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Workshop on

Nuclear Reaction Data and Nuclear Reactors: Physics, Design and Safety

13 March - 14 April 2000

Miramare - Trieste, Italy

Accelerator Driven Systems (ADS) and Transmutation of Nuclear Waste: Options and Trends

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Instructional Material for the lecture
"Accelerator Driven Systems (ADS) and Transmutation of Nuclear Waste: Options and Trends"

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IAEA, Vienna

Scope

The scope of the lecture is to present:

- the rationale for transmutation
- the principle of ADS (spallation source, sub-critical blanket)
- an overview of the main concepts being investigated and the ongoing R&D activities in this area
- development trends for this technology.

Introduction

One of the greatest challenges facing nuclear energy is the highly radioactive long-lived material generated during power production. A sustainable development of the nuclear energy option[∇] requires a safe and effective way to deal with this material. While technical solutions exist, including deep geological disposal technologies, progress on the road to disposal of radioactive waste has been influenced and, in many cases delayed, by public perceptions about the safety of the technology. One of the primary reasons for this is the long life of many of the radioisotopes generated from fission, with half-lives in the order of 10^5 to 10^6 years. Problems of perception could be reduced to an essential degree if there were a way to utilize and/or incinerate the most radiotoxic long-lived isotopes during the production of energy.

A new technological option, or rather a viable development of earlier ideas, has been introduced recently. This option merges accelerator and fission reactor technologies into a single system that has the potential to efficiently generate electricity from nuclear fission and/or transmute the long-lived waste material. In its simplest form, this accelerator driven energy production concept uses neutrons produced in a spallation source by a high-energy proton beam to drive a blanket assembly containing fissionable fuel and radioactive waste

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[∇] an indispensable option, if one considers that demand for all energy sources will increase over the next couple of decades, if only to meet the needs of the world's growing population, which the United Nations estimates will approach 8.5 billion people by the year 2025 material. The blanket assembly is like a reactor, in that fission processes are the source of power. Unlike a conventional reactor, however, this blanket assembly is sub-critical, and thus the chain reaction cannot be sustained without an external neutron source, in the case of the ADS without the accelerator providing a high-energy proton beam to the spallation source. The fuel for this system could be uranium, plutonium or thorium.

Why transmutation?

Per year, the operation of a 1 GW_e UO_2-fuelled light water reactor, producing approximately 6100 GWh_e, yields about 21 t of spent fuel. Most of this radioactive material (about 20 t) is depleted uranium (approximately 0.9 % ^{235}U content). The remaining 1t of spent fuel consists of fission products (~760 kg), plutonium (~200 kg) and other, so called "minor actinides" (~21 kg, of which Am and Np are the major contributors, with roughly 10 kg each, and the remaining 1 kg is Cm).

The concept of a closed nuclear fuel cycle was traditionally considered as transmutation (incineration) of only Pu and the recycled U, with the minor actinides and the long-lived fission products destined for final geological disposal. But as time goes on, a new understanding is emerging: reduction of the minor actinide and long-term fission products inventory has the potential to ease the requirements for final repositories and reduce the associated costs.

The rationale for transmutation is based on this new perspective. Thus, the goal of transmutation is twofold: (a) to reduce the source of potential radio-toxicity in the spent fuel, and (b) to reduce the long-term residual radio-toxicity risk in the repository. The former goal is determined by the actinide (Pu, Am, Np, Cm) inventory in the spent fuel, while the latter, i.e. the long-term risk of radio-toxic leaks from the repository into the biosphere (hence taking into consideration the actual physical (storage barriers) and geological environment in the repository which influences the solubility and migration of the radio-toxic isotopes) is determined by the inventory of some of the long-lived fission products.

