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Consultancy on the

Potential of Fusion/Fission Sub-critical Neutron Systems for Energy Production and Transmutation

Conducted within the frame of IAEA's
Technical Working Group on Fast Reactors
(Technology Advances in Fast Reactors and Accelerator Driven Systems)

IAEA Headquarters, Vienna, Austria

15 – 17 June 2005

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International Atomic Energy Agency

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Executive Summary

The Workshop on Sub-critical Neutron Production held at the University Of Maryland and the Eisenhower Institute on 11-13October 2004 brought together members of fusion, fission and accelerator technical communities to discuss issues of spent fuel, nonproliferation, reactor safety and the use of neutrons for sub-critical operation of nuclear reactors. The Workshop strongly recommended that the fusion community work closely with other technical communities to ensure that a wider range of technical solutions is available to solve the spent fuel problem and to utilize the current actinide inventories. Participants of the Workshop recommended that a follow-on Workshop, possibly under the *aegis* of the IAEA, should be held in the first half of the year 2005. The Consultancy Meeting is the response to this recommendation.

The objectives of the Consultancy meeting were to hold discussions on the role of fusion/fission systems in sub-critical operations of nuclear reactors. The participants agreed that development of innovative (fourth generation) fission reactors, advanced fuel cycle options, and disposition of existing spent nuclear fuel inventories in various Member Sates can significantly benefit from including sub-critical systems, which are driven by external neutron sources. Spallation neutrons produced by accelerators have been accepted in the past as the means of driving sub-critical reactors. The accelerator community deserves credit in pioneering this novel approach to reactor design. Progress in the design and operation of fusion devices now offers additional innovative means, broadening the range of sub-critical operations of fission reactors. Participants felt that fusion should participate with accelerators in providing a range of technical options in reactor design. Participants discussed concrete steps to set up a small fusion/fission system to demonstrate actinide burning in the laboratory and what advice should be given to the Agency on its role in possible activities to be implemented under IAEA *aegis*.

The Consultancy examined existing experimental facilities and devices that could produce 14 MeV neutrons in the near future to permit the first concrete steps toward fusion-fission systems and how such a facility can become an integral part of the effort to develop sub-critical reactors, presently spearheaded by accelerator driven systems. In support of this effort, the Consultancy discussed and proposed a set of studies that permit future inter-comparison between various utilization and/or transmutation technologies, including accelerator driven systems and possible DT-plasma fusion devices for such application in the near future.

The Consultancy recommended enhanced coordinated efforts for developing DT-plasma fusion driven sub-critical core designs. The main areas requiring enhanced research and technology development are nuclear data, forms and preparation of fuel, chemistry control, sub-critical core design, and systems integration.

The Consultancy endorsed the following steps:

- **The Russian institutes will submit a joint ISTC proposal** for developing a DT fusion plasma-driven actinide burning experiment to be completed within one year, in preparation for its utilization in DT-fusion plasma driven sub-critical cores.
- **European participant members will consider examining fusion-fission systems** for disposing of spent nuclear fuel, as well as energy production within the EU's 7th Framework Programme (FP7)
- **Some participants (e.g., Sweden and UK) will contact industries and research institutes** for supporting development of fusion-fission systems for disposing of spent nuclear fuel and energy production
- **The US members will seek involvement of US organizations** in the development of fusion-fission systems for disposing of transuranic elements and transmuting long-lived fission products.
- The consultancy recommended a follow-on Workshop under the *aegis* of the IAEA to be held in Moscow in February or March 2006. **Mr. Smirnov from the RRC "Kurchatov Institute" was asked to make the necessary arrangements for hosting this Workshop**
- **Representatives of Member States will also be invited to discuss** perspectives and developments of fusion-fission systems

