Regulatory Independence and Nuclear Safety Governance in South Asia: A Comparative Analysis of Pakistan and India in Light of IAEA Standards

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Abstract

For civilian nuclear safety governance, independent nuclear regulators are imperative to eliminate conflicts of interest and to prioritize safety over political and economic pressures. It is important that national practices of nuclear regulatory authorities align with the best international practices. To understand the nuclear safety governance of South Asia, this study undertakes a comparative analysis of the nuclear regulatory frameworks of Pakistan and India by examining the Atomic Energy Regulatory Board (AERB) and the Pakistan Nuclear Regulatory Authority (PNRA) against the safety standards and guidelines of the International Atomic Energy Agency (IAEA). The main argument of this research is that regulatory independence is essential for sustainable nuclear safety governance, and the absence of regulatory autonomy creates structural vulnerabilities that can affect long-term safety outcomes. In the context of Pakistan and India, it is significant because both states operate a civilian nuclear program in a shared geopolitical environment where regulatory failures carry transboundary consequences. The comparative analysis has been conducted across different dimensions such as regulatory independence, decision making and enforcement effectiveness, Integrated Regulatory Review Service (IRRS) implementation in both jurisdictions, and preparedness for emerging technological risks. For research methodology, the research adopts a qualitative approach to examine nuclear regulatory frameworks in Pakistan and India. The findings indicate that, as per IAEA safety standards, PNRA possesses a formally robust and independent institutional structure along with mature international engagement compared to AERB, which operates under a subordinated institutional architecture.

Keywords: IAEA, PNRA, AERB, Regulatory Independence, Safety Standards, Nuclear Governance, South Asia

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Introduction

Nuclear energy has become one of the important elements in the global energy mix due to its application in multiple sectors, which has led the international community to place significant emphasis on the safety of nuclear governance as an important domain of public administration. Any failure and negligence in nuclear governance and regulation can produce repercussions that can cross national boundaries and engulf entire regions with an unlimited timeline.[1] Chernobyl[2] and Fukushima[3] are demonstration of this catastrophic failure. For safe nuclear regulation, regulatory independence[4] carries much of the weight as it allows the central authority to take sound decisions regarding the safety of the facilities and installation without any pressure from promotional entities that are responsible for expansion of nuclear energy. At the global level, the IAEA has presented itself as cooperative platform, aiming at establishing a global regulatory architecture and facilitating safe nuclear governance through its Safety Standards Series comprised of binding Safety Requirements and recommended Safety Guides[5]. These international safety standards emphasize harmonization between national and international institutions and the incorporation of legal independence, financial autonomy, transparency obligations, and peer review mechanisms into states' regulatory frameworks.[6]

Pakistan and India have extensive civilian nuclear programs where both states are operating thirty functioning nuclear power reactors[7] with ambitious growth trajectories. Additionally, both states are operating radiation facilities with Pakistan's 6,732 medical radiation facilities[8] and India operating comparably extensive radiological infrastructure.[9] Nuclear

[1] Joy Rempe and Laurence Williams, "Overview of Nuclear Regulation and Regulatory Framework," *in Nuclear Engineering Handbook*, ed. Kenneth D. Kok (Oxford: Academic Press, 2020), https://doi.org/10.1016/B978-0-12-409548-9.12156-6.

[2] U.S. Nuclear Regulatory Commission, *"*Backgrounder on Chernobyl Nuclear Power Plant Accident,*"* fact sheet, accessed February 24, 2026, https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/chernobyl-bg.html.

[3] World Nuclear Association, *"*Fukushima Daiichi Accident,*" World Nuclear Association Information Library*, updated February 23, 2026, https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-daiichi-accident.

[4] International Atomic Energy Agency, "*Independence in Regulatory Decision Making,"* IAEA Publication No. 1172, (Vienna: IAEA, 2003), accessed February 24, 2026, https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1172_web.pdf.

[5] International Atomic Energy Agency, "Safety Standards," IAEA, accessed February 24, 2026, https://www.iaea.org/resources/safety-standards.

[6] Stephen G. Burns, "Milestones in Nuclear Law: A Journey in Nuclear Regulation," in *Nuclear Law: The Global Debate* (The Hague: T.M.C. Asser Press, 2022), https://doi.org/10.1007/978-94-6265-495-2_4.

[7] Atomic Energy Regulatory Board (AERB), *Design of Fuel Handling and Storage Systems for Nuclear Power Plants,* Document No. AERB/NPP/SG/D-24 (Rev. 1) (Mumbai: AERB, 2025), accessed February 25, 2026, https://www.aerb.gov.in/images/PDF/CodesGuides/NuclearFacility/NuclearPowerPlant/Design/24.pdf.

[8] Pakistan Nuclear Regulatory Authority, *Annual Report 2024* (Islamabad: PNRA, 2024), accessed February 24, 2026, https://www.pnra.org/upload/pnrarpt/Annual%20Report%202024.pdf.

[9] Baljinder Singh *et al.*, "India's Growing Nuclear Medicine Infrastructure and Emergence of Radiotheranostics in Cancer Care: Associated Challenges and the Opportunities to Collaborate," *Indian Journal of Nuclear Medicine*, 38, no. 3 (2023): 201–207, accessed February 24, 2026, https://pmc.ncbi.nlm.nih.gov/articles/PMC10693374/.

regulators of both states (PNRA and AERB) are in place to ensure the safety standards of nuclear technology as per IAEA standards.

There is ample literature on IAEA safety standards, as well as nuclear regulatory authorities of both Pakistan and India. Some scholars have discussed the importance of coordination between international policy and national regulatory framework for the safety of commercial nuclear facilities[10] while others have shed light on the significance of regulatory independence to ensure safety decisions without subjugation of external interference.[11] The scholarly literature on PNRA explains its evolutionary journey, alignment with IAEA safeguards, and its independent regulatory structure[12], whereas, assessment of AERB demonstrates an institutional structure that does not comply with the IAEA requirement of regulatory independence.[13] The literature review provides important insights into institutional design, and the regulatory efficacy of PNRA and AERB. However, the comparative analysis of nuclear regulatory frameworks of both states against regulatory independence and its impact receives a disproportionate amount of scholarly attention. Furthermore, the literature offers very little analysis for cyber threats, small modular reactors (SMRs) accommodation, and climate scenarios incorporation into regular safety reviews of both regulators.

