is one of many countries utilizing nuclear technology for peaceful purposes. This utilization is aimed at benefiting humanity and advancing socio-economic development. Being a responsible nuclear power and a signatory of the IAEA, Pakistan has always ensured that its nuclear activities follow international standards of safety, security and peaceful use. The peaceful nuclear program in Pakistan is diverse and covers five primary areas, namely energy, research and education, healthcare, agriculture, and industry. Each of these sectors has played its own distinct role in Pakistan's development. Moreover, peaceful applications of nuclear technology are widespread which not only fulfill the domestic requirements of Pakistan but also underscores the positive role of Pakistan in IAEA-led activities and technical cooperation programs. Based on the regulatory regime of Pakistan and its dual responsibilities of ensuring nuclear safety and security, this section explores the practical manifestation of Pakistan's commitments in the domain of peaceful uses of nuclear technology.

Nuclear Energy for Climate-Resilience

Pakistan views nuclear and renewable energy as key components of its energy mix to support socio-economic development and mitigate the impacts of climate change. Pakistan remains highly vulnerable to climate change,[4] regardless of its minimal contributions to greenhouse gas emissions. The Government of Pakistan Vision 2030 states, "Nuclear energy is becoming attractive again, and so is renewable energy. We will expand our existing knowledge base in nuclear power and build up the same in renewables to meet a growing part of our energy needs in this century."[5] Under its Energy Security Plan 2005-2030, Pakistan aims to achieve 8800 MWe of nuclear capacity by 2030, including recent additions such as the K-2 and K-3 Pressurized Water Reactors (PWRs) with a power capacity of 1100 Mwe, each at the Karachi Coast.

A total of six nuclear power plants – PWR-type reactors - are currently operational in Pakistan, comprising four Chashma Nuclear Power Generating Stations (CNPGS) and two Karachi Nuclear Power Generating Stations (KNPGS), with a combined electricity generation capacity of 3,256 MWe, contributing significantly to the country's energy requirements. One nuclear plant - a Canada Deuterium Uranium (CANDU)-type Pressurized Heavy Water Reactor (PHWR) was shut down permanently for decommissioning in August 2021, following nearly six decades of service to the nation.

Research and Education

"Pakistan Institute of Nuclear Science and Technology (PINSTECH)" is one of the main research and development (R&D) facilities for nuclear science, radiopharmaceuticals, radiation safety, and nuclear physics.

[4] Rabia Maqsood and K. Abbas, "Climate Change and Fisheries: A Global Perspective," *Progress in Aqua Farming and Marine Biology* 2024, no. 1 (July 16, 2024): 180033, https://academicstrive.com/PAFMB/PAFMB180033.pdf

[5] Planning Commission, Pakistan 2030: Vision for the Future (Islamabad: Government of Pakistan, 2007), 66, https://file.pide.org.pk/pdf/vision-2030.pdf.

Enormous contributions are being made to environmental protection, food security, biotechnology, development of climate resilient crops, sustainable agriculture and scientific education by several institutes in Pakistan. These institutions are "Nuclear Institute for Agriculture (NIA)," "National Institute for Biotechnology and Genetic Engineering (NIBGE)," "Nuclear Institute for Food and Agriculture (NIFA)," and "Nuclear Institute for Agriculture and Biology (NIAB)." A comprehensive nuclear safety and security regime in Pakistan ensures the use of nuclear and radioactive materials safely and securely by following national regulations of PNRA, developed according to international standards set by the IAEA.

Significant contributions are made by nuclear medical centers in Pakistan to the research work on the development of radiopharmaceuticals, treatment planning, radiotherapy, cancer imaging and diagnosis, radiation oncology, and biomarker research. Clinical fellowships are also offered by these medical centers to physicians and technologists, a significant contribution to human resource development in this field.

Human Health

Currently, PINSTECH, under the supervision of Pakistan Atomic Energy Commission (PAEC), operates two research reactors - Pakistan Atomic Research Reactor (PARR 1&2), for research, development, education, and training purposes. PARR-1 is a 10 MW pool-type research reactor, supplied by the USA in 1965 under the "Atoms for Peace" program. PARR-2 is an indigenous 30kW miniature neutron source reactor (MNSR). Operational since 1974, this reactor uses highly enriched uranium (HEU) fuel and is based on the Chinese design.[6] Additionally, PARR-1 supports the Molybdenum production facility, which fulfills the national demand for radiopharmaceuticals and supplies to all nuclear medical centers across the country for both diagnostic and therapeutic applications.

[6] Pakistan Nuclear Regulatory Authority (PNRA), "Research Reactors," *PNRA*, https://www.pnra.org/r-reactors.html

Currently, nineteen nuclear medical centers (Cancer hospitals) are being operated by PAEC, treating nearly one million patients annually.[7] One nuclear medical center – Nuclear Medicine, Oncology and Radiotherapy Institute (NORI), Islamabad, has been designated as an Anchor Center under the flagship initiative of the IAEA "Rays of Hope" and will support regional countries in expanding access to cancer treatment. Additionally, 21 full-fledged medical centers, 6,237 Diagnostic X-ray centers, 8 radiotherapy centers, 12 nuclear cardiology centers, 6 irradiators (blood), 14 isotope production & PET/CT (Cyclotron), and 10 Radioimmunoassay (RIA) labs are supporting this goal in the private and public sectors.[8]

