Chapter 5: Outlook – The Adoption of a Fusion Treaty

In this chapter, a novel holistic approach to the proliferation potential of fusion is proposed. As the last chapter has shown, approaches to adapt the existing regime are constrained by concerns regarding legitimacy, bindingness, proportionality, and absence of a political incentive to adopt treaty changes. To address these challenges, this chapter proposes the establishment of a new treaty specifically for fusion, as opposed to adapting the existing framework to address the risks of the new technology. The proposed treaty would not only focus on the safeguards dimension of fusion regulation, but also seek to establish a comprehensive international regulatory approach to fusion technology.

This chapter commences with arguing why fusion's proliferation system should be regulated outside the NPT regime (1). It proceeds to set out the structure and content of such a fusion treaty (2) before going into detail on its mechanisms of preventing the proliferation of nuclear weapons aided by fusion technology (3).

1 Regulating Fusion Outside the NPT System

This section explores the benefits of regulating fusion's proliferation risks outside the NPT regime. The rational for this is manifold. The first aspect is the fact that the NPT regime is based on fission, while there are fundamental physical and technological differences between fission and fusion technology (1.1). In addition, as the NPT regime has demonstrated significant shortcomings in recent decades, addressing one issue would open the Pandora's box, quickly stalling any development (1.2). Furthermore, regulating fusion outside the NPT would enable to address aspects of nuclear weapons law that are beyond the scope of the NPT regime, namely vertical proliferation (1.3). Finally, there are precedents where aspects of nuclear weapons law have been deliberately addressed outside the NPT regime (1.4).

1.1 Fusion is not Fission

The most evident reason for regulating fusion's proliferation risks outside the NPT is the fundamental distinction between fusion and fission: Fusion is not fission. The NPT and the entire regime are designed to limit the dual-use characteristics of fission. Those States that customarily handle fissionable material such as uranium and plutonium may also use these materials and the corresponding infrastructure to develop nuclear weapons. As shown in Chapter 1, there are significant differences in the proliferation potential. To simplify, a uranium enrichment facility, for instance, can produce reactor-grade material, or if run long enough and reconfigured, also weapon-grade material. Reprocessing nuclear waste from reactors may result in the recycling of material or the extraction of plutonium for nuclear weapons. These are just two examples where the operation of nuclear fission power plants is closely related to the construction of nuclear weapons.

However, in the case of fusion, there is no direct connection to the bomb comparable to the fission fuel cycle. The basis of any nuclear weapon remains fission. Fusion only has an auxiliary character in the development of nuclear weapons. A State that operates a fusion power plant will not be able to build a nuclear weapon solely based on fusion. Fusion can support a nuclear weapons programme but cannot replace the fission part. Consequently, the proliferation potential is significantly lower compared to the proliferation potential of fission. Thus, it makes only limited sense to include fusion into the regime that is specifically designed and developed for fission.

As the last chapter has shown, a risk-proportionate incorporation of fusion into the regime requires more than mere surgical modifications. Appropriately addressing fusion's proliferation potential within the regime demands fundamental changes to the regime. Rather than fundamentally changing an existing system to include a different technology with different risk characteristics, it would be more rational to initiate a new treaty. This approach would facilitate the development of new approaches to address a different risk profile in a proportionate manner.

1.2 The NPT as Pandora's Box

Moreover, as shown in the previous chapter, including fusion comprehensively into the existing regime would require fundamental changes, including the amendments of the IAEA Statute and the NPT. These amendments are unlikely to occur. As outlined above, preserving the status quo of the NPT is challenging, changes to its foundation are improbable. A full-scope incorporation of fusion into the regime would further require the adoption of new protocols to the existing Safeguards Agreements in order to extend the authority of the IAEA. This process is lengthy and complicated, potentially raising further concerns regarding the entire regime.

As there are many shortcomings to the system, it is unlikely that one single aspect would be addressed while the other shortcomings are ignored. This is especially true with regard to some NNWS not accepting new safeguards as long as there is no progress towards nuclear disarmament. Other shortcomings of the NPT would be brought to the negotiation table. This, in turn, quickly halts any negotiation. While addressing other persistent questions of the regime itself might be beneficial for the system as a whole, this could further delay any progress in adopting the framework for fusion. The allocation of diplomatic resources for safeguarding fusion could be optimised by establishing a dedicated system specifically for fusion outside the NPT regime.

1.3 Vertical Proliferation

Another argument against including fusion into the NPT regime is the fact that essential proliferation risks of fusion are of vertical nature. Fusion will eventually increase the availability of tritium, which is used in multi-staged nuclear weapons and is essential for the miniaturisation of nuclear warheads. Without a fusion boost, there are only gravity bombs with a limited yield and no large-scale strategic nuclear weapons capable of eliminating entire cities nor nuclear warheads for missiles. However, vertical proliferation is largely outside the scope of the NPT. While this assertion is contested by some States[849] and scholars[850], the prevailing

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[849] See UN/RES/71/371; Statement of the Non-Aligned Movement during the General Debate of the First Session of the Preparatory Committee (PrepCom1) for the 2020 Review Conference of the NPT, at para. 10.

[850] *Katarzyna Kubiak*, Vertical Proliferation in Light of the Disarmament Commitment, in: Tom Sauer/Jorg Kustermans/Barbara Segaert (eds.), Non-Nuclear Peace: Beyond the Nuclear Ban Treaty, Cham: Springer International Publishing 2020, 59–84; *Vitaly Goldansky*, Connection Between Horizontal and Vertical Proliferation of Nuclear Weapons, in: Joseph Rotblat/Laszlo Valki (eds.), Coexistence, Cooperation

opinion is based on the practise of NWS, which are of the opinion that the NPT allows NWS to freely expand their nuclear arsenals both in number and sophistication; an interpretation which is further substantiated by the *travaux préparatoires*.[851] The disarmament obligation stipulated in Article VI may limit vertical proliferation in severe cases, while a future increased use of fusion technology in nuclear weapons by NWS would not constitute a violation of the NPT. In other words: Fusion's proliferation risks are to a large extent also questions of vertical proliferation, while vertical proliferation remains outside the scope of the NPT. As a consequence, including fusion into the NPT regime would either lead to changes to fundamental principles of the NPT by addressing vertical proliferation issues, which is highly unlikely, or the incorporation of fusion into the regime would have to exclude a significant portion of its proliferation potential.

1.4 Precedents

Dealing with nuclear weapons-related issues outside the NPT regime is nothing new, as evidenced by several precedents. Yet, most treaties were either not even adopted or lack ratification of key States. The first example is the establishment of a separate regime for the verification that no nuclear tests are conducted. States adopted a new treaty, the Comprehensive Test Ban Treaty (CTBT), and established a new international organisation to verify, the CTBTO. Rather than mandating the IAEA to verify that there are no nuclear tests, States opted for a separate international organisation.[852] Moreover, proposals have been made for the establishment of a separate verification system and body for a Fissile Material Cut-Off Treaty.[853]

Arguments against the inclusion of a verification system into the NPT regime are twofold: Firstly, compatibility issues with the existing instru-

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and Common Security: Annals of Pugwash 1986, London: Palgrave Macmillan UK 1988, 21–36, at 27.