The study has employed IAEA safety standards as theoretical framework to analyze the regulatory independence of PNRA and AERB. IAEA's INSAG-17 report titled Independence in Regulatory Decision Making indicate that autonomy in legal, financial, and procedural decision making is essential for regulatory independence that impacts overall performance of the regulator.[14] The objective of this research is to critically analyze the regulatory independence of PNRA and AERB against the IAEA benchmark along with regulators' responsiveness to IRRS recommendations, enforcement capacity and their preparedness for emerging technological challenges. These objectives lead to a central question: To what extent does regulatory independence determine the effectiveness of nuclear governance in Pakistan and India across different dimensions of regulatory framework, IRRS implementation, enforcement capability, and preparedness for emerging challenges?

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[10] Joy Rempe and Laurence Williams, "Overview of Nuclear Regulation and Regulatory Framework," in *Nuclear Engineering Handbook*, ed. Kenneth D. Kok (Oxford: Academic Press, 2020), https://doi.org/10.1016/B978-0-12-409548-9.12156-6.

[11] Anthony Wetherall, "Normative Rule Making at the IAEA: Codes of Conduct," *Nuclear Law Bulletin* 2005, no. 1 (July 25, 2005): 71–93, https://doi.org/10.1787/nuclear_law-2005-5k9d19g4m348.

[12] Muhammad Rizwan, "Genesis and Contours of Pakistan's Regulatory Regime for Safety of Nuclear Power Plants in Comparison with International Standards," *CISS Insight Journal* 8, no. 1 (July 15, 2020): 94–117, accessed February 26, 2026, https://journal.ciss.org.pk/index.php/ciss-insight/article/view/138.

[13] Andrews-Speed, Philip, and Nur Azha Putra. "Breaking the iron triangle around nuclear safety regulation: The cases of France, Japan, and India." *Regulation & Governance* (2024). https://doi.org/10.1111/rego.12577.
S. S. Bajaj, "Regulatory practices for nuclear power plants in India," published in *Sādhanā*, Volume 38, Part 5, pages 1027–1050, October 2013. https://link.springer.com/article/10.1007/s12046-013-0174-9#citeas.

[14] International Nuclear Safety Advisory Group, *Independence in Regulatory Decision Making*, INSAG-17 (Vienna: International Atomic Energy Agency, 2003), https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1172_web.pdf.

For analyzing nuclear regulations with trans-boundary consequences, South Asia (Pakistan and India) presents a particularly compelling and under-examined case. The study adopts a qualitative research methodology that utilizes both primary and secondary resources. The study relies on research articles, book chapters, IAEA reports, policy documents and national legislative bills. Given the fact that both states are members of the IAEA, a comparative design will provide a meaningful understanding of both regulators with similar standards and conditions of IAEA safety standards, IRRS recommendations, and IAEA guidelines.

The next section of this paper provides a theoretical foundation for the analysis. The paper further compares the legal and functional independence of PNRA and AERB as per IAEA criteria, international engagement, and IRRS responsiveness. Finally, the paper evaluates how both regulators are getting ready for emerging challenges such as cybersecurity, SMR governance, adapting to climate change, and integrating Artificial intelligence (AI). The discussion is followed by a Conclusion.

Theoretical Framework

- ***Regulatory Independence in Nuclear Regulation***

There are three important functions that every regulatory body is expected to perform. The first is to develop sound, comprehensive regulations; the second is to verify compliance with these regulations; and the third is to enforce corrective regulatory measures in cases of malpractice or wrongdoing by persons or organizations. To perform these functions, the regulatory authority must possess competence, authority, and regulatory independence. For successful nuclear regulatory governance, regulatory independence[15] has been recognized as foundational bedrock that impacts the integrity of the institution by freeing it from external pressures and strengthening its legal, financial, operational, and procedural dimensions of regulation. For this research, the IAEA's frameworks, especially the INSAG-17 Report "Independence in Regulatory Decision Making", are utilized as the primary theoretical lens to systematically evaluate the institutional design and safety governance of both regulators. The IAEA framework defines regulatory independence as both structural autonomy, which is the formal separation of the regulatory body from entities that promote or operate nuclear facilities, and functional authority, which is the practical capacity to make and enforce safety decisions without subjection to external interference.[16]

Within this theoretical lens, four principal indicators can systematically assess regulatory independence across jurisdictions. The first principle is legal and decision-making autonomy that

[15] Ibid.
[16] Anthony Wetherall, "Normative Rule Making at the IAEA: Codes of Conduct," *Nuclear Law Bulletin* 2005, no. 1 (July 25, 2005): 71–93, https://doi.org/10.1787/nuclear_law-2005-5k9d19g4m348.

requires the regulatory body to possess unambiguous authority to adopt safety regulations, develop binding subordinate instruments, and impose sanctions, with explicit legal barriers protecting specific safety decisions from political or industry pressure.[17] The second principle is appointment and removal safeguards that demand transparent, criteria-based processes. Financial independence is the third principle that requires stable, adequate funding mechanisms separated from both promotional bodies and licensee influence. The fourth principle is transparency, which demands that decision-making processes be open and accessible to public scrutiny.[18]

The second aspect of this theoretical framework is the relationship between regulatory independence and safety outcome that establishes a central theoretical argument for this research. Autonomy in nuclear governance is essential for positive safety performance of the regulatory authority.[19] Several mechanisms have been articulated by IAEA that shows how institutional independence translates into enhanced safety performance. The institutional autonomy and independence create legal barriers to all the essential technical safety decisions from commercial and developmental pressures. Furthermore, technical regulatory capacity is directly connected with financial independence, which prevents the regulatory administration from unnecessary delays. Availability of resources shapes the regulator's ability to employ, train, and retain staff capable of independent judgment, and to engage external scientific experts.[20] Regulatory independence is also essential for effective radioactive waste management. As reflected in IAEA safety frameworks such as Radioactive Waste Safety Standards (RADWASS)[21], independent regulators are in a better position to implement international standards of safety without commercial and political pressure.

