The Impact of Nuclear Science on Energy Science

Introduction

J.P. Schapira,
Institut de Physique Nucléaire, F-91406 Orsay cedex, France

To-day, energy production throughout the world is facing a number of issues related to the foreseen increasing energy needs during this century, especially in the developing countries. Two important questions, i.e. resources preservation and environmental impacts (especially those related to climate change), can largely be answered by a significant use of nuclear energy. Nuclear Science and Technology have a variety of applications in the field of nuclear energy (as well as conventional energy) and are therefore the basis for a large and safe nuclear contribution to the production of energy.

Discovered in the early days of nuclear physics, neutron induced fission of some heavy nuclei and fusion between two light elements are the basic nuclear processes responsible for the energy production in fission and fusion reactors (the latter being not presently at an industrial stage). Beside these, there are other applications of nuclear science and technology in non-nuclear energy fields. One example is the intensive use of nuclear detection and accelerator techniques in the field of petroleum prospecting. An other one is the environment and waste monitoring as a consequence of energy related activities.

As in the previous 1994 NuPECC report on the Applications of Nuclear Science in the field of Energy, the present report concentrates on two essential subjects. One is the development of so-called Accelerator Driven Systems (ADS) which seems to be best suited for the transmutation of some long-lived and highly radiotoxic radionuclides present inside spent nuclear fuels unloaded from reactor. The second one is related to the energy production by heavy ions inertial confinement fusion (ICF), an alternative to the strongly supported magnetic confinement fusion (MCF) and a variant to the laser induced ICF.

Why having focused on these two subjects?

In the early days of nuclear energy development, neutronic and reactor physics were just one branch of nuclear science just as nuclear and particle physics or radiochemistry. People like E. Fermi, E. Wigner or F. Joliot-Curie are distinguished examples of physicists who were able at that time to deeply contribute to most of these branches. Since then, these have gained more and more autonomy with respect to each other due to their increase technical complexity and specialization. As a consequence, different and separated scientific and technical communities have emerged with their own culture and scientific approaches. Moreover, the nuclear energy community was, and still is, in charge of developing peaceful as well as military applications of nuclear energy and became therefore more and more linked to technical, industrial and strategic issues. On the other side, the academic world, i.e. universities, national and international research organisations (e.g. CERN at an European level), has been dealing almost exclusively with fundamental nuclear science and related techniques such as accelerators.

In the 80s the proposal of Heavy-Ion driven ICF is probably the first example of using accelerators as a tool in the context of a power plant. It appears as an alternative to the laser induced ICF as well as the MCF and relies to a much larger extent on the expertise of nuclear and particle physicists in the field of high-energy accelerators. Later on, in the beginning of the 90s when nuclear waste became on the front scene, nuclear physicists like Ch. Bowman in Los Alamos and C. Rubbia at CERN revived some proposals for breeding artificial fissile materials such as Plutonium or U-233, developed in various American and Canadian laboratories since 1952. This revival was based on the new idea to make use of high-energy accelerators as drivers for waste transmutation, often including considerations of using Thorium, a fuel which has the advantage of a very low actinide discharge and low radiotoxicity. These activities have led to the proposal of using a sub-critical reactor to burn large quantities of actinides presently produced in commercial light water reactors (LWR). Indeed this appears to be a promising and flexible option for the nuclear energy sector satisfying many demands of the society. In addition it has the potential to exploit the Thorium cycle which increases significantly the availability of fuel resources and reduces the hazard of proliferation.

A sub-critical reactor needs to be driven by an intense external neutron source. These neutrons are produced inside a so-called neutron spallation target bombarded by a proton beam from a high power accelerator (typically 1 to few 10 MW). Because the nuclear and high energy physics communities are very familiar with these two components (spallation target, accelerator) as well as with the related Monte-Carlo computing techniques, they can bring a major and specific contribution to the concept and even to an advanced design of such an ADS. Moreover, they are acquainted with nuclear data measurements needed for the design of novel reactors dedicated to actinide transmutation or based on the Thorium fuel cycle. To work out specific proposals for waste transmutation requires a tight collaboration of nuclear physics, reactor physics and material sciences. This is particularly true for the development of ADS.