[851] *Mohamed Ibrahim Shaker*, The Nuclear Non-Proliferation Treaty – Origin and Implementation 1959–1979, Dobbs Ferry: Oceana Publication 1980, at 926; *Kubiak* (n 850), at 65 f.

[852] *Rebecca Johnson*, Unfinished Business – The Negotiation of the CTBT and the End of Nuclear Testing, Geneva: United Nations Institute for Disarmament Research 2009, at 172.

[853] *Shannon N. Kile/Robert E. Kelley*, Verifying a Fissile Material Cut-Off Treaty – Technical and Organizational Considerations, SIPRI Policy Paper 33 (2012), 1–42.

ments, and secondly, a lack of experience in verification.[854] Both of these considerations apply to fusion as well. The existing instruments are not compatible with the specific proliferation potential of fusion and the IAEA does not have any experience with verification activities for fusion.

Similarly, the TPNW opted for an approach partially outside the NPT regime. For former NWS, the TPNW intends the adoption of new safeguards agreements outside the NPT, and potentially even the establishment of a new international organisation. Rather than including the verification regime of the elimination of nuclear weapons into the NPT/IAEA system, the TPNW has opted for designating a "competent international authority" to verify the irreversible elimination of nuclear weapons in former NWS.[855] The TPNW's State Parties have yet to designate this competent international authority. This authority might be the IAEA, but there are also discussions to establish a new organisation.[856]

Additionally, the Model Nuclear Weapons Convention (NWC) included a departure from the NPT system and the IAEA. While this proposal failed and was only partially used as a basis for the TPNW, it offers noteworthy insights into the inclusion of fusion into nuclear weapons law outside the NPT regime. The NWC draft explicitly included a reference to fusionable material and the prohibition to use such material for nuclear weapons.[857] It also included the establishment of a new international organisation, the Agency for the Prohibition of Nuclear Weapons.[858] Such an Agency would have been responsible for verifying the compliance with the NWC based on newly concluded safeguards agreements,[859] including those related to fusion.

The reasons for new sub-regimes within the disarmament regime are due to the different requirements for verification.[860] Verifying the elimination of a nuclear weapons programme differs from verifying the absence of

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[854] Ibid, at 26 ff.

[855] Article 4 TPNW.

[856] *Stuart Casey-Maslen*, The Treaty on the Prohibition of Nuclear Weapons: a Commentary, Oxford: Oxford University Press 2019, at para. 4.16 ff.; *Adina Carla Loghin*, Which International Authority Should Be Designated for Verifying the Irreversible Elimination of Nuclear Weapons under Article 4 of Nuclear Ban Treaty (TPNW) Scientific, Amsterdam Law Forum 11 (2019), 73–96.

[857] Paras II.D.23, 24, 28, 29 of the NWC.

[858] Para. VIII.1 of the NWC.

[859] Para. XI.A.15 of the NWC.

[860] *Jürgen Scheffran*, Verification and Security of Transformation to a Nuclear-Weapon-Free World: The Framework of the Treaty on the Prohibition of Nuclear Weapons, Global Change, Peace & Security 30 (2018), 143–162, at 157 ff.; *Loghin* (n 856), at 87.

undeclared nuclear material, a rationale that extends to fusion. Verifying that fusion technology is not used for military purposes goes beyond the existing safeguards. While there is common ground with respect to verifying that fusion power plants are not used to produce fissile material, verifying that tritium or inertial confinement fusion is not used for military purposes is different from the existing safeguards regime.

2 Structure of a Fusion Treaty

This section explores the structure of the proposed Fusion Treaty. By taking what is good from the NPT and addressing the lessons learnt from the regime, such a Fusion Treaty offers the opportunity to risk-adequately address not only fusion's proliferation potential, but also to harmonise international fusion regulation in other regulatory areas.

The section starts with an analysis of the politics of such a treaty (2.1), continuing with an exploration of the potential scope and context of a Fusion Treaty (2.2). It proceeds with an analysis of the forum for negotiation (2.3) and the institutional framework for this new treaty (2.4).

2.1 Politics of a Fusion Treaty

As already presented in the introduction, fusion has the potential to supply humanity with a virtually unlimited source of clean energy and may play an essential role in the fight against the climate crisis. The climate crisis is an existential threat to humanity, and fusion may play an important role in mitigating such a threat, as analysed in the introduction to this book. Another existential threat to humanity is nuclear weapons, whose destructive potential was demonstrated on 6 and 9 August 1945 in Japan, as well as in numerous tests. While the potential of fusion to mitigate climate change is direct, fusion's potential to be exploited for nuclear weapons programmes is only indirect. Fusion may support existing nuclear weapons programmes, but it does not replace the importance of fission as the basis of nuclear weapons. Adapting and applying the non-proliferation and disarmament regime to fusion must consider both the risks and benefits.

As discussed in the context of safety regulations for fusion,[861] any regulatory response must be risk-appropriate. With regards to nuclear weapons law, this entails two considerations: First, regulation must not overburden a young and promising technology where the risk is limited. Second, as there is a risk, some form of regulation should apply. This is where the international character of the legal framework plays an essential role: Non-proliferation law allows to establish a level playing field among all States by ensuring that there is no competition for the most lenient safeguards, which could potentially endanger international security. States acknowledge the authority exercised by the IAEA to ensure international security, but only as long as there is reciprocity in the legal obligations.

The Fusion Treaty could draw on lessons learnt from the NPT. In order for States to accept the discriminatory nature of the NPT and the exercise of authority by the IAEA, they were offered the incentives of the prospect of nuclear disarmament and technical assistance. In case an international instrument addresses safeguards only, there is no clear political incentive for States to accept such safeguards. As shown in the last chapter, while there are various pathways to address fusion's proliferation risk both under the existing regime and by amending the regime, there are only limited incentives for States to accept new safeguards and to extend the IAEA's authority. The Fusion Treaty has the opportunity to not only address the non-proliferation and disarmament dimension of fusion, but to include multiple aspects of fusion regulation and the promotion of fusion energy throughout the world. The broader the scope of the treaty and the more benefits it includes for NNWS, the more likely the acceptance of new safeguards for fusion is. A broader scope of the treaty, addressing multiple aspects of fusion and the technology's regulation, could serve as such an incentive.

2.2 Incentivising Scope and Content

This section explores the scope and content of the proposed Fusion Treaty. Such a Fusion Treaty could not only include safeguards (see Section 3), but also adopt a holistic approach to fusion and all relevant aspects of the tech-

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[861] *Matthew Lukacs/Laurence G. Williams*, Nuclear Safety Issues for Fusion Power Plants, Fusion Engineering and Design 150 (2020), 111377; *Neill Taylor/Pierre Cortes*, Lessons Learnt From ITER Safety & Licensing for DEMO and Future Nuclear Fusion Facilities, Fusion Engineering and Design 89 (2014), 1995–2000.

nology's regulation. This comprehensive approach encompasses a range of aspects of nuclear law (2.2.1), a provision offering technical assistance (2.2.2), and the incorporation of disarmament and vertical proliferation components (2.2.3), along with other regulatory aspects (2.2.4).

2.2.1 International Nuclear Law

As mentioned in the introduction, international nuclear law focuses mainly on three pillars – safety, security and safeguards –[862] and encompasses various international treaties and conventions. These include, among others, the Convention on Nuclear Safety, the Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, or the Convention on the Physical Protection of Nuclear Material.