The actinides dominate the source of potential radio-toxicity because they and their progenies are mostly high-dose _-emitters (as an example, consider ^{241}Pu which decays to ^{241}Am (_$^-$ decay, 14 years half-life), which in turn is a _-emitter (432 years half-life) becoming ^{237}Np, another _-emitter (2.1×10^6 years half-life) becoming ^{233}Pa, a short lived isotope (27 days half-life) transformed by _$^-$ decay into ^{233}U which, again, is a _-emitter (1.6×10^5 years half-life) and becomes ^{229}Th, another _-emitter (7880 years half-life) leading eventually through a few other short lived progenies to the stable isotope ^{209}Bi). It is therefore obvious that a reduction of the potential radio-toxicity source asks for the incineration (i.e. fission) of as many Pu and minor actinides isotopes as possible. A closer look at the potential radio-toxicity in the spent fuel reveals the following picture: Pu and Am isotopes determine the radio-toxicity level between approximately 100 and 100'000 years, after which ^{237}Np and its progenies ^{233}U and ^{229}Th become dominant. More quantitatively, e.g., the contributions to the potential radio-toxicity (for ingestion, expressed in Sv per TWh_e) of typical PWR spent fuel after 100'000 years are approximately 3.9×10^6 for Pu, Am and Np (with the relative share of these three nuclides being about 96 %, 3 % and 1 %, respectively); 6.2×10^5 for U (depleted uranium after enrichment, uranium from reprocessing, and mill tailings); and only about 3.2×10^{-2} from long-lived fission products. If only Pu were to be recycled, with 0.1 % Pu losses at reprocessing and fabrication going into the repository, the potential radio-toxicity from Pu, Am and Np in the spent fuel after 100'000 years would decrease to approximately 6.7×10^4 Sv/TWh_e (ingestion), i.e. by a factor of ~60. If, in addition to Pu, also Am, Np and Cm were removed from the spent fuel (and properly transmuted), and only 1 % losses would end up in the repository, the potential radio-toxicity after 100'000 years would be reduced by an additional factor of approximately 100, as compared to the case where only Pu is reprocessed. However, if one considers that (a) transmutation of all actinides leads, after approximately 50'000 years, to a potential radio-toxicity level in the repository comparable to that of the natural uranium used to fabricate the original fuel, and (b) solubility and migration properties are really determining the long-term residual radio-toxicity risk in the repository, it must be recognized that for transmutation to have an impact, also long-lived fission products must be considered. The most important contributors to the long-lived fission products radio-toxicity are ^{99}Tc, ^{126}Sn, ^{129}I, ^{93}Zr, ^{135}Cs and ^{79}Se. The long-term risk of the repository would be vastly reduced, should it be possible to partition and transmute also these isotopes: in this case, one could indeed argue, that appropriate packaging of the waste would be sufficient to ensure safe geological disposal. Efficient transmutation of long-lived fission products, relying on neutron capture processes, requires high thermal neutron fluxes (e.g., the (n,γ) processes for ^{99}Tc → ^{100}Tc, decaying by _$^-$ (16 s half-life) to the stable ^{100}Ru, and for ^{129}I → ^{130}I, decaying by _$^-$ (12.4 h half-life) to the stable ^{130}Xe). ADS offers interesting options also for long-lived fission products transmutation (high-energy proton beams being used to produce a spallation neutron source, for either a high thermal flux irradiation in the sub-critical blanket, or the adiabatic resonance crossing, as will be discussed later).

Brief history of ADS

The ADS is based on "revived" ideas from the early 1950s. Building on Glenn Seaborg's pioneering work (it is reminded that Seaborg had produced the first few μg of plutonium with the help of an accelerator), E. O. Lawrence (the inventor of the cyclotron) in the US at Livermore National Laboratory, and W. B. Lewis at Chalk River Laboratory in Canada, have both, in the early 1950s, initiated accelerator based breeding projects: Lawrence for producing military ^{239}Pu ("Material Test Accelerator" project, 1950 – 1954), and Lewis, starting in 1952, for breeding ^{233}U in view of the thorium-based, heavy-water moderated CANDU line being established in Canada.

These early projects were abandoned mainly due to economical reasons. In the late 1970s and early 1980s, in the wake of INFCE, and the US administration's decision to slow down the development of the fast breeder reactor, scientists at Brookhaven National proposed several concepts for accelerator breeders such as the Na-cooled fast reactor target, the Molten Salt target, the He-gas-cooled target, as well as the LWR fuel regenerator.

Furthermore, the original idea of exploiting directly the spallation process to transmute actinides and long-lived fission products was soon abandoned. The proton beam currents required for direct transmutation by the spallation process were much larger than the most optimistic theoretical designs that an accelerator could achieve, which are around 300 mA. Indeed, it was shown that the yearly transmutation rate of a 300 mA proton accelerator would correspond only to a fraction of the waste generated annually by a 1 GWe LWR.

