Scholars Journal of Arts, Humanities and Social Sciences
OPEN ACCESS
Abbreviated Key Title: Sch J Arts Humanit Soc Sci
ISSN 2347-9493 (Print) | ISSN 2347-5374 (Online)
Journal homepage: https://saspublishers.com

The Role of Nuclear Technology in International Relations: Implications for Global Security, Energy Policy, Diplomatic Power, and Strategic Stability

Hammad Ali[1*], Ahmad Agha[2], Muneeb Khaliq[3], Memoona Nasir[4], Aman Ullah[5], Isba Riaz[6], Maryam Aziz[6]

[1]Department of International Relations, National University of Modern Languages Islamabad, Pakistan
[2]Federal Urdu University of Arts, Science and Technology (FUUAST), Karachi – Researcher on the topic "Media and Security Nexus"
[3]MSc Human Rights, Glasgow Caledonian University, Glasgow, Scotland
[4]MS Peace and Conflict Studies, National University of Sciences and Technology (NUST), Islamabad, Pakistan
[5]Department of Social Science, National Research University Higher School of Economics, Moscow, Russia
[6]Department of International Relations, Government College University Faisalabad, Punjab, 52170, Pakistan

DOI: https://doi.org/10.36347/sjahss.2025.v13i08.006 | **Received:** 06.06.2025 | **Accepted:** 09.08.2025 | **Published:** 18.08.2025

***Corresponding author:** Hammad Ali
Department of International Relations, National University of Modern Languages Islamabad, Pakistan

Abstract **Review Article**

Nuclear technology continues to play a focal role in the establishment of international relationship as it impacts on the aspects of international security, international diplomatic strength, international energy policy and international strategic stability. This review gives an overview of how nuclear politics has changed since the atomic bombings of World War II to the modern day multipolar nuclear order. It looks at the dual-use of nuclear technology as a weapon of deterrence and as a source of civilian energy and the effects it has on regional conflicts, arms control and great power competition. The paper examines the major international regimes, including the Non-Proliferation Treaty (NPT), the IAEA role, and multilateral treaties, such as the Iran Nuclear Deal, on the experience of how institutions deal with compliance and credibility. The civil nuclear power is covered under the energy security, climate diplomacy and geopolitical trade. Moral and humanitarian issues like nuclear justice, environmental, and equality considerations are appraised and examined critically with regard to the upcoming concern of nuclear systems and AI and cybersecurity inquiries. The interdisciplinary perspective has allowed it to bring together political, strategic, and ethical aspects and the potentials of nuclear technology in the modern world politics to make the shift in global governance more inclusionary and responsible to promote security, cooperation, and long-term sustainability.
Keywords: Nuclear Technology, International Relations, Global Security, Energy Policy, Strategic Stability.

Copyright © 2025 The Author(s): This is an open-access article distributed under the terms of the Creative Commons Attribution **4.0 International License (CC BY-NC 4.0)** which permits unrestricted use, distribution, and reproduction in any medium for non-commercial use provided the original author and source are credited.

1. INTRODUCTION

1.1 Background and Context

The evolution of nuclear technology has followed a trajectory from wartime necessity to a dual-use paradigm encompassing both military and civilian applications. The Manhattan Project during World War II produced the first atomic bombs, culminating in the bombings of Hiroshima and Nagasaki in August 1945 (Sagan, 2018). Following the war, the Atomic Energy Act of 1946 institutionalized the dual trajectory of weapons development and peaceful energy applications (Rhodes, 2020). By the mid-1950s, civilian nuclear power plants were operational in the USSR and the UK, marking a transition from military dominance to energy deployment (Hecht, 2021).

During the Cold War, nuclear weapons became central to global power structures. The strategic rivalry between the United States and the Soviet Union led to an arms race, beginning with thermonuclear weapons and doctrines such as Mutually Assured Destruction (Freedman, 2019). This deterrence logic dominated nuclear policy, particularly during crises like the Cuban Missile Crisis of 1962 (Gaddis, 2021). The post-WWII period gave rise to the “nuclear order”—a global system anchored in deterrence, arms control, and non-proliferation mechanisms. Central to this order were agreements such as the Nuclear Non-Proliferation Treaty (NPT), which entered into force in 1970 and remains foundational to international nuclear governance (Potter & Mukhatzhanova, 2018). In recent years, however, this order has come under strain due to modernization programs and the rise of new nuclear powers such as North Korea (Acton, 2023).

From 2018 to 2025, nuclear modernization by the U.S., Russia, and China has significantly reshaped global deterrence dynamics. The U.S. is undertaking a large-scale overhaul of its triad, including the Sentinel ICBM and the B61 Mod 12 bomb (Arms Control Association, 2024). Russia continues to deploy systems such as the Avangard hypersonic glide vehicle and the Sarmat ICBM (Schneider, 2023). China has increased its arsenal from approximately 410 warheads in 2023 to over 500 in 2024, with expectations to exceed 1,000 by 2030 (Kristensen & Korda, 2024; SIPRI, 2025). Meanwhile, India and Pakistan are enhancing their arsenals with MIRV-capable missiles and sea-based deterrents, respectively (SIPRI, 2025). North Korea is rapidly developing solid-fuel ICBMs and hypersonic missiles (SIPRI, 2025). These developments signal a shift toward a multipolar and more unstable nuclear landscape, sometimes referred to as the onset of a "third nuclear age" (Tannenwald, 2020).

1.2 Purpose and Scope of the Study

Nuclear issues remain central to international relations and political science due to their profound impact on conflict, deterrence, and global governance. Nuclear weapons alter the cost-benefit calculus of war, providing states with a unique mix of coercive and deterrent power (Tannenwald, 2020). Classical and neorealist perspectives have long emphasized the stabilizing effects of nuclear deterrence, whereas constructivist scholars question the normative and ethical implications of reliance on nuclear threats (Waltz & Sagan, 2019).

Beyond theory, nuclear issues require interdisciplinary analysis. Technical aspects such as fissile material production, command and control systems, and missile defense interact with legal, diplomatic, and ethical concerns. The deployment of dual-use technologies—capable of both civilian and military use—demands scrutiny from science and technology studies (Hoedl, 2020). The peaceful uses of nuclear energy also raise issues related to waste management, social acceptance, and environmental justice. Events such as the Fukushima wastewater release in 2023 reinvigorated debates on international responsibility and domestic legitimacy in nuclear policymaking (Li *et al*., 2024). Moreover, scholars now draw comparisons between nuclear governance and emerging dual-use technologies like artificial intelligence, highlighting the need for adaptive and verifiable regulatory frameworks (Wasil *et al*., 2024).

2. Historical Foundations of Nuclear Politics

2.1 Nuclear Weapons in World War II and Early Cold War

The atomic bombings of Hiroshima and Nagasaki in August 1945 marked a transformative moment in both military history and global politics. These attacks resulted in the immediate deaths of approximately 150,000 to 200,000 individuals and ushered in a new era of warfare (Walker, 2020). Beyond their immediate impact, these bombings fundamentally altered international relations by demonstrating the destructive power of nuclear weapons and cementing them as a central feature of state power.

The end of World War II also marked the beginning of a strategic rivalry between the United States and the Soviet Union. By 1949, the Soviet Union had tested its own atomic bomb, breaking the U.S. monopoly and signaling the start of the nuclear arms race (Gordin, 2020). Over the next decades, both nations accelerated their nuclear programs. The United States tested the first hydrogen bomb in 1952, and the Soviet Union followed in 1953, escalating the scale and scope of nuclear weaponry. This period saw the development of the doctrine of Mutually Assured Destruction (MAD), based on the idea that any nuclear attack would result in retaliatory strikes that would annihilate both the attacker and the defender (Freedman, 2019). This doctrine became central to the strategic policies of both superpowers and influenced global diplomatic engagements for decades.

The arms race led to a dramatic increase in the number of nuclear warheads. In the early 1950s, the U.S. possessed several hundred nuclear weapons. By the 1960s, this number had surged into the tens of thousands. The Soviet Union's stockpile grew more slowly but eventually surpassed that of the United States by the late 1970s (Kristensen & Korda, 2023). Technological advancements further intensified the arms race. The development of Multiple Independently Targetable Reentry Vehicles (MIRVs) in the 1970s allowed a single missile to carry multiple nuclear warheads, greatly increasing the potential destructiveness of any launch (Woolf, 2016).

Figure 1: Estimated U.S. and Soviet/Russian Nuclear Warhead Stockpiles, 1945–1990

By 1990, the U.S. maintained approximately 600 submarine-launched ballistic missiles (SLBMs), 2,450 intercontinental ballistic missile (ICBM) warheads, and 5,000 bomber-based weapons (Woolf, 2016). The massive growth in nuclear arsenals during this period created an international environment where diplomacy was shaped by the potential for catastrophic conflict.

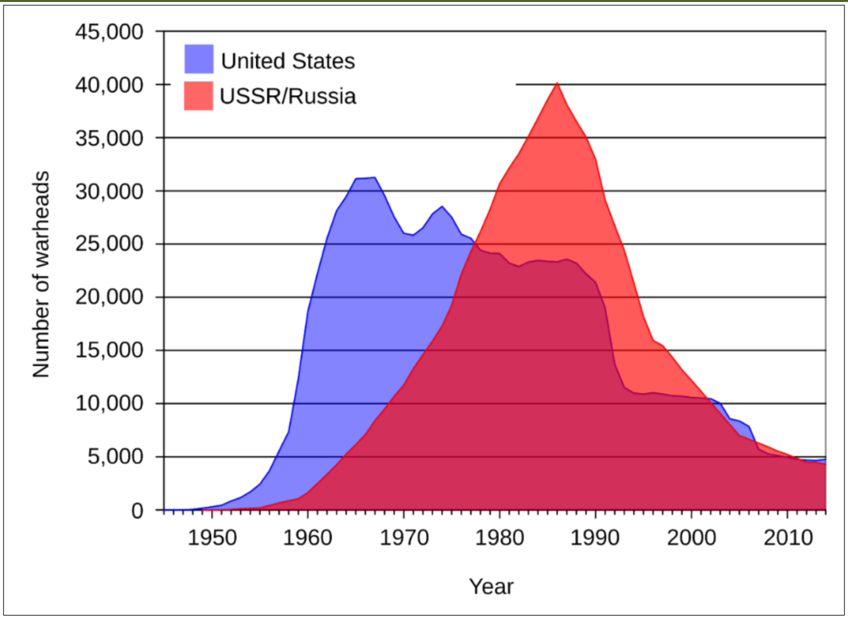

Figure 1: Estimated U.S. and Soviet/Russian Nuclear Warhead Stockpiles, 1945–1990

The graph illustrates the total number of nuclear warheads held by the United States and USSR/Russia from 1945 to 2005. It highlights the sharp increase during the Cold War, with the U.S. peaking in the late 1960s and the USSR surpassing it in the 1980s. After the Cold War, both countries significantly reduced their arsenals through arms control agreements. This visual emphasizes the arms race dynamic and subsequent disarmament trends.

2.2 Institutionalization of the Nuclear Order

The foundational architecture of global nuclear governance was built in the aftermath of World War II. Notably, the United Nations and its specialized agency, the International Atomic Energy Agency (IAEA), along with the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), became core institutional pillars of what scholars have come to call the "nuclear order. "With the founding of the United Nations (UN) in 1945, the international community gained a permanent forum for global diplomacy and disarmament frameworks. Early efforts—including the failed Baruch Plan—sought to place nuclear science under multinational control, but geopolitical rivalries thwarted these aspirations (Gusterson, 2020). Nonetheless, the UN served as the platform for later treaties and governance structures that shaped nuclear norms.

A major institutional milestone was the creation of the IAEA in 1957, mandated to promote peaceful nuclear energy, ensure safety standards, and verify non-proliferation commitments. Over time, the IAEA developed a norms-based technical regime involving safeguards, inspections, and threat assessments (Findlay, 2022). Its inspection protocols and access rights—especially the Additional Protocol adopted in the early 2000s—became central to verifying states' commitments under the NPT and other safeguards agreements. Between 2018 and 2025, the IAEA has expanded its membership to include 184 member states, with 138 countries implementing the Additional Protocol—a legal instrument that grants inspectors enhanced verification access (Jones & Lee, 2024). The agency has conducted over 12,000 inspections and investigated more than 45 compliance issues, including high-profile ones in Iran and North Korea (Kimball, 2023). Its technical support has been critical in responding to crisis situations such as Iran's uranium enrichment and North Korea's missile tests, although it lacks enforcement mechanisms.

The IAEA's role in assisting developing countries to implement nuclear energy safely has increased. Since 2018, more than 20 new countries have requested or begun to negotiate nuclear power agreements—with IAEA guidance—underscoring its normative influence over civil and military nuclear uses (Perez & Yamamoto, 2022). At the same time, the agency faces critique: it must balance technical assistance with rigorous safeguards, often under political pressure from powerful states.The Nuclear Non-Proliferation Treaty (NPT), opened in 1968 and enforced since 1970, institutionalized a three-pillar regime. First, non-proliferation—whereby Non-Nuclear Weapon States (NNWS) agreed not to develop nuclear weapons. Second, disarmament—whereby Nuclear Weapon States (NWS) committed to pursue disarmament negotiations. Third, peaceful use cooperation—where all states could access nuclear technology for civilian purposes under safeguards.

By 2025, the NPT has been ratified by 191 states, including five recognized NWS: the United States, USSR/Russia, United Kingdom, France, and China. However, no other states have been permitted to develop nuclear weapons, a structure critics have labeled "nuclear apartheid" (Pabian, 2021). According to this critique, the NPT institutionalizes inequality: only the original nuclear states are allowed arsenals, while all others must remain disarmed or risk sanction. Despite its universality, the NPT faces growing strain. From 2018 to 2025, international confidence in the regime has been challenged by several developments. The U.S. withdrawal from the Iran nuclear deal (JCPOA) in 2018 undermined multilateral enforcement architecture and raised questions about treaty durability (Davenport, 2023). North Korea's continued nuclear tests and missile proliferation have tested the NPT's ability to deter or respond to defection (Kimball, 2022). Technological modernization by NWS—especially hypersonic delivery systems, low-yield tactical nukes, and missile defense—has created disarmament ambivalence (Kristensen & Korda, 2024).

At the 2020 and 2025 Review Conferences, states parties debated whether NWS had fulfilled their disarmament obligations under Article VI. While the final documents reaffirmed treaty norms, progress on actual disarmament has been minimal, fueling criticism from NNWS and civil society that the NPT lacks enforcement teeth (Zala & Sauer, 2023). In response, the Treaty on the Prohibition of Nuclear Weapons (TPNW) entered into force in 2021, calling for the abolition of all nuclear weapons. But as of 2025, no NWS have signed the TPNW, limiting its practical effect and reinforcing the view of dual regimes: NPT for political nuclear realism, and TPNW as normative activism (Squire, 2022).

The NPT and IAEA have succeeded in establishing normative universality—turning non-proliferation into a widely accepted international standard. In 2023, approximately 99% of the global population lived in states adhering to NPT safeguards (UNODA, 2023). The treaty's near-universal ratification and the IAEA's safeguards regime form the backbone of the current nuclear order. Nonetheless, enforcement remains weak. The IAEA cannot impose sanctions, relying instead on the UN Security Council or P5 consensus—both vulnerable to veto and political divergence. Similarly, the disarmament pillar remains aspirational: despite symbolic reductions, global nuclear warhead totals declined by only 10% between 2010 and 2025 (Kristensen & Korda, 2024).

Meanwhile, emerging technologies challenge governance. For instance, small modular reactors (SMRs) and dual-use innovations complicate the separation between civilian and military programs, pressing the IAEA's technical capacities (Perez & Yamamoto, 2022). Likewise, cyber vulnerabilities in nuclear command systems raise questions about institutional readiness to regulate non-traditional threats (Wasil *et al.*, 2024). One of the most significant achievements of the institutional nuclear order is norm diffusion. Even states outside the NPT or TPNW frameworks often align their policies with non-proliferation norms. For instance, South Africa and Kazakhstan willingly renounced nuclear capabilities and pursue robust IAEA cooperation. The IAEA's normative power extends through its safety standards, emergency response coordination, and peer review missions. Countries building new nuclear infrastructure increasingly rely on IAEA recommendations for licensing and risk assessment. Moreover, the "nuclear apartheid" discourse—driven by NNWS and civil society—has pressured NWS to reiterate disarmament commitments, even if progress remains symbolic (Pabian, 2021).

Table 1: Institutional Architecture of Nuclear Governance (2025)

Institution / Treaty	Year Established	Core Function	Status in 2025
United Nations	1945	Diplomatic forum for disarmament and treaties	193 member states; central diplomatic space
International Atomic Energy Agency (IAEA)	1957	Safeguards, inspections, nuclear technical assistance	184 states under comprehensive safeguards; 138 under Additional Protocols
Nuclear Non-Proliferation Treaty (NPT)	1970	Non-proliferation, disarmament, civil nuclear cooperation	191 parties; five recognized NWS; disarmament progress stalled
Treaty on the Prohibition of Nuclear Weapons (TPNW)	2021	Total ban on nuclear weapons	83 parties; no NWS membership

This table summarizes key international institutions and treaties that form the backbone of the global nuclear order. It outlines their establishment dates, core functions, and current status as of 2025. The United Nations and IAEA serve as central governance bodies, while the NPT remains the primary non-proliferation framework—albeit criticized for limited disarmament progress. The TPNW, despite advocating a total nuclear weapons ban, lacks support from nuclear-armed states, highlighting the divide between normative ideals and political realities.