There are ongoing discussions whether and to which extent these conventions apply to fusion.[863] As analysed in the introduction, there is not only ambiguity in the applicability of these instruments, but discussions surround the same question whether the rules, which were developed specifically for fission, should be applicable to fusion as well. While there are safety[864] and security[865] concerns with fusion, these are fundamentally different from those of fission in many aspects.

Instead of addressing the ambiguity and the specific requirements of fusion within several separate frameworks that have all been developed for fission, there are compelling arguments for addressing these concerns within a single separate and specialised treaty for fusion. First, the inclusion

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[862] Some also consider the aspect of civil liability in case of a nuclear accident as a fourth pillar, see for instance *Rafael Mariano Grossi*, Nuclear Law: The Global Debate, in: Nuclear Law: The Global Debate, The Hague: T.M.C. Asser Press 2022, 1–27, at 2. The question of civil liability is discussed below in Section 2.2.4.

[863] *Wolfram Tonhauser/Karoly Tamas Olajos*, Nuclear Fusion: Legal Aspects, Nuclear Law Bulletin 2023/2 (2024), 57–74; *International Atomic Energy Agency*, IAEA World Fusion Outlook 2023 – Fusion Energy: Present and Future, Vienna: IAEA 2023, at 24 ff. On 15 November 2023, the IAEA hosted the First Meeting Focusing on Safety and Regulation of Fusion.

[864] *Carley Willis/Joanne Liou*, Safety in Fusion, IAEA Bulletin 62–2 (2021), 14–16; *Lukacs/Williams* (n 861); *M. Nakamura/K. Tobita/W. Gulden et al.*, Study of Safety Features and Accident Scenarios in a Fusion DEMO Reactor, Fusion Engineering and Design 89 (2014), 2028–2032; *Neill Taylor/Dennis Baker/Sergio Ciattaglia et al.*, Updated Safety Analysis of ITER, Fusion Engineering and Design 86 (2011), 619–622.

[865] Karoly Tamas Olajos/Fusion For Energy (eds.), Fusion For Energy Roundtable 2024 Proceedings, Barcelona: European Commission 2024, at 63 f.

of fusion technology in a treaty developed for fission technology puts fusion and fission on the same level of perceived risks. However, as this is scientifically inaccurate, such a step could harm the prospects of an emerging technology as this could influence public opinion and investor interests. Second, the creation of a new treaty would allow for the drafting of obligations that are based on the individual risks of fusion, thereby recognising the technological differences between fusion and fission technology.

All aspects of nuclear law – safety, security and safeguards considerations – are relevant for the design of a fusion facility. As many startups are entering the design stage of their power plant concepts, they have an expressed interest in having clarity on the regulation of fusion. Consequently, incorporating all of these aspects in one international treaty regime would be a rational course of action. Adopting a holistic approach to fusion regulation within the framework of a Fusion Treaty would offer the opportunity to use the synergy of addressing all three design-relevant issues (safety, security and safeguards) at the same time, thereby preventing both the creation of gaps and the imposition of overburdening regulation. Addressing this matter on an international level is also the rational choice. Safeguards can only be regulated on an international level, as they pertain to State action. Using the synergies in design requirements for safety, security and safeguards would thus also require an international approach. In addition, harmonizing fusion regulation on an international level would facilitate the timely deployment of fusion energy across several countries in the fight against the clock in tackling the climate crisis, which is in the interest of all States.

2.2.2 Technical Assistance

Another aspect of the proposed Fusion Treaty draws on the NPT: Technical assistance. Accepting the discriminatory nature of the NPT, as well as the safeguarding powers of the IAEA, required a bargain, a *quid pro quo*, between NWS and NNWS. NWS offered the prospect of a cessation of the nuclear arms race as well as technical assistance for civilian nuclear programmes.[866] As the proposed treaty will also include an extension of safeguarding powers by an international organisation,[867] the instrument

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[866] Articles IV and VI of the NPT.

[867] See below, Section 3.

would also have to offer benefits for all States. One incentive would be the inclusion of technical assistance in the development of a fusion energy infrastructure. Either advanced States or the competent international institution[868] could provide technical support for all interested States and foster the deployment in States without the necessary financial or technical means. Such technical assistance could financially be supported by global endeavours on Climate Finance, such as the New Collective Quantified Goal on Climate Finance, which aims to mobilise 1.3 trillion USD annually by 2035.[869]

2.2.3 Vertical Proliferation and Disarmament

Unlike the NPT, the Fusion Treaty could also include obligations towards vertical proliferation and pave a clear way towards nuclear disarmament. Such an inclusion might also be necessary to gain support by NNWS to adhere to a Fusion Treaty that includes new safeguarding obligations. While nuclear disarmament may currently seem out of reach, diplomatic[870] and scholarly[871] efforts remain active to prepare solutions should the geopolitical landscape shift.

Under the NPT, NNWS accept the discriminatory nature of the NPT and the international oversight of the IAEA, in return for technical assistance in civilian nuclear weapons programmes, the promise of a cessation of the nuclear arms race, and the prospect of both nuclear and conventional disarmament. Accepting additional levels of safeguards for fusion would require additional concessions. While including a provision on technical assistance might be a factor, stronger commitments to the goal of Article VI of the NPT with regard to limiting nuclear arsenals would be a necessary requirement, as demonstrated by previous discussions of enhancing the

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[868] See below, Section 2.3.2.

[869] Following Article 9 of the Paris Agreement. The New Collective Quantified Goal on Climate Finance was adopted by Decision -/CMA.6.

[870] For example, the British Foreign, Commonwealth and Development Office organised jointly with the Norwegian Ministry of Foreign Affairs a three-year long conference series on irreversibility in nuclear disarmament.

[871] See for example Wilfred Wan/Vladislav Chernavskikh (eds.), Expanding Perspectives on Nuclear Disarmament, Uppsala: SIPRI/Alva Myrdal Centre for Nuclear Disarmament 2023.

non-proliferation system.[872] Promising technical assistance in the future for a technology that is not yet commercially available would not serve as sufficient incentive for NNWS to proactively address the proliferation potential of fusion by implementing a new system within the upcoming years. Such a proactive initiative would require a focus on vertical proliferation and nuclear disarmament.

This is especially of relevance given that vertical proliferation lies mostly outside the scope of the NPT regime. The NPT allows NWS to freely expand their nuclear arsenals both in number and sophistication. International law imposes minimal restrictions on vertical proliferation of nuclear weapons within the limits of Article VI.

Addressing the vertical dimension of tritium within a Fusion Treaty could draw on existing proposals to regulate tritium under nuclear weapons law. First, as mentioned above, an international tritium control regime has been proposed.[873] Such a treaty, including tritium safeguards, has been specifically seen in the context of a wider treaty regime also tackling fissile material, not only to strengthen non-proliferation, but to work towards nuclear disarmament.[874] Second, a tritium cut-off treaty has been proposed,[875] with the objective of ceasing the further supply of tritium for military purposes while at the same gradually achieving nuclear disarmament. Given the half-life of tritium of twelve year and its use in a large portion of nuclear warheads, such a treaty would progressively reduce the number of operational nuclear warheads equitably across all nine nuclear arsenals worldwide, ultimately resulting in the number zero. Such a treaty regime would also require verification mechanisms, such as environmental gas-sampling.[876] A focus on fusion safeguards, especially within a Fusion Treaty, might draw on these existing proposals and produce new momentum towards nuclear disarmament. While previous proposals on regulating

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[872] *Marcos Valle Machado da Silva*, Brazil and the Refusal to the Additional Protocol: Is It Time to Review this Position?, Carta Internacional 16 (2021), 1–26; *Togzhan Kassenova*, Nuclear Safeguards in Brazil and Argentina: 25 Years of ABACC, AIP Conference Proceedings 1898 (2017), 1–6.