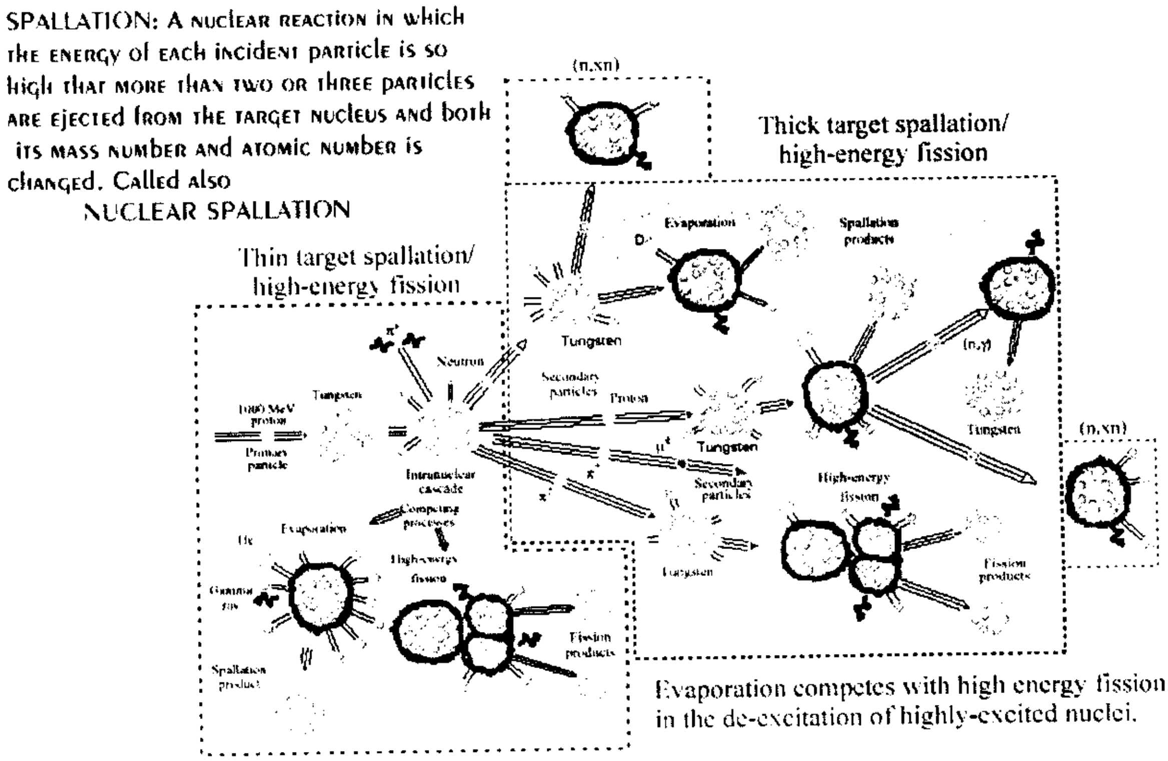
C. Bowman at Los Alamos National Laboratory and H. Takahashi at Brookhaven National Laboratory in the late 1980s and early 1990s introduced the ADS concept proposing to use the high-energy proton beam from an accelerator to produce spallation neutrons which in turn would drive a sub-critical blanket. Bowman aimed at accelerator driven transmutation and energy production on the basis of a thermal system, while Takahashi's PHOENIX project (using a 1.6 GeV, 104 mA LINAC) was based on a fast spectrum sub-critical blanket and aimed at the incineration of actinides.

In 1994, C. Rubbia proposed the "Energy Amplifier" (EA) concept, originally as an accelerator driven, liquid metal cooled, fast, energy producing system based on the uranium-thorium cycle. In later variants, the EA has also been proposed as incinerating/transmuting device for actinides and long-lived fission products.

Physics principles of ADS

A brief overview of the physics principles for both the spallation target and sub-critical blanket are given.

