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Reflecting on the Annexes to the Model Additional Protocol in Support of Nuclear Governance

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Cover image:

Vienna International Centre with Buildings A and B, headquarters of the International Atomic Energy Agency – Photo Credit: Rodolfo Quevenco/IAEA

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Executive Summary

The Model Additional Protocol (MAP), approved in 1997 by the Board of Governors of the International Atomic Energy Agency (IAEA), is a voluntary legal instrument supplementary to safeguards agreements between States and the IAEA. An additional protocol based on the MAP gives the IAEA more tools to verify the absence of undeclared nuclear activities or material in a State. Among these tools are expanded reporting requirements, including (but not limited to) those outlined in the MAP's two Annexes. The purpose of the Annexes is to provide the IAEA with a fuller picture of a State's nuclear-related activities in order to help with the planning for, implementation and evaluation of safeguards.

Annex I of the MAP requires reporting to the IAEA on the scale of operations for each location engaged in activities contained in Annex I and was designed to address key chokepoints along the nuclear fuel cycle. Annex II, which requires reporting on the exports and imports of specified equipment and non-nuclear material, was crafted based on technological capabilities along the fuel cycle at the time the MAP was approved by the Board.

A quarter century after the Board approved the MAP, the provision to update the Annexes has yet to be invoked. Meanwhile, technological advancements since the MAP's approval may necessitate the inclusion of further materials and technologies that are not reflected in the Annexes but have implications for safeguards. The following report is the result of a study conducted by the Vienna Center for Disarmament and Non Proliferation (VCDNP), which examines these technological advancements and their potential impacts on the effectiveness and efficiency of the safeguards system.

1. Introduction

In the 1990s, spurred in large part by the discovery of a clandestine nuclear weapons programme in Iraq, the International Atomic Energy Agency (IAEA) and its Member States engaged in a range of activities aimed at strengthening the effectiveness and improving the efficiency of the safeguards system.

One of the first activities undertaken by the IAEA was the consideration of and, in February 1993, approval by the Board of Governors (hereafter "the Board"), of a voluntary reporting scheme on imports and exports of nuclear material and exports of specified equipment and non-nuclear material.[1,2]

In December 1993, the IAEA formalised the effort to strengthen safeguards in Programme 93+2, a coordinated and intensive process conducted in consultation with the Member States to fill the gaps in safeguards implementation.[3] At the conclusion of Programme 93+2, the Secretariat, at the June 1995 Board meeting, submitted a report by the Director General (GOV/2807) for consideration, which included a comprehensive proposal for measures to strengthen safeguards in two parts.[4] Part 1 consisted of measures that could be implemented using the IAEA's existing legal authority; Part 2 consisted of measures for which the Secretariat recommended additional legal authority. In the report, the Director General "recommended that the Board take note of the Director General's plan to implement at an early date the measures described in Part 1" and urged States with comprehensive safeguards agreements (CSAs) "to co operate with the Secretariat to facilitate such implementation." The Board accepted that recommendation, prompting the Secretariat to put Part 1 measures in motion.[5]

Between June 1996 and June 1997, the Secretariat worked intensively with Member States to create a draft model protocol to operationalise the Part 2 measures. That draft was then the subject of deliberations in the Committee on Strengthening the Effectiveness and Improving the Efficiency of the Safeguards System, or Committee 24.[6] The result of Committee 24's efforts was the Model Protocol Additional to the Agreements Between

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1 Hiroshi Tani, "Reporting Scheme Endorsed by the IAEA Board of Governors," International Nuclear Safeguards 1994: Vision for the Future, Proceedings of a Symposium, page 243, 14-18 March 1994. Available at: https://inis.iaea.org/collection/NCLCollectionStore/_Public/26/008/26008772.pdf?r=1#page=261.

2 The list used for the voluntary reporting scheme (VRS) was based on the list contained in INFCIRC/254/Rev.1/Part 1, dated 1 July 1992, available at: https://www.iaea.org/sites/default/files/infcirc254r1p1.pdf. The Board modified the VRS list twice; the resulting modified list served as the basis for Annex II of the MAP. See also Filippo Sevini, Renaud Chatelus, Malin Ardhammar, Jacqueline Idinger and Peter Heine ,"States' reporting of Annex II exports (AP) and the significance for safeguards evaluation," Symposium on International Safeguards: Linking Strategy, Implementation and People, 20–24 October 2014. Available at: https://www.iaea.org/sites/default/files/19/03/cn-220-paper-000263.pdf.

3 Laura Rockwood, "Safeguards and Non-Proliferation: The First Half Century from a Legal Perspective," Institute for Nuclear Materials Management, 2007.

4 International Atomic Energy Agency (hereafter "IAEA"), "Strengthening the Effectiveness and Improving the Efficiency of the Safeguards System," A Report by the Director General to the General Conference (GC(39)/17), 22 August 1995. Available at: https://www.iaea.org/sites/default/files/gc/gc39-17_en.pdf.

5 *Ibid.*

6 Laura Rockwood, "Legal Framework for IAEA Safeguards," IAEA, 2013. Available at: https://www.iaea.org/sites/default/files/16/12/legalframeworkforsafeguards.pdf.

State(s) and the International Atomic Energy Agency for the Application of Safeguards – or simply Model Additional Protocol (MAP) – which was approved by the Board on 15 May 1997.[7]

The MAP was developed as a voluntary legal instrument supplementary to CSAs required of non-nuclear-weapon States Parties to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT).[8] An additional protocol based on the MAP gives the IAEA more tools to verify the absence of undeclared nuclear activities or material in a country. Among these tools are expanded reporting requirements, including (but not limited to) those outlined in the MAP's two Annexes.

Article 2.a.(iv) of the MAP obligates NNWSs with additional protocols in force to provide a declaration containing a "description of the scale of operations for each location engaged in the activities specified in Annex I."[9] The activities listed in Annex I reflect key chokepoints in the nuclear fuel cycle that could be used to produce weapons-usable nuclear material; they relate to the manufacture, assembly or upgrading of certain equipment and materials related to enrichment, reactor operation, heavy water production and reprocessing of spent fuel.[10]

Article 2.a.(ix) obligates NNWSs with additional protocols to provide data pertaining to international transfers of specified equipment and non-nuclear material listed in Annex II.[11] This information includes the identity, quantity, location of intended use and date of export, in the case of exports of such items, and, upon request from the IAEA, confirmation by importing countries of such information. The list of equipment and non-nuclear material required to be reported was based on the list adopted by the Board in connection with the Voluntary Reporting Scheme (VRS) as it stood in 1996 which, in turn was based on Annex B of the Trigger List of the Nuclear Suppliers Group, chosen simply as a practical matter to avoid having to negotiate a whole new list.[12]

Article 16.b. of the MAP provides that the list of activities in Annex I and the list of equipment and material in Annex II may be amended by the Board "upon the advice of

7 IAEA, Model Protocol Additional to the Agreements Between State(s) and the International Atomic Energy Agency for the Application of Safeguards, INFCIRC/540 (Corr.), September 1997. Available at: https://www.iaea.org/publications/documents/infcircs/model-protocol-additional-agreements-between-states-and-international-atomic-energy-agency-application-safeguards.

8 While States with comprehensive safeguards agreements are to use the Model Additional Protocol as the standard for an AP, additional protocols may be concluded with any State with a safeguards agreement with the IAEA – this includes NPT nuclear-weapon States as well as States with item-specific agreements. In such cases, the State chooses what elements of the Model Additional Protocol it will implement.

9 IAEA, INFCIRC/540, Article 2.a.(iv).

10 Laura Rockwood, Noah Mayhew, Artem Lazarev and Mara Pfneisl (Zarka), "IAEA Safeguards: Staying Ahead of the Game," Swedish Radiation Safety Authority, 18 September 2019. Available at: https://vcdnp.org/wp-content/uploads/2019/09/201914-iaea-safeguards-staying-ahead-of-the-game.pdf.