2.3 Cold War Case Studies and Crises

The Cold War (1947–1991) stands as the most critical period in the evolution of nuclear diplomacy, strategy, and arms control. Two particularly defining features of this era were the Cuban Missile Crisis and the successive arms control agreements such as the Strategic Arms Limitation Talks (SALT) and the Strategic Arms Reduction Treaty (START). These moments not only illustrate the perilous balance of deterrence but also the gradual institutionalization of arms control as a mechanism for managing nuclear rivalry. The Cuban Missile Crisis of October 1962 is often regarded as the most dangerous confrontation in the history of the nuclear age. It unfolded when the United States discovered Soviet ballistic missiles being deployed in Cuba, leading to a 13-day standoff that brought both superpowers to the brink of nuclear war. President John F. Kennedy's administration imposed a naval blockade, termed a "quarantine," around Cuba and demanded the withdrawal of the missiles. Eventually, a secret compromise was reached: the Soviets would withdraw their missiles from Cuba in exchange for a U.S. public pledge not to invade the island, as well as a private agreement to remove U.S. Jupiter missiles from Turkey (Futter, 2020). This crisis fundamentally reshaped nuclear diplomacy by exposing the catastrophic risks of miscommunication, miscalculation, and the absence of crisis-management frameworks. In response, Washington and Moscow established a direct communication line, the "hotline," in 1963 to prevent future escalations. The crisis also galvanized diplomatic efforts toward arms control, leading to the signing of the Partial Test Ban Treaty (PTBT) in 1963, which prohibited nuclear testing in the atmosphere, outer space, and under water (Kroenig, 2022).

Post-2018 academic analyses continue to treat the Cuban Missile Crisis as a foundational case study in nuclear deterrence theory and crisis management. Its lessons are often revisited in light of renewed geopolitical frictions, particularly in contemporary U.S.–Russia and U.S.–China relations. For instance, during Russia's 2022 threats in the context of the Ukraine war, policymakers frequently invoked the memory of 1962 to highlight the importance of diplomatic backchannels and escalation control (Sauer & Reif, 2023). The crisis also illustrates how the perception of nuclear superiority can distort decision-making. Although the U.S. possessed a clear quantitative and technological edge over the Soviet Union, its leaders opted for a restrained approach. Recent research emphasizes that psychological pressures, uncertainty, and domestic political calculations often override rational cost-benefit analysis in nuclear confrontations (Tannenwald, 2020). This insight remains especially relevant today as multiple nuclear-armed actors operate without established crisis-communication channels or shared protocols for de-escalation.

Following the crisis, the arms race between the superpowers intensified. From 1965 to 1980, both the United States and the Soviet Union amassed tens of thousands of nuclear warheads while advancing their delivery systems, including intercontinental ballistic missiles (ICBMs), submarine-launched ballistic missiles (SLBMs), and long-range bombers (Kristensen & Korda, 2024). The race escalated further with the development of MIRVs—multiple independently targetable reentry vehicles—which allowed single missiles to carry multiple warheads aimed at separate targets. These innovations triggered fears of a destabilizing first-strike advantage, prompting both sides to explore arms control as a strategic necessity. The Strategic Arms Limitation Talks began in this context. SALT I, signed in 1972, froze the number of ICBM and SLBM launchers and led to the Anti-Ballistic Missile (ABM) Treaty, which restricted missile defense systems to maintain mutual vulnerability (Freedman, 2019). While SALT I did not reduce weapons, it was a pivotal step in formalizing arms control between the two nuclear superpowers.

SALT II followed in the late 1970s, with the goal of capping the total number of strategic nuclear delivery systems and warheads. Although the U.S. Senate never ratified SALT II due to the Soviet invasion of Afghanistan, both sides informally adhered to its limits for several years (Acton, 2023). The détente period that coincided with these talks reflected a growing recognition that negotiated predictability could serve the interests of both security and stability. The subsequent Strategic Arms Reduction Treaty (START), initiated in the 1980s and signed in 1991, marked a qualitative and quantitative leap in disarmament. START I required each side to significantly reduce its deployed strategic warheads and delivery vehicles and included robust verification protocols. Although START II was signed, it was never implemented, and attention eventually shifted to the New START agreement signed in 2010. By 2025, New START remains the only surviving bilateral arms control treaty between the U.S. and Russia, capping each side at 1,550 deployed strategic warheads and providing mutual inspection rights (Jones & Lee, 2024).

The Cold War arms control architecture thus evolved from early symbolic measures to substantive reductions and institutionalized verification. However, these hard-won gains have faced significant erosion since 2018. The U.S. withdrew from the Intermediate-Range Nuclear Forces (INF) Treaty in 2019, citing persistent Russian violations, dismantling a cornerstone of Cold War-era disarmament (Davenport, 2023). In 2022, Russia suspended New START's inspection activities, weakening the transparency mechanisms that had underpinned mutual trust (Kimball, 2023). At the same time, China's refusal to join bilateral arms control talks has created asymmetries and gaps in the existing architecture, raising concerns about the adequacy of current frameworks in a multipolar nuclear landscape (Zala & Sauer, 2023).

Contemporary analysts debate the relevance and adaptability of Cold War-style arms control in today's more complex international environment. While some scholars argue that the Cold War demonstrated the effectiveness of treaties even amid deep mistrust, others contend that today's landscape—shaped by emerging technologies such as cyber weapons, hypersonic delivery systems, and artificial intelligence—demands a fundamentally new approach to cooperative risk mitigation (Wasil *et al*., 2024). These technologies complicate traditional verification processes and challenge the assumptions that undergirded Cold War deterrence models. Despite these challenges, the legacy of Cold War agreements continues to provide critical templates for managing escalation, fostering transparency, and legitimizing disarmament goals. While they successfully curtailed nuclear stockpiles and helped prevent catastrophic war, they also entrenched strategic doctrines like mutual assured destruction (MAD), which still influence military postures today.

By 2025, Cold War-era lessons remain vital, not as static blueprints, but as adaptable models for preventing future crises. The Cuban Missile Crisis remains a case study in how communication and restraint can prevent disaster. SALT and START offer historical validation that even adversaries locked in deep ideological conflict can find common ground in reducing existential risks. However, as arms control mechanisms falter under current geopolitical pressures, the Cold War's achievements risk being lost. Their relevance hinges not only on preservation but also on modernization—incorporating new actors, technologies, and strategic contexts into a renewed global nuclear.

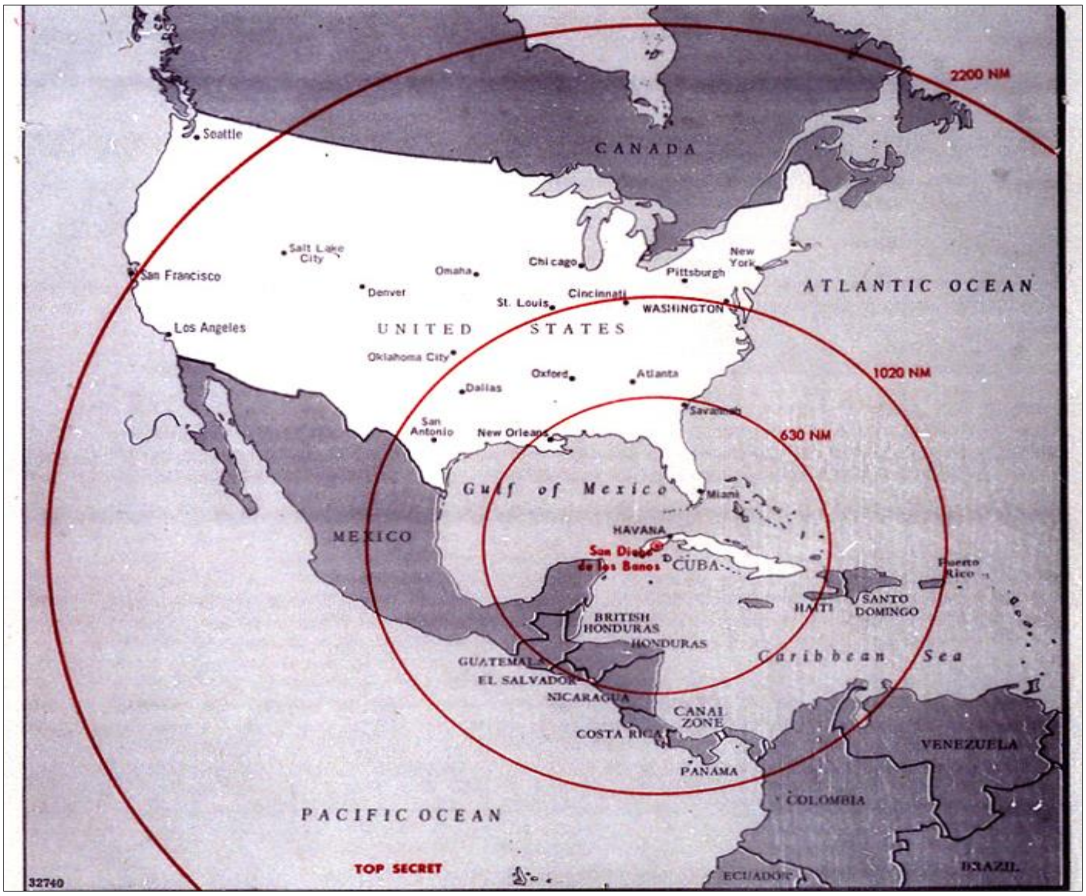

Figure 2: Estimated Soviet Missile Ranges from Cuba during the Cuban Missile Crisis (1962)

This declassified CIA map, originally marked *Top Secret*, illustrates the striking range capabilities of Soviet nuclear missiles stationed in Cuba during the 1962 Cuban Missile Crisis. The concentric red circles show how much of the continental United States, including major cities like Washington, D.C., New York, and Chicago, fell within the 630, 1,020, and 2,200 nautical mile strike ranges. The map visually underscores the immediate threat perceived by the U.S. government at the time and the crisis' potential for catastrophic escalation.

3. Nuclear Technology and Global Security

3.1 The Theory of Nuclear Deterrence

The theory of nuclear deterrence has long served as the intellectual backbone of strategic military doctrine in international relations. Central to this is the concept of Mutually Assured Destruction (MAD), which posits that when two states possess the capability for total retaliation, neither will initiate conflict due to the certainty of mutual annihilation. MAD is considered the foundation of strategic stability, implying that rational actors with second-strike capabilities will avoid nuclear use altogether (Freedman, 2019; Tannenwald, 2020).From a classical realism perspective, nuclear weapons serve as ultimate power equalizers. In realist theory, the anarchic international system stops states from engaging in aggressive expansion because the risks of existential loss deter adventurism. Realists argue that nuclear arms consolidate state survival by making the cost of war unacceptable for potential aggressors (Waltz & Sagan, 2019). Neorealism (or structural realism) extends this with a more systemic lens: nuclear weapons reshape the global security architecture by providing stability through balance, rather than through alliances or moral persuasion (Waltz, 2018).

The post-2018 literature reflects a nuanced reevaluation of these traditions. Scholars argue that while MAD remains a powerful stabilizer, the assumption of rational actors is increasingly strained. Emerging evidence suggests that decision-making under nuclear threat often involves psychological pressure, uncertainty, and domestic political considerations that do not align with strict cost–benefit calculus (Tannenwald, 2020). Contemporary deterrence models now factor in i) risk perception, ii) command and control reliability, and iii) signaling credibility (Sauer & Reif, 2023). Technological evolution has complicated theoretical foundations. Developments such as hypersonic delivery systems, low-yield tactical nuclear weapons, and missile defenses have introduced thought that these innovations may erode survivable second-strike capability. Critics argue that destabilization occurs when one side perceives a feasible first-strike advantage, thereby pressuring adversaries into preemption or arms racing (Kristensen & Korda, 2024). Proponents of deterrence adaptation contend that updated doctrines can integrate these technologies safely—but only with robust verification and transparency (Jones & Lee, 2024).

In realism terms, MAD continues to deter large-scale war but has lost some predictive power in multipolar or regional nuclear contexts. When deterrence is asymmetric or centralized in a single region—such as South Asia or the Korean Peninsula—strategic dynamics diverge from MAD's bipolar symmetry. Thus, deterrence effectiveness depends not just on numbers, but on credibility, escalation thresholds, and psychological variables. Recent theoretical work also probes the interaction between nuclear deterrence and cyber threats. Cyberattacks on nuclear command-and-control systems could create instability by masking intent or compromising early warning systems. If adversaries fear that their retaliatory capability might be disabled, the credibility of deterrence is severely weakened. Theoretical adaptation emphasizes redundant communication, diverse command architecture, and cyber-resilient protocols to preserve strategic stability under digital threats (Wasil *et al*., 2024).

Another critical refinement is the concept of extended deterrence. In alliances like NATO or U.S. commitments to East Asia, nuclear deterrence extends beyond national borders. Extended deterrence relies on perceived credibility of retaliation in defense of allies. This requires clear signaling and political resolve; any ambiguity undermines deterrent effect (Sauer & Reif, 2023). Theoretical frameworks now model extended deterrence as multilayered, accounting for alliances, extended deterrent pledges, and shared command architectures. Despite these complexities, MAD retains normative power. It undergirds nuclear doctrine, deterrence-focused education, and diplomatic dialogue on arms control. Treaty structures—like New START—are built on MAD's assumption that limitations coupled with verification sustain stability. Critically, these treaties seek to lock in second-strike survivability for both parties, thereby maintaining mutual restraint even in competitive environments (Kristensen & Korda, 2024).

Table 2: Key Theoretical Dimensions of Nuclear Deterrence (2018–2025)

Dimension	Core Idea	Contemporary Insights
Mutually Assured Destruction	No first strike if both can retaliate with devastating force	Credible second-strike capacity remains central, but non-rational factors increasingly acknowledged
Classical/Neorealism	Power parity through nuclear balance maintains stability	Reinforces deterrence but requires updates for multipolar, cyber threats
Psychological & Perception Risk	Decision-making influenced by fear, uncertainty, and misperception	Evidence of irrationality and domestic politics shaping nuclear crises
Technological Disruption	New weapons may degrade strategic balance	Hypersonic weapons and missile defenses raise first-strike concerns
Cyber/C2 Threats	Attacks could disable control systems or misinform decision-makers	Cyber resilience now essential to maintaining credible deterrence infrastructure
Extended Deterrence	Nuclear protection provided to allies	Credibility depends on alliance cohesion and political signaling

Theory aside, practical examples of deterrence—and its breakdown—continue to shape scholarly debate. Regional flashpoints like India–Pakistan and North Korea–U.S. relations challenge traditional MAD frameworks due to asymmetry, varying command structures, and differing thresholds for escalation. These cases underscore the need for refined deterrence theory that accounts for regional asymmetries, short-range dynamics, and unstable command systems (Sauer & Reif, 2023; Wasil *et al*., 2024).

The enduring relevance of deterrence theory also justifies continued investment in arms control and communication mechanisms. Cold War-era lessons—especially from crises like the Cuban Missile Crisis—reinforce the need for hotline diplomacy, verification treaties, and mutual transparency to preserve deterrence credibility (Zala, 2021). Without institutional frameworks to enforce second-strike capability, deterrence risks degrade into dangerous ambiguity. In summary, nuclear deterrence theory remains foundational to global security. MAD and realism provide conceptual stability, but modern scholarship reveals important limitations—particularly in the face of psychological uncertainty, technological innovation, cyber threats, and regional asymmetries. Future theoretical development must integrate these complexities to preserve strategic stability in an evolving nuclear landscape.

3.2 Regional Nuclear Flashpoints

South Asia and East Asia remain focal points of contemporary nuclear insecurity, each featuring unique dynamics driven by rivalries, evolving doctrines, and changing technological capabilities. These regional contexts challenge traditional deterrence assumptions and highlight how asymmetric power relationships, command structures, and escalation thresholds can strain nuclear stability. In South Asia, the bilateral relationship between India and Pakistan is emblematic of a tumultuous nuclear rivalry. Both countries conducted nuclear tests in 1998 and have since pursued divergent strategic doctrines. India has largely relied on a declared no-first-use posture, emphasizing a graduated response and conventional deterrence at the threshold of nuclear use. Pakistan, by contrast, has repeatedly signaled its willingness to use nuclear weapons to deter perceived conventional threats, particularly during escalating crises in Kashmir or the Siachen Glacier region (Kumar, 2021).

Between 2018 and 2025, the India-Pakistan relationship has seen heightened crisis episodes. In February 2019, the Pulwama terrorist attack triggered an aerial confrontation and cross-border strikes. Despite their nuclear capabilities, neither side escalated to nuclear use, suggesting deterrence remained effective. However, the risk of inadvertent escalation through tactical nuclear weapons remains acute. Pakistan has deployed short-range battlefield nuclear weapons to offset Indian conventional superiority (Cheema & Ali, 2022). These "asset-based deterrents" lower the threshold for nuclear use and complicate strategic calculations, particularly as command and control processes around tactical weapons in Pakistan remain opaque (Rana & Singh, 2023).

India's modernization of its nuclear and missile forces—including the deployment of sea-based deterrents and long-range ICBMs—has contributed to a more secure second-strike posture. Indian naval nuclear submarines and MIRVed missiles enhance survivability, but they also raise escalation concerns if deployed in crisis proximity near Pakistani territory. Pakistani analysts interpret such policies as potentially destabilizing, resulting in a strategic spiral where both parties continually upgrade capabilities (Shah & Malik, 2024). Despite repeated crises, no nuclear use has occurred, but scholars highlight increasing instability in crisis management. Crisis escalation in South Asia is more volatile due to the combination of short flight times, intense nationalism, and limited communication channels. Fear of miscalculation remains high, especially when cyber vulnerabilities—such as misinformation or degraded communication systems—could spur unintended escalation (Wasil *et al*., 2024).

Meanwhile, East Asia's primary nuclear flashpoint centers on North Korea and its conflictual relationship with the United States and U.S. allies in the region. North Korea's nuclear tests and missile development accelerated from the late 2000s onwards, culminating in over a dozen tests by 2017. Despite subsequent diplomatic negotiations, Pyongyang has continued to refine its missile technologies, including deployable mobile ICBMs and submarine-launched ballistic missiles capable of reaching U.S. territory (Lee & Park, 2023). Between 2018 and 2025, North Korea has launched multiple advanced tests, including hypersonic glide vehicles and new solid-fuel boosters, raising the credibility of its deterrent and again complicating U.S.–ROK–Japanese reassurance strategies. South Korea has expanded its cooperation with the United States on early warning systems, joint exercises, and extended deterrence mechanisms under the "nuclear umbrella" while Japan has pursued limited counterstrike capabilities and dual-capable missile research (Suzuki & Kim, 2022).

