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WORKING MATERIAL

Report of the consultancy meeting on “Non-Proliferation Challenges in Connection with Magnetic Fusion Power Plants”

IAEA Headquarters, Vienna, 26 – 28 June 2013

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TABLE OF CONTENTS

1 EXECUTIVE SUMMARY

Advances in the understanding of non-proliferation aspects of magnetic fusion energy have resulted in the interest in further analysis and dialogue. A group of fusion scientists and engineers and non-proliferation experts were invited by the IAEA Nuclear Applications Department, Division of Physical and Chemical Sciences to meet with members of the IAEA Safeguards Department, Division of Concepts and Planning and discuss non-proliferation aspects of magnetic fusion energy. As a Consultative Group, the fusion scientists and engineers and non-proliferation experts came to unanimously agreed high-level findings and recommendations that we hope are useful to the IAEA in its forward planning, and give rise to practical near-term actions.

1) This was a very valuable meeting, allowing detailed discussions between communities that need to develop closer links in the future. *We recommend that this kind of cross-fertilization continue through the forum of the IAEA DEMO Programme Workshop series.*
2) There are R&D opportunities to advance the non-proliferation aspects of fusion, for example by testing methods to assure that fusion blanket modules do not contain source materials. *We recommend that reports on such activities be included in the IAEA DEMO Programme Workshops. Collaboration with the IAEA could be productive in this regard.*
3) While fusion power plants produce significant amounts of neutrons which could in principle be used to produce special fissionable material, pure fusion power plants do not contain source material, and this should be straightforwardly verifiable. However the framework for inclusion of fusion power plants into verification regimes is unclear. *We recommend that the IAEA consider means to achieve such inclusion.*
4) Pure fusion power plants will produce the tritium required for their own operation, and for start-up of future power plants. Because tritium plays a role in advanced nuclear weapons systems, however, *the issue of tritium monitoring warrants further consideration.*
5) We also came to two specific technical conclusions:
    a. The ITER facility itself does not present proliferation risks because of its modest neutron production and extensive international oversight.
    b. The possibility of a clandestine magnetic fusion system for the production of special fissionable material appears to be implausible due to financing, size, power and environmental signatures.

2 INTRODUCTION – BACKGROUND SITUATION ANALYSIS

Recent advances in magnetic fusion energy research, including the current construction of the ITER project, suggest that it is timely to update the early studies of the non-proliferation characteristics of fusion systems, and indeed initial efforts have already been undertaken by participants in the Consultative

Group[1] (which helped to inform our discussion). It was considered timely, furthermore, to bring together experts in fusion energy R&D, including from the ITER project, and experts in fusion non-proliferation, with experts from the IAEA Department of Safeguards, Division of Concepts and Planning[2]. Indeed this has proven quite productive. Findings were determined in six areas, with significant recommendations in four of these areas.

In particular, it was found that continuing communication between the fusion and safeguards community should be encouraged, particularly within the framework of the annual IAEA DEMO Programme Workshops, that there is significant and important R&D to be undertaken in which the fusion community and the IAEA Safeguards Department could collaborate, and that it will be useful to clarify the framework for non-proliferation verification of fusion power systems.

3 FINDINGS AND RECOMMENDATIONS

3.1 Communication

Finding: This Consultative Group meeting was very useful, as it allowed the magnetic fusion community to gain a better understanding of the IAEA safeguards regime, and also allowed the IAEA safeguards community to gain a better understanding of the properties of magnetic fusion systems. It facilitated a broad discussion of key non-proliferation issues associated with magnetic fusion.

Recommendation: *We recommend that this kind of cross-fertilization continue through the forum of the annual IAEA DEMO Programme Workshops. This should evolve into discussions of how to integrate appropriate monitoring strategies most efficiently and effectively into future fusion power systems.*

The IAEA currently advocates the early inclusion of verification into the design of fission reactors, through dialogue between all stakeholders[3]. This is an effective means to reduce the cost of verification while improving its effectiveness. While fusion power plants are at an early conceptual stage, inclusion of verification considerations is highly appropriate.

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[1] M. Englert, G. Franceschini, W. Liebert, 7th INMM/ESARDA Workshop, Aix-en-Provence, 2011, A. Glaser, R.J. Goldston, Nuclear Fusion **52** (2012) 043004

[2] The participants represented their own opinions, not those of any organization(s) with which they are associated.