11 IAEA, INFCIRC/540, Article 2.a.(ix).

12 IAEA, INFCIRC/540, Annex II/1, footnote. The list used for the VRS was drawn from the Nuclear Suppliers Group (NSG) Trigger List, reproduced in INFCIRC/254/Rev.1/Part 1. Available at: https://www.iaea.org/sites/default/files/infcirc254r1p1.pdf. The Board originally approved this list for use in the VRS in February 1993, and subsequently amended it in 1994 and 1996. For further information on the VRS and its amendments see: IAEA Archives, "Universal reporting system on nuclear material and specified equipment and non nuclear material" (GOV/2629), 22 January 1993; IAEA Archives, "Record of the Eight Hundred and Third Meeting" of the Board of Governors (GOV.OR.803), 10 March 1993; IAEA Archives, "Proposed Amendment to the List Being Used for the Reporting Scheme Endorsed by the Board of Governors" GOV/2767, 19 October 1994; and IAEA Archives, "Proposed Amendment to the List Being Used for the Reporting Scheme Endorsed by the Board of Governors" GOV/2842, 14 February 1996.

an open-ended working group of experts established by the Board."[13] However, 25 years after the MAP was approved by the Board, this provision has never been invoked and the Annexes have remained unchanged since 1997.

Meanwhile, the pace of technological advancements has increased significantly in the past decades, including in the more proliferation-sensitive parts of the nuclear fuel cycle.

The open-ended Advisory Committee on Safeguards and Verification within the Framework of the IAEA Statute – Committee 25 – was established in 2005 with a two-year mandate to consider ways and means to further strengthen safeguards.[14] Committee 25 met on six occasions to consider a wide range of proposals, including a proposal to consider updating the Annexes. However, by the end of its mandate, the Committee, largely viewed as a political process rather than a technical one, was unable to agree on a single consensus recommendation on any topic. To date, no open-ended working group has been convened for the purpose of making recommendations on amendments to the Annexes.

This study provides an analysis of technological advancements since the MAP was approved by the Board in 1997 with a view to providing clarity on their respective potential impacts on the effectiveness and efficiency of IAEA safeguards.

2. Study Methodology and Analytical Framework

As this study specifically relates to technology and material that are not covered under Annexes I and II of the MAP, the structure of the study is based on the structure of the Annexes themselves, as detailed below. The study first considers developments in fuel cycle capabilities that are not covered by MAP Annex I. The study then moves through Annex II, section by section. The analysis is captured through the use of case studies for each section, chosen because reporting to the IAEA on the technologies that the case studies address would improve the effectiveness and/or efficiency of safeguards, inter alia, by providing the IAEA with a more complete picture of a State's nuclear activities. Rather than an exhaustive list, the case studies are meant to be illustrative of potential gaps in the Annexes which the Board of Governors could choose to address.

In order to conduct this analysis, the author has considered several frameworks.

The first is a reference to a discussion during Committee 24 on considering the inclusion of beryllium metal, boron-10 and tritium in Annex I. During that discussion, Richard Hooper (then the Director of the Division of Concepts and Planning at the IAEA) noted that the underlying aim in crafting Annex I had been to list all known processes by which nuclear material could be obtained, and to identify and describe indicators of the existence of those processes.

13 IAEA, INFCIRC/540, Article 16.b.

14 IAEA Archives, "The Work of the Advisory Committee on Safeguards and Verification within the Framework of the IAEA Statute" (GOV/2007/27), 1 June 2007.

> "Such indicators fell into two groups, those which were necessary and sufficient conditions for the presence of a process producing nuclear material, and those which were only indicative of such a process. Beryllium metal, for instance, fell into the latter category, as it was possible to achieve the same effects without using beryllium. Boron-10 was used to manufacture control rods for reactors but was even more important from a safeguards point of view as a means of criticality control; however, it was a dual-use material and did not necessarily imply any non-peaceful activity. The case of tritium was different: although its primary use was a component of sophisticated weapons, its existence, in itself, indicated the presence of nuclear material somewhere."[15]

In considering case studies, the author has prioritised (but not limited himself to) cases where a material or technology was necessary for a known process for the production of nuclear material, or a by-product thereof, rather than simply indicative of such a process. In other words, items involved in the production of nuclear material, or materials which inherently indicate the existence of nuclear material, were prioritised as case studies.

Another consideration in both the selection of case studies, and the analysis thereof, is the language often found in Annex II of the MAP to describe categories of technologies: "especially designed or prepared" or EDP. This language has its roots in Article III.2 of the NPT, which states that each "State Party to the Treaty undertakes not to provide […] equipment or material <u>especially designed or prepared for the processing, use or production of special fissionable material</u>, to any non-nuclear-weapon State for peaceful purposes, unless the source or special fissionable material shall be the subject to the safeguards required by this Article" (emphasis added).[16] Where "EDP" language is used in the MAP, it was intended to as a guide to ensure that only nuclear-use (single-use) items are referred to. For example, Annex II, entry 1.2 defines reactor pressure vessels as metal vessels, which are especially designed or prepared to contain the core of a nuclear reactor, rather than just any metal vessel.

Given significant advances in technology, the EDP concept is important to bear in mind in the interpretation of Annex II entries and in contemplating other technologies that it does not currently include. However, it is worth noting that Annex II was specifically and intentionally formulated so as not to limit the list solely to single-use items, should the Board decide to expand the list.

Finally, it is important in assessing the technologies identified in this study to recall what the purpose of the MAP Annexes is and what it is not. The purpose of the Annexes is not to control the transfer of non-nuclear material and sensitive technology, but rather to provide the IAEA with a fuller picture of a State's nuclear-related activities. This helps the IAEA to plan for, implement and evaluate safeguards.

The use of case studies helps to focus the analysis in this study on particularly compelling examples of technology and material that are not covered by the MAP Annexes. However, many other technologies and materials were considered, the full list of which is available in the **Appendix**.

15 IAEA Archives, "Committee on Strengthening the Effectiveness and Improving the Efficiency of the Safeguards System, Established by the Board of Governors on 14 June 1996, Record of the Thirty Ninth Meeting" (GOV/COM.24/OR.39), 27 March 1997.
16 Treaty on the Non-Proliferation of Nuclear Weapons, Article III.2. Available at: https://www.un.org/disarmament/wmd/nuclear/npt/text/.

3. Annex I: List of Activities Referred to in Article 2.a.(iv) of the Protocol

As noted above, Annex I contains a list of activities about which States are required to provide a declaration that includes a description of the scale of operations for each location that engages in them. These activities include the manufacture, assembly, construction and upgrade of enrichment-related, reactor-related and reprocessing-related equipment and materials. At present, that list includes:

(1) The manufacture of centrifuge rotor tubes or the assembly of gas centrifuges;
(2) The manufacture of diffusion barriers;
(3) The manufacture or assembly of laser-based systems;
(4) The manufacture or assembly of electromagnetic isotope separators;
(5) The manufacture or assembly of columns or extraction equipment;
(6) The manufacture of aerodynamic separation nozzles or vortex tubes;
(7) The manufacture or assembly of uranium plasma generation systems;
(8) The manufacture of zirconium tubes;
(9) The manufacture or upgrading of heavy water or deuterium;
(10) The manufacture of nuclear-grade graphite;
(11) The manufacture of flasks for irradiated fuel;
(12) The manufacture of reactor control rods;
(13) The manufacture of criticality safe tanks and vessels;
(14) The manufacture of irradiated fuel element chopping machines;
(15) The construction of hot cells.

While all but one of these entries refers to manufacturing, it is important to note that there is no requirement that Annex I be limited to manufacturing. Rather, Annex I is meant to target key chokepoints along the nuclear fuel cycle and could thus include the scale of operations at locations engaged in any activity relevant to the production of weapons-usable material.

