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THE JURISPRUDENCE OF THE ATOM: NAVIGATING THE LEGAL ARCHITECTURE OF CIVIL NUCLEAR ENERGY

~ *Abhiraj Verma*

ABSTRACT

This article analyses the complex legal architecture governing civil nuclear energy and its ongoing stress-testing by next-generation advanced designs like Small Modular Reactors (SMRs). Operating at the intersection of technological risk, sovereign grid security, and multi-generational ecological liabilities, nuclear jurisprudence relies on a delicate balance between absolute state sovereignty and mandatory global oversight.

The analysis unpacks the four international pillars established by the International Atomic Energy Agency (IAEA) Safety, Security, Safeguards, and Third-Party Liability explaining how strict liability and legal channeling protect the global supply chain while managing transboundary risk. At the domestic level, it traces the critical structural shift from rigid, prescriptive licensing toward technology-neutral, risk-informed frameworks.

Furthermore, the article addresses the statutory hurdles and contractual litigation surrounding back-end high-level radioactive waste storage, the unique jurisdictional conflicts introduced by transportable floating power plants, and the stringent export control matrices designed to prevent military proliferation. Finally, it highlights the expanding legal battlegrounds of Environmental Impact Assessments (EIAs) and Environmental Justice mandates.

The article concludes that the long-term viability of the global civil nuclear renaissance depends heavily on the structural harmonization and modernization of its international regulatory architecture.

INTRODUCTION

The global energy landscape is undergoing a profound structural transformation. Driven by the dual imperatives of mitigating climate change and securing baseline energy grids, nuclear power has re-emerged at the forefront of macroeconomic policy. However, the expansion of civil nuclear infrastructure is fundamentally distinct from any other industrial endeavour. It is bound by an intricate web of international treaties, overlapping domestic statutory frameworks, and unique tort principles that have evolved over more than seven decades.

Nuclear jurisprudence operates at the intersection of extreme technological risk, multi-generational ecological responsibilities, and volatile geopolitical realities. As the sector witnesses a shift from legacy gigawatt-scale Light Water Reactors (LWRs) toward next-generation advanced designs such as factory-fabricated Small Modular Reactors (SMRs), micro-reactors, and molten salt systems traditional legal frameworks are being severely tested. Analyzing the core legal issues governing nuclear energy requires an examination of the international regulatory pillars, civil liability regimes, domestic licensing innovations, the legal mechanics of the back-end fuel cycle, and the emerging challenges of cross-border technology commercialization.

THE QUADRIPARTITE PILLARS OF INTERNATIONAL NUCLEAR LAW

International nuclear law balances absolute state sovereignty with mandatory global oversight. The International Atomic Energy Agency (IAEA) serves as the normative epicenter of this architecture. According to the IAEA's foundational tenets, nuclear governance rests upon four interconnected legal pillars:

- **Safety:** Rooted in the *Convention on Nuclear Safety (CNS)*¹, this pillar establishes a peer-review mechanism where contracting parties must submit national reports demonstrating compliance with rigorous safety objectives. Because the IAEA lacks supranational enforcement powers to close non-compliant facilities, compliance is driven by international peer pressure and the incorporation of IAEA Safety Standards into domestic law.
- **Security:** Focused on preventing malicious human intent, the primary legal instrument is the *Convention on the Physical Protection of Nuclear Material*

¹ Convention on Nuclear Safety (CNS), adopted June 17, 1994, INFCIRC/449. The CNS peer-review mechanism requires contracting parties to submit national reports every three years to verify structural compliance with international safety norms.

(CPPNM). This framework binds states to secure nuclear materials during domestic use, storage, and transport, while criminalizing the sabotage of nuclear facilities.

- **Safeguards:** Operating under Article III of the *Treaty on the Non-Proliferation of Nuclear Weapons (NPT)*², states conclude bilateral Safeguards Agreements with the IAEA to verify that civil nuclear programs are not diverted to military applications. The *Additional Protocol* grants inspectors short-notice access to both declared and undeclared locations.
- **Liability:** Ensures financial compensation regimes are in place to address transboundary damages in the event of an industrial failure.

NUCLEAR THIRD-PARTY LIABILITY AND CIVIL COMPENSATION REGIMES

Traditional principles of negligence and fault-based liability are inadequate for handling the catastrophic, transboundary, and latent damages associated with a major nuclear accident. To provide commercial certainty to investors and ensure equitable recourse for victims, international law devised a highly structured regime based on specific doctrines.