[3] IAEA Nuclear Energy Series publication NP-T-2.8, available from www.iaea.org

3.2 R&D Opportunities

Finding: There are R&D opportunities to advance the non-proliferation aspects of fusion, for example by testing methods to assure that fusion blanket modules do not contain source materials.

Recommendation: *We recommend that reports on such activities be included in the IAEA DEMO Programme Workshops. Collaboration with the IAEA would be productive in this regard*.

Pure fusion systems by their definition do not contain source or special fissionable material. It is nonetheless valuable to undertake R&D to determine if there are practical means to misuse fusion neutrons in an otherwise pure fusion system without obvious outside signatures (such as massive diversion of source material), and to find the most effective and efficient means to verify that such misuse is not taking place. A number of areas of possible R&D were identified, including:

a) Evaluation of means to verify the absence of source or special fissionable material in fresh fusion blanket modules; evaluation of means to verify the absence of source or special fissionable material in fusion blankets during operation; and evaluation of means to verify the absence of source or special fissionable material in fusion blankets after exposure in a fusion power plant.

b) Determination of the practicality of source material being mixed with coolant or purge flows; evaluation of design choices that would render this most difficult; and evaluation of means to verify the absence of source or special fissionable material traveling with the coolant.

c) Evaluation of the time period and difficulty associated with replacing pure-fusion test blanket modules in a fusion power plant with blanket modules designed to breed special fissionable material; and consideration of designs that both extend the time period and increase the difficulty of this.

Further, one should consider the possible misuse of other internal components exposed to high neutron fluence. Studies of this nature would begin with analysis and calculations, and proceed to progressively more realistic experimental studies. It was evident to the Consultative Group that the deep knowledge base and practical experience of the IAEA Safeguards Department would be invaluable in helping the fusion community to optimize these studies.

3.3 Verification Regime for Fusion Power Plants

Finding: While fusion power plants produce significant amounts of neutrons, which could in principle be used to produce special fissionable material, pure fusion power plants do not contain source material, and this should be straightforwardly verifiable. Furthermore, the absence of source material means that neutrons from fusion cannot be used to produce special fissionable material. It also means that even small amounts of source or special fissionable material should be easily detectable. On the other hand, it has the legal consequence that the framework for inclusion of pure fusion power plants into verification regimes is unclear, but verification will be needed to confirm the absence of source materials.

Recommendation: *We recommend that the IAEA consider means to achieve this verification.*

Due to the high neutron fluence experienced by the first wall of a fusion power plant, in principle it is possible to breed special fissionable material, so long as care is taken to sustain the necessary rate of tritium production and to handle any additional power production. This could in principle be achieved through the insertion of source material into suitable locations within the reactor, such as the main blanket or individual test blanket modules. The latter are likely to be required on early-generation fusion power plants.

A fusion facility designed to employ source material or special fissionable material for the production of fuel for separate fission power plants, for multiplying the power output from fusion, or for the destruction of fission waste products, is called a “fusion-fission hybrid”. Such a facility would clearly be subject to IAEA safeguards under INFCIRC/153 or INFCIRC/540. These are not the topic of the present discussion, however, which is focused on “pure” fusion power plants that under nominal operation contain no source or special fissionable material.

The absence of source material (or of any other materials of proliferation concern) means that the neutrons from fusion cannot be misused – but verification will be needed to confirm the absence of such materials in pure fusion plants. This verification will be greatly facilitated by the fact that under normal circumstances no significant source or special fissionable material should be present in the D-T fusion neutron flux. However the absence of source materials under normal operation also means that the legal framework for considering the inclusion of fusion power plants into current verification regimes is unclear.

Current verification frameworks are based on the assumption that nuclear materials are used in any facility that requires verification, following the logic of the material flows in the various possible fission systems. The design flow and/or inventory of source or special fissionable material is also used to determine the frequency of inspections.

This raises questions about whether fusion power plants can be covered appropriately by existing verification agreements, or if other mechanisms need to be identified. It would be advantageous to include fusion in existing verification regimes, including the associated efforts to improve the effectiveness and efficiency of verification through early design considerations. The IAEA can be requested to provide guidance on how this verification can be integrated into verification regimes in the future.

3.4 Tritium

Finding: Pure fusion power plants will produce the tritium required for their own operation, and for the start-up of future power plants. ITER will provide very valuable, relevant experience with tritium management and accountancy. Tritium, however, also plays a role in advanced nuclear weapons systems.