It is also worth noting that many, but not all, of the technologies identified in Annex I are also referred to in Annex II. For example, the first item in Annex I is the manufacture of centrifuge rotor tubes or the assembly of gas centrifuges, which are defined in Annex II, entries 5.1.1(b) and 5.1, respectively. Thus, in addition to the technologies used as case studies for Annex I, it may be advantageous to consider whether modifications to Annex II should be accompanied by commensurate modifications to Annex I. In this regard, consideration should be given to the added value of new or revised entries in the Annexes in improving the effectiveness and efficiency of safeguards.

This section considers three cases not included as entries in Annex I: accelerator-driven systems, the extraction of tritium and breeding blankets.

Accelerator-Driven Systems

The use of high-energy particle accelerators for transmutation – the conversion of one element or isotope into another – is not itself new. It dates back to 1947, when the method was recommended for use in the United States' nuclear weapons programme due to the limited availability of natural uranium for the programme. However, the use of accelerators for the acquisition of uranium was later terminated when ample supplies of uranium were discovered.[17] While the use of accelerators for this purpose was not pursued for the U.S. nuclear weapons programme, the technical feasibility of transmutation using accelerators was established. Indeed, experimentation continued through the decades.

As of the 1990s, advances in beam power levels for small accelerators began to raise the possibility that accelerator-driven systems (ADS) could be of interest to a potential proliferator for the production of nuclear material.[18] A 1998 analysis performed by experts from the U.S. Department of Energy, Oak Ridge National Laboratory and Argonne National Laboratory noted that, depending on the configuration of the system, two kilograms of plutonium per year could be produced using ADS.[19]

An ADS can look much like a traditional nuclear reactor, except the core is designed to remain subcritical, relying instead on neutrons supplied by an accelerator.[20] While an ADS for power production using uranium would require enriched uranium, it could also operate using plutonium-240 or heavier plutonium isotopes.[21]

A 2013 report commissioned by the Swedish Radiation Safety Authority notes that an ADS with power density analogous to a typical heavy water reactor can produce three to four kilograms of plutonium per year.[22] The report concludes that an ADS is an effective tool for producing weapons-grade plutonium because the production of the heavier plutonium isotopes is minimised and fuel replacements, which are costly or would normally be revealed by their frequency, can be avoided.[23] The latter may be particularly important for an actor with a limited supply of fuel.

The IAEA defines a significant quantity of plutonium – i.e. the approximate amount for which the possibility of manufacturing a nuclear explosive device cannot be excluded – as 8 kilograms,[24] but in reality any amount of unsafeguarded plutonium presents a proliferation concern.[25] Working with microgram quantities of plutonium – ostensibly easier to conceal than larger quantities – a potential proliferator could improve their understanding of

17 Meyer Steinberg, "Accelerator Spallation Reactors for Breeding of Fissile Fuel and Transmuting Fission Products," Brookhaven National Laboratory, January 1981. Available at: https://www.osti.gov/servlets/purl/6570456.

18 Christine D. Riendeau, David L. Moses and Arne P. Olson, "Proliferation Potential of Accelerator-Driven Systems: Feasibility Calculations," U.S. Department of Energy, June 1999. Available at: https://www.osti.gov/servlets/purl/12464-s1ZzJe/webviewable/.

19 *Ibid.*

20 Per Andersson, Fredrik Nielsen and Daniel Sunhede, "Acceleratordrivna subkritiska system – en analys med fokus på icke-spridning och exportkontroll," Swedish Radiation Safety Authority, 2013. Available at: https://inis.iaea.org/collection/NCLCollectionStore/_Public/44/057/44057153.pdf?r=1.

21 *Ibid.*

22 *Ibid.*

23 *Ibid.*

24 IAEA, "IAEA Safeguards Glossary," 2001 Edition. Available at: https://www.iaea.org/sites/default/files/iaea_safeguards_glossary.pdf.

25 It may also be possible to produce a nuclear weapon with as little as two to four kilograms of plutonium. Olli Heinonen, "North Korea's 5th Nuclear Test – What Now?," Foundation for Defense of Democracies, 16 September 2016. Available at: https://www.fdd.org/analysis/2016/09/16/north-koreas-5th-nuclear-test-what-now/.

mechanical properties related to nuclear weapons. This could include, for example, how much pressure would be needed to compress it to sustain a chain reaction in the core of a nuclear weapon.

While utilising ADS for any purpose requires significant up-front financial investment for even a relatively small nuclear material production capability, work continues on the development of this technology. Indeed, a variety of accelerator technologies with significant energy output could be used to manufacture nuclear material, if not necessarily economical or conventional.[26]

Reporting under Annex I on the scale of operations for locations using an ADS would help the IAEA provide credible assurance that the neutron flux of the ADS is not misused to produce nuclear material. The MAP does provide for complementary access to any place on a *site* as defined in Article 18.b of the MAP, but an ADS, even if used for a legitimate purpose, may not necessarily be located on a *site*.[27] The MAP also provides for access to any location specified by the Agency for the purpose of performing location-specific environmental sampling, but this provision depends upon the Agency having prior knowledge that an ADS is being used in a particular location.

As the technical feasibility of producing nuclear material using an ADS is well established, a requirement that NNWSs with additional protocols report on the scale of operations for locations engaged in transmutation using an ADS would be advantageous for the IAEA. Alternatively, the IAEA may wish to receive reports on the scale of operations for locations engaged in the manufacture of neutron sources (often consisting of a proton accelerator and a spallation target, though not exclusively) for use in ADS.

Tritium

There are two proliferation-significant aspects of tritium. The first is that tritium, an isotope of hydrogen, has clear applications for nuclear weapons, as it is a component in advanced, boosted-type nuclear weapons to increase the yield. The same is true for deuterium. However, unlike for deuterium, neither activities associated with the production of tritium, nor its export or import, are required to be reported under the MAP. Tritium is absent from both Annex I and Annex II of the MAP.

26 R. Scott Kemp, "Nuclear Proliferation with Particle Accelerators," Science and Global Security, 2005. Available at: https://scienceandglobalsecurity.org/archive/sgs13kemp.pdf.

27 INFCIRC/540, Article 18.b. defines a site as an area delimited by the State concerned "in the relevant design information for a facility, including a closed-down facility, and in the relevant information on a location outside facilities where nuclear material is customarily used, including a closed-down location outside facilities where nuclear material was customarily used (this is limited to locations with hot cells or where activities related to conversion, enrichment, fuel fabrication or reprocessing were carried out). It shall also include all installations, co-located with the facility or location, for the provision or use of essential services, including: hot cells for processing irradiated materials not containing nuclear material; installations for the treatment, storage and disposal of waste; and buildings associated with specified items identified by" the State pursuant to Annex I.

The second proliferation-sensitive aspect of tritium is that its mere existence indicates the presence of nuclear material somewhere, as it is a by-product of reactor activities.[28] Tritium rarely occurs in nature and, in realistic terms, can only be produced through the operation of a nuclear reactor.[29] While various technologies and methods can be used to produce tritium, countries most commonly rely on two approaches: detritiation of heavy water (a hydrogen isotope separation technique); and exposure of lithium targets to a neutron flux in a nuclear reactor.[30]

Countries that are known to produce or have produced tritium include eight of the nuclear-weapon-possessing States (China, France, India, Israel, Pakistan, Russia, the United Kingdom and the United States of America), as well as Canada, Germany, Japan, Romania, Slovenia, South Korea, Spain and Taiwan, China.[31,32] There is a modest specialist commercial market for tritium (particularly in small quantities) for such uses as producing radioluminescence for gun sights, watches, airport runway lights and other commercial applications. There is, however, no dedicated customs code (harmonised system code) for tritium at the time of this writing, which complicates the use of publicly available data to track tritium trade.