The IAEA's formal articulation of regulatory independence, against which the PNRA and AERB are assessed, has evolved substantially through its Safety Fundamentals and General Safety Requirements (specifically GSR Part 1 and Part 3). Together these documents constitute the authoritative international reference for the design of national regulatory framework. GSR Part 1 (requirement 4) positions regulatory independence as foundational to the entire nuclear safety regime. It establishes that independence must be clearly reflected in the national legal framework and grounded in instruments enacted at the highest political level. The framework openly demands that there should be operational separation of the regulator from the entities

[17] Nuclear Energy Agency, *Nuclear Regulatory Decision Making*, NEA No. 5356 (Paris: OECD/Nuclear Energy Agency, 2005), https://www.oecd-nea.org/upload/docs/application/pdf/2019-12/nea5356-decision.pdf.
[18] INSAG, *Independence in Regulatory Decision Making*, INSAG-17 (Vienna: International Atomic Energy Agency, 2003). https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1172_web.pdf.
[19] Alexander Anastassov, "Some Aspects of the Effectiveness of the International Regulatory Framework to Ensure Nuclear Safety," in *Nuclear Non-Proliferation in International Law – Volume III*, ed. Jonathan Black-Branch and Dieter Fleck (The Hague: T.M.C. Asser Press, 2016), https://doi.org/10.1007/978-94-6265-138-8.
INSAG, *Independence in Regulatory Decision Making*, INSAG-17 (Vienna: International Atomic Energy Agency, 2003).https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1172_web.pdf.
[21] International Atomic Energy Agency, *Classification of Radioactive Waste: A Safety Guide*, IAEA Safety Series No. 111-G-1.1, STI/PUB/950 (Vienna: IAEA, 1994), accessed February 25, 2026, https://gnssn.iaea.org/Superseded%20Safety%20Standards/Safety_Series_111-G-1.1_1994_Pub950e_web.pdf.

promoting or operating nuclear facilities.[22] The Convention on Nuclear Safety[23], Joint Convention frameworks[24], and the IAEA Safety Standards[25] reinforces these requirements for national regulators.

The theoretical framework further incorporates the significance and limitations of the IRRS[26] that acts as the IAEA's primary instrument for translating abstract standards into practical regulatory improvement through systematic, country-specific peer review. IRRS missions provide host regulators with objective evaluation against IAEA safety standards, recommendations for improvement, and structured opportunities for knowledge exchange with international regulatory peers possessing direct applicable experience. However, there are fundamental structural limitations in the international nuclear safety governance architecture. This standard binding force is applicable only to the IAEA's own operations and IAEA-assisted operations, leaving the vast majority of global nuclear activity subject exclusively to voluntary national application. The absence of enforcement mechanisms beyond IAEA-assisted operations means that states can adopt the appearance of compliance while maintaining promotional-regulatory integration that is fundamentally incompatible with genuine independence, and face no binding consequences for doing so.[27]

[22] International Atomic Energy Agency, *Governmental, Legal and Regulatory Framework for Safety (GSR Part 1, Rev. 1)* (Vienna: IAEA, 2016), viewed February 25, 2026, NSS-OUI, https://nucleus-apps.iaea.org/nss-oui/Content/Index?CollectionId=m_8fd5e365-0c72-4e28-9ec7-3a2452df2b43&type=PublishedCollection.

[23] International Atomic Energy Agency, *Convention on Nuclear Safety*, IAEA Information Circular No. INFCIRC/449 (Vienna: IAEA, 5 July 1994), accessed February 25, 2026, https://www.iaea.org/sites/default/files/infcirc449.pdf.

[24] International Atomic Energy Agency, *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*, IAEA INFCIRC 546 (Vienna: IAEA, adopted 5 September 1997; entered into force 18 June 2001), accessed February 25, 2026, https://www.iaea.org/sites/default/files/23/09/23-03660e_web.pdf.

[25] International Atomic Energy Agency, *IAEA Nuclear Safety and Security Glossary*, (Vienna: IAEA, 2022 (Interim Edition)), accessed February 25, 2026, https://www-pub.iaea.org/MTCD/Publications/PDF/IAEA-NSS-GLOweb.pdf.

[26] International Atomic Energy Agency, *Integrated Regulatory Review Service (IRRS): Technical Brochure* , (Vienna: IAEA, November 2024), accessed February 25, 2026, https://www.iaea.org/sites/default/files/24/11/22-00616e_ns_tech_bro_irrs_final.pdf.

[27] Anguel Anastassov, Some Aspects of the Effectiveness of the International Regulatory Framework to Ensure Nuclear Safety, in *Nuclear Non-Proliferation in International Law – Volume III: Legal Aspects of the Use of Nuclear Energy for Peaceful Purposes*, ed. Jonathan L. Black-Branch and Dieter Fleck (The Hague: T.M.C. Asser Press, 2016), 215–46, https://link.springer.com/chapter/10.1007/978-94-6265-138-8_7.

Comparative Analysis

Statutory Independence of AERB and PNRA

- ***Legal Independence***

PNRA is Pakistan's national nuclear regulator and it is committed to ensure and integrate international safety protocols into the national regulatory framework. Throughout its journey of regulatory independence, Pakistan has completed multiple milestones, including the establishment of the Pakistan Nuclear Safety and Radiation Protection Ordinance in 1984, the Directorate of Nuclear Safety and Radiation Protection in 1985, and finally, the Pakistan Nuclear Regulatory Authority in 2001.[28] The establishment of PNRA was a deliberate attempt to meet international expectations for a genuinely independent oversight authority.[29] AERB, on the other hand, was constituted on November 15, 1983, under Sections 16, 17, and 23 of the Atomic Energy Act of 1962, legislation whose primary legislative purpose was advancing nuclear energy development rather than independently governing it.[30]