Food and Agriculture

Four agriculture and biotech institutes (NIAB, NIBGE, NIFA, and NIA), owned by PAEC, have introduced 150 different crop varieties and treated millions of acres through Integrated Pest Management (IMP). Equipped with advanced facilities such as gamma irradiators, Polymerase Chain Reaction (PCR) systems, and mass spectrometers, these institutes also offer national and international training and academic programs through Pakistan Institute of Engineering and Applied Sciences (PIEAS). In the realm of food safety, Pakistan has established its first ISO/IEC 17025-accredited veterinary drug residue laboratory at the NIAB, enabling the analysis of export–bound meat and training hundreds of professionals and farmers. Addressing climate change challenges, Pakistan has adopted Climate Smart Agriculture practices with IAEA support, utilizing isotopic techniques to optimize fertilizer use, manage soil salinity, and reduce greenhouse gas emissions. These achievements have enhanced national food security and agricultural resilience. Food and agriculture institutes are licensed by PNRA

[7] International Atomic Energy Agency (IAEA), *Pakistan Partnering with IAEA for Strengthening South-South Cooperation* (Vienna: IAEA, 2023), https://www.iaea.org/newscenter/news/pakistan-and-iaea-accelerate-nuclear-cooperation-to-address-climate-food-and-health

[8] Pakistan Nuclear Regulatory Authority (PNRA), *Annual Report 2023* (Islamabad: PNRA, 2023), https://www.pnra.org/upload/pnrarpt/PNRA%20Annual%20Report%202023.pdf

to allow them the use of radiotracers and irradiators for nuclear techniques such as radiation processing, isotope tracer studies, and mutation breeding.

Industrial Applications

Nuclear and radiation technologies have several applications in industrial sectors. These applications include Non-Destructive Testing (NDT) of materials and welds, industrial radiography, gauging and process control (e.g., moisture/density gauges, process control), radiation sterilization of medical devices and packaging, and nuclear gauges for mining and mineral exploration. Since these applications involve the use of sealed radioactive sources, accelerators, and radiation-producing devices, they require stringent regulatory oversight. In this regard, PNRA ensures that operators and workers handling radioactive sources are well-trained and well-qualified experts.

Furthermore, other industrial applications of radiation sources include well logging in oil exploration, non-destructive testing for material inspection, food irradiation, and the sterilization of food and other products. PNRA has licensed 243 industrial facilities for these purposes. Licensees are bound to comply with all regulations and standards, such as PNRA's regulation PAK/926[9] on "Security of Radioactive Sources" and IAEA's "code of conduct on the Safety and Security of Radioactive Sources." Safe and secure use of radioactive sources ensures a safe environment that improves quality of life, health, education, equality, and sustainability, demonstrating how nuclear technology can support not just energy or health, but industrial modernization as well.

Global Nuclear Safety and Security Regime

The Global Nuclear Safety Regime is a set of international legal, institutional and technical systems that guarantee safe operation of nuclear

[9] Pakistan Nuclear Regulatory Authority (PNRA), *Management of Nuclear Security Events Involving Radioactive Sources: Pakistan Nuclear Regulatory Authority Regulatory Guide* (Islamabad: PNRA, 2023), https://www.pnra.org/upload/guidelines/PNRA-RG-926.02.pdf

facilities.[10] Whereas, the Nuclear Security Regime, defined by the IAEA is as "the legislative and regulatory framework and administrative systems and measures governing the security of nuclear material, other radioactive material, associated facilities, and associated activities; the institutions and organizations within the State responsible for ensuring the implementation of the legislative and regulatory framework and administrative systems of nuclear security; and nuclear security systems for the prevention and detection of and response to nuclear security events."[11]

The global nuclear safety and security regime is based on a range of instruments, conventions, and protocols. These include binding agreements, non-binding protocols, and voluntary commitments to govern the safe and secure utilization of nuclear technologies, materials, and installations. This regime relies on national efforts within a country's jurisdiction. The regime is supported by the relevant national and international institutions, intergovernmental organizations, and multinational regulators' as well as operators' networks. Since 1986, the IAEA has held a central position in advancing global nuclear safety and security by acting as the secretariat for multiple international legal frameworks - both binding and non-binding. Notable among these are the "1986 Convention on Early Notification of a Nuclear Accident (ENCA),"[12] the "1987 Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (CACNARE),"[13] and the "Convention on the Physical Protection of Nuclear Material

[10] International Nuclear Safety Advisory Group (INSAG), *INSAG-21: Strengthening the Global Nuclear Safety Regime* (Vienna: International Atomic Energy Agency, 2006), https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1277_web.pdf

[11] International Atomic Energy Agency (IAEA), *Objective and Essential Elements of a State's Nuclear Security Regime* (Vienna: IAEA, 2013), https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1590_web.pdf

[12] International Atomic Energy Agency (IAEA), *Convention on Early Notification of a Nuclear Accident and Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency*, Legal Series No. 14 (Vienna: IAEA, 1986), https://www.iaea.org/sites/default/files/infcirc335.pdf

[13] International Atomic Energy Agency (IAEA), *Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency*, INFCIRC/336 (Vienna: IAEA, 1986), https://www.iaea.org/sites/default/files/infcirc336.pdf

(CPPNM)," originally adopted in 1987 and extended in scope in 2005.[14] Furthermore, Pakistan is a party to the "1994 Convention on Nuclear Safety (CNS)"[15] and the "2001 Joint Convention on the Safety of Spent Fuel Management and on the safety of Radioactive Waste Management."[16] It has expressed political commitment to the IAEA's "2003 Code of Conduct on the Safety and Security of Radioactive Sources,"[17] and follows IAEA guidance outlined in the "2006 Code of Conduct on the Safety of Research Reactors."[18]

IAEA Safety Standards and Security recommendations represent a central part of the international nuclear governance framework. They provide technical requirements, practical guidance and good practices to facilitate harmonized approaches for the safe operation and regulation of facilities and activities involving nuclear and radiological materials.