Moreover, as the development of fusion reactors continues, an increase in the commercial demand for tritium can be expected. The International Thermonuclear Experimental Reactor (ITER) is being used to test tritium breeding blanket concepts, the fuel for which will be procured from existing tritium supplies. However, the DEMOnstration Power Plant (DEMO), envisioned as the next step in commercial fusion power, will require approximately 300 grams of tritium per day, and will therefore need to be able to produce its own tritium in its breeding blanket.[33]

It is worth noting that many types of reactors can be used to produce both tritium and plutonium.[34]

> "For example, in heavy-water reactors, driver fuel rods of highly enriched uranium can provide the neutron flux to irradiate target rods of either lithium (to produce tritium) or depleted uranium (to produce plutonium). In the future, states could therefore secretly produce plutonium and attempt to avoid detection by other states by declaring production of tritium or other non-restricted isotopes."[35]

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28 IAEA Archives, “Committee on Strengthening the Effectiveness and Improving the Efficiency of the Safeguards System, Established by the Board of Governors on 14 June 1996, Record of the Thirty Ninth Meeting” (GOV/COM.24/OR.39), 27 March 1997.

29 Steven Wyrick, Joseph Cordaro, Nanette Founds and Curtis Chambellan, “National Nuclear Security Administration Tritium Supply Chain,” Institute for Nuclear Materials Management, 2013. Available at: https://resources.inmm.org/annual-meeting-proceedings/national-nuclear-security-administration-tritium-supply-chain.

30 Julien de Troullioud de Lanversin, Malte Göttsche and Alexander Glaser, Nuclear Archaeology to Distinguish Plutonium and Tritium Production Modes in Heavy-Water Reactors,” Office of Nonproliferation and Verification Research and Development, National Nuclear Security Administration, 14 January 2019. Available at: https://www.osti.gov/pages/servlets/purl/1525318.

31 *Ibid.*

32 Ministry of Economy, Trade and Industry of Japan, “Basic policy on handling of the ALPS treated water,” 13 April 2021. Available at: https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/202104_bp_breifing.pdf#page=29.

33 “Tritium Breeding,” The ITER Organization. Available at: https://www.iter.org/mach/TritiumBreeding.

34 Julien de Troullioud de Lanversin, Malte Göttsche and Alexander Glaser, Nuclear Archaeology to Distinguish Plutonium and Tritium Production Modes in Heavy-Water Reactors,” Office of Nonproliferation and Verification Research and Development, National Nuclear Security Administration, 14 January 2019.

35 *Ibid.*

Tritium was considered for inclusion in the MAP during Committee 24, but ultimately was not in order to achieve consensus on the MAP. While it may be argued as impractical to report on the scale of operations for all facilities which are capable of producing tritium, as this could apply to a number of nuclear power reactors with experimentation channels on which States already report, it would be advantageous for the IAEA to receive declarations on the scale of operations for facilities which specialise in the extraction of tritium from irradiated material or heavy water.

The same result could be accomplished by including in the MAP a requirement to report on the scale of operations for facilities engaged in the manufacture of lithium-6 targets by amending Annex I. Like tritium, lithium is used in a number of civilian applications, including the manufacture of lithium-ion batteries.[36] However, lithium-6 must be enriched for use in tritium production, differentiating the lithium used for lithium ion batteries from that used for tritium production.[37]

Breeding Blankets

There are at least two distinct types of breeding blankets relevant for different applications. In nuclear fission reactors, a breeding blanket can be used to transform fertile material, such as uranium-238 or thorium (the latter is theoretically possible, but is not done today), into plutonium.[38] In nuclear fusion, breeding blankets loaded with lithium-6 can be used to "breed the tritium required for [the deuterium-to-tritium] reaction and to convert nuclear energy into heat extracted by a coolant under pressure and temperature conditions appropriate for driving an acceptable thermodynamic cycle."[39]

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36 Lithium, World Nuclear Association, updated in October 2017. Available at: http://www.world-nuclear.org/information-library/current-and-future-generation/lithium.aspx.

37 The proportion of lithium 6 in natural lithium is approximately 7.56 percent, whereas a concentration approximately 40 percent of lithium-6 is used for tritium production; lithium 6 must be even further enriched to produce tritium for use in nuclear weapons. This differentiates enriched lithium 6 for tritium production from lithium cobalt oxide (LiCoO2) used for the production of lithium ion batteries. See David Albright, Sarah Burkhard, Mark Gorwitz and Allison Lach, "North Korea's Lithium 6 Production for Nuclear Weapons," Institute for Science and International Security, 17 March 2017. Available at: https://isis-online.org/uploads/isis-reports/documents/North_Korea_Lithium_6_17Mar2017_Final.pdf. See also Claus Daniel, "Lithium Ion Batteries and Their Manufacturing Challenges," Frontiers of Engineering, National Academy of Engineering, 2015. Available at: https://www.nap.edu/read/18985/chapter/11.

38 The IAEA Safeguards Glossary notes that there are two naturally occurring fertile materials, namely uranium-238 and thorium-232. In breeding blankets using uranium-238, excess plutonium is concentrated in the blanket. See IAEA, "Safeguards Glossary," 2001 Edition. See also Moritz Kutt, Friederike Frieß, and Matthias Englert, "Plutonium Disposition in the BN-800 Fast Reactor: An Assessment of Plutonium Isotopics and Breeding," Science & Global Security, 2014. Available at: https://scienceandglobalsecurity.org/archive/sgs22kutt.pdf.

39 Science Direct, "Breeding Blanket." Available at: https://www.sciencedirect.com/topics/mathematics/breeding-blanket.

In general terms, a breeding blanket consists of material and structural components, the latter of which are specific to the type of reactor for which the blanket is designed. In the case of fission reactors, the uranium in a breeding blanket, as well as the plutonium resulting from its use, is already required to be reported under INFCIRC/153.

The breeding blankets envisioned for fusion reactors do not use nuclear material and are not required to be declared under INFCIRC/153 or under an additional protocol. For example, breeding blankets which are envisioned for fusion reactors involve the use of a lithium-6 source which, when bombarded with neutrons, produces tritium for the deuterium-tritium fusion reaction that fuels the reactor.[40] As noted above, the DEMO Power Plant will require approximately 300 grams of tritium per day, which indicates a likely increase in the commercial demand for tritium.[41]

As also noted above, tritium is a component used in advanced, boosted nuclear weapons to increase the yield of the weapon. In this regard, a State intent on developing a nuclear weapons programme could seek to acquire tritium under the guise of experimentation with breeding blanket loaded with lithium-6 for use in nuclear fusion.

The added value for safeguards of reporting on breeding blankets is to better understand the technical capabilities of a State in terms of its know how for creating breeding blankets, in particular those using nuclear material. Reporting to the IAEA on the scale of operations for facilities engaged in the manufacture or assembly of any breeding blankets would give the IAEA more tools to assess the growing nuclear capabilities of States with such facilities.

40 Pat Brans, "Perfecting Tritium Breeding for DEMO and Beyond," The ITER Organization, 18 May 2020. Available at: https://www.iter.org/newsline/-/3447.

41 "Tritium Breeding," The ITER Organization. Available at: https://www.iter.org/mach/TritiumBreeding.

4. Annex II: List of Specified Equipment and Non-Nuclear Material for the Reporting of Exports and Imports According to Article 2.a.(ix)

Annex II of the MAP contains a list of specified equipment and non-nuclear material, the export of which (and on request, the import of which) is required to be reported to the IAEA. While case studies were chosen based on the EDP principle for maximum impact, as indicated above, there is no legal requirement that Annex II items be especially designed or prepared for nuclear use, which is why the title of Annex II refers to specified equipment and non-nuclear material.

Annex II includes seven categories:

(1) Reactors and equipment therefor;
(2) Non-nuclear material for reactors;
(3) Plants for the reprocessing of irradiated fuel elements, and equipment especially designed or prepared therefor;
(4) Plants for the fabrication of fuel elements;
(5) Plants for the separation of isotopes of uranium and equipment, other than analytical instruments, especially designed or prepared therefor;
(6) Plants for the production of heavy water, deuterium and deuterium compounds and equipment especially designed or prepared therefor;
(7) Plants for the conversion of uranium and equipment especially designed or prepared therefor.