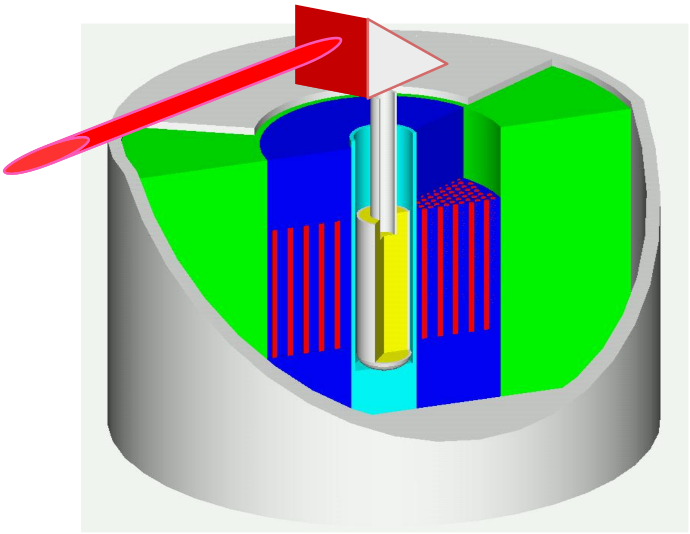

Fig. 1: Schematic view of an Accelerator Driven System (ADS)

Worldwide most of the studies related to transmutation deal almost exclusively with ADS and with the development of advanced fuels and fuel processing methods related to ADS (e.g. inert matrix, pyrochemistry). Recently increased effort in the nuclear energy sector are observed in the US, with the AAA (Advanced Accelerator Applications) supported by DOE (68 MEuro in the 2001-FY), in Japan (OMEGA project, especially the joined KEK-JAERI accelerator project) and in the European Community as it will be discussed in more detail below.

Tab. 1: Transmutation part of the (P&T) programme of the 5th EU FWP (28 M€)

Acronym	Research area	Coordinator	Number of partners	Length (month)	EU funding (M€)
Basic researches					
MUSE	Experiments for Sub-critical Neutronics Validation	CEA (France)	13	36	2.0
HINDAS	High and Intermediate Energy Nuclear Data for ADS	UCL (Belgium)	16	36	2.1
n-TOF-ND-ADS	ADS Nuclear Data	CERN	18	36	2.4
Technological researches					
SPIRE	Effects of Neutron and Proton Irradiation in Steels	CEA (France)	10	48	2.3
TECLA	Materials and Thermo-hydraulics for Lead Alloys	ENEA (Italy)	16	36	2.5
CONFIRM	Uranium Free Nitride Fuel Irradiation and Modeling	KTH (Sweden)	7	48	1.0
THORIUM CYCLE	Development of Thorium Cycle for PWR and ADS	NRG (NL)	7	48	1.2
ADOPT	Thematic Network on Advanced Options for P&T	SCK.CEN (Belgium)	16	36	0.4
MEGAPIE	Megawatt Pilot Experiment	FZK (Germany)	16	36	2 43
FUTURE	Fuel for Transmutation of Transuranic Elements	CEA (France)	10	36	1.7
PDS-XADS	Preliminary Design Studies of an Experimental ADS	Framatome (France)	26	36	6.0

There is an increasing support from the European Union for transmutation and ADS through the Nuclear Fission Action of the EURATOM programmes. Although still modest, the 28 M€ allocated to partitioning and transmutation on a total of 142 M€ for Nuclear Fission in the present 5th Frame Work Program (FWP) indicates, with respect to the 4th and 3th FWP (5.8 and 4.8 M€ respectively), an increasing interest of the community in these issues. Within the 5th FWP 3 basic research and 8 technologically oriented programmes are funded under the title of partitioning and transmutation dealing exclusively with ADS and involving up to 28 partners (see Tab. 1). It is worthwhile to point out the tight collaboration of research institutions and industrial partners such as Framatome or Ansaldo, making use of the valuable synergies in some of these programmes.