The fundamental framework of the Global Nuclear Safety Regime has been established very well and it operates in a way that complements the national nuclear infrastructure of individual nations. The regime, despite its existing structure, still holds the potential for gradual reforms that may lead to the improvement of international safety standards. The "International Nuclear Safety Advisory Group (INSAG)," a group of internationally recognized experts convened by the IAEA, gives authoritative advice on nuclear safety principles and policies, emphasizing that high levels of safety at nuclear

[14] International Atomic Energy Agency (IAEA), *Convention on the Physical Protection of Nuclear Material*, INFCIRC/274/Rev.1 (Vienna: IAEA, 1979), https://www.iaea.org/sites/default/files/infcirc274.pdf

[15] International Atomic Energy Agency (IAEA), *Convention on Nuclear Safety* (Vienna: IAEA, 1994), https://www.iaea.org/sites/default/files/infcirc449.pdf

[16] International Atomic Energy Agency (IAEA), *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*, INFCIRC/546 (Vienna: IAEA, 2001), https://www.iaea.org/topics/nuclear-safety-conventions/joint-convention-safety-spent-fuel-management-and-safety-radioactive-waste

[17] International Atomic Energy Agency (IAEA), *Code of Conduct on the Safety and Security of Radioactive Sources* (Vienna: IAEA, 2003), https://www-pub.iaea.org/MTCD/publications/PDF/Code-2004_web.pdf

[18] International Atomic Energy Agency (IAEA), *Code of Conduct on the Safety of Research Reactors* (Vienna: IAEA, 2006), https://www-pub.iaea.org/MTCD/publications/PDF/CODEOC-RR_web.pdf

facilities can be realized through effective application of frameworks based on the Global Nuclear Safety Regime. The Group underlines that the recommendations provided in its reports are not only achievable, but they should be followed by all nuclear stakeholders on a regular basis.[19]

Key Aspects of Pakistan's Nuclear Safety and Security Regime

Pakistan, a founding member of the IAEA, has served the Chairmanship of the Board of Governors of the IAEA three times.[20] Pakistan is a party to many international instruments that seek to reinforce the national as well as international nuclear security infrastructure. The next section addresses the main features of Pakistan's nuclear safety and security regime.

Independent Regulator

The regulatory and operational nuclear industry of Pakistan is structured in various institutions and legislations. In this regard, the PNRA is mandated to offer "radiation protection," "nuclear safety" and "physical protection of nuclear materials and installations,"[21] but the PAEC is mandated to facilitate peaceful uses of nuclear energy and to manage the activities of nuclear installations. The "National Safety Policy (NP-02/2020)" was issued in 2020, which also contributes to the work of Pakistan to attain nuclear safety and radiation protection. Pakistan has established a robust and sustainable regulatory framework that has safety and security as the top priority.

Pakistan has evolved its nuclear regulatory system. This started with the establishment of "Pakistan Nuclear Safety Committee" in 1964 and subsequent establishment of "Pakistan Nuclear Regulatory Board" in 1994.

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[19] International Nuclear Safety Advisory Group (INSAG), *INSAG-21: Strengthening the Global Nuclear Safety Regime* (Vienna: International Atomic Energy Agency, 2006), https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1277_web.pdf

[20] International Atomic Energy Agency (IAEA), "Previous Board Chair: 1957 to Present," *IAEA*, January 30, 2015, https://www.iaea.org/about/policy/board/previous-chair-1957-to-present

[21] International Atomic Energy Agency (IAEA), *Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5)*, Nuclear Security Series No. 13 (Vienna: IAEA, 2011), https://www-pub.iaea.org/MTCD/publications/PDF/Pub1481_web.pdf

PNRA is a nuclear regulatory authority which was enacted under the PNRA Ordinance, 2001. The primary goal of this institution was to separate the regulator of the nuclear power generation and the agency that oversees it. PNRAs structure comprises one chairman, two permanent members, and seven serving on a part-time basis.

PNRA holds complete authority to perform all regulatory functions and procedures related to radiation protection, nuclear safety, and nuclear security. Moreover, this institution supervises the import, export, transit, transport and disposal of radioactive material. PNRA issues relevant certificates such as No Objection Certificates and Radiation Free Certificates. PNRA ensures due compliance with its legislative and regulatory framework with the help of well-defined enforcement mechanism. This enforcing mechanism is further facilitated by PNRA "Enforcement Regulations- (PAK/950)."

Additionally, PNRA serves as the national contact point for all relevant international agreements that deal with nuclear and radiological emergencies. PNRA also plays an important role in inter-agency coordination, generating public awareness, and performing safety related research in case a nuclear or radiological emergency occurs. The organization's priorities are enhancing regulatory effectiveness through capacity-building and institutional development. PNRA has adequate skilled human resources, access to knowledge and technical as well as financial resources to support effective and efficient work of the organization.

As part of its commitment to maintaining regulatory effectiveness, PNRA employs a comprehensive monitoring and assessment framework that includes both internal and external evaluation mechanisms. Internally, the latest PNRA report (2023) indicates satisfactory performance, evaluated through ten well-defined strategic performance indicators. Externally, PNRA reinforced its commitment to transparency and international best

practices by hosting a full-scope IAEA "Integrated Regulatory Review Service (IRRS)" mission in April 2014. IAEA conducted a follow-up IRRS mission in February-March 2022 which confirmed that all recommendations from the initial review, had been successfully implemented by Pakistan. A significant advancement in national-level regulatory infrastructure of Pakistan was also reported with a focus on efficiency and effectiveness.

