U.S. Commercial Launches of Space Nuclear Systems – Insurance and Indemnification Considerations

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The U.S. commercial space launch sector is expanding rapidly. As interest grows in leveraging space nuclear systems (SNSs) to establish a permanent presence on the Moon and Mars, explore deep-space, harvest extraterrestrial resources, and otherwise unlock the multi-trillion dollar space economy, the industry is pressed to address unique insurance and indemnification challenges related to liability, potential for radioactive contamination, and other risks specific to launches of mission-enabling nuclear technologies and materials. Within this context, this study reviews the relevant law, regulations, technical literature, and government reports to describe the challenges and opportunities for U.S. commercial launches of SNSs.

I. BACKGROUND

I.A. U.S. Commercial Space Launch Trends

The U.S. commercial space launch landscape has evolved significantly over the past three decades, boasting 730 Federal Aviation Administration (FAA)-licensed launches by private sector providers from January 1989 through September 2024.[1] Based on FAA data, the history of U.S. commercial launches can be largely divided into three phases: (i) the "early years" from 1989 to 200l; (ii) a "moderate growth" phase from 2000 to 2010; and (iii) a "rapid expansion" phase from 2017 to present.

Between 1989 and 2000, U.S. commercial launches were limited, averaging 5 to 10 launches annually and peaking at 17 launches in 1997 and then 22 in 1998. This early period was dominated by established aerospace contractors such as Lockheed Martin and McDonnell Douglas, whose launch programs focused on deploying government and commercial satellites. The commercial space sector at this time could thus be described as nascent.

From 2000 to 2010, the frequency of commercial launches in the U.S. remained consistent and generally within 15 per year. In the background, future "big players" such as Blue Origin made their way to the scene, marking the start of the transition toward an era of greater commercial activity and private sector involvement in space. This period thus paved the way for the rapid growth of the U.S. space industry that ensued in the decades that followed.

The frequency of U.S. commercial space launches grew most notably from 2017 onward. Specifically, annual launches reached 23 in 2017, rose to 54 in 2021, continued to 79 in 2022, and reached 117 by 2023. As of late September 2024, there were 107 2024-year commercial launches from the U.S. This period's growth was primarily driven by SpaceX which leveraged reusable rocket technology with its Falcon 9 launch vehicle to become the most frequent launcher. Other significant contributors included Rocket Lab, which launched smaller payloads primarily for commercial and scientific research purposes, and United Launch Alliance (ULA), a joint venture between Boeing and Lockheed Martin.

By September 2024, SpaceX was responsible for 375 (nearly half) of the total 730 launches since 1989. This rapid scaling of commercial spaceflight activity, along with the continued growth of the overall U.S. commercial space industry, points to the critical role that commercial sector activity has and will continue to play in driving U.S. leadership and strategic advantages in space. They also suggest, as this paper will explore, the need for U.S. legal, regulatory, and policy frameworks designed to derisk and catalyze public-private sector development and launches of advanced space nuclear power and propulsion (SNPP) and SNS which will be critical to establishing permanent settlements on the Moon and Mars, powering deep-space exploration, and enabling other specialized missions and objectives of the future.

I.B. Space Nuclear Systems

In 2019, National Security Presidential Memorandum-20 on Launch of Spacecraft Containing Space Nuclear Systems (NSPM-20) established the U.S. policy to "develop and use space nuclear systems when such systems safely enable or enhance space exploration or operational capabilities."[2] SNSs include radioisotope power systems (RPSs) and fission reactors used for power and propulsion. Various fusion machine designs could also someday provide ample power and propulsion in extraterrestrial applications,[3] though they lie beyond the scope of this work.

RPSs can be further subdivided into radioisotope thermoelectric generators (RTGs) and radioisotope heater units (RHUs). Both RTGs and RHUs use plutonium-oxide (PuO_2) fuel with plutonium-238 (Pu-238) as the primary

isotope. RTGs convert heat generated by radioisotope decay into electricity and can provide reliable power and heat over long-duration missions with minimal post-deployment maintenance requirements.[4] To date, 11 multi-hundred watt (MHW) RTGs, 13 general purpose heat source (GPHS) RTGs, eight Space Nuclear Auxiliary Power-19 (SNAP-19) RTGS, and two SNAP-27 RTGs have collectively powered flyby, orbit, and landing missions to virtually every planet in the local Solar System, the Moon, the Kuiper Belt, and beyond.[5] Multi-mission radioisotope thermoelectric generators (MMRTGs) have enabled NASA's Curiosity and Perseverance rovers on the Martian surface and are fueled by 4.8 kilograms (kg) of PuO_2 fuel.[6] By contrast RHUs traditionally employ pencil eraser-sized fuel pellets to heat electronic and mechanical instruments.[7] To date, RHUs have enabled the Apollo 11 Moon landing and the Mars Sojourner, Spirit, and Opportunity rover missions.

