JUNE 2025

Safeguarding a Nuclear Energy "Boom"

The IAEA's Needs by 2050

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About the Paper

This paper was commissioned by NTI to inform projects aimed at promoting the responsible scaling of nuclear energy. The views in this paper do not necessarily reflect those of NTI, its Board of Directors, or institutions with which they are associated.

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Contents

Acronyms and Abbreviations

ABACC	Argentine-Brazilian Agency for Accounting and Control
AP	Additional Protocol
ASHI	After-Service Health Insurance
ATSE	Academy of Technological Sciences and Engineering
CANDU	Canadian Deuterium Uranium Reactor
CFE	cost-free experts
COMPASS	Comprehensive Capacity-Building Initiative for SSACs and SRAs
CSA	Comprehensive Safeguards Agreement
D&IS	Development and Implementation Support
DIV	design information verification
DOE	U.S. Department of Energy
EDF	Electricité de France
EPGR	Encapsulation and Geological Repository
GAIN	Gateway for Accelerated Innovation in Nuclear
HALEU	high assay low-enriched uranium
HTGR	high-temperature gas-cooled reactors
IAEA	International Atomic Energy Agency
ILSA	Integrated Life Cycle Management of Safeguards Assets
IT	information technology
JCPOA	Joint Comprehensive Plan of Action
JPO	junior professional officer

KEPCO	Korea Electric Power Company
LOF	locations outside facilities
LWR	light water reactor
MOX	mixed oxide fuels
MSSP	Member State Support Programme
NHSI	Nuclear Harmonization and Standardization Initiative
NNWS	non–nuclear-weapon state
NPT	Treaty on the Non-Proliferation of Nuclear Weapons
NWS	nuclear-weapon state
OECD	Organisation for Economic Cooperation and Development
QMS	Quality Management System
R&D	research and development
RMP	Resource Mobilization Priorities
SLA	state-level safeguards approaches
SMR	small modular reactors
SQP	Small Quantities Protocol
SRA	state or regional authorities
SSAC	State System of Accounting and Control
TC	Technical Cooperation
TRISO	TRi-structural ISOtropic
UAE	United Arab Emirates
UNFCCC	UN Framework Convention on Climate Change
VOA	Voluntary Offer Agreements
WNA	World Nuclear Association
ZRG	Zero Real Growth

Executive Summary

The world is witnessing a wave of interest in nuclear energy. Many states are considering an increased role for nuclear energy to meet their electricity demands and combat climate change. For example, in December 2023, 25 states committed to tripling nuclear energy by 2050; in 2024, six more countries joined the pledge. Some experts doubt the feasibility of such an ambitious goal—but even if the effort is only partially successful, a nuclear energy footprint that is any larger will have implications for the International Atomic Energy Agency's (IAEA) mission of verifying that nuclear material and technologies are used exclusively for peaceful purposes.

Depending on how the expansion of nuclear energy programs unfolds across the globe, it could challenge the IAEA's ability to safeguard nuclear material and facilities. Uncertainty in both the type and amount of new nuclear builds limits the IAEA's ability to plan for increased demand. However, the current pace of deployment provides time for the IAEA to work with the international community to prepare for a surge in activity.

The burden on the IAEA will depend on both the type and location of future nuclear energy activity. New builds in nuclear-weapon states—where much of the current expansion is underway—are unlikely to seriously burden the IAEA because the agency has less responsibility in these countries. Expansion in non–nuclear-weapon states, especially those without an established nuclear industry, will be a heavier lift for the IAEA, which will need to develop and implement new safeguards approaches, particularly for small modular reactors (SMRs). Some SMR designs are essentially scaled-down versions of large light-water reactors that have been deployed since the dawn of the nuclear energy age, which could make them easier to build and safeguard. However, the IAEA may need to adapt new monitoring and accounting approaches for novel reactor and fuel types that pose different proliferation pathways.

Support from the international community will be necessary to help the IAEA absorb the additional tasks of a significant nuclear energy expansion. This support may take many shapes, including extra-budgetary funding, cost-free experts (or junior professional officers), R&D collaboration, or a newcomers fund for states planning new reactors to preemptively contribute to the IAEA's safeguards work in their country.

Even with reasonably accurate estimates of a nuclear energy expansion, assessing the corresponding needs of the IAEA by 2050 is fraught with uncertainty. Nevertheless, the IAEA needs to be ready to meet its member states' expectations and needs, and the agency must be afforded the resources to prepare for whatever scenario unfolds.

Introduction

Driven by rising demand for electricity and a dawning realization that climate change goals will be impossible to meet without rapid decarbonization of their economies, many states are considering or reconsidering nuclear energy for generating electricity and other peaceful uses.[1] Large-scale, multi-unit nuclear reactor projects are currently underway and planned in several states. In addition, there is burgeoning enthusiasm about the potential of small modular reactors (SMRs)—mass-produced, self-contained "off-the-shelf" units with supposedly multiple advantages over traditional large nuclear power plants.

The surge of interest in nuclear energy has been reflected in its increasing acceptance at international gatherings as an acceptable part of an energy mix capable of battling climate change, after long being marginalized by anti-nuclear sentiment. For the first time, nuclear energy was included in the Global Stocktake agreed at the Conference of the Parties (COP28) to the UN Framework Convention on Climate Change (UNFCCC) held in Dubai in December 2023.[2] Some participating states pledged to triple nuclear capacity worldwide, inviting the World Bank, regional development banks and international financial institutions to include nuclear in their lending policies.[3] In March 2024, the International Atomic Energy Agency (IAEA) and the government of Belgium co-hosted in Brussels the first Nuclear Energy Summit "to highlight the role of nuclear energy in addressing the global challenges to reduce the use of fossil fuels, enhance energy security and boost economic development."[4] The IAEA, under the leadership of Director General Rafael Grossi, has been increasingly active in promoting the link between nuclear energy and climate change. In November 2022, the IAEA launched its Atoms4Net Zero initiative to support efforts by its member states to "harness the power of nuclear energy in the transition to net zero."[5]

If such a vision for the future of nuclear energy eventuates, it implies a corresponding need for increased political, financial and technical support for the IAEA, which for almost 70 years has provided a global governance regime for the safe, secure, and non-proliferant uses of nuclear energy for peaceful purposes. The IAEA will be expected to assist and advise possible newcomers considering adopting nuclear energy; help those that decide to proceed in planning and implementing their programs; and contribute to ensuring that new

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1 Including desalination, heat production, and civilian ship propulsion.

2 Jeffrey Donovan, "Nuclear Energy Makes History as Final COP28 Agreement Calls for Faster Deployment," IAEA News Centre, December 13, 2023, https://www.iaea.org/newscenter/news/nuclear-energy-makes-history-as-final-cop28-agreement-calls-for-faster-deployment.

3 Donovan, "Nuclear Energy Makes History."

4 Nuclear Energy Summit 2024, Brussels, Belgium, March 21, 2024, https://www.iaea.org/events/nuclear-energy-summit-2024; for the pledge, see U.S. Department of Energy, "At COP28, Countries Launch Declaration to Triple Nuclear Energy Capacity by 2050, Recognizing the Key Role of Nuclear Energy in Reaching Net Zero," December 1, 2023, https://www.energy.gov/articles/cop28-countries-launch-declaration-triple-nuclear-energy-capacity-2050-recognizing-key.

5 IAEA, Atoms4NetZero, https://www.iaea.org/atoms4netzero.

facilities are held to the highest nuclear security and safety standards and recommendations. In addition, the IAEA will be legally obliged to apply nuclear safeguards to additional nuclear facilities in non-nuclear weapons states to verify that they are being used only for peaceful purposes and that such states are meeting their safeguards obligations. The IAEA's anticipated needs will encompass increased funding, additional personnel with new competencies, and advanced techniques and technology.

This paper focuses on the safeguards question. It seeks to identify the likely extent and pace of the deployment to 2050 of new nuclear power reactors of all types and the resulting requirements of the IAEA to successfully apply safeguards in such circumstances. It also considers other potential increased demands on safeguards resources, such as those resulting from the expected mass decommissioning of older generations of power reactors and the construction of additional nuclear fuel cycle facilities, including those needed for the growing requirement for long-term disposal of nuclear spent fuel and waste. This report will not consider research reactors, microreactors, or nuclear fusion. Faced with great uncertainties about the likely course of any nuclear boom, this report does not seek to provide cost estimates for safeguards for the coming decades (even the IAEA Secretariat is unable to do that) but rather outlines potential trends and their likely resource implications.

Projecting Trends in Nuclear Energy Use to 2050

The pace of growth in the deployment of nuclear power reactors has historically been notoriously difficult to predict. From Eisenhower-era prognostications that nuclear power would be too cheap to meter, to flamboyant projections of a "nuclear renaissance" in the early 2000s, to the current euphoria over SMRs, successive waves of expectations have fallen flat. An IAEA press release in August 2024 spoke of "the emergence of a new global consensus to accelerate the deployment of nuclear energy."[6] In fact, a consensus is far from emerging. Only 25 of the 198 UNFCCC states parties pledged at COP28 to triple global nuclear power capacity by 2050.[7] Six more states joined at COP29 in Baku, Azerbaijan, in 2024.[8]

Fulfilling the pledge would require significant industrial mobilization, not to mention incurring the opportunity costs of not investing in cheaper alternative energy sources, which were also pledged at COP28.[9] The nuclear pledgers themselves underscored the challenge of establishing "secure supply chains to ramp up deployment of the technology."[10] The initiator of the pledge, the United States, currently the world's largest producer of nuclear power, is unlikely to be able to triple its own capacity by 2050. The U.S. Department of Energy (DOE) concedes that a major barrier to an American nuclear "commercial liftoff" is a lack of "nuclear and megaproject delivery infrastructure," along with inconsistent compensation for nuclear electricity and project cost overruns.[11] Likely the most expensive such plant ever constructed, the two-unit Vogtle facility in Georgia in the United States, commenced operations in 2023, US$17 billion over budget and seven years over

[6] Marta Maria Gospodarczyk, "IAEA Releases Nuclear Power Data and Operating Experience for 2023," August 20, 2024, https://www.iaea.org/newscenter/news/iaea-releases-nuclear-power-data-and-operating-experience-for-2023.

[7] U.S. Department of Energy (DOE), "At COP28, Countries Launch Declaration to Triple Nuclear Energy Capacity."

[8] World Nuclear Association News, "Six More Countries Endorse the Declaration to Triple Nuclear Energy by 2050," November 14, 2024, https://world-nuclear.org/news-and-media/press-statements/six-more-countries-endorse-the-declaration-to-triple-nuclear-energy-by-2050-at-cop29.

[9] The Agency has estimated that to reach IAEA high-case projections (950 gigawatts (GW) by 2050, scaling of 2.5 compared to today), the grid connection rates need to increase from an average of 5–6 GW per year to about 25 GW per year. In 1984 and 1985, the grid connection rates were more than 30 GW per year.

[10] U.S. Department of Energy, "At COP28, Countries Launch Declaration to Triple Nuclear Energy Capacity." The 31 current pledgers are: Armenia, Bulgaria, Canada, Croatia, Czechia, El Salvador, Finland, France, Ghana, Hungary, Jamaica, Japan, Kazakhstan, Kenya, Kosovo, Moldova, Mongolia, Morocco, Netherlands, Nigeria, Poland, Romania, South Korea, Slovakia, Slovenia, Sweden, Turkey, Ukraine, the UAE, the United Kingdom, and the United States. Russia and China, major nuclear users, declined to join. Also missing are Egypt and Bangladesh, both currently building substantial new nuclear facilities.

[11] U.S. Department of Energy, "Advanced Nuclear Pathways to Commercial Liftoff: Report Update," Summary Presentation, September 2024, https://liftoff.energy.gov/wp-content/uploads/2024/09/Nuclear-Liftoff-Update-Summary-Presentation.pdf. The DOE has suggested that a total of 200 GW of new nuclear energy would be needed by the United States by 2050 to help it achieve net zero carbon emissions.

schedule at a total construction and finance cost of US$35 billion.[12] The DOE argues that costs will fall in subsequent projects due to a learning process from such first-of-a-kind facilities. The cost of constructing reactors in low-labor cost markets, like the United Arab Emirates (UAE), is also considerably smaller. States with authoritarian governments are able to subsidize nuclear energy, including defraying construction costs.

China, which did not join the COP28 pledge, is likely to be the only country able to triple its national capacity by 2050. At the other end of the scale, it is unclear what pledgers like El Salvador, Ghana, Jamaica, Mongolia, and Morocco—which currently have no nuclear power at all—could contribute to the tripling of global nuclear by 2050. Currently the World Nuclear Association (WNA), a nuclear industry promotion body, lists about 30 countries that are, in its view, considering, planning, or starting nuclear power programs.[13] The IAEA projects the same number.[14] In examining individual states' track records, the realization of such plans, as in the past, is far from certain. Although some newcomers are likely to realize their nuclear ambitions, a large number of states that express interest in acquiring nuclear power plants (some of them repeatedly for decades, like Indonesia) will never do so.

