IAEA

General framework

The Statute of the IAEA includes the following functions: (under Article III-A.1):

"To encourage and assist research on, and development and practical application of, atomic energy for peaceful uses throughout the world", and, (under Article III-A.3),

"To foster the exchange of scientific and technical information on peaceful uses of atomic energy."

Consistent with the above functions, Major Programme 1 ("Nuclear Power and Fuel Cycle") has the following strategic objective:

"to assist Member States in the peaceful uses of nuclear energy, its fuel cycle and associated radioactive waste management, and to support Member States interested in promoting the safe and economic use of nuclear power, for a sustainable energy development, particularly in developing counties.".

Within Major Programme 1, Programme A ("Nuclear Power") has the specific objective of providing:

"state-of-art guidance and assistance to member states in designing and in implementing national nuclear power programmes, promoting comprehensive management of nuclear power plants for excellence in overall performance, and….to serve as a forum for exchange of information in all areas of nuclear power plant technology development and operation.".

Within Programme A, Sub-programme A2 ("Nuclear Power Technology Development and Applications"), which is performed under the jurisdiction of the Nuclear Power Technology Development Section (NPTDS), exists to foster the global realization and sharing of the benefits of the technology advances in nuclear energy by facilitating international information exchange and co-operation. Consistent with the IAEA Statute, NPTDS through Sub-programme A2, provides balanced, objective information to all Member States on technology status and development trends for current and future reactor systems, and a global forum for experts from Member States to exchange information on technology advances and development needs, and to establish and carry out co-operative research projects.

For the last four decades, the IAEA has fulfilled these objectives and its mission in providing all Member States with an international source of balanced and objective information on advances in nuclear technology, and in providing an international forum for information exchange and co-operative research. The IAEA sees its role in continuing to support joint efforts in Innovative and Advanced Nuclear Energy Systems development, and will continue to play a major role as the nuclear industry faces the challenges and opportunities of the 21st century.

IAEA Past and Current Activities

In the frame of the Project on *Nuclear Systems for Utilization and Transmutation of Actinides and Long-lived Fission Products* (from 2002 on "Technology Advances in Fast Reactors and Accelerator Driven Systems for Actinide and Long-lived Fission Product Transmutation") the

IAEA initiated a number of activities on utilization of plutonium and transmutation of waste, accelerator driven systems, thorium fuel option, innovative nuclear reactors and fuel cycles, non-conventional nuclear energy systems, and fission/fusion hybrids. All activities are coordinated by IAEA's "Technical Working Group on Fast Reactors (TWG-FR)", previously called "International Working Group on Fast Reactors (IWG-FR)", established in 1967.

ADS and Transmutation

In recent years, an old idea has re-surfaced and is gaining attention in nuclear technology: the sub-critical, spallation neutron source driven nuclear system, or hybrid system. In this concept, a powerful proton accelerator produces a spallation neutron source that drives a subcritical core to a relatively high fission power. Accelerator driven spallation targets and their proposed applications are hybrid technologies, coupling the fields of accelerator design, particle beam physics, spallation target design, and nuclear as well as reactor physics and the related engineering disciplines. Particle accelerator and nuclear reactor technologies have developed for several decades along parallel paths, with an important similarity being the capacity to produce large numbers of neutrons, via fission (reactors) or spallation. Because of the improvements in particle accelerator technology and economics, several large-scale applications of accelerator driven systems have been proposed. One of the earliest proposed hybrid applications involved using spallation neutrons to supplement the fission process in accelerator driven breeder reactors. More recently, a wider range of applications for hybrid technologies was proposed to incinerate/transmute materials produced in nuclear reactors. These applications rely on the larger availability of neutrons from hybrid systems and on their operation flexibility as compared to critical nuclear reactors. Specifically, these applications include spallation neutron sources, accelerator driven transmutation of waste, and accelerator driven power production.

Nuclear waste contains large quantities of plutonium, other fissionable actinides, and long-lived fission products that pose challenges for long-term storage of waste and that are potential proliferation concerns. If one assumes the same level of global nuclear power generation as exists today, then in the year 2015 there will be more than 2000 tons of plutonium in the spent fuel worldwide.

Different strategies for dealing with nuclear waste are being followed by various countries because of their geologic situations and their views on nuclear energy, reprocessing and non-proliferation. The current United States policy is to store unprocessed spent reactor fuel in a geologic repository. Other countries are opting for treatment of nuclear waste, including partial utilization of the fissile material contained in the spent fuel, prior to geologic storage.