Nuclear fission reactors stand to bring the advantages of terrestrial fission reactors to space colony or vessel contexts. In achieving criticality, fission reactors could conceivably provide stable, uninterrupted power production for long-duration, power-intensive missions. On the propulsion side, nuclear thermal rockets (NTRs) are being designed to utilize highly enriched uranium (HEU) or high-assay low-enriched uranium (HALEU) to vaporize hydrogen fuel to generate thrust. Cited advantages of NTRs include a roughly 10,000 times greater thrust-to-weight ratio and a two to five times greater specific impulse (I_{sp}) compared with in-space chemical propulsion.[8]

Also on the propulsion side, nuclear electric propulsion (NEP) systems incorporate a heat-generating nuclear reactor, thermal-to-electric power converters, and a primary power distributor in a power subsystem, as well as a secondary power distributor and power processing module for the thruster engines in a propulsion subsystem. With high exhaust velocity, high I_{sp}, and ability to generate a wide range of electric power, multimegawatt NEP systems stand to reduce propellant mass and shorten mission durations.[9]

I.C. Challenges Identified

Academic literature and government reports alike highlight the complex insurance challenges faced by the U.S. commercial space launch sector which affect operational costs, risk management, and market competitiveness before space nuclear systems are even added to launch or mission profiles. For example, the U.S. Department of Transportation (DOT) and FAA had noted that private insurance markets have limited capacity to cover high-liability space launch activities, which could drive up costs and place U.S.-based launch companies at a disadvantage compared with foreign competitors that enjoy unlimited government-backed coverage (i.e., indemnification).[10] Additionally, the Government Accountability Office (GAO) has noted that the FAA's Maximum Probable Loss (MPL) methodology has at times been outdated and yielded insurance requirements based on casualty and property damage estimates that did not reflect modern launch technologies and risks.[11] Outdated MPL methodologies can thus lead to sub-optimal insurance requirements, with operators potentially paying excessive premiums or being exposed considerable risks.[12] Other GAO reports and sources noted inadequate coverage options and requirements[13] as well as other regulatory oversight shortcomings[14] for non-launch activities such as spaceport operations.

There has also been considerable discourse on the challenges related to government indemnification and the payment of excess third-party liability claims in the space context. For example, the Commercial Space Launch Act of 1984 (CSLA)[15] indemnification sunset provision was critiqued for creating uncertainty about the long-term availability of financial protections beyond insurance and for complicating liability planning for operators competing with foreign counterparts who enjoy more stable, longer term indemnification frameworks.[16] Additionally, the requirement of Congress to provide appropriations in advance of catastrophic events created unpredictability about the availability of government support despite the fact that insurance companies had long assumed that the government would pay for losses that later become eligible under the CSLA regime.[17]

To that point, GAO had also noted that the U.S. regime's $1.5 billion (1998 USD, inflation adjusted; roughly $3.06 billion 2015 USD) indemnification cap may not sufficiently cover the growing volume of U.S. commercial launches and could also expose the U.S. government to increased financial liability during significant incidents.[18] And by not covering satellite relocation, space station docking, or other on-orbit operations, U.S. indemnification had left companies financially exposed during certain mission-critical phases.

With due consideration of all of the above, this paper therefore provides a review of relevant legal and regulatory authorities governing both commercial space launches and civil nuclear liability in the U.S. It then discusses potential insurance and government indemnification considerations for derisking and enabling commercial launches of SNSs in the U.S.

II. ANALYSIS

II.A. Legal and Regulatory Authorities

II. A. 1. U.N. Space Treaties

Five United Nations (U.N.) treaties on outer space form the core international space law framework. These treaties establish principles for peaceful uses, cooperation, and accountability among space-faring nations. In doing

so, they influenced the CSLA mandate that private space entities obtain government authorization and carry liability insurance in line with international standards for state responsibility.