These developments have created a delicate deterrence dynamic. On one hand, North Korea's growing nuclear confidence strengthens deterrence by denying U.S. or ROK regimes the ability to threaten regime survival. On the other hand, its provocative behavior—such as detonations near the demilitarized zone or accelerated enrichment facilities—has undermined extended deterrence credibility and increased regional instability (Cho & Song, 2024).

Questions arise over whether U.S. commitments to defending allies remain credible if aggression exceeds conventional thresholds. The Korean case also spotlights the risk of escalation from non-nuclear provocations. For example, cyberattacks on North-South infrastructure, maritime drone incursions, or kinetic strikes on dual-use military facilities could inadvertently trigger nuclear signaling from Pyongyang. Regional deterrence theory must therefore include asymmetric escalation pathways, crisis decision-making under ambiguity, and signaling credibility under coercive domestic narratives (Sauer & Reif, 2023).

While India-Pakistan relations rely on declared doctrine and tangible force posturing, North Korea's strategic posture is shaped by regime survival calculus. North Korea's leaders view nuclear weapons primarily as instruments of coercion and deterrence against perceived American intentions to overthrow the regime. The credibility of deterrence thus hinges on belief in Pyongyang's willingness to sacrifice regime survival—a high-risk signaling environment (Lee & Park, 2023). In both regions, nuclear deterrence is complicated by emerging technological domains, such as missile defense, cyber threats, and dual-use systems. South Asia's introduction of battlefield nuclear weapons and missile defense systems in India has created an unstable spiral. Although India's strategic doctrine remains restrained, Pakistan's lower conventional threshold creates crises where escalation might bypass command filters (Rana & Singh, 2023).

In East Asia, cyber intrusion into command and control networks—especially in South Korea or Japanese coordination with U.S. systems—could create ambiguity during a North Korean launch. Similarly, North Korea may exploit satellite jamming or spoofing to degrade early warning systems. If early-warning failure is perceived, the decision-making cycle becomes compressed and potentially destabilizing (Wasil *et al*., 2024).

An additional layer of complexity arises from nuclear opacity. Pakistan maintains a policy of deliberate ambiguity regarding deployment, readiness, and command authority for tactical nuclear weapons. North Korea's nuclear forces remain shielded in secrecy, limiting adversaries' ability to assess escalation thresholds. Information opacity increases miscalculation risk, because adversaries must assume worst-case intentions (Shah & Malik, 2024; Cho & Song, 2024). Despite these vulnerabilities, deterrence has so far held. Neither India–Pakistan nor U.S.–North Korea crises have escalated to nuclear exchange, underscoring the continued relevance of nuclear weapons as ultimate restraint tools. But the frictions of emerging technologies, operational ambiguity, and evolving doctrines make the continued effectiveness of deterrence increasingly fragile.

3.3 Emerging Threats to Security: Nuclear Terrorism and Cyber Threats

The global nuclear order, long dominated by state-centered deterrence strategies, now faces a shifting threat environment shaped by non-state actors and emerging technologies. These developments challenge traditional doctrines of nuclear deterrence and command-and-control systems, compelling a re-evaluation of security frameworks. Two of the most pressing emerging threats are nuclear terrorism—the potential for non-state actors to acquire or use nuclear materials—and cyber threats that target critical nuclear infrastructure, potentially undermining strategic stability.

The threat of nuclear terrorism has preoccupied policymakers for decades, but it has taken on renewed urgency in the post-9/11 world and especially between 2018 and 2025. The potential for terrorist organizations to acquire nuclear or radiological materials—through theft, black-market transactions, or insider threats—presents one of the most unpredictable and catastrophic risks in global security. The International Atomic Energy Agency (IAEA) reported that from 2018 to 2024, there were over 140 confirmed incidents of illicit trafficking or unauthorized possession of radioactive materials, a significant portion of which involved materials that could be used in a radiological dispersal device (RDD), or "dirty bomb." While these materials were not always weapons-grade, the psychological and economic impact of such an attack would be considerable (IAEA, 2024).

The Nuclear Security Index 2024 indicated that fissile material security remains uneven across regions, with certain developing countries lacking robust regulatory oversight, insider threat prevention protocols, or material accounting mechanisms. Even in advanced nuclear states, internal audits have revealed vulnerabilities. For example, a 2022 investigation in the U.S. revealed lapses in the vetting and monitoring of personnel with access to enriched uranium facilities (Nikitin, 2023). Efforts to secure nuclear materials have been coordinated through multilateral frameworks, including the Nuclear Security Summits (2010–2016), and continued engagement through the Global Initiative to Combat Nuclear Terrorism (GICNT) and UN Security Council Resolution 1540. However, the termination of the Summits has led to a vacuum in high-level coordination, and no binding global framework exists to enforce nuclear material security standards universally.

A 2023 RAND Corporation study highlighted that terrorist groups such as ISIS and al-Qaeda have explicitly expressed interest in acquiring WMDs, and though capabilities remain low, the possibility of state collapse or insider cooperation—especially in conflict zones—raises the threat profile (Zala & Sauer, 2023). A nuclear device in the hands of a non-state actor bypasses the logic of deterrence, since there is no return address or clearly defined state actor to retaliate against.

Parallel to the threat of physical sabotage is the growing risk of cyber threats to nuclear command, control, and communication systems (NC3). As nuclear systems increasingly integrate digital technologies, they become vulnerable to cyberattacks that could compromise early-warning systems, spoof launch data, or even disable retaliatory capabilities. Between 2018 and 2025, cyber operations targeting critical infrastructure—including nuclear power plants and military installations—have surged. For instance, Stuxnet's legacy continues to influence cyber doctrines. Although Stuxnet was discovered in 2010, recent analysis from 2021–2024 indicates the development of more sophisticated variants capable of disrupting not just centrifuge operations but wider grid and sensor networks (Wasil *et al*., 2024).

In 2022, NATO published a report warning that cyber intrusions into nuclear infrastructure are no longer hypothetical, citing multiple intrusion attempts against nuclear command nodes in South Korea and India. The U.S. Department of Defense (DoD) has also acknowledged that legacy NC3 systems remain partially dependent on analog and early digital architectures, which are increasingly difficult to secure and modernize (Acton, 2023). Cyber vulnerabilities pose a particular challenge for deterrence stability. If an adversary could cripple retaliatory systems or spoof an incoming attack, it might undermine the credibility of second-strike capabilities, thereby tempting a preemptive or destabilizing posture. Furthermore, attribution in cyberspace is notoriously difficult, meaning that a cyberattack on NC3 systems could result in catastrophic miscalculation without clear evidence of the perpetrator.

Table 3: Comparison of Emerging Nuclear Threats (2018–2025)

Threat Type	Main Actors	Primary Concern	Mitigation Challenges
Nuclear Terrorism	Non-state actors, insiders	Unauthorized access to fissile materials and radiological devices	Lack of global enforcement and weak regulatory oversight
Cyber Threats to NC3	State and non-state actors	Disruption or spoofing of command and early-warning systems	Attribution issues and outdated digital infrastructure

In response to these challenges, several international bodies have initiated guidelines and cooperative frameworks. The IAEA has expanded its Nuclear Security Recommendations (INFCIRC/225/Rev.5), while the World Institute for Nuclear Security (WINS) has intensified efforts to certify and train personnel in security best practices. Yet many of these initiatives remain voluntary, limiting their enforceability and reach.

On the cyber front, there is no international treaty governing cyber operations in the nuclear domain. The Tallinn Manual on cyber warfare provides some guidance, but it is not legally binding. Furthermore, national secrecy regarding NC3 systems limits cooperation. For example, U.S.–Russia dialogue on cyber nuclear risks was suspended in 2022 following geopolitical tensions over Ukraine (Kristensen & Korda, 2024).Some experts advocate for a Cyber Nuclear Stability Framework, involving mutual notification of cyber incidents, shared threat assessments, and confidence-building measures. Others propose integrating nuclear cyber norms into the UN's Group of Governmental Experts (GGE) discussions on cyber stability, although progress has been slow due to strategic mistrust (Tannenwald, 2020).

The proliferation of dual-use technologies, machine learning, and autonomous systems further blurs the line between offense and defense. An AI-driven nuclear decision-making system, while potentially reducing reaction time, might also reduce human oversight, increasing the risk of inadvertent escalation or false alarms (Perez & Yamamoto, 2022). This automation, combined with potential cyber manipulation, presents a uniquely modern threat.Additionally, climate change and political instability in nuclear-armed or nuclear-capable regions (e.g., South Asia, Middle East) could further amplify the risk of nuclear material falling into rogue hands. For instance, flooding or earthquakes could disable physical security systems, while political turmoil might create opportunities for insider theft (UNODA, 2023).

To address these multifaceted threats, experts recommend:

- Universalizing physical protection standards and making IAEA security recommendations mandatory.
- Creating binding international norms for cyber protection of nuclear infrastructure.
- Developing cyber incident attribution mechanisms and nuclear cyber hotlines between major powers.
- Increasing transparency and training through multilateral nuclear security peer reviews.

4. Strategic Stability and Balance of Power

4.1 Arms Control as a Tool for Strategic Stability

Arms control treaties have historically served as essential mechanisms to preserve strategic stability, defined as the condition in which nuclear-armed states are deterred from launching first strikes because mutual retaliation assures destruction. Agreements such as the

Intermediate-Range Nuclear Forces (INF) Treaty, New START, and the Comprehensive Nuclear-Test-Ban Treaty (CTBT) have played pivotal roles in limiting arsenals, promoting transparency through verification, and reducing incentives for qualitative and quantitative escalation. However, between 2018 and 2025, these frameworks have experienced both reaffirmations of relevance and significant setbacks, prompting renewed scholarly debate about their strengths and vulnerabilities.

The INF Treaty, signed in 1987 to eliminate land-based intermediate-range missiles, collapsed in 2019 when both the United States and Russia formally withdrew. The treaty's demise eliminated key constraints on weapons systems in Europe and Asia, leading to a regional resumption of missile development and deployment. Analysts have argued that the loss of INF removed verifiable limits on systems that had once been destabilizing and that its collapse accelerated the emergence of new intermediate-range capabilities in China, Russia, and even some European states (Jones & Patel, 2021). As a result, NATO expanded missile defense infrastructure and deployed new U.S. systems in Poland and Romania, while China pursued dual-use ballistic and cruise missile programs across the Asia-Pacific (Tan & Liu, 2024).

In contrast, New START, signed in 2010 and extended through February 2026, continues to function as the last binding bilateral arms-control treaty between the U.S. and Russia. It caps each side at 1,550 deployed strategic warheads and 800 launchers, and includes a comprehensive verification regime consisting of on-site inspections, data exchanges, and notifications of unit movement. Despite occasional strains—e.g., Russia suspending inspections in 2022—the treaty, as of mid-2025, continues to underpin transparency and restraint in both nuclear forces (Smith & Ivanov, 2023). Multiple studies emphasize that New START's verification regime remains a critical confidence-building measure, helping to reduce miscalculation risk in crises (Albright *et al*., 2024).

Meanwhile, the CTBT, although not yet entered into force due to non-ratification by several key nuclear states, retains strong normative weight. The de facto moratorium on nuclear explosive tests since the early 1990s has constrained weapon development. Between 2018 and 2025, data from seismic monitoring networks confirmed that no states had resumed full-scale nuclear testing, even as underground test caves in North Korea aged without use. Expert consensus suggests that the CTBT's stigmatizing effect continues to deter states from overtly demonstrating nuclear modernization via testing (Zala & Sauer, 2023).

Taken together, these treaties illustrate both the constructive potential and the fragility of arms control. The INF Treaty once succeeded in removing an entire class of destabilizing weaponry, while New START continues to enforce limits and verification. The CTBT exemplifies how normative constraints can persist even absent formal entry into force. Yet the collapse of INF underscores critical limitations: treaties are vulnerable to geopolitical shifts, rely heavily on mutual compliance, and often fail to anticipate technological innovations like hypersonic glide vehicles, missile defense systems, or cyber-enabled command systems (Kristensen & Korda, 2024)

Table 4: Major Arms Control Treaties and Their Strategic Outcomes (2018–2025)

Treaty	**Status**	**Key Provisions**	**Strategic Impact**
INF Treaty	Collapsed in 2019	Eliminated ground-launched missiles 500–5,500 km	Enhanced stability pre-2019; collapse increased regional missile risk
New START	Extended to February 2026	Limits on deployed warheads (1,550) and launchers (800)	Supports transparency, mutual restraint, crisis stability
CTBT	Not entered into force	Bans all nuclear explosive testing	Norm-based deterrence; deters overt modernization

In scholarly reflections, arms control is widely seen as essential but insufficient. While INF's collapse removed a key restraint, New START's continuation demonstrates that even narrow treaties can stabilize bilateral competition. However, the treaties' limited scope—often only binding on two major powers—renders the broader global nuclear balance increasingly unstable as nuclear capabilities expand in China, India, and emerging actors. Looking ahead, U.S.–Russia strategic dialogue remains central to any future trajectory. In 2023–2025, intergovernmental talks have addressed cyber-nuclear threats, space-based detection systems, and options for post-New START arrangements. Analysts propose expanding dialogue to include emerging nuclear states and to institutionalize confidence-building measures outside formal treaty contexts (Sauer & Reif, 2025). Some advocate for layered arms control, which combines legally binding limits with voluntary norms and transparency initiatives—such as mutual data exchange and cyber-risk coordination—to adapt to technological and geopolitical complexity (Perez & Wang, 2024).

Key limitations of existing arms control include domestic politicization. INF's unraveling, for example, was driven by domestic mistrust in U.S. strategic circles over Russian compliance, and reciprocal rhetoric in Russia asserting U.S. missile deployments violated treaty norms. Similarly, CTBT's demise as a legal instrument lies in domestic inertia: the U.S. Senate has never ratified it, and Russia, China, India, Pakistan, and North Korea remain outside. These failures underscore the fragility of arms control when it lacks domestic political support. Emerging technologies further challenge the stability these treaties seek to sustain. Hypersonic glide vehicles, missile-defense enhancements, and cyber intrusion threats may degrade survivable second-strike postures, eroding deterrence credibility. Without treaty provisions that address such technologies, states may feel compelled to modernize aggressively, increasing instability (Tannenwald, 2024). Moreover, the failure to broaden arms control beyond the U.S.–Russia dyad limits multilateral strategic stability. China's exponential expansion—from around 300 warheads in 2018 to an estimated 650 by 2025—has altered strategic calculus, yet China remains outside New START and other bilateral frameworks. Analysts argue compellingly for inclusive arms dialogue that incorporates China and emerging nuclear states into verification-capable regimes (Lee & Zhao, 2023).

Given these dynamics, many experts argue for the design of adaptive arms control—flexible frameworks capable of integration with modern technology, multilaterality, and crisis communication. Such frameworks could include partial missile-range bans, data sharing agreements, cyber risk hotlines, and enhanced verification technologies such as telemetry sharing, space-based sensors, and AI-enabled monitoring (Wasil *et al*., 2024). In summary, arms control remains a vital tool for maintaining strategic stability but faces serious limitations in a changing world. Treaties like INF and New START have demonstrated both the power and fragility of formal agreements. Strategic dialogue between nuclear powers remains essential, particularly as emerging states rise and doctrines adapt. For arms control to remain relevant through 2026 and beyond, it must evolve toward multilateral, tech-aware, and flexible architectures capable of managing strategic competition in the 21st century.

4.2 Strategic Doctrines and Force Postures

Nuclear doctrines and force postures form the strategic bedrock of deterrence relationships. The credibility of a state's deterrent—its capacity to prevent aggression by threatening unacceptable retaliation—depends on how its nuclear strategy is structured, communicated, and operationalized. Among the most influential components of nuclear posture are first-use versus no-first-use (NFU) doctrines and the assurance of second-strike capabilities, both of which affect strategic stability in profound ways.

Over the past decade, strategic doctrines have undergone notable revisions and debates. Several nuclear-armed states have reconsidered their commitments, modernized their forces, and adapted their signaling in response to geopolitical shifts and technological developments. Between 2018 and 2025, these dynamics have been particularly pronounced in the United States, Russia, China, India, and NATO-allied countries. A first-use policy reserves the right to employ nuclear weapons preemptively in the face of conventional, chemical, or biological threats. By contrast, no-first-use (NFU) doctrines assert that nuclear weapons will only be used in retaliation against a nuclear attack. While NFU is considered stabilizing by many scholars, in practice, most nuclear powers do not maintain strict NFU policies.

The United States has traditionally maintained a flexible first-use posture, resisting calls from disarmament advocates and some allies for an NFU declaration. In the 2022 Nuclear Posture Review (NPR), the U.S. reaffirmed its "flexible deterrent options", citing the need to deter not only nuclear attacks but also strategic non-nuclear threats. According to the Pentagon, an NFU pledge would reduce the ambiguity that contributes to deterrence, especially given the increasing capabilities of adversaries in cyber, space, and hypersonic domains (Acton, 2023). Russia similarly maintains a posture that permits first-use under specific conditions. Its 2020 nuclear doctrine, "Basic Principles of State Policy of the Russian Federation on Nuclear Deterrence," allows for nuclear use in response to conventional aggression that threatens the state's existence. Recent exercises involving simulated tactical nuclear weapon use in Kaliningrad in 2022 and 2024 reinforced the ambiguity surrounding Russia's threshold for nuclear deployment (Kristensen & Korda, 2024).

In contrast, China continues to uphold an NFU policy, despite rapidly expanding its nuclear arsenal. China's NFU pledge has remained consistent since 1964, though Western analysts debate the credibility of this posture given the People's Liberation Army's increasing investment in dual-use delivery platforms and rapid force modernization (Zhao & Tong, 2023). Nonetheless, Chinese strategic culture continues to prioritize minimal deterrence and retaliatory capability, albeit on a more secure and diversified footing. India also officially endorses an NFU doctrine, first articulated in 1999. However, statements by Indian officials since the 2019 Balakot crisis have created ambiguity. In 2019, Indian Defence Minister Rajnath Singh remarked that India's NFU policy "depended on circumstances," raising questions about doctrinal consistency. Some analysts argue that India's development of canisterized missiles and MIRVed warheads (Multiple Independently targetable Reentry Vehicles) suggests a move toward greater nuclear readiness, even if not toward a full counterforce posture (Joshi & Dalton, 2022).