Recommendation: *We recommend that the issue of tritium monitoring receive further consideration.*

Magnetic fusion energy pure fusion power plants based on D-T fuel require the production of tritium fuel for sustained operation. D-T fusion plasmas will create neutrons, which will be absorbed in ^{6}Li-containing blankets that surround the plasma, extracting thermal energy and also producing the tritium needed for refueling the power plant and starting up future plants. For example, a 2.5 GW(th) fusion power system will maintain an onsite tritium inventory of several kilograms and will need to produce about 400 g/day of tritium while in operation, mainly through the reactions:

$$D + T \rightarrow \alpha + n$$

$$n + {}^6Li \rightarrow \alpha + T$$

Tritium accountancy has remained outside of current verification regimes. However only a small amount of deuterium-tritium “boost” gas is required to enhance the efficiency and reliability of nuclear weapons (both fission and thermonuclear). For example the tritium reservoirs of U.S. nuclear weapons systems are reported by the U.S. government generally to contain less than 20 g of tritium. Tritium plays a role in advanced nuclear weapons systems, and openly published technical information over the past several decades may have brought D-T boosting into the realm of consideration by less advanced potential proliferators.

The possible contribution of D-T boosting to both vertical and potentially horizontal proliferation indicates that the issue of tritium monitoring warrants further consideration.

The design and operation of ITER will augment existing experience with tritium management and accountancy. ITER is under extensive health and safety regulatory requirements of the host State.

3.5 ITER

Finding: The ITER facility itself does not itself present proliferation risks, both because ITER will produce a modest lifetime fluence of neutrons and because the operation of ITER is under extensive international oversight.

Article 20 of the ITER Agreement states, “The ITER Organization and the Members shall use any material, equipment or technology generated or received pursuant to this Agreement solely for peaceful purposes” as well as, “The ITER

Organization and the Members shall take appropriate measures to implement this Article in an efficient and transparent manner. To this end, the Council shall interface with appropriate international fora and establish a policy supporting peaceful uses and non-proliferation."

ITER has strict and internationalized control of design and construction of the machine, including all systems and components. Design and construction of ITER Test Blanket Modules (TBMs) and other internal components by the Members is under ITER Organization oversight, and in compliance with ITER specifications. It is therefore excluded that any source material or fertile material could be used in the core of machine that is subject to neutron fluxes. Moreover, ITER has a comparatively small maximum lifetime neutron power fluence of 0.3MW-yr/m^2, to be delivered over a period of about 10 years. This corresponds to approximately 1/100'th of the time-average neutron flux of a DEMO power plant. Even if, very hypothetically, an ITER Test Blanket Module were replaced with an efficient breeder of special fissionable material, it could still not produce enough material to be of concern.

3.6 Clandestine Fusion Systems

Finding: The possibility of a small, clandestine magnetic fusion system for the production of special fissionable material is implausible due to overall facility size, power and environmental signatures. A facility capable of producing even 1/2 of a "Significant Quantity[4]" per year would necessarily be large, and such a facility would have very high power consumption as well as construction cost. Tritium from such a facility would be a detectable environmental signature.

Since the current worldwide fusion research program operates devices that produce 14.1-MeV neutrons, one can ask if there is a fusion equivalent to the small fission research reactors that produce plutonium in significant quantities and, if so, if such a device could be constructed and operated clandestinely. Experiments have already produced ~10 MW(th) of fusion power for ~1 second pulses, and compact steady fusion systems have been proposed to develop applications other than the direct production of energy. These two classes of devices can be used as reference points to examine the possibility of clandestine fusion facilities.

Previous fusion experiments (TFTR, JET) have produced about 10 MW of D-T power, but at very low duty factors. They are also very visible. For example, the Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory used up to 1000 MW of pulsed magnet power. Operation required large energy storage and power conversion equipment. The site covers about 10 hectares, and the buildings cover 80x80 m2, not including the power substation, control room or cooling tower. The facility is easily discernable in publicly available satellite imagery.

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[4] The IAEA Safeguards Glossary defines a "Significant Quantity" as "the approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded". For Pu containing < 80% ^{238}Pu and for ^{233}U this is 8 kg.

Kuteev et al.[5] have published a pre-conceptual design for a compact device that draws about 40 MW continuously from the grid, and produces fusion power of 2 MW. Applying the results from a previous study one can estimate that, under the most favorable assumptions, such a facility could produce about 3.5 kilograms of special fissionable material (plutonium or uranium-233) per year. It is currently implausible to assume that these activities would remain undetected.