Core Legal Principles

The international liability architecture is built upon three foundational legal doctrines:

1. **Strict Liability:** The operator of a nuclear facility is held legally responsible for any nuclear damage regardless of fault, negligence, or intent. Victims must only establish a causal link between the incident and the resulting damage.
2. **Legal Channelling:** All liability for nuclear damage is channeled exclusively to the operator of the installation. Even if the accident was caused by a defective component supplied by a third-party manufacturer, legal channelling prevents fragmented litigation and protects the global supply chain from crippling liability exposure.
3. **Congruent Financial Capitalization:** The operator is legally required to maintain continuous financial security typically through specialized nuclear insurance pools equal to the maximum liability limit established by domestic law.

The Fragmented Treaty System

² Statute of the International Atomic Energy Agency (IAEA), Article III.A.6. While the IAEA is authorized to establish safety standards, its publications function as "soft law" guidelines that are not strictly binding on member states unless expressly integrated into domestic legislation or during IAEA-assisted operations.

Despite the logical appeal of these principles, the global liability regime suffers from systemic legal fragmentation. The architecture is split across several competing international instruments, including the Paris Convention (1960)³, the Vienna Convention (1963)⁴, and the Convention on Supplementary Compensation (CSC) (1997)⁵.

DOMESTIC REGULATORY PARADIGMS AND THE BURDEN OF LICENSING

While international treaties establish the boundaries, the operational reality of nuclear energy is dictated by domestic administrative law. Nuclear licensing is arguably the most stringent and time-consuming regulatory process in the global industrial sector.

The Prescriptive Legacy vs. The Risk-Informed Shift

For decades, major nuclear jurisdictions like the United States Nuclear Regulatory Commission (NRC) operated under highly prescriptive regulatory models custom-built around large-scale Light Water Reactors. These regulations mandate explicit design parameters, including specific coolant chemistry, massive reinforced concrete containment structures, and rigid on-site staffing layouts.

However, as the industry shifts toward advanced reactor technologies, these prescriptive regulations have transformed into significant structural barriers to entry. Advanced concepts operate on entirely different physical principles, rendering rules tailored to large water-cooled cores obsolete. Consequently, major regulatory overhauls are underway globally to shift toward technology-neutral, risk-informed, and performance-based licensing.

A key example of this shift is the finalization of **10 CFR Part 53**⁶ by the US NRC. Part 53 provides an alternative, flexible pathway designed specifically for advanced reactors. Instead of forcing developers to comply with rigid engineering specifications, it allows applicants to prove safety by demonstrating that their specific technology maintains radiological doses below strict performance thresholds.

The Administrative Law and Litigation Battlefield

³ Paris Convention on Third Party Liability in the Field of Nuclear Energy, concluded July 29, 1960, under the auspices of the Organisation for Economic Co-operation and Development (OECD), as amended by the 2004 Protocol.

⁴ Vienna Convention on Civil Liability for Nuclear Damage, concluded May 21, 1963, 1063 U.N.T.S. 265, under the auspices of the IAEA, which targets a broader global geographic footprint.

⁵ Convention on Supplementary Compensation for Nuclear Damage (CSC), adopted September 12, 1997, entering into force on April 15, 2015. The CSC sets up an international fund to increase the total pool of financial compensation available for regional or transboundary nuclear damage

⁶ 10 CFR Part 53, Risk-Informed, Technology-Inclusive Regulatory Framework for Commercial Nuclear Plants, affirmed by the US NRC on March 25, 2026. This regulatory overhaul completely bypasses light-water reactor design prerequisites in favour of risk-informed safety goals

Nuclear licensing is also a battleground for administrative litigation. In many jurisdictions, the regulatory process grants broad rights to third-party intervention. Opponents can raise technical contentions, demand extensive evidentiary hearings, and file environmental lawsuits under statutes like the *National Environmental Policy Act (NEPA)*. While public participation is essential for democratic legitimacy, it creates a high-stakes legal environment where protracted litigation can delay projects for years, compounding capital costs and driving up financial risks for private investors.

THE BACK-END CYCLE: RADIOACTIVE WASTE AND DECOMMISSIONING LAW

A central legal challenge facing nuclear energy is the long-term management of high-level radioactive waste (HLW) and spent nuclear fuel (SNF). Under international customary law and domestic statutes, states bear the ultimate responsibility for the safe disposal of nuclear waste generated within their borders.

The Statutory Dilemma of Permanent Disposal

Most nuclear-producing nations have passed dedicated legislation, such as the *Nuclear Waste Policy Act (NWPA)*⁷ in the United States, which legally mandates the government to develop a permanent deep geological repository (DGR). Despite these statutory obligations, political gridlock, public opposition, and NIMBY ("Not In My Back Yard") dynamics have stalled permanent disposal programs in almost every nation except for a few trailblazers like Finland.