With respect to statutory independence, the regulatory authorities of both states — AERB and PNRA — have adopted different approaches**.** PNRA is a fully autonomous regulatory organization responsible for nuclear safety regulation and radiation protection. The Ordinance No. III of 2001 provided explicit legislative authority to PNRA, where the Chairman reports directly to the Prime Minister, the highest political authority of Pakistan. Furthermore, the ordinance also created a formal separation of PNRA from the promotional body of the Pakistan Atomic Energy Commission (PAEC).[31] AERB, on the other hand, operates under the administrative control of the Atomic Energy Commission**.**[32] The very entity responsible for exploiting or promoting nuclear technologies. This creates an irreconcilable conflict of interest, as the regulatory authority is held accountable to the very body whose activities it is mandated to scrutinize, and it compromises the independent relationship that effective nuclear governance requires. The structural subordination of AERB to Atomic Energy Commission contradicts the

[28] Naeem Ahmad Salik, *Learning to Live with the Bomb: Pakistan, 1998–2016* (Karachi: Oxford University Press, 2017), chap. 7, "Pakistan's Nuclear Regulatory Regime," 257-291.
[29] Muhammad Rizwan, "Genesis and Contours of Pakistan's Regulatory Regime for Safety of Nuclear Power Plants in Comparison with International Standards," *CISS Insight Journal* 8, no. 1 (July 15, 2020): 94–117, accessed February 26, 2026, https://journal.ciss.org.pk/index.php/ciss-insight/article/view/138.
[30] Atomic Energy Regulatory Board (AERB), Government of India, *Acts — Acts & Regulations*, accessed February 26, 2026, https://www.aerb.gov.in/english/acts-regulations/acts.
[31] Pakistan Atomic Energy Commission, "PAEC Contact Us," *PAEC*, accessed February 24, 2026, https://paec.gov.pk/contact/index.aspx.
[32] Atomic Energy Regulatory Board (AERB), Government of India, "*Annual Reports*," accessed February 26, 2026, https://www.aerb.gov.in/english/publications/annual-report.

IAEA's explicit requirement[33] that regulatory budgets and authority should not be decided by or be subject to the approval of those parts of the government which are responsible for exploiting or promoting nuclear technologies.

- ***Operational Independence***

The structure of PNRA has been established in accordance with IAEA regulatory standards and separates operational regulatory authority from institutional support. For that there are two primary wings within PNRA. The Executive Wing is for central regulatory functions, and the Corporate Wing functions as a Technical Support Organization. Furthermore, there are specialized directorates for nuclear safety, radiation safety, transport, and waste safety. The Center for Nuclear Safety, School of Nuclear and Radiation Safety, and National Radiation Emergency Coordination Center collectively demonstrate genuine regulatory ambitions, align with international safety standards.[34] The regulatory activities of PNRA also reflect institutional independence and confidence, aligning closely with IAEA frameworks across multiple, independently verifiable dimensions. The regulatory structure of PNRA (Ordinance at top, Regulations at second tier, Regulatory Guides at third tier) reflects IAEA's hierarchical standards architecture.[35] PNRA has a history of cooperating with the nuclear regulators of other countries, especially China, where bilateral relations are quite strong in terms of nuclear safety, and it has been involved in bilateral arrangements with multiple Chinese organizations,[36] such as National Nuclear Safety Administration (NNSA), China Nuclear Power Operations Technology Corporation (CNPO), and Nuclear and Radiation Safety Center (NSC).[37] The enforcement and operational autonomy has helped PNRA in achieving high level of safety standards.

The structural subordination of AERB can be seen by its deep operational embeddedness within the broader Department of Atomic Energy (DAE)[38] ecosystem. The first problem is that the experts in multi-tiered safety review committees are predominantly from organizations within DAE, and these committees are responsible for AERB's technical decision making. The

[33] International Atomic Energy Agency, "*IAEA Safety Standards*, IAEA Safety Standards Series," (Vienna: IAEA, 2023), section on financial aspects of regulatory independence, accessed February 26, 2026, https://www-pub.iaea.org/MTCD/Publications/PDF/P1801_web.pdf.
[34] Tariq Majeed, "Assessment of Nuclear Safety and Security Regime of Pakistan," *CISS Insight Journal* 13, no. 1 (June 30, 2025), accessed February 26, 2026, https://journal.ciss.org.pk/index.php/ciss-insight/article/view/413.
[35] Pakistan Nuclear Regulatory Authority (PNRA), "*Establishment of Regulatory Framework*," accessed February 26, 2026, https://pnra.org/estab-rf-work.html.
[36] Dr. Allauddin Kakar, Azeem Khalid, and Malik Muhammad Ali, "Pakistan-China Nuclear Energy Cooperation: Emerging Trends to Achieve Sustainable Development Goals," *Pakistan Journal of International Affairs* 4, no. 1 (January 2021), accessed February 26, 2026, https://www.researchgate.net/publication/350496752_Pakistan-China_Nuclear_Energy_Cooperation_Emerging_Trends_to_Achieve_Sustainable_Development_Goals.
[37] Pakistan Nuclear Regulatory Authority (PNRA), "*International Cooperation*," accessed February 26, 2026, https://www.pnra.org/int-cooperation.html.
[38] Department of Atomic Energy (DAE), "Government of India," *Homepage*, accessed February 25, 2026, https://dae.gov.in/.

Nuclear Power Corporation of India Limited[39] and Bharatiya Nabhikiya Vidyut Nigam[40] are two regulated entities which themselves are DAE subsidiaries. Bharat Atomic Research Centre[41] and Indira Gandhi Centre for Atomic Research[42] are promotional research organizations upon whom AERB relies for primary technical support. The Safety Research Institute at Kalpakkam also conducts technical research, however, it is very limited with respect to the total dimensions of regulatory research needed.[43] The training of AERB recruits at nuclear training schools under Homi Bhabha National Institute, which is a DAE institution[44], can potentially inculcate promotional values during professional development. These operational and technical dependencies have potential to create conflict of interest and external pressure on AERB.