Comprehensive Regulatory Framework

A comprehensive regulatory framework has been established by PNRA for all operational nuclear facilities, radiation facilities, research reactors and associated activities in Pakistan. The PNRA regulatory system is based on a holistic paradigm to monitor the radioactive material in its entire life cycle, from "Cradle to Grave." This paradigm covers the systematic tracking of all stages in the lifecycle of a nuclear or radioactive substance, including its origin, which is the initial production stage, to its final disposal. This approach is used to ensure continuous accountability and safety of nuclear and radioactive materials throughout their lifecycle. There is another set of rules that regulate the control of nuclear radiation facilities which incorporates all the phases of the facility, site selection, construction to operation, decommissioning once the facility stops operating, and the final release of the sites out of the regulatory control.

Nuclear Power Plants

Pakistan has shown a strong determination to uphold highest standards of nuclear safety by ensuring safe operation of Karachi Nuclear Power Plant (KANUPP) since its inception in 1971. Pakistan signed the CNS on 20 September 1994 and ratified on 30 September 1997, to be in line with the international standards to facilitate its peaceful nuclear energy program.

Moreover, since the creation of PNRA in 2001, it has issued 23 regulations, nearly 20 of which relate directly or indirectly to the safety of nuclear power

plants. These regulations have special provisions which deal with "licensing and safety requirements" of site selection, design and operational characteristics of nuclear power plants. These rules are based on the IAEA Safety Standards and are also complemented by a set of IAEA regulatory guidelines. Other international or national industrial standards and codes, where applicable, are also recommended by PNRA to cover regulation and be in line with international best practices.

The PNRA regulations are regularly updated and changed as and when it is needed to address the changes in technology and safety needs. To maintain transparency and participation of stakeholders, these regulations are posted on the PNRA website.[22] The fact that Pakistan has a very good record in the safety of its nuclear power plants is an indication of a good safety culture. Also, the presence of a strong regulatory authority- PNRA, and a leadership that is deeply interested in upholding the best safety standards confirm that Pakistan is a responsible nuclear power. The accident of Fukushima presented numerous lessons that reinforced the emphasis of Pakistan on the vigilance of regulation and continuous enhancement.

In addition, PNRA requires a gradual licensing process. This process involves granting a site license, construction license, operating license, and a decommissioning license. To facilitate transparency and community participation, every stage of this process involves an in-depth Environmental Impact Assessment (EIA), submission of a Safety Analysis Report (SAR), and consultation with the community. PNRA conducts regular checks and audits to guarantee high-level of safety and security. It also incorporates the input of operational experience, promotes a strong safety culture, develops cybersecurity standards and prepares to react to emergencies.

[22] www.pnra.org

Research Reactors

An effective regulatory system is necessary to ensure safe and secure operations of research reactors since they use nuclear and radioactive materials in their operations. To this end, PNRA has established stringent national policies that are compliant with international standards. Its regulatory system is consistent with the key IAEA safety publications, including "IAEA SSR-3, "SSG-20, and INFCIRC/225/Rev.5." It is worth noting that PNRA has developed some regulations known as "Regulations on the Safety of Research Reactors (PAK/932)" that encompass all the concerns related to research reactor safety. Pakistan, in accordance with the IAEA "Code of Conduct on the Safety of Research Reactors, is particularly concerned with the problem of equipment obsolescence, and it is well aware of the necessity of regular maintenance, timely replacement of components and strict adherence to technical specifications to ensure the integrity of operations.

Simultaneously, PNRA facilitates the development and implementation of quality assurance programs even in low-power reactors that reflects the compliance of Pakistan with the best practices worldwide, despite the historical exemptions. In Pakistan, licensing of research reactors is a staged and stringent procedure, and it has adopted a model similar to that of nuclear power plants. PNRA also ensures the safety of its staff, the general population and the environment at all levels and the use and storage of nuclear materials. PNRA allows safe scientific advancement with strict regulatory oversight and compliance with the needs of licensees, without undermining Pakistan's non-proliferation commitments or nuclear safety obligations.

Radiation Facilities

PNRA has a detailed licensing and regulatory system of the facilities that utilize ionizing radiation which is in line with its regulatory framework. These are "PAK/908 (Rev.1)," Regulations of the Licensing of Radiation

Facilities Other than Nuclear Installation(s)," and "PAK/904" which describes the Radiation Protection Regulations. The safe use of radiation sources in non-nuclear facilities is based on these rules, which increase occupational and population safety. These regulations ensure that all the activities that involve radiation are undertaken in a safe way with the priority being given to the protection of human health and the environment. PNRA takes a graded approach in regulating such radiation facilities. In addition, the facilities are categorized based on the radiation hazards and safety significance that they possess.

In the licensing process, PNRA duly evaluates the required submissions that include SARs, Physical Protection Plans (PPPs), Emergency Preparedness Plans (EPPs), and Radiation Protection Programs (RPPs). In this regard, a national database for occupational exposure as specified by "PAK/908," has been developed and maintained by PNRA. By 2023, records for 14,800 radiation workers were maintained. Over 97.1% of workers received below 5mSv per annum, indicating effective implementation of "ALARA (As Low as Reasonably Achievable)" principles.

