IAEA ACTIVITIES IN THE AREA OF PARTITIONING AND TRANSMUTATION

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Abstract

In recent years, in various countries and at an international level, more and more studies have been carried out on advanced and innovative waste management strategies (i.e., actinide separation and elimination). In the frame of the Project on *Technology Advances in Fast Reactors and Accelerator Driven Systems for Actinide and Long-lived Fission Product Transmutation* (http://www.iaea.org/inis/aws/fnss/), the IAEA initiated a number of activities on utilization of plutonium and transmutation of long-lived radioactive waste, accelerator driven systems, thorium fuel options, innovative nuclear reactors and fuel cycles, non-conventional nuclear energy systems, and fusion/fission hybrids. The paper will present an overview of these activities.

Introduction

Based on an experience of more than 10^5 reactor-years, nuclear power is a mature technology that makes a large contribution to the energy supply worldwide. As of end 2004, there were 441 nuclear power plants operating in the world with a total net installed electrical capacity of 367 GW, and 25 nuclear power plants under construction [1]. Nuclear power supplied 16% of global electricity generation in 2002 [2].

According to the projections published by the Intergovernmental Panel on Climate Change (IPCC), the median electricity increase till 2050 will be by a factor of almost 5. It is reasonable to assume that nuclear energy will play a role in meeting this demand growth. However, there are four major challenges facing the long-term development of nuclear energy as a part of the world's energy mix: improvement of the economic competitiveness, meeting increasingly stringent safety requirements, adhering to the criteria of sustainable development, and public acceptability. Meeting the sustainability criteria is the driving force behind the topic of this paper. More specifically, in this context sustainability has two aspects: natural resources and waste management. IAEA's activities in the area of Partitioning and Transmutation (P&T) are mostly in response to the latter. While not involving the large quantities of gaseous products and toxic solid wastes associated with fossil fuels, radioactive waste disposal is today's dominant public acceptance issue. In fact, small waste quantities permit a rigorous confinement strategy, and mined geological disposal is the strategy followed by some countries. Nevertheless, political opposition arguing that this does not yet constitute a safe disposal technology has largely stalled these efforts. One of the primary reasons that are cited is the long life of many of the radioisotopes generated from fission. This concern has led to increased R&D efforts to develop a technology aimed at reducing the amount of long-lived radioactive waste through transmutation in fission reactors or accelerator driven hybrids. In recent years, in various countries and at an international level, more and more studies have been carried out on advanced and innovative waste management strategies (i.e., actinide separation and elimination). In the frame of the Project on *Technology Advances in Fast Reactors and Accelerator Driven Systems for Actinide and Long-lived Fission Product Transmutation* (http://www.iaea.org/inis/aws/fnss/), the IAEA initiated a number of activities on utilization of plutonium and transmutation of long-lived radioactive waste, accelerator driven systems, thorium fuel options, innovative nuclear reactors and fuel cycles, non-conventional nuclear energy systems, and fusion/fission hybrids. The paper will present an overview of these activities.

IAEA Activities

As in all the other fields of advanced nuclear power technology development, the Agency is relying also in the P&T area on broad, in-depth staff experience and perspective. The framework for all the IAEA activities in the P&T area is the Technical Working Group on Fast Reactors (TWG-FR). In responding to strong common R&D needs in the Member States, the TWG-FR acts as a catalyst for international information exchange and collaborative R&D.

Given the common technical ground between plutonium utilization R&D activities and the development of technologies for the transmutation and utilization of long-lived fission products and actinides, both activities are performed within the framework of a single Agency project: *Technology Advances in Fast Reactors and Accelerator Driven Systems for Actinide and Long-lived Fission Product Transmutation* [3].

The TWG-FR is a standing working group within the framework of the IAEA. It provides a forum for exchange of non-commercial scientific and technical information, and a forum for international co-operation on generic research and development programmes on advances in fast reactors and fast spectrum accelerator driven systems. Its present members are the following 14 IAEA Member States: Belarus, Brazil, China, France, Germany, India, Italy, Japan, Kazakhstan, Republic of Korea, Russia, Switzerland, United Kingdom, and United States of America, as well as the OECD/NEA, and the EU (EC). The TWG-FR advises the Deputy Director General-Nuclear Energy on status of and recent results achieved in the national technology development programmes relevant to the TWG-FR's scope, and recommends activities to the Agency that are beneficial for these national programmes. It furthermore assists in the implementation of corresponding Agency activities, and ensures that through continuous consultations with officially nominated representatives of Member States all the project's technical activities performed within the framework of the Nuclear Power Technology Development sub-programme are in line with expressed needs from Member States.