- ***Financial Independence***

PNRA's budget is also independent and separate from promotional and regulated entities. It is generated through federal grants, license fees, and Public Sector Development Program, making PNRA free from financial approval from other entities.[45] Whereas, AERB's budget needs DAE approval, which is the body that AERB regulates.[46] This goes against IAEA rules that say regulatory budgets should not be tied to organizations that promote nuclear technologies. This financial subordination structurally undermines the independence asserted by AERB. If funding is flowing through promotional entity than regulatory authority can face pressure to align with promotional agendas of licensing, or incorporation of new technologies. Similarly, without an independent budget, regulators cannot freely provide funds for research and inspections, etc. The

[39] International Atomic Energy Agency, *"Nuclear Power Corporation of India Limited," (IAEA Publication P1574 Addendum, Section 075)* (Vienna: IAEA, n.d.), accessed February 25, 2026, https://www-pub.iaea.org/MTCD/publications/PDF/IAEA-NSS-GLOweb.pdf.

[40]Government of India, Ministry of Finance, "*Statement of Budget Estimates 2011-2012," (Demand No. 5: Department of Atomic Energy*, Expenditure Budget Volume II) (New Delhi: Government of India, 2011), accessed February 25, 2026, https://www.indiabudget.gov.in/budget2011-2012/ub2011-12/eb/sbe5.pdf.

[41] R. D. Kale, "India's Fast Reactor Programme — A Review and Critical Assessment," *Progress in Nuclear Energy* (2020), accessed February 26, 2026, https://www.sciencedirect.com/science/article/abs/pii/S0149197020300251.

[42] Indira Gandhi Centre for Atomic Research, "*IGCAR Annual Report 2025"* (Kalpakkam: Department of Atomic Energy, Government of India, 2025), accessed February 26, 2026, https://www.igcar.gov.in/publications/igc_annual_report_2025.pdf.

[43] S. S. Bajaj, "Regulatory practices for nuclear power plants in India," published in *Sādhanā*, Volume 38, Part 5, pages 1027–1050, October 2013. https://www.ias.ac.in/article/fulltext/sadh/038/05/1027-1050.

[44] Government of India, "*National Report of India for the Sixth Review Meeting of the Contracting Parties to the Convention on Nuclear Safety,"* (New Delhi: Government of India, 2014), accessed February 26, 2026, https://aerb.gov.in/images/cns2014.pdf.

[45] Pakistan Nuclear Regulatory Authority, "*History of PNRA*," accessed February 26, 2026, https://www.pnra.org/history.html.

[46] Comptroller and Auditor General of India, "*Report No. 9 of 2012-13 — Performance Audit on Activities of the Atomic Energy Regulatory Board," Union Government, Atomic Energy Department: Chapter 2 — Regulatory Framework for Nuclear and Radiation Facilities* (New Delhi: CAG, 2012), accessed February 26, 2026, https://cag.gov.in/uploads/download_audit_report/2012/Union_Performance_Atomic_Energy_Regulatory_Board_Union_Government_Atomic_Energy_Department_9_2012_Chapter_2.pdf.

2025 SHANTI Bill[47] seeks to provide statutory power and some independence in financial matters but the bill has gaps and risks that need to addressed. This bill was aimed at resolving the autonomous issue that caused the prolonged scholarly criticism of AERB. However, it has also been observed that there are certain gaps that may cause difficulty in the implementation of the SHANTI Bill. These gaps include supplier liability, the failure to establish independent regulatory funds, ambiguous liability caps across different reactor categories, lack of clarity about the regulation of SMRs, and the absence of explicit public participation mechanisms.[48]

- ***Procedural Transparency***

As far as transparency is concerned, it also impacts legitimacy and autonomy. The transparency mechanisms of PNRA are also proactive and aligned with international safety standards. Section 52 of the 2001 Ordinance declares the chairman and members of PNRA as public servants, whereas sections 55 and 56 grant PNRA the power to make rules and regulations.[49] PNRA translates these rules and regulations into Urdu, conducts stakeholder consultations prior to official gazette notification, and submits annual reports to both the government and the public. These actions align with the procedural transparency standards of the IAEA. AERB's public engagement appears reactive where Press releases are used to keep the public informed and responses to Parliamentary queries, rather than proactive transparency mechanisms.[50] When the regulator is independent and autonomous, it reflects in effective decision-making and operational enforcement. The overall evaluation of both regulators against the key indicators of regulatory independence shows PNRA as the overall superior regulatory infrastructure.

IAEA IRRS Implementation in Pakistan and India

IRRS acts as the IAEA's primary instrument for translating abstract standards into practical regulatory improvement through systematic, country-specific peer review. PNRA documents explicitly show active participation in the IRRS mission to Vietnam as an IAEA expert. PNRA has participated in multiple projects and workshops to improve IRRS implementation and improve self-assessment capabilities. PAK/9/028 and PAK/9/034 were IAEA Technical Cooperation Projects that were focused on the self-assessment of PNRA using self-assessment

[47] Press Information Bureau, Government of India, "*The Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India (SHANTI) Bill, 2025,"* (New Delhi: Government of India, 19 December 2025), accessed February 26, 2026, https://static.pib.gov.in/WriteReadData/specificdocs/documents/2025/dec/doc20251222741701.pdf.
[48] JMMF Institute, *The Gaps and the Risks of the Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India (SHANTI) Act, 2025* (New Delhi: JMMF Institute, 2025), https://www.informaticsjournals.co.in/index.php/jmmf/article/view/54225/36096.
[49] Pakistan, "*Pakistan Nuclear Regulatory Authority Ordinance, 2001,"* (Ordinance No. III of 2001), available at: https://www.pnra.org/upload/legal_basis/Ordinance%202001(Amennded).pdf.
[50] CAG, *Report No. 9 of 2012-13*.

tools.[51] Developments were also made at the national level by establishing the Directorate of Regulatory Affairs (RAD) for self-assessment of regulatory effectiveness and development of performance indicators to provide quantifiable benchmarks for measuring regulatory maturity. For that, PNRA documented 12 strategic performance indicators.[52] These developments and institutional improvement mechanisms show strong alignment with IRRS methodologies.[53]

AERB, on the other hand, has also been engaged with the IAEA's peer-reviewed system and IRRS missions in 2015 and 2022. According to IRRS Mission 2015, the government of India should formally embed regulatory independence of AERB into law and separate it from promotional entities, independence in internal functioning of AERB, formulation of a national safety strategy for waste management, and further suggestions about power plant inspection and emergency preparedness.[54] The second mission in 2022 also identified the same gaps regarding the regulator's legal independence, safety assessment of nuclear plants, consistency in regulations related to IAEA safety standards, and a clear national policy regarding radioactive waste management that has been lost.[55] The analysis also shows that Pakistan demonstrates superior documentation and discipline with respect to IRRS implementation and engagement.