[873] See Chapter 4, Section 4.2.3.

[874] *Martin Kalinowski*, International Control of Tritium for Nuclear Nonproliferation and Disarmament, Boca Raton: CRC Press 2004, at 52, 197.

[875] *Robert E. Kelley*, Starve Nuclear Weapons to Death with a Tritium Freeze (*Stockholm International Peace Research Institute*, 2020), https://www.sipri.org/commentary/topical-backgrounder/2020/starve-nuclear-weapons-death-tritium-freeze, last accessed 17 July 2025.

[876] Ibid proposes to add tritium detectors to the existing network of gas detectors set up by the Comprehensive Nuclear Test Ban Organization (CTBTO).

tritium were not picked up by States, addressing tritium in a broader framework not limited to the weapons-dimension only might incentivise NNWS to at least consider any kind of international oversight on tritium.

Furthermore, the fact that tritium is rare might further push for nuclear disarmament.[877] ITER is expected to consume all of the world's civilian inventory of tritium.[878] As analysed above, global civilian tritium production of all CANDU reactors is in the range of several kilograms per year, a quantity that a single fusion power plant would consume. While a future fusion power plant will produce in its operation more tritium than it consumes, the tritium quantity required for the startup of the first commercial fusion power plants will be a crucial topic.[879] Such a discrepancy might require the access of military resources of tritium, which are currently stored within nuclear warheads. When the question will be to either maintain nuclear arsenals or to power a solution to climate change, the latter might prevail as a heating world cannot afford a cold war.[880] A potential approach to maintaining a balance of nuclear powers, and making military tritium accessible for fusion energy, is within the framework of a Fusion Treaty.

2.2.4 Further Regulatory Aspects

Another aspect of a Fusion Treaty could be to address the question of civil liability in the case of a nuclear accident, also covered under international nuclear law, where similar considerations as with safety and security are applicable. As nuclear accidents create outstandingly high damages, the nuclear regime includes specific rules of private international law and the application of certain principles to ensure uniform rules of dealing with such damages. Within fusion, the risk of accidents, as well as the extent

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[877] *Taylor Loy*, Speculating on Tritium Futures – Why Defense Material Should Fuel Fusion Innovation (2023), https://www.newamerica.org/political-reform/briefs/tritium-fuel-futures/, last accessed 17 July 2025.

[878] *Richard J. Pearson/Armando B. Antoniazzi/William J. Nuttall*, Tritium Supply and Use: a Key Issue for the Development of Nuclear Fusion Energy, Fusion Engineering and Design 136 (2018), 1140–1148.

[879] Ibid; *M. Kovari/M. Coleman/I. Cristescu et al.*, Tritium Resources Available for Fusion Reactors, Nuclear Fusion 58 (2018), 026010.

[880] *Mads Christensen*, A Heating World Can't Afford a Cold War in: Greenpeace, https://www.greenpeace.org/international/story/60291/a-heating-world-cant-afford-a-cold-war/, last accessed 17 July 2025.

of damages, is significantly reduced.[881] The existing instruments[882] do not apply to fusion,[883] yet there are ongoing discussions on amending the instruments to fusion.[884] While there is the desire of investors and insurances to have clear rules on the liability in the event of a fusion accident, such a clarification is necessary. However, as the risks differ significantly from those of fission and the existing regimes are designed with fission accidents in mind, addressing fusion in a separate instrument such as the Fusion Treaty would be beneficial.

In addition, other aspects of fusion regulation in a broader term might be included in such a treaty as well. They include questions on intellectual property,[885] rule on public-private partnerships[886] or the handling of supply chains with a focus on trade barriers.[887]

2.2.5 Summary

This section has developed the scope and content of a Fusion Treaty necessary to incentivise States to accept fusion safeguards. The scope of the Treaty is comprehensive, extending to other aspects of nuclear law, especially safety and security aspects, technical assistance in the deployment of fusion technology, an increased commitment to reduce vertical prolifera-

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[881] *Nakamura/Tobita/Gulden et al.* (n 864).

[882] There are two conventions dealing with the topic. Under the auspices of the IAEA, there is the Vienna Convention on Civil Liability for Nuclear Damage. Under the auspices of the OECD, there is the Paris Convention on Third Party Liability in the Field of Nuclear Energy. The application of these two treaty regimes is to some extent harmonised by the Joint Protocol Relation to the Application of the Vienna Convention and the Paris Convention.

[883] On this, see the extensive work of *Claire Portier*, Le droit de la responsabilité à l'épreuve des activités de fusion nucléaire, Aix-en-Provence: Aix-Marseille Université 2022. Also, *Tonhauser/Tamas Olajos* (n 863), at 62 f.; *William E. Fork/Charles H. Peterson*, Fusion Energy and Nuclear Liability Considerations, Nuclear Law Bulletin 93 (2014), 43–62.

[884] *Exposé des Motifs of the Paris Convention*, NEA/NLC/DOC(2020)1, at 9.

[885] *Elias G. Carayannis/John Draper*, The Growth of Intellectual Property Ownership in the Private-Sector Fusion Industry, Fusion Engineering and Design 173 (2021), 112815.

[886] *Scott C. Hsu*, U.S. Fusion Energy Development via Public-Private Partnerships, Journal of Fusion Energy 42 (2023), 12; *David Kingham/Mikhail Gryaznevich*, The Spherical Tokamak Path to Fusion Power: Opportunities and Challenges for Development via Public–Private Partnerships, Physics of Plasmas 31 (2024), 1–7.

[887] *Richard J. Pearson*, Barriers to Fusion Commercialization: Understanding Innovation, 2020.

tion and to work towards nuclear disarmament, as well as other regulatory aspects.

Such a comprehensive character of the Treaty incentivises wide-spread acceptance of both NNWS and NWS. Regarding NNWS, they would have to accept additional safeguards, yet they receive several benefits in return. First, technical assistance helps them to quickly deploy fusion energy without the cost and time associated with developing their own fusion industry. Second, provisions on vertical and horizontal disarmament would address NNWS' frustration regarding the non-implementation of Article VI of the NPT, which is a pivotal reason why the Additional Protocol has not yet been universally adopted. Third, a harmonisation of fusion regulation would provide assistance for many developing NNWS in creating a regulatory framework for fusion regulation.

Regarding NWS, a Fusion Treaty with a comprehensive scope also provides incentives for them. Safeguards on fusion technology in NNWS give NWS the assurance that this technology is not used in ways that would threaten their nuclear weapons monopoly. In addition, technical assistance would provide these States, which are also at the forefront of fusion development, with a global market for exporting fusion technology. Harmonising other aspects of fusion regulation further facilitates exports as the designs of machines does not have to be adapted to national regulation. These political and economic benefits might also be an incentive for these States to at least engage in negotiations on vertical proliferation and disarmament.