The case studies in this section are based on the answers to four questions:

(1) What is the technology or material?
(2) What is the nuclear purpose or use of the technology or material?
(3) What else is the technology or material used for?
(4) What is the significance of the technology or material for safeguards?

1. Reactors and equipment therefor

Exclusion of "Zero Energy Reactors"

Entry 1.1 of Annex II refers to complete nuclear reactors, but exempts "zero energy reactors," defined as those "with a designed maximum rate of production of plutonium not exceeding 100 grams per year."[42] This exemption is apparently aimed at reducing the reporting burden on States exporting small research reactors, but in practice presents two weaknesses in terms of non-proliferation and safeguards.

42 IAEA, INFCIRC/540, Annex II/1, 1.1. Complete nuclear reactors.

The first relates to the possibility of a gradual build up of gram quantities of plutonium, one of two principal nuclear materials (the other being uranium-235) used to produce nuclear weapons.[43]

As previously noted, the IAEA defines a quantity of 8 kilograms of plutonium as a "significant quantity," meaning "the approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded."[44] In this regard, zero energy reactors – many of which are research reactors – may not pose an immediate risk for proliferation (though they can be used to test fuel for other reactors).[45] It should also be kept in mind that the fissile material to be used in such a reactor would be subject to safeguards. A larger quantity of plutonium and a more reliable source than a zero energy reactor, would be required to support a serious nuclear weapons programme. However, the insights gleaned from laboratory-scale experiments with gram or microgram quantities of plutonium could improve a country's nuclear know-how on how to work with separated plutonium.

The second weakness relates to the thorium fuel cycle. As noted, the MAP entry addressing complete nuclear reactors does not define a zero energy reactor by its power output, but rather by its designed maximum rate of plutonium production. The thorium fuel cycle does not produce plutonium, which is why reactors that might run on the thorium fuel cycle are not explicitly covered by Annex II.

While thorium is not widely used in nuclear fuel,[46] it is considered "source material" which in turn is included in the definition of nuclear material in CSAs.[47] While thorium is not itself fissile – meaning that it cannot support a self-sustaining chain reaction of fission – it is fertile, meaning that it can be used to create another material which is fissionable. In the case of thorium, the material it can create is uranium-233. While modern nuclear weapons are predominantly made from the isotopes uranium-235 and plutonium-238, it is theoretically possible to produce a nuclear weapon with uranium-233. Moreover, less of it would be required for a nuclear weapon than uranium-235.[48]

43 Neptunium and, to a lesser extent, americium can also be used for the manufacture of a nuclear explosive device. When the Statute was approved in 1956, the quantities of separated neptunium and americium were negligible and as such were not included in the definition of special fissionable material. Since that time, technological developments have lead to comparably larger quantities of separated neptunium and americium, largely driven by increased incentive to separate such products from high-level waste. For more information, see Jill N. Cooley et al., "IAEA Implementation of the Board of Governors Decision on Neptunium and Americium," Institute for Nuclear Materials Management, 2000. Available at: https://resources.inmm.org/annual-meeting-proceedings/iaea-implementation-board-governors-decision-neptunium-and-americium.

44 IAEA, "IAEA Safeguards Glossary," 2001 Edition. Available at: https://www.iaea.org/sites/default/files/iaea_safeguards_glossary.pdf.

45 IAEA, Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran (GOV/2013/40), 28 August 2013. Available at: https://www.iaea.org/sites/default/files/gov2013-40.pdf.

46 IAEA, "Thorium fuel cycle – Potential benefits and challenges," IAEA-TECDOC-1450, Table 1, page 4, May 2005. Available at: https://www-pub.iaea.org/mtcd/publications/pdf/te_1450_web.pdf.

47 IAEA, INFCIRC/153, Paragraph 112.

48 Jungmin Kang and Frank N. von Hippel, "U-232 and the Proliferation Resistance of U-233 in Spent Fuel," Science & global Security, 2001. Available at: https://scienceandglobalsecurity.org/archive/sgs09kang.pdf.

Both of these activities – the operation of a zero energy reactor (or any reactor) and the operation of a reactor under the thorium fuel cycle – are required to be reported to the IAEA.[49] While there is little risk that a State could import and operate a reactor of any size completely undetected, the exemption of zero energy reactors from Annex II has no real justification; there is no reason to exempt reporting on the export of any type of a reactor.

Removing the zero energy exception would provide additional assurances to cover the use of the thorium fuel cycle in zero energy reactors and provide further assurance that States are unable to amass undetected small quantities of plutonium for laboratory-scale experimentation through this route.

Coolant Circulators and Outdated Standards

MAP Annex II covers primary coolant pumps, defined as "pumps especially designed or prepared for circulating the primary coolant for nuclear reactors," encompassing pumps "certified to NC-1 or equivalent standards."[50] There are two weaknesses in the way in which this entry is written, one related to clarity and the other to industry standards.

The issue regarding clarity is related to gas-cooled reactors, which require circulators to move gas coolant through the reactor core rather than a pump for liquid coolant. While the argument could be made that a circulator and a pump, both especially designed or prepared (EDP) for use in a nuclear reactor, are not effectively different in purpose as each of them move coolant through the reactor core, the explicit inclusion of circulators would help to mitigate any confusion among States with respect to the reporting of EDP circulators.

Gas-cooled reactors represent a relatively small number of the operating reactors globally. According to the IAEA, only approximately three percent of the commercially operating reactors in the world are currently gas-cooled.[51] The 12 gas-cooled reactors in operation today, all of which are slotted for phase-out in the mid-2020s, are located in the United Kingdom.[52] However, among the six designs chosen for the Generation IV International Forum, the very-high-temperature reactor design is closest to deployment; China is already completing construction of an advanced modular high-temperature reactor.[53]

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49 Under INFCIRC/153, States are required to submit design information for facilities as early as possible before the introduction of nuclear material, as specified in the Subsidiary Arrangements. In accordance with the decision by the Board of Governors in 1992 on the early provision of design information, Code 3.1 of the model Subsidiary Arrangements General Part requires States to submit design information as soon as the decision to construct or to authorize construction of a facility is taken. INFCIRC/540 contains other relevant requirements, including the submission of a general description of each building on the site of a nuclear facility and ten-year plans for the development of the nuclear fuel cycle. See footnote 25 for the definition of a site as it relates to the MAP.

50 INFCIRC/540, Annex II/3, 1.7. Primary coolant pumps.

51 IAEA, "Gas cooled reactors." Available at: https://www.iaea.org/topics/gas-cooled-reactors.

52 IAEA, Power Reactor Information System, United Kingdom. Available at: https://pris.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=GB.

53 "IAEA, GIF call for faster deployment of next generation reactors," World Nuclear News, 20 July 2020. Available at: https://www.world-nuclear-news.org/Articles/IAEA-GIF-call-for-faster-deployment-of-next-genera.

There are eight advanced gas-cooled reactors in various stages of design, conceptual design and construction.[54] As the development of advanced gas-cooled reactors continues, it would be prudent to ensure that key components therefor are covered explicitly by Annex II.

Regarding industry standards, in the more than two decades that have passed since the MAP was approved by the Board, national and international standards have evolved. The NC-1 standards referenced in the MAP are U.S. national standards of the American Society of Mechanical Engineers (ASME) (Section III, Division I, Subsection NC), which have been revised since 1997. A revision to this entry could involve updating the reference to modern ASME standards or switching to International Organization for Standardization (ISO) standards. Alternatively, a revision could involve removing references to specific standards in order to eliminate the possibility of unintended loopholes for equipment that can be used but is not certified under a given standard (for example, some advanced reactor concepts work under lower pressure and could conceivably use lesser certified equipment).

