Towards Export Controls Instead of Safeguards for Commercial Fusion Power Plants

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Abstract:

Fusion energy is progressing towards commercial deployment, evidenced by the rise of private fusion enterprises, the US National Ignition Facility announcing the first controlled thermonuclear experiment achieving ignition and scientific breakeven, and the first private company signing a power purchase agreement. This progress has spurred questions as to the role of IAEA safeguards in prospective, commercial fusion power plants (FPPs). This paper discusses the applicability of the Treaty on the Non Proliferation of Nuclear Weapons (NPT) and safeguards to FPPs and as well as the existing multilateral export control regimes and the role they should play in ensuring the safe use of fusion energy to the extent necessary to enable global clean energy. This paper concludes that the traditional safeguards on nuclear (fissionable) material do not apply to FPPs, nor should they apply. The international export control regime is discussed as a primary regulatory framework and avenues of future work, particularly pertaining to scale-up, are proposed.

1. Introduction: the precipice of commercial fusion energy begs the question

Fusion energy is quickly approaching commercialization, evidenced by the National Ignition Facility achieving the first controlled ignition and scientific breakeven event;[1] the emergence of private fusion ventures totaling over $5 billion in funding;[2] and the industry securing its first customer via a power purchase agreement – meaning electricity from fusion energy could be on the grid as early as 2029.[3] Once fusion energy begins to deploy, it will do so quickly, consistent with the White House's Bold Decadal Vision and the demand to curb climate change.[4] The advent of the global fusion industry and the prospect of global clean electricity has technology developers, regulators, policy makers, and other experts beginning to discuss regulatory frameworks, and in particular, how fusion is differentiated from fission.[5] For example, both the US and UK recently completed multi-year analyses and decided to regulate fusion systems similar to particle accelerators (e.g., irradiators, medical cyclotrons), and not like fission reactors.[6,7] Similar questions and analyses are being asked about the role of the Treaty on the Non Proliferation of Nuclear Weapons (NPT).

This paper establishes scope; lists the theoretical proliferation pathways hypothesized for fusion; and reviews solutions by way of safeguards and export control. This paper assumes familiarity with the NPT and IAEA; it is meant to facilitate discussions and provide an update of ongoing work. Additional details, references, and analysis are left to other publications and IAEA TECDOCs.

2. Background: fusion, fission, hybrids, and the scope of IAEA safeguards

Nuclear nonproliferation is tied to the NPT, which sets for the international consensus approach as to limiting risk of creating or otherwise obtaining nuclear warheads while also enabling growth in peaceful uses of nuclear energy. The thrusts of the NPT are to prevent the spread of nuclear weapons, promote cooperation in the peaceful uses of nuclear energy, and further the goal of achieving disarmament. The NPT is deliberately written to only establish controls over "(a) source or special fissionable material, or (b) equipment or material especially designed prepared for the processing, use or production of special fissionable material."[8] The flagship tool of the NPT-based regime is safeguards, implemented by the International Atomic Energy Agency (IAEA).

In this work we define "fusion system" to mean the fusion vacuum vessel and those components that are directly connected and related. Fusion systems may also be referred to as fusion device of fusion generator. "Auxiliary system" refers to those systems that are separate from the fusion system, but still handle or contain radioactive materials, e.g., tritium management systems or the bioshield. A breeding blanket may be part of the fusion system or an auxiliary system, depending on where it is located and how it is integrated. A "fusion plant" is the fusion system and all auxiliary systems at a given licensed site.

We further make the distinction that fusion system refers to fusion-only systems, which contrast with fusion-fission hybrid systems that use fusion products to drive fission (chain) reactions, e.g., in a subcritical assembly. Safeguards under a comprehensive safeguards agreement (CSA) will apply to fission-fusion hybrid systems having or using nuclear material (defined as source material or special fissionable material). A CSA with the IAEA is required of each non-nuclear-weapon state party to the NPT. Similarly, a fusion system designed to use or to have nuclear material (e.g., depleted uranium shielding) might be subject to IAEA safeguards under a CSA, and it may also be subject to safeguards under a Voluntary Offer Agreement (VOA, if included in the list of eligible facilities by the State and selected by the IAEA for the application of safeguards) or an item-specific safeguards agreement (if required to be safeguarded under a transfer agreement or requested by the State). Application of safeguards will depend in case-by-case on the scope of the safeguards agreement in force with the State concerned.[9,10]

The scope of this paper is henceforth limited to fusion systems that do not use nuclear material.