Transport of Radioactive Material

Safe and effective use of nuclear technology requires a cross-cutting component of transporting radioactive material. Most radioactive materials, except those produced domestically as radiopharmaceuticals used to treat cancer, are imported to Pakistan; international and domestic radioactive material shipments are controlled by the "Regulations for the Safe Transport of Radioactive Material (PAK/916)" of the PNRA. These rules are based on the "SSR-6 (2018 Edition)" of the IAEA and are aimed at establishing safety in all modes of transport. The PNRA is the regulatory body that has the mandate of regulating Class 7 radioactive materials and operates in close cooperation with national transport agencies to ensure that there is harmonization of regulatory application and maintenance of safety standards during the transport process.

Radioactive Waste Management, Spent Fuel Management, and Decommissioning

The safe, secure, and sustainable management of radioactive waste is an important element of nuclear governance in the modern world. All radioactive facilities and nuclear plants in Pakistan handle radioactive waste in complete adherence to the internationally accepted principles and best practices. The Government of Pakistan has institutionalized its commitment to this field by issuing a national policy document titled "National Policy on Safe Management of Radioactive Waste, Decommissioning, and Spent Nuclear Fuel in the Islamic Republic of Pakistan (RWP-01/2018)." The policy offers a long-term strategic direction of responsible management of radioactive waste, which is environmentally friendly, safe for the population, and in line with international standards.[23] This policy sets goals, requirements, and responsibilities of different stakeholders, allowing for safe management of disused radioactive sources which could not be returned to the main supplier in other country, along with orphan sources, and ownerless radioactive waste in the national radioactive waste storage or disposal facilities, operated by PAEC and licensed by PNRA. The policy also ensures the availability of funds for these purposes. Moreover, to implement the policy, PAEC has established strategies for radioactive waste management, spent fuel management, and decommissioning.

For the last six decades, spent nuclear fuel generated by the operation of nuclear power plants and research reactors is considered an asset by the Government of Pakistan. Therefore, it is being stored at spent fuel storage facilities operated by PAEC and licensed by PNRA. The first dry spent fuel storage facility to safely manage spent fuel of CANDU reactor is KANUPP Spent Fuel Dry Storage Facility (KSFDF). It is currently operational, and a second one is under construction at Chashma to safely manage PWR-type spent fuel.

[23] Pakistan Nuclear Regulatory Authority (PNRA), "Regulations," *PNRA*, https://www.pnra.org/regulations.html

Pakistan has not yet acceded to the "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management." This convention entered into force in 2001. While Pakistan is not a part of the Joint Convention, it has developed a comprehensive national regulatory framework for spent fuel management, radioactive waste management, and decommissioning of nuclear facilities.[24] These regulations place the primary responsibility for safety on licensed operators, requiring them to implement robust waste management programs, conduct regular safety assessments, and ensure long-term containment and control. Sustainability of the basic safety principles is ensured across all stages of spent fuel management and radioactive waste management by the implementation of this regulatory framework.

Emergency Preparedness and Response

In 1989, Pakistan signed two significant IAEA Conventions, ENCA and CACNARE. PNRA is at the center of emergency preparedness and response to all nuclear and radiological incidents at the national level. It has been well-stated in "National Radiation Emergency Plan (NREP) on nuclear and radiological emergencies." PNRA offers technical assistance to the concerned government agencies at any level. PNRA has established elaborate regulations (PAK/914) in accordance with international best practices and lessons learnt, which require all facilities to include emergency communications, response to contaminated persons, protective measure taking, provision of containment measures, and long-term safety measures in their emergency planning procedures. PNRA ensures that the concerned organizations formulate emergency plans in the event of radiological incidents and that the plans are coordinated properly with the organizations involved. PNRA as the national competent authority of Pakistan, coordinates with IAEA and other states in events of radiological

[24] *The Gazette of Pakistan*, "S.R.O. 1236(I)/2018," August 15, 2018, https://www.pnra.org/upload/policies/National%20Policy%20on%20Safe%20Management%20of%20Radioactive%20Waste,%20Decommissioning%20and%20Spent%20Nuclear%20Fuel%20in%20Islamic%20Republic%20of%20Pakistan-_RWP-012018_.pdf

emergencies, as per the obligations of the "International Conventions on Early Notification and Assistance."

The National Radiation Emergency Coordination Centre (NRECC) is the national point of contact in radiation emergency under the direction of PNRA. It has the responsibility of informing and liaising with national and international stakeholders, assessing radiological incidents using in-house tools and specialized Radiation Monitoring Teams (RMTs), and giving advice to the government and other relevant parties on appropriate response measures. NRECC is important in making sure that there is timely communication, good decision making and coordinated emergency preparedness and response at the national level.

Environmental Safety

As per the Ordinance 2001- Section 39 "Environmental surveillance and radiation emergency plans," PNRA is responsible for implementing and coordinating a national environmental monitoring program to detect any build-up of radioactivity that could pose a risk to public health. PNRA conducts regular environmental monitoring around nuclear power plants, research reactors, and industrial sites to ensure safe levels of radioactivity. It independently verifies data submitted by nuclear operators and uses high and low volume air samplers for the detection of airborne radioactive substances.

In 2023, monitoring near CNPGS and KNPGS showed no radiological risk to the public. PNRA also assessed Naturally Occurring Radioactive Material (NORM) in industrial sectors like oil, coal, gas, and phosphate, with results showing activity levels well below regulatory limits. Additionally, PNRA issues radiation analysis certificates for exported edible and non-edible items. In this regard, 381 samples were analyzed by PNRA by 2023. PNRA also provides dosimetry services for the protection of occupational workers by monitoring their radiation exposure and ensuring that enforcement actions are taken if radiation exposure exceeds

the safety limits. Calibration labs to ensure the accuracy of radiation monitoring equipment, being used across nuclear and radiation facilities, have been established by PNRA in Islamabad and Kundian.