2.3 Forum for Negotiation

As seen with the TPNW,[888] a key question for the success of a treaty is its forum of negotiation. Historic examples may serve as a role model for the negotiation of a Fusion Treaty. The NPT was negotiated under a UN mandate by the Eighteen Nations Committee on Disarmament. Today, this forum has evolved into the Conference on Disarmament (CD), based in Geneva, making it an obvious candidate as forum for negotiation. This forum has been proven to be successful in negotiating the NPT, the Biological Weapons Convention, the Chemical Weapons Convention as well as the

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[888] *Gro Nystuen/Kjølv Egeland/Torbjørn Graff Hugo*, The TPNW: Setting The Record Straight, Norwegian Academy of International Law 2018, at 6.

CTBT. Nevertheless, the Conference on Disarmament has been labelled as dysfunctional in recent times, mainly due to its limited membership and procedures.[889] The CD consists of only 65 Member States and operates on a consensus basis. These restrictions have led to no progress in negotiations for many years.[890]

Another option could be the context of NPT Review Conferences. Although a Fusion Treaty would ultimately fall outside the NPT regime, its RevCons offer a unique opportunity for nearly all States to come together and to discuss progress on nuclear non-proliferation and disarmament. These discussions are not confined exclusively to the scope of the NPT regime; as drafts of the Nuclear Weapons Convention were proposed within the Review Cycle of the NPT.[891]

Depending on the scope of the Fusion Treaty, another forum could be a separate international conference on this topic. Such a conference could be mandated by a resolution of the UN General Assembly similar to the TPNW in 2016,[892] or initiated by a core group of States. The more such a treaty includes other aspects of fusion in order to develop a comprehensive fusion treaty, the more the treaty negotiations would likely be separated from the nuclear weapons regime.

2.4 Institutional Framework

Another question pertains to the institutional framework, especially with regard to the authority which would be mandated to operationalise and verify the treaty.

An obvious candidate for this role would be the IAEA. The IAEA has more than 70 years of experience in the nuclear sector. It is the international organisation that identifies itself with its motto *Atoms for Peace and Development*. It has 180 State Parties and a functional organisational structure. The IAEA is the depositary of numerous treaties and conventions related to the broader question of nuclear issues, including the Convention

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[889] *Judith Thorn*, The UN Conference on Disarmament, in: Eric Myer/Thilo Marauhn (eds.), Research Handbook on International Arms Control Law, Cheltenham: Elgar 2022, 77–88, at 78 ff.; *Nystuen/Egeland/Hugo* (n 888), at 6.

[890] *Paul Meyer*, Does the Conference of Disarmament Have a Future?, Journal for Peace and Nuclear Disarmament 4 (2021), 287–294.

[891] NPT/CONF.2010/PC.I/WP.17.

[892] A/RES/71/258.

on Nuclear Safety, the Convention on the Physical Protection of Nuclear Material, and the Vienna Convention on Civil Liability for Nuclear Damage. Given the overlap with fusion, mandating the IAEA with the oversight of a Fusion Treaty would be a logical choice. The IAEA already considers itself as the leading international organisation in the field of fusion.[893] In addition, the IAEA has extensive experience with safeguards and employs around 275 safeguards inspectors.[894] As shown in Chapter 3, the mandate of the IAEA is broad enough to also cover fusion.

However, there are arguments against mandating the IAEA with fusion. First, there is the clear distinction between fusion and fission. Both States and private actors try to keep fusion and fission separate. This is, for example, demonstrated in the use of the expression *fusion* rather than *nuclear fusion* and the intentional omission of the word *nuclear* when talking about fusion technology. This seeks to avoid conflating nuclear fusion with fission, especially to distance fusion from the negative connotations that fission and nuclear energy holds in public discourse. Mandating the institution which is often referred to as nuclear watchdog with fusion could do the contrary.

The second argument against the IAEA is that it has no experience with fusion and vertical proliferation. The IAEA is well-versed in implementing safeguards to prevent proliferation in a fission fuel cycle, the same expertise does not extend to a fusion fuel cycle. As there are fundamental differences between fission and fusion, fusion safeguards would require new know-how and procedures. This is especially true with the vertical proliferation dimension of fusion. The IAEA is experienced in preventing horizontal proliferation, but has no experiences in administering safeguards on preventing vertical proliferation. Given the limited resources in funding and staff of the IAEA, a new international institution might be better suited to apply safeguards to fusion power plants and the fusion fuel cycle.

Thus, the establishment of a new international organisation might be the best approach. Such an International Fusion Energy Agency (IFEA) could draw on the experiences of the IAEA, especially with regard to its organisational structure. Such an IFEA could equally comprise a General Conference, comprising all Member States, a Board of Governors, representing all regions of the world and the most advanced nations in fusion technology, and a Secretariat, comprising different departments focussing

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[893] *International Atomic Energy Agency* (n 863), at 5.

[894] *Rafael Mariano Grossi*, IAEA Safeguards for International Peace and Security, IAEA Bulletin 63–3 (2022), 1–1.

on all aspects of fusion energy. Similar to the CTBTO, setting up the IFEA in Vienna, at the Vienna International Centre alongside the United Nations, IAEA and CTBTO Headquarters, would be a rational choice to maximise collaborative effects. Given the reduced safeguards problematic of fusion compared to fission, the size and costs of the IFEA would be lower than the 430-million-euro regular budget and roughly 2,500 employees of the IAEA.

2.5 Summary

This section has analysed the structure of a Fusion Treaty. Given the risk potential of fusion, it is necessary to develop risk-appropriate approaches to the technology's regulation and to include incentives for States to accept fusion safeguards. A comprehensive regulation of several regulatory aspects of fusion would be such an incentive. In addition, the institutional framework has been discussed, with options of negotiating the treaty in- or outside existing nuclear weapons law fora, as well as the options of creating a new international organisation for fusion.

3 Safeguards Under a Fusion Treaty

The proposed Fusion Treaty is predicated on the incorporation of risk-appropriate safeguards mechanisms to ensure that fusion energy is only used for peaceful applications. The development of a number of these instruments can draw upon existing safeguards for the nuclear fission fuel cycle, while others are newly developed specifically for fusion. This section first explores the possibility of including nuclear weapon States into the regime (3.1). It further addresses the legal architecture of the fusion's safeguards regime (3.2). The section continues to develop approaches for the three different proliferation concerns: the risk of fissile material production (3.3), the substantial availability of tritium (3.4) and the knowledge transfer of inertial confinement fusion (3.5). It concludes with an analysis of the relevance of export control regimes (3.6).