The scope of the TWG-FR is broad, covering all technical aspects of fast reactors and ADS research and development, design, deployment, operation, and decommissioning. It includes, in particular: design and technologies for current and advanced fast reactors and ADS; economics, performance and safety of fast reactors and ADS; associated advanced fuel cycles and fuel options for the utilization and transmutation of actinides and long-lived fission products, including the utilization of thorium. Given the TWG-FR's broad scope, the coverage will generally be in an integrative sense to ensure that all key technology areas are covered. Many specific technologies are addressed in detail by other projects within the IAEA and in other international organizations. The TWG-FR keeps abreast of such work, avoiding unproductive overlap, and engages in co-operative activities with other projects where appropriate. The TWG-FR thus coordinates its activities in interfacing areas with other Agency projects, especially those of the International Working Group on Nuclear Fuel Cycle Options, and the Department of Nuclear Safety, as well as with related activities of other international organizations (OECD/NEA, and EC).

Recent accomplishments

In responding to Member States' needs for information exchange in the fields covered by the Project's scope, the IAEA has published a series of Technical Reports (IAEA-TECDOCs) dealing with innovative reactor technology development in view of the utilization and transmutation of actinides and long-lived fission products.

Justified by the existing and growing interest in many IAEA Member States to investigate the potential of advanced thorium fuel cycles and the related reactor technologies, the first Technical Report [4] attempts an assessment of 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's advanced technology development projects. Apart from current commercial reactors, the report covers all types of evolutionary and innovative nuclear reactors, including molten salt reactors and hybrid systems. The report addresses the main physics aspects of thorium fuelled reactor cores, assesses advantages and disadvantages of thorium fuel utilization, presents the various options and concepts under investigation, and reviews remaining problems and uncertainties linked to thorium fuel utilization and reactor technologies based on thorium fuel. Two issues are identified as main reasons for the renewed interest in thorium fuel cycles: the potential to incinerate plutonium and reduce actinide production, on the one side, and better material properties and fuel behaviour, on the other side.

The report's most important conclusion is that there is a need for a unified systematic approach in assessing thorium fuel utilization: a methodology (metrics) to evaluate the performance parameters of the thorium fuel cycle must be developed. This methodology would have to define the performance parameters matrix as well as the algorithms for the evaluation. Another important conclusion highlighted in the report is the necessity to develop and maintain a database of all available information relevant to thorium fuel cycles, their utilization and related reactor technology.

To further investigate one of the two issues identified as main reasons for the renewed interest in thorium fuel cycles, i.e., their potential to incinerate plutonium and reduce actinide production, the IAEA has implemented a Coordinated Research Project (CRP) on *Potential of Thorium Based Fuel Cycles to Constrain Plutonium and to Reduce Long Lived Waste Toxicity*, and published the final results as an IAEA-TECDOC [5]. This CRP examined through computer simulations the different fuel cycle options in which plutonium can be recycled with thorium to incinerate plutonium. In the course of the CRP, the participants performed three benchmark tasks for different reactor concepts. Their incentive was the comparison of the various codes and nuclear data. The assessment of thorium fuelled thermal reactors in view of their potential for the incineration of plutonium and of a possible combined reduction of the waste radio-toxicity has been performed. Generally, the agreement of the benchmark results was very satisfying. The participants concluded that the results obtained constitute a sufficiently reliable basis for overall conclusions on the potential of thorium-based cycles to constrain plutonium and to reduce the long-term potential radiotoxic hazard of the waste. The overall conclusions can be summarized as follows: Generally, there is a remarkable potential to effectively constrain the production of plutonium and to reduce existing plutonium stockpiles by implementing the thorium fuel cycle in a large number of current reactors. This path offers a promising near-future plutonium management option. However, plutonium incineration in thermal reactors turns out to be less effective from the point of view of the reduction of the long-term radio-toxicity of the nuclear waste. A reduction by an order of magnitude or more of the potential long term radiotoxic hazard of the waste seems not to be achievable by any of the considered plutonium incinerating thermal reactors. Most of the calculations performed for LWR plutonium indicate that the waste radio-toxicity will be decreased by not more than a factor of 2 to 4, and only for an intermediate period; the waste radio-toxicity is even increased during the first decades and for extremely long times after disposal.

In another Technical Report [6], the IAEA reviewed the major R&D developments in the area of lead and lead–bismuth eutectic cooled reactor technology, for both critical and sub-critical systems. Particular emphasis is put on reviewing critical and sub-critical concepts, coolant properties, and experimental and analytical validation work. The fast reactor concept BREST-OD-300 under investigation in Russia, as well as various conceptual designs of heavy liquid metal cooled fast reactors pursued in Japan are described. Research and development work on hybrid (accelerator driven) sub-critical systems ongoing in various Member States are reviewed. The report concludes that nuclear energy is a realistic solution to satisfy the energy demand, considering the limited resources of fossil fuel, its uneven distribution in the world and the impact of its use on the planet, as well as the expected doubling of the world population in the 21st century and tripling of the electricity demand (especially in the developing countries). The report stresses that the development of innovative nuclear technologies must be pursued meeting the following requirements: (a) deterministic exclusion of any severe accident; (b) proliferation resistance; (c) cost competitiveness with alternative energy sources; (d) sustainable fuel supply; and (e) innovative solutions to the radioactive waste management problem.