In addition to "irrational exuberance" on the part of governments, industry, and nuclear advocates, multiple factors contribute to the challenge of projecting nuclear power growth. These include:

- **Politics.** Nuclear projects have such long lead-times that politics, whether in the form of changing public opinion or changes in government, may intervene to change, delay, or cancel projects.
- **Costs.** Nuclear projects, at least in highly regulated Western states, face construction cost overruns (often major) and scheduling delays (often for years), sometimes leading to outright cancelations.
- **Competition.** Other forms of electricity generation and storage, when costs are rapidly falling, as currently the case with solar and wind, may render the economic case for nuclear, especially in market economies, tenuous.
- **New Technologies.** Those already foreseen in the current era, such as green hydrogen and fusion, promise further uncertainty.
- **Nuclear Events.** A major nuclear event such as Chernobyl or Fukushima can lead to overnight reconsideration and scrapping of nuclear plans.

The current volatility in the international situation makes predictions even more hazardous. Whether inadvertent or deliberate, a radioactivity-releasing attack on Ukraine's besieged Zaporizhzhia nuclear complex or on Russia's Kursk plant would instantly dampen public support for nuclear energy by reminding everyone of its hazards. Even without such an attack, the reminder that nuclear power plants can be military targets (as they have been in the past, in Iran, Iraq, and Syria) cannot help the case of nuclear advocates.

Although the past is not necessarily a guide to the future, the recent history of nuclear energy, despite the heralded "nuclear renaissance" of the early 2000s and more recent post-Fukushima "revival," is sobering. The 2023 edition of Mycle Schneider's annual World Nuclear Industry report, which always errs on the side of skepticism, portrays an industry in relative decline. It notes that as of mid-2023 (the latest period for which figures were available), there were 407 reactors worldwide, four fewer than a year earlier and 31 below the 2002 peak of 438.[15] In 2022, seven units were connected to the grid and five were closed. Four new reactors started up in the first half of 2023 and five were closed. Schneider notes that over the two decades from 2002 to 2023, there were 99 start-ups and 105 closures worldwide. Longtime nuclear industry observer Stephanie Cooke, in her introduction to the report, notes that the global nuclear industry,

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[12] Jeff Amy, "Georgia Nuclear Rebirth Arrives 7 Years Late and $17 B Over Cost," May 25, 2023, https://apnews.com/article/georgia-nuclear-power-plant-vogtle-rates-costs-75c7a413cda3935dd551be9115e88a64.

[13] World Nuclear Association, "Emerging Nuclear Energy Countries," https://world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.

[14] IAEA News Center, "IAEA Outlook for Nuclear Power Increases for Fourth Straight Year, Adding to Global Momentum for Nuclear Expansion," Press release 87/2024, Vienna, September 16, 2024.

[15] Mycle Schneider et al., *The World Nuclear Industry Status Report 2023* (Paris, March 2024), p. 20, https://www.worldnuclearreport.org/IMG/pdf/wnisr2023-v5.pdf.

despite the "immense" changes that have occurred since the Fukushima disaster, remains in its broader characteristics much as it was then, "opaque when it comes to costs and timetables, prone to wildly inflated growth forecasts, and stubbornly fighting the rapid growth in renewables, although the gaps between the two in terms of growth, cost and performance widen by the year."[16]

Nonetheless, despite all these uncertainties, in order to make some reasonable estimates of IAEA requirements to safeguard a growing global nuclear enterprise, it is necessary to make informed calculations (or at best guesstimates). One solution widely adopted is to make high, moderate, and low estimates, but even these provide only a rough guide. This paper references the IAEA's official estimates. It also takes into account analysis by the WNA and independent outside observers, notably Schneider and associates' annual World Nuclear Industry report.[17]

The IAEA's most recent report, *Energy, Electricity and Nuclear Power Estimates for the Period up to 2050,* released in September 2024, presents low and high cases, "encompassing the uncertainties inherent in projecting trends."[18] It relies on reporting by member states and its own in-house analysis.[19] The methodology involves a "bottom up" approach that considers "all operating reactors, possible license renewals, planned shutdowns and plausible construction projects foreseen for the next several decades."[20] The study concludes that:

> Relative to a global nuclear operational capacity of 372 GW(e) [gigawatt electric] at the end of 2023, the low case projects an increase of about 40% to 514 GW(e) by 2050. In the high case global nuclear operational capacity is projected to increase to 2.5 times the current capacity, reaching 950 GW(e) by 2050.[21]

The report estimates that SMRs would account for 24 percent of the capacity added by 2050 in the high case and for 6 percent in the low case.[22] An IAEA press release announced: "IAEA outlook for nuclear power increases for fourth straight year, adding to global momentum for nuclear expansion." The report itself cautions, however, that its estimates "are not intended to be predictive nor to reflect the whole range of possible futures from the lowest to the highest feasible."[23]

The IAEA's assumptions for the low case, "which was designed to produce a 'conservative but plausible'" set of projections, are instructive: "current technology and resource trends continue and there are few additional changes in explicit laws, policies and regulations affecting nuclear power." Additionally, the IAEA's low case does not assume that targets for nuclear power in a particular country, which are provided to the IAEA by the state concerned, will "necessarily be achieved." The high case, on the other hand, is "much more ambitious but in the IAEA Secretariat's judgement still plausible and technically feasible." National policies on climate change, which are increasingly seen as driving energy policies, are factored into the high case, but apparently not in the low case.

In either case it is difficult for external observers to estimate how the projected increases in GW(e) translate into numbers and types of new reactors and the likely increased demand for the application

16 Stephanie Cooke, "Foreword" in *The World Nuclear Industry Status Report 2023,* Schneider (Paris, March 2024), p. 1.

17 Schneider et al., *The World Nuclear Industry Status Report 2023.*

18 IAEA, *Energy, Electricity and Nuclear Power Estimates for the Period up to 2050,* Reference Data Series no. 1, 2024 ed. (Vienna: IAEA, 2024), p. 2.

19 Statistical data is to the end of 2023, collected by the IAEA's Power Reactor Information System (PRIS), in addition to estimates of external experts involved in the IAEA's annual Consultancy Meeting on Nuclear Capacity Projections up to 2050; national projections supplied by countries for the Nuclear Energy Agency (NEA) of the Organisation for Economic Cooperation and Development (OECD); and IAEA publications on uranium resources, production, and demand through 2040.

20 "Uprates," increased electricity production by existing reactors, were also considered in the projections.

21 IAEA, *Energy, Electricity and Nuclear Power Estimates for the Period up to 2050,* 2024, p. 1.

22 IAEA, *Energy, Electricity and Nuclear Power Estimates,* p. 1.

23 IAEA News Center, "IAEA Outlook for Nuclear Power Increases."

of IAEA safeguards.[24] Such uncertainties obviously complicate the IAEA's planning for its future safeguards needs.

Small Modular Reactors: A Future Wave or a Trickle?

One reason for the current optimism about the future of nuclear energy globally lies in the promise of SMRs, defined by the IAEA as "advanced reactors that produce electricity of up to 300 MW(e) [megawatts electric] per module."[25] Under the heading "flexible and affordable power generation," the IAEA describes such reactors as having "advanced engineered features, are deployable either as a single or multi-module plant, and are designed to be built in factories and shipped to utilities for installation as demand arises."[26] A key advantage identified is that large nuclear plants have become so expensive as to "place them beyond the reach of all but the richest nations working hand-in-hand with large state-backed engineering firms."[27]

Some SMR designs are based on traditional reactor technology and thus pose relatively few technical (and by implication safeguards) challenges. Cindy Vestergaard observes that "Many next-generation SMRs are essentially shrunken versions (up to 300 MW) of water-cooled reactors and use the same fuel."[28] Other designs, however, sometimes collectively known as "Advanced Modular Reactors (AMR),"[29] envisage new concepts. These include high-temperature gas-cooled reactors (HTGR), liquid metal, sodium and gas-cooled fast neutron spectrum reactors, and molten salt reactors.[30]

The IAEA's own survey identifies more than 90 SMR designs and concepts globally, most of them still at various stages of development, with some claimed to be "near-term deployable."[31] Leading developers are in Argentina, Canada, China, Denmark, France, Russia, the United Kingdom, and the United States. Several are proceeding through regulatory approval and licensing processes, notably in Canada, the United Kingdom, and the United States. The WNA currently lists 18 designs of "small nuclear reactors" as being in "near term deployment—development well advanced."[32] However, the list misleadingly toggles between SMRs and "small nuclear reactors" in its calculations, without identifying those that are potentially modular, a key feature of SMRs that may not be replicable in all designs.[33]

What is certain is that currently only China and Russia have operating SMRs (one each) connected to the electricity grid. Russia's is on a floating barge, the *Akademik Lomonosov,* docked in Siberia since 2019.[34] China's prototype 200 MW(e) HTGR was

[24] IAEA internal projections contain country data projections with different types of reactors, but only aggregated data per region are published.

[25] IAEA, "Small Modular Reactors," https://www.iaea.org/topics/small-modular-reactors. The IAEA also recognizes a sub-category of SMRs called micro-modular reactors, with electrical power typically up to 10 MW(e); medium-size reactors are defined as those between 300 and 700 MW(e).

[26] IAEA, "Small Modular Reactors."

[27] IAEA, "Small Modular Reactors."

[28] Cindy Vestergaard, "Disruption and the Nuclear Industry: The New Era of Nuclear Energy," Issue Brief, Stimson Center, Washington DC, September 3, 2024.

[29] See Ross Peel, George Foster, and Sukesh Aghara, "Nuclear Security and Safeguards Considerations for Novel Advanced Reactors," Centre for Science & Security Studies, King's College London, 2022, p. 1.

[30] IAEA, *Advances in Small Modular Reactor Development,* 2020 Edition, Vienna, 2020, p. 1, https://aris.iaea.org/Publications/SMR_Book_2020.pdf.

[31] See list of over 70 in IAEA, *Advances in Small Modular Reactor Development,* p. 2.

[32] Small Nuclear Power Reactors, February 16, 2024, https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors, pp. 20–21.

[33] Its world map of SMRs has a confusing legend that at first glance suggests that multiple SMRs are connected to a grid (see Small Modular Reactor Global Map, https://world-nuclear.org/information-library/current-and-future-generation/small-modular-reactor-smr-global-map, p. 5). It also suggests that a Chinese SMR is connected, contrary to a claim by the Australian Academy of Technological Sciences & Engineering (ATSE) that none of the reactors classified as SMRs in China are intended for commercial production (see ATSE reference below).

[34] IAEA, *Advances in Small Modular Reactor Development,* p. 1.

connected to the grid in 2021.[35] Four SMRs are reportedly in advanced stages of construction–in Argentina, China, and Russia–all of them prototypes, not necessarily fated to be connected to an electricity grid. Several countries have signed memoranda of understanding with private and state-owned energy companies to study possible deployment of SMRs, including Poland, Romania, Saudi Arabia, Ukraine, and the UAE, but with "appropriate caveats on timing, performance and cost."[36] Not a week seems to pass without another country announcing an interest in SMRs, including such unlikely candidates as Bolivia, Cambodia, Guinea, Myanmar, Rwanda, Sudan, and Uganda. Some states are investigating floating reactors or the use of SMRs to power ships, whether civilian or military.[37] This author has personally witnessed great excitement on the part of almost all Southeast Asian countries, mostly after extensive promotion tours by U.S. company NuScale Power Corp., which invites visitors to its website to "Explore the immense potential of SMRs to revolutionize our energy future."[38]

Despite all the hyperbole surrounding SMRs, it is prudent to be skeptical about many of the claims, especially the economics, before these are conclusively demonstrated. As the Australian Academy of Technological Sciences and Engineering (ATSE) soberly noted in its July 2024 report on the potential for Australia to acquire SMRs, "project costs and performance attributes could only be accurately demonstrated once full-scale prototype SMRs are built."[39] Even the cost of building a prototype SMR, according to ATSE, is "speculative and will not be known until the market matures." Although an individual SMR will certainly be cheaper than a large conventional nuclear power plant, it remains to be demonstrated whether serial deployment of SMRs will amount to a saving. An analysis by the Ohio-based nonpartisan Institute for Energy Economics and Financial Analysis has calculated that the typical Australian household could see its annual electricity bill rise on average by AUD665 (US$447) as a result of the Australian Opposition's plans to introduce nuclear energy at seven current coal-fired plant sites around the country (it remains unclear whether these would be large-scale reactors or SMRs).[40]

American, and by extension global, hopes for an SMR-led nuclear revival suffered a significant blow in 2023 when NuScale, the first new nuclear company to obtain a design certificate from the U.S. Nuclear Regulatory Commission, lost its only firm utility customer, the Utah Associated Municipal Power System. The heavily government-subsidized project aimed to have six reactors generating a combined 462 MW(e) by 2030.[41] However, there was insufficient interest from utilities across several mid-western states to make the project financially viable, especially after the company raised the target price of its electricity to US$89/MWh from a previous estimate of US$58/MWh.[42]

The barriers to an SMR-led nuclear revival appear formidable. After witnessing the SMR & Advanced Reactor 2022 event in Atlanta, Georgia, Markku Lehtonen concluded that:[43]

35 WNA, Nuclear Reactor Database, https://world-nuclear.org/nuclear-reactor-database/details/SHIDAO%20BAY-1.

36 ATSE, "Small Modular Reactors: The Technology and Australian Context Explained," ATSE Report, Canberra, July 2024, https://www.atse.org.au/media/yxpma4xl/atse-small-modular-reactors-240722.pdfATSE, p. 5.