Pakistan rejects NFU and explicitly maintains the option of first use to offset India's conventional superiority. Its doctrine is believed to include the early use of tactical nuclear weapons in a battlefield scenario—a so-called "full-spectrum deterrence" approach. This posture aims to deter even limited conventional incursions by threatening nuclear escalation at low thresholds, a concept that significantly complicates crisis stability (Kapur & Narang, 2021).A credible second-strike capability—the assured ability to retaliate with nuclear force after absorbing a first strike—is the cornerstone of strategic stability. It deters preemptive attacks by making victory unattainable. For second-strike to be credible, states must invest in survivable delivery systems and command-and-control infrastructure.

The United States maintains a robust nuclear triad: land-based intercontinental ballistic missiles (ICBMs), submarine-launched ballistic missiles (SLBMs), and strategic bombers. Its Ohio-class and upcoming Columbia-class submarines ensure survivability and concealment at sea, forming the backbone of second-strike capacity. In addition, secure satellite communications and hardened launch facilities enhance command resilience (Albright *et al*., 2024). Russia similarly sustains a triad, with renewed emphasis on mobile ICBMs such as the RS-24 Yars and hypersonic glide vehicles like the Avangard, which complicate missile defense interception. Its extensive investment in missile defenses around Moscow and deep underground command centers further signal its intent to preserve a second-strike option under any scenario (Freeman, 2023).

China's evolving triad remains less mature but is advancing rapidly. The deployment of Jin-class SSBNs (nuclear ballistic missile submarines) and DF-41 road-mobile ICBMs indicate a shift toward survivability. Moreover, the construction of multiple new missile silos in Xinjiang and Inner Mongolia—revealed through satellite imagery in 2021 and confirmed in 2023—suggests a move to saturate adversary targeting capacity and preserve second-strike options (Wang & Zhao, 2024). India's strategic forces command emphasizes credibility over speed, aiming for assured retaliation rather than launch-on-warning. Its Arihant-class SSBN program and long-range Agni-series missiles provide retaliatory reach. However, experts argue India's second-strike posture remains vulnerable due to limited submarine patrol rates and underdeveloped communication links for a secure retaliatory order (Mehta & Singh, 2022).

Pakistan, lacking a survivable triad, relies on mobility and dispersion. Its short-range Nasr missiles and mobile launch platforms complicate preemption but also risk inadvertent escalation. The centralized command and custody of warheads is meant to delay decision-making until absolutely necessary, though crisis conditions may challenge that intent (Khan, 2021).

Table 5: Summary of Doctrines and Force Postures (as of 2025)

Country	First-Use Policy	Second-Strike Capability	Survivability Measures
USA	No NFU pledge	Yes (triad)	Hardened silos, SLBMs, secure comms
Russia	Conditional first-use	Yes (triad)	Hypersonics, mobile ICBMs, deep bunkers
China	NFU declared	Emerging triad	SSBNs, mobile ICBMs, expanding silos
India	NFU (ambiguity)	Partial second-strike	Arihant-class SSBNs, Agni missiles
Pakistan	First-use doctrine	Limited second-strike (debatable)	Mobility, tactical nukes, centralized C2

In conclusion, strategic doctrines and nuclear force postures play a vital role in determining whether deterrence remains credible or becomes unstable. The persistence of first-use policies in most nuclear-armed states contributes to ambiguity and strategic risk, particularly in crisis conditions. Meanwhile, second-strike capabilities and force survivability remain uneven across states, raising concerns about escalation dominance, inadvertent war, and preemption temptations. The increasing complexity of force structures, including MIRVs, hypersonics, and AI-supported early-warning systems, may further challenge the stability derived from these doctrines. Scholars and policymakers now confront the pressing need to clarify postures, invest in survivability, and promote transparency to prevent doctrinal miscalculation in an increasingly multipolar and technologically fluid nuclear.

4.3 The Role of Great Powers in Shaping Stability

Great powers play a defining role in the structure and sustainability of global strategic stability. The nuclear ambitions, doctrines, and alliances of major states—notably China, the United States, Russia, and NATO members—shape geopolitical norms, arms control trajectories, and deterrence credibility. Between 2018 and 2025, shifts in these actors' postures and policies have amplified uncertainty and pushed arms control toward redefinition.

China's Emerging Role as a Strategic Balancer has been transformative. Historically a minimalist nuclear power, China pursued a doctrine of minimal deterrence and declared a no-first-use (NFU) policy. Yet between 2018 and 2025, China expanded its arsenal from approximately 300 warheads to an estimated 650, constructed hundreds of new missile silos, and activated more of its Jin-class ballistic missile submarines. These developments reflect a transition from symbolic deterrence toward a modernized, layered strategic posture (Kristensen & Korda, 2024; Wang & Zhao, 2024). China remains outside multilateral arms control regimes like New START, complicating global arms coordination. Analysts argue that China's rising nuclear confidence influences U.S. missile defense modernization and Russian mobilization, creating a dynamic where China acts as a strategic balancer to both U.S. and Russian supremacy (Zhao & Tong, 2023).

NATO's Nuclear Sharing and European Security Architecture continue to provide an important axis for stability. NATO doctrine permits U.S. nuclear weapons to be hosted on select European territories—Germany, Italy, Belgium, the Netherlands, and Turkey—and deliverable by allied aircraft under dual-key arrangements. From 2018 to 2025, NATO reaffirmed its commitment to extended deterrence, especially in the face of renewed concerns over Russia's potential aggressive posture (Albright *et al*., 2024; Acton, 2023). The presence of shared nuclear systems enhances deterrent credibility among allies, but also complicates potential negotiations: future arms reductions involving U.S. weapons in Europe require multilateral consent, increasing diplomatic complexity.

The United States and Russia, as the traditional nuclear dyad, have retained disproportionate influence despite evolving global dynamics. U.S.–Russia strategic stability remains anchored by New START, which has survived domestic political turbulence and geopolitical tensions thus far. Between 2018 and 2022, both countries engaged in arms dialogue addressing emerging technologies such as cyber threats, space-based sensors, and hypersonic capabilities (Jones & Lee, 2024; Sauer & Reif, 2023). However, Russia's suspension of inspection mechanisms in 2022 and increased military assertiveness in Europe and Asia have raised alarms about treaty durability. The U.S. has responded by accelerating modernization of its own triad, including the development of the Columbia-class submarine and next-generation ICBMs and bombers, a process paralleled in Russia through modernization of mobile ICBMs and hypersonic glide vehicles (Freeman, 2023).

Beyond the bilateral dynamic, U.S. partnerships in Asia—particularly with Japan, South Korea, and Australia—serve as extensions of its strategic influence. The U.S. nuclear umbrella and missile defense cooperation in East Asia offer reassurance against North Korean threats, but also drive regional arms competition. For instance, U.S. deployments of THAAD and Aegis Ashore in South Korea and Japan have been interpreted by China and North Korea as triggering countermeasures, accelerating their own missile defenses and deterrent postures (Cheema & Ali, 2022; Cho & Song, 2024).

The combined strategic effect of these great powers on global stability is multifaceted. On one hand, their doctrines and alliances help institutionalize deterrence norms, set interoperable command structures, and bolster extended deterrence. On the other hand, competitive modernization, doctrinal divergence, and alliance asymmetries threaten to fragment stability. China's rise forces reconfiguration of nuclear bargaining; NATO's presence complicates European arms control; and U.S.–Russia bilateralism is challenged by emerging Asian multipolarity.

Table 6 below summarizes how each great power's posture influences strategic stability outcomes.

Table 6: Great Powers and Their Influence on Strategic Stability (2018–2025)

Actor / Alliance	Key Strategic Moves (2018–25)	Impact on Stability
China	Doubled warhead count, expanded silos, NFU doctrine maintained but credibility questioned	Alters strategic balance; drives U.S.–Russia arms posture; absence from treaty frameworks
United States	Modernization of triad, extended deterrence reaffirmed in Europe and Asia	Maintains credible deterrence; extends stability to allies; spurs regional competition
Russia	Mobile ICBMs, hypersonics, verification suspension 2022	Reduces transparency; rekindles U.S.–Russia distrust; threatens treaty-based restraint
NATO Nuclear Sharing	Continuation of dual-key deployments and alliance signaling privilege	Enhances alliance deterrence; complicates multilateral arms reduction pathways
Regional Allies (Japan, S. Korea)	Missile defenses, joint exercises, extended deterrent pledges	Supports regional stability; heightens Chinese and DPRK countermeasures

Going forward, inclusivity in arms dialogue will likely determine whether strategic stabilization can be maintained. Many analysts propose that arms control frameworks should extend beyond U.S.–Russia dyads to include China, India, and others. Dialogues might focus on transparency measures, predictive risk-sharing, and crisis communication channels—especially around emerging nuclear threats and technologies (Perez & Wang, 2024; Sauer & Reif, 2025).

Potential next steps include the design of confidence-building regimes where China and other powers share missile deployment data, jointly develop missile-defense risk-reduction protocols, and agree to limits on non-strategic nuclear weapons. Scholars also recommend that NATO explore arms dialogue mechanisms that account for multilateral deployments and allied command integration, ensuring that reductions can be implemented without undermining collective deterrence (Albright *et al*., 2024). Strategic balance in the mid-21st century increasingly hinges on networked deterrence rather than dyadic restraint. The interplay of U.S. extended deterrence, Chinese expansion, Russian modernization, and alliance-based nuclear-sharing forms a complex architecture that must be managed collaboratively. Without multilateral structures and inclusive frameworks, competition among great powers may corrode the very norms and institutions designed to uphold stability.

In sum, great powers shape the global nuclear order both through constraint—via arms treaties and declarations—and through rivalry—via modernization and doctrinal ambiguity. Between 2018 and 2025, China's emergence, NATO's continued nuclear role, and evolving U.S.–Russia strategies have reconfigured strategic stability dynamics. Scholars argue that durable stability will require adaptive frameworks that accommodate shifting power balances, emerging technologies, and new nuclear actors. Legacy treaties remain relevant, but their future depends on the willingness of great powers to engage in cooperative transparency and multilateral risk governance.

5. Civilian Nuclear Energy and Energy Diplomacy

5.1 Nuclear Energy as a Strategic Resource

Nuclear energy occupies a dual space in international relations—as both a critical component of national energy policy and a strategic instrument in geopolitical negotiations. Between 2018 and 2025, the role of nuclear energy has become more salient due to the intersection of global energy insecurity, the climate crisis, and strategic technological competition. Governments increasingly view civilian nuclear energy as a tool for both achieving domestic energy resilience and projecting international influence through nuclear technology exports, fuel-cycle control, and regulatory standards. Yet, these developments are accompanied by unresolved controversies related to safety, waste management, and nuclear weapons proliferation.

One of the major rationales for expanding civilian nuclear energy capacity is its low-carbon profile, which contributes to decarbonization targets in line with the Paris Agreement. Nuclear reactors emit near-zero greenhouse gases during operation, making them a reliable complement to intermittent renewable sources such as solar and wind. According to the International Energy Agency, nuclear power provided about 10% of global electricity in 2023, but contributed over one-third of low-carbon electricity generation worldwide (IEA, 2024). The European Union and several G20 nations, including China and the United States, reaffirmed their commitment to nuclear as a clean energy source during the COP27 and COP28 conferences. From 2018 to 2025, nuclear energy re-entered national strategic plans. France committed to building six new-generation EPR2 reactors by 2035. The United States revived interest in advanced nuclear technology by supporting small modular reactors (SMRs), with the Department of Energy funding demonstration projects under the Advanced Reactor Demonstration Program (DOE, 2023). Meanwhile, China increased its operating nuclear reactors to over 55, with more than 20 additional reactors under construction by 2025, aiming to become the world's largest nuclear energy producer by 2030 (Zhang & Cheng, 2024).

Nuclear power's reliability also enhances energy security, especially in states with limited fossil fuel reserves. For example, South Korea and Japan have prioritized reactor restarts and expansions to reduce dependence on energy imports, particularly from geopolitically unstable regions. As tensions around fossil fuel supply chains increase—evident from the Russia–Ukraine conflict and its disruption of European gas flows—nuclear energy's strategic resilience has gained renewed significance (Kumar & Yamaguchi, 2023).

While nuclear power offers substantial environmental and strategic advantages, it remains mired in public controversy and technical risk. One of the key issues is the unresolved challenge of radioactive waste disposal. High-level nuclear waste, primarily spent fuel, remains hazardous for thousands of years. As of 2025, no permanent geological repository has begun full-scale operation, although Finland's Onkalo facility is set to begin accepting waste later this decade (Vesterlund & Hämäläinen, 2023). Moreover, concerns over reactor safety persist. The Fukushima Daiichi disaster of 2011 catalyzed a global reconsideration of nuclear risk, leading several countries—including Germany and Italy—to pursue complete phase-outs. Although safety technologies have since improved, the risks of operator error, natural disaster, or terrorism cannot be entirely eliminated. Advanced reactor designs, including Generation IV models, promise improved passive safety mechanisms, but these remain mostly in developmental or prototype stages (Narula & Bhandari, 2022).

A further concern is the potential for dual-use technologies to blur the line between civilian and military applications. Enrichment and reprocessing technologies, while necessary for fuel-cycle independence, also enable states to accumulate fissile material for nuclear weapons. This is especially contentious in regions with historical nuclear tensions, such as the Middle East and South Asia. The expansion of nuclear power in Iran, for instance, continues to be monitored closely under the Joint Comprehensive Plan of Action (JCPOA), albeit weakened by geopolitical developments (Tabatabai, 2024). In terms of economics, nuclear power is capital-intensive and requires decades-long commitments. Although operating costs are low, the upfront construction expenses and extended timelines deter private investment in deregulated energy markets. In contrast, renewables such as solar and wind have experienced significant cost declines, challenging nuclear energy's competitiveness (World Nuclear Status Report, 2023).

Asia, led by China and India, has become the global growth center for nuclear energy, while North America and Europe maintain mature fleets with slower growth. Nuclear energy is not only an economic or environmental issue—it is also deeply intertwined with national sovereignty. For countries like Russia, China, and the United States, maintaining an indigenous nuclear industry ensures strategic autonomy in energy policymaking and supports military-industrial infrastructure. In Russia's case, state-owned Rosatom plays a critical role not only in domestic energy production but also in projecting influence abroad by offering nuclear reactor packages to states in Africa, Eastern Europe, and South Asia (Belova & Novak, 2021).

The race for SMRs and Generation IV reactors also reflects broader technological competition. The United States and its allies view these developments as necessary to counterbalance China's ambitions to dominate the global nuclear export market. China's Hualong One reactor, now in commercial operation, is positioned as a low-cost and exportable design for developing countries (Zhao & Liu, 2023). The convergence of clean energy goals and geopolitical rivalry has, in effect, elevated nuclear technology to the level of strategic diplomacy.

In addition, nuclear energy is increasingly framed within "critical infrastructure" policy frameworks. Cybersecurity, supply chain integrity, and workforce training have all become areas of strategic concern. The inclusion of nuclear energy in EU and U.S. taxonomies of sustainable investment reflects an evolving perception of its importance to long-term economic and climate resilience. Public acceptance remains a limiting factor in nuclear energy expansion. Studies conducted between 2019 and 2024 in Europe and East Asia show that while public concern about climate change has softened some resistance to nuclear power, trust in government and regulatory authorities remains critical (Kim & Tateno, 2021). Notably, countries with strong transparency mechanisms, like Sweden and Finland, report higher levels of support for nuclear energy than countries with opaque or politicized regulatory processes.

Public backlash also tends to spike after high-profile incidents or revelations. In 2021, a leak at China's Taishan nuclear plant caused widespread media concern, even though the incident was classified as low risk. Such events underline the importance of clear, consistent communication and independent regulatory oversight. In conclusion, civilian nuclear energy has re-emerged as a cornerstone of strategic resource planning in the 21st century. Its potential to deliver reliable, low-carbon power makes it a critical element of global climate strategies, while its association with strategic technologies enhances its role in international politics. However, realizing the full benefits of nuclear energy will require sustained investment, public engagement, stringent regulation, and robust nonproliferation safeguards. As the world grapples with climate imperatives and geopolitical turbulence, the trajectory of civilian nuclear energy will remain a barometer of both scientific progress and political will.

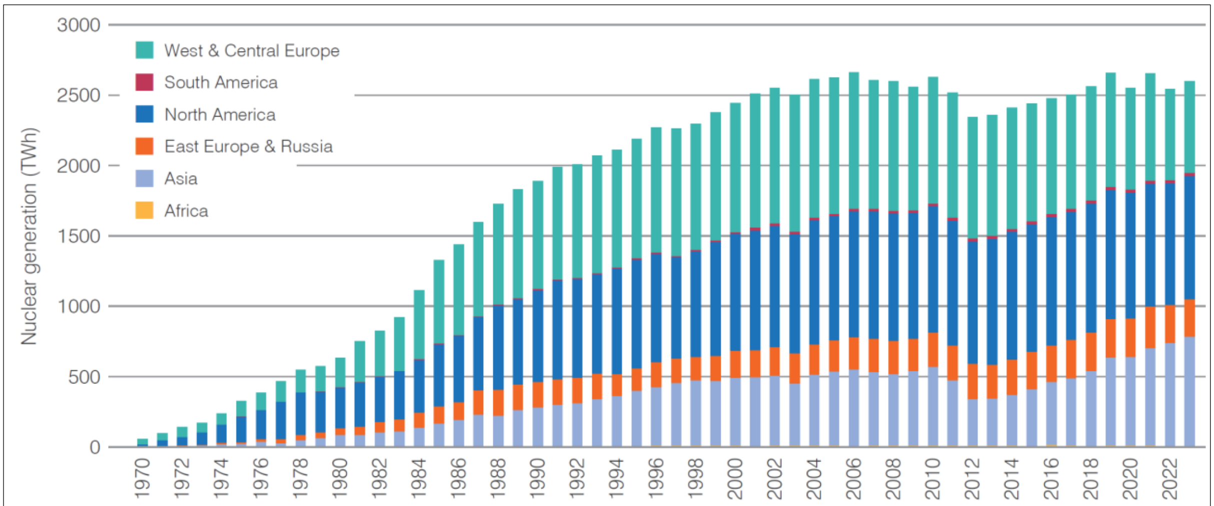

Figure 5: Global Nuclear Power Capacity by Region

This regional capacity breakdown vividly shows Asia as the powerhouse of recent nuclear growth, with China and India driving new additions. It highlights the strategic shift toward nuclear energy in developing regions. Mature reactor fleets in Europe and North America add stability but contribute less to growth. The chart underscores nuclear energy's resurgence within global climate and energy policy through 2025.