The U.N. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies of 1967 ("Outer Space Treaty" or OST), signed by 109 countries (including the U.S. and the Soviet Union), went into effect on October 10, 1967. It establishes principles for the peaceful use of outer space, prohibits national appropriation of celestial bodies, and holds states accountable for their space activities. OST Article VI stipulates that treaty parties "shall bear international responsibility for national activities in outer space," applying to both governmental and non-governmental entities. OST Article VII imposes liability on each state for damage inflicted on other states or other states' citizens by the liable state's "object or…component parts on the Earth, in air space or in outer space…"[19]

The U.N. Convention on International Liability for Damage Caused by Space Objects of 1972 ("Liability Convention"), signed by 95 countries (including the U.S. and the Soviet Union), was adopted on March 29, 1972 and became effective on September 01, 1972. It establishes liability standards based on the location of damage incurred. For damage incurred on the Earth's surface or by aircraft in flight, Article II imposes "absolute liability" on the launching state which must then compensate affected parties regardless of fault. For damage incurred in space, Article III applies a fault-based liability standard requiring the claimant to prove that the damage was caused by negligence or wrongful acts of the launching state. Additionally, Article V allows joint and several liability among states involved in joint launches.[20]

Additionally, the U.N. Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space of 1968 ("Rescue Agreement"), signed by 98 states (including the U.S. and the Soviet Union), outlined obligations for state parties to rescue, assist, and promptly return another launching state's astronauts in distress or space objects.[21] Thereafter, the U.N. Convention on Registration of Objects Launched into Outer Space of 1976 ("Registration Convention"), signed by 71 countries (including the United States and the Soviet Union), established national and international space object registration requirements.[22] Finally, the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies of 1979 ("Moon Agreement"), signed by 18 countries (but neither the U.S. nor the Soviet Union), focused on equitable resource management on celestial bodies.[23]

While these latter three agreements encourage cooperation and transparency among space-faring nations, they address liability indirectly and to the extent that they complement the OST and Liability Convention.

II.A.2. The U.S. Commercial Space Launch Act Regime

In the United States, the Commercial Space Launch Act of 1984 (CSLA), 51 United States Code (U.S.C.) § 50901 et seq., as amended, was introduced by Senator Barry Goldwater (R-AZ) in the Senate and by Representative Dan Glickman (D-KS) in the House of Representatives. Signed into law by President Ronald Reagan on October 30, 1984, CSLA was enacted "to promote economic growth and entrepreneurial activity through the use of the space environment for peaceful purposes… " and to facilitate the safety and efficiency of the U.S. commercial space launch industry. CSLA assigns licensing authority to the FAA Office of Commercial Space Transportation (FAA/AST), which oversees mission compliance, safety, and regulatory standards for all non-governmental space launches. 51 U.S.C. § 50904(a) mandates, inter alia, that a person may not launch a launch vehicle or operate a launch site within the United States, or cause a launch or reentry outside the United States, without obtaining the licenses, authorizations, or permits required by the DOT.

CSLA also establishes a three-tiered liability risk sharing regime that is structured to support both operators and third parties in the event of a launch-related incident. Tier I of the regime requires licensees to "obtain liability insurance or demonstrate financial responsibility in amounts to compensate for the maximum probable loss…" associated with each launch. Using data and technical information related to the launch vehicle, payload, and other specific mission assets, the FAA calculates the MPL based on an assessment of potential damage scenarios involving third-party property, government property, and public safety. This MPL determination then informs the minimum insurance or financial assurance requirements for each launch or reentry to be licensed by the FAA. And such insurance or assurances must be able to cover up to $500 million in damages to third parties and up to $100 million in damages to government property arising from eligible claims involving licensed space activities.

Tier II of the CSLA liability risk sharing regime, allows the U.S. government to indemnify up to $1.5 billion (1988 USD, inflation adjusted) in damages for eligible third-party claims that exceed statutorily required insurance coverages. And Tier III of the regime holds licensees responsible for any liability above Tier II government-indemnified levels, placing final financial responsibility on launch providers.