3. Discussion: hypothesized proliferation pathways

The lack of use of nuclear material in fusion systems substantially reduces the proliferation risks of fusion plants as compared to (fission) nuclear facilities. In fact, whereas safeguards at nuclear fission facilities involves materials control and accountancy to ensure that nuclear material that exists at the facility stays at the facility, stays within safeguarded streams, and is not misused, supposed controls at a fusion plant involve ascertaining the lack of nuclear material.

Prior works have identified hypothetical proliferation pathways for fusion: exposing source material to fusion neutrons to breed special fissionable material, using tritium to boost nuclear weapons, and gleaning specialized knowledge from inertial confinement fusion systems to inform the design of thermonuclear weapons.[11] Breeding material is a horizontal proliferation risk, whereas developing nuclear explosives into thermonuclear explosives is a vertical proliferation risk. Vertical proliferation risks still require nuclear material and a fission chain reaction that drives device performance.

4. Solutions by way of safeguards

The IAEA will not apply safeguards to fusion systems without nuclear material under the existing safeguards agreements. The IAEA may, working with a member state as appropriate, however request access to a fusion plant, e.g., under the Additional Protocol, to assure the absence of undeclared nuclear material and activities at such plant. The Model Additional Protocol was created in 1997 to enhance IAEA environmental sampling and inspection capabilities following the discovery of clandestine weapons programs in the 1990s.[12,13] This access is referred to as complementary access.

IAEA safeguards as currently applied do not extend to tritium or lithium-6 (which creates tritium upon ^{6}Li(n,alpha)^{3}H neutron capture reactions). Fusion energy systems and fusion fuels are not listed in the Zangger Committee or Nuclear Suppliers Group "Trigger Lists" that identify what is meant in Article III.2 of the NPT (equipment "especially designed" to work with nuclear material).[14] Indeed, it does not appear to have been the purposes of the NPT to cover fusion. To this point, the US Permanent Representative to the United Nations said on 15 May 1968 regarding the NPT that "controlled thermonuclear fusion technology will not be affected by the treaty,"[15,16] an intent that was recognized and mirrored by the depository notes provided by other nations. For example, Germany again quotes that its interpretation of the NPT was that "controlled thermonuclear fusion technology will not be affected by the Treaty,"[17,18] and Japan considered that "thermonuclear fusion reactors should not come under the prohibitions of the NPT"[19]. This helps explain that over years of progress in fusion research and development, and in use of tritium in industrial applications, fusion has never fallen under the safeguards regime.

Other tools exist to effectively manage the limited proliferation risks from fusion. These tools include export controls of dual-use items, discussed further in Section 5 and safety-related material control and accountancy programs, which if required as part of licensing a fusion power plant, would enable monitoring of tritium inventories. Furthermore, safeguards are applicable to nuclear material (e.g., source material before it could enter a fusion plant) and activities including reprocessing, which would be required to effectively generate special fissionable material from fusion.

5. Solutions by way of export control

Existing multilateral export control regimes for dual-use items serve as a mechanism to prevent the proliferation of nuclear technology, materials, and equipment to State or non-State actors. Such controls have been adopted and implemented by the countries leading the development of fusion (which is a limited set to date). Moreover, United Nations Security Council Resolution 1540 has helped extend export controls to many countries across the globe to prevent proliferation of nuclear weapons, their means of delivery, and related materials.

Core fusion technologies and materials (e.g., tritium, lithium-6, and related technologies to produce or handle these materials) are already covered by existing export control regimes for dual-use items. Indeed, the NSG Guidelines mentioned above track fusion-related components on a separate dual use export controls list, instead of placement on a safeguards-oriented list. Similarly, knowledge obtained by operating inertial confinement fusion (ICF) systems (as it pertains to thermonuclear weapons) and equipment used to obtain that knowledge can be subject to export controls. In fact, export control is an apt regime to control technology and know-how.

6. Conclusions and future work

As fusion develops, the export control regimes are well positioned to bring together stakeholders to ensure that export controls remain updated to address proliferation risks for fusion. As well, world governments can promote research into improved use of export controls mechanisms for dual-use items to address fusion, for example by tailoring export controls to incentivize developers to build non-proliferation into the early-stage design of fusion energy systems. The IAEA may have at its disposal complementary access to fusion plants for environmental sampling to confirm the absence of nuclear material.

Fusion technology developers with near-term deployment timelines should strive to work closely with the IAEA and other stakeholders to foster transparency and help ensure that the deployment of fusion does not unintentionally increase proliferation concerns. Governments should undertake further research to explore how to effectively apply the existing non-proliferation authorities discussed above to fusion as it deploys.

As fusion develops and scales, fusion technology developers, Member States, and the IAEA should evaluate the capacity of the IAEA to scale with the fusion industry and perform relevant work.

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