The Accelerator driven Transmutation of Waste (ATW) concept offers potential alternative paths that would essentially eliminate plutonium, higher actinides, and environmentally hazardous fission products from the waste stream destined for permanent storage. ATW does not threaten but instead enhances the viability of permanent waste repositories. As such, ATW has increasingly become of worldwide interest and could be an important component of strategies to deal with international nuclear materials management requirements.

Accelerator Driven Systems: Energy Generation and Transmutation of Nuclear Waste (Status Report). Participants of the Special Scientific Programme on "Use of High Energy Accelerators

for Transmutation of Actinides and Power Production" held in Vienna, in 1994 in conjunction with the 38th IAEA General Conference recommended the IAEA to prepare a status report on Accelerator Driven Systems (ADS). The general purpose of the Status Report was to provide an overview of ongoing development activities, different concepts being developed and their status, as well as typical development trends in this area and to evaluate the potential of this system for power production, Pu burning and transmutation of minor actinides and fission products. This document includes the individual contributions by the experts from six countries and two international organisations, as well as executive summaries in many different areas of the ADS technology. The document was published and more than 500 copies were distributed by the IAEA in 1997 (IAEA-TECDOC-985).

Coordinated Research Project (CRP) on the Use of Thorium-based Fuel Cycles in Accelerator Driven Systems (ADS) to Incinerate Plutonium and to Reduce Long-term Waste Toxicities is now in progress. The participating countries and international organizations in the CRP are Belarus, Czech Republic, France, Germany, Italy, the Netherlands, Russian Federation, Sweden, CERN and Spain (as an observer). The purpose of the CRP is to assess the uncertainties of the calculated neutronic parameters of a simple model of thorium or uranium fuelled ADS, in order to get a consensus on the calculational methods and associated nuclear data. Participants identified a number of issues which should be considered to get a better understanding of the ADS and agreed that some points, such as comparison of the different approaches and tools used by the different groups, should be reviewed. Three Research Coordination Meetings (RCM) were held: in 1997 in Bologna, Italy, in 1998 in Petten, Netherlands, and in 1999 in Vienna. Detailed papers on the results of these RCMs were reported to several international meetings, e.g., the Technical Committee Meeting on *Feasibility and Motivation for Hybrid Concepts for Nuclear Energy Generation and Transmutation* (Madrid, Spain, September 1997), and the *Third International Conference on Accelerator Driven Transmutation Technologies and Applications* (Prague, Czech Republic, June 1999). As agreed at the Consultancy in Minsk, Belarus, in July 2000, the present stage of the CRP will be based on the YALINA setup, a well-defined and refined experiment considered by the experts as having the potential to resolve some of the existing discrepancies in simulation of sub-critical systems and to give an indication on the quality of widely used evaluated nuclear data libraries. Moreover, the present stage of the CRP gives an opportunity to widen international participation in benchmarking and validation activities and lays the ground for future activities in this area. The participants had committed themselves to perform in advance “blind” test simulations of the first experiments. Already the preliminary results and comparisons presented during the Consultancy are of the great interest for the participating parties.

Technical Committee Meeting on Feasibility and Motivation for Hybrid Concepts for Nuclear Energy Generation and Transmutation. The purpose of this TCM was to assess the advantages and disadvantages of hybrid concepts for nuclear energy generation and transmutation of minor actinides and their potential role relative to the current nuclear power programmes and potential future direction to promote these concepts worldwide. The TCM was hosted by CIEMAT (Centro de Investigaciones Energeticas Medicamentales y Tecnologicas) and held at its

headquarters in Madrid, Spain, on 17-19 September 1997. Several major programmes/concepts on ADS development were presented, i.e., the CERN ADS concept, the OMEGA Program and Neutron Science Project for Developing Accelerator Hybrid Systems at JAERI, the Los Alamos ATW Program, and the Hybrid Systems For Nuclear Waste Transmutation Project in France. The most salient observations resulting from the TCM were: (1) several accelerator systems and source concepts can be developed for ADS, (2) importance to have a very reliable neutron source coupled with the reactor system, (3) the associated sub-critical reactor will likely be liquid lead (or lead/bismuth) cooled , with efforts to use natural convection for coolant circulation, (4) effort to develop neutronic benchmarks and codes for ADS should be pursued at the international level under the aegis of the Agency, (5) even if ADS is tentatively presented by some as a way to solve all nuclear waste issues, ADS is not an alternative to geological disposal. However, ADS has the potential to drastically reduce the waste toxicity, thanks to their capacity to burn minor actinides and fission products. As a reprocessing stage will be required, non-proliferation concerns should be addressed, (6) further development of ADS requires the building of a demonstration device with a thermal power, in the 100-300 MW range. Efforts should be co-ordinated at international level on this matter, and (7) this pre-industrial test should provide input on the feasibility of the industrial deployment of ADS, including fuel cycle requirements, and a better understanding of the safety issues to be addressed. The proceedings of this TCM were published by CIEMAT and distributed recently by IAEA.