Congress also enacted CSLA to encourage and regulate private sector space launches, reentries, and services while ensuring compliance with international obligations. It should thus catalyze private firm

compliance with domestic regulations and broader adherence to U.N. Liability Convention mandates (e.g., launch state liability for space activity-derived damages) and U.N. OST obligations (e.g., launch state authorization and supervision of domestic space activities).

Notably, the Commercial Space Launch Amendments Acts of 1988 and 2004 refined the CSLA framework to further support private sector involvement in space activities. Specifically, the Amendments Act of 1988 focused on streamlining the licensing process, enhancing safety regulations, and encouraging private sector investment,[24] while the Amendments Act of 2004 aimed at establishing a clear regulatory framework for commercial human spaceflight, encouraging innovation, and providing permits for novel human spaceflight.[25]

Furthermore, the U.S. Commercial Space Launch Competitiveness Act of 2015 (CSLCA) was enacted to encourage private sector investment and create more stable and predictable regulatory conditions for the U.S. commercial space industry.[26] CSLCA recognizes commercial actors' property rights in resources extracted from celestial bodies[27] and extended two provisions through the year 2023: (i) the U.S. government indemnification of third-party damages from commercial launch accidents to up to roughly $3 billion above MPL levels (which had yet to be invoked at the time); and (ii) the "learning period" designed to restrict the FAA's ability to enact regulations affecting the safety of spaceflight participants and allow industry to build up experience that could serve as the basis for subsequent regulations.[28] And most recently, the National Defense Authorization Act (NDAA) for fiscal year 2025 extends the aforementioned FAA learning period through December 2027 and the aforementioned indemnification through September 2028. (Ref. 29).

Given their role in furthering the CSLA legal framework, the CSLA Amendment Acts of 1998 and 2004, the CSLCA, and related NDAAs are invoked, in this paper and the broader literature, in assessments of the fundamental elements of the overarching "CSLA regime."

II.A.3. 14 C.F.R. Part 440 – Financial Responsibility

14 Code of Federal Regulations (C.F.R.) Part 440 ("Part 440") was enacted in part to implement CSLA and provide a regulatory framework for financial responsibility and risk-sharing in commercial space activities. Specifically, Part 440 was designed to ensure that (i) licensees obtain and maintain liability insurance or otherwise demonstrate financial ability to cover potential third-party and U.S. government damage claims; and (ii) those who might be adversely affected by licensed launch or reentry activities would be protected.[30]

§ 440.5 requires commercial space launch licensees to demonstrate sufficient financial wherewithal to cover third-party liability claims for both bodily injury and property damage. Licensees may do so by obtaining insurance or other financial guarantees to satisfy the FAA's required coverage limits, set by the FAA through the determination of MPL for each licensed activity as outlined in § 440.7. § 440.9 further specifies insurance requirements for licensed or permitted activities, specifying that insurance should meet or exceed the MPL. Additionally, § 440.11 provides that insurance coverage must begin at the start of licensed activities and continue through the completion of launch and reentry.

The regulations also establish a reciprocal waiver of claims framework in § 440.17, where launch parties, contractors, and the U.S. government waive claims against each other. And § 440.19 allows the U.S. government to indemnify up to $1.5 billion (1988 USD, inflation adjusted) in third-party claims exceeding statutory insurance requirements absent willful misconduct. Together, these insurance, indemnification, and waiver provisions function to limit risks to space-faring companies while prioritizing public health and safety and protecting public and private property.

II.A.4. The Price-Anderson Act

The Price-Anderson Nuclear Industries Indemnity Act of 1954 (PAA), 42 U.S.C. § 2210 et seq., as amended,[31] was introduced by Senator Clinton Anderson (D-NM) in the Senate and Representative Melvin Price (D-IL) in the House. It was signed into law by President Dwight Eisenhower on September 02, 1957 and with the purpose of encouraging private sector participation in the burgeoning nuclear power industry while ensuring both public compensation and the prompt, fair settlement of claims following nuclear incidents.

To do so, PAA requires nuclear reactor operators to carry insurance and contribute to an industry-wide pool to compensate for third-party claims, including bodily injury, sickness, disease, or death, and property damage, resulting from nuclear incidents. Beyond large, 100 megawatt-electric (MWe) or greater commercial-scale reactors, the modern PAA regime also covers less-than-100-MWe reactors operated by federal licensees and nonprofit institutions, small modular reactors (SMRs) and microreactors, plutonium processing plants, and fuel fabrication facilities. Moreover, the U.S. Nuclear Regulatory Commission (NRC) retains authority to expand PAA coverage to additional licensees who leverage distinct or novel nuclear technologies.