Spallation refers to nuclear reactions that occur when energetic particles (e.g. protons, deuterons, neutrons, pions, muons, etc.) interact with an atomic nucleus - the target nucleus. In this context, "energetic" means kinetic energies larger than about 100 MeV per nucleon. At these energies it is no longer correct to think of the nuclear reaction as proceeding through the formation of a compound nucleus. The initial collision between the incident projectile and the target nucleus leads to a series of direct reactions (intranuclear cascade) whereby individual nucleons or small groups of nucleons are ejected from the nucleus. At energies above a few GeV per nucleon, fragmentation of the nucleus can also occur. After the intranuclear cascade phase of the reaction, the nucleus is left in an excited state. It subsequently relaxes its ground state by "evaporating" nucleons, mostly neutrons. The spallation process is depicted in Fig. 1, showing two stages of the process (intranuclear cascade and evaporation). For thick targets, high energy (> 20 MeV) secondary particles (and their progenies) can undergo further spallation reactions. For some target materials, low energy (< 20 MeV) spallation neutrons (i.e., the cascade-evaporation neutrons) can enhance neutron production through low energy (n,xn) reactions. For heavier nuclei, high-energy fission can compete with evaporation in a highly excited nucleus.



SPALLATION: A nuclear reaction in which the energy of each incident particle is so high that more than two or three particles are ejected from the target nucleus and both its mass number and atomic number is changed. Called also NUCLEAR SPALLATION

Evaporation competes with high energy fission in the de-excitation of highly-excited nuclei.

Fig. 1: Illustration of the spallation process in thin and thick targets with evaporation competing with high-energy fission as de-excitation ways for highly excited nuclei

High-energy fission competition with evaporation in highly excited nuclei is also illustrated in Fig. 1. Tantalum, tungsten, and lead are examples of materials that can undergo spallation / high-energy fission.

Some spallation-target fissionable materials such as thorium and depleted uranium can (in addition to undergoing high-energy fission) be fissioned by low-energy (~1 MeV to ~20 MeV) neutrons. Spallation, high-energy fission and low-energy neutron fission produce different nuclear debris (spallation and fission products).

These processes are calculated by intra- and inter-nuclear cascade codes developed by several laboratories.

Deuteron and triton projectiles produce more neutrons than protons in the energy range below 1-2 GeV; thus, the efficiency of transmutation can be increased using them. However, the high yield of neutrons among the low-energy deuterons and triton can easily contaminate the low-energy part of the accelerator with radio-activity from these spilled charged particles; this causes trouble in hand-maintaining the accelerator. Thus, the maintenance cost of the accelerator becomes high, unless spilling of the beam, which is more likely to occur in the low-energy section than in the high-energy section, is extremely limited.

The function of the target in the ADS is to convert the incident high-energy particle beam into low energy neutrons (quite a task, considering the 9 or 10 orders of magnitude in between). These requirements can be summarized as:

- Compact size to enable good coupling to the surrounding sub-critical blanket;
- High power operation, of the order of 10 to 100 MW;
- High neutron production efficiency;
- Reliable and low maintenance operation;
- Safe and low hazard operation;
- Small contribution to the waste stream.

It is believed today that molten lead or lead-bismuth eutectic (LBE) are the best choices to meet most of these requirements. A significant problem with LBE, however, is the production of radioactive and highly mobile polonium from high-energy proton and neutron reactions on bismuth. This becomes a concern in accident scenarios where the polonium contained in the LBE is rapidly released at high temperatures. Lead, on the other hand, has a much reduced polonium production, but higher operating temperatures. Experimental experience and further assessments are needed to make the best choice.

In accelerator driven transmutation of minor actinides or long-lived fission products, the sub-critical blanket surrounding the spallation target multiplies the spallation neutrons. In quantitative terms, N_{fiss}, the total number of fissions in the sub-critical blanket, can be expressed by:

$$N_{fiss} = N_h \Gamma_h \frac{k_{eff}}{(1-k_{eff})\upsilon}$$

where:

N_h = total number of fissions by high-energy proton reactions,

Γ_h = number of neutrons produced by high-energy proton reactions per fission in the sub-critical blanket (spallation, evaporation, and very high energy fission)

ν = number of neutrons per "regular" fission

k_{eff} = multiplication factor for "regular" fission neutrons.