37 The American Bureau of Shipping (ABS) and the Korea Ship & Offshore Plant Research Institute (KRISO) are collaborating to advance the commercialization of SMR-powered ships and floating SMR platforms. "Korean, US Exploring Partnership to Study Maritime SMRs." *Nuclear News & Views,* July 22, 2024.

38 "Exploring SMRs," https://www.nuscalepower.com/en/exploring-smrs.

39 ATSE, "Small Modular Reactors," p. 3.

40 Johanna Bowyer and Tristan Edis, "Nuclear in Australia Would Increase Household Power Bills," Institute for Energy Economics and Financial Analysis, September 2024.

41 Adam Duckett, "NuScale Cancels First Planned SMR Nuclear Project due to Lack of Interest," *The Chemical Engineer,* November 27, 2023, https://www.thechemicalengineer.com/news/nuscale-cancels-first-planned-smr-nuclear-project-due-to-lack-of-interest/.

42 Paul Day, "Cancelled NuScale Contract Weighs Heavy on New Nuclear," Reuters, January 10, 2024, https://www.reuters.com/business/energy/cancelled-nuscale-contract-weighs-heavy-new-nuclear-2024-01-10/.

43 Markku Lehtonen, "Building Promises of Small Modular Reactors–One Conference at a Time," *Bulletin of the Atomic Scientists,* December 22, 2024.

> To turn SMR promises into reality, the nuclear community will need no less than to achieve sufficient internal cohesion, attract investors, navigate through licensing processes, build up supply chains and factories for module manufacturing, win community acceptance on greenfield sites, demonstrate a workable solution to waste management, and reach a rate of deployment sufficient to trigger learning and generate economies of replication.

ATSE estimates that commercial releases of SMRs (at least in member states of the Organisation for Economic Cooperation and Development (OECD)) could commence only by the late 2030s to mid-2040s, with a mature market likely arriving in the mid to late 2040s, depending on the usual caveats of regulatory approvals, investment and resource allocation.[44] The European Union's European Industrial Alliance for SMRs, in contrast, hopes to "facilitate and accelerate the development, demonstration, and deployment" of SMRs in European states by the early 2030s, just five years away.[45] Kings College London researchers expect that SMR deployments based on "evolutionary" technology derived from traditional large nuclear power plants (essentially small light water reactors (LWRs)) will "accelerate within the next ten years."[46] Advanced modular reactors, they expect, will not be deployed "at grid scale" for at least 20 years–the 2040s. In the meantime, some information technology companies like Microsoft and Apple may satisfy their voracious energy needs by building dedicated nuclear power plants, including SMRs, or resuscitating closed traditional plants, although innovation is likely to lower their electricity requirements over time.

Developments could proceed faster in non-OECD countries with a higher tolerance for public subsidies and fewer regulatory barriers, like China and Russia, and wealthy Middle Eastern states like Saudi Arabia. Exports to other countries by China and Russia, supported by generous financial terms, may follow. However, even if all these cases eventuate, it is likely to be an SMR trickle rather than a flood by the 2030s. By 2050, if the technology proves itself, there could be a more sustained, but today incalculable, deployment of SMRs.

44 ATSE, "Small Modular Reactors," p. 3.

45 European Commission, "European Industrial Alliance on SMRs," https://single-market-economy.ec.europa.eu/industry/industrial-alliances/european-industrial-alliance-small-modular-reactors.

46 Peel et al., "Nuclear Security and Safeguards Considerations," p. 6.

Safeguards: Current Status and Future Demand

If the foregoing survey is accurate, it is clear that estimating the impact of future nuclear energy trends to 2050 on the demand for IAEA safeguards is problematic, although it is also clear that given the likely pace of any boom the IAEA has enough time to prepare. Global projections of nuclear energy use, whether high or low, may also give a misleading impression about the demand for IAEA safeguards. Although global trends provide context and indicate technological momentum, it is notably the size and type of reactor, its safeguardability, and, most critically its location in which category of country, that matter most. The key is to drill down into individual country plans, capabilities, and requirements.

States with Nuclear Weapons

To begin with, nuclear power developments in nuclear-weapon states (NWS) party to the 1968 Treaty on the Non-Proliferation of Nuclear Weapons (NPT) (China, France, Russia, United Kingdom, and United States) are not directly relevant to future IAEA safeguards requirements, because such states are not subject to IAEA safeguards in the same comprehensive way as are non–nuclear-weapon states (NNWS).[47] Much of the hyperbole about nuclear energy's future in fact reflects the extraordinary growth in just one country, China, which is a nuclear weapon state. China continues to undertake by far the biggest reactor construction effort, despite a slowdown after the Fukushima disaster, with 30 reactors under construction as of August 2024.[48] None will be subject to IAEA safeguards.

The other NWS are planning to add modest numbers of reactors to their domestic fleets, none of which are mandated to be placed under safeguards. The NWS do designate a tiny number of facilities to be subject to safeguards under their Voluntary Offer Agreements (VOA) with the IAEA, but the Secretariat typically devotes few, if any, resources to such activities.[49] This situation is unlikely to change given the pressure on IAEA budgets.

In addition, three states not party to the NPT—Israel, Pakistan, and North Korea—do not have any facilities under comprehensive IAEA safeguards and are unlikely to put existing and future reactors under such safeguards. Israel and Pakistan each have facilities under old item-specific safeguards, but neither is likely to add to the IAEA's safeguards

[47] Many civilian facilities in the United Kingdom and France are subject to safeguards under their VOAs but the IAEA chooses where to apply them in practice, based on several considerations. Some facilities, due to bilateral cooperation/supply agreements between those states and NNWS, must be safeguarded to ensure their peaceful use.

[48] "Nuclear Power in China," Country Profiles, WNA, https://world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.

[49] There is no provision in IAEA budgets for VOA verification; it is typically considered "unfunded" (see IAEA, The Agency's Programme and Budget 2024–2025, GC(67)/5, July 2023, p. 153).

workload by adopting comprehensive safeguards agreements anytime soon.[50] If a new multi-lateral deal is reached with North Korea that returns its facilities to safeguards, the IAEA remains prepared to do so, but such an eventuality seems increasingly unlikely now that the country possesses nuclear weapons.[51]

India is the great (and expensive) outlier. Although not a party to the NPT, it agreed in 2009 to place most of its civilian nuclear facilities under a bespoke safeguards agreement with the IAEA in order to encourage international collaboration with its nuclear energy sector.[52] Initially 22 facilities, including 12 reactors, were placed under safeguards, plus another two reactors in 2014.[53] Currently there are 22 Indian reactors, in addition to other facilities, under safeguards.[54] This has resulted in a considerable burden on the IAEA, arguably to limited nonproliferation purpose because India has nuclear weapons. India has a perpetually ambitious civilian nuclear energy expansion program and is currently building six civilian power reactors, all of which are likely to be placed under safeguards.[55] The country's nuclear plans have, however, for decades been thwarted by constant delays and cost overruns, meaning that the pace of increased safeguards requirement in India is likely to be protracted, permitting the IAEA to prolong its preparations.

States Without Nuclear Weapons

This leaves future safeguards requirements in the vast majority of countries, all NNWS party to the NPT, to be considered. As of June 2024, the IAEA applied safeguards to 190 states with safeguards agreements in force with the IAEA.[56] This represents all but three of the 193 member states of the United Nations–North Korea, Somalia, and South Sudan.[57] Only three NNWS party to the NPT do not have a Comprehensive Safeguards Agreement (CSA) in force–Equatorial Guinea, Guinea, and Somalia–but only Somalia has no agreement at all.[58] Long-running efforts by the Secretariat and member states to encourage all relevant states to adopt CSAs have been highly successful.

In 2023, safeguards were implemented for 142 states with both a CSA and an Additional Protocol (AP) in force, leaving only 45 states without such a Protocol–another sign of a successful campaign by the IAEA and member states to achieve universality. The AP, which is appended to a state's CSA, provides for more intensive and intrusive verification activity by the IAEA, while the state for its part is obliged to provide "cradle to grave" information about its peaceful nuclear activities.

After a state begins implementing an AP, the Secretariat works to draw a so-called "broader conclusion" to account for all nuclear material in the state. Thereafter the IAEA seeks to apply so-called integrated safeguards to optimize the safeguards activities for the state (this applied to 70 states

[50] Israel and Pakistan have what is known as INFCIRC/66/Rev.2 agreements.

[51] The 2024–2025 IAEA budget allocates €561,096 for such activity but it is completely "unfunded" (see IAEA, The Agency's Programme and Budget 2024–2025, p. 153).

[52] IAEA, Agreement Between the Government of India and the International Atomic Energy Agency for the Application of Safeguards to Civilian Nuclear Facilities, INFCIRC/754, May 29, 2009.

[53] WNA, "Nuclear Power in India," Country Profile, https://world-nuclear.org/information-library/country-profiles/countries-g-n/india.

[54] Agreement Between the Government of India and the International Atomic Energy Agency for the Application of Safeguards to Civilian Nuclear Facilities: Addition to the List of Facilities Subject to Safeguards Under the Agreement, INFCIRC/754/Add.101, January 10, 2020, https://www.iaea.org/sites/default/files/publications/documents/infcircs/2009/infcirc754a10.pdf.

[55] With the possible exception of a Prototype Fast Breeder Reactor (PFBR) under construction since October 2004.

[56] IAEA General Conference, Strengthening the Effectiveness and Improving the Efficiency of Agency Safeguards: Report by the Director General, GC (68)/0, July 19, 2024, p. 2.

[57] In addition to non-UN member state Taiwan or Taipei China.

[58] Under a comprehensive or "full scope" safeguards agreement, safeguards are to be applied on "all source of special fissionable material in all peaceful nuclear activities within the territory of the State, under its jurisdiction or carried out under its control anywhere" (see *IAEA Safeguards Glossary,* 2022 edition, Vienna, 2022, para. 2.4).

in 2023).[59] This effort is conducted as part of the State Level Concept, which involves customizing the implementation of safeguards in each state, within the scope of its safeguards agreement, by developing state-level safeguards approaches (SLAs).[60] Due to the greater confidence that undeclared facilities do not exist in a state with both an AP and a broader conclusion, the level of effort and resources needed to safeguard the nuclear fuel cycle in the state may be reduced. Moreover, the customized SLA focuses verification efforts on the most relevant acquisition paths, taking into account the state's technical capabilities.[61] Over time, as more states adopt APs, this can help reduce pressure on the IAEA safeguards budget.

Only a few significant holdouts from adopting an AP remain. The ones with substantial or potentially substantial nuclear holdings that could have an impact on IAEA safeguards resources if they adopt an AP are Argentina, Brazil, Egypt, Iran, and Saudi Arabia. In the case of Argentina and Brazil, although the IAEA cooperates trilaterally with the Argentine-Brazilian Agency for Accounting and Control (ABACC) in ensuring that their bilateral nuclear safeguards function effectively, the IAEA draws its own independent findings and conclusions. This will continue into the foreseeable future. Saudi Arabia, which currently has no nuclear power plants but has ambitious plans for a nuclear energy program, has announced it will rescind its Small Quantities Protocol (SQP) as it firms up such plans, but has not indicated it will acquire an AP.[62] The SQP, adopted by states with only small (or no) quantities of nuclear material, sets aside most safeguards requirements, including inspections.

A revised SQP was promulgated in 2005 that relevant states are encouraged to adopt, which substantially reduces the safeguards requirements held in abeyance and requires greater transparency and acceptance of inspections. [63] Even the revised SQP is, however, unsuitable for a country with a nuclear power plant.

The case of Iran, currently once more without an AP (although it has provisionally implemented one in the past), is unique. Iran currently has a sizeable impact on the IAEA's safeguards workload and budget (totaling €17.1 million annually) due to the additional bespoke verification arrangements for the 2015 Joint Comprehensive Plan of Action (JCPOA). Over the years, this has increasingly been covered by the regular budget (€12.6 million), but extra-budgetary voluntary contributions (currently €4.5 million) are still required. Although the costs associated with JCPOA verification may continue to shrink due to Iranian obstruction that began in earnest in 2019, it is not easy to calculate the impact on future IAEA workload and resources.[64] Verification requirements will remain high even if JCPOA-related activities disappear altogether, as long as Iran continues to have a CSA in force. Verification activities under its CSA have recently intensified due to Iran's increased nuclear activities, specifically its production of uranium enriched to 60 percent. If the JCPOA were to be revived or a new agreement reached, the safeguards workload would need to rise significantly in order to the restore the IAEA's loss of continuity of knowledge about Iran's program since the degradation of the JCPOA began.

Altogether, regardless of any future nuclear boom, the number of facilities and other locations under IAEA safeguards worldwide continues to slowly rise. In 2023, safeguards were applied worldwide to 724 facilities and 643 material balance areas in locations outside facilities (LOFs). In total 2,324 inspections, 136 complementary accesses (under an AP), and 676 design information verifications (DIVs) were

[59] The broader conclusion is a safeguards conclusion that all nuclear material in a state remains in peaceful activities; integrated safeguards is an optimized combination of all safeguards measures available to the IAEA under CSAs and APs for states that have been accorded the broader conclusion (see *IAEA Safeguards Glossary,* para. 3.6). The effort involves not just the Safeguards Department but the Director General's Office and the Office of Legal Affairs.

[60] *IAEA Safeguards Glossary,* pp. 24–25.