Database of Experimental Facilities and Computer Codes for ADS Related R&D. The needs for strengthening international cooperation in the field of the R&D for accelerator driven systems was emphasized at several international forums, e.g., (a) Scientific Program on "Use of High Energy Accelerators for Transmutation of Actinides and Power Production", Vienna, 21 September 1994 (in conjunction with the 38th IAEA General Conference), (b) The Second International Conference on Accelerator Driven Transmutation Technologies and Applications, Kalmar, Sweden, 3-7 June 1996, and (c) The 8th International Conference on Emerging Nuclear Energy Systems (ICENES'96), Obninsk, Russian Federation, 24-28 June 1996.The Consultancy on Hybrid Concepts for Nuclear Energy Generation and Transmutation held in Vienna, in December 1996 noted that an increasing number of groups are entering this field of research; many of these groups are not embedded in wider national activities; for these groups there is a need for co-ordinating their efforts and jointly funding projects as also for getting access to information from nationally or internationally coordinated activities.Discussing organizational aspects of a possible IAEA involvement, the consultants came to the conclusion that an effective co-ordination would necessitate the creation of an information document on existing and planned experimental facilities which can be used for ADS related R&D. To substantiate this recommendation, several consultancies were organized in 1997 - 2000 to work out and finalize the format of the document. In June 1998, a draft of the database was distributed by the Agency to all contributors in the form of Working Material. Presently an "electronic" version of the database is available on CD-ROM and will be publicly accessible on the Internet very soon.

Advisory Group Meeting (AGM) on Review of National Accelerator Driven System (ADS) Programs. This AGM was hosted by KAERI in Taejon, Republic of Korea, from 1-4 November

1999. Its purpose was to review the current R&D programs in the Member States, and to assess the progress in the development of hybrid concepts, as well as their potential role relative to both the current status and the future direction of nuclear power worldwide. Further, the AGM participants provided advice and guidance for the IAEA activities in the ADS area.

Technical Committee Meeting (TCM) on Core Physics and Engineering Aspects of Emerging Nuclear Energy Systems for Energy Generation and Transmutation. This TCM was hosted by the Argonne National Laboratory in Argonne, Illinois, USA, from 28 November – 1 December 2000. Its objective was to review the status of R&D activities in the area of hybrid systems for energy generation and transmutation, to discuss in depth specific scientific and technical issues covering the different R&D topics of these systems, and to recommend to the IAEA activities that would be specifically targeted to the needs of the Member States performing R&D in this field.

Co-ordinated Research Project (CRP) on Safety, Environmental and Non-Proliferation Aspects of Partitioning and Transmutation (P&T) of Actinides and Fission Products. The overall objectives of the CRP were to study the possibility of reduction of the long-term hazard arising from the disposal of high level waste. More specifically, the CRP aimed to identify the critical nuclides to be considered in a P&T strategy, to quantify their radiological importance in a global nuclear fuel cycle analysis and to establish a priority list of radionuclides according the hazard definition. In the framework of the CRP the radionuclides hazard was studied in order to identify the critical nuclides to be considered in a P&T strategy and to quantify their radiological importance in a global nuclear fuel cycle analysis.

Thorium Fuel Option

Since the start of nuclear power development, thorium was considered to be the nuclear fuel to follow uranium. The technology to utilize thorium in nuclear reactors was sought to be similar to that of uranium, thorium resources to be larger than those of uranium, and the neutron yield of ^{233}U in thermal and epithermal regions is higher than that for ^{239}Pu in the U/Pu fuel cycle. In more detail the major reasons for the introduction of the thorium-based nuclear fuel cycles are: enlargement of fissile resources by breeding ^{233}U; large thorium deposits in some countries, coupled with a lack of uranium deposits in those countries; potential reduction in fuel cycle cost; reduction in ^{235}U enrichment requirements; safer reactor operation because of lower core excess reactivity requirements; safe and more reliable operation of thorium oxide fuel at high burnup as compared to uranium oxide, due to the higher irradiation and corrosion resistance of the former.However, thorium has some disadvantages when compared with uranium, and this was also recognized right from the beginning: thorium is more radioactive than uranium, making its handling in the fabrication stage more challenging; the nuclear reactions induced by neutron absorption in thorium and the decay schemes of the resulting nuclides are complicated, and the time for spent fuel storage in water is longer due to the higher residual heat; potential difficulties in the back-end of the fuel cycle.In spite of the above-mentioned disadvantages, R&D efforts on the thorium/uranium fuel cycle and thorium-fuelled reactor programmes started in the early 50s in several countries.