Pillars of Nuclear Safety and Security Regime in Pakistan

All sensitive installations, including nuclear installations of Pakistan, are under custodial control. The nuclear security regime in Pakistan aims at a layered defense approach that attempts to address numerous threats, such as hostile external forces, internal corruption, and cyberattacks. The security regime, inter alia, includes physical protection, material control and accounting, emergency preparedness to radiological incidents, and border security measures. In addition, the primary aim of nuclear safety and security is to protect individuals, societal structures, and the environment from the harmful effects of radiation. Therefore, basic principles overlap, whereas the implementation might differ. Actions and measures taken in one domain also carry implications for the other. The Nuclear Security Regime in Pakistan is anchored on three key interrelated pillars. First is "Legislative and Regulatory Framework," second is "Physical Protection and Security Measures" and the third pillar is "Institutional Coordination and Capacity Building." These pillars contribute collectively to Pakistan's strong and robust nuclear security stance.

The first pillar consists of a comprehensive and structured legal and regulatory framework that governs nuclear security for materials, facilities, and associated activities involving radioactive substances. The legislative framework encompasses the "National Command Authority (NCA) Act (2010),"[25] "Pakistan Nuclear Regulatory Authority Ordinance (2001),"

[25] Pakistan Nuclear Regulatory Authority (PNRA), *Regulations on Radioactive Waste Management (PAK/915) (Rev.1)* (Islamabad: PNRA, 2019), https://www.pnra.org/upload/regs/PAK-915.pdf. Pakistan Nuclear Regulatory Authority (PNRA), *Regulations for the Safe Management of Spent Nuclear Fuel (PAK/918)* (Islamabad: PNRA, 2020), https://www.pnra.org/upload/regs/PAK-918.pdf.Pakistan Nuclear Regulatory Authority (PNRA), *Regulations on Decommissioning of Facilities Using Radioactive Material (PAK/930)* (Islamabad: PNRA, 2016), https://www.pnra.org/upload/regs/PAK-930.pdf

"Pakistan Strategic Export Control Act (2004),"[26] and "Pakistan Atomic Energy Commission Ordinance (1965)." Over time, this legal and regulatory framework has undergone gradual development. This development introduced the "Pakistan Nuclear Safety and Radiation Protection (PNSRP)" Regulations in 1990, marking its initial milestone. These regulations outlined the core provisions for ensuring the physical security of the nuclear materials and those facilities that are associated with them. Additionally, Pakistan incorporated IAEA "INFCIRC/225/Rev.4" to regulate physical protection measures at nuclear facilities, aligning them with the provisions of the CPPNM framework.

The "Physical Protection of Nuclear Material and Nuclear Installations regulation (PAK/925)" was introduced by Pakistan in 2019 to set standards consistent with international practices and to strengthen its nuclear security framework. These provisions, following a graded approach, cover the protection of nuclear facilities and materials during operational use, storage phases, and transportation. Furthermore, requirements for security measures regarding insider threat mitigation and prevention of cyberattacks were also established. These regulatory measures draw from the IAEA's nuclear security guidance "INFCIRC/225/Rev.5" and are structured to comply with the provisions of the CPPNM and its 2005 Amendment.

The "Security of Radioactive Sources regulation (PAK/926)" was similarly enacted to ensure protection of such materials during their manufacture, application, transit, and storage. Consistency is maintained between these regulations and the provisions of the "Code of Conduct on radioactive source safety and security," including its two supplementary guides. They mandate graded security measures that encompass detection, delay, response, and comprehensive management of radioactive sources.[27]

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[26] *National Command Authority Act, 2010*, Government of Pakistan, published in *The Gazette of Pakistan*, December 20, 2010, https://na.gov.pk/uploads/documents/1300934282_934.pdf
[27] *The Pakistan Strategic Export Control Act, 2004*, Government of Pakistan, https://fas.org/nuke/guide/pakistan/export-control.pdf

The second pillar is the organizations and institutions, which are the responsible authorities in this field. Under the NCA Act, authority over the management of Pakistan's nuclear assets and the protection of its nuclear program is vested in the NCA. PNRA oversees the physical safety of nuclear assets and is tasked with ensuring their secure and responsible use. "Strategic Export Control Division (SECDIV)," which was created through legislation, has been appointed as the key body that is supposed to oversee the rules and regulations governing export and import of sensitive materials, and dual-use equipment and technologies. PAEC is the promotional body overseeing nuclear applications in all sectors of Pakistan.

The third pillar encompasses a multi-layered array of systems and measures, designed to ensure effective implementation of nuclear safety and security. This primarily includes the implementation of physical protection systems, nuclear material accounting and control, as well as detection and response mechanisms. Radiation detection systems, including portal monitors and handheld devices, have been installed at Pakistan's border checkpoints under the NNDA to address cross-border trafficking of nuclear and radioactive materials. Additionally, an Integrated Cargo Container Control system has been operating since 2007 at Port Qasim near Karachi. These are operated by the officials of Pakistan Customs as Front-Line Officers (FLOs).

To assist FLOs, Radiological Assistance Groups (RAGs) and technical support units have been constituted to provide on-the-spot support for a range of critical functions, including identifying unknown radioactive sources, conducting checks for surface contamination, undertaking extensive searches and recovery operations for radioactive materials that are not under regulatory control. The amendments in the "Customs Act 1969 (IV of 1969)" have included NCA and PNRA to enhance oversight of the import and export of nuclear and radioactive materials. Relevant offences and penalties have been defined to criminalize malicious acts involving

these materials.[28] "Nuclear Material Accounting and Control (NMAC)" mechanism exist as part of physical protection regime and efforts are being made to establish modern training facility to enhance capabilities of professionals on advanced techniques of NMAC. In fulfillment of its national and international commitments, Pakistan has established these systems and measures as the main pillar of its nuclear security regime. These systems and measures are designed to provide detection, delay and response to potential nuclear security threats including the physical protection, and robust cyber security protocols to prevent attacks on nuclear installations and radiation facilities, all of which are informed by regular threat assessments to ensure their effectiveness.