[61] Due to assurances of the absence of undeclared material the IAEA can apply, at certain facilities, safeguards measures on declared nuclear material at reduced levels when compared to the Safeguards Criteria. *IAEA Safeguards Glossary,* para. 3.7.

[62] Simon Henderson, "Saudi Arabia Increases Its Cooperation with World's Nuclear Watchdog," *Policy Analysis,* The Washington Institute for Near East Policy, August 8, 2024, https://www.washingtoninstitute.org/policy-analysis/saudi-arabia-increases-its-cooperation-worlds-nuclear-watchdog.

[63] See *IAEA Safeguards Glossary,* para 1.27. The Secretariat has been seeking to convince all SQP holders to adopt the revised version.

[64] Figures provided by the IAEA. See also IAEA, The Agency's Programme and Budget 2024–2025, p. 153). Over time, JCPOA-related activities gradually moved increasingly to the regular budget.

conducted. A decade earlier, in 2012, safeguards were applied to 692 facilities and 625 LOFs.[65] In total, 1,962 inspections, 57 complementary accesses, and 604 DIVs were conducted. The amounts of safeguarded material all increased in 2022, with the exception of heavy water.[66] They have done so for several years. Meanwhile, the IAEA's financial resources have not risen commensurately.[67]

In considering the demand for safeguards in any nuclear energy boom, it is important to recognize that the IAEA's safeguards work begins long before a nuclear power plant is connected to the grid. Under Modified Code 3.1, a state with a CSA is obliged to provide early design information to the IAEA for a new facility as soon as the decision to construct or authorize construction is made.[68] This allows the IAEA to track progress and begin preparatory work with the state on the application of safeguards, including design verification, even before nuclear fuel has been introduced. Initial design information verification, critical to the application of safeguards, is performed on a newly built facility to confirm that it is constructed according to the declared design and periodically thereafter for the lifetime of the facility to ensure that it not been altered.[69] CSAs also require the negotiation of supplementary arrangements specifying in detail how the procedures laid down in a safeguards agreement are to be applied.[70] Ideally, the state will negotiate an AP and forego an SQP if it has one.

Future Safeguards in "Newcomers" and "New Builders"

Currently there are around 30 large reactors, each of around 1,000 MW(e) and above, under construction in NNWS (plus seven in India). In addition, around 56 new large reactors are at various stages of "planning" or "proposal" in NNWS (see Annex). Most of them will be added to an existing fleet, but others are starting from scratch.

The most notable "newcomers" are Bangladesh, Egypt, and Türkiye, where construction is well under way. Each is building large, multi-unit nuclear power facilities, all of which will be placed under IAEA safeguards. The other large multi-reactor new builds currently planned in "newcomer" NNWS, which are most likely to eventuate but where construction has yet to commence, are in Poland (3), Saudi Arabia (2),[71] and Uzbekistan (2), although all are subject to continuing uncertainties. Among the other NNWS apparently giving nuclear power serious consideration today are Ghana, Italy (contemplating a return decades after scrapping its nuclear fleet), Kazakhstan (approved by referendum), Kenya, Mongolia, and the Philippines (perhaps restarting the mothballed Bataan reactor). Many appear to be considering SMRs, although this is often unclear.

The cost of a traditional nuclear power plant is still out of the question for many developing countries. African states in particular are unable to afford a large-scale nuclear power plant, even with external assistance. Even South Africa, which already has nuclear power plants, is struggling to maintain and upgrade them, much less build new ones. Russia's Rosatom's "build, own and operate" arrangement for constructing large reactors in other countries (as in Bangladesh, Egypt, and Turkey) is one alternative, although states may be concerned about the resulting high levels of debt, even at favorable interest rates, and impingements on their sovereignty. In these circumstances, potentially cheaper SMRs seem an attractive alternative.

As mentioned, the application of comprehensive safeguards to a state for the first time involves

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[65] IAEA, Safeguards Statement for 2012, para. B.1

[66] IAEA, Safeguards Statement and Background for 2023, Fact box 1, "Safeguards Activities in 2023," https://www.iaea.org/sites/default/files/24/06/20240607_sir_2024_part_ab.pdf.

[67] IAEA, Safeguards Statement and Background for 2023, para. 57

[68] See *IAEA Safeguards Glossary,* p. 14. Only Iran refuses to accept the revised code.

[69] See *IAEA Safeguards Glossary,* p. 100.

[70] This includes points of contact with the state on safeguards matters and procedures for the application of safeguards, as well as attachments that detail safeguards procedures for each individual facility and Material Balance Areas at LOF (see *IAEA Safeguards Glossary,* p. 14).

[71] World Nuclear News, "Saudi Arabia Reiterates Plans for Nuclear Energy," September 28, 2023, https://www.world-nuclear-news.org/articles/saudi-arabia-reiterates-plans-for-nuclear-energy.

a greater degree of preparation (and therefore resources) on the part of the IAEA (and the country concerned) compared to states with existing plants. However, all of the current newcomer countries have longstanding CSAs and an extensive history of interaction with the IAEA, including in most cases the application of safeguards to research reactors.[72] Uzbekistan, for its part, has long exported uranium under its CSA.[73] This situation lessens the burden on the IAEA, especially if the state already has an AP and an effective State System of Accounting and Control (SSAC). Of the newcomer states with expansive plans, only Egypt does not have an AP.[74]

The other NNWS building or credibly planning new nuclear reactors are not newcomers but already have at least one reactor in operation. At present they are mostly planning only one additional unit. These include, at the time of writing: Argentina, Belarus, Brazil, Bulgaria, Canada, Czechia, Hungary, Iran, Japan, Romania, Slovakia, South Korea, the UAE, and Ukraine (see Appendix for estimated numbers). All of these states have CSAs and an AP in force except, as noted above, Argentina, Brazil, and Iran. All have longstanding safeguards experience with the IAEA. Some of the plants are being built next to or near existing facilities, which also facilitates the application (and in theory lessens the cost) of safeguards. Many of the new reactors are being built in Eastern European states with good nonproliferation records dating from the Soviet era and with established State Systems of Accounting and Control.

If all of the large nuclear power plants currently under construction in NNWS are completed they will probably add around 20 large nuclear facilities to the IAEA's safeguards workload by the early 2030s (plus seven in India if all are placed under safeguards). These numbers hardly represent a sudden quantum leap. Rather, their rollout will likely be protracted since, as already noted, large nuclear power plants take several years to construct and deploy and are often subject to delays. Even technologically advanced NNWS are not immune from such complications. Finland's Olkiluoto 3 reactor took 18 years, even with French involvement. In building three South Korean reactors the UAE, according to the WNA, "demonstrated that it is possible to proceed faster by doing a number of things in parallel, by using experienced expatriates initially and transitioning to local expertise over time, and by committing to an experienced reactor and power plant builder with a track record of on-time and on-budget performance."[75] It still took 16 years–from 2008 to 2024. It is unclear whether other states can replicate even these outcomes. Rosatom has made surprisingly quick progress in Bangladesh and Egypt, but it remains to be seen how long it will take to connect the plants successfully to an unstable or undeveloped power grid. Hence, as the new reactors mentioned in this brief survey will be progressively brought online rather than all at once, the IAEA should have sufficient time to prepare for placing them under safeguards.

One advantage for safeguards from the current pattern of new builds in NNWS is that it is dominated by a limited number of companies, mostly Russian, but also French and South Korean, all of them state-owned or state-controlled: Russia's Rosatom, Electricité de France (EDF)[76] and Korea Electric Power Company (KEPCO) of South Korea.[77] Russia dominates the international sellers market, with Rosatom currently building 19 units in seven countries, all of which, except four in China, will be under IAEA safeguards. France is building one nuclear power station in the UK (which may offer to put its new plant under VOA safeguards). France is also involved in the construction of six reactors in

[72] Turkey has three, Egypt two, and Bangladesh one.

[73] Russia's regulator, Rostechnadzor, and the IAEA will reportedly help set up the new independent Uzbek regulator and, on IAEA advice, Russia's standards and regulations will be the basis of Uzbekistan's. Uzbekistan country profile, WNA, https://world-nuclear.org/information-library/country-profiles/countries-t-z/uzbekistan.

[74] Egypt was involved in a safeguards non-compliance episode in 2004–2005, although it was resolved to the satisfaction of the IAEA (see Trevor Findlay, *Proliferation Alert! The IAEA and Non-Compliance* Reporting, Belfer Center for Science and International Affairs, Harvard Kennedy School, October 2015, pp. 75–79).

[75] WNA, "Nuclear Power in the United Arab Emirates," Country Profile, https://world-nuclear.org/information-library/country-profiles/countries-t-z/united-arab-emirates.

[76] The EDF Group was renationalized in 2022.

[77] 51 percent state-owned, 49 percent public and foreign owned shares. WNA, "Nuclear Power in South Korea," Country Profile, https://world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.

India.[78] China is currently not building any reactors abroad, although it has built them for Pakistan in the past (not under safeguards) and is seeking further export opportunities. Japan and Canada continue to seek new customers. Schneider et al. calculate that 90 percent of all current construction projects worldwide are either in NWS or by companies controlled by NWS in other countries.[79] The limited number of companies involved and the small number of reactor models for these large facilities, all of them LWRs except Romania's planned new CANDU units, ensures that the IAEA is familiar with the reactor types and designs, rather than having to design bespoke safeguards for each facility.

This situation is likely to change as so-called Next Generation, Generation IV, or Advanced reactors, using novel technologies, are tested and potentially deployed in large nuclear power plants.[80] These include reactors using high assay low-enriched uranium (HALEU) or liquid fuel (such as molten salt) or pebble beds. The IAEA will be required to devise new safeguards arrangements for such novel plants, whether they are used in large-scale or small and medium reactors.

Safeguards for SMRs

There is currently no experience with applying IAEA safeguards to modern SMRs. The only operating SMRs are in NWS, China and Russia, and therefore not under safeguards. Currently only one SMR is being built in an NNWS, Argentina, and it is a small pilot project, although it will be placed under safeguards. In Canada the Ontario Provincial Government has submitted an application for construction but not yet obtained regulatory approval for an SMR of GE-Hitachi design. Other advanced states like Denmark are also developing their own designs, but without yet building prototypes. Most NNWS, including those in Africa, the Caribbean, Latin America, and Southeast Asia (see Annex) are only at the stage of developing SMR "wish lists" that may or may not reach fruition.

Given the great uncertainty about the scale, nature, and pace of SMR deployments in the coming decades, it is difficult to calculate the impact on the IAEA safeguards workload and budget. Although unlikely to happen until the 2030s at the earliest, if commercialization and the promised mass production rollouts do lead to a surge of deployments, the IAEA will need to be in a position to ramp up its capacities and resources quickly. Safeguards (along with safety and security guidelines and recommendations) will need to be applied to the bewildering array of SMRs, whether deployed singly or in multiples. This activity, which has already begun, will require substantial resources and assistance from member states and other stakeholders, including for the safeguards aspects. Fortunately, the IAEA has time to prepare for any emerging surge should it occur.

In the meantime, safeguards will need to be applied to pilot projects and first-of-a-kind or bespoke units in a small number of NNWS, which will present its own challenges. Demands are growing on the IAEA's time and resources solely from the increased interest in SMRs by its member states, even before safeguards are applied to any unit. The IAEA is inevitably involved in advising newcomer states on how to make complex decisions about selecting and deploying SMRs from the wide array being (potentially) offered. The IAEA says plainly that "the increasing global interest in new nuclear technologies to meet future energy demands places greater pressure" on the Safeguards Department.[81]

For the last several years the IAEA has been gearing up to handle the SMR issue in all its nuclear governance aspects. In August 2024, the IAEA published a revised version of its *Milestones Guidance in the Development of National Infrastructure for Nuclear Power* to include, for the

[78] The EDF Group is helping develop what will be the world's largest nuclear power plant in the Indian state of Maharashtra, which will have six EPR reactors with an installed capacity of 9.6 GW(e). EDF, "The EDF Group Around the World," https://www.edf.fr/en/the-edf-group/edf-at-a-glance/promoting-our-low-carbon-model-around-the-world.

[79] Schneider et al., *The World Nuclear Industry Status Report 2023,* p. 20.

[80] Different terminology is used by different stakeholders.

[81] IAEA, *Development and Implementation Support Programme for Nuclear Verification 2024–2025,* STR-405, Vienna, January 2024, p. 47.

first time, SMRs.[82] The IAEA Department of Nuclear Energy has also produced an impressive array of publications to assist states in its *Nuclear Energy Series about SMRs, including a Technology Roadmap for Small Modular Reactor Deployment* and various reports on safety standards, environmental impact, and back end fuel cycle issues.[83]

As early as 2014, the IAEA began convening an SMR Regulators Forum to identify and resolve common safety issues "that may challenge regulatory reviews associated with SMRs."[84] In 2018, the IAEA established a Technical Working Group on Small and Medium Sized or Modular Reactors (TWG-SMR) to provide advice, recommendations, and support to the IAEA in planning and implementing its programs related to technology development, design, deployment, and economics of SMRs.[85] In 2021, the IAEA launched two interconnected mechanisms: the IAEA Platform on SMRs and their Applications (SMR Platform) and the Nuclear Harmonization and Standardization Initiative (NHSI).[86] The SMR Platform provides coordinated support and expertise from across the IAEA, "encompassing all aspects relevant to the development, early deployment, and oversight of SMRs" to facilitate cooperation and collaboration among member states and other stakeholders. The NHSI, meanwhile, aims to "advance the harmonization and standardization of SMR design, construction, regulatory and industrial approaches." This initiative comprises two separate but complementary tracks: a Regulatory Track and an Industry Track. All of these initiatives are relevant to the eventual effective and efficient application of safeguards to SMRs. They also encompass some safeguards-specific activities. The SMR Platform, for instance, includes safeguards expertise in both its Steering Committee and Platform Implementation Team.