By increasing the k_{eff} value of the sub-critical blanket, one can reduce the proton current required to attain criticality. If the k_{eff} -value reaches 1, then the blanket becomes critical and does not require the external neutron source provided by the proton accelerator. However,

safety issues limit the amount of minor actinides that can be loaded into a "conventional" critical reactor[×]. Thus, ADS offers the potential to attain higher minor actinide loadings. So far, the k_{eff}-value that is most suitable for actinide incineration is still being debated. The main aspects to be considered are: safety, operational procedures, choice of material, and cost of the ADS. k_{eff} -values studied in many cases span over an interval of 0.9 - 0.98.
The outstanding ADS design feature is its inherent sub-criticality and stability of the reactivity. As already mentioned, this feature can significantly improve the safety of the ADS, and may eliminate furthermore the necessity of control rods. Control rods are not only a safety concern (in most cases it is a mechanically driven device); they also degrade, in most cases, the neutron economy of the system. Good neutron economy is the crucial issue for ADS because it determines the power and consequently the cost of the accelerator.

Similar to conventional nuclear reactors, ADS can operate in different neutron spectrum modes. The thermal cross-sections for processes needed to transmute minor actinides and long-lived fission products are larger than the cross-sections in a fast spectrum, so that, in a thermal system, the inventory of these materials in the core can be reduced substantially. However, the thermal neutron cross-section of the transmuted products is also large, and, as soon as these progeny isotopes are produced in the core, it is desirable to remove them, otherwise the neutrons will be wasted by neutron capture by the poison isotopes. The capture of fast neutrons by the fission products and the structural material is small, and from the point of view of neutron economy, the fast reactor has advantages over the thermal reactor. Also, one would like to take advantage of the high η-value for ^{239}Pu, the other actinides as well as minor actinides to further improve the neutron economy through produced high-energy fission, and use these extra neutrons for transmuting long-lived fission products. It should also not be forgotten, that, in principle, transmutation best serves its purposes when the actinides are "incinerated", which requires fission processes to dominate as much as possible. Again, this implies that fast or very fast neutron spectra are best suited.

The thorium-uranium fuel cycle is an attractive option for ADS. The main advantages of the thorium-uranium fuel cycle over the uranium-plutonium cycle used in today's nuclear reactors are:

- The thorium-uranium cycle produces a relatively small amount of higher actinides compare with uranium-plutonium cycle, because of the small capture to fission ratio in ^{233}U and because of the presence of two other fissionable uranium isotopes of ^{235}U and ^{237}U in the chain leading to plutonium and the other minor actinides;
- The thorium-uranium cycle is regarded as safer than the uranium-plutonium cycle from a nuclear weapons proliferation standpoint, because of the presence of the hard γ-emitter in the ^{232}U decay chain, and because of the possibility of straightforward isotopic dilution of ^{233}U with depleted or natural uranium in the feed or start-up fuel.

Various ADS concepts and overview of activities

Various technical options for transmutation and power production using ADS are nowadays under investigation in several countries and international organisations. A number

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[×] In a fast neutron spectrum reactor, the β_{eff} values of minor actinides fuel is considerably lower (2.5 times in the case of ^{237}Np and 8 times in the case of ^{241}Am) than the β_{eff} value for mixed uranium-plutonium oxide fuel (typically 350 pcm). This is due to the fact that β_{eff} does not depend only on the fraction of delayed neutrons (which is similar for all the actinide isotopes), but also on the fission cross section of the isotopes averaged over the delayed neutron spectrum. Since the delayed neutrons stemming from minor actinides are "softer" than in the case of mixed uranium-plutonium oxide fuel, their averaged fission cross section will be higher