Emerging Technological Challenges: Comparative Regulatory Adaptation in PNRA and AERB

As per the IAEA mandate, it is essential for nuclear regulators to address emerging technological challenges to ensure safety standards across all dimensions. For that, regulatory independence plays a pivotal role because a regulator that is under the subordination of a promotional entity is unable to independently assess the impact of emerging challenges and, therefore, incapable of fulfilling its central safety governance tasks. Regulatory independence in cyber-security, SMR application, climate change, and AI not only requires policy understanding but also a dedicated institutional infrastructure that can work freely from external influence. The following analysis provide details of regulatory adaptation in PNRA and AERB.

[51] Pakistan Nuclear Regulatory Authority, "*Fifth National Report of Pakistan Under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*," (Islamabad: PNRA, 2020), accessed February 26, 2026, https://pnra.org/upload/reports/Pakistan-5NR.pdf.
[52] PNRA, "*Fifth National Report of Pakistan,"*. https://pnra.org/upload/reports/Pakistan-5NR.pdf.
[53] Pakistan Nuclear Regulatory Authority, *Fifth National Report of Pakistan under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*, (Islamabad: PNRA, 2020), accessed February 26, 2026, https://pnra.org/upload/reports/Pakistan-5NR.pdf.
[54] Press Information Bureau, Government of India, "IAEA Reviews the Nuclear Regulatory Infrastructure of India," Press Release, March 27, 2015, accessed February 26, 2026, https://www.pib.gov.in/newsite/PrintRelease.aspx?relid=117817&reg=3&lang=2.
[55] International Atomic Energy Agency, "*Integrated Regulatory Review Service (IRRS) Follow-Up Mission to India: Final Report* (Vienna: IAEA, 2022)," accessed February 26, 2026, https://www.iaea.org/sites/default/files/documents/review-missions/final_irrs_follow-up_report_india.pdf.

- ***Cyber-Security***

Cybersecurity of the nuclear facilities has become imperative to prevent major accidents, sabotage, and system failure. It has become an essential element of safety and security of nuclear facilities. At the national level, Pakistan has established a dedicated National Center for Cyber Security (NCCS)[56] in 2018**,** a tangible institutional investment providing training for cybercrime investigation and malware analysis. The research and development labs of NCCS operate around 11 different universities to provide cybersecurity solutions. However, this facility is not associated with PNRA, and Pakistan has not publicly issued any cybersecurity strategy for its nuclear facilities.[57] Despite the absence of cyber-security strategy, PNRA has been conducting training courses and exercises on Digital safety and Cyber Security to strengthen its safety protocols. Apart from in-house training, Pakistan National Institute of Safety and Security (NISAS) has also been collaborating with IAEA for nuclear security education, training, and technical support. The cybersecurity frameworks of AERB put lots of emphasis on securing digital control and instrumentation systems.[58] Despite principal alignment with IAEA's guidelines, the AERB cybersecurity framework still lacks specific regulatory guidelines with specific procedures, and there is no public record of a structured cyber incident response framework. These gaps exist not solely due to a resource deficit but also due to the structural consequences of institutional dependence.

- ***Small Modular Reactors (SMR)***

Small Modular Reactors have emerged as a transforming technology, and they are also mandated by the IAEA to be incorporated in the regulatory framework. This adaptation requires institutional autonomy for licensing and engaging with international partners or vendors. PNRA's SMR regulatory preparation demonstrates forward planning for integrating SMRs into energy infrastructure. For example, in 2013, Directorate of SMRs[59] was established to enhance SMR design, engineering capabilities and to identify challenges in development and deployment of SMR technology. PNRA has also established research group to conduct studies and provide

[56] National Centre for Cyber Security (NCCS), "*About NCCS*," accessed February 26, 2026, https://nccs.pk/#:~:text=The%20Government%20of%20Pakistan%20established%20the%20National,make%20Pakistan%20a%20leader%20in%20cyber%20security.

[57] Haleema Saadia, "Cybersecurity Framework for Pakistan's Nuclear Facilities," *South Asian Voices*, May 10, 2023, accessed February 26, 2026, https://southasianvoices.org/cybersecurity-framework-for-pakistans-nuclear-facilities/.

[58] Neeraj B. R., "Cybersecurity in Indian Nuclear Facilities," *Electronic Journal of Social and Strategic Studies* 4, no. 3 (December 2023–January 2024): 314–338, accessed February 26, 2026, https://www.ejsss.net.in/uploads/172/15025_pdf.

[59] Syed Mobashir Banoori, "Technical Requirements of Pakistan for Small Modular Reactor Design & Technology for Near Term Deployment," IAEA Technical Working Group on Small and Medium-Sized or Modular Reactors (TWG-SMR), July 2019, https://nucleus.iaea.org/sites/htgr-kb/twg-smr/Documents/TWG-2_2019/B06_Syed_Pakistan_TWG_2019.pdf.

solutions to regulatory challenges in licensing of SMRs and provide assistance in national regulation consistent with IAEA standards.[60] PNRA is also interacting with IAEA through hosting meeting with experts and coordinates research initiatives. However, PNRA, despite having an independent regulatory body, has not yet developed a legal framework pertaining to SMRs, which reveals a gap between strategic necessity and regulatory infrastructure. AERB, on the other hand, claims that existing Nuclear Power Plant (NPP) regulations are largely applicable to SMRs with specific reviews for unique features, an adaptation approach that prioritizes institutional continuity over SMR-specific innovation.[61] This position indicates that indigenous designs (BSMR-200[62], SMR-55[63]) will be reviewed within established frameworks. Additionally, the SHANTI Bill 2025 promised some regulatory independence that will somehow create space for private sector participation for independent SMR oversight. However, the persistent gap and ambiguities in SHANTI Bill tell another story. AERB frameworks were designed for large-scale state-run plants and require a 10-15-year permitting cycle, which is not suitable for private sector business models for SMRs.[64] The Civil Liability for Nuclear Damages Act (CLNDA) 2010[65] has further complicated SMR deployment frameworks because it creates obstacles for foreign and domestic participation, particularly for technology transfer arrangements[66].