This harmonious interplay of legislative, institutional, and technical components enables Pakistan to maintain a vigilant and proactive approach to nuclear security. In its "Nuclear Security Index 2020," the US based nuclear threat initiative (NTI), which assesses countries' progress on nuclear security, categorized Pakistan as most improved country for its nuclear security measures, being quoted as "Most improved among countries with materials in 2020 is Pakistan, which was credited with adopting new on-site physical protection and cybersecurity regulations, improving insider threat prevention measures, and more." [29]

Human Capacity Building

The development of human capacity is a fundamental pillar of developing a robust nuclear safety and security regime in any nation. In Pakistan, the dire shortage of skilled human resources in this field has been overcome by the creation of several reputable institutions, most of which are operated

[28] Ministry of Foreign Affairs, *Pakistan's Overview of Nuclear Security Regime* (Islamabad: Ministry of Foreign Affairs, Government of Pakistan, 2024), https://mofa.gov.pk/nuclear-safety-security

[29] Government of Pakistan, *The Customs Act, 1969 (IV of 1969)* (Islamabad: Printing & Publication Customs Budget, FBR, 2024), https://bwcimplementation.org/sites/default/files/resource/Customs%20Act%201969%20as%20of%202024.pdf

under the supervision of the PAEC. The most notable of these is the PIEAS which also supervises a chain of affiliated institutions. PIEAS has a varied academic program that offers Bachelor's, Master's, and doctoral degrees. In addition, PIEAS also offers professional development courses and research opportunities in many scientific and engineering fields. It is worth noting that PIEAS has been recognized as an IAEA Collaborating Centre in Nuclear Engineering, which indicates its international status and contribution to nuclear education and training in the world.

PNRA has also established the "National Institute of Safety and Security (NISAS)" to fulfill the essential requirements of developing human resources in nuclear safety and security field. NISAS offers dedicated training courses along with refresher courses related to nuclear security, radiation detection systems, physical protection systems, which are used for security of nuclear and radioactive materials and related facilities, emergency preparedness, and detection of nuclear and radioactive materials out of regulatory control for professionals from various national and international organizations. NISAS also serves as a collaborating center for the IAEA for the nuclear security discipline.

Another important institution that plays a significant role in human resource development in nuclear safety and security is "Pakistan Centre of Excellence in Nuclear Security (PCENS)." [30] PCENS also provides a variety of training courses, including specialized courses in the fields of nuclear security and physical protection systems to facilitate the best practices in nuclear security. It is an internationally recognized facility for both domestic and international participants. In March 2016, PCENS organized an annual meeting of the "International Network of Nuclear Security Support Centers (NSSC)." It was the first meeting of this Network, which was held outside of the IAEA Headquarters.

[30] Nuclear Threat Initiative (NTI), "The 2020 NTI Nuclear Security Index," *The Nuclear Threat Initiative*, February 22, 2022, https://www.nti.org/analysis/articles/2020-nti-nuclear-security-index/

Extended International Cooperation

PNRA has greatly emphasized the pivotal role of international collaboration in enhancing the effectiveness of regulatory systems and the reinforcement of global nuclear safety and security frameworks. In this regard, PNRA has established good partnerships with IAEA and the regulatory bodies of several other nations in order to support the exchange of regulatory experiences, knowledge sharing and other initiatives for capacity-building. Pakistan maintains an active participation in all IAEA Safety Standard Committees, including the "Nuclear Security Guidance Committee (NSGC)," "Radiation Safety Standards Committee (RASSC)," "Nuclear Safety Standards Committee (NUSSC)," "Waste Safety Standards Committee (WASSC)," "Transport Safety Standards Committee (TRANSCC)," "Commission on Safety Standards (CSS)," and "Global Nuclear Safety and Security Network (GNSSN)." Additionally, PNRA also maintains coordination with several IAEA forums like the "Incident Reporting System (IRS)," "Illicit Trafficking Database (ITDB)," "International Nuclear and Radiological Event Scale (INES)," "Regulatory Cooperation Forum (RCF)," "Response and Assistance Network (RANE)," "International Generic Ageing Lessons Learned (IGALL)," "United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)," and "Radiation Safety Information Management System (RASIMS)."

In addition to participation, PNRA facilitates the IAEA with expert support for conducting "International Physical Protection Advisory Service (IPPAS)" missions, "Integrated Regulatory Review Service (IRRS)" missions, developing training materials and safety standards, and conducting workshops and training courses in Member States. PNRA also participates in various IAEA Technical Cooperation Programs intended for enhancement of the capabilities of its regulatory personnel, resulting in consolidation of Pakistan's regulatory infrastructure. Pakistan also serves as

a designated point of contact for the IPPAS Good Practices Database,[31] maintained by the IAEA since 2016. The main purpose of this database is to share the lessons learnt from IAEA IPPAS missions with the international nuclear security community.