• 1. Introduction and Background

From 11-13 October 2004, the East-West Centre of the University of Maryland (UM) organized the "Workshop on Sub-critical Neutron Production". The Workshop was co-hosted by the Eisenhower Institute in Washington, DC, and by the East-West Centre of the UM. The subject of the Workshop was the application of sub-critical neutrons to transmutation of actinides. As stated by the organizers, the desired outcome of the Workshop was to arrive at a consensus on how the three communities [i.e., fission, accelerator driven systems (ADS) and fusion] can join forces to provide solutions to the technical challenges of developing practical devices to achieve the utilization and transmutation of actinides and long-lived fission products. Members of all the three communities attended the Workshop. Participation from outside the USA was from Russia (Messrs. Avrorin and Simonenko from the RFNC-All-Russian Institute of Technical Physics (VNIITF), Snezhinsk, and Mr. Smirnov from the RSC Kurchatov Institute), France (Mr. Rebut, JET Director-Emeritus), the UK (Mr. Hunt from the University College of London), Japan (Mr. Saito from the Tokyo Institute of Technology), and from the IAEA (the Scientific Secretary of the Technical Working Group on Fast Reactors). In addition to the hosts from the Eisenhower Institute (Ms. Susan Eisenhower), and from the UM (Messrs. Sagdeev, Sadowski, and Milikh), US participation included representatives from the US Department of Energy, Georgia Institute of Technology, Princeton Plasma Physics Laboratory, Argonne National Laboratory, Sandia National Laboratory, Los Alamos National Laboratory, Oak Ridge National Laboratory, Lawrence Livermore National Laboratory, and the Naval Research Laboratory. Papers on the state of development of neutron production by accelerators, fusion devices, and fission reactors were presented. Discussions were held on the potential of these technologies to solve the problems of storage and non-proliferation presented by current and future nuclear power reactors. To set the frame for the current activity, the Workshop's proceedings are briefly summarized below.

Development and introduction of innovative fuel cycle options is essential, if nuclear power is to become a long-term sustainable option for the world's energy mix. The environmental benefits of the carbon emission free nuclear energy will only be realized if its use is extended beyond electricity production to other energy carriers. In such scenarios, a substantially higher share of nuclear energy will be a necessary condition, and novel approaches to spent fuel management will have to emerge. In addition to plutonium recycle as MOX (an option to stabilize the plutonium stockpiles), and to various plutonium utilization scenarios in fast and epithermal spectrum present-technology reactors (an option necessary for the transition phase from today's technology to the next generation's), the transmutation and incineration of various long-lived isotopes (actinides and fission products) is being put forward and steadily gaining interest, as indicated by various national and bi/multi-lateral R&D efforts pursued by IAEA Member States. The main advantages cited for sub-critical reactors, as compared to critical fast reactors, are enhanced flexibility as regards the actinide fuel to be used, reduced production of transuranics, and enhanced safety characteristics. The main lines of research are mostly addressing fast spectrum, heavy liquid metal cooled, sub-critical fission reactors fuelled with solid fuels, and driven by a spallation source (however, alternative concepts based on epithermal neutron spectra and fluid fuels are also considered by some R&D groups). Recently, the idea of coupling a sub-critical fission reactor and a DT-plasma and using the 14 MeV neutrons generated by the thermo-nuclear reaction for the incineration and transmutation of long-lived isotopes has generated increasing interest. Such DT-plasma-fission coupled systems promise some advantages when compared to accelerator, spallation source driven concepts. First, one has to notice, from a physics point of view that, at 14 MeV, the considerably higher energy of thermo-nuclear neutrons offers additional flexibility with regard to the neutron economy because of additional neutrons from (n,2n), and (n,3n), … reactions, as well as from ^{238}U fission, which is a threshold reaction. Moreover, the 14 MeV neutrons provide also greater incineration/transmutation capabilities of the coupled system, since this permits even lower k_{eff} regimes. Finally, the larger dimension of the neutron source (i.e., of the plasma) in a fusion-fission system opens new design possibilities for the sub-critical fission blanket, ultimately leading to more efficient incineration/transmutation machines. It is important to note that the coupling of a plasma device with a sub-critical fission blanket relaxes the requirements on the tokamak. The fact that the DT-plasma's energy is amplified by a factor greater than 5 in the sub-critical blanket allows designing compact fusion/fission systems, which have excellent transmutation characteristics and are thought to have a much reduced price tag (super-conducting magnets are not required, compact dimensions, simplified maintenance, reduced operating costs,…). Therefore, current fusion technology is perfectly adapted to this kind of applications.