While not a direct loophole in terms of safeguards, the use of outdated or antiquated standards that are no longer used by industry may lead to declarations of exports that do not include pumps (or circulators) which newer codes do cover, or conversely to incorrect reporting or overreporting of pumps (or circulators) which are covered under older codes but not under newer ones. Using current standards also contributes to ensuring the integrity of the EDP concept, as this would help delineate true EDP items from other equipment.

2. Non-nuclear materials for reactors

While there have been advances in non-nuclear materials for reactors, no such material examined for this study has an immediate impact of safeguards significance.

3. Plants for the reprocessing of irradiated fuel elements, and equipment especially designed for prepared therefor

Neutron Measurement Systems for Process Control

As currently formulated, MAP Annex II explicitly defines the following EDP equipment as falling within the section for reprocessing: irradiated fuel chopping machines to remove the fuel cladding for dissolution; dissolvers for the irradiated fuel; solvent extractors and related equipment meant to separate the uranium, plutonium and fission products;

54 Advanced gas-cooled reactor designs include the following: the Gas Turbine High Temperature under conceptual design in Japan; the Steam Cycle High Temperature Gas-cooled Reactor under conceptual design in the United States; the Prismatic Modular High Temperature GCR under design in the United States; the High Temperature GCR - Pebble-Bed Module under construction in China; and the Pebble Bed Modular Reactor on hold in South Africa. See IAEA, Advanced Reactors Information System, GCR. Available at: https://aris.iaea.org/sites/GCR.html. Advanced fast-neutron gas-cooled reactor designs include the following: the Energy Multiplier Module under conceptual design in the United States; the KAMADO FBR under conceptual design in Japan; and the ALLEGRO under design in the European Union. See IAEA, Advanced Reactors Information System, GFR. Available at: https://aris.iaea.org/sites/GFR.html.

storage vessels for use in reprocessing plants; as well as systems for the conversion of plutonium nitrate to oxide and then to metal. What it does not include is an entry for neutron measurement systems for process control.

Neutron measurement systems play two roles in reprocessing. First, they are used to monitor the inventory of fissile material in tanks during the solvent extraction process, i.e. when uranium and plutonium are being separated from irradiated fuel.[55] Second, they provide a secondary safety control system against criticality accidents.[56] As such, neutron measurement systems which are EDP for process control during reprocessing could be expected to exist in any reprocessing facility. The export of such systems could indicate that reprocessing activities are taking place in the importing State, or that the importing State intends to conduct such activities.

The EDP principle is particularly important to note here, as neutron measurement systems are used for a variety of purposes, including by the IAEA to implement safeguards. However, neutron measurement systems for reprocessing plants are generally configured to the plant in which they will be installed, making them difficult to mistake for other neutron measurement systems. In this regard, the provision of information about the export of EDP neutron measurement systems for use in reprocessing plants may help the IAEA maintain a better picture of a State's nuclear activities, in particular reprocessing.

Electrorefiners

The MAP Annex II section on reprocessing explicitly focuses on the Purex process, as it "has become the most commonly used and accepted process."[57] However, recent years have seen advances in techniques for reprocessing spent fuel that entail the use of technologies not covered under Annex II, including electrometallurgical and electrochemical techniques. Though they are not new processes, their continued development raises questions about reprocessing technologies which are not yet addressed comprehensively in Annex II. A common thread in these advancements is the use of electrorefiners, which are used to remove uranium from irradiated fuel elements.[58]

In the case of electrorefiners, a few countries with large nuclear installations are exploring advanced reprocessing technologies with the aim of supporting advanced fuel cycles. The designs for the electrorefiners envisioned for use in their respective advanced reprocessing campaigns may differ from each other.[59] In addition, "electrorefiner" can be a generic item, with applications to gold and silver refining and recycling alloys for semiconductors.

55 F.S. Moore et al, "An Automated Neutron Monitor Maintenance System," Institute for Nuclear Materials Management, 1996. Available at: https://inis.iaea.org/collection/NCLCollectionStore/_Public/28/001/28001844.pdf?r=1&r=1.

56 *Ibid.*

57 INFCIRC/540, Annex II/4, 3. Plants for the reprocessing of irradiated fuel elements, and equipment especially designed or prepared therefor.

58 National Research Council, "Electrometallurgical Techniques for DOE Spent Fuel Treatment," The Electrometallurgical Process at Argonne National Laboratory, The National Academies Press, 2000. Available at: https://www.nap.edu/read/9883/chapter/5.

59 IAEA, "Status and Trends in Pyroprocessing of Spent Fuel," IAEA Techdoc Series, 2021. Available at: https://www-pub.iaea.org/MTCD/Publications/PDF/TE-1967web.pdf.

Features that could differentiate electrorefiners EDP for reprocessing activities from electrorefiners for other purposes include, inter alia, the need for a radiation heat shield in the primary vessel of the electrorefiner and the need for the primary vessel to be corrosion resistant.[60] Especially as Generation IV reactors move closer to commercial deployment and research continues on advanced nuclear fuel cycles, it may be useful for the IAEA to receive information on the export of items that support those technologies, such as electrorefiners EDP for use in the reprocessing of irradiated fuel elements.

4. Plants for the fabrication of fuel elements

Fuel Fabrication Equipment

Despite the fact that fuel fabrication is one of the main stages of the nuclear fuel cycle, the language on fuel fabrication in MAP Annex II is relatively less detailed, compared to the processes it entails and as compared with other sections in Annex II. Notably, the section only refers broadly to equipment which "normally comes in direct contact with, or directly processes, or controls, the production flow of nuclear material," or "seals the nuclear material within the cladding."[61]

As cladding is meant to provide performance and safety benefits, it may be useful to more explicitly refer to equipment relating to safety and quality of the fabricated fuel elements. This could include, but would not necessarily be limited to, automatic machines for welding end caps onto fuel pins, automatic inspection and testing stations or EDP systems for the manufacture of the cladding.

As the section stands, the vague language could lead to inadvertent underreporting, which increases the burden on the IAEA in terms of follow-up with the State(s) concerned.

5. Plants for the separation of isotopes of uranium and equipment, other than analytical instruments, especially designed or prepared therefor

Special Shut-Off and Control Valves

In a gas centrifuge enrichment plant, auxiliary systems, equipment and components are required: to feed UF_6 into the centrifuges; to link individual centrifuges to one another to form cascades (a series of centrifuges); and to extract the product (enriched uranium) and the tails (depleted uranium).[62] MAP Annex II explicitly covers the following EDP items: feed systems/product and tail withdrawal systems; machine header piping systems; UF_6 mass spectrometers/ion sources; and frequency changers.[63]

60 Ting-shu Wu, C. A. Blomquist and J. E. Herceg, "Structural Evaluation on the Design of Electrorefiner," Argonne National Laboratory, 19 June 1995. Available at: https://inis.iaea.org/collection/NCLCollectionStore/_Public/27/007/27007556.pdf?r=1.

61 INFCIRC/540, Annex II/8, 4. Plants for the fabrication of fuel elements.

62 INFCIRC/540, Annex II/12, 5.2. Especially designed or prepared auxiliary systems, equipment and components for gas centrifuge enrichment plants.

63 *Ibid.*

What Annex II does not cover are valves used to regulate or shut off the feed of UF_6 to and from individual centrifuges. Such valves might be, but are not necessarily, bellow-sealed – so called "zero-leak" valves.[64] In the abstract, these valves have a variety of applications, but EDP valves needed for a gas enrichment plant are resistant to corrosion by UF_6 (and other fluoride compounds such as hydrogen fluoride that can be in the gaseous mixture) and designed to work under vacuum pressure, and as such would be distinguishable from valves used for non-nuclear purposes. A State that wished to create or maintain a gas centrifuge enrichment programme would certainly need to produce such valves domestically or import them.