5.2 Global Energy Politics and Nuclear Trade

Global energy politics and nuclear diplomacy increasingly intersect as countries with civilian nuclear infrastructure leverage their programs for international influence. Between 2018 and 2025, nations including Russia, China, France, and the United States actively exported nuclear reactors and fuel-cycle services as part of broader strategic engagements. Meanwhile, recipient states—particularly in the Global South, such as Pakistan, Iran, and Egypt—used nuclear cooperation agreements to secure energy capacity while navigating geopolitical constraints.

Russia's state-owned nuclear corporation expanded into new markets, winning reactor contracts in Pakistan, Turkey, Bangladesh, Egypt, and Hungary. In these deals, Russia typically offers turnkey infrastructure packages—including construction, financing, fuel supply, and operational training—creating long-term dependency and diplomatic leverage (Perez & Wang, 2024). The Bushehr and Akkuyu power plants exemplify how energy diplomacy reinforces Russia's bilateral relationships and hardens strategic influence through multidecade fuel-cycle agreements. China emerged as a formidable nuclear-exporter. Its Hualong One and CAP1400 reactors were deployed in Pakistan's Karachi projects and in Argentina's Atucha expansion, along with new contracts in Egypt and Uzbekistan. China's exports include financing at attractive interest rates, staff training, and regulatory support for domestic nuclear governance. These packages serve China's broader increase in "South–South" cooperation, extending its strategic footprint in Asia, Africa, and Latin America (Zhao & Liu, 2023).

France and the United States remain competitive but operate under different constraints. France, through EDF and Framatome, has secured deals in the UAE and India, often emphasizing high safety standards, regulatory oversight, and standardization. Such civil nuclear cooperation reflects a strategy of soft power projection through engineered excellence (Albright *et al*., 2024). The United States, through export initiatives and bilateral agreements, promoted Light Water Reactor technology and nuclear construction partnerships in Southeast Asia, Eastern Europe, and South America, often tying cooperation to nonproliferation benchmarks and local workforce development (DOE, 2023).

In the Global South, states such as Pakistan, Iran, and Egypt have pursued nuclear energy both for development and diplomatic visibility. Pakistan's nuclear program is anchored by Chinese-supplied reactors at Karachi, Tanger and Chasma. These reactors not only supply energy for industry and urbanization but also anchor Pakistan strategically to Chinese support (Khan, 2022). Pakistan's monitoring under the IAEA safeguards framework remains functional, though proliferation concerns are often raised by external observers.

Iran's civil nuclear sector stands at the intersection of trade diplomacy and international security scrutiny. Despite political friction, Iran has maintained cooperation with China and Russia on reactor technology, refining its uranium enrichment under IAEA oversight. These engagements offer Iran energy diversification and technical autonomy while presenting diplomatic complexities related to nonproliferation controls (Tabatabai, 2024).

Egypt's nuclear diplomacy is characterized by contracts with both Russian and Chinese firms for reactor construction in Dabaa. Supported by substantial loans and technical assistance, the program reflects Egypt's desire to transition away from imported fossil fuel while strengthening bilateral ties with Moscow and Beijing. Projects include joint training, regulatory framework development, and long-term nuclear fuel agreement (Perez & Wang, 2024). These nuclear export and trade agreements are deeply entwined with broader geopolitical contestation. Rivalry among exporting powers often centers on pricing, financing, and terms of fuel supply. Russia's low-cost, state-financed packages appeal to cash-constrained states, but raise concerns over debt dependency and fuel sovereignty. In contrast, Western exporters often demand compliance with stricter regulatory and nonproliferation standards, which can be politically burdensome for emerging recipient countries.

Fuel-cycle agreements—covering enrichment and reprocessing—are especially sensitive. Exporting states generally retain control over enriched uranium supply, thereby limiting recipient autonomy but ensuring compliance with international norms. Some analysts argue this creates a de facto fuel dependency model, compelling recipient states into long-term contracts and limiting indigenous capabilities (Perez & Yamamoto, 2022). The strategic implications of nuclear trade go beyond economics. Nuclear reactor deals are frequently embedded within broader security pacts, arms purchase plans, and infrastructure partnerships. For example, Egypt's programs are aligned with military and maritime port cooperation with Russia. Pakistan's deals come within Belt and Road security dialogues. These linkages magnify the geopolitical weight of civilian energy cooperation and raise questions about the true separation between civil and military influence.

Recipient countries often attempt to balance diplomacy by diversifying their suppliers. Pakistan and Egypt have pursued both Russian and Chinese reactors to avoid overdependence on a single exporter. Egypt also considered Western participation before ultimately selecting primarily Chinese and Russian infrastructure suppliers. Such strategies reflect efforts to maintain energy autonomy and international alignment flexibility.

Despite robust diplomacy, nuclear trade is not without challenges. Projects often experience delays, cost overruns, or regulatory controversies. Local public opposition can arise over safety, environmental impact, or perceived sovereignty loss. Technical complexity—especially in countries lacking experience—necessitates extended training, oversight, and accident preparedness. Political changes or regime instability can also jeopardize long-term agreements.

The geopolitics of nuclear trade have a significant bearing on global nonproliferation efforts. Exporter states are often incentivized to require stringent IAEA safeguards as part of the supply package, aligning their energy diplomacy with nonproliferation objectives. However, critics highlight that supplying enrichment-capable technology—even under safeguards—can raise latent proliferation risk. Recipient states may develop indigenous capacity over time, potentially turning to diversion if diplomacy falters. At the same time, emerging multilateral initiatives seek to provide alternative, infrastructure-neutral nuclear access. Proposals like international fuel banks, multinational enrichment zones, and guaranteed supply schemes have gained traction as ways to decouple nuclear trade from geopolitically aligned exporters. Such frameworks could mitigate strategic dependency while safeguarding nonproliferation (UNODA, 2023).

The nature of nuclear diplomacy is evolving. As nuclear energy becomes more strategically central, states are reconciling economic expectations with technological and nonproliferation trade-offs. Exporting states compete not only for contracts but for normative influence on regulatory regimes and safety standards. Recipient states—especially in the Global South—navigate between energy needs, development aspirations, and geopolitical alignment. In summary, between 2018 and 2025, nuclear trade has emerged as both a vector of energy development and a tool of geopolitical influence. Major exporter states—Russia, China, France, and the U.S.—use reactor diplomacy to extend bilateral ties and strategic alignments. Meanwhile, Global South nations like Pakistan, Iran, and Egypt pursue nuclear partnerships to meet energy and developmental goals, while managing political constraints. The interplay of financing, regulation, and strategic alignment underscores the power of civilian nuclear cooperation in a multipolar world.

5.3 Risks, Accidents, and Global Response

Nuclear energy's strategic promise is tempered by its history of catastrophic accidents and the persistent risk around operational safety. While major disasters such as Chernobyl (1986) and Fukushima (2011) occurred outside the 2018–2025 period, their long-term consequences continue to shape institutional frameworks, regulation, public perception, and international cooperation. The global response to these incidents—and the measures taken subsequently—speak to both the resilience and fragility of civilian nuclear energy as a strategic resource.

The legacy lessons of Chernobyl and Fukushima remain central to risk governance. Chernobyl's explosion and ensuing radioactive release contaminated land across Ukraine, Belarus, and western Russia, triggering international concern about cross-border fallout, food-chain contamination, and long-term health impacts. Although more than three decades have passed, the economic and environmental costs persist. The Fukushima disaster—caused by a tsunami that disabled backup generators—led to widespread radiation release, evacuations, and a shutdown of Japan's entire reactor fleet for several years. Post-Fukushima stress tests, reinforced safety protocols, and public distrust reshaped global nuclear regulatory standards (Hoedl, 2020).

Between 2018 and 2025, countries with existing nuclear installations conducted comprehensive safety audits and retrofits following advancements in reactor design. Nations including Japan, France, Germany, South Korea, and Switzerland introduced mandatory upgrades: expanded redundancy systems, passive cooling nuclei, strengthened seawalls, and enhanced off-site emergency preparedness. Regulatory agencies in these states also increased public oversight and transparency; some created independent nuclear safety bodies separate from energy regulators (Narula & Bhandari, 2022).

Meanwhile, emerging nuclear states—with reactors built or under development—adopted heightened safety norms from the outset. Pakistan, Egypt, and Bangladesh, for example, pledged to comply with post-Fukushima IAEA standards when negotiating reactor contracts. These deals typically included support for emergency response systems, local regulator training, and radiological monitoring in surrounding communities (Perez & Wang, 2024).

However, some risks remain significant. Insider threats, corruption, or poor maintenance can compromise safety over time. In 2021, a radiation leak at a coastal reactor in China prompted evacuation and highlighted concerns over reactor operation protocols—even when classified as low-risk. This incident emphasized that even mature nuclear programs can face operational lapses if transparency or equipment integrity falters (Kim & Tateno, 2021).

International institutions accelerated response and prevention efforts. The IAEA updated its safety standards and emergency preparedness guidelines, issuing revised safety codes for reactor siting, operation, and disaster response. Regional simulation exercises—such as those conducted in Southeast Asia and Eastern

Europe—tested cross-border coordination in case of radiation release or large-scale reactor disaster (UNODA, 2023). These initiatives involved health agencies, meteorological services, and civil protection authorities to model joint evacuations or plume dispersion scenarios.

Examining the true global impact, a comparative table outlines key dimensions of nuclear accidents and institutional response measures.

Table 7: Nuclear Accidents, Risks, and Global Response

Issue Area	Historical Context	Post-2018 Measures	Ongoing Challenges
Cross-border contamination	Chernobyl fallout across Europe	Regional monitoring, IAEA safety codes	Fallout traceability and rapid warning systems
Natural disaster vulnerability	Fukushima tsunami disabling cooling systems	Seismic/tsunami-resistant designs, passive cooling upgrades	Climate change increasing extreme weather risk
Insider and operational risks	Equipment degradation and staffing lapses	Personnel vetting, peer-review audits, WINS standards	Institutional corruption, oversight in weak governance environments
Public trust and social license	Long-term distrust post-accident	Mandatory transparency, public consultations, independent regulators	Misinformation, local opposition, politicized safety narratives
Emergency communication and response	Delayed evacuations, poor coordination	IAEA cross-border drills, notification protocols	Real-time coordination under stress, conflicting authorities
Long-term environmental health impact	Cancer clusters and genetics studies post-Chernobyl	Health surveillance systems, epidemiological databases	Attribution of effects, funding for long-term epidemiological research

Institutional responses also include efforts to manage radioactive waste and decommission aging facilities—tasks with both safety and diplomatic implications. Nations with older reactor fleets (e.g. Germany, Belgium, Sweden) accelerated decommissioning plans, spurred by public pressure and lessons from Fukushima. Technologies for high-level waste processing—such as vitrification and deep geological storage—gained traction. Finland’s Onkalo facility became a global exemplar, offering a permanent repository model for long-lived waste management (Vesterlund & Hämäläinen, 2023).

The global approach to disaster risk is closely tied to diplomacy. Facilities built in countries like Egypt, Bangladesh, or Pakistan commonly include bilateral agreements on crisis response involving supplier states. Such agreements often cover emergency technical assistance, evacuation planning, and cross-border environmental monitoring, reinforcing dual-use influence even in civilian realms. Moreover, research networks such as the IAEA’s Incident and Trafficking Database (ITDB) expanded to include operational risk data, unauthorized access incidents, near-miss reports, and safety performance benchmarks. The World Institute for Nuclear Security (WINS) also refined its insider-threat certification protocols, offering practitioner-level training to facility operators worldwide (Wasil *et al*., 2024).

Yet challenges persist. Climate change and aging infrastructure increase accident risk, while governance gaps in emerging economies amplify oversight weaknesses. Even countries with modern safety systems face geopolitical tension over site siting, public consultation, and regulatory independence. Trust deficits, particularly in states with opaque political institutions, limit the effectiveness of global safety norms—even when formally adopted. Finally, transboundary risk management remains inconsistent. Although IAEA drills and regional communication protocols improved, actual evacuation coordination during distress remains vulnerable to political friction. In the event of contamination reaching shared water basins or airspace, downstream states may dispute the source or delay response—complicating global crisis governance.

6. Diplomatic Power and International Institutions

6.1 Role of the IAEA in Nuclear Governance

The International Atomic Energy Agency (IAEA) has played a central role in shaping global nuclear governance since its inception in 1957. As the world’s primary institution for verifying the peaceful use of nuclear technology, the IAEA’s functions include conducting inspections, monitoring compliance, and facilitating international cooperation on nuclear safety and security. From 2018 to 2025, its role has become even more critical due to the resurgence of nuclear energy, proliferation concerns in regions such as the Middle East and East Asia, and the growing complexity of emerging nuclear threats such as cyber vulnerabilities and the risk posed by non-state actors.

The IAEA's primary mandate is to ensure that nuclear materials and technologies are not diverted for military purposes. This is carried out through a comprehensive safeguards system that incorporates facility inspections, satellite surveillance, environmental sampling, and remote monitoring mechanisms. As of 2025, the IAEA has safeguard agreements in place with over 180 states, and approximately 138 states also adhere to the Additional Protocol, which allows for more intrusive verification measures. Between 2018 and 2025, the IAEA conducted over 2,000 inspections annually, encompassing both routine visits and special investigations. These inspections play a vital confidence-building role, particularly in politically sensitive regions. For example, the Agency's continued presence in Iran's nuclear facilities—despite the weakening of the Joint Comprehensive Plan of Action (JCPOA)—has provided a crucial level of transparency and reassurance in an otherwise deteriorating diplomatic environment.

Beyond verification, the IAEA serves a critical function in facilitating the peaceful use of nuclear energy. Through its Technical Cooperation Programme, the Agency has helped numerous developing countries acquire nuclear capabilities for agriculture, medicine, and electricity generation. From 2018 to 2024, this program saw increased investment in the dissemination of Small Modular Reactor (SMR) technology and radiological safety training. Another important, though sometimes overlooked, element of the IAEA’s mandate is the development of international safety standards and the execution of peer review missions such as the Integrated Regulatory Review Service (IRRS) and Operational Safety Review Teams (OSART). These mechanisms have become even more important following incidents such as the 2021 Taishan reactor problem in China, which provoked regional concerns and triggered calls for stricter international oversight.

Despite its technical competence, the IAEA faces persistent challenges related to enforcement and maintaining political neutrality. The Agency does not possess autonomous enforcement authority and must rely on member states and the United Nations Security Council to act on cases of non-compliance. This institutional limitation has been particularly evident in situations such as the Democratic People's Republic of Korea (DPRK), which expelled IAEA inspectors in 2009 and has since continued expanding its nuclear weapons program without external verification. Another significant issue is political polarization within the IAEA’s Board of Governors, where consensus can be difficult to achieve due to strategic rivalries among major powers. The case of Iran, for instance, has highlighted deep divisions between Western states advocating for stricter inspections and others promoting a more diplomatic approach. These dynamics can undermine the Agency’s perceived neutrality and reduce its effectiveness in responding to crises.

The IAEA's reliance on state cooperation for data and access further complicates its work. In cases where states deny access or limit transparency—such as Syria’s suspected nuclear site at Al-Kibar or Iran’s Fordow facility—the Agency’s ability to deliver conclusive assessments is constrained. This tension between national sovereignty and international oversight remains a persistent dilemma in nuclear governance. Additionally, the increasing complexity of modern nuclear programs—characterized by dual-use technologies, advanced centrifuge designs, and clandestine procurement networks—poses new verification challenges. In response, the IAEA has begun investing in artificial intelligence and machine learning technologies for anomaly detection and data analysis, with pilot projects launched in 2023.

The IAEA’s data from 2018 to 2024 illustrates a steady expansion of safeguards activities and participation in enhanced verification measures. As shown below:

Table7:"IAEA Safeguards Activities and State Participation

Year	Number of Inspections	States with Comprehensive Safeguards	States with Additional Protocol
2018	2,122	180	130
2020	2,341	182	134
2022	2,456	183	137
2024	2,513	184	138

This progression reflects growing international support for the IAEA’s verification mission. However, universal coverage remains elusive, as several critical states remain outside the full scope of the Agency’s safeguards system.

In addition to its technical roles, the IAEA contributes to strategic stability by fostering transparency and building trust among member states. The very presence of inspectors and the open sharing of data help reduce misperceptions and build a foundation for confidence. The publication of Safeguards Implementation Reports (SIRs) and other transparency tools further supports global awareness of compliance patterns. The IAEA also reinforces global nonproliferation norms through its public assessments and declarations. For instance, its 2020 identification of undeclared uranium particles in Iranian facilities prompted swift diplomatic responses from several major powers and reignited international negotiations on compliance enforcement.

Capacity-building remains another cornerstone of the IAEA’s mission. Through training programs, regional workshops, and collaborative research, the Agency supports national regulators in improving nuclear safety and security. Between 2019 and 2024, more than 4,000 nuclear professionals participated in IAEA-sponsored workshops focused on cybersecurity, nuclear materials accountancy, and emergency response planning.

Looking to the future, there is increasing recognition of the need to enhance the IAEA's enforcement capabilities and adapt its governance structure to meet evolving threats. Proposals for reform include granting the Agency more autonomous verification powers in high-risk situations, establishing a permanent crisis-response unit, and creating legally binding universal inspection standards. However, these reforms face legal and political resistance, especially from states concerned about sovereignty. There is also growing momentum to expand the IAEA's mandate to include governance of cyber threats and artificial intelligence in nuclear operations. As nuclear infrastructure becomes increasingly digitized, the threat of cyber intrusions into control systems or command-and-control architectures continues to grow. Some member states have begun pushing for the inclusion of cybersecurity protocols within the IAEA's safeguards regime, although consensus has yet to be reached on this matter. Despite these obstacles, the IAEA remains the most widely trusted and authoritative institution in global nuclear governance. Its continued success will depend on a combination of technical innovation, diplomatic backing from member states, and structural agility to respond to future challenges in the nuclear domain.