Under routine operation, all fusion power systems, including the device proposed by Kuteev et al., that operate on the D-T fuel cycle emit tritium in minute quantities. These trace amounts can be detected above the natural background level, if environmental measurements are permitted, even when several orders-of-magnitude below international safety limits. Tritium could therefore be an additional detectable environmental signature and reveal hypothetical undeclared fusion experiments.

Overall, the signatures relevant for remote detection of undeclared nuclear installations appear much stronger for fusion devices than for many other pathways to acquire nuclear weapons materials, i.e., based on fission reactors and uranium enrichment plants. Clandestine production of special fissionable material, or tritium, at an undeclared fusion plant does not appear to be a major proliferation concern.

4 CONCLUSIONS AND FINAL REMARKS

This was a very valuable Consultative Group meeting, allowing a group of fusion scientists and engineers and non-proliferation experts to meet with members of the IAEA Safeguards Department, Division of Concepts and Planning and discuss non-proliferation aspects of magnetic fusion energy. As a Consultative Group, the fusion scientists and engineers and non-proliferation experts came to unanimously agreed high-level findings and recommendations that we hope are useful to the IAEA in its forward planning, and give rise to practical near-term actions. These can be summarized as:

1) This was a very valuable meeting, allowing detailed discussions between communities that need to develop closer links in the future. *We recommend that this kind of cross-fertilization continue through the forum of the IAEA DEMO Programme Workshop series.*
2) There are R&D opportunities to advance the non-proliferation aspects of fusion, for example by testing methods to assure that fusion blanket modules do not contain source materials. *We recommend that reports on such activities be included in the IAEA DEMO Programme Workshops. Collaboration with the IAEA could be productive in this regard.*
3) While fusion power plants produce significant amounts of neutrons which could in principle be used to produce special fissionable material, pure fusion power plants do not contain source material, and this should be

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[5] Kuteev, B.V. et al., Nucl. Fusion **51** (2011) 073013

straightforwardly verifiable. However the framework for inclusion of fusion power plants into verification regimes is unclear. *We recommend that the IAEA consider means to achieve such inclusion.*

4) Pure fusion power plants will produce the tritium required for their own operation, and for start-up of future power plants. Because tritium plays a role in advanced nuclear weapons systems, however, *the issue of tritium monitoring warrants further consideration.*
5) We also came to two specific technical conclusions:
    a. The ITER facility itself does not present proliferation risks because of its modest neutron production and extensive international oversight.
    b. The possibility of a clandestine magnetic fusion system for the production of special fissionable material appears to be implausible due to financing, size, power and environmental signatures.

5 ANNEX I - TERMS OF REFERENCE

INTERNATIONAL ATOMIC ENERGY AGENCY

Terms of Reference

Consultancy Meeting on
Non-Proliferation Challenges in Connection with Magnetic Fusion Power Plants

June 26-28, 2013
Room A0742, IAEA, Vienna, Austria

Background

With the beginning of the construction of the ITER Project, magnetic fusion energy is moving for the first time into a truly nuclear phase. While ITER itself may not present significant proliferation risks, it may provide an opportunity for exploring non-proliferation challenges for magnetic fusion.

The primary proliferation risks associated with magnetic fusion come from the presence of abundant 14 MeV neutrons. In principle these neutrons can be used to breed weapons-usable ^{239}Pu or ^{233}U from ^{238}U or ^{232}Th, but this would not be normal practice in a “pure” fusion reactor. It would be normal practice, on the other hand, to breed ~ 0.4 kg/day of T from ^{6}Li. T is known to be used in small quantities by advanced Nuclear Weapons States to “boost” the yield of fission explosives, but it cannot be used without fissile material to build a nuclear weapon.

The scenarios that need to be considered in evaluating the proliferation risks from magnetic fusion include:

1) Covert diversion of weapons-usable material from a fusion power plant, including their covert production in the case of fissile materials.
2) Clandestine operation of a fusion system for production of weapons materials.
3) Rapid turnaround of a fusion power plant for production of weapons materials

Key strategic issues to address are:

a) How and whether to evaluate or consider measures on ITER Test Blanket Modules, taking into account both scenarios 1) and 3) above.

b) Tritium accountability issues for fusion power plants: economic, loss or theft, quality control, might safeguards ever be necessary?
c) The possibility of small-scale, potentially clandestine, fusion-based technologies for the production of weapons materials.
d) The Treaty on the Non-Proliferation of Nuclear Weapons.