After considering all the technologies that offer prospects to deal with spent nuclear fuels and current actinide inventories, the Workshop reached the conclusion that a projected substantial increase in nuclear power production will require novel approaches to the issue of spent nuclear fuel management. The Workshop further concluded that 14 MeV DT-plasma neutrons could be used to incinerate/transmute nuclear reactor by-products, some of which would otherwise have to be stored for geologic periods of time. The production of 14 MeV neutrons is based on existing fusion technologies at different research institutions in several countries around the world. At the present time this technology is used to produce 14 MeV neutrons in JET. More development work will be required, however, to bring fusion technology to the level where it can be used for actinide and long-lived fission products incineration/transmutation on an industrial scale. The Workshop concluded that the potential of current fusion technology to utilize the actinides for generating energy and destroying long-lived fission products calls for a greater international effort in the area of fusion driven sub-critical systems. Therefore the Workshop recommended that the technical community carry out a series of steps leading to a small demonstration for fusion-fission systems. The Workshop strongly recommended that the fusion community work closely with other technical communities to ensure that a wider range of technical solutions is available to solve the spent fuel problem and to utilize the current actinide inventories. Finally, the Workshop formed a small group to facilitate follow-up interactions and cooperative work. In addition, it was agreed to hold a follow-on Workshop, possibly under the *aegis* of the IAEA.

Underlying these recommendations is the perception that the fusion community should participate in advancing fusion/fission system research and technology development work on a broader scale. In addition, there is a need expressed by the scientific community involved in these activities, for facilitation and coordination by the IAEA.

Therefore, IAEA's Department of Nuclear Energy has decided to enhance its activities in the field of fusion-fission systems for energy production and transmutation, and to closely coordinate and cooperate with the Division of Physical and Chemical Sciences within the Department of Nuclear Sciences and Applications. These activities are implemented in the Nuclear Power Technology Development Section.

As a first step, the Agency has convened this Consultancy to provide an international forum for follow-on discussions to the UM Workshop.

The consultancy, a collaborative initiative between IAEA´s Nuclear Energy (NE) and Nuclear Sciences and Applications (NA) Departments, was opened by the IAEA Deputy Director General and NE Department Head, Mr. Y.A. Sokolov, and attended by a group of 12 consultants from 5 countries and 2 IAEA staff members (see attachment fro complete list of participants).

2. Objectives

The main objectives of the Consultancy are to

i) To foster discussion on the potential of fusion/fission systems to provide innovative solutions to spent nuclear fuel issues, and to utilize the current actinide inventories;

ii) Discuss concrete steps that lead to a small demonstration for fusion/fission systems;

iii) Advise the Agency on its role and on possible activities to be implemented under IAEA *aegis*.

More specifically, the Consultancy addressed the following topics:

i) Starting from a systematic analysis of the physics prospects of possible fusion-based neutron sources that would drive a sub-critical blanket, the Consultancy reviewed existing experimental facilities and devices (e.g., the Gas Dynamic Trap GDT and other fusion devices thought to be capable of producing 14 MeV neutrons in the near future) that could provide the first concrete step towards the small demonstration for fusion-fission systems. The Consultancy discussed which experimental device should be proposed as the first facility to produce 14 MeV neutrons for actinide utilization/transmutation and how this facility can become an integral part of the effort to develop sub-critical reactors, presently spearheaded by accellerator driven systems.

ii) The Consultancy discussed and proposed a set of studies that permit future inter-comparison between various utilization/transmutation technologies including accelerator driven systems and possible DT-plasma fusion devices for such application in the near future.

iii) The Consultancy provided advice to the Agency on its role in the area of research and technology development of fusion-fission sub-critical neutron systems for energy production and transmutation, and on possible activities to be implemented under IAEA *aegis* with regard to both the topics i) and ii) above (roadmap proposal).