A series of three meetings was organized by IAEA in the period 1997-1999 on the Thorium Fuel Options: (1) Advisory Group Meeting on Thorium Fuel Cycle Perspectives, Vienna, Austria, 16-18 April 1997, (2) Advisory Group Meeting on Thorium Fuel Utilization: Options and Trends, Vienna, Austria, 28-30 September 1998, and (3) Technical Committee Meeting on Utilization of Thorium Fuel: Options in Emerging Nuclear Energy Systems, Vienna, Austria, 15-17 November 1999. The meetings were organized jointly by the Nuclear Power Technology Development Section of the Division of Nuclear Power and by the Nuclear Fuel Cycle & Materials Section of the Division of Nuclear Fuel Cycle and Waste Technology. The purpose of the meetings was to assess the advantages, shortcomings, and options of the thorium fuel under current conditions, with the aim of identifying new research areas and fields of possible co-operation within the framework of the IAEA "Programme on Emerging Nuclear Energy Systems". Apart from current commercial reactors, the scope of the meetings covered all types of evolutionary and innovative nuclear reactors, including Molten Salt Reactors and Hybrid Systems.
Preparations for publication of the proceedings (IAEA-TECDOC) of the above mentioned meetings is under way. Contributions to these meetings in the form of Working Material were distributed to the participans.

Status Report on Thorium-based Fuel Options. Within the framework of IAEA activities, the Agency has maintained an interest in the thorium fuel cycle and its utilization worldwide. Its periodic reviews have assessed the current status of this fuel cycle, its applications worldwide, its economic benefits, and its perceived advantages vis-à-vis other nuclear fuel cycles. Since 1994 the IAEA has convened a number of technical meetings on the thorium fuel cycle and related issues. Between 1995-1997 individual contributions also were solicited from experts of France, Germany, India, Japan, Russia and the United States of America, in many different areas of the thorium fuel cycle. They included evaluations of the current status of the thorium fuel cycle worldwide, evaluation of new incentives for using thorium as a result of the large stockpiles of plutonium produced in nuclear reactors, new reactor concepts that can utilize thorium, strategies for thorium use, and an evaluation of the toxicity of thorium fuel cycle waste as compared to other fuel cycles. The results of this updated evaluation are summarized in the present publication "Thorium based fuel options for the generation of electricity: developments in the 1990s", IAEA-TECDOC 1155. Additionally, this document is a contribution to the important task of preserving a large amount of past experience.
Coordinated Research Program (CRP) on the Potential of Thorium-based Fuel Cycles to Constrain Plutonium and to Reduce the Long-term Waste Toxicity. At the Consultancy on "Important Consideration on the Status of Thorium" held in Vienna from 29 November to 1 December 1994, participants recommended the IAEA to organize a CRP on thorium-based fuel cycle issue. In 1995, the Agency approved the topic for the CRP: "Potential of Thorium-based Fuel Cycles to Constrain Plutonium and to Reduce Long-term Waste Toxicity." The scope of this CRP was discussed and agreed upon by the participants of the Consultancy on "Thorium-based Fuel Cycles", held from 6 to 9 June 1995 at the Agency's Headquarters in Vienna. The participating countries in the CRP are: China, Germany, India, Israel, Japan, Republic of Korea, the Netherlands, Russian Federation and the United States of America.

This CRP examines the different fuel cycle options in which plutonium can be recycled with thorium to incinerate plutonium. The potential of the thorium-matrix has been examined through computer simulations. Each participant has chosen his own cycle, and the different cycles are compared on the basis of certain predefined parameters (e.g., annual reduction of plutonium stockpiles). The toxicity accumulation and the transmutation potential of thorium-based cycles for current, advanced and innovative nuclear power reactors are investigated. The research program has been divided into three stages: (1) benchmark calculations, (2) optimization of the incineration of plutonium in various reactor types, and (3) assessment of the resulting impact on the waste toxicity.
The results of stage 1 were presented at ICENES 1998. As agreed at the last RCM in Taejon (Republic of Korea), in October 1999, the paper reporting the results of stage 2 was submitted to ICENES 2000.