3.1 The Question of Nuclear Weapon States

A fundamental question of a safeguards system under a Fusion Treaty is on how to treat NWS. States have to decide on whether and to which extent the safeguarding measures include fusion facilities within NWS. Fusion facilities may provide NWS with benefits for their nuclear weapons programmes, especially inertial confinement fusion as it is already used in the United States and France for military purposes, as well as a cost-effective source of tritium and an efficient method to produce plutonium. Including the civilian infrastructure in NWS under international fusion safeguards would not only serve to limit vertical proliferation and play a role in disarmament, it would also increase acceptance among NNWS. Under the NPT regime, NWS recognised by the NPT have placed their civilian fusion infrastructure under voluntary safeguards for increasing acceptance.[895]

The extent of the inclusion of NWS depends on how closely the treaty mirrors the NPT. Under the NPT, NWS are free from any safeguarding obligations. However, as argued above, fusion should be regulated outside the NPT. Dealing with safeguards outside the NPT would allow for a more equal treatment of all States and could overcome the discriminatory nature of the NPT regime.

It seems feasible that NWS would accept voluntary safeguards for their civilian fusion infrastructure similar to how they accept voluntary safeguards for their civilian fission infrastructure. Whether obligations go beyond a purely voluntary nature depends on the bargaining power of NNWS. As NNWS are often critiques of new safeguards as long as NWS do not agree on limiting their own nuclear weapons capacities, the acceptance of NNWS of fusion safeguards could depend on obligations of NWS rather than voluntary action only.

3.2 Legal Architecture of Fusion Safeguards

Another question is on how to incorporate fusion safeguards. If the NPT is taken as an example, fusion safeguards could be mandated (either only for NNWS or all States) in general, with further details to be included in safeguards agreements between the States and the competent international authority. Alternatively, the fundamental outline of fusion safeguards,

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[895] *Frank S. Houck*, The Voluntary Safeguards Offer of the United States – A Review of its History and Implementation, IAEA Bulletin 27 (1985), 13–18.

including the competences of the institution could be incorporated directly into the Fusion Treaty itself.

A balanced consideration of both approaches reveals their respective advantages and disadvantages. In the event that safeguards are specified in further agreements, the competent international authority – to use language from the TPNW – has more leeway on implementing and developing. Especially, should the competent international authority be the IAEA, the basis of the agreement would be a decision by the Board of Governors. As the Board only has limited membership, such a process would not be as inclusive as Treaty negotiations with all Member States. Conversely, safeguards are evolving, particularly in relation to a technology that still exists only in research laboratories. The conceptualisation of fusion power plants at present may differ significantly from those that will be constructed in the future. Setting the safeguards regime in stone in the form of a Treaty might impede future adaptations. As seen with fission, the NPT has remained unchanged, while there have been four iterations of IAEA safeguards on fission.[896] Establishing the foundation in an international treaty, and then subsequently mandating international organisations to develop the framework, has demonstrated to allow for flexibility. This valuable lesson, learnt from the NPT, underscores the need for a dynamic and adaptable safeguards regime.

To find a balance between these advantages and disadvantages, one approach might be to include negotiations on a first set of safeguards into the Treaty conference itself. In order to maintain a level of flexibility for future developments, the Fusion Treat could mandate the competent international authority with the future development of fusion safeguards. Furthermore, the Treaty could include a provision that all future changes to the system will be mandatory for all Parties to the Fusion Treaty. This would avoid the repetition of today's situation, where not all States have adopted the Additional Protocol of 1998, leading to 44 States still having in place safeguards levels that were developed in the early 1970s. Such a scenario would shift power from the States, especially their parliaments, to an international organisation. Today, any modification to the safeguards system requires ratification by each State, thus also the involvement of parliaments. Modifications to the IAEA safeguards system have been drafted in bodies of the IAEA where all States were included, meaning that at least each State's government had the opportunity to influence the modifications

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[896] INFCIRC/26; INFCIRC/66; INFCIRC/153; INFCIRC/540.

to the system. However, the influence of an individual State in discussions of bodies of international organisations is limited given power structures and the exercise of hegemony, while the requirement of signing and ratifying a new treaty or protocol effectively provides every State with a veto power.

As a consequence, there would have to be an incentive for States to accept such a treaty provision that would take power away and shifts it to an international organisation. An effective safeguards system capable to act proactively rather than reactively is such an incentive. Historic examples have shown that existing safeguards mechanisms often do not suffice to adequately address the proliferation potential of nuclear technology. As there is a shared interest among both NNWS and NWS that no further State acquires nuclear weapons, there is also a shared interest to close loopholes in the system as early and as efficiently as possible.

3.3 Addressing the Risk of Fissile Material Production

A key task of safeguards under a Fusion Treaty is to address the proliferation potential of high-energetic neutrons. As analysed above,[897] neutrons from fusion reactions have the capability to transform fertile materials (such as uranium ore) into fissile material (such as ^{239}Pu). A Fusion Treaty can address this potential by implementing safeguards measures. This section discusses some safeguarding measures that could be implemented, while not providing a comprehensive list. Specific safeguards depend on specificities such as the design and scale of the facility, and have to be developed by technical experts.

3.3.1 Gamma Radiation Detectors

Under peaceful operations of fusion facilities, no fertile or fissile material is present on site. As even the smallest amounts of such material indicate a breakout scenario,[898] a focus on detecting these materials is key to safe-

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[897] Chapter 1, Section 5.1.3.

[898] One limitation might be traces of uranium in the breeding blanket if it is made of beryllium as natural beryllium ore contains some uranium, *B. N. Kolbasov/V. I. Khripunov/A. Yu Biryukov*, On Use of Beryllium in Fusion Reactors: Resources, Impurities and Necessity of Detritiation After Irradiation, Fusion Engineering and

guarding fusion. These materials are detectable through gamma radiation, especially the detection of ^{238}U based on its 1.001 MeV gamma line.[899] Consequently, a key safeguards measure would entail the installation of gamma radiation detectors on-site. These detectors could be remotely observed from the headquarters of the competent international safeguarding authority, such as the IAEA or IFEA. This approach would guarantee a minimally invasive measure while simultaneously providing a high level of certainty that the fusion facility is used solely for peaceful purposes.

3.3.2 Design Review and Monitoring of Energy Output

Another approach to prevent the use of fusion facilities for the production of fissile material is the combined use of a design review and the monitoring of the energy output.

A design review would serve two purposes. First, the designs could be reviewed to assess if the plant has any unusual characteristics that could be used for producing fissile material. As fertile material has to enter the machine at some point and the produced fissile material must be removed, there have to be some technological features that would be recognisable in the design. Second, a design review would allow for estimating the energy output of the facility. Parameters of the fusion device such as heating power, magnetic fields and spatial dimensions of the reactor can be used to determine the power output of the fusion machine.

In fission, States fill out a Design Information Questionnaire (DIQ) and submit it to the IAEA. This questionnaire includes general information about the facility, a description of the types, use and flow of nuclear material, information about handling of nuclear material, accountancy measures as well as protection measures. The IAEA performs a Design Information Verification (DIV) of the facility to verify the correctness and completeness of the design information provided in the DIQ. Implementing DIQ and DIV would be essential for safeguarding fusion facilities.

Design 109–111 (2016), 480–484. On different breeding blanket designs, cf. *G. Federici/L. Boccaccini/F. Cismondi et al.*, An Overview of the EU Breeding Blanket Design Strategy as an Integral Part of the DEMO Design Effort, Fusion Engineering and Design 141 (2019), 30–42.

[899] *Alexander Glaser/Robert J. Goldston*, Proliferation Risks of Magnetic Fusion Energy: Clandestine Production, Covert Production and Breakout, Nuclear Fusion 52 (2012), 043004, at 5.