The failure of governments to fulfill their statutory duties to accept high-level waste has created significant contractual and litigation liabilities. In the US, utilities have successfully sued the Department of Energy (DOE) for breaching standard contracts to take possession of spent fuel. These lawsuits have resulted in billions of dollars in damages paid from the government's Judgment Fund to reimburse utilities for the ongoing costs of maintaining independent dry-cask storage installations on plant sites.

Decommissioning Liabilities and Trust Funds

⁷ Nuclear Waste Policy Act of 1982 (NWPA), 42 U.S.C. § 10101 et seq., legally establishing the US federal government's absolute statutory obligation to take title to and permanently dispose of high-level radioactive waste.

When a nuclear facility reaches the end of its operational lifespan, it enters the decommissioning phase complex legal and engineering process aimed at decontaminating the site to allow for unrestricted use. The primary legal issue here is ensuring that adequate funds are available decades in advance to cover these massive expenses.

Governments enforce this through strict *Decommissioning Trust Fund (DTF)* regulations. Operators must systematically set aside a fraction of ratepayer revenue into external, legally protected trusts. Legal conflicts frequently arise during the transfer of these funds when a plant is sold to specialized decommissioning companies. Regulators must carefully scrutinize these transactions to ensure that the acquiring entity possesses both the technical capability and sufficient financial reserves to complete the remediation without exposing the public to financial bailouts.

SMALL MODULAR REACTORS (SMRS): A DISRUPTIVE PARADIGM FOR NUCLEAR LAW

The commercialization of Small Modular Reactors (SMRs) and micro-reactors introduces a paradigm shift that challenges the fundamental assumptions of existing nuclear law. Traditional nuclear jurisprudence was built around stationary, monolithic facilities constructed entirely on-site over many years. SMRs, by contrast, rely on a business model of mass factory fabrication, standardization, and global transportability.

The Double-Licensing Conflict

Under current international frameworks, nuclear regulation is strictly territorial. A reactor design certified by the regulator of Country A holds no legal standing in Country B. For traditional large-scale projects, this local adaptation was manageable. For SMRs, however, requiring every importing nation to independently re-license a standard design destroys the economic benefits of mass production.

This friction has triggered intense pushback within international investment law and regulatory bodies. The industry is actively calling for **regulatory harmonization** framework akin to commercial aviation, where a design certified by a leading authority enjoys streamlined validation globally. Developing these frameworks requires addressing deep-seated sovereignty concerns, as domestic regulators are legally obligated to protect their public and are often hesitant to delegate safety determinations to foreign entities.

Transportable and Floating Power Plants

Certain SMR designs are transportable, including marine-based floating nuclear power plants (FNPPs). These installations present unique maritime law challenges:

- **Jurisdictional Ambiguity:** When a floating reactor operates in territorial waters or exclusive economic zones (EEZs), it triggers overlapping legal regimes under both the IAEA conventions and the *United Nations Convention on the Law of the Sea (UNCLOS)*.
- **Flag-State Responsibility:** If a floating reactor flagged under Country A operates in the waters of Country B, establishing legal clarity regarding regulatory oversight, emergency response liability, and physical security enforcement is an intricate challenge.
- **Fuel Leasing and Export Bans:** Many SMR deployment models rely on fuel-leasing agreements where the vendor nation retains ownership of the fuel and re-imports it upon depletion. This model frequently clashes with domestic environmental statutes that strictly ban the import or export of radioactive waste.

NUCLEAR ENERGY, TRADE LAW, AND GEOPOLITICAL EXPORT CONTROLS

Because civilian nuclear technology shares a dual-use relationship with military weapons programs, international trade in nuclear materials is governed by some of the strictest export control regimes in global commerce.

The Mechanics of 123 Agreements

At the state level, the commercial export of nuclear reactors and components requires a comprehensive legal framework of bilateral cooperation. In the United States, these are known as **Section 123 Agreements**⁸. A 123 Agreement is a legally binding prerequisite that commits the partner nation to strict non-proliferation standards, prohibiting the enrichment or reprocessing of transferred material without explicit prior consent.

Negotiating these agreements is a high-stakes legal exercise. Developing nations often view demands for a "gold standard" agreement where they explicitly renounce their sovereign rights to domestic enrichment and reprocessing as an encroachment on their autonomy.