3. Conclusions and Recommendations

The participants in the Consultancy discussed the potential of sub-critical systems driven by DT plasma sources of neutrons for utilizing transuranic elements and transmuting long-lived fission products. The discussion included a comparative analysis of accelerator driven systems.

The development of innovative (fourth generation) fission reactors, advanced fuel cycle options, and disposition of existing spent nuclear fuel inventories in various Member Sates can significantly benefit from including sub-critical systems, which are driven by external neutron sources. After considering the current technologies that can produce these neutrons and their characteristics, the consultants reached the following conclusions:

Because of their high energy, DT fusion neutrons offer advantages for incinerating and utilizing transuranic materials and eliminating long-lived fission products. In addition, the energy required for their production is relatively low. DT fusion devices with power in the range of 10 to 50 MW are adequate for driving such sub-critical cores. Elements of the current fusion technologies could be used for constructing these neutron sources. Development work in the mainline fusion programme will provide further enhancement of the performance of these systems.

Mobile fuels can be advantageous for these fusion-fission sub-critical systems, because they eliminate burnup limits, avoid the development of new solid fuel designs, allow low transuranics material inventories without unduly penalizing the transmutation performance, and limit reprocessing operations. When used for spent fuel disposal, mobile fuels avoid the need for pure fissile material streams, strengthening the proliferation resistance of the system.

The Consultancy recommended enhanced coordinated efforts for developing DT fusion plasma driven sub-critical core designs. The main areas requiring enhanced coordinated research and technology development are nuclear data, forms and preparation of fuel, chemistry control, sub-critical core design, and system integration.

The Consultancy discussed different possibilities for advancing the fusion-fission systems development, and the following steps were endorsed:

i) **The Russian institutes will consider submitting a joint ISTC project** for developing DT fusion plasma driven sub-critical concepts with a mobile fuel, preparing the spent nuclear fuel for its utilization in these DT fusion plasma driven sub-critical cores, and characterizing possible fusion devices for utilizing the transuranic elements and transmuting the long-lived fission products.

ii) **Some European members will consider examining the fusion-fission systems** for disposing of spent nuclear fuel as well as energy production within the transmutation activities of EU's 7th Framework Programme (FP7)

iii) **Some participants (e.g., Sweden and UK) will contact industries and research institutes** for supporting the development of fusion-fission systems for disposing spent nuclear fuel and energy production

iv) **The US members will seek involvement of US organizations** in the development of fusion-fission systems for disposing of transuranic elements and transmuting long-lived fission products.

The consultancy recommended a follow-on Workshop under the *aegis* of the IAEA to be held in Moscow during February or March 2006. **Mr. Smirnov from the RRC "Kurchatov Institute" was asked to make the necessary arrangements for hosting this Workshop**. **Participants of this Consultancy will be invited to report on progress** achieved in the areas mentioned above. **Representatives of Member States will also be invited to discuss** perspectives and developments of fusion-fission systems.

The proceedings of this Consultancy will be made available to the attendees and to those who responded to the invitation but were not able to attend because of conflicts of schedule. **The presentations and the summaries from the Maryland Workshop, as well as of this consultancy will be posted on the Website** of IAEA's project "Technology Advances in Fast Reactors and ADS". The Consultancy recommends utilizing this website for exchanging related information. In addition, **the Member States will be informed** about this consultancy and the next workshop. The consultancy suggested that the **IAEA contact and invite the Member States** performing fusion fission development for the next Workshop.

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