Potential advantages of accelerator driven systems — apart from their intrinsic low production of long lived radioactive waste, and transmutation capability — are also enhanced safety characteristics and better long term resources utilization (e.g. in connection with thorium fuels). The Technical Reports [7, 8] review the R&D programmes that are being undertaken by various institutions in IAEA Member States to substantiate these claims and advance the basic knowledge in this innovative area of nuclear energy development, and examine needs and possible opportunities for international collaboration. While long term objectives for developing innovative nuclear systems for energy production and transmutation may not be unanimously agreed upon by the different groups participating in this effort, it is clear that in many cases the short term goals are similar. Therefore, quite a few generic R&D areas that would benefit from international collaboration are identified. The most important technical issues identified and discussed are: (a) Thermal fatigue due to beam trips; (b) Toxicity of the spallation products; (c) The lack of a safety strategy for severe accidents with fertile-free transuranics fuel; and (d) The lack of data on irradiation damage effects on the structural properties of the beam window and the adjacent core, which are induced by both proton and neutron irradiation. The reports conclude on the need and opportunity for collaboration in the following areas: (a) Major demonstration facilities, for which international participation should be considered; (b) Testing of special effects (e.g. fuels and materials tests, and zero power coupled systems) which offers practical opportunities for dividing up the work, and (c) Analytical benchmarks.

Ongoing and planned activities

In response to Member States information exchange needs, the project on *Technology Advances in Fast Reactors and Accelerator Driven Systems for Actinide and Long-lived Fission Product Transmutation* is preparing a series of publications on R&D topics of interest, specifically, Technical Reports (a) to review solid and mobile fuels for partitioning and transmutation systems, (b) on theoretical and experimental studies of heavy liquid metal thermal hydraulics, (c) to perform a comparative assessment of the dynamics and safety characteristics of transmutation systems, (d) to update the status of accelerator driven systems research and technology development, and (e) on the use of fusion / fission / accelerator based systems for the utilization and transmutation of actinides and long-lived fission products. Another activity planned for 2005 addresses formation and training needs expressed by the Member States: in collaboration with the International Centre for Theoretical Physics (ICTP), the IAEA is organizing the Workshop on *Technology and Applications of Accelerator Driven Systems*, in Trieste, Italy, from 17-28 October 2005. The Workshop will consist of lectures, tutorials, and computer exercises covering all the areas of ADS research and technology development, as well as the applications, i.e., accelerator technology, nuclear data, ADS concepts (design), simulation methods, ADS safety, and fuel cycle issues.

With regard to collaborative R&D, the project has an ongoing (2002-2006) CRP on Studies of Advanced Reactor Technology Options for Effective Incineration of Radioactive Waste, and will start a new CRP (2005-2009) on Analytical and Experimental Benchmark Analyses of Accelerator Driven Systems (ADS). The former CRP was joined by participants from 17 institutions in 13 Member States, and the EC (JRC). Its objective is to produce a comparative assessment of the transient behaviour of advanced transmutation systems, both critical and sub-critical. The CRP performs benchmarks on critical liquid metal, and gas cooled fast reactor, heavy liquid metal, and gas cooled ADS, critical and sub-critical molten salt concepts, and fusion-fission hybrid sub-critical systems. The objective of the latter CRP is to improve the understanding of the physics of the coupling of external neutron sources with sub-critical cores. Experimental backing of analytical benchmarks is the major thrust of this CRP, and the participants will apply integrated calculation schemes to perform computational and experimental benchmark analyses.

Last but not least, the Agency has implemented the "ADS Research and Development Database". It provides information about ADS related R&D programmes, existing and planned experimental facilities as well as programmes, methods and data development efforts, design studies, and so forth. While operational on the WWW and open to all users (*http://www-adsdb.iaea.org/index.cfm),* the database has to rely on content contributed by the interested community. Data and information can be provided on-line, and contributions are solicited (the author will gladly provide, upon request, access privileges as editor to everybody wanting to contribute content).

Conclusions

For nuclear energy to remain a long-term option in the world's energy mix, nuclear power technology development must meet sustainability goals with regard to fissile resources and waste management. The utilization of breeding to secure long-term fuel supply remains the ultimate goal of fast neutron spectrum system. Plutonium recycling in fast reactors, as well as incineration/ transmutation of minor actinides and long-lived fission products in various hybrid reactor systems (e.g., ADS) offers promising waste management options. Several R&D programmes in various Member States are actively pursuing these options, along with the energy production and breeding mission of fast reactor systems.

In line with the statutory objective expressed in Article II (The Agency shall seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. It shall ensure, insofar as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose), the IAEA will continue to assist the Member States' activities, also in the area of advanced technology development for utilization and transmutation of actinides and long-lived fission products, by providing an umbrella for information exchange and collaborative R&D to pool resources and expertise.

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LIST OF RELATED IAEA PUBLICATIONS

(Most of these publications can be downloaded as pdf files from the Web Site of the project on *Technology Advances in Fast Reactors and Accelerator Driven Systems for Actinide and Long-lived Fission Product Transmutation*: http://www.iaea.org/inis/aws/fnss/)

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