IAEA Consultant Meeting
"Coolant Technologies for Sub-critical Blankets of Fusion-Fission Hybrid Reactors"

ITEP, Moscow, Russia, 6 – 7 July 2000

Summary Report

The IAEA consultant meeting on "Coolant technologies for subcritical blankets of fusion-fission hybrid reactors" was held in Moscow on 6 – 7 July 2000. It was jointly organised by the NENP Division (A. Stanculescu) and the NAPC Division (T. Dolan). The meeting was hosted by the State Science Center of Russian Federation Institute of Theoretical and Experimental Physics (ITEP), Moscow, Russia.

The purpose of the meeting was twofold:
a) to review the status of fusion/fission hybrid R&D activities; and
b) to recommend IAEA activities in this area.

The objective of the meeting was to identify the interfaces and the areas of common interest between the fusion and fission communities, and the respective development needs, with the goal of better defining the Agency's role in supporting R&D efforts in this area (through, e.g., information exchange and collaborative R&D). To help focus the scientific and technical discussion, contributions were invited centered on coolant technology issues (a topic on which much R&D effort is concentrated in both communities). The output of the consultancy meeting was expected to be an outline/content of a background report on the use of fusion/fission hybrids for utilization and transmutation of actinides and long-lived fission products, which will identify the needs of the R&D groups involved, and thus provide justification and incentives for the Agency's future initiatives in this area.

The meeting was opened by representatives of the IAEA and participants were welcomed by Mr. N. Rabotnov, Russian Federation Ministry of Atomic Energy (MINATOM), and Mr. O. Shvedov, Deputy Director of ITEP.

The Consultancy consisted of 24 presentations/statements and was attended by 23 scientists from China, France, Italy, Japan, Russia, the USA, and CERN, and about 20 observers from Russia. On Friday 7 July a tour of the ITEP heavy water research reactor MAKET and a demonstration of the IAEA database about Accelerator Driven Systems (ADS) that is under development, were organised.

An outline for the background report on the use of fusion/fission hybrids for utilization and transmutation of actinides and long-lived fission products was drafted and various people were assigned to write sections of it. That draft outline, meeting agenda, and list of participants are attached to this report.

Results

There were about 24 individual presentations on various aspects of ADS and fusion-fission hybrids. Some technical highlights are given below.

In the 1970s scientists in the **USA** studied fusion-fission hybrids for power generation and destruction of spent fuel, but found that the systems would have low fuel burnup and a large heavy metal inventory. In the 1980s they found that fuel breeders with fission-suppressed blankets were feasible, but this work was discontinued, due to proliferation concerns. In the 1990s effective waste transmutation blankets, with smooth power density distributions and minimum heavy metal inventories were studied. They looked at solid blanket concepts with U+Zr fuel and Pb-Bi coolant. They found that the fission products were confined and that the hard neutron spectrum generated more excess neutrons, but there was a radioactivity problem with polonium generated from Bi and with keff varying during operation. They also considered HTGR type blankets, as well as molten salt liquid blanket concepts with online fuelling & extraction, constant fusion power. For the latter concepts, they found that there would be fission products in the liquid, more heavy metal inventory, a high vapor pressure of tritium, and a need to keep the coolant hot to prevent solidification. A fusion-fission system could operate successfully at Q (fusion power)/(input power) ~ 1 (vs. Q > 10 for pure fusion). With 30 transmutation plants at 75 % availability they could destroy 870 tonnes of transuranic elements in 40 years. Accelerator driven systems require blankets with k_{eff} ~ 0.95 - 0.97 for efficient transmutation, while fusion-fission hybrids could operate satisfactorily with k_{eff} ~ 0.9 and even lower, increasing the margin to criticality. (E. Cheng)

Italy is working on an accelerator driven system for power generation and transmutation (blanket keff = 0.95), based on a proposal by Carlo Rubbia. This activity is known under the name EADF (Energy Amplifier Demonstration Facility). The basic design parameters of the EADF are: 80 MW_{th}, two stage cyclotron, Pb-Bi target (both the window and window-less options are considered) multiplication factor keff~0.95, uranium-plutonium mixed oxide fuel, Pb-Bi coolant, gas bubbles to enhance natural circulation. The use of Pb as a moderator also affords the possibility to transmute the most radiotoxic long-lived fission products through the adiabatic capture resonance crossing effect. Extensive R&D is performed in the area of the application of computational fluid dynamics simulation of liquid metal flows (for coolants like Hg, Na, and Pb-Bi). (L. Maciocco)

Japan is working on ITER blanket studies, with power generation as the primary focus. They do not study fusion-fission hybrids for power production or for fissile breeding, but they recently started looking at broader uses of fusion generated neutrons, e.g. for waste transmutation. Their study has a solid, super-critical-water-cooled (500 °C) blanket with ferritic steel structure. Secondary structural materials under consideration are V alloy and SiC, and alternative coolants are Li-Pb or FLiBe molten salt. (S. Konishi)