The PAA insurance structure outlined in 42 U.S.C. § 2210(b) and implemented under 10 C.F.R. Part 140 (Ref. 32) mandates that nuclear operators maintain a first tier of private ("primary") insurance coverage of up to $500 million per site. If damages exceed this limit, a second tier of ("secondary") insurance requires licensees to provide up to $158 million per reactor (i.e., the "maximum

deferred premium") through an industry-wide pool, making a total of roughly $15.012 billion available across all reactors.[21] Following a nuclear incident, each reactor operator may also be required to pay a pro rata share of damages above amounts available via first and second tier coverage, not to exceed 5% of the $158 million maximum deferred premium (e.g., approximately $7.9 million per reactor). This "retrospective premium" could thus potentially add up to $775.6 million to the PAA insurance pool. And collectively, the two PAA insurance tiers and retrospective premium make roughly $16.288 billion available for all 95 reactors in the PAA insurance pool.[33]

Additionally, PAA § 2210(c) allows the government to provide unlimited indemnification to NRC licensees operating in the U.S. for claims exceeding primary and secondary insurance. PAA § 2210(d) further authorizes the DOE to indemnify contractual activities involving nuclear materials outside of U.S. territory, historically covering liability for public damages up to $500 million per incident and including legal costs as approved by the Secretary of Energy. These indemnification provisions harmonize with the International Atomic Energy Agency (IAEA) nuclear liability framework and fundamentally enable the U.S. government to extend nuclear liability protections to space launches of nuclear material.

Since the PAA was enacted in 1957, 243 claims have been filed for alleged nuclear incidents, primarily through American Nuclear Insurers (ANI) policies, with a total of $522 million paid in insured losses.[34] Of these, the 1979 Three Mile Island (TMI) accident remains the costliest, resulting in $71 million paid (including $42 million in indemnity and $29 million in expenses). In April 2024, Congress extended the PAA through 2065, maintaining its primary and secondary insurance tiers and federal indemnification. The extension also increased the DOE's indemnification authority for incidents outside the United States from $500 million to $2 billion.[35]

As a tested liability risk-sharing framework designed to support industry growth while protecting public safety, the PAA model may provide useful insights for incorporating insurance and indemnification frameworks which balances potential public and private sector risks inherent in launches of nuclear payloads.

II.A.5. IAEA Convention on Supplementary Compensation

The IAEA Convention on Supplementary Compensation for Nuclear Damage (CSC) was signed on September 29, 1997, and entered force on April 15, 2015 (Ref. 36). The CSC was designed to harmonize nuclear liability laws globally and establish a uniform framework for compensation to third parties affected by nuclear incidents. It applies to operators within IAEA member countries who must provide compensation for third-party claims arising from incidents involving "nuclear installations" and the transport of nuclear material. It thereby complements the PAA by covering cross-border incidents and allowing additional accident compensation.

CSC Article III renders nuclear operators strictly liable for compensating third parties for personal injury or property damage resulting from nuclear incidents, regardless of fault. And similar to the PAA regime, the CSC establishes a tiered compensation framework for third-party claims. In Tier 1, nuclear operators are required to provide minimum liability coverage of 300 million Special Drawing Rights (SDRs) (approximately $415 million USD), funded through private insurance or financial guarantees. Resembling PAA primary insurance, this initial layer of protection compels operators have substantial financial resources to cover damages without immediate recourse to government or international funds.

If damages exceed Tier 1 coverage, CSC Tier 2 provides an avenue for additional compensation via government indemnification, financed by contributions by CSC member states to an international supplementary fund. These contributions are calculated based on each country's nuclear capacity and economic circumstances. Notably, certain types of incidents, such as those caused by acts of war, willful misconduct, or other specific causes, are explicitly excluded from CSC Tier 2 coverage.

Finally, like the PAA, CSC Article III channels economic liability exclusively to nuclear operators, holding them financially responsible while shielding suppliers, contractors, and other parties from liability.