PNRA has also forged bilateral cooperation agreements with several international organizations, like "China's Nuclear Safety and Radiation Protection Center (NSC)," "China Nuclear Power Operations Technology Corporation Ltd. (CNPO)," and "China's National Nuclear Safety Administration (NNSA)." The main objectives of these agreements are to promote professional development, facilitate assistance in regulatory matters, and exchange regulatory experiences. Additionally, a Memorandum of Understanding (MoU) has been signed by PNRA with Nigerian Nuclear Regulatory Authority (NNRA) to facilitate capacity building of NNRA through scientific visits and fellowships under the sponsorship of the IAEA.

Pakistan's longstanding and constructive engagement with the IAEA was duly recognized by the IAEA Director General, Rafael Mariano Grossi, during his visit to Pakistan in February 2025. He also asserted the IAEA's commitment, in the same spirit, for sustained collaboration with Pakistan. Grossi also described Pakistan's nuclear power generation program as one of the most globally successful programs, by highlighting the country's substantial progress in nuclear power generation, healthcare, agricultural advancements, and industrial development, all leading to its socio-economic growth. Notably, in recognition of Pakistan's sustained dedication to nuclear safety, Chairman PNRA, Faizan Mansoor, was unanimously elected as President of the Tenth Review Meeting of CNS in September 2024, with the meeting scheduled to continue through April 2026.

[31] International Atomic Energy Agency (IAEA), "Nuclear Security Commitments and Actions," *IAEA Bulletin* 57, no. 4 (2016), https://www.iaea.org/sites/default/files/publications/magazines/bulletin/bull/bull574_nuclearsecurity.pdf

Related to Nuclear Security, Pakistan is dedicated to strengthening its nuclear security by ratifying several key international instruments. Pakistan became a state party to the CPPNM in 2000 and its 2005 amendment in 2016, which seeks to "physically protect nuclear facilities and materials utilized for peaceful purposes in domestic use, storage, and transport." It also involves the criminalization of certain offences related to nuclear material. Additionally, Pakistan has adopted the IAEA "2004 Code of Conduct on Safety and Security of Radioactive Sources," its "supplementary Guidance on the Import and Export of Radioactive Sources, and Management of Disused Radioactive Sources."

Pakistan is fully committed to implementing the obligations outlined United Nations Security Council Resolutions (UNSCRs) 1373, 1540, and 1887, which focuses on the prevention of nuclear weapon proliferation, combating terrorism, and promoting nuclear security and non-proliferation. Pakistan has been presenting implementation reports to UNSCRs committees, as necessary, in pursuance of the objectives of these UNSCRs. The active cooperation of Pakistan with international partners and agencies, compliance with international instruments, and institutional approach is evidence of the utmost importance of a strong nuclear safety and security regime in Pakistan.

Highly Valued Safety and Security Culture

PNRA encourages the existence of safety and security culture in organizations which are involved in nuclear activities. These are operators, regulators and designers. The global nuclear community has significantly focused on the incorporation of safety culture in regulatory agencies following the Fukushima accident. To align with this worldwide trend, PNRA has undertaken a Safety Culture-Self Assessment (SCSA) initiative to enable the evaluation and improvement of the role of safety culture through leadership practices and in the organizational processes.

Data collection was done through a number of approaches at all levels of the organization. This involves interviews, surveys, focus groups, document analysis and observations. The primary goal of this program was to encourage open communication, increase safety awareness and build a common vision of safety objectives. The SCSA results were used to design safety culture improvement activities, strengthening the strong areas and working on the improvement of weak areas. By undertaking this self-assessment, PNRA not only reinforced its position as a leader in nuclear safety regulations but also demonstrated its commitment to continuous safety culture enhancement, a cornerstone of its leadership and regulatory strategy. PNRA has established regulations that emphasize the role of leadership in safety and the commitment to creating a safety-conscious organizational culture.

Similarly, a strong security culture among professionals and nuclear organizations plays a critical role in strengthening the security regime in a country. Being vigilant of this fact, all responsible organizations related to nuclear security are making efforts to guarantee a strong nuclear security culture. In 2018, PNRA conducted an international workshop focused on the practical application of nuclear security culture. The event aimed to deepen understanding of its core principles and practices. PNRA, through its regulatory processes, promotes a safety and security culture among its licensees. They have also introduced a nuclear security culture assessment procedure (a survey) among scientists and engineers as per IAEA guidelines.

Conclusion

The nuclear safety and security regime in Pakistan is robust, mature, as well as fully aligned with the international nuclear governance framework. Pakistan has demonstrated a consistent commitment to maintaining the exemplary standards of nuclear safety and nuclear security which places its regulatory infrastructure at par with those of technologically advanced countries. All components of the national nuclear regulatory framework are

clearly defined, actively implemented, and continuously enhanced. PNRA's regulations fully cover the comprehensive regulatory sectors such as licensing and inspection, physical protection, radioactive waste management, emergency preparedness and occupational and public safety. Significant efforts are made to strengthen the capacity of the regulator, promote a strong safety and security culture in the country, and contribute to global nuclear knowledge-sharing platforms.

This was also acknowledged by the DG IAEA during his visit to Pakistan in February 2025. Through close cooperation with the IAEA, along with active participation in regional and international forums, Pakistan not only upholds its own safety and security responsibilities but also supports other countries embarking on peaceful nuclear programs. This cooperative spirit reinforces Pakistan's image as a responsible country in the nuclear sector. It also projects Pakistan as a proactive partner in promoting nuclear safety and security. Lastly, Pakistan's nuclear regulatory regime reflects Pakistan's steadfastness to ensuring nuclear safety, international obligations, and peaceful development. Through continuous improvement, transparency, and international cooperation, Pakistan maintains a robust and responsible nuclear infrastructure to ensure environmental stewardship and scientific advancement for its socio-economic development.