Researchers at **CERN** performed a first comparative study of fusion-fission hybrids with ADS for Pu transmutation efficiency. Given the limited scope of this very first study, they simply replaced in the EADF the spallation source by a fusion source, and used a computer simulation to derive the isotope variations in time. No noticeable differences between the two cases were observed from these preliminary results. The EADF had k_{eff} = 0.96 and a neutron flux close to the target = $6x10^{14}$ $cm^{-2}s^{-1}$. (Yacine Kadi)

Russia has an active program in **Accelerator Driven Systems** (ADS) for power generation and transmutation, which have applications for fuel breeding and for transmutation and/or incineration of actinides. The following institutions are involved: Arzamas, Gatchina, Dubna, PLUTON, Institute for Theoretical and Experimental Physics (ITEP), PNPI proton synchrotron, and Institute of Physics and Power Engineering (IPPE) Obninsk. Russia needs external funding to employ their scientific manpower more fully. (Shvedov) In the case of accelerators the spallation products in the liquid metal target can damage the protective oxide films that inhibit corrosion. The accelerators at Los Alamos and the Paul Scherrer Institute (Switzerland) experience about 30 beam trips per day, so accelerator designs with drastically improved reliability are required. A pulsed accelerator for Los Alamos to deliver 0.6 ms pulses at 100 Hz is under test in Moscow. (E. I. Efimov)

Russia is considering a **gas-cooled** “Thorium accelerator subcritical system for energy production” (TASSEP). It would be a system that could expand rapidly, producing no actinide wastes, but it would need to operate at $k_{eff} < 0.9$ to enhance safety characteristics, and the lack of neutrons would require a very high power accelerator. This system could have a high thermal efficiency. A depressurization accident would be a big problem, however. The system could transmute the most cumbersome long-lived fission products ^{129}I, ^{99}Tc, and ^{135}Cs. (Igor Shatalov)

According to Russian studies, **liquid metals** can handle heat fluxes of 20-100 MW/m^2. Since 1980 their heat transfer and mass transfer information center has developed a large database of methods, programs, data evaluation, thermal hydraulic models, and codes dealing with liquid metals, such as Na, Pb-Bi, and K. (Pawel Kirillov) The Russians have also studied Hg coolant for use in a spallation neutron source with 2.6 GeV protons. (Yuri Titarenko) Russia favors Pb-Bi coolant for all nuclear systems (fission reactors, ADS, fusion reactors, and hybrids), because of its low pressure, low chemical activity, good heat transport parameters, and high temperature capability. In the case of fusion reactors, oxide films would be needed inside coolant ducts to avoid high magnetohydrodynamic flow resistance in magnetic fields. (Yuri Orlov)

Russian studies of **molten salt** coolants indicate that the salts could have low Pu and minor actinide inventories, minimal neutron losses, low solubility of gaseous fission products, use of any fissile fuel, and satisfactory radiation stability, chemical stability, vapor pressure, and neutron balance. Fluoride salts with modified hastelloy-N structure (for low corrosion rates and Redox potential) appear to be best. Mo and W coatings on may be used on surfaces to reduce corrosion rates. (Viktor Ignatyev)

Russian scientists have considered a fusion reactor blanket containing thorium and lithium-6 to **breed ^{233}U** and tritium. In addition to that, they are considering concepts that rely on fuels containing the burnable poison ^{231}Pa. This isotope is produced by (n,2n) and (n,3n) reactions from ^{232}Th and transforms into ^{232}U, and then becomes ^{233}U after neutron absorption. In a LWR core based on ^{231}Pa containing fuel with either Pu or ^{233}U as fissile material, they could maintain criticality for 40 years with 60% ^{231}Pa, or for 18 years with 15% ^{231}Pa. The fusion-fission hybrid system would be used to produce the ^{231}Pa needed for the fuel of such “ultra-long life time” LWR cores. In the case of the Th/U cycle, the ^{233}U produced would not be suitable for military use, because of its high ^{232}U content. (Shmelev)

The Kurchatov Institute has been studying fusion-fission hybrid systems for 30 years, but now they are optimistic about pure fusion reactors, which have passive safety, low afterheat, and possible recycling of reactor materials feasible. (60% in 30 y, 80-85% in 100 y). Near surface repositories could be used for the other 15% of wastes. There would be low releases of radioactive materials from pure fusion reactors during accidents. (Shatalov)