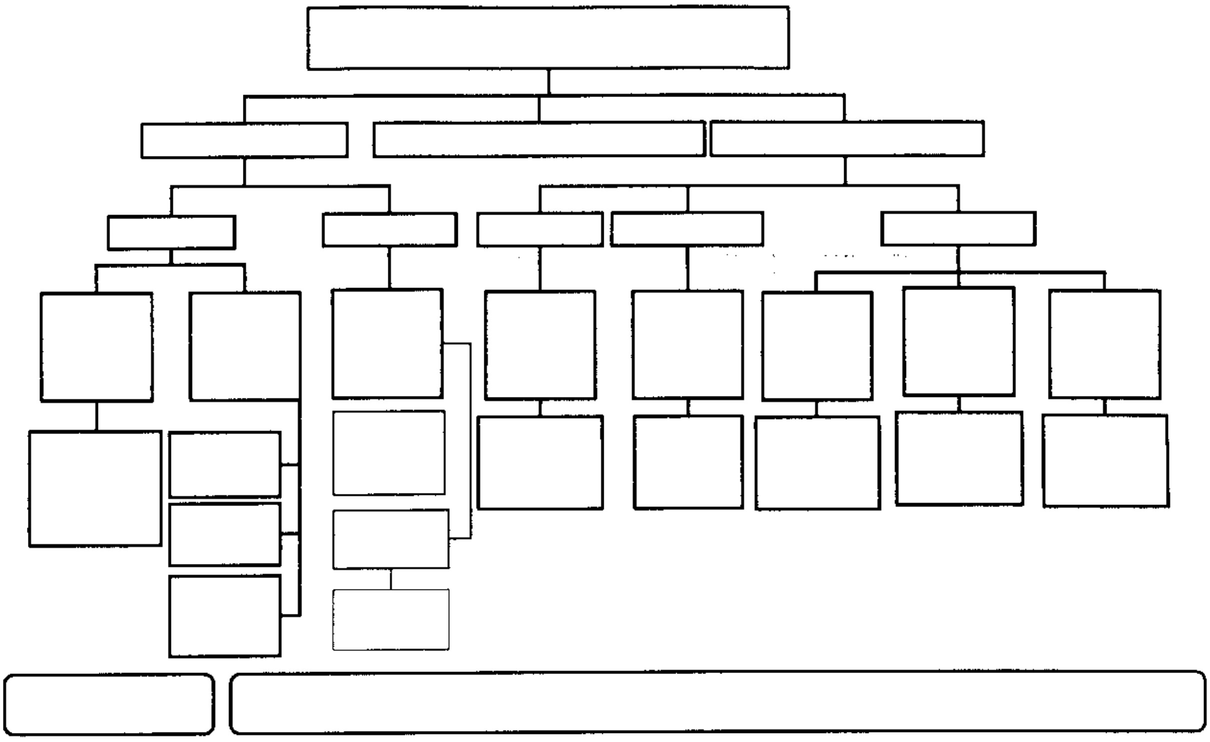

Fig. 2: Classification of existing ADS concepts according to their physical features and final objectives

of ADS schemes are being studied in the frame of the OMEGA project in Japan (Options Making Extra Gain from Actinides), in the USA (at Los Alamos National Laboratory and Brookhaven National Laboratory), in France (CEA), in the Russian Federation, at CERN, at Nuclear Energy Agency (NEA) and at the European Commission (EC).

ADS concepts can be classified according to their physical features and final objectives. The classification is based on the neutron energy spectrum, fuel form (solid, liquid), fuel cycle and coolant/moderator type, and objectives for the system. Fig.2 shows a classification of existing ADS concepts according to both their physical features and final objectives.

ADS systems - like reactors - can be designed to work in two different neutron spectrum modes - in fast or thermal spectra. There are also attempts at CERN to design a system which will exploit the neutron capture cross section resonances in what could be termed a "neutron capture resonance mode" (or, as already mentioned, the adiabatic resonance crossing).

Both, fast and thermal systems are considered for solid and liquid fuels. Even quasi-liquid fuel has been proposed based on the particle fuel (pebble bed) concept developed by Brookhaven National Laboratory.

The objective for some ADS is to transmute existing nuclear waste from nuclear reactors, mainly plutonium and minor actinides, with or without concurrent energy production. Other systems are designed to take advantage of the thorium fuel cycle for energy production. As can be seen in Fig. 2, most concepts are based on linear accelerators. However, the CERN group and Brookhaven National Laboratory propose to use a proton cyclotron.