In addition to the design review, the energy output of the fusion machine would be measured. Any neutron that is not used for fusion processes or heat production but rather to produce fertile material is a neutron that does not contribute to the energy production or production of tritium. Using a fusion machine for fertile material production will influence its energy output.[900] Comparing the actual energy output with the estimated output of the fusion reactor could allow to detect discrepancies that might indicate the production of fertile material.

3.3.3 Physical Access to Fusion Facilities and Environmental Sampling

Similar to fission plants, international safeguards inspectors could have the competence to access fusion facilities. These inspections could verify that the detectors proposed above are adequately placed and properly functioning. Also, these visits could verify if the actual design of the plant corresponds to the design reviewed by the competent international authority. Facility access could also be used to take further samples and measurements to ensure that no fissile material has been produced. These inspections could place and check seals to verify that the fusion device has not been opened for adding or replacing a second wall containing uranium for plutonium production.

As under the existing Additional Protocol, physical access and sampling should not only be limited to the facility itself, but could also allow access to random locations on a State's territory in order to take environmental samples. As the handling of fissionable material leads to traces in the environment,[901] such an approach would add another level of certainty. This is especially true with fusion, as the production of fissile material would require the operation of a clandestine plutonium separation plant. The implementation of these safeguards measures would not only enhance fusion safeguards, but also further strengthen fission safeguards.

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[900] Ibid.

[901] *David L. Donohue*, Strengthening IAEA Safeguards Through Environmental Sampling and Analysis, Journal of Alloys and Compounds 271–273 (1998), 11–18.

3.3.4 Satellite Imagery

A further approach to verify the information obtained could be satellite imagery. In the event that a fusion facility was to be used for the breeding of nuclear weapons material, such material would need to be reprocessed, and the facilities used for this process might be detectable from satellite imagery. Furthermore, this approach would address the risk of clandestine fusion facilities, as they are, at least the first generation, large facilities as well.[902] The utilisation of satellite imagery in the broader context of non-proliferation has garnered increased attention,[903] and could further support the verification that fusion facilities remain in peaceful uses only.

3.4 Addressing the Risk of Tritium

Addressing the proliferation potential associated with tritium can be addressed by implementing a tritium accounting system. The proper installation of tritium accountancy devices can be verified by regular visits to the facility, as proposed above. There are, however, various technological challenges in implementing tritium accountancy.

Tritium accountancy is based on plasma measurements, from which the production and consumption of tritium can be calculated. However, as tritium is gaseous, accounting is more difficult than with metals such as uranium and plutonium. Furthermore, tritium is highly reactive and gets absorbed in dust and surfaces. Accounting for tritium is not only a safeguards concern, but a safety and security concern of fusion facilities.[904] Given the value of tritium, currently about USD 30,000–35,000 per

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[902] *Glaser/Goldston* (n 899), at 2.

[903] *Irmgard Niemeyer*, Perspectives of Satellite Imagery Analysis for Verifying the Nuclear Non-Proliferation Treaty, in: Gotthard Stein/Bernd Richter/Sven Nussbaum/Irmgard Niemeyer/Bhupendra Jasani (eds.), International Safeguards and Satellite Imagery, Berlin, Heidelberg: Springer Berlin Heidelberg 2009, 35–44; *Frank V. Pabian/Guido Renda/Rainer Jungwirth et al.*, Commercial Satellite Imagery: An Evolving Tool in the Non-proliferation Verification and Monitoring Toolkit, in: Irmgard Niemeyer/Mona Dreicer/Gotthard Stein (eds.), Nuclear Non-Proliferation and Arms Control Verification: Innovative Systems Concepts, Cham: Springer International Publishing 2020, 351–371.

[904] *Didier Perrault*, Nuclear Safety Aspects on the Road Towards Fusion Energy, Fusion Engineering and Design 146 (2019), 130–134; *Elahe Alizadeh*, Environmental and Safety Aspects of Using Tritium in Fusion, Journal of Fusion Energy 25 (2006), 47–55.

gram,[905] there is also an economic interest in clear tritium accountancy. Currently, research is being conducted focusing on simulations to account for tritium within the fusion fuel cycle.[906] However, tritium accounting must overcome several difficulties.

Firstly, excess tritium is needed in order to compensate for calculation uncertainties. In other words, it is unclear exactly how much tritium will be consumed by the fusion reactions themselves. The presence of calculation uncertainties makes the implementation of an accounting system difficult.

Secondly, the proliferation potential is increased by the fact that unused tritium will be transferred through a piping system to a tritium processing plant. Not only could tritium escape through microscopic leaks – tritium is, after all, hydrogen, i.e., a gas that tends to escape very easily – but there is also a potential for circumvention due to a potentially covert access to pipes.[907] If a proliferator was to extract some tritium from a small section of a long piping system, it could potentially do so undetected.

Another difficulty for accounting is the question of detecting tritium. The low energy of beta rays emitted from tritium makes detection particularly challenging.[908] ITER foresees daily measurements of the tritium inventory within the fuel cycle, based on several factors including the tritium burn-up rate within the plasma.[909] However, this burn-up rate is difficult to measure and includes significant uncertainties. A 2008 study demonstrated that there is a substantial probability to not detect 100g of tritium diver-

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[905] *Daniel Clery*, Out of Gas, Science 376 (2022), 1372–1376; *Richard J. Pearson/Olivia Comsa/Liviu Stefan et al.*, Romanian Tritium for Nuclear Fusion, Fusion Science and Technology 71 (2017), 610–615.

[906] *Samuele Meschini/Sara E. Ferry/Rémi Delaporte-Mathurin et al.*, Modeling and Analysis of the Tritium Fuel Cycle for ARC- and STEP-Class D-T Fusion Power Plants, Nuclear Fusion 63 (2023), 1–34. Also, the UKAEA has recently started its Tritium Inventory Project.

[907] *Rachel Lawless/Barry Butler/Anthony Hollingsworth et al.*, Tritium Plant Technology Development for a DEMO Power Plant, Fusion Science and Technology 71 (2017), 679–686; *Tetsuo Tanabe*, Tritium Handling Issues in Fusion Reactor Materials, Journal of Nuclear Materials 417 (2011), 545–550; *Jürgen Raeder/Arthur Weller/Robert Wolf et al.*, Review of the Safety Concept for Fusion Reactor Concepts and Transferability of the Nuclear Fission Regulation to Potential Fusion Power Plants, GRS 2016.

[908] *Andrew J. Parker/Michael D. Aspinall/Colin Boxall et al.*, Radiometric Techniques for the Detection and Assessment of Tritium in Aqueous Media – a Review, Progress in Nuclear Energy 162 (2023), 104733; *Kalinowski* (n 874), at 5.

[909] *R. Lässer/D. K. Murdoch/M. Glugla*, Tritium Accountancy Issues of the ITER Fuel Cycle, Fusion Science and Technology 48 (2005), 337–342.

sion within an 18-year timespan.[910] However, others argue that there are technical means to introduce a control procedure capable to detect even quantities of 1 gram.[911] The development of verification mechanisms for the use of tritium requires further scientific research.