In 2050, **China** will have 1.5 billion people, and it will need 1200-1500 GWe power. For hybrid systems, performing multiple functions of power generation, fuel breeding, and waste transmutation, the design of the fusion core is easier than for a pure fusion reactor, since the hybrid can operate with lower fusion energy gain ratios Q. Therefore, hybrids are given very serious consideration in China. China has strong fusion-fission hybrid studies activities at the Academica Sinica Institute of Plasma Physics (Hefei) and at the Southwestern Institute of Physics (Chengdu). In 1980-85 they did physics concepts studies, in 1991-95 a conceptual design, and they reported the design with a wall power flux of 0.5-1 MW/m^2 at the IAEA Fusion Energy Conference in 1998. The hybrid reactor is a compact tokamak with a liquid metal cooled center post, dual coolant blanket, and divertor. The HL-2A Tokamak (1 MA, 5-10 s) will begin operation in 2001 and the superconducting HT-7U tokamak (1 MA, 1000 s) will start up in 2003. They are also doing tritium production and permeation experiments and reactor materials development. They plan to build an experimental reactor 2010-2020, to build a demonstration power plant 2020-2030, and to operate a commercial reactor about 2035. A preliminary cost comparison of ADS, fast breeder reactors, and fusion driven hybrids indicates that the fusion-fission hybrid is superior, fast breeders are second, and ADS are the most expensive. The fusion-fission hybrid system is considered to be a step towards pure fusion. (Yican WU)

In **France**, comparative assessments of different coolants are being performed. An overview was presented, based on both the basic thermo-physical properties and the reactor physics characteristics. With regard to the ADS vs. fusion-fission hybrid comparison, a few salient features were pointed out: (a) the dynamics properties of the two systems are quite different, hence assessing the safety potential on the grounds of the sub-criticality level alone can be misleading; (b) the requirement of tritium breeding in the fusion-fission hybrid decreases the available neutron surplus; (c) a critical feature for the fusion-fission hybrid is the first wall reliability (neutron wall loading), while the spallation source (window/windowless) demands particular attention in the ADS case; (d) cost comparisons are very difficult. From this follows the relevance of one of the scopes of the consultant report, i.e., the comparative assessment of fusion-fission hybrids and ADS. (Igor Slessarev)

Conclusions

The meeting produced a detailed report outline, contents and writing assignments. The IAEA will produce a report of the Working Material, which will include all the papers presented at the meeting (to be provided by the participants to the Scientific Secretaries.)

Russia and China are working industriously to develop fusion-fission hybrids. ADS studies are also pursued in many countries. It appeared that further studies are needed to compare fusion-fission hybrids with accelerator-driven systems for waste transmutation. The consultant report on the use of fusion/fission hybrids for utilization and transmutation of actinides and long-lived fission products will be an important contribution towards this objective.

Recommendations

1. The ITEP did a good job of hosting this meeting, so it is recommended as a possible future host for IAEA meetings on this topic.

2. Future IAEA activities dealing with fusion-fission hybrids would be consistent with the IAEA mandate to promote peaceful uses of nuclear energy, and they would facilitate international cooperation in a field of growing importance.

3. The consultant report will recommend specific activities in the area of fusion-fission hybrid systems for transmutation of nuclear waste and excess plutonium. It is recommended that IAEA should try to incorporate those suggestions in future programme plans.

Outline of the background report on the use of fusion/fission hybrids for utilization and transmutation of actinides and long-lived fission products; writing assignments, deadlines

The consultancy agreed on the following outline of the report (in some cases, writing assignments were proposed involving persons not present at the consultancy; it is understood that these writing assignments are tentative, and that the Scientific Secretaries will have to approach these persons in view of their possible involvement):

0 Introduction (hybrids, different uses)
1 Review of Fusion Neutron Sources
1.1 Historical Background (Cheng)
1.2 Technology of Fusion/Fission Hybrids
1.2.1 Neutron Source (Konishi)
1.2.2 Blanket and Coolant (Wu, Konishi, Lipatkin, Chatalov)
2 Comparison of Advantages/Disadvantages of Different Coolants [Gas: Cheng; Water: Konishi; Molten Salt: Ignatiev, Slessarev; Lead/Bismuth: Efimov, Orlov, Abderrahim; Lead: Efimov, Orlov; Lithium/Lead: Cheng; Heavy Molten Salts (lead-based fluorides): Vakhrushon, Orlov); Mercury: Filges; Sodium: Konishi, Slessarev, Cheng (ANL)] with regard to the following criteria:
2.1 Neutronics and Transmutation Effectiveness (Slessarev, Koucherov)
2.2 Material Technology (corrosion)
2.3 Thermalhydraulics
2.4 Safety Characteristics
2.5 Activation
2.6 Maintenance/Reliability
2.7 Costs
3 R&D Activities (current and planned), Needs
3.1 Nuclear Data (Kadi, Chubin, Titarenko, Wu, Konishi)
3.2 Coolants (Maciocco, Abderrahim)
3.3 Integral Facilities (Kosodaiev, Abderrahim, Kadi, Chigrinov, Slessarev)
4 Comparison of Different Hybrids (Fusion/Fission, ADS) and Critical Reactors (Koucherov, Orlov, Lipatkin, Konishi, Wu, Slessarev, Kadi, Chmelov, Wade)
4.1 Various Strategies and Applications (energy production, fuel production, transmutation)
4.2 Criteria for Comparative Assessments of Various Strategies/Applications
4.3 Comparative Assessments of Various Strategies/Applications
5 Conclusions and Recommendations to IAEA

The first draft of the various contributions should reach the Scientific Secretaries by the end of September 2000.