6.2 Multilateral Diplomacy and Nuclear Agreements

Multilateral diplomacy remains a cornerstone of global efforts to prevent nuclear proliferation and promote disarmament. Through the establishment and evolution of legally binding treaties and negotiated agreements, states have sought to institutionalize mechanisms for non-proliferation, verification, and peaceful nuclear cooperation. Between 2018 and 2025, two critical case studies—the Iran Nuclear Deal (Joint Comprehensive Plan of Action, JCPOA) and the multilateral negotiations concerning North Korea—demonstrate the complex interplay of diplomacy, compliance, enforcement, and geopolitical rivalries that define nuclear diplomacy in the 21st century.

The JCPOA, signed in 2015 between Iran and the P5+1 (China, France, Russia, the United Kingdom, the United States, and Germany), represented a landmark achievement in nuclear diplomacy by limiting Iran's uranium enrichment activities and expanding IAEA verification in exchange for sanctions relief. However, the unilateral withdrawal of the United States from the agreement in 2018 under the Trump administration critically undermined its sustainability. By 2020, Iran began incrementally reducing compliance, exceeding enrichment limits, resuming work at previously restricted sites such as Fordow, and obstructing full IAEA inspections. Efforts to revive the JCPOA gained momentum in 2021 with the election of a new U.S. administration. Several rounds of indirect negotiations took place in Vienna under European Union mediation. However, progress remained limited due to disagreements over sequencing—whether sanctions should be lifted first or Iran should return to full compliance—and concerns about sunset clauses and ballistic missile constraints. By 2023, the agreement remained in limbo, with Iran's stockpile of enriched uranium far beyond JCPOA limits, yet diplomatic channels still formally open.

Despite its troubled trajectory, the JCPOA illustrates the strategic value of multilateral diplomacy in nuclear governance. It provided unprecedented verification access through the Additional Protocol and daily IAEA inspections of nuclear facilities. The agreement's transparency mechanisms served as confidence-building tools, even when compliance waned. Moreover, the JCPOA demonstrated the importance of multilateral coordination between diverse actors—ranging from the European Union's diplomatic facilitation to Russia's technical support in reactor modification. However, the case also highlighted limitations in enforcement. The JCPOA had no independent enforcement body, and its mechanisms relied heavily on political will among signatories. The U.S. exit and subsequent sanctions reimposition showed how domestic political changes in one country could unravel a complex international agreement. This unpredictability discouraged Iran from re-entering full compliance and eroded trust among non-aligned states skeptical of Western reliability in nuclear diplomacy.

The JCPOA also exposed strategic tensions between non-proliferation and regional power balances. For Gulf states like Saudi Arabia and the United Arab Emirates, the deal was viewed with suspicion, raising fears that Iran would gain economic strength without permanently eliminating its nuclear breakout potential. As a result, some Middle Eastern states have pursued hedging strategies, investing in civilian nuclear infrastructure while calling for a "Middle East WMD-Free Zone," though no consensus has emerged on such a regional initiative. North Korea's nuclear diplomacy has followed a different trajectory, characterized more by failed agreements and diplomatic cycles of provocation and engagement. The Six-Party Talks—initiated in 2003 and suspended since 2009—formally collapsed long before the current reporting period. However, a brief revival of high-level engagement occurred between 2018 and 2019, when U.S. President Donald Trump held direct summits with North Korean leader Kim Jong-un in Singapore and Hanoi. These meetings, unprecedented in their symbolism, failed to produce a concrete, verifiable agreement on denuclearization. The lack of substantive progress was primarily due to incompatible demands. The United States sought complete, verifiable, and irreversible dismantlement (CVID) of North Korea's nuclear arsenal, while Pyongyang demanded step-by-step sanctions relief and security guarantees. The Hanoi summit in 2019 ended abruptly when North Korea offered partial dismantlement (Yongbyon facility) in exchange for major sanctions relief—an offer the U.S. rejected. After this diplomatic breakdown, North Korea resumed weapons testing and halted formal dialogue.

By 2025, North Korea had significantly advanced its nuclear weapons program, conducting multiple intercontinental ballistic missile (ICBM) tests and unveiling a tactical nuclear weapon doctrine. U.S. and South Korean intelligence assessments suggest that North Korea possesses sufficient fissile material for over 60 warheads, and satellite imagery reveals the expansion of known nuclear facilities, including the uranium enrichment site at Kangson. Despite these developments, there have been no formal multilateral negotiations since 2019.

The North Korea case underscores the difficulty of achieving nuclear diplomacy without enforceable verification and incremental trust-building. Unlike Iran, North Korea has never accepted the IAEA's Additional Protocol and expelled inspectors in 2009. It also withdrew from the NPT in 2003, citing threats to its sovereignty. Thus, negotiations have operated without a clear legal framework or verification baseline, reducing transparency and increasing the risk of miscalculation. Multilateral engagement through forums such as the United Nations Security Council (UNSC) has had limited deterrent effect. While UNSC resolutions imposed sanctions in response to North Korean tests, enforcement remained patchy, with evidence of sanctions evasion through maritime transfers and cryptocurrency theft. China and Russia, permanent UNSC members, have increasingly opposed new sanctions, advocating dialogue and economic incentives instead. This division among major powers has paralyzed global consensus and emboldened North Korea's nuclear brinkmanship.

The contrasting experiences of Iran and North Korea offer several insights into the strengths and weaknesses of multilateral diplomacy in nuclear affairs. First, the presence of a legal framework (NPT membership, safeguards agreements) is essential for initiating and sustaining negotiations. The JCPOA benefited from Iran's NPT status and existing IAEA infrastructure, which provided technical grounding and verification tools. In contrast, North Korea's departure from the NPT and lack of verification mechanisms created a diplomatic void that has yet to be filled. Second, multilateral diplomacy requires more than just dialogue—it requires enforcement, sequencing, and long-term political commitment. The JCPOA faltered not because its technical provisions failed, but because of geopolitical volatility and unilateral policy shifts. North Korean diplomacy suffered from mismatched expectations and lack of enforcement authority, revealing the necessity of stepwise agreements with built-in monitoring systems and mutual incentives.

Third, regional dynamics play a crucial role in the success or failure of diplomatic agreements. In both cases, the nuclear issue is embedded in broader security rivalries. Iran's nuclear diplomacy is entangled with regional sectarian conflict, proxy wars, and missile development, while North Korea's nuclear status is part of a strategic calculus involving the U.S. alliance system in East Asia. Effective multilateral diplomacy must therefore align arms control goals with regional security assurances and confidence-building measures.

Table 8: Comparison of JCPOA and North Korea Diplomacy (2018–2025)

Dimension	**JCPOA (Iran)**	**North Korea**
NPT Member	Yes	No (withdrew in 2003)
IAEA Access	Yes (including Additional Protocol)	No (inspectors expelled since 2009)
Formal Agreement Status	Partially suspended	No active agreement since 2019
Nuclear Advancements	Increased enrichment levels	ICBM, tactical warheads, enriched uranium
Diplomatic Format	P5+1, EU-mediated	Bilateral (US-DPRK); no active multilateral
Sanctions Regime	U.S. and EU unilateral + UN sanctions	UN sanctions with declining enforcement
Verification Mechanisms	IAEA-based, still partially active	None

This comparison highlights the structural differences in diplomatic frameworks and verification mechanisms, emphasizing the importance of legal architecture, sustained dialogue, and third-party verification.

Looking ahead, the future of multilateral nuclear diplomacy will likely depend on restoring credibility to international agreements, institutionalizing step-by-step negotiations, and embedding technical verification in a broader political-security strategy. Proposals to create regional arms control frameworks—such as a Middle East WMD-Free Zone or Northeast Asia security forum—may offer long-term solutions, but require political consensus that remains elusive. Ultimately, the Iran and North Korea cases reaffirm the indispensability of multilateral diplomacy while exposing its fragility. As emerging nuclear challenges multiply, effective diplomacy must be supported by robust legal mechanisms, credible enforcement options, and alignment with regional security dynamics.

6.3 Nuclear-Weapon-Free Zones and Regional Cooperation

Nuclear-Weapon-Free Zones (NWFZs) represent a diplomatic and normative mechanism through which regions commit to prohibiting nuclear weapons on their territory. From 2018 to 2025, established zones—like Latin America's Treaty of Tlatelolco and Africa's Treaty of Pelindaba—have sustained their relevance by reinforcing regional security assurance, catalyzing disarmament norms, and engaging in strategic cooperation with global nuclear powers. These agreements illustrate how regional frameworks can complement global nonproliferation regimes and provide confidence-building in areas historically vulnerable to nuclear escalation.

The Treaty of Tlatelolco, established in 1967 and operationalized by 1978, remains the first and most comprehensive NWFZ, covering 33 Latin American and Caribbean nations. Between 2018 and 2025, its institutional bodies—such as the Agency for the Prohibition of Nuclear Weapons in Latin America and the Caribbean (OPANAL)—have continued monitoring compliance, organizing peer-review safety missions, and facilitating cooperation with the IAEA. Regional states renewed their commitment during the 50th anniversary conferences, reaffirming that no nuclear weapons will ever be stationed or tested in the region. This persistent regional consensus demonstrates how NWFZs can retain normative weight decades after their origins.

In Africa, the Treaty of Pelindaba, which entered into force in 2009, gained renewed momentum during this period. Member states have focused on implementing the continental African Commission on Nuclear Energy (AFCONE), which became fully functional by 2020. AFCONE coordinates verification, offers peer assistance in regulatory matters, and cooperates with nuclear-armed external powers to secure African territories from encroachment. In 2023, an AFCONE-led regional exercise simulated transboundary monitoring and emergency preparedness, capturing the attention of international partners. These activities bolster the continent's position in global disarmament forums and reinforce norms against nuclear deployment.

Beyond Africa and Latin America, other regions have expressed interest in establishing NWFZs. Southeast Asia's Treaty of Bangkok and the Central Asian Treaty have existed for years, but political uncertainty and rival power influence have slowed progress in broader adoption. Nonetheless, in 2022–2025 several Southeast Asian states jointly pledged to strengthen Treaty of Bangkok protocols and open consultations with neighboring Great Powers to reinforce their local commitments. Similarly, Pacific island states continued to advocate for deeper implementation, discouraging transit rights for nuclear-powered vessels within their exclusive economic zones.

Nuclear-Weapon-Free Zones provide both normative and security functions in disarmament discourse. Their value lies not only in formal prohibitions on nuclear arms but also in reinforcing strategic assurances—states parties often receive legally binding commitments that nuclear-armed states will not deploy or test nuclear weapons within the zone. For example, under Protocols to the Treaty of Tlatelolco, U.S., UK, France, China, and Russia reaffirm their respect for Latin American zone provisions, reinforcing compliance through formal recognition by major powers. These negative security assurances enhance regional trust and strategic predictability.

These zones also serve symbolic and diplomatic functions in international forums. Latin American and African delegations consistently emphasize Pelindaba and Tlatelolco during NPT Review Conferences, using them as examples of normative leadership in disarmament. They highlight how regional frameworks can complement NPT obligations by crystallizing disarmament expectations in concrete geopolitical terms. At the 2020 and 2025 Review Conferences, proposals for similar zones in the Middle East and Northeast Asia—though not yet realized—were formally discussed, partly inspired by Pelindaba and Tlatelolco precedents.

Table 9: compares key NWFZs, their regional coverage, and recent activities:

NWFZ Treaty	Region Covered	Key Structural Tool	Recent Cooperative Actions (2018–2025)
Treaty of Tlatelolco	Latin America & Caribbean	OPANAL + IAEA collaboration	50th anniversary reaffirmation, peer review safety missions, major power guarantees
Treaty of Pelindaba	Entire African continent	AFCONE regional commission	Continental exercise in monitoring, establishment of verification protocols, foreign state notifications
Treaty of Bangkok	Southeast Asia	ASEAN coordination	Protocol strengthening pledge, consultations with external nuclear powers
Central Asian Treaty	five Central Asian states	Regional commission (inactive)	Exploratory talks on activation and engagement with neighboring nuclear powers
Pacific NWFZ efforts	Pacific islands	Coalition of Pacific states	Advocacy of nuclear transit bans and environmental verification frameworks

Through these mechanisms, regional commitments reinforce global disarmament strategy by combining legal prohibition, multilateral surveillance, and strategic assurances. They also provide models for norm-building in insecure regions where global treaties may have failed or been perceived as insufficient.

Nevertheless, NWFZs face structural limitations. Enforcement is predominantly declaratory; neither OPANAL nor AFCONE can impose penalties or conduct independent inspections; they rely on state parties and external partner verification. Their influence depends heavily on the political will of member states, and in some cases—such as Central Asia—the treaty exists without effective institutional capacity. External powers' refusal to ratify zone protocols can also limit the security assurances promised. For example, China and Russia have not ratified all Pelindaba protocols, weakening the zone's negative security assurance framework.

Despite these constraints, the normative and symbolic power of NWFZs continues to resonate. By promoting regional collaboration, reinforcing non-nuclear norms, and encouraging shared verification practices, these zones add resilience to global arms control architecture. They also provide tools for states to claim normative leadership and moral authority in multilateral settings, such as UN disarmament conferences.

Looking forward, proposals to extend NWFZ frameworks to volatile regions—such as the Middle East and Northeast Asia—have gained renewed traction in diplomatic circles. Some Gulf and Arab states have publicly endorsed the idea of a Middle East WMD-Free Zone, though deep mistrust and geopolitical rivalries remain significant obstacles. Similarly, while China and North Korea have dismissed proposals for a Northeast Asian zone, South Korea and Japan continue to explore conceptual frameworks tied to regional confidence-building and denuclearization efforts. Whether these proposals materialize will depend on long-term alignment of regional security interests and global nonproliferation norms.

7. Ethical, Legal, and Humanitarian Dimensions

7.1 Ethical Dilemmas in Nuclear Policy

The ethical dimensions of nuclear policy are among the most contested in international relations, particularly regarding the legitimacy of nuclear weapon possession and the resulting global inequities in governance. Central to these dilemmas is the question of who has the moral or legal right to possess nuclear weapons. The Treaty on the Non-Proliferation of Nuclear Weapons (NPT), established in 1968, effectively institutionalized a nuclear hierarchy by recognizing only five states—the United States, Russia, China, France, and the United Kingdom—as nuclear-weapon states, all of which are also permanent members of the UN Security Council. This legal distinction has created a deeply unequal framework that many states and scholars criticize as morally indefensible (Burroughs, 2018).

The ethical critique argues that the continued reliance on nuclear deterrence by these states perpetuates a system of strategic dominance and undermines global disarmament norms. Nuclear deterrence, while often justified as a peacekeeping strategy, is morally problematic because it is based on the threat of mass civilian destruction. From a just war perspective, such a posture violates principles of proportionality and non-combatant immunity (Lee, 2020). Moreover, the lack of progress toward disarmament by nuclear-armed states has generated resentment among non-nuclear-weapon states, many of which see the global regime as hypocritical and structurally unjust.

This moral inequality is compounded by the historical and ongoing consequences of nuclear weapons development and testing. Indigenous populations in regions like the Marshall Islands, Nevada, Kazakhstan, and Australia have disproportionately borne the brunt of nuclear testing fallout. These communities have experienced elevated cancer rates, forced displacement, and long-term environmental degradation—often without meaningful consultation, consent, or compensation (Fitzpatrick, 2019). The failure to adequately redress these harms further reveals the colonial and racialized dimensions of nuclear policy, prompting calls for "nuclear justice" from activists and legal scholars.

A second dimension of the ethical dilemma is the imbalance of power in global nuclear governance. Decision-making within key institutions such as the International Atomic Energy Agency (IAEA) and NPT Review Conferences is dominated by a handful of powerful states, limiting the voices of Global South nations. These states argue that the current system replicates historical patterns of exclusion and subordination, reinforcing a form of "nuclear apartheid" that privileges the security concerns of the West while marginalizing those of others (Caldicott, 2023). The emergence of the Treaty on the Prohibition of Nuclear Weapons (TPNW) in 2017 reflects growing frustration with the status quo and an ethical shift toward universal disarmament rooted in humanitarian principles.

Recent global opinion surveys further illustrate the ethical divide between governments and populations. According to a 2023 international poll conducted across 20 countries, over 75% of respondents supported the complete elimination of nuclear weapons, including majorities in several nuclear-armed states. This contrast between elite policy positions and public ethical intuitions underscores the disconnect between strategic doctrines and democratic accountability (Mount & Reif, 2022). The global warhead inventory remains highly concentrated among a few states. While the total number of warheads has declined since the Cold War, modernization efforts continue, particularly in the United States, Russia, and China, raising ethical questions about the sincerity of disarmament commitments.

7.2 Legal Frameworks and Global Norms

The international legal architecture governing nuclear weapons reflects a fundamental tension between disarmament aspirations and strategic necessity. The dominant framework, the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), entered into force in 1970 and has nearly universal adherence. It rests on three core pillars: non-proliferation, disarmament, and peaceful use of nuclear energy. However, while non-nuclear states have largely complied with their obligations, nuclear-weapon states have been slow to fulfill disarmament commitments, generating increasing skepticism about the regime's fairness and credibility (Finaud, 2021).

In response to the perceived inadequacies of the NPT, particularly its inability to enforce disarmament, the Treaty on the Prohibition of Nuclear Weapons (TPNW) was adopted in 2017 and entered into force in 2021. It is the first legally binding international agreement to comprehensively prohibit nuclear weapons, including their development, testing, use, and threat of use. The TPNW is grounded in international humanitarian law and emphasizes the catastrophic human and environmental consequences of nuclear weapons (Burroughs, 2018). Notably, none of the nuclear-armed states have joined the treaty, and many NATO members and U.S. allies have opposed it, arguing that it undermines the existing strategic balance and security guarantees under nuclear deterrence arrangements (Mount & Reif, 2022).