3.5 Addressing the Risk of Knowledge Transfer in ICF

In contrast to the concerns surrounding the production of fissile material or tritium, the proliferation potential from inertial confinement fusion does not come from the material used in nuclear weapons, but rather from the knowledge gained. Addressing this issue through safeguards measures poses significant challenges. Given the classified nature of many aspects of ICF, it is difficult to quantify the proliferation potential. One potential approach involves a design review, wherein experts from universities and/or NWS could assess whether the facility in question might produce data that could support a nuclear weapons programme. While this approach might risk industrial espionage, procedures could be implemented to mitigate such threats and ensure that the review is confined to the prevention of military knowledge transfer. As the main benefit from ICF for weapons development stems from variations in the experimental set-up, a future ICF power plant will be limited to a specific configuration optimised for power output. Future fusion power plants are designed in one specific configuration to maximise energy output, not to gain insights in nuclear weapon research. The combination of design reviews and limited configurations would ensure that ICF plants are not used for nuclear weapons development. Although limits could come from the protection of intellectual property, transparency in the design stage could be a step to address the proliferation potential. Such a *Safeguards by Design* approach would be minimally invasive, reducing the necessity for safeguards inspections.[912] Another possibility would be to allow NNWS only to import turn-key fusion reactors which are developed in NWS and do not allow for a change of physical parameters. Regulation of ICF could go as far as prohibiting

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[910] *Jörg Reckers*, Tritiumbilanzierung zur Überprüfung der Nichtweiterverbreitung im Fusionsreaktor ITER, in: DPG (ed.), 72. Jahrestagung der DPG, Berlin: 2008.

[911] *Kalinowski* (n 874), at 176 and 197 f.

[912] *Jeremy Whitlock*, Safeguards by Design: Designing Nuclear Facilities with Safeguards in Mind, IAEA Bulletin 63 (2022), 22–22. The IAEA has also published seven guidance documents on the Safeguards by Design approach for fission, IAEA Nuclear Energy Series No. NF-T-2.8, 2.9, 3.1, 3.2, 4.7, 4.8 and 4.10.

one type of ICF, indirect-driven ICF, in NNWS, as this technology has the closest resemblance to hydrogen bombs, however such a prohibition would be disproportionately restricting the development and deployment of ICF power plants and would not completely eradicate the proliferation potential.

The dual-use character of ICF is less pronounced than in classical fission or the other two proliferation issues as it is not material but knowledge than can benefit nuclear weapon development. It must further be noted that the information than can be gained from a specific ICF configuration is especially beneficial for States that are already in possession of nuclear weapons.[913] Consequently, this is primarily[914] a vertical proliferation issue. Existing military-used ICF facilities are research facilities designed for a wide range of research, including military research.

3.6 Relevance of Export Control Regimes

Under to Article III.2 NPT, the regime based on fission requires export controls to support the implementation of safeguards. The export of specific dual-use goods is only permitted to States which apply safeguards to these goods.[915] Within a Fusion Treaty, a similar approach could be followed, implementing a lesson learnt from the NPT. As analysed above, export control regimes are relatively easy to adapt to fusion, as they are based on soft-law guidelines. The combination of a mandate to apply safeguards if a country wants to import certain dual-use fusion goods, especially with a focus on tritium and tritium technology as well as ICF-related technology, and soft-law approaches on setting up the details would be an approach to further support a fusion safeguards system. Such a system would serve to complement the verification mechanisms established by an international organisation, thereby enabling other international fora to develop rules and procedures. This, in turn, would serve to maximise the degree of insurance that fusion technology is not used for military purposes.

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[913] Expert statement of Christian Häfner, Fraunhofer Institute for Laser Technology, during a hearing of the German Bundestag, Committee for Education, Research and Technology Assessment, 3 July 2024.

[914] *Kalinowski* (n 874), at 39 ff. argues that tritium has a significant horizontal component as well.

[915] Article III.2 NPT. On this, see above Chapter 3, Section 2.

3.7 Summary

This section has developed approaches on how to include safeguards into a Fusion Treaty regime. It has discussed the possibility of including nuclear weapon States as equals to non-nuclear-weapons States into the regime. Furthermore, this section has analysed the extent to which safeguards are already defined in the treaty, or is left open for elaboration within an international organisation. The chapter has proposed both technical and legal approaches to address fusion's proliferation concerns within the proposed treaty regime, focussing on all three proliferation aspects of the risk of fissile material production, the abundance of tritium and the knowledge transfer of inertial confinement fusion.

4 Conclusion

This chapter has proposed a novel, holistic approach to addressing the proliferation potential of fusion technology. Rather than adapting the existing non-proliferation framework, which is primarily designed for fission, a new treaty tailored to fusion is advocated. This treaty would encompass not only safeguards but also the comprehensive regulation of fusion on an international level.

Fusion's proliferation risks should be regulated outside the NPT regime. The primary reason is that fusion differs fundamentally from fission, both in its technological characteristics and its proliferation potential. Fusion does not directly contribute to the development of nuclear weapons but can support and enhance existing nuclear weapons programmes. This distinction necessitates a separate regulatory framework. In addition, there is a lack of political incentive to address fusion within the existing regime.

The NPT's successes, such as setting an international norm against nuclear proliferation and stopping several nuclear weapons programmes, are acknowledged. However, its shortcomings, including its lack of universality, retroactive rather than proactive nature, and the absence of consensus on fundamental questions, underscore the need for a new approach for fusion. The NPT's struggles to maintain the nuclear status quo and its limited success in achieving universal adherence further support the argument for a separate fusion treaty.

Adapting the existing NPT framework to include fusion would require extensive changes, including amendments and new protocols, a process that is both lengthy and complicated. Given the challenges in amending the NPT, a more efficient use of diplomatic resources would be to create a new treaty specifically for fusion.

The limited scope of the NPT, which does not adequately address vertical proliferation, is another reason for a separate fusion treaty, as fusion's proliferation potential is to a large extent also of vertical nature.

Precedents for dealing with nuclear weapons-related issues outside the NPT regime, such as the CTBT, proposals for a Fissile Material Cut-Off Treaty and the TPNW, provide a basis for advocating a separate fusion treaty. These precedents demonstrate that creating new international organisations and treaties can be an effective approach to addressing specific proliferation risks.

The structure of the proposed fusion treaty is outlined, emphasizing the need for a holistic approach that includes safety, security, and safeguards considerations. The treaty would address technical assistance, vertical proliferation, and disarmament, as well as other regulatory aspects such as civil liability and intellectual property, in order to serve as an incentive.

The IAEA is considered a potential competent international authority, but the establishment of a new International Fusion Energy Agency (IFEA) is proposed to address the unique requirements of fusion safeguards.

Safeguards mechanisms would be central to a fusion treaty. These mechanisms include gamma radiation detectors, design reviews, energy output monitoring, physical access to fusion facilities, environmental sampling, tritium accountancy systems, and addressing the risk of knowledge transfer in ICF. Export control regimes are another aspect in supporting the implementation of fusion safeguards.

This chapter has presented a pathway toward a new, comprehensive Fusion Treaty, that addresses the proliferation potential of fusion technology in a risk-appropriate way while providing clear incentives in order to adapt the framework to fusion. Such a Treaty would ensure that that both global interests are balanced to an optimal degree: Limiting the risks of the spread of nuclear weapons, while at the same time enabling the development of a new technology to address the climate crisis.