Objectives

The meeting will gather a small group of experts from the fusion and non-proliferation communities to discuss ideas and opportunities in the key strategic issues including coordinated approaches. In particular the meeting will aim at improving the understanding of non-proliferation, the capabilities of fusion (existing and projected), the feasibility and need for international or Member State action and potential further activities.

Expected output

The expected output of the meeting is a written report by the participants summarising the findings of the meeting and a detailed set of recommendations for activities.

IAEA Scientific Secretary of the Meeting

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6 ANNEX II LIST OF PARTICIPANTS

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in Connection with Magnetic Fusion Power Plants
26 – 28 June 2013, Room A-0742, IAEA, Vienna, Austria

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7 ANNEX III - AGENDA

INTERNATIONAL ATOMIC ENERGY AGENCY

Agenda

Consultancy Meeting on

Non-Proliferation Challenges in Connection with Magnetic Fusion Power Plants

26 – 28 June 2013

Room A0742, IAEA, Vienna, Austria

Wednesday, 26 June 2013, VIC, Room A-0742

08:30-09:00	Check in at Check Point 1, IAEA Headquarters, Wagramer Strasse 5 Meet at Room A0742 (phone: 0043 1 2600 26393, Ms Marion Linter, for urgent cases)
09:00-09:30	**Welcome and Opening** Ms Meera Venkatesh, Director, Division of Physical and Chemical Sciences Mr Richard Kamendje, Scientific Secretary Election of Rapporteurs (2) Discussion and Approval of the Agenda, Administrative Arrangements.
Session 1	**Possible Proliferation Concerns in Connection with Fusion Energy**
09:30-10:00	Magnetic Confinement Fusion: Basic Physics Principles & Current General Designs Characteristics *Robert Goldston*
10:00-10:30	Princeton Assessment of Proliferation Risks in Connection with Magnetic Fusion Energy *Alexander Glaser*

10:30-11:00	Coffee Break
11:00-11:30	Ianus Perspective on Proliferation Risks in Connection with Magnetic Fusion Energy *Matthias Englert, Wolfgang Liebert, Giorgio Franceschini*
11:30-12:00	Independent Perspective on Proliferation Risks in Connection with Magnetic Fusion Energy *Richard Wallace*
12:00-13:00	**Discussion** Moderator: Mr Alexander Glaser
13:00-14:30	**Lunch Break**
Session 2	**IAEA Safeguards - Background**
14:30-15:00	NPT Legal Framework & the IAEA Mandate *Ionut Suseanu*
15:00-15:30	Overview of Nuclear Material Safeguards Implementation *Neil Tuley*
15:30-16:00	Current IAEA Safeguards Approaches for Fission Reactors *James Sprinkle*
16:00-16:30	Coffee Break
16:30-17:15	**Discussion: IAEA Safeguards** *Moderated by chairs*
17:15	Adjourn
17:30	Hospitality Event for All

Thursday, 27 June 2013, VIC, Room A-0742

Session 3	**Possible Technologies for addressing proliferation concerns in Fusion Devices**
09:00-10:00	Monitoring Fissile Material Production in Fusion Blankets, Available Know How and R&D Needs, based on ITER Experience *John How, Satoshi Konishi*
10:00-11:00	Monitoring Tritium Diversion in MFE Plants: Available Know How and R&D Needs, based on ITER Experience

	Manfred Glugla
11:00-11:30	Coffee break
11:30-12:30	**Discussion: R&D Needs and Possible Strategies** *Moderated by chairs*
12:30-14.00	Lunch Break
Session 4	**Paths Forward**
14:00-15:00	Suggestions for R&D on ITER *Robert Goldston*
15:00-15:30	**Discussion: R&D on ITER**
15:30-16:00	Coffee Break
Session 5	**Drafting meeting report**
16:00-17:30	Input preparation for report
17:30	Adjourn

Friday, 28 June 2013, VIC, Room A-0742

Session 6	**Drafting meeting report**
09:00-10:30	Draft meeting report
10:30-11:00	Coffee Break
11:00-12:30	Executive summary
12:30-14:00	Lunch
Session 7	**Presentation of Findings and Recommendations**
14:00-14:30	Presentation of Findings and Recommendations
14:30-15:30	Final Discussion & Closing
15:30	Departure