Safeguards by Design

The key to SMR verification will be "safeguards by design," permitting the most effective and efficient safeguards to be built into each reactor design as it is on the drawing boards. Some SMRs will be essentially scaled-down versions of large LWRs that have been built since the dawn of the nuclear power age.[87] Novel SMR technologies are likely to pose different proliferation concerns, requiring novel methods of accounting, containment, and control and the consideration of novel proliferation pathways.

In preparation, the SMR Regulators Forum has conducted a study on Safeguards by Design as part of the Phase 3 work plan of its Design & Safety Analysis working group. For its part, the Safeguards Department has established a Safeguards by Design for SMRs project. It is also seeking to identify pilot facilities and projects in member states that have the potential to contribute significantly to the development and testing of new safeguards methodologies and equipment for nuclear material verification at advanced reactors.[88] However, some states considering SMRs have difficulty nominating potential SMR vendors for use as model cases, which "limits the Department's potential for accruing experience from diverse resources."[89] Although commercial confidentiality about highly competitive new technologies has been raised by some observers as a barrier to full transparency, such design data are protected by the IAEA Secretariat at

[82] IAEA, *Milestones Guidance in the Development of National Infrastructure for Nuclear Power,* NG-G-3-1 (Rev. 2), Vienna, June 2024, https://www-pub.iaea.org/MTCD/Publications/PDF/PUB2073_web.pdf.

[83] See *Technology Roadmap for Small Modular Reactor Deployment,* IAEA Nuclear Energy Series No. NR-T-1.18, Vienna, 2021, https://www.iaea.org/publications/14861/technology-roadmap-for-small-modular-reactor-deployment and related publications.

[84] IAEA, "Small Modular Reactor (SMR) Regulators' Forum," https://www.iaea.org/topics/small-modular-reactors/smr-regulators-forum.

[85] IAEA, "Technical Working Group for Small and Medium-Sized or Modular Reactor (TWG-SMR)," https://nucleus.iaea.org/sites/htgr-kb/twg-smr/SitePages/Home.aspx.

[86] IAEA, "SMR Platform and Nuclear Harmonization and Standardization Initiative (NHSI)," https://www.iaea.org/services/key-programmes/smr-platforms-nhsi.

[87] The Shippingport Atomic Power Station in Pennsylvania, considered to be the first commercial nuclear power station, which went critical in 1957, generated 60MW(e), well within the modern definition of an SMR (see Richard G. Hewlett and Jack M. Holl, *Atoms For Peace and War 1953-1961: Eisenhower and the Atomic Energy Commission* (Berkeley: University of California Press, 1989), p. 420).

[88] IAEA, STR-405, p. 47.

[89] IAEA, STR-405, p. 48.

the same level as design data that a state is already obliged to provide, in confidence, to the IAEA under its safeguards agreement.

The IAEA has also already begun to identify potential specific challenges to safeguarding SMRs, particularly in regard to a state's legal reporting requirements about the technology, notably the distinct material flows associated with such installations. Concepts and model safeguards approaches for at least nine small modular and/or Generation IV reactors are envisaged, a harbinger of the scope and complexity of the challenge facing the IAEA.[90] This report cannot cover these in detail, but some brief examples may illustrate the challenge.

Molten salt reactors and pebble bed HTGR using TRISO fuel, in which fuel is not static but flows through the reactor, may require near real time accounting principles and continuous process monitoring, similar to safeguards at fuel cycle facilities.[91] Liquid fuels may also present challenges for the monitoring of reprocessing.[92] The IAEA has safeguards experience at selected reactor types that are likely to be analogous (but not identical) to some new SMR types.

For sodium-cooled fast reactors, the IAEA has experience at Joyo and Monju in Japan, the KNK-II in Germany, and the BN-350 in Kazakhstan. For the pebble bed reactor, the IAEA has relevant experience at Germany's *Arbeitsgemeinschaft Versuchsreaktor* (translated to "experimental reactor working group") and thorium cycle high-temperature reactor (THTR-300) as well as cooperation with China on HTR-10 and HTR-PM reactors. The latter has been in commercial operation since December 2023. The IAEA has no direct experience relating to molten salt reactors, but it does have analogous experience from reprocessing. The use of thorium envisaged by some designs requires securing, monitoring, and accounting for uranium-233, which "there is no experience handling in the civilian nuclear fuel cycle."[93] The application of existing IAEA experience and knowledge to all of these SMR types will depend on the precise design among many alternatives currently under development.[94]

From a nonproliferation perspective, some of the concepts being advanced depart from the traditional type of fuel–low-enriched uranium (LEU)–moving closer to weapons-grade fuels. These include uranium enriched up to 20 percent in the case of HALEU, uranium-plutonium mixed oxide fuels (MOX), and thorium. A Kings College London study by Ross Peel and colleagues reported that some developers intend to use "plug and play" cores assembled as a module separate from the reactor. They will be installed, irradiated, removed when used, and exchanged for new ones. This is in contrast to traditional reactors where fuel is "often either removed from the core, partially replaced, shuffled, and reintroduced, or cores are refueled continuously on a 'channel-by-channel basis.'"[95] The longer fuel cycle envisaged for some SMR models will, according to Peel et al., "challenge the IAEA's current equipment, requiring changes to the technology that is used, the inspection activities, the inventory recording and reporting requirements."[96]

As for waste materials from SMRs, new computational approaches and measurement tools will be needed to determine unused fuel composition for safeguards purposes.[97] Controversy erupted in 2022 over a report in the Proceedings

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90 IAEA, STR-405, pp. 50–51.

91 See Nathan Shoman and Michael Higgins (Sandia National Laboratories), "MSR Safeguards Modelling," PowerPoint, Advanced Reactor Safeguards and Security Stakeholder Meeting, Office of Nuclear Energy, U.S. Department of Energy, Washington, DC, April 13–15, 2021, and Peel et al., "Nuclear Security and Safeguards Considerations," p. 14. TRi-structural ISOtropic (TRISO) particle fuel comprises tiny particles made up of a uranium, carbon, and oxygen fuel kernel encapsulated by three layers of carbon- and ceramic-based materials that prevent the release of radioactive fission products ("TRISO Particles: The Most Robust Nuclear Fuel on Earth," U.S. Department of Energy, July 9, 2019, https://www.energy.gov/ne/articles/triso-particles-most-robust-nuclear-fuel-earth.

92 Peel et al., "Nuclear Security and Safeguards Considerations," p. 15.

93 Peel, et al., "Nuclear Security and Safeguards Considerations," p. 21.

94 See Robert T. Otto, Pacific Northwest National Laboratory, "Leveraging IAEA Safeguards Experience for U.S. Advanced Reactors," PowerPoint, Advanced Reactor Safeguards and Security Stakeholder Meeting, Office of Nuclear Energy, U.S. Department of Energy, Washington, DC, April 13–15, 2021.

95 Peel et al., "Nuclear Security and Safeguards Considerations," p. 15.

96 Peel et al., "Nuclear Security and Safeguards Considerations," p. 22.

97 Peel et al., "Nuclear Security and Safeguards Considerations," p. 22.

of the National Academy of Science by former Nuclear Regulatory Commission experts that claimed that SMRs will produce "more voluminous and chemically/physically reactive waste than LWRs, which will impact options for the management and disposal of this waste."[98] NuScale has publicly challenged the findings.[99] Such waste issues will have obvious safeguards implications.

One of the touted benefits of SMRs is their deployability, singly, in remote locations, potentially making access by inspectors difficult, particularly for unannounced inspections. Other plans envisage grouping several of them together in one location, for instance on the sites of former coal-fired power stations. But it is not clear what the budgetary implications for the IAEA will be from a flood of SMR deployments in remote locations versus serial deployment at single sites. Some SMRs designs promote the absence of on-site personnel and control of the reactors off-site. It is unclear how inspectors will interact with reactor personnel who are traditionally on-site and expected to cooperate with inspectors. Although one advantage of sealed and/or buried SMRs is that they may never need refueling or not for decades (some designs envisage refueling only after 30 years), they will not be directly accessible by safeguards inspectors. Some SMRs will simply be disposed of at the end of their lifetimes. A particular concern is floating reactors, due to their mobility and transferability. Further engagement with marine-based examples would, the IAEA says, "enhance [its] efforts in this domain."[100]

Mass production of sealed reactors at a factory assembly-line site will require new safeguards approaches, as will their transport by road, rail, or air, to the reactor site. Generally, SMRs will require lower nuclear fuel inventories, meaning fewer inspector hours. Some SMRs (and microreactors) will be continually mobile, mounted on barges, trucks, or ships, others intended for rapid deployment in disaster zones where quick access to reliable power is required. Again, new safeguards approaches, perhaps continuous remote monitoring (for safety, security, and safeguards purposes) will be necessary. Terrorist and cyber attacks may threaten safeguards integrity in a way not previously apparent at large-scale, heavily protected and immovable facilities.

The advent of mobile or movable SMRs will necessitate greater integration of safety, security, and safeguards. This may lead to efficiencies in implementation but is unlikely to ease the budgetary burden safeguards, as the IAEA will always have a legal obligation to use dedicated safeguards inspectors to carry out inspections.

In any scenario, additional inspectors well-versed in SMR technology and characteristics will be required, but the impact on overall IAEA inspector numbers is not yet known. Such vastly different scenarios call for different safeguards concepts and approaches and requisite work to prepare them at IAEA headquarters. This has already begun.

Research on the safeguardability of innovative nuclear reactor technologies is being conducted by U.S. nuclear laboratories under the DOE's Gateway for Accelerated Innovation in Nuclear (GAIN) program, both for IAEA safeguards and U.S. domestic ones, but research is still at an early stage. It is not known at the time of writing whether other countries are conducting similar research. The IAEA's own research budget is small and reliant on member state support programs to essentially conduct research on its behalf.

The emerging SMR phenomenon already puts pressure on safeguards resources. The IAEA reports, for instance, that the Safeguards Department's Concepts and Approaches Section has had difficulty filling regular posts due to budgetary constraints and relies on "cost-free experts" (CFEs) from member states to meet demand, as is the case in other sections of the Department.[101] This is where the Development and Implementation Support Program for Nuclear Verification, supported by member states, is so vital (see analysis below).

[98] Lindsay M. Krall, Allison M. McFarlane, and Rodney C. Ewing, "Nuclear Waste from Small Modular Reactors," Proceedings of the National Academy of Sciences, Washington, DC, May 31, 2022, https://www.pnas.org/doi/full/10.1073/pnas.2111833119.

[99] Daniel Moore, "Mini Nuclear Reactors Land in Scientific Spat over Waste Output," *Environment and Energy,* July 8, 2022.

[100] IAEA, STR-405, p. 48.

[101] IAEA, STR-405, p. 47.

Decommissioning and Nuclear Exits

In considering the demand for IAEA safeguards, it is also necessary to consider states exiting the nuclear energy business as well as those staying in it but decommissioning old reactors. The IAEA reports that as of March 2023 a total of more than 200 nuclear facilities had "permanently ceased to operate, either because they had reached the end of their natural life cycle or due to national policy decisions."[102] States currently exiting the nuclear business altogether (although this can change abruptly due to sudden political changes) are Belgium, Germany, Spain, and Taiwan. Belgium, which has five nuclear reactors, generating about half of its electricity, had planned to close all of them by 2025. These plans were delayed in March 2022 by 10 years, with the country's two newest reactors, Doel 4 and Tihange 3, allowed to remain operating to 2035.[103] Spain has seven nuclear reactors, generating about a fifth of its electricity.[104] Under its nuclear phase-out, its entire nuclear fleet is scheduled to shut down by 2035. The first reactor is planned to be taken offline in 2027. Germany's exit from nuclear power is the most dramatic. Until March 2011, it obtained one-quarter of its electricity from nuclear energy, using 17 reactors.[105] After 75 years of nuclear power history, its last three operating reactors were closed in April 2023.[106] However, some industrial nuclear activities are continuing, such as nuclear fuel manufacturing and uranium enrichment that require continuing IAEA verification.[107] Taiwan is also in the process of permanently shutting down its two nuclear power plants by 2025.[108]

Safeguards continue to be applied to nuclear reactors until their fuel is removed and to a lesser degree as they are decommissioned and dismantled. As the decommissioning process is inevitably "variable and lengthy," the IAEA crafts bespoke arrangements with the state for each facility concerned. Typically, additional safeguards surveillance and/or monitoring equipment is installed to monitor a "campaign" to remove nuclear material, spent fuel, and waste, with regular reviews of the recorded data.[109] States must report changes to the facility as decommissioning proceeds. Removal of equipment from the site, including the all-important reactor core, is monitored by updated DIVs and random inspections. Once nuclear material is removed from a nuclear facility and verified by the IAEA, its role in applying safeguards is substantially reduced, although not ended.[110] Only when a determination has been made that a facility has been decommissioned for safeguards purposes does the IAEA discontinue routine inspection and DIVs at the site.[111] When such sites are eventually reduced to greenfield status, the IAEA's role ends, although it continues to monitor spent fuel and nuclear waste wherever it is located, whether in interim storage or long-term disposition.