In 1998 an important initiative has been taken by the Research Ministers of France, Italy and Spain to investigate the potential of ADS for transmutation. A Minister's Advisory Group (MAG) as well as a Technical Working Group (TWG) were set, the latter one under the chairmanship of Carlo Rubbia. In October 1998, an interim report, endorsed by the MAG in March 1999, concluded to the need for an ADS demonstration programme and the corresponding basic and technological researches. Soon after, the MAG was enlarged to other European countries (Austria, Belgium, Denmark, Finland, Germany, Portugal UK and Sweden) on the basis of this TWG interim report. The TWG was also enlarged to new EU members and in its last report, issued in April 2001, it concludes to the need for an European demonstration facility (XADS: Experimental ADS) and defines a roadmap to achieve such a goal (see Tab. 2). With the programme PS-XADS of the 5th FWP (see Tab. 1), the choices of options are carried out by 28 partners from 3 ADS proposals (France, Italy and Belgium) using all fast neutrons and mixed U-Pu oxide fuels but differing in accelerator type, cooling fluid and target technology.

Tab. 2: Roadmap for a 100 MWth X-ADS

(TWG report, April 2001)															
Time schedule (starting date: 2000)															
Years (in 20--)	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Euratom FWP	5th		6th				7th								
R&D	■	■	■	■	■	■	■	■	■	■	■	■			
Choices of options	■	■	■	■											
Design & Licensing			■	■	■	■	■	■	■						
Construction						■	■	■	■	■	■	■			
Power testing													■	■	
Operation															■
Estimated costs (M€)															
Years (in 20--)	01	02	03	04	05	06	07	08	09	10	11	12	Total		
Euratom FWP	5th		6th				7th								
R&D	30		90				70				10		200		
Engineering design	5		75				60				10		150		
Construction	0		80				300				70		450		
Fuel	0		10				120				50		180		
Total	35		255				550				140		980		

As far as the development of controled fusion based energy release is concerned, the impact of nuclear physics is greatest for ICF, while the required main developments for MCF are related to other fields, e.g. plasma physics and material sciences. At present the support of ICF within the 5th FWP is rather modest (about 1% from 700MEuro dedicated for fusion) and most of the funding is provided at the national level via basic research. The state of the art on heavy ion induced ICF is well described by D. Hoffman together with some attempt to evaluate environmental impact of this option.

In a general introduction to ADS, H. Condé reviews the basic reasons for waste transmutation, the specific contribution of ADS to this technique and how these dedicated reactors could be deployed within a park of light water reactors. Emphasis is put on the double strata strategy where the major actinides – uranium and plutonium – are used in a first stratum to produce energy, whereas minor actinides – neptunium, americium and eventually curium – could be recycled in a second stratum made of ADS.

Basic nuclear physics researches concerning the neutron spallation target is reviewed in a second paper by P. Armbruster and J. Bennlliure. This concerns neutron and spallation residues production characteristics as well as nuclear data measurements above 20 MeV in order to achieve a better theoretical description of spallation and neutron transport. It shows the implication of many European nuclear physics laboratories in France, Germany, Belgium, Sweden and the Netherlands. Primarily designed for exotic nuclei studies with relativistic heavy ion beams, the FRS facility at GSI has been used for the measurement of spallation residues by inverse kinematic reactions; this is a very good example of a nuclear physics technique applied to the ADS, specially with respect to material issues.

In a third contribution, the various issues of high power accelerator technology in the ADS context is reviewed by M. Napolitano. Low energy injection are presently studied in France and Italy.

In the fourth paper, M. Salvatores describes the basic physical principles and neutron transport formalism in the case of a sub-critical reactor and refers to the important experimental program called MUSE, carried out at Cadarache on the mock up reactor Masurca. This program is the result of a very fruitful collaboration between nuclear and reactor physicists.