II.B. Space and Nuclear Liability Insurance

II.B.1. Commercial Space Insurance

Specialized insurers provide coverage across the space industry: AXA XL, headquartered in Connecticut, offers pre-launch, launch, in-orbit, satellite contingency, and third-party liability coverage of satellites, launch vehicles, payload systems and other assets for satellite companies, launch providers, governments and institutions, and telecommunications and earth observation organizations. Munich Re, headquartered in Germany, insures both commercial and military satellite missions, covering risks related to the launch, commission, and in-orbit operation of communication and earth-observation satellites. Starr Aviation, based in New York, specializes in launch plus in-orbit risks, in-orbit coverage, satellite incentive coverage, launch risk guarantees, third-party liability, rocket engine testing, and general property. And Lloyd's of London, a major global insurance market, offers a broad range of customizable insurance options for missions, from crewed launches to deep-space projects.

Space insurance policies typically cover a range of assets throughout distinct mission phases: pre-launch, launch, in-orbit, and post-mission. Pre-launch insurance generally protects assets during manufacturing, testing, transportation, integration, and fueling. Launch insurance

usually covers failures and accidents during the launch phase, protecting against such risks as explosions and improper orbit insertion. In-orbit insurance typically safeguards assets, once in space, against component failures, debris collisions, and solar array damage. And third-party liability insurance generally addresses potential legal claims arising from damage to property or injury during launch or in-orbit operations.

Conventional space insurance policies thus may not fully cover the unique risks posed by commercial launches involving forthcoming SNPP systems, including potential radioactive contamination of both autonomous and crewed spacecraft. This underscores the need for tailored insurance to address these unique risks.

II.B.2. Civil Nuclear Liability Insurance

Nuclear liability insurance in the U.S. and internationally is offered by both national pools and mutual insurance associations. ANI, based in Connecticut, is the main U.S.-based third-party liability insurance provider whose coverages are designed to enable compliance with PAA requirements. ANI policies cover bodily injury, property damage, and environmental cleanup, with primary liability policies for nuclear operators and reinsurance options for other sectors.

Nuclear Electric Insurance Limited (NEIL), based in Delaware, offers coverage for property damage, decontamination, and lost revenue from electricity disruptions primarily at U.S. facilities. And European Mutual Association for Nuclear Insurance (EMANI) and European Liability Insurance for the Nuclear Industry (ELINI), both based in Belgium, offer similar mutual insurance structures abroad, covering property damage, decommissioning, liability, and terrorism risks for plant operators across Europe, North America, and elsewhere.

While the PAA and CSC liability frameworks require financial safeguards for terrestrial nuclear installations, it is unclear whether these would be suitable for SNS launches, orbits, in-space operations, or reentries. SNS-dependent missions present unique risks (e.g., source terms beyond national borders and in non-terrestrial environments) which the PAA and CSC do not fully address. Thus, while nuclear liability principles may serve as valuable references, applying them to the commercial space launch regime could require legal and regulatory reforms and novel arrangements among states and insurers for managing cross-border and in-space impacts.

II.C. Potential Government Indemnification

The U.S. government has historically provided indemnification for a range of activities critical to national interests. For example, the FAA War Risk Insurance Program under 49 U.S.C. Chapter 443 grants the FAA authority to provide insurance coverage for American civilian or government aircraft against losses from war or terrorism which are typically excluded from private policies.[37] Another historical example is the Civil Reserve Air Fleet (CRAF) Program, established under the authority of the Defense Production Act of 1950 (Ref. 38) and with support from Executive Order 10219 issued in 1951. Therein, the U.S. Department of Defense (DOD) and DOT established an indemnity agreement in which the FAA could extend premium-free war risk insurance to airlines performing missions for the DOD while the DOD would reimburse any insurance claim losses.[39]

Additionally, Public Law 85-804, enacted in 1958, authorizes the U.S. government to indemnify contractors engaged in high-risk national defense activities. It specifically grants the President authority to allow agencies such as the DOD and NASA to enter into contracts that protect private contractors from liabilities stemming from activities deemed essential to national security. It thereby allows contractors to be indemnified for unusually hazardous or nuclear-related activities that are not fully covered by private insurance.[40]

Public Law 85-804 primarily supports industries involved in missile development, space launches, and the handling of hazardous materials such as rocket propellants and chemical agents. Examples of its application include indemnification for both NASA space launch contractors and companies developing Anthrax vaccines or other bioterrorism countermeasures. Though the law is enabling on its face (e.g. fostering industry participation in defense-critical projects), it suffers from its limited scope (e.g., its strict application to defense-related projects) and complex approval process.