Even with the projected deployment of new reactors and life extensions for the existing fleet, scores of reactors inevitably will be taken offline and decommissioned in the coming decades.

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[102] Jennifer Wagman, "Applying Safeguards During Decommissioning," *IAEA Bulletin,* April 2023, https://www.iaea.org/bulletin/applying-nuclear-safeguards-during-decommissioning.

[103] WNA, "Nuclear Power in Belgium," https://world-nuclear.org/information-library/country-profiles/countries-a-f/belgium.

[104] WNA, "Nuclear Power in Spain," https://world-nuclear.org/information-library/country-profiles/countries-o-s/spain.

[105] WNA, "Nuclear Power in Germany," https://world-nuclear.org/information-library/country-profiles/countries-g-n/germany.

[106] Schneider et al., *The World Nuclear Industry Status Report 2023,* p. 134.

[107] Schneider, et al., *The World Nuclear Industry Status Report 2023,* p. 134.

[108] WNA, "Nuclear Power in Taiwan," https://world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan. Two advanced reactors were under construction but have been cancelled. Nuclear safeguards are applied to the Republic of China (Taiwan) which, although an original NNWS state party to the NPT in 1970, is no longer officially listed as one by the UN, due to the People's Republic of China's opposition to it being treated as a separate state.

[109] Wagman, "Applying Safeguards During Decommissioning."

[110] According to the IAEA "A facility or location outside facilities (LOF) is considered to be decommissioned for safeguards purposes when the IAEA has determined that the operations have been permanently stopped, the nuclear material has been removed, and residual structures and equipment essential for use of the facility or LOF have been removed or rendered inoperable so that the facility or location is not used to store and can no longer be used to handle, process or utilize nuclear material." *IAEA Safeguards Glossary,* p. 45.

[111] *IAEA Safeguards Glossary,* p. 45.

Schneider et al. have calculated that without new build, the current global nuclear fleet is likely to decline from 437 reactors in mid-2023 to around 150 in 2050.[112] The IAEA is of course aware of the situation. In 2022, it significantly revised its statistics on operating nuclear reactors by excluding those in shutdown mode, primarily those closed but never restarted in the aftermath of the Fukushima disaster.[113] Clearly such statistics inform the eventual level of safeguards activity required in Japan, Germany, and in other states shutting down facilities, but the impacts will not be immediate.

Decommissioning can be a complex and lengthy process, complicated by a lack of planning by national authorities for decommissioning when facilities were constructed and a failure in many cases to provide adequate funding for decommissioning. Italy, which shut down its nuclear reactors in the 1990s after the Chernobyl accident, is only now completing decommissioning.[114] The complexity and protracted nature of reactor decommissioning produces additional uncertainty for IAEA safeguards planning and budgetary projections. The IAEA reports, though, that it has successfully created safeguards guidance for decommissioned facilities and is nearing completion of the same for post-accident facilities.[115]

Safeguards on Enrichment and Reprocessing Facilities

Safeguards apply of course to producing enriched uranium and plutonium in NNWS and to exporting any such materials to NNWS from any source. Of the current states enriching their own uranium as well as supplying it to the international market, only Germany and the Netherlands (through the trilateral UK/Netherlands/Germany URENCO Corporation) are NNWS subject to IAEA safeguards. Brazil enriches uranium for its long-running nuclear submarine project, subject to safeguards. North Korea has been building a secret enrichment plant outside safeguards.

As for meeting future demand, at COP28, the "Sapporo 5" (Canada, France, Japan, United Kingdom, and the United States) committed themselves to pursuing US$4.2 billion in government-led and private investment in their collective enrichment and conversion capacities over the next three years, but it is unlikely that Canada and Japan, the only two NNWS in the group and the only two subject to safeguards, will build enrichment facilities..[116]

As for plutonium, except for Japan, no NNWS is currently advanced in its plans for separating plutonium from used nuclear fuel (much less building dedicated plutonium production reactors). Japan's effort to recycle plutonium in MOX fuel has taken decades and its plant is still not fully operational.[117] Studying how to apply safeguards to such a facility has been an expensive and time-consuming activity for the Safeguards Department. As South Korea may still resurrect its longstanding desire to initiate pyro reprocessing, the IAEA is working on a safeguards approach for such a plant in case it materializes.[118] Such an installation using such novel technology would add to the safeguards workload.

Safeguards on Spent Fuel and Waste Repositories

Safeguards are also applied to spent fuel and waste repositories. Traditionally, interim storage at nuclear plants has facilitated monitoring and verification of spent fuel and waste. However, with several countries now constructing, planning, or considering

[112] Schneider et al., *The World Nuclear Industry Status Report 2023,* pp. 59 and 75.

[113] Stephanie Cooke, "Foreword," in *The World Nuclear Industry Status Report 2023,* Schneider, pp. 16–17. It appears that the Japanese resisted changing the calculations due to domestic political reasons.

[114] WNA, "Nuclear Power in Italy," https://world-nuclear.org/information-library/country-profiles/countries-g-n/italy#radioactive-waste-management-amp-decommissioning.

[115] IAEA, STR-4, p. 47.

[116] Canada's CANDU reactors rely on natural uranium, whereas Japan is committed to using MOX fuel combining reprocessed plutonium and imported LEU.

[117] Japan Nuclear Fuel Limited now expects the reprocessing plant and MOX fuel plant under construction at Rokkasho to be completed in fiscal years 2026 and 2027 respectively. *World Nuclear News,* August 27–September 2, 2024.

[118] IAEA, STR-405, p. 50.

permanent high-level waste repositories, including Canada, Finland, France, Sweden, and Switzerland, the IAEA is obliged to work with such states to design safeguards approaches for such facilities. This includes encapsulation plants to treat and contain the waste prior to disposition, and deep geological repositories to store it permanently.[119] The need to safeguard long-term nuclear waste repositories that are nearing completion in "first-movers" Finland and Sweden, and in other countries such as in Canada as their repositories are progressively established, is adding to the IAEA's long-term safeguards workload.[120]

In 2022, the IAEA launched an Encapsulation and Geological Repository (EPGR) project to address safeguards implementation challenges posed by the new types of facilities, especially given the impossibility of inspectors directly accessing repositories that are by design meant to be impenetrable for centuries. New technologies are being considered, including seismic monitoring and laser-based containment systems, as well as "safeguards by design" approaches. All this requires funding, although collaboration with the European Commission and pioneer states like Finland (its repository will be ready in 2025) is helping. The safeguards workload will increase as more early players begin to construct their repositories for legacy materials (and conduct spent fuel transfer campaigns, a particularly time-consuming field activity). A revival in nuclear energy will over time increase the pressure for more long-term solutions to the nuclear spent fuel and waste problem, including from SMRs, which may produce new types of nuclear waste. This in turn will increase safeguards requirements for such arrangements.

119 Eva Morelo Lam Redondo, "Verifying Spent Nuclear Fuel in Deep Geological Repositories," IAEA Bulletin, September 2023, https://www.iaea.org/bulletin/verifying-spent-nuclear-fuel-in-deep-geological-repositories.

120 A town in northern Ontario has just agreed to be the site of Canada's long-term geological repository for nuclear waste.

Resources for Safeguarding a Nuclear Energy Boom

The IAEA Programme and Budget for Safeguards

Due to statutory requirements, most of the funding for IAEA safeguards comes from the IAEA's regular budget, contributed to by all member states. The regular annual budget for safeguards, Nuclear Verification (Major Program 4), for the 2024–2025 biennium is €167.7 million (US$187 million).[121] This amounts to 39 percent of the total IAEA regular budget, the largest of all the IAEA's programs.[122] It has hovered between 37 percent and 40 percent since at least the year 2000.[123] It is telling that the IAEA spent 100 percent of its safeguards budget in 2023, a pattern that has persisted for years.[124]

The context for considering any increase in the IAEA regular budget to accommodate increasing demand for safeguards is that the IAEA continues to operate under Zero Real Growth (ZRG) budgeting. In the last two biennia, no real growth occurred in the IAEA's regular budget—only inflation-related increases.[125] The period between 2019 and 2023 was particularly challenging. The regular budget for Program 4 grew by 12.5 percent, compared with real inflation in the Euro area for the same period of 17.6 percent. Not only was there no budget growth for increasing verification activities, but purchasing power was diminished.[126] As a result, the IAEA increasingly has to freeze regular budget-funded safeguards positions (these cannot be funded through voluntary funding or replaced with CFEs).

The 2024–2025 budget for nuclear verification identifies as one of its main challenges the ongoing preparations to safeguard new types of nuclear facilities and more complex or larger-scale nuclear facilities. The budget document specifically mentions Japan's MOX plant, as well as encapsulation plants and geological repositories in Finland and Sweden. In addition, one of the program's budgetary challenges is the need to apply safeguards to the decommissioning of nuclear facilities. The document also notes, for the first time,

[121] IAEA, The Agency's Programme and Budget 2024–2025, p. 7.

[122] IAEA, The Agency's Programme and Budget 2024–2025, p. 7.

[123] See Trevor Findlay, *What Price Nuclear Governance?: Funding the International Atomic Energy Agency,* Belfer Center for Science and International Affairs, Harvard Kennedy School, March 2016, p.16.

[124] Safeguards Statement for 2023, para. 68.

[125] In January 2023, for instance, the regular budget was increased to account for the impact of high inflation on program delivery, including increased energy costs (see IAEA, The Agency's Programme and Budget 2024–2025, p. 1).

[126] See Figure 1, IAEA, Safeguards Statement and Background for 2023, para. 67

the challenge of preparing safeguards approaches for SMRs, "including through securing sources of financing."[127] Other safeguards needs identified in order to help the IAEA cope with a surge in the use of nuclear energy include:[128]

- Longstanding efforts to improve SSACs and state or regional authorities (SRAs) responsible for safeguards implementation through the COMPASS program (detailed below),
- Facilitating the conclusion of CSAs and APs (which becomes more pressing as more states acquire nuclear power plants),
- Efforts to amend or rescind SQPs,
- Ensuring a safeguards workforce with the necessary expertise and skills,
- Maintaining and enhancing the IAEA's information technology (IT) infrastructure, including information security (this will require constant attention if a major increase occurs in nuclear energy requiring safeguards).

The 2024–2025 safeguards budget also includes several "wild card" budgetary items, unrelated to any increase in nuclear energy, which could affect the availability of funds for the regular safeguards program. These are ongoing, if only partial, verification of the JCPOA (most funding of which now comes from the regular budget, not voluntary contributions); maintaining enhanced readiness to return to North Korea in the event of a new nuclear agreement there; and "operating in a challenging security environment, which may require additional measures to ensure the physical safety of staff operating in the field and to ensure information security."[129]

The Russian invasion of Ukraine and the IAEA's deployment of permanent staff at the Zaporizhzhia and other Ukrainian facilities has also resulted in extra expenditure for the IAEA, including the Safeguards Department. The Director General reported, however, that although the invasion of Ukraine created "unprecedented challenges" in implementing safeguards there, the IAEA was able to conduct sufficient in-field verification activities to draw the necessary safeguards conclusion for Ukraine in 2023. Expenditures from extra-budgetary contributions for safeguards in 2022 increased by 9 percent in 2023 to €28.4 million, compared with 2022.[130] The increase resulted mainly from additional costs arising from logistical and organizational efforts associated with the implementation of safeguards in Ukraine.[131]

Additional expenditures by the IAEA that benefits safeguards are to be found in other parts of the regular budget besides that for the Safeguards Department. This includes safeguards-relevant capital works (€1.3 million in 2025).[132] In 2024–2025, it also included continuing development and implementation of safeguards approaches for J-MOX and SF-EPGR and continuing work on Integrated Life Cycle Management of Safeguards Assets (ILSA), which will improve the efficiency of managing safeguards equipment and other safeguards assets.[133]

Safeguards naturally benefit from general upgrading of infrastructure and common facilities at the IAEA's Seibersdorf laboratories outside Vienna (€0.4 million in 2024) and IT infrastructure and information security investment (€3.3 million in 2024).[134]
One example of a significant rise in demand for safeguards is a 15 percent increase in the number of environmental and nuclear material samples in the 2020–2021 biennium compared to the previous

[127] IAEA, The Agency's Programme and Budget 2024–2025, p. 139.

[128] IAEA, The Agency's Programme and Budget 2024–2025, p. 139.

[129] IAEA, The Agency's Programme and Budget 2024–2025, p. 140.

[130] Safeguards Statement for 2023, para. 69.

[131] Safeguards Statement for 2023, para. 69.

[132] IAEA, The Agency's Programme and Budget 2024–2025, p. 8.

[133] IAEA, The Agency's Programme and Budget 2024–2025, p. 31.