Efforts pursued jointly with other international organizations

Two salient recent examples of collaboration between the Agency and other international organizations are worthwhile mentioning. The first one is the joint benchmark program set up by the IAEA and the European Commission (EC) to assess the potential of reducing the sodium void reactivity effect in innovative fast reactor designs and to perform comparative assessments of the consequences of severe accident scenarios on such advanced fast reactor designs with near-zero sodium void reactivity effect (this joint benchmark program has resulted in IAEA-TECDOC-731, and IAEA-TECDOC-1139). The second example is the Agency's participation in OECD/NEA's Expert Group on "Actinide and Fission Product Partitioning and Transmutation (P&T) Study 'Comparative Study of ADS and FR in Advanced Nuclear Fuel Cycles'" whose objective is to assess whether ADS deliver distinctive benefits in an advanced fuel cycle that includes P&T, as compared to Fast Reactors.

Fission/Fusion cooperation on technology aspects

Along with the ongoing efforts to establish fusion as an energy source, there is renewed interest in fusion neutron source applications. In addition to fundamental neutron research, fusion R&D activities are becoming of interest to nuclear fission power development. Indeed, for nuclear power development to become sustainable as a long-term energy option, innovative fuel cycle and reactor technologies will have to be developed to solve the problems of resource utilization and long-lived radioactive waste management. Both the fusion and fission communities are currently investigating the potential of innovative reactor and fuel cycle strategies that include a fusion/fission hybrid. The attention is mainly focused on substantiating the potential advantages of such hybrid systems: utilization and transmutation of actinides and long-lived fission products, intrinsic safety features, enhanced proliferation resistance, and fuel breeding capabilities. An important aspect of the ongoing activities is comparison with the accelerator driven sub-critical system (spallation neutron source), which is the other main option for producing excess neutrons. A Consultancy held in Moscow in July 2000 (hosted by ITEP) initiated the preparation of a background report on the use of fusion/fission hybrids for utilization and transmutation of actinides and long-lived fission products, identifying the needs of

the R&D groups involved, and thus providing justifications and incentives for the Agency's future initiatives in this area.

IAEA Planned Activities

The following activities have been proposed for the Agency's 2002/2003 Planning and Budget cycle, and will be implemented subject to budget approval:
- CRP on "*Benchmark on Data and Calculational Methods for ADS Source Related Neutronic Phenomenology with Experimental Validation"* (to be initiated in 2001)
Specific objective: to improve the present understanding of the coupling of ADS spallation sources with multiplicative sub-critical nuclear systems. The CRP will address all major physics phenomena of the spallation source and its coupling to the sub-critical system. The participants will use integrated calculation schemes to perform computational and experimental benchmark analyses. Experimental backing of the analytical benchmarks is extremely important and is expected from collaboration with ISTC projects (YALINA, SAD)
- CRP on "*Comparative Assessment of Advanced Power Reactor Options for Effective Incineration of Radioactive Waste"* (in close cooperation with OECD/NEA, to be initiated in 2001). This CRP builds on conclusions of NEA's 2nd Expert Group P&T report. Its emphasis is likely to beon kinetics/dynamics benchmarks.
- CRP on "*Technical Assessment of the Beam-Target Interface for ADS"* (to be initiated in 2002). Specific objective: to characterise the beam-target interface for both window and windowless target designs for ADS. The CRP will address the comprehensive modelling of the complicated beam injection environment in a ADS (e.g., for designs with window: assessment of the thermo-mechanical stability and resulting life-time of the window; for windowless designs: assessment of the contamination of the accelerator)
- CRP on "*An Assessment Based on an Unified Methodology of Thorium Fuel in Emerging Nuclear Energy Systems"* (to be initiated in 2002). Specific objectives: to develop a methodology to evaluate the performance parameters of the thorium-based fuel cycle, and to apply this methodology to both existing and new reactor designs, aiming at a comparative assessment of the various designs. The CRP will develop a matrix of parameters (e.g., proliferation potential, savings in natural uranium, etc), as well as their evaluation methodology (e.g., formulas, algorithms, dimensions) to facilitate comparisons between reactor concepts based on thorium fuel cycles.
- Technical Committee Meeting (TCM) on "*Assessment of Methods and Comparison of Different Proposals for ADS Neutron Source Enhancement"*
- TCM on "*Developments in the Field of Heavy Liquid Metal Thermal Hydraulics Related to ADS"*
- TCM on "*Assessment of ADS Dynamics and Safety Physics"*
- TCM on "*Comparative Assessment of Solid and Mobile Fuels for ADS, and Non-Proliferation Aspects"*
- Publication of a "*Background Report on the Use of Fusion/Fission Hybrids for Utilization and Transmutation of Actinides and Long-Lived Fission Products"*.