While each of the above are bring unique, risk-mitigating mechanisms to inherently risky public-private pursuits, none are necessarily or inherently suitable for U.S. commercial SNS launches. For example, existing PAA provisions were originally tailored to terrestrial, generally low-enriched uranium (LEU)-fueled, large (e.g. over 700 MW(e) capacity) light water reactors (LWRs), and even the most recently amended PAA sections may not clearly or directly be applicable to forthcoming SNS technologies of unique fuel (e.g., HEU or HALEU), design and capacity (e.g. kW-scale microreactors) or operational environment (e.g., vessels or colonies in interstellar space or on the surface of the Moon, Mars, or other celestial bodies) details. Moreover, while indemnification programs under the FAA's War Risk Insurance address risk-sharing for aviation, they do not cover specialized risks associated with nuclear propulsion in space. Furthermore, while Public Law 85-804 is designed to allow the indemnification of contractors performing defense-related hazardous activities, its scope could exclude exploration, resource extraction or other commercial space ventures which lack explicit links to defense-related objectives. All of this suggests the current space launch indemnification framework will be further

developed to ensure the ongoing safety, viability, and innovation of the U.S. commercial space launch industry.

III. CONCLUSIONS

The PAA two-tier insurance framework, combining mandatory private coverage with an industry-funded pool for catastrophic events, has bolstered the U.S. civil nuclear industry by addressing liability risks and enabling compensation without overburdening operators. Though it may not be directly applicable to commercial SNS launches due to technical and operational differences, the PAA model highlights the importance of nuclear technology-specific risk-sharing mechanisms.

Key SNS risks include radioactive contamination, criticality accidents, extended liability periods, and unique space hazards (e.g. micrometeoroid impacts) which are all generally excluded from space insurance. Filling these gaps through specialized coverage and cross waivers of liability could support the safe deployment of SNS. The previous literature had identified broad, insurance-related measures for enhancing risk management among launch sector participants which could feasibly aid in de-risking commercial launches of emerging SNS technologies. These include: (i) modernizing MPL methodologies and risk evaluation tools to reflect actual risks; (ii) allowing flexible, mission-specific coverage; (iii) requiring spaceport asset and non-launch activity coverage; (iv) creating industry-funded pools; and (v) offering tax incentives to offset insurance costs.

Regarding indemnification, under the PAA, government coverage of damages in excess of mandated insurance has been instrumental in addressing nuclear technology-inherent risks faced by NRC licensees and DOE contractors in the U.S. and abroad. Frameworks which similarly compel extensive indemnification of U.S. commercial space launches, perhaps akin to the unlimited indemnification historically provided by both spacefaring partners (e.g. France, Japan) and rivals (e.g. Russia, China), may offer the financial reassurances that both small-to-medium newcomers and established players might need to scale up commercial SNS launch activity.

Industry participants and regulators previously highlighted several potential modifications to the U.S. commercial space launch indemnification regime which could enhance public-private cooperation and reinforce U.S. leadership in space. These measures, which also stand to catalyze broader SNS integration into the commercial space launch regime, include: (i) raising or eliminating indemnification caps; (ii) extending indemnification to non-launch activities; (iii) eliminating or extending the indemnification sunset clause; and (iv) establishing a pre-allocated indemnification trust fund.

Modernizing commercial space launch insurance and indemnification frameworks to accommodate SNS technologies and materials could fill liability risk gaps and support U.S. leadership, competitiveness, and broader space industry growth. Establishing SNS-inclusive liability regimes, risk-sharing mechanisms, and other regulatory strategies aligned with international and industry best practices are among the key steps which will enable the U.S. public and private sectors to leverage nuclear technologies in groundbreaking future missions and fully unlock the multi-trillion-dollar space economy.

ACKNOWLEDGMENTS

The authors would like to thank Association of Commercial Space Professionals (ACSP) 2024 U.S. Space Nuclear Policy Summit organizers and participants and Pillsbury Winthrop Shaw Pittman LLP Nuclear Energy Partners Michael Lepre and William Fork for their constructive feedback which greatly aided this work.

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