[134] IAEA, The Agency's Programme and Budget 2024–2025, p. 32. Analysis of nuclear material samples and environmental samples taken by inspectors is conducted at the Nuclear Material Laboratory (NML) and the Environmental Sample Laboratory (ESL) located at Seibersdorf. A third laboratory, the On Site Laboratory (OSL) at the Rokkasho Reprocessing Plant in Japan, a joint facility staffed by the IAEA and Japanese scientists, also conducts analysis of nuclear material samples from the reprocessing plant. "The IAEA Safeguards Analytical Laboratories," Fact Sheet 12-4278, October 2012, https://www.iaea.org/sites/default/files/safeguardslab.pdf.

biennium. The IAEA expects that although the number of nuclear material samples may return to previous levels, the number of environmental samples is expected to rise even further.[135]

A significant program has been mounted by the IAEA to improve the performance of national authorities responsible for safeguards implementation and their SSACs. The Comprehensive Capacity-Building Initiative for SSACs and SRAs (COMPASS) offers state-specific support in outreach, national training, software and equipment, legal and regulatory matters, and human resources. This has been almost entirely funded through extra-budgetary contributions, like virtually all the member state capability development efforts for safeguards. Safeguards implementation also benefits from certain activities of the voluntarily funded Technical Cooperation (TC) program, which provides assistance to member states in improving nuclear governance at the national level.[136] Over time, as state competency is enhanced, it is hoped the program will lessen the burden on the IAEA itself, but this is probably some way off and, in any case, difficult to calculate.

Despite gradual increases in safeguards funding and numerous programs outlined above, it will surprise an outside observer that an astonishing array of IAEA safeguards activities that could be considered essential remain repeatedly unfunded or underfunded through the regular budget. Instead, voluntary funding is expected to be used (and is usually forthcoming). These activities are detailed in the IAEA's annual program and budget. In 2025, apart from the complete absence of funding for safeguards for nuclear-weapon state VOAs (which are arguably not money well spent), and excluding Iran and North Korea activities, various Safeguards Department activities will be unfunded or underfunded through the regular budget. They include the following:[137]

- Overall management and coordination (€846,393)
- Strategic planning, including Member States Support Program coordination (€653,756)
- Safeguards approaches and concepts (€549,474)
- Quality and management system performance and improvement (€115,150)
- Training implementation, safeguards traineeship program, and development of safeguards training courses (€3,152,742)
- Declared information analysis development activities and methodology and support tasks (€1,752,011)
- Nuclear fuel cycle information analysis development activities and methodology and support tasks (€1,947,103)
- State infrastructure analysis development activities and methodology and support tasks (€2,730,340)
- Information collection and analysis development activities and methodology and support tasks (€2,423,381)
- Provision of safeguards instrumentation and services (€10,258,723)
- Development of safeguards instrumentation (€537,659)

135 IAEA, The Agency's Programme and Budget 2024–2025, p. 141.

136 In 2023, for instance, the IAEA provided member states with assistance on nuclear law through four regional projects. The Legislative Assistance Programme covers all branches of nuclear law and includes interregional, regional, sub-regional, and national activities that help countries raise awareness of decision-makers, policymakers, and legislators, to assess, review, and draft nuclear legislation and to benefit from the training of officials in nuclear law. These activities also support the promotion of adherence to and effective implementation of the relevant international legal instruments. IAEA, Technical Cooperation Report for 2023: Report of the Director General, GC(68)/INF/7, August 2024, pp. 20–25, https://www.iaea.org/sites/default/files/gc/gc68-inf-7.pdf.

137 Major Programme 4 – Nuclear Verification Activities unfunded in the Regular Budget (excluding Major Capital Investment), IAEA, The Agency's Programme and Budget 2024–2025, p. 153.

- Analytical services and sample analysis (€2,522,452)
- Information and communications technology updates (€5,727,872)
- Information and communications technology infrastructure and support (€1292,339)
- Business continuity and disaster recovery (€283,292).

In 2024, activities currently unfunded in the regular budget for which extra-budgetary resources would be required amount to €159.4 million for the operational portion and €29.5 million for the capital portion.[138] Many activities involve not just "business as usual" but are essential if the IAEA is to maintain its capabilities and prepare for a potential increase in nuclear energy use and new types of nuclear energy generation.

Although all organizations have unrealizable "wish lists," in the case of IAEA safeguards it is clear that constantly increasing amounts of nuclear material, numbers of states with CSAs, APs, and safeguards agreements, along with the demands of the post-Iraq strengthened safeguards system have left the IAEA with severe deficits even in managing the current safeguards load. As the IAEA's Safeguards Statement for 2023 points out:

> …the number of safeguards agreements and APs in force, the quantities of nuclear material and other items under safeguards and the number of facilities and LOFs under safeguards have all increased in recent years. In contrast the Agency's financial resources have not risen commensurately.[139]

The 2024–2025 safeguards budget identifies one of its challenges as securing "predictable sources of funding in order to continue delivering high-quality safeguards services and implementing effective safeguards," including for safeguards equipment and efficient safeguards approaches.

Increasing the Safeguards Regular Budget?

Whether or not member states will be willing to steadily increase the safeguards budget to help maintain its technical capabilities and accommodate the increased safeguards workload as a result of a nuclear energy boom, even if that boom could be accurately predicted, remains to be seen, but seems unlikely. The IAEA as a whole is still being held to annual ZRG in its budget, although occasional, one-off boosts have occurred. Competing political demands on the budget during the budget negotiation process (which start in the Programme and Budget Committee, before moving to the Board of Governors and the annual General Conference for endorsement) do not usually allow for major re-allocation of funding from one department to another.[140] There is already a perception that the Safeguards Department, as the largest recipient of regular budget largesse, overall does well. However, unlike other departments, the Safeguards Department must carry out activities mandated by the IAEA Statute and in fulfilment of legally binding obligations of states party to the NPT. It must rely on the regular budget for such statutory, core activities and is unable to fund them with voluntary contributions.

Any agreement to increase safeguards spending is also linked to a roughly proportionate increase in TC as a result of longstanding demands by the developing countries.[141] As more such countries seek or acquire nuclear power, the traditional bifurcation of the IAEA membership on this issue may weaken, but this depends on developing states recognizing the security benefits of

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[138] IAEA, The Agency's Programme and Budget 2024–2025, p. 7.

[139] IAEA, Safeguards Statement and Background for 2023, para. 57, https://www.iaea.org/sites/default/files/24/06/20240607_sir_2024_part_ab.pdf.

[140] For a handy guide to the arcane IAEA budgetary process, see Noah Mayhew and Ingrid Kirsten, "Navigating the IAEA Budget Process," Governing the Atom Brief No. 3, Vienna Centre for Disarmament and Nonproliferation, Vienna, 2024.

[141] Mayhew and Kirsten describe the tradeoff as a balance between what they call "promotional" activities (TC, Nuclear Power, Fuel Cycle, and Nuclear Science and Nuclear Techniques for Development and Environmental Protection) and "non-promotional activities" (safeguards and nuclear security), although the former involves more than promotional activities. In an era of expanding interest in nuclear energy, such programs can make a material difference in helping states assess their energy needs and prepare for nuclear energy if they decide to proceed. Mayhew and Kirsten, "Navigating the IAEA Budget Process."

safeguards. Current increasing interest in nuclear energy by the large membership bloc of African states, including Egypt, Ghana, Kenya, Morocco, Nigeria, and Uganda, may eventually translate into greater support for safeguards, but this will come too late to meet current needs. One bright spot is that the so-called "shielding" system, whereby developing countries received partial relief from paying their full share of safeguards costs, is retreating into history.[142] The phase-out of shielding which began in 2006 was completed in 2023 for all but the least-developed countries. De-shielding even for those member states will end in 2031, although they will still receive a discount on their overall contribution to the IAEA budget in line with UN system-wide practice.

Overall, the IAEA regular budget is plagued by periodic cash-flow crises that affect both short-term and long-term planning, including for safeguards. This occurred again in early 2024, largely as a result of unpaid annual dues by the United States and China.[143] Such difficulties were overcome, as Director General Grossi explained: "After interventions at the Board meetings, a number of Member States paid their outstanding contributions as well as advances for 2024, solving the liquidity challenges and allowing the Agency to start 2024 in a better cash position."[144]

Nonetheless, Grossi has also noted that "While the Agency's overall financial health remains strong, the net asset position in the Regular Budget Fund continues to be negative, mainly driven by the Agency's unfunded long-term employee benefits liabilities."[145] The main culprit is the After-Service Health Insurance (ASHI) scheme, representing 50 percent of the IAEA's total liabilities.[146] These schemes operate on what the auditor has called a "pay as you go" approach, with no funds set aside in escrow for future liabilities.[147] Member states and the Board of Governors have studiously ignored the growing problem, despite periodic warnings from the IAEA's auditors.[148] Although beyond the scope of this study, one option would be for one-off or a series of substantial top ups of the ASHI fund or an annual earmarking of bespoke funding, to relieve the constant pressure on the annual IAEA budget. Paradoxically, then, one way to ensure more funding for safeguards (and all the other IAEA functions) is to resolve the arcane issue of employee liabilities, which has dogged the IAEA regular budget for years.[149]

Increasing Efficiency and Mobilizing Resources

The IAEA has attempted to cope with increased safeguards and other demands on the one hand, and continuing budgetary pressures on the other, through three principal means. The first is improved efficiency through various cost-cutting measures, while attempting to maintain effectiveness. This includes Quality Management System (QMS) processes. Six internal quality audits and assessments of key processes have recently been conducted to identify process improvements and to provide information on effective implementation, although it is not clear over what time period these took place. It is not possible to evaluate these

[142] For an explanation of the "shielding" system see Findlay, *What Price Nuclear Governance?,* pp. 35–37.

[143] Jonathan Tirone, "Nuke Watchdog Risks Running Out of Money Amid U.S.-China Tensions," *Japan Times,* September 15, 2023.

[144] According to the IAEA's 2023 financial statement, "Cash, cash equivalents and investment balances increased by €113.9 million (14.4 percent) to €902.3 million as of December 31, 2023. The increase was mainly driven by the high collection of assessed contributions toward the end of the year as well as receipt of extrabudgetary contributions during the year." IAEA, Financial Statements for 2023, GC-68-4, July 9, 2024, pp. 9–10, https://www.iaea.org/sites/default/files/gc/gc68-4.pdf.

[145] The IAEA's employee benefit liabilities increased to €92.6 million in 2023, primarily due to a one-off increase of €48.1 million in the ASHI liability. The increase was driven by changes in financial assumptions (determined by independent external advisors) and partially offset by cost containment measures. IAEA, Financial Statements for 2022, GC-67-4, July 14, 2022, p. 156.

[146] IAEA, Financial Statements for 2023, p. 16. This assessment was confirmed by the IAEA's auditor, the Supreme Audit Institution of India: "The overall financial position of the Agency continues to be sound for the year ended 31 December 2023." IAEA, Financial Statements for 2023, p. 150.

[147] IAEA, Financial Statements for 2023, p. 2.

[148] The auditor's recommendations for in its current report were relatively modest but have been more strident in the past: "We recommend the Agency identify milestones and timelines for fully funding the post-employment benefit liabilities." IAEA, Financial Statements for 2023, p. 156.

[149] For further details and analysis see Findlay, *What Price Nuclear Governance?,* p. 49.

efforts from afar, but the external auditor each year selects a particular program or activity at the IAEA for an in-depth evaluation of effectiveness and efficiency, along with recommendations for improvements. The IAEA usually responds to these recommendations, although sometimes with a significant time lag. The safeguards function of the IAEA has not been comprehensively reviewed by the external auditor for some years. It would be useful to have this done in the light of expectations about a nuclear energy boom.[150]

A second approach to meeting the IAEA's needs is the longstanding tradition of seeking extra-budgetary funding and other support from member states. Today this is being shaped by agency-wide Strategic Guidelines on Partnerships and Resource Mobilization linked to the IAEA's Mid-Term Strategy 2024–2029.[151] A systematic approach to resource mobilization has long been recommended by outside observers (including this author) that replicates the strategy practiced for many years by other UN organizations. In 2023, perhaps as an indication that the strategy is working, voluntary contributions dramatically increased revenue for the IAEA from €242.4 million in 2022 to €280.3 million.[152] It is unclear whether this sudden largesse will be replicated in future years.

The IAEA has been well ahead of the curve in seeking to mobilize external support for safeguards. In 2012, it began releasing a research and development (R&D) plan setting out a "roadmap" for research collaboration with partners. In 2022, it was re-titled "Enhancing Capabilities for Nuclear Verification: Resource Mobilization Priorities" (RMP) to signal that the Department needs much more than R&D support from external stakeholders to enhance its capabilities.[153] The document identifies the highest priority needs that are especially reliant on external support. It aims to encourage member states and outside donors to provide co-funding or in-kind contributions to support such capabilities.[154] The document notes, though, that all aspects of safeguards development need extra-budgetary support, including equipment procurement, development of IT tools, improvement of measurement techniques, and training.[155] The document keys (with helpful emojis) the type of assistance–finance, collaboration, expertise, R&D, or equipment and materials–to specific priorities. In some areas all types of assistance are required.