- ***Climate-induced Hazards***

IAEA[67] has identified changing seawater levels and severe weather conditions as climate-induced hazards and new regulatory challenges. It is imperative for regulatory bodies to act proactively and introduce measures and programs that can tackle climate-induced threats. Regulators must be institutionally autonomous to assess risks to existing facilities without being

[60] Rahman Khalil ur, Younus Irfan, Muhammad Nouman Mayo, Muhammad Zahid Hussain, S. A. N. Bhatti, Faiza Batool, and Mudassir Shah, "Small Modular Reactors: A Regulatory Perspective," paper presented at an International Atomic Energy Agency conference, https://conferences.iaea.org/event/374/papers/31383/files/12715-Paper%20-Small%20Modular%20Reactors%20-%20A%20Regulatory%20Perspective-modified.pdf.

[61] *Press Information Bureau — Government of India reply on AERB and SMRs (Feb 4 2026)*: https://www.pib.gov.in/PressReleseDetailm.aspx?PRID=2223305.

[62] *World Nuclear News*, August 14, 2025, https://www.world-nuclear-news.org/articles/eil-to-assist-in-development-of-indian-smr-design.

[63] *World Nuclear News*, December 10, 2025, https://www.world-nuclear-news.org/articles/maharashtra-and-andhra-pradesh-proposed-for-first-indian-smrs.

[64] JMMF Institute, *The Gaps and the Risks of the Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India (SHANTI) Act, 2025* (New Delhi: JMMF Institute, 2025), https://informaticsjournals.co.in/index.php/jmmf/article/view/54225/36096.

[65] T*he Civil Liability for Nuclear Damage Act, 2010*, No. 38 of 2010, Government of India, accessed March 4, 2026, https://www.indiacode.nic.in/bitstream/123456789/2084/5/A2010-38.pdf.

[66] JMMF Institute, *The Gaps and the Risks of the Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India (SHANTI) Act, 2025* (New Delhi: JMMF Institute, 2025), https://informaticsjournals.co.in/index.php/jmmf/article/view/54225/36096.

[67] "New CRP: Climate Change Challenges to the Safety of Nuclear Installations (J72007*)," "* International Atomic Energy Agency, June 21, 2023, accessed March 4, 2026, https://www.iaea.org/newscenter/news/new-crp-climate-change-challenges-to-the-safety-of-nuclear-installations-j72007.

constrained by the interests of other entities. PNRA has climate engagement centers which are focused on facilitating Pakistan's target of 8,800 MWe nuclear capacity by 2030.[68] This approach shows that Pakistan is framing nuclear energy as a climate challenge solution. However, due to Pakistan's documented vulnerability to rising inflation and natural disasters, there is a possibility of climate-driven infrastructure risks, and it needs systematic climate scenario integration into facility licensing requirements. Nevertheless, Pakistan is working towards this goal and held NREE-2024 emergency preparedness exercise[69] to addresses response capabilities. AERB, after Fukushima, demonstrated reactive capacity by establishing AERBSC-EE committee to assess the safety of all the NPPs against Tsunamis, earthquakes, cyclones and power shortage along with mandatory plant-wide safety reassessment, and tiered corrective actions.[70] However, multiple climate-driven challenges related to infrastructure, coastal facilities, and long-term temperature rise remain undocumented. IAEA's demands enhanced efforts to monitor the external environment to prepare for future challenges, and this requires climate projection integration into safety reviews, a requirement that both regulators need to fulfill.

- ***Artificial Intelligence (AI)***

IAEA identifies AI's positive and negative impact implications. This requires more collaboration, information exchange, and the capability to detect malicious software and protection against cyber-attacks.[71] PNRA's AI engagement is spread over surveillance, emergency response, physical protection, and regulatory modernization.[72] This shows that PNRA acknowledges AI as a multi-domain regulatory challenge rather than a simple security concern. However, documentation of AI regulations needs operationalization and specific regulatory guidance for AI-equipped facility systems. It is imperative for PNRA to demonstrate its institutional independence by operationalizing regulatory inspection protocols and investing in specialized human capital to facilitate credible AI governance. AERB's AI framework also needs responsible AI implementation based on accountability, safety, and resilience with human

[68] Pakistan Country Nuclear Power Profile 2020, International Atomic Energy Agency, updated 2020, accessed March 4, 2026, https://www-pub.iaea.org/MTCD/Publications/PDF/cnpp2020/countryprofiles/Pakistan/Pakistan.html.
[69] Pakistan Nuclear Regulatory Authority, *Emergency Exercise ConvEx-2C*, accessed March 4, 2026, https://www.pnra.org/emergency-excercise-convex.html.
[70] S. S. Bajaj, "Regulatory practices for nuclear power plants in India," published in *Sādhanā*, Volume 38, Part 5, pages 1027–1050, October 2013. https://link.springer.com/article/10.1007/s12046-013-0174-9#citeas.
[71] *Considerations for Deploying Artificial Intelligence Applications in the Nuclear Power Industry*, IAEA Nuclear Energy Series (Vienna: International Atomic Energy Agency), accessed March 4, 2026, https://www-pub.iaea.org/MTCD/publications/PDF/p15866-PUB2119_web.pdf.
[72] Pakistan Nuclear Regulatory Authority, *Annual Report 2024* (Islamabad: PNRA, 2024), accessed February 24, 2026, https://www.pnra.org/upload/pnrarpt/Annual%20Report%202024.pdf.

control, and a risk-based approach.[73] Furthermore, the establishment of an independent AI regulatory capacity is also difficult for AERB amid its structural reliance on DAE technical assistance.