The provision of trade data related to the export of shut-off and control valves EDP for use in auxiliary systems for gas centrifuge enrichment plants would give the IAEA another layer of data in the IAEA's trade analysis activities, resulting in a more complete picture of a State's nuclear activities as a whole.

6. Plants for the production of heavy water, deuterium and deuterium compounds and equipment especially designed or prepared therefor

Ammonia (NH_3) Synthesis Converters or Synthesis Units

Heavy water is a common material for use in nuclear reactors as a neutron flux moderator. Nuclear reactors which use heavy water are able to run on natural uranium, which has the advantage of not requiring uranium enrichment for nuclear fuel. However, fuel rods irradiated in such reactors, once reprocessed, yield high-quality, weapons-grade plutonium.[65] In this respect, heavy water and its associated equipment and production facilities are important for safeguards.

There are two processes which have proven to be commercially viable for the production of heavy water, one of which is the ammonia-hydrogen exchange process.[66] The ammonia-hydrogen exchange process can extract deuterium (the key component of heavy water) from synthesis gas (nitrogen and hydrogen). This requires EDP exchange towers, related internals and pumps, ammonia crackers, infrared absorption analysers, catalytic burners and ammonia converters.[67] The MAP Annex II covers each of these EDP items with the exception of ammonia converters, which are used to remove synthesis gas from the exchange towers and return synthesised ammonia. What makes these items EDP is that they are designed to be placed on the top of the exchange towers, which is not a requirement in non-nuclear industry.

The addition of ammonia synthesis converters to Annex II would provide the IAEA another layer of confidence related to the presence of EDP items that could be used to produce heavy water.

64 Dutch Valve Vision, "Bellow sealed valve." Available at: https://www.dutchvalvevision.com/bellow-sealed-valve/.
65 Robert J. Einhorn, "Iran's Heavy-Water Reactor: A Plutonium Bomb Factory," Arms Control Association, 9 November 2006. Available at: https://www.armscontrol.org/pressroom/2006-11/iran%E2%80%99s-heavy-water-reactor-plutonium-bomb-factory.
66 INFCIRC/540, Annex II/36. 6. Plants for the production of heavy water, deuterium and deuterium compounds and equipment especially designed or prepared therefor.
67 *Ibid.*

Complete Heavy Water Upgrade Systems or Columns Therefor

While the Annex II of the MAP, in conjunction with Article 2.a.(ix) of the MAP, provides for reporting on exports for EDP equipment for the production of heavy water (with the exception of ammonia synthesis converters), it does not account for the need for periodic upgrading of heavy water. The equipment currently covered under Annex II noted above – EDP exchange towers, related internals and pumps, ammonia crackers, infrared absorption analysers, catalytic burners – are potential parts of a heavy water production system, but are not sufficient to detritiate heavy water (i.e. remove the tritium build-up to increase deuterium purity).

In a State that uses heavy water in its reactors, the State will either need to upgrade the heavy water domestically or export the heavy water to other countries that have upgrading facilities. While the MAP does require the reporting of the export of heavy water, it does not currently require the reporting of exports of upgrade systems for detritiation. Adding complete heavy water upgrade systems (or columns therefor) to Annex II would help the IAEA track a country's capabilities with regard to a domestic heavy water upgrade capability.

7. Plants for the conversion of uranium and equipment especially designed or prepared therefor

Especially designed or prepared systems for the conversion of uranium dioxide (UO_2) to uranium tetrachloride (UCl_4)

MAP Annex II covers equipment used for a number of different uranium enrichment methods, including gas centrifuge, gaseous diffusion, aerodynamic, chemical or ion exchange and laser-based enrichment, as well plasma separation and electromagnetic isotope separation (EMIS).[68] While Annex II covers the majority of technologies used for the enrichment processes themselves, it would be worth considering the systems required to create the feedstock for such processes.

For example, the EMIS process works by accelerating uranium metal ions and passing them through a magnetic field that causes the ions of different isotopes to follow different paths, effectively separating one uranium isotope from another.[69] The process was used by Iraq in its clandestine nuclear programme because of its relative simplicity and, at that time, Iraq's ability to procure the magnet material without export control issues.[70]

The feedstock for the EMIS process is uranium tetrachloride (UCl_4), which must be converted from uranium dioxide (UO_2).[71] Much of the equipment required to conduct the

68 INFCIRC/540, Annex II/8-36. Plants for the separation of isotopes of uranium and equipment, other than analytical instruments, especially designed or prepared therefor.

69 INFCIRC/540, Annex II/34.5.9. Especially designed or prepared systems, equipment and components for use in electromagnetic enrichment plants.

70 "Electromagnetic Isotope Separation Uranium Enrichment," Global Security. Available at: https://www.globalsecurity.org/wmd/intro/u-electromagnetic.htm.

71 *Ibid.*

EMIS process is covered under Annex II. However, section 7 covering uranium conversion plants does not include the systems that are required to produce UCl_4, which is also used for other activities in the nuclear fuel cycle, such as in molten salt reactors and in some emerging reprocessing techniques. Considering the relative technological ease related to the EMIS process, it would be advantageous for the IAEA to receive reports on the export of EDP systems for the conversion of uranium dioxide UO_2 to UCl_4 to have a fuller understanding of the production of feedstock for the EMIS process.

5. Conclusions

It has been said that safeguards are only as effective as the IAEA's Member States wish them to be.[72] This paper has identified case studies of sensitive equipment and non-nuclear material that are not covered under the MAP Annexes, but which are significant in terms of safeguards. Reporting to the IAEA on the scale of operations of facilities that specialise in the extraction of tritium or the manufacture of lithium-6 targets, those which operate accelerator-driven systems and those which manufacture or assemble breeding blankets would strengthen the IAEA's understanding of the capabilities of a State with an additional protocol. Likewise, reporting to the IAEA on the export of non-nuclear material and sensitive EDP equipment identified in this report would take into account advances in technology since the MAP was approved in 1997.

This study is not meant to be exhaustive, but rather illustrative. There may be other installations, non-nuclear material or equipment the reporting of which would be critical for ensuring the effectiveness and efficiency of safeguards. Conversely, there may be entries currently in the Annexes, Annex II in particular, for which the reporting requirements do not advance the IAEA's safeguards mission and might even be removed or their scope reduced. This paper did not address those cases, but they do warrant further study.

INFCIRC/153, on which all comprehensive safeguards agreements are based, requires the IAEA to "take full account of technological developments in the field of safeguards," in implementing its safeguards responsibilities.[73] In this regard, the type of review conducted in this study should be ongoing with a view to ensuring the most effective and efficient safeguards system possible. This is particularly salient in the context of new and emerging types of reactors, fuels and coolants, which may entail the use of non-nuclear material and sensitive EDP equipment not yet widely known.

A complete list of facilities, non-nuclear material and equipment examined in the course of this study is available in the **Appendix** to this paper.

72 Laura Rockwood, "The Politics of Safeguards," a session during the Carnegie International Nuclear Policy Conference 2015 with Rafael Grossi, Anton Khlopkov and Laura Rockwood, 24 March 2015. Transcript available at: https://carnegieendowment.org/files/15-politicssafeguard240315wintro-formatted1.pdf.

73 INFCIRC/153, Paragraph 6.

Appendix: Matrix of Material and Equipment Considered Under the Project

The following items were considered in the course of the VCDNP's study on the Model Additional Protocol Annexes. Though some were selected for more detailed case studies, the items below are either not covered by the Annexes or are contained but would be worth amending due to technological advancements.