The priorities—which were updated recently for 2024–2025—are of course all relevant to continuing efforts to improve the effectiveness of safeguards overall, but some stand out for their importance in coping with a nuclear expansion. These include the ability to implement effective and efficient safeguards for SMRs and microreactors (funding, equipment and materials, and collaboration are required) and to perform process monitoring and associated data analysis for safeguarding facilities, particularly advanced reactors with liquid or pebble fuel (funding, collaboration, expertise, and R&D are needed). A further priority, especially relevant to SMRs is the ability to rapidly detect, characterize, and address breaches of unattended systems, and evaluate their vulnerabilities more broadly, particularly from threats arising from technological advances (expertise, R&D, and collaboration are needed). Because one of the selling points of microreactors—a subcategory of SMRs— potential location at unmanned, often remote, sites, an IAEA capacity to detect interference remotely could be critical in guaranteeing the integrity of safeguards. Expertise, R&D and collaboration are especially required. A final desirable capability relevant to a nuclear energy surge is "increased organizational resilience and preparedness to recover from major disruptions to the IAEA's work and prepare for changes in the nuclear landscape." The IAEA needs the capability to maintain awareness of such changes and their associated impact on safeguards

[150] In examining other parts of the IAEA's operations over the years, the External Auditor has not had the necessary specialized expertise and experience needed to make realistic recommendations.

[151] IAEA, Strategic Guidelines on Partnerships and Resource Mobilization, https://www.iaea.org/sites/default/files/16/05/strategic_guidelines_on_partnerships_and_resource_mobilization.pdf and IAEA, Mid-Term Strategy 2024–2029, https://www.iaea.org/sites/default/files/23/02/mts2024_2029.pdf.

[152] IAEA, Financial Statements for 2023, p. 6.

[153] IAEA, "Enhancing Capabilities for Nuclear Verification: Resource Mobilization Priorities," STR-399, Vienna, January 2022. The top priorities were revised in January 2024 and communicated as a separate update document for the period 2024–2025.

[154] IAEA, The Agency's Programme and Budget 2024–2025, July 2023, p. 139.

[155] Massimo Aparo, "Foreword," in IAEA, "Enhancing Capabilities for Nuclear Verification."

implementation, including “the impact of emerging technologies and non-state actors.”[156] In this instance, collaboration and R&D are essential.

The primary mechanism for implementing the IAEA’s RMP for safeguards and vital to its success is a web of partnerships with member states. Member States Support Programmes (MSSPs) currently operate with 23 states: Argentina, Australia, Belgium, Brazil, Canada, China, the Czech Republic, Finland, France, Germany, Hungary, Japan, Netherlands, Norway, South Africa, South Korea, the Russian Federation, Spain, Sweden, Switzerland, the UAE, the United Kingdom, and the United States, as well as the European Union. ABACC and Euratom are observers at MSSP meetings. MSSPs have long been a means for providing voluntary funding, no-cost staff secondments, and in-kind support for the IAEA’s safeguards work.[157] Such support targets specific development and implementation needs for safeguards, traditionally through collaboration, R&D, and the provision of equipment, materials, and access to facilities for training or equipment testing purposes. “In-kind” assistance still predominates, rather than direct financial support.

The Safeguards Department’s current most pressing near-term needs have been detailed in a 230-page Development and Implementation Support Programme (D&IS) for Nuclear Verification 2024–2025, as well as in handy “Pocket Plans” (presumably for busy delegations to consult on the run).[158] The aim is to communicate 27 safeguards-relevant Development and Implementation Plans to current and potential future partners. One identified need that sharpens language used in the original RMP document is “leverage emerging technologies, such as AI and machine-learning, for exploiting large volumes of safeguards-relevant data to enhance prioritization, change detection, and consistency verification.”[159] In his foreword to the RMP document, the head of the Safeguards Department, Deputy Director Massimo Aparo, stressed that reliance on extra-budgetary support was most acute in the IT domain. Clearly any significant expansion in demand for safeguards will require commensurate IT capabilities, particularly in an era when AI promises enhanced monitoring, verification, and analytical techniques. These may help the IAEA keep within its budgetary constraints on hiring additional staff, although the need for in-house IT and AI expertise is likely to increase.

The IAEA is acutely aware that it must maintain effective safeguards and optimize existing methodologies and technical capacities while simultaneously preparing to implement safeguards on new types of nuclear materials, processes, and facilities before they come online.[160] The most needed external support for immediate tasks in 2024–2025 seems relatively modest: financial support for travel, expert meeting participation, CFEs, junior professional officers (JPOs), R&D, and studies.[161] The latter two items can of course be expensive. As for CFEs and JPOs, the IAEA sees them as one of the most valuable contributions an MSSP can make, not only “driving forward” the activities and objectives of the nuclear verification support program but helping develop the next generation of safeguards professionals.

Recognizing that its regular budget will be increasingly devoted to simply running the safeguards system, the IAEA’s strategy now is to build and deepen its partnerships, both traditional and non-traditional, even extending to NGOs, which used to be anathema to the IAEA. Eight new partnership agreements have been signed with non-traditional partners for in-kind support.[162] The IAEA stresses, though, the importance of sufficient communication with partners, particularly on in-kind support to increase chances of success, which is why it issues documents such as the RMP and D&IS Programme.[163] The IAEA is also working on a more

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[156] IAEA, “Enhancing Capabilities for Nuclear Verification,” p. 12.

[157] IAEA, Safeguards Statement and Background for 2023, para. 65.

[158] STR-405 and IAEA Department of Safeguards, Development and Implementation Support Programme for Nuclear Verification 2024–2025 Pocket Plans, January 2024.

[159] STR-405, p. 9.

[160] STR-405, p. 47.

[161] STR-405, p. 49.

[162] STR-405, p. 53.

[163] STR-405, p. 53.

comprehensive framework for introducing new MSSPs into the process and directing their support to the most pressing safeguards needs.

Other Ideas

One idea to encourage voluntary contributions specifically to help the IAEA prepare for a nuclear boom, is a Newcomers Fund. States planning "new build," along with construction and operating companies stand to benefit enormously from the IAEA's services, including its Milestones approach to preparing states for adopting nuclear energy, as well safety and security reviews and missions and technical assistance. Such stakeholders could be encouraged to financially support the initial application of safeguards in newcomer countries.

Another idea might be to establish additional IAEA regional safeguards offices, replicating those in Tokyo and Toronto. Eastern Europe, where much of the growth in NNWS is taking place, can be readily serviced from Vienna. But for more distant regions, such as Africa, the Middle East, Latin America, and South Asia, regional centers might be established to facilitate safeguards, as well as signaling that safeguards are a global concern, not just a first world obsession. Whether such offices would result in budgetary savings needs to be investigated but the UN itself has several regional centers which could be used to defray costs and provide mutual administrative support.

Another proposal is for a Nuclear Contingency Fund. This could be used for safety, security, and safeguards crises. In the case of safeguards, it would relieve the regular budget of the need to provide unanticipated verification "services" in cases of safeguards noncompliance, such as those of Iraq and Iran, and sudden challenges to safeguards implementation such as in Ukraine. These cases can arise overnight and require a major verification effort and frantic fundraising to support the increased activity, which is, meanwhile, borne by the regular budget and existing staff and resources.

Conclusions

Even with reasonably accurate estimates of a likely nuclear boom, assessing the corresponding needs of the IAEA to 2050 is fraught with uncertainty. In the short- to medium-term this is due to a lack of finalized technical details about the new types of facilities and technologies requiring the application of safeguards and, importantly, their location. In the longer term, it is due to the difficulty of knowing whether the current renewed wave of enthusiasm for nuclear energy, driven partly by concerns about climate change, will endure and produce multiple deployments of nuclear reactors worldwide that require safeguarding. Past bouts of excitement have not lasted. Nuclear deployments have never come close to the great surge of the 1970s and 1980s. Today, alternative energy sources, such as wind and solar are expanding exponentially in coverage and rapidly declining in price. Battery technology and other energy storage methods like pumped hydro, as well as distributive networks are obviating the need for large power plants of all kinds. Looking to 2050 it is possible that fusion power may begin, finally, to play a role, along with so-called green hydrogen. Artificial intelligence and other advances in energy usage management technology will render energy use much smarter and less carbon intensive, including meeting the intensifying electricity demands of AI itself.

Despite these uncertainties, the IAEA needs to be ready to meet its member states' expectations and needs in whatever scenario unfolds. Not just SMRs but large- and medium-sized reactors will likely use novel technologies and fuels, requiring the IAEA to develop new approaches, techniques, and technologies and train its inspectors and other staff accordingly. It must work with reactor designers, construction companies, vendors, and regulators to implement "safeguards by design" for new reactor types in order to facilitate the application of robust safeguards and allow it to estimate its own needs. Calculating safeguards needs will also depend on the location of individual facilities, whether remote and unmanned, or adjacent to existing plants and whether they are owned by states with longstanding safeguards experience or newcomers. Strengthening states' own systems of accounting and control needs to continue apace, whether there is a surge in nuclear energy use or not.

The construction of large, traditional LWRs takes years, sometimes decades, giving the IAEA sufficient time to foresee and pace its safeguards needs. Luckily, too, the slow development and deployment of new types of reactors allows the IAEA time to develop its new approaches, but this window will not remain open indefinitely. With reactor development increasingly in private sector hands and if learning from first-of-a-kind deployments accelerates, this timespan may shorten considerably in the coming decade. If and when the technology proves itself, a sudden flood of SMR deployments in NNWS in the coming decades (they are, after all, supposed to be deployed serially to achieve their touted economies of scale) would put the safeguards system under enormous strain if it does not prepare in advance.

The IAEA has decades of safeguards experience, an established cohort of skilled inspectors and high-functioning technical and management capabilities. It has engaged in meaningful cost-cutting measures to keep its budget in line with ZRG, supplemented by one-off infusions of funds. However, it cannot absorb the additional tasks heralded by a significant nuclear energy expansion without commensurate additional resources.

Beyond operating the current system effectively and efficiently, the IAEA must also carry out developmental work, which in the corporate world would be regarded as essential to an organization's survival, such as strategic planning, R&D, resilience preparations, and staff training. Much vital work has for decades been funded not through the IAEA regular budget but through the voluntary contributions of member states. The Safeguards Department is especially reliant on R&D from states with capable laboratories. More states need to launch state support programs. Although certain member states have long factored their voluntary contributions into their annual financial support for the IAEA, and the Secretariat has over the years become used to operating this way, there is a precariousness to the arrangement that begs for a more strategic long-term solution.

In the meantime, continuing efforts to improve effectiveness and efficiency are a welcome token of the Secretariat's earnestness in seeking multiple ways to tackle the problem of a mismatch between needs and resources. But member states must do their part to tackle budgetary reform, including confronting the legacy staff obligations.[164] The IAEA's efforts to promote partnerships with other international organizations, the corporate world, and civil society are long overdue and are already paying dividends. The Secretariat's transparency in communicating in impressive detail the needs of the nuclear verification development and support program is exactly what is required to engender contributions from member states, rather than vague calls for more assistance.

The Secretariat and Director General can, however, only do so much to stimulate increased support. The IAEA ultimately relies on its member states and the broader international community, including those who will benefit most from a surge in nuclear energy use, to contribute willingly to the safeguards enterprise that keeps us all safe. In summary, despite the uncertainties in predicting the future course of nuclear energy to 2050 and beyond, the IAEA must be afforded the resources it needs now to prepare for whatever scenarios unfold.

[164] This author has proposed a "grand budgetary bargain" whereby all the IAEA's critical functions would be funded by the regular budget, including nuclear security and TC. This may have the disadvantage of reducing the safeguards budget, although at the same time regularizing funding for nuclear security, which enhances safeguards. See Findlay, *What Price Nuclear Governance?,* pp. 67–69.

Annex: Nuclear Power Reactors in NNWS (plus India) Subject or Potentially Subject to IAEA Safeguards[165]

Country	Number of reactors	Number of reactors being built	Estimated number of reactors planned or proposed[166]	Number of SMRs being built	SMRs under consideration	Number of reactors shut down or decommissioned
Argentina	3			1	✓	1
Armenia	1				✓	
Bangladesh		2	2			
Belarus	1		1			
Belgium	6					
Brazil	2	1	8			
Bulgaria	2		2			4
Canada	19		1		✓	5
Czechia	6		2		✓	
Egypt		4				
Finland	5				✓	
Germany						33
Ghana					1	
Hungary	4		2			
India	31	7	12		✓	1
Iran	1	2	2			
Italy					✓	4
Japan	33[167]	2				22
Kazakhstan			1		✓	
Korea, Republic of	26	2	2		✓	2
Lithuania						2
Mexico	2					
Netherlands	1		2			1

[165] IAEA, "Overview of Power Reactors and Nuclear Share," *Nuclear Power Reactors in the World,* Vienna, 2023, p.7-8; World Nuclear Association, "Country Profiles," accessed August-December 2024, https://world-nuclear.org/information-library/country-profiles.

[166] These numbers are highly speculative, subject to constant change as governments make, amend, cancel, or quietly shelve their plans.

[167] 23 in suspended operation.

Country	Number of reactors	Number of reactors being built	Estimated number of reactors planned or proposed[166]	Number of SMRs being built	SMRs under consideration	Number of reactors shut down or decommissioned
Norway					✓	
Poland			3			
Romania	2		2		✓	
Saudi Arabia			2		✓	
Slovakia	5	1	4		1–3	3
Slovenia	1		1			
South Africa	2		1			
Spain	7					3
Sweden	6				✓	6
Switzerland	4					2
Türkiye		4	1–8		✓	
Taiwan	1					2
UAE	4					
Ukraine	15	2	4			
Uzbekistan			2			
Totals	**190**	**27**	**64**	**1**	**N/A[168]**	**91**

[168] Impossible to provide a total as numbers are so speculative at present.

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