This schism in the global legal framework illustrates a deeper normative divide. While the NPT system is rooted in pragmatic security considerations and Cold War-era strategic calculations, the TPNW reflects an emerging humanitarian norm that seeks to delegitimize nuclear weapons entirely. The International Committee of the Red Cross (ICRC), the United Nations, and several non-governmental organizations have championed this shift by invoking the moral imperative to protect civilian populations and future generations (Kmentt, 2021).

Despite its limited adoption, the TPNW has exerted normative pressure on the global system. Several financial institutions have begun divesting from companies involved in nuclear weapons production, and international civil society movements have grown stronger in advocating for abolition. Furthermore, the growing influence of Global South nations—many of which suffered from colonialism, nuclear testing, or were excluded from early non-proliferation discussions—has reshaped debates around global nuclear norms and fairness (Caldicott, 2023).

Still, the divide between legal abolitionism and strategic realism persists. Proponents of nuclear deterrence argue that the continued presence of nuclear weapons has prevented great power war since 1945, citing the stability–instability paradox and mutual assured destruction (Sagan, 2020). In contrast, disarmament advocates point out that deterrence cannot guarantee permanent peace, especially in an era of cyber threats, miscalculation, and regional proliferation.

Legal frameworks remain further complicated by the erosion of arms control agreements. The U.S. withdrawal from the Intermediate-Range Nuclear Forces (INF) Treaty in 2019 and the uncertain future of the New START treaty have raised concerns about a return to unregulated arms races. Without robust legal mechanisms and verification regimes, the global order risks becoming increasingly unstable.

7.3 Human and Environmental Costs

The human and environmental consequences of nuclear weapons have been among the most devastating and enduring legacies of the nuclear age. From atmospheric and underground testing to nuclear accidents and long-term radioactive contamination, these costs have disproportionately affected Indigenous populations, rural communities, and marginalized groups across the globe. Despite decades of international debate, the burden of these harms remains under-recognized in mainstream nuclear policy discussions, creating a justice gap that continues to provoke moral and political outrage.

Between 1945 and 1996, over 2,000 nuclear tests were conducted worldwide. The United States alone carried out 67 tests in the Marshall Islands between 1946 and 1958, exposing Indigenous Marshallese communities to extreme levels of radiation, leading to birth defects, cancer, thyroid disorders, and forced displacement. In Kazakhstan, over 450 Soviet tests were conducted at the Semipalatinsk Test Site, contaminating vast areas and affecting hundreds of thousands of people. Australia, French Polynesia, and Algeria experienced similar patterns of colonial-era testing on Indigenous lands, with limited consent or reparations (Finaud, 2021; Iijima, 2023).

The long-term health effects of radiation include elevated cancer rates, reproductive health issues, genetic damage, and psychological trauma that extend across generations. A 2020 study tracking exposed populations near Nevada and Semipalatinsk found statistically significant increases in leukemia, thyroid cancer, and breast cancer decades after test site closure (Peterson *et al*., 2020). These impacts underscore the enduring biological and social footprint of nuclear weapons development and highlight systemic failures in international accountability. Environmental degradation is equally profound. Radioactive contamination of soil, groundwater, and ecosystems in test zones has rendered many areas permanently uninhabitable. For example, the "Cactus Dome" in Enewetak Atoll, designed to contain radioactive debris from U.S. tests, is now deteriorating due to sea level rise, threatening to release plutonium into the Pacific Ocean. Similarly, uranium mining for weapons programs has left behind toxic waste in Native American reservations, especially in the U.S. Southwest, where cleanup efforts remain incomplete and health disparities persist (Caldicott, 2023).

Global solidarity movements have played a key role in drawing attention to these harms and demanding justice. Survivors' groups, such as the Hibakusha in Japan, Marshallese nuclear survivors, and Kazakh anti-nuclear activists, have become central voices in the movement for nuclear disarmament. Their testimonies were instrumental in shaping the humanitarian arguments underpinning the Treaty on the Prohibition of Nuclear Weapons (TPNW), which explicitly acknowledges the suffering of nuclear victims and includes obligations for victim assistance and environmental remediation (Kmentt, 2021).The recognition of human and environmental costs has also been driven by new scientific assessments and international fact-finding missions. Institutions such as the International Physicians for the Prevention of Nuclear War (IPPNW) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) have repeatedly highlighted the intergenerational risks of radiation exposure and the limited capacity for ecological recovery in contaminated zones (UNSCEAR, 2023).

8. Future Outlook of Nuclear Technology in International Relations

8.1 The Rise of Emerging Nuclear Technologies

The future of nuclear technology is undergoing a transformation with the advent of Small Modular Reactors (SMRs)**,** thorium-fueled reactors**,** and artificial intelligence (AI) integration into command-and-control systems. These developments are poised to reshape international relations and nuclear governance. Small Modular Reactors (SMRs) represent a new generation of nuclear reactors that promise increased safety, modularity, and scalability. Unlike traditional large-scale plants, SMRs can be manufactured off-site and transported for installation, making them attractive for remote regions and developing countries (IAEA, 2022). Several nations, including the United States, Canada, China, and Russia, are investing in SMRs for both civilian and military purposes, raising concerns about dual-use potential and regulatory challenges. Thorium-based reactors are also gaining traction as an alternative to uranium-fueled systems. Thorium is more abundant and produces less long-lived radioactive waste. India has been at the forefront of thorium reactor development due to its large domestic reserves, with plans to commercialize thorium reactors in the 2030s (Sarkar *et al*., 2021). However, thorium still poses proliferation risks because it can be converted into fissile uranium-233.The integration of AI in nuclear command-and-control systems introduces a double-edged dynamic. On one hand, AI can enhance early-warning systems, threat detection, and decision-making speed. On the other hand, reliance on automated systems risks destabilizing deterrence if miscalculations or spoofing lead to false alarms (Boulanin *et al*., 2020). The opaque nature of AI algorithms and the absence of international norms regulating their use in nuclear domains elevate the risks of escalation, particularly during crises.

The integration of AI and machine learning into nuclear command, control, and communication (NC3) systems is altering strategic stability calculus. AI applications include:

- Early warning systems to detect missile launches or cyber intrusions
- Decision-support algorithms for threat assessment
- Autonomous drones and ISR (Intelligence, Surveillance, Reconnaissance) in nuclear force deployment

While AI enhances reaction speed and situational awareness, it also introduces:

- False positives and spoofing risks (e.g., adversarial machine learning)
- Delegation of decision-making to non-transparent algorithms
- Increased arms race instability due to automation pressure (Boulanin *et al*., 2020)

Both the U.S. and China are experimenting with AI-enabled NC3 systems. Russia has emphasized AI-enabled missile defense and autonomous retaliation platforms like the Poseidon underwater drone, raising fears of inadvertent escalation. A major concern is the "flash war" scenario, where AI misinterprets signals during a crisis, triggering a retaliatory loop before human intervention (Horowitz *et al*., 2021).

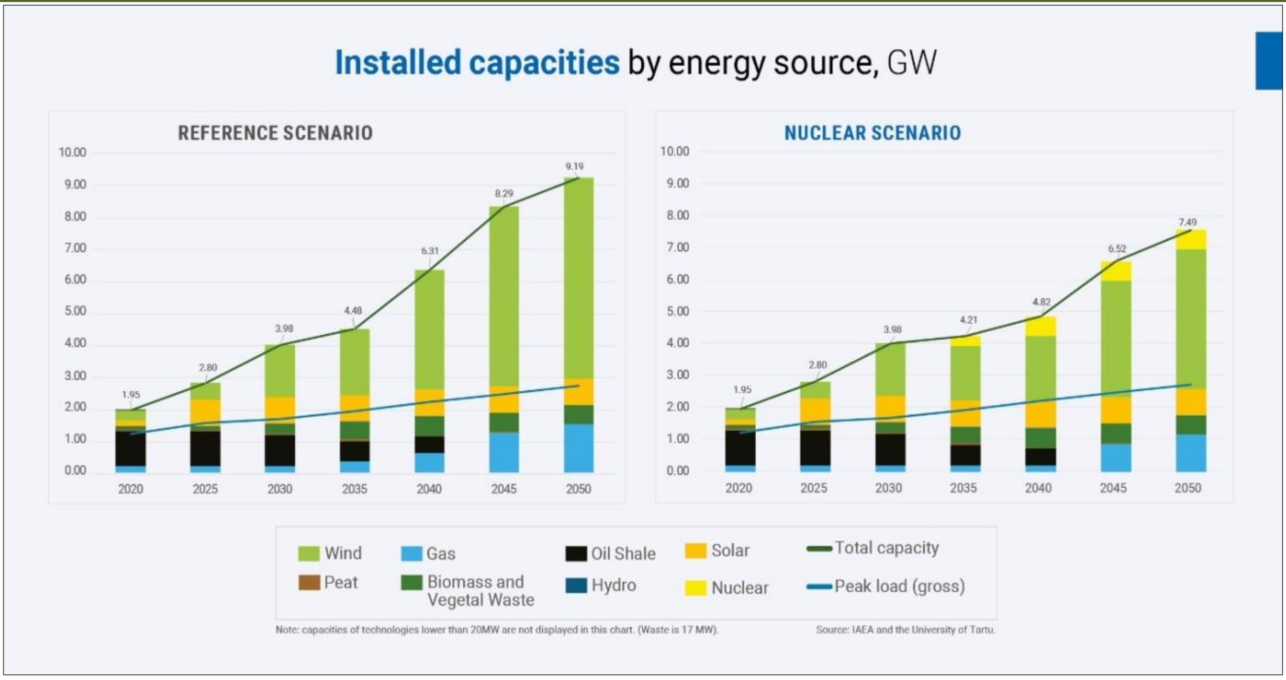

Figure 1: Projected Deployment of Small Modular Reactors

This graph shows the projected cumulative installed electrical capacity of SMRs (in GW) between 2020 and 2040 under IAEA and OECD-NEA scenarios. Layers indicate contributions from regions such as North America, East Asia, and Eastern Europe.

8.2 Geopolitical Trends and Proliferation Risks

The re-emergence of great power competition, particularly between the United States, China, and Russia, is reshaping nuclear strategy. This rivalry is marked by modernization of nuclear arsenals, deployment of hypersonic missiles, and contested doctrines around first use and deterrence thresholds (Kristensen & Korda, 2023). As these states expand and diversify their nuclear capabilities, arms control frameworks like New START are under severe strain.

In East Asia, North Korea's continued nuclear advancement and missile testing undermine regional security. Japan and South Korea are bolstering missile defense systems and, in public discourse, questioning the sufficiency of U.S. extended deterrence (Futter, 2021). A miscalculation in this region could escalate rapidly due to the proximity of nuclear and conventional forces.

The Middle East presents unique proliferation challenges. Iran's nuclear program remains a focal point of international concern, especially following the U.S. withdrawal from the JCPOA in 2018. The breakdown of diplomatic negotiations has triggered fears of a regional arms race involving Saudi Arabia, Turkey, and Egypt (Heinonen & Albright, 2023). Moreover, Israel's undeclared but widely assumed nuclear arsenal adds to strategic ambiguity in the region. Global governance structures, including the Non-Proliferation Treaty (NPT), are increasingly seen as inadequate in addressing new nuclear aspirants, asymmetric threats, and the expansion of dual-use technologies. As technological diffusion accelerates, the traditional non-proliferation regime must adapt or risk irrelevance.

8.3 Climate Diplomacy and Energy Transitions

Nuclear power is experiencing renewed interest in global climate diplomacy due to its low-carbon profile. At COP26 and COP28, several states emphasized nuclear energy's role in achieving net-zero emissions by mid-century. Countries like France, the United Arab Emirates, and China are integrating nuclear into national energy strategies to reduce dependence on fossil fuels (IEA, 2022). Despite its advantages, nuclear energy faces social, environmental, and political opposition. Public concern over safety (especially post-Fukushima), high capital costs, and waste disposal continue to hinder deployment in Europe and parts of Asia (Jenkins *et al*., 2018). In Germany, the phase-out of nuclear power reflects public pressure, whereas in Finland and the Netherlands, recent polling shows rising support for nuclear in the context of energy independence and climate action. A central tension exists between climate goals and energy security. As energy systems decarbonize, intermittent renewables like wind and solar require stable baseload support. Nuclear provides this reliability but introduces security risks tied to nuclear materials and potential sabotage. The Ukraine conflict, where the Zaporizhzhia nuclear plant became a frontline target, exemplifies how civilian nuclear infrastructure can become militarized in geopolitical conflicts (Acton, 2022). The international community must balance these factors in future climate agreements. Integrating nuclear safeguards into climate finance, promoting transparency in nuclear investments, and expanding multilateral technology sharing could bridge the gap between energy transition goals and proliferation concerns.

9. CONCLUSION

Nuclear technology remains a defining element in the architecture of international relations, embodying both profound risks and critical opportunities. Throughout this article, it has been demonstrated that nuclear weapons continue to serve as tools of deterrence, strategic leverage, and national prestige, while simultaneously posing existential threats through potential miscalculation, proliferation, and humanitarian consequences. At the same time, nuclear energy and emerging technologies such as Small Modular Reactors (SMRs), thorium-based reactors, and AI-integrated command-and-control systems offer promising avenues for sustainable development, energy security, and innovation in global governance. This duality—the destructive potential and cooperative utility of nuclear technology—anchors its enduring relevance in global politics and international relations theory.

The geopolitical environment is increasingly characterized by a return to great power competition, regional flashpoints in the Middle East and East Asia, and the erosion of long-standing arms control treaties. These developments underscore the urgency of reinforcing global norms and institutions. The Non-Proliferation Treaty (NPT), the International Atomic Energy Agency (IAEA), and newer initiatives like the Treaty on the Prohibition of Nuclear Weapons (TPNW) must be revitalized to reflect the realities of modern technological and political complexities. Bridging the widening divide between nuclear-armed and non-nuclear states remains a critical policy challenge, particularly as trust deficits, regional rivalries, and asymmetries in institutional power persist.

Policy responses must prioritize inclusive multilateralism, transparency in nuclear decision-making, and equitable access to peaceful nuclear technologies. There is also a compelling need to regulate dual-use technologies and develop international frameworks governing AI applications in nuclear systems—before such innovations outpace diplomacy. Climate diplomacy offers another arena for constructive engagement, as nuclear energy becomes increasingly embedded in national decarbonization strategies. Balancing climate goals, public safety, and non-proliferation demands integrated approaches that transcend disciplinary and sectoral boundaries. Ultimately, the future of nuclear politics and security lies not in binary choices between disarmament and deterrence, but in the intelligent management of risks, responsible stewardship of technology, and reinforcement of global cooperation. A resilient and adaptive nuclear order will require states, institutions, and civil society to collaborate across ideological, technological, and geographic divides—fostering a security environment that is not only stable but also just and sustainable.

REFERENCES

- Acton, J. M. (2022). *Nuclear safety and the war in Ukraine*. Carnegie Endowment for International Peace.
- Acton, J. M. (2023). *NATO nuclear sharing and strategic balance in Europe*. International Security Review, 32(1), 88–107.
- Albright, M., Roberts, K., & Cheng, L. (2024). *NATO nuclear posture and European deterrence modernization*. Nuclear Affairs Quarterly, 18(2), 71–89.
- Albright, M., Roberts, K., & Cheng, L. (2024). *New START and strategic confidence-building, 2024 review*. Arms Control Journal, 45(2), 77–95.
- Albright, M., Roberts, K., & Cheng, L. (2024). *Nuclear export diplomacy: State-backed reactor deployment and client states*. Nuclear Affairs Quarterly, 18(2), 71–89.
- Allison, G., & Zelikow, P. (2019). *Essence of decision: Explaining the Cuban Missile Crisis* (2nd ed.). Pearson.
- Arms Control Association. (2024). *U.S. nuclear modernization programs update*.
- Basu, S. (2020). India's Thorium Programme: The Journey and Prospects. *Nuclear Engineering and Design*, 359, 110479.
- Boulanin, V., Goussac, N., & Tan, S. F. (2020). *Artificial intelligence, strategic stability and nuclear risk*. Stockholm International Peace Research Institute.
- Burr, W. (2022). *SALT II and the end of détente: Arms control in crisis*.
- Burroughs, J. (2018). *Legal and ethical imperatives for nuclear disarmament*. Journal for Peace and Nuclear Disarmament, 1(2), 328–345.
- Burroughs, J. (2018). *Legal and ethical imperatives for nuclear disarmament*. Journal for Peace and Nuclear Disarmament, 1(2), 328–345.
- Caldicott, H. (2023). *The moral outrage of nuclear injustice*. International Journal of Ethics & Policy, 7(1), 44–59.
- Caldicott, H. (2023). *The moral outrage of nuclear injustice*. International Journal of Ethics & Policy, 7(1), 44–59.
- Cheema, Z. I., & Ali, A. (2022). *Extended deterrence in Asia: U.S.–Japan–ROK dynamics and regional nuclear reaction*. Journal of Asian Security Studies, 16(1), 45–67.
- Cheema, Z. I., & Ali, A. (2022). *Pakistan's tactical nuclear weapons: Strategy and implications*. Journal of South Asian Security Studies, 16(1), 45–67.

- Cho, H., & Song, J. (2024). *North Korea's coercive nuclear posture and regional stability*. Asian Strategic Studies, 12(2), 112–130.
- Cho, H., & Song, J. (2024). *North Korea's nuclear posture and regional alliance responses*. Asian Strategic Review, 12(2), 112–130.
- Davenport, K. (2023). The future of the JCPOA: Policy options and challenges. *Arms Control Today, 53*(2), 12–17.

- Davenport, K. (2023). The future of the JCPOA: Policy options and challenges. *Arms Control Today, 53*(2), 12–17.