⁸ Section 123 of the Atomic Energy Act of 1954, 42 U.S.C. § 2153, which mandates the structural boundaries of peaceful nuclear cooperation agreements, preventing the transfer of US nuclear material or technology without specific non-proliferation guarantees.

Consequently, states frequently navigate a complex choice between Western suppliers bound by stringent non-proliferation conditions and state-backed entities from nations like Russia or China, which may offer alternative bilateral financing structures.

The Role of Multilateral Export Control Regimes

Beyond bilateral treaties, nuclear commerce is governed by multilateral groups, primarily the *Nuclear Suppliers Group (NSG)* and the *Zangger Committee*. The NSG maintains comprehensive "Trigger Lists" of nuclear materials, equipment, and technology that require stringent export licenses and end-user verifications.

Violating these export controls carries severe legal consequences, including heavy corporate fines, criminal sanctions for executives, and complete exclusion from global financial markets. As advanced reactors increasingly incorporate novel materials, high-assay low-enriched uranium (HALEU), and digital control systems, the legal definitions of what constitutes controlled "dual-use" technology are constantly expanding, requiring continuous compliance oversight from technology developers.

ENVIRONMENTAL IMPACT ASSESSMENT AND PUBLIC CONSULTATION

No civil nuclear project can proceed without navigating the complex statutory processes of Environmental Impact Assessments (EIAs)⁹. These requirements, mandated by domestic laws like NEPA in the United States or the EIA Directive in the European Union, serve as the primary legal bridge between technical safety reviews and broader public interest considerations.

The Expanding Scope of Environmental Litigation

Historically, EIAs focused primarily on localized ecological effects, such as thermal pollution from cooling water discharge. However, modern environmental law has vastly expanded this scope. Today, an EIA for a nuclear facility must comprehensively analyse:

- **The Life-Cycle Carbon Footprint:** Quantifying emissions from uranium mining and fuel fabrication through construction, operations, and eventual decommissioning.

⁹ Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (Aarhus Convention), adopted June 25, 1998, binding signatory states to explicit standards regarding transparency, public hearings, and local administrative standing during infrastructure reviews.

- **Severe Accident Scenarios:** Evaluating the long-term, low-probability consequences of catastrophic failures, climate-induced extreme weather events, or malicious acts of sabotage.
- **Alternative Energy Analysis:** Documenting why alternative clean energy sources, such as solar or wind power, cannot fulfil the grid's demand for baseline power.

Because these analyses involve making predictions about complex systems over long periods, they are highly vulnerable to legal challenges from opposition groups. A single procedural error in how a regulatory agency reviews a complex environmental variable can result in a federal court overturning a project's license, delaying construction and exposing investors to substantial financial losses.

Environmental Justice and Consultation

Modern nuclear law emphasizes the principle of *Prior Informed Consent* and extensive public participation. International frameworks like the *Aarhus Convention* guarantee the public the right to access environmental information, participate in decision-making, and seek judicial review in environmental matters.

Furthermore, **Environmental Justice (EJ)** mandates have become central to the nuclear licensing process. Regulators are legally required to evaluate whether the siting of a nuclear facility, a fuel fabrication plant, or an interim waste storage site disproportionately impacts minority, low-income, or indigenous communities. Failing to properly manage these public consultation procedures and environmental justice evaluations creates profound legal and reputational risks that can derail a project even after it achieves technical safety certification.

CONCLUSION

Nuclear energy law stands at a critical historical crossroads. The foundational structures conceived in the mid-20th century built for centralized, state-backed, large-scale gigawatt reactors are becoming increasingly mismatched with the decentralized, private-sector driven deployment of advanced modular technologies.

To successfully unlock the potential of advanced nuclear energy as a cornerstone of the global clean energy transition, the international community must actively pursue deep structural reforms across three key areas:

1. **Accelerating Regulatory Harmonization:** Establishing mechanisms for mutual recognition of reactor design certifications among trusted national regulators to enable the mass production and global commercialization of SMRs.
2. **Unifying the Liability Framework:** Resolving the historical fragmentation between the Paris, Vienna, and CSC regimes to create a single, clear, and predictable global liability framework for transboundary and maritime nuclear installations.
3. **Resolving Back-End Statutory Liabilities:** Overcoming political gridlock to establish functioning permanent deep geological repositories, ensuring that the multi-generational responsibilities of nuclear waste are safely managed rather than passed down to future generations.

Ultimately, the future of nuclear energy will not be determined solely by breakthroughs in physics or engineering, but by the adaptability of its jurisprudence. Only by creating an agile, legally certain, and globally unified regulatory architecture can the international community safely and efficiently harness the power of the atom for a sustainable future.