Policy Recommendations

Based on above analysis, the following recommendations should be considered by Pakistan for better nuclear governance.

- PNRA should utilize its mature IRRS engagement to move further by strengthening its position as a peer reviewer and utilize different platforms for international collaboration for nuclear technology transfer.
- PNRA should also work on capacity building challenges that stem from the shortage of young engineers and nuclear scientists and the aging technical workforce.[74] To tackle this challenge, PNRA should again leverage its IRRS engagement to collaborate with the IAEA for knowledge exchange and training programs.
- PNRA has a history of cooperating with the nuclear regulators of other countries, especially China, where bilateral relations are quite strong in terms of nuclear safety. PNRA has been involved in bilateral arrangements with multiple Chinese organizations.[75] This cooperation should be further utilized for SMR adaptation and governance. On the legislative side, PNRA should develop an SMR-specific regulatory framework to address the incorporation of SMR in large-scale facilities on a priority basis. The focus of the SMR-specific regulatory framework should be on the licensing process, capacity building training, cybersecurity requirements for SMRs, waste management requirements (SMRs produce more waste), and emergency preparedness and response for SMRs.
- For cyber-security, PNRA should invest in existing institutional infrastructure and develop independent inspection competencies for cyber-security governance across all facilities. For that, PNRA can collaborate with NCCS established by the government of Pakistan. NCCS's main goal is to protect critical infrastructure, and its labs can be utilized for specialized research related to digital nuclear safety and security.

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[73] D. K. Shukla, *"Artificial Intelligence – Use, Challenges and Regulatory Perspectives"* (speech presented at the 54th meeting of the International Nuclear Regulators' Association, September 16, 2024), Atomic Energy Regulatory Board, accessed March 4, 2026, https://aerb.gov.in/images/PDF/AI-chairman.pdf.

[74] International Atomic Energy Agency, *Pakistan: National Presentation—Workshop on National Strategies on Capacity Building for Nuclear Safety*, Vienna, September 9–13, 2024, presented by Muhammad Waqas Sherani (Director General, International Cooperation and Human Resources, Pakistan Nuclear Regulatory Authority), accessed February 26, 2026, https://gnssn.iaea.org/regnet/SC%20Documents/Steering%20Committee%20Meeting/Workshop%20National%20Strategies%20on%20Capacity%20Building/20%20National%20presentations/Pakistan.pdf.

[75] Dr. Allauddin Kakar, Azeem Khalid, and Malik Muhammad Ali, "Pakistan-China Nuclear Energy Cooperation: Emerging Trends to Achieve Sustainable Development Goals," *Pakistan Journal of International Affairs* 4, no. 1 (January 2021), accessed February 26, 2026, https://www.researchgate.net/publication/350496752_Pakistan-China_Nuclear_Energy_Cooperation_Emerging_Trends_to_Achieve_Sustainable_Development_Goals.

- Inspection and regulatory review of nuclear installation is an essential function of the regulatory body, and it requires highly technical and competent personnel. It is difficult for any new regulatory body to perform these functions without external technical support. In case of PNRA, Pakistan relied on China for the review of safety analysis during the licensing of Chashma-1. Along with that Pakistan has also been developing the competence of its own manpower to perform all of its regulatory functions. Pakistan intends to further engage in bilateral collaboration with IAEA and its training centers to strengthen the capacity of technical manpower and expertise.[76] Pakistan should further engage in bilateral collaboration and IAEA training centers to build technical manpower and expertise.
- To improve the nuclear safety governance in South Asia, both states need to improve bilateral information-sharing mechanisms for safety. The transboundary radiological consequences of regulatory failure in this densely populated region demand more than national compliance narratives.

Conclusion

The research analyzed the regulatory frameworks of Pakistan and India through the theoretical lens of regulatory independence highlighted in IAEA Safety Standards GSR 1 and INSAG-17. It reveals that regulatory independence in nuclear governance is not merely a normative, procedurally inspired ideal, but rather a structural necessity for maintaining sustainable nuclear safety standards. The regulatory independence of both regulators was measured across legal, financial, and procedural transparency aspects, along with IRRS implementation responsiveness, and emerging technological challenges. It is also revealed that the PNRA has an overall superior regulatory structure, independent from promotional entities and aligned with international safety standards, which can be seen in the overall operations of PNRA. The inspection and enforcement details and outcomes of PNRA also demonstrate institutional maturity and effectiveness. At the international level, PNRA shows effective engagement, and its documents show active participation in the IRRS mission to Vietnam as an IAEA expert. The operational record of India's AERB shows explicit vulnerabilities in its regulatory architecture.

The major vulnerability is that the institutional architecture of AERB does not meet the IAEA Safety requirement for regulatory independence, which means that a regulatory body should not be subordinated to the promotional entity whose facilities it oversees. Efforts have also been made to overcome this structural flaw through the Nuclear Safety Regulatory Authority Bill 2011 and SHANTI Bill 2025. However, despite this legislative effort, the structural flaw in AERB's institutional proximity to DAE remains unresolved. Moreover, in the

[76] Naeem Ahmad Salik, ed., *Nuclear Regulatory Regime in Pakistan, 1956–2020: 64 Years of Regulating Nuclear Industry* (Islamabad: Pakistan Nuclear Regulatory Authority, 2026), 59-64.

domain of emerging technological and environmental challenges, both regulators face converging threats from cybersecurity, climate-induced hazards, and AI. These challenges carry significance beyond India and Pakistan, and only timely accommodation can prevent catastrophic incidents that have transboundary effects. To counter these threats, timely regulatory adaptations, grounded in international safety standards, are imperative. Finally, it is evident that those regulators that possess genuine regulatory independence, reflected in the institution's legal, financial, enforcement, and international engagement aspects are structurally equipped to fulfill the demands of nuclear safety governance, and they have more potential and will to resist the pressure of emerging challenges.