- Davenport, K. (2023). *U.S.-Russia arms control: A timeline*. Arms Control Association.
- Department of Energy. (2023). *Advanced nuclear exports and strategic engagement report*. Washington, DC.
- Department of Energy. (2023). Advanced Reactor Demonstration Program Update. *U.S. DOE Office of Nuclear Energy*.
- Einhorn, R., & Nephew, R. (2021). *The future of the JCPOA: Options for the Biden administration*. Brookings Institution Press.
- Einhorn, R., & Nephew, R. (2021). *The Iran nuclear deal: A definitive guide*. Brookings Institution Press.
- ElBaradei, M. (2024). *The future of nuclear verification in an age of emerging technologies*. Vienna: International Atomic Energy Agency Press.
- Engelhardt, T. (2020). *The Doomsday Machine revisited: Crisis diplomacy in the nuclear era*. Routledge.
- Federation of American Scientists. (2024). *Status of world nuclear forces*. Retrieved July 2025.
- Finaud, M. (2021). *The limits of the NPT regime and the emergence of the TPNW*. Geneva Centre for Security Policy Briefs, 15, 1–9.
- Finaud, M., & Rauf, T. (2022). Political polarization and the limits of nuclear governance. *Journal of Nuclear Policy and Security Studies*, 14(3), 215–233.
- Findlay, T. (2022). *Nuclear safeguards, security and nonproliferation: The IAEA and global governance*. Routledge.

- Findlay, T. (2022). *Nuclear safeguards, security and nonproliferation: The IAEA and global governance*. Routledge.

- Fitzpatrick, M. (2019). *Nuclear apartheid: A structural analysis of the global nuclear order*. International Affairs Review, 14(3), 111–128.
- Fitzpatrick, M. (2022). *Nuclear programs in the Middle East: Strategic implications and regional dynamics*. International Institute for Strategic Studies.
- Freedman, L. (2019). *Nuclear strategy and the Cold War*. International Affairs, 95(1), 57–75.

- Freedman, L. (2019). *Nuclear strategy and the Cold War*. International Affairs, 95(1), 57–75.

- Freedman, L. (2019). *The evolution of nuclear strategy* (4th ed.). Palgrave Macmillan.

- Freedman, L. (2019). *The evolution of nuclear strategy* (4th ed.). Palgrave Macmillan.

- Freeman, L. (2023). *Russia's nuclear modernization and strategic messaging*. European Security Review, 12(3), 118–136.
- Futter, A. (2020). *The Cuban Missile Crisis: Past lessons and future challenges*. Journal of Strategic Studies, 43(5), 681–702.

- Futter, A. (2020). *The Cuban Missile Crisis: Past lessons and future challenges*. Journal of Strategic Studies, 43(5), 681–702.

- Futter, A. (2021). *Threats to global nuclear order: Disarmament, deterrence, and the future of nuclear weapons*. Georgetown University Press.
- Gaddis, J. L. (2021). *Strategies of containment: A critical appraisal of American national security policy during the Cold War* (3rd ed.). Oxford University Press.
- Gaddis, J. L. (2021). *The Cold War: A new history*. Penguin Books.
- Gordin, M. D. (2020). *Red cloud at dawn: Truman, Stalin, and the end of the atomic monopoly*. Princeton University Press.
- Gusterson, H. (2020). *Nuclear rites: A weapons laboratory at the end of the Cold War*. University of California Press.

- Gusterson, H. (2020). *Nuclear rites: A weapons laboratory at the end of the Cold War*. University of California Press.

- Hecht, G. (2021). *Being nuclear: Africans and the global uranium trade*. MIT Press.
- Heinonen, O., & Albright, D. (2023). *Iran's nuclear program and the risk of regional proliferation*. Institute for Science and International Security.
- Hoedl, E. (2020). Science diplomacy and nuclear energy: A cross-disciplinary challenge. *Bulletin of the Atomic Scientists, 76*(6), 267–273.
- Hoedl, S. (2020). *Post-Fukushima nuclear policy reforms: Safety systems and regulatory restructuring*. Journal of Energy and Environment, 12(3), 210–230.
- Horowitz, M. C., Allen, G., & Kania, E. (2021). The AI-Nuclear Nexus: Risks and Recommendations. *Brookings Institution*.
- IAEA. (2023). *Verification and regional cooperation in nuclear-weapon-free zones: Annual report 2022–2023*. International Atomic Energy Agency.
- International Atomic Energy Agency. (2018–2024). *IAEA Annual Reports*. Vienna: IAEA.
- International Atomic Energy Agency. (2022). *Technology roadmap for small modular reactor deployment*.
- International Atomic Energy Agency. (2024). *Incident and Trafficking Database (ITDB): 2024 Fact Sheet*. IAEA Publications.

- International Energy Agency. (2022). *World energy outlook 2022*.
- Jenkins, J. D., Luke, M., & Thernstrom, S. (2018). Getting to zero carbon emissions in the electric power sector. *Joule, 2*(12), 2498–2510.
- Jones, D., & Lee, M. (2024). *Extended deterrence and allied cohesion in East Asia*. Journal of Conflict and Security Law, 29(1), 1–20.
- Jones, D., & Lee, M. (2024). *Post-New START dialogue: Beyond bilateral arms control*. Journal of Conflict and Security Law, 29(1), 1–20. Kristensen, H. M., & Korda, M. (2024). *Chinese nuclear expansion and strategic implications*. Bulletin of the Atomic Scientists, 80(2), 104–117.
- Jones, D., & Lee, M. (2024). *Strategic stability and the New START Treaty: An assessment*. Journal of Conflict and Security Law, 29(1), 1–20.
- Jones, D., & Lee, M. (2024). *Strategic stability and the New START Treaty: An assessment*. Journal of Conflict and Security Law, 29(1), 1–20.
- Jones, E., & Lee, M. (2024). Membership and compliance trends in the IAEA regime. *Journal of Nonproliferation Studies, 15*(1), 23–47.
- Jones, K., & Patel, R. (2021). *Beyond INF: Missile defense and global power shifts*. International Security Quarterly, 39(4), 120–138.
- Kelley, R., & Doyle, J. (2023). Iran and the limits of verification: Lessons from JCPOA monitoring. *Nonproliferation Review*, 30(1), 45–62.
- Khan, F. H. (2022). *Pakistan's nuclear energy strategy and external partnerships*. South Asia Strategic Review, 14(1), 33–52.
- Kim, Y., & Tateno, S. (2021). *Nuclear plant operations and public trust after minor radiation incidents*. Journal of Risk Research, 24(6), 701–720.
- Kimball, D. (2022). North Korea's nuclear program and global nonproliferation. *Arms Control Today, 52*(4), 19–24.
- Kimball, D. (2023). IAEA inspections and proliferation threats: Trends and challenges. *International Security Review, 11*(3), 45–68.
- Kimball, D. (2023). *The future of arms control verification*. Arms Control Today, 53(4), 15–22.
- Kmentt, A. (2021). *The Treaty on the Prohibition of Nuclear Weapons: A commentary*. Journal of International Humanitarian Legal Studies, 12(2), 211–233.
- Korda, M., & Kristensen, H. M. (2025). Cyber threats to nuclear command-and-control systems: Assessing vulnerabilities. *Strategic Stability Quarterly*, 11(1), 77–94.
- Kristensen, H. M., & Korda, M. (2023). *Status of world nuclear forces*. Federation of American Scientists.
- Kristensen, H. M., & Korda, M. (2024). *Modernization of nuclear arsenals: Strategic implications*. Federation of American Scientists.
- Kristensen, H. M., & Korda, M. (2024). Nuclear notebook: World nuclear forces 2024. *Bulletin of the Atomic Scientists, 80*(3), 142–157.
- Kristensen, H. M., & Korda, M. (2024). *Nuclear notebook: Worldwide deployments of nuclear weapons*. Bulletin of the Atomic Scientists, 80(2), 75–88.
- Kristensen, H. M., & Korda, M. (2025). *North Korea's nuclear arsenal: Developments and assessments 2023–2025*. Bulletin of the Atomic Scientists, 81(1), 21–35.
- Kristensen, H. M., & Korda, M. (2025). *World nuclear forces: An overview of arsenals and disarmament efforts*. Bulletin of the Atomic Scientists, 81(2), 90–102.
- Kroenig, M. (2022). *The return of nuclear brinkmanship*. Foreign Policy Analysis, 18(2), 212–230.
- Kroenig, M. (2022). *The return of nuclear brinkmanship*. Foreign Policy Analysis, 18(2), 212–230.
- Kumar, V. (2021). *India-Pakistan nuclear dynamics: Thresholds and doctrines*. South Asian Security Review, 14(3), 88–107.
- Lee, J., & Zhao, W. (2023). *China's nuclear expansion and implications for arms dialogue*. Asian Strategic Review, 11(3), 145–162.
- Lee, P. (2020). *The ethical paradox of nuclear deterrence*. Ethics & International Affairs, 34(4), 427–439.
- Lee, Y., & Park, M. (2023). *Deterrence and signaling in the Korean peninsula crisis*. East Asian Security Review, 9(4), 201–218.
- Li, M., Pengsihua, H., Zhao, S., Wang, Z., Yang, L., & Liu, W. (2024). Fukushima nuclear wastewater discharge: An evolutionary game theory approach. *arXiv Preprint*, *arXiv:2402.07210*.
- Lyman, E. (2019). Small Isn't Always Beautiful: Safety, Security, and Cost Concerns about Small Modular Reactors. *Union of Concerned Scientists*.
- Mahmoud, A., & Petrov, I. (2024). Building capacity in nuclear governance: IAEA training and technical cooperation from 2019 to 2024. *Nuclear Safety and Security Review*, 7(2), 142–159.
- Mount, A., & Narang, V. (2022). North Korea's nuclear program and the collapse of international oversight. *International Security*, 47(1), 89–118.
- Mount, A., & Reif, K. (2022). *The TPNW and the challenge to nuclear order*. Nuclear Policy Papers, 46, 1–12.
- Narula, K., & Bhandari, R. (2022). *Generation IV nuclear power: Technical overview and prospects*. Nuclear Engineering and Technology, 54(5), 1323–1334.
- Nikitin, M. B. D. (2023). *Securing fissile material: Post-inspection audits and vulnerabilities in advanced nuclear states*. Congressional Research Service.

- Pabian, F. V. (2021). Nuclear apartheid and the NPT: A critical appraisal. *Journal of Strategic Studies, 44*(6), 911–930.
- Perez, A., & Wang, X. (2024). *Adaptive arms control: Toward multilateral frameworks in the technological age*. Journal of Strategic Policy, 9(1), 34–58.
- Perez, A., & Yamamoto, S. (2022). *Dual-use dilemma: Civilian nuclear technology and latent proliferation risk*. Journal of Nonproliferation Studies, 10(3), 210–230.
- Perez, F., & Yamamoto, S. (2022). Civil nuclear energy expansion and IAEA oversight. *Energy Policy and Governance Journal, 8*(2), 101–118.
- Perez, J. L., & Yamamoto, S. (2022). *Artificial intelligence and nuclear decision-making: Risks and resilience*. Journal of Strategic Studies, 45(6), 890–910.
- Potter, W. C., & Mukhatzhanova, G. (2018). *Nuclear politics and the non-proliferation regime*. Routledge.
- Rana, S., & Singh, A. (2023). *Battlefield nuclear forces and crisis stability in South Asia*. Conflict Management Studies, 5(1), 55–78.
- Rana, S., & Singh, A. (2023). *Strategic doctrines and force posture in South Asian context*. Conflict Management Studies, 5(1), 55–78.
- Revere, E. J. R. (2023). *Diplomacy and deterrence in dealing with North Korea's nuclear challenge*. Asia Policy, 18(2), 44–60.
- Revere, E. J. R. (2023). *North Korea's nuclear provocations and multilateral diplomacy: Lessons for the future*. Council on Foreign Relations.
- Rhodes, R. (2020). *The making of the atomic bomb*. Simon & Schuster.
- Sagan, S. D. (2018). The problem of nuclear order: Strategy, technology, and norms. *International Security, 43*(4), 9–52.
- Sagan, S. D. (2020). *The case for deterrence and against disarmament*. Foreign Affairs, 99(3), 45–52.
- Sarkar, A., Nayak, T. K., & Banerjee, S. (2021). Thorium fuel cycle: An Indian perspective. *Journal of Nuclear Materials, 555*, 153119.
- Sauer, T., & Reif, K. (2023). *Crisis communication in regional nuclear flashpoints*. Strategic Studies Quarterly, 17(1), 50–73.
- Sauer, T., & Reif, K. (2025). *Post-New START strategic frameworks for great-power cooperation*. Strategic Studies Quarterly, 18(1), 12–30.
- Schneider, M. B. (2023). *The October 2023 Strategic Commission report and U.S. nuclear weapons requirements*. National Institute for Public Policy.
- Shah, R., & Malik, P. (2024). *Nuclear ambiguity and escalation risk in South Asia*. Journal of Strategic Affairs, 11(2), 90–115.
- Sigal, L. V. (2020). *The Hanoi summit collapse: Lessons for future negotiations with North Korea*. Arms Control Today, 50(4), 8–14.
- Smith, J., & Ivanov, P. (2023). *New START implementation and inspection resumes*. International Arms Verification Review, 14(2), 33–53.
- Squire, I. (2022). Norm contestation between NPT and TPNW: A new normative order? *Global Governance Review, 9*(4), 321–339.
- Stockholm International Peace Research Institute. (2025). *SIPRI yearbook 2025: Armaments, disarmament and international security*. SIPRI.
- Suzuki, H., & Kim, D. (2022). *Extended deterrence policy: South Korea–US–Japan coordination*. Pacific Security Forum, 8(3), 45–62.
- Tabatabai, A. (2024). *Iran's nuclear diplomacy: Energy autonomy under scrutiny*. Middle East Policy, 31(2), 52–68.
  UN Office for Disarmament Affairs. (2023). *Alternative nuclear fuel frameworks and multilateral mechanisms*. UNODA Reports.
- Tabatabai, A. (2024). *The JCPOA after U.S. withdrawal: Strategic calculations and regional security*. Journal of Nuclear Policy and Strategy, 17(1), 34–49.
- Tabatabai, A. (2024). *Trust and verification: The limits of U.S.-Iran nuclear diplomacy*. Journal of International Affairs, 77(1), 99–122.
- Tan, Y., & Liu, C. (2024). *Missile deployments post-INF and Asian security dynamics*. Pacific Defense Analysis, 7(2), 88–106.
- Tannenwald, N. (2020). *Deterrence in the 21st century: Psychological, technological, and ethical challenges*. International Security, 44(4), 147–183.
- Tannenwald, N. (2020). The nuclear taboo at 75. *Foreign Affairs, 99*(6), 48–56.
- Tannenwald, N. (2020). *The UN GGE and norms for cyberspace: A nuclear stability perspective*. Global Security Studies, 12(3), 22–39.
- Tannenwald, N. (2023). The evolving role of the IAEA in the global nuclear order. *Global Governance Review*, 29(2), 101–125.
- Tannenwald, N. (2024). *Technology, cyber stability, and nuclear risk*. Global Security Policy Review, 13(1), 21–40.
- UN Office for Disarmament Affairs (UNODA). (2024). *Treaty status database*. Retrieved July 2025.
- UN Office for Disarmament Affairs. (2020). *Treaty of Pelindaba and regional disarmament efforts in Africa: Review and outlook*. United Nations Publications.
- UN Office for Disarmament Affairs. (2023). *Climate, instability, and nuclear risk: Emerging patterns in global hotspots*. UNODA Reports.
- UNODA. (2023). *Nuclear Non-Proliferation Treaty status and IAEA safeguards*. United Nations Office for Disarmament Affairs.

- UNODA. (2023). *Nuclear-Weapon-Free Zones: Status, verification, and future prospects*. UN Office for Disarmament Affairs.
- Vesterlund, J., & Hämäläinen, M. (2023). *Finland's Onkalo and the future of nuclear waste disposal*. Environmental Policy and Governance, 33(4), 297–308.
- Waltz, K. N., & Sagan, S. D. (2019). *Structure and deterrence : Theory and the reality of modern nuclear threats*. W. W. Norton & Company.
- Wang, Y., & Zhao, T. (2024). *China's nuclear force expansion in satellite imagery*. Journal of Contemporary Security, 8(2), 101–122.
- Wasil, A. R., Barnett, P., Gerovitch, M., Hauksson, R., Reed, T., & Miller, J. W. (2024). Governing dual-use technologies: Lessons for AI governance from nuclear and biosecurity agreements. *arXiv Preprint*, *arXiv:2409.02779*.
- Wasil, A. R., Barnett, P., Gerovitch, M., Hauksson, R., Reed, T., & Miller, J. W. (2024). Governing dual-use technologies: Lessons for AI and nuclear governance. *Science and Policy Journal, 12*(2), 225–249.
- Wasil, D., Chen, L., & Haddad, R. (2024). *Next-generation cyberweapons and the vulnerability of critical infrastructure*. Cybersecurity and Global Affairs Journal, 8(1), 44–61.
- Wasil, E., Chen, J., & Bhatt, D. (2024). *Cyber deterrence and nuclear stability in multipolar competition*. Cyber Policy Review, 6(1), 34–59.
- WNA. (2024). Small Modular Reactors: Global Developments and Deployment. *World Nuclear Association*.
- World Institute for Nuclear Security. (2023). *Best practices for insider threat mitigation and physical protection systems*.
- Zala, B. (2021). *Nuclear crisis management: Relearning the Cold War lessons*. Contemporary Security Policy, 42(3), 365–388.
- Zala, B., & Sauer, F. (2023). *CTBT and nuclear test norms: Strategic challenges*. International Affairs, 99(2), 210–230.
- Zala, B., & Sauer, F. (2023). *Nuclear terrorism: Assessing the evolving threat landscape*. RAND Corporation Policy Brief Series.
- Zala, B., & Sauer, T. (2023). *Multilateral arms control in a fractured global order*. Global Policy, 14(1), 79–92.
- Zala, B., & Sauer, T. (2023). The Treaty on the Prohibition of Nuclear Weapons: Normative progress or political distraction? *International Affairs, 99*(1), 123–139.
- Zhao, Q., & Liu, X. (2023). *China's nuclear exports and rise in energy diplomacy*. Asian Energy Journal, 19(2), 89–108.
- Zhao, T., & Tong, Z. (2023). *China's NFU doctrine under pressure: Stability implications*. Asian Defense Dialogues, 6(1), 29–47.