1. Reactors and equipment therefor

Equipment or material	Reason for consideration
Breeding blankets	Reporting on the scale of operations for facilities engaged in the manufacture of assembly of breeding blankets would allow the IAEA to better understand the fuel cycle capabilities of the relevant State.
External thermal shields	EDP external thermal shields reduce heat loss from the reactor and reduce temperature within the containment vessel.
Heat exchangers	Heat exchangers are essential parts of most nuclear reactors and not otherwise explicitly covered under Annex II.
Neutron detectors EDP for use in nuclear reactors	In-core and ex-core neutron detectors to monitor neutron flux are a common component of nuclear reactors.
Nuclear fuel cladding	Zirconium metal and alloys in the form of tubes or assemblies of tubes are covered under Annex II, but in quantities exceeding 500 kilograms in a period of 12 months. For the purposes of the Annexes, it may be desirable to reduce that quantity.
Nuclear reactor internals	The entry on reactor pressure vessels includes an explanatory note, which observes that while reactor internals are normally supplied with the reactor itself, the prospect that they would not be should "not necessarily be considered as falling outside the area of concern." In this regard, it may be useful for Annex II to have a separate entry on reactor internals.
Primary coolant pumps or circulators	This entry in Annex II does not explicitly include coolant circulators and notes antiquated and vague standards for the coolant pumps it explicitly does cover.
Zero energy reactors	MAP Annex II currently exempts zero energy reactors, which it defines as those with a maximum rate of production of plutonium not exceeding 100 grams per year.

2. Non-nuclear material for reactors

Equipment or material	Reason for consideration
Americium	Americium, as a material which could theoretically be used in a nuclear explosive device, was considered during Committee 25.
Beryllium metal	The manufacture of beryllium metal was considered in Committee 24 for inclusion in Annex I, as it can be used as a reflector in nuclear reactors.
Boron-10	The manufacture of boron-10 was considered under Committee 24 for inclusion in Annex I, as it is used to manufacture control rods for reactors and as a means of criticality control in reactors.
Lithium-6	During Committee 24, some argued that if tritium were to be included in the Annexes, it would make sense also to include lithium-6.
Neptunium	Neptunium, as a material which could theoretically be used in a nuclear explosive device, was considered during Committee 25.
Nuclear grade graphite	Advances in the accessibility of nuclear-grade graphite have given rise to consideration of adjusting the threshold of nuclear-grade graphite in Annex II, currently 30 metric tons. Consideration could be given to lowering it, raising it or removing it.
Tritium	Tritium is a component in boosted-type nuclear weapons and its mere presence is an indication of nuclear activities having taken place, which is why it was considered during Committee 24.

3. Plants for the reprocessing of irradiated fuel elements, and equipment especially designed or prepared therefor

Equipment or material	Reason for consideration
Electrorefiners	The entry in Annex II on reprocessing primarily focuses on the Purex process, but does not address technologies which are used for some reprocessing methods which are increasing in salience due to technological developments.
Irradiated fuel element decladding equipment and chopping machines	The Annex II entry specifically refers to irradiated fuel element chopping machines, allowing for some ambiguity in how the fuel element is decladded to expose irradiated nuclear fuel.
Neutron measurement systems for process control	While this entry of Annex II covers much of the equipment required for reprocessing of irradiated fuel elements, it does not cover the neutron measurement systems common to reprocessing activities for process control.

4. Plants for the fabrication of fuel elements

Equipment or material	Reason for consideration
Especially designed or prepared for the fabrication of nuclear reactor fuel elements	The Annex II section on plants for the fabrication of fuel elements does not include specific information about the kinds of equipment used for fuel fabrication, potentially leading to underreporting of items which are meant to fall under the section.

5. Plants for the separation of isotopes of uranium and equipment, other than analytical instruments, especially designed or prepared therefor

Equipment or material	Reason for consideration
Active magnetic suspension bearings	The current formulation of the entry concerning magnetic suspension bearings in Annex II could be interpreted as referring only to passive magnetic suspension bearings. This interpretation would exclude active magnetic suspension bearings, which are also used in gas centrifuge enrichment.
Diffuser housings	Annex II covers diffuser housings used for the gaseous diffusion enrichment process, but it may be desirable to reconsider the measurements associated with this entry.
Frequency changers	Frequency changers used for the supply of motor stators in gas centrifuge enrichment are covered under Annex II, but have advanced since the MAP was approved by the Board. It may be worth examining the specifications in Annex II, in particular as regards the output and frequency control.
Gaseous diffusion barriers and barrier materials	While Annex II covers gaseous diffusion barriers used for gaseous diffusion enrichment, it does not explicitly refer to barrier materials.
Laser systems	This entry in the MAP covers lasers or laser systems EDP for uranium separation. However, as there have been advances in laser technology, it may be advantageous to revisit.
Liquid or vapour uranium metal handling systems and components (atomic vapour based methods)	While the current entry in Annex II covers EDP systems for molten uranium or uranium alloys, it does not explicitly include systems for handling uranium metal vapour.
Liquid uranium metal handling systems	As this process is generally not used, it may be worth considering removal of this entry from Annex II.

Molecular pumps	The entry concerning molecular pumps is currently limited to those having a diameter of between 75 and 400 milometers. While these measurements reflected the state of centrifuge designs when the MAP was approved by the Board, it may be useful to revisit if these measurements should be expanded or reduced.
Rotating centrifuge components	The entry concerning centrifuge rotor tubes, rings, bellows, baffles and top/bottom caps are currently specified as having a diameter between 75 and 400 milometers. While these measurements reflected the state of centrifuge designs when the MAP was approved by the Board, it may be useful to revisit if these measurements should be expanded or reduced.
Separation element housings	The current entry in Annex II on separation element housings includes measurements in its explanatory note, which may exclude EDP separation element housings that fall outside of those measurements.
Special shut-off and control valves	The entry of Annex II pertaining to EDP auxiliary systems, equipment and components for gas centrifuge enrichment plants does not explicitly cover the shut-off and control valves meant to regulate the feed, product or tails for UF6 gas streams.
UF6 mass spectrometers/ ion sources	Annex II provides for reporting on the export of mass spectrometers EDP for taking online samples from UF6 streams during uranium enrichment, but includes only magnetic or quadrupole mass spectrometers. However, these are not the only kinds of mass spectrometers; in addition to magnetic sector and quadrupole spectrometers, there are also time of flight, sector, quadrupole ion trap and ion cyclotron resonance methods that are not covered by Annex II.
Uranium plasma generation systems	The specification in this entry is limited to delivered power of more than 2.5 kilowatts per centimetre. It may be advantageous for the IAEA to receive reports on the export of uranium plasma generation systems with any output.

6. Plants for the production of heavy water, deuterium and deuterium compounds and equipment especially designed or prepared therefor

Equipment or material	Reason for consideration
Complete heavy water upgrade systems or columns therefor	While Annex II provides for reporting on exports for EDP equipment for the production of heavy water (with the exception of ammonia synthesis converters), it does not account for the need to upgrade heavy water.
NH_3 synthesis converters or synthesis units	Annex II covers each of the EDP items related to common heavy water production processes with the exception of ammonia converters, used to take the synthesis gas from the exchange towers and return the synthesised ammonia.

7. Plants for the conversion of uranium and equipment especially designed or prepared therefor

Equipment or material	Reason for consideration
Especially designed or prepared systems for the conversion of UO_2 to UCl_4	The feedstock for the EMIS process is uranium tetrachloride (UCl_4), which must be converted from uranium dioxide (UO_2). While much of the equipment required to conduct the EMIS process is covered under Annex II, section 7 covering uranium conversion plants does not include the systems which are required to produce UCl_4.
Plants for the conversion of plutonium and equipment especially designed or prepared therefor	This section of Annex II current refers to plants for uranium conversion and related EDP equipment. What this section lacks is a reference to plutonium conversion plants, which are usually associated with reprocessing activities, but can also be used for the fabrication of plutonium-based fuel.

Additional Considerations

Equipment or material	Reason for consideration
Accelerator Driven Systems	Transmutation might be carried out in an accelerator, which might be operated to produce undeclared fissile material.
Storage Installations for Annex II Items	While the IAEA would have access to any installations, including storage facilities, which are co-located with nuclear facilities and other locations to which the IAEA has access through complementary access, a separate non-co-located storage installation would not necessarily be covered.

Author

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