The accelerator driven energy production system at Los Alamos National Laboratory includes a high-energy proton beam linear accelerator, a heavy metal target (lead or lead-bismuth eutectic) and liquid fuel. Liquid fuel is attractive because it avoids the steps of fuel fabrication and fuel bundle handling/management while at the same time allowing continuous extraction of a significant fraction of long-lived fission products during operation. This removal improves both fuel economy and enables destruction of the long-lived component of the fission products. One of the early ideas proposed by the Los Alamos scientists was based on a super-thermal, high flux concept. It is worthwhile recalling that this concept has a very interesting feature with regard to ^{237}Np: at thermal neutron fluxes higher than $\sim 5\times10^{15}$ n/cm^{2}s, ^{237}Np does not act as a neutron poison anymore, since it captures two neutrons in sequence, eventually becoming ^{239}Np which is fissionable (thus, ^{237}Np is transformed in a high thermal flux from neutron poison to fissile). Such high fluxes would require in "conventional" solid fuel reactors very high reloading frequencies. The molten salt option provides an answer to this problem. It was also chosen because it operates at low pressures, has simpler mechanical structures, lower neutron absorption losses and lower liquid fuel inventory.

The accelerator driven sub-critical nuclear system proposed by C. Rubbia at CERN is a fast neutron system. Fuel elements are in solid form, with cladded fuel pins. The nominal fuel is Th/^{233}U but it can also run on plutonium (either military or reactor grade) and can fission also the minor actinides. Liquid lead serves as spallation neutron target, heat carrying medium, as well as neutron diffuser (weak moderator). A number of passive safety features of the concept are based on its physical properties. Particularly noteworthy is the absence of pumps. Heat is evacuated by natural convection.

During the last two decades, the Japan Atomic Energy Research Institute (JAERI) has been carrying out the partitioning and transmutation program in the areas of design studies of transmutation systems. Two types of ADS concepts are being studied: a solid target/core system and a molten-salt target/core system. Either system utilises the hard neutron spectrum of spallation neutrons to efficiently transmute minor actinides by fission. Concepts of accelerator driven molten salt reactors are under study in several universities in Japan. JAERI has launched the Neutron Science Project, which aims at bringing scientific and technological innovation for the 21st century in the fields of basic science and nuclear technology using neutrons. The accelerator driven transmutation system studies and the development of an intense proton accelerator are also under way as important parts of this project.

In France, CEA's different laboratories have been working in recent years on several aspects of the technology and of the physics of the ADS (high intensity accelerator technology, physics of source driven multiplying systems, spallation physics). In 1995 it has been decided to launch a limited program, devoted to the experimental validation of the major items related to a generic ADS (namely, accelerator technology, target physics and multiplying sub critical system physics).

Several groups in the Russian Federation Scientific Centres have been working in recent years on several aspects of the technology and of the physics of ADS systems. Different concepts of ADS with different structures and materials for target and blanket are under consideration. Some studies related to P&T, so called conversion projects, are financially supported by international institutions, mainly in the frame of the International Science and Technology Centre.

Six leading European nuclear companies (Ansaldo Nucleare, Italy; Belgatom, Belgium; Empresarios Agrupados, Spain; Framatome, France; NNC Limited, United Kingdom; Siemens, Germany) have established an industrial partnership (EIP) to promote and develop engineering design studies of a demonstration facility to assess the industrial feasibility of an accelerator driven sub-critical system for high level, long-lived waste transmutation. This industrial partnership will act both at national and at European Union level, in particular within the fifth framework programme for Research, Technological Development and Demonstration Activities. The contribution of the EIP is constituted by the draft proposal "Preliminary Design Studies of a Demonstration Facility of an ADS" which has been prepared to be discussed with R&D bodies, and eventually be submitted to the EU under the fifth framework programme call for proposals. The draft proposal has the purpose to identify a minimum set of design activities which are considered mandatory by the EIP to assess the engineering feasibility of the two reference options (the lead-bismuth cooled and the gas cooled ADS) and to perform the selection of one solution to be further developed in detail within the 6th EU framework programme.

The EC itself co-ordinates projects of the EU Member States on a cost-shared basis and performs studies on minor actinide fuels and partitioning at the European Institute of Transuranium Elements. The main emphasis has been target and fuel development. Studies on minor actinide containing fuels have led to a series of irradiation experiments, some of which are already completed while others are still in progress. The objective of the EC programme "Impact of the Accelerator Based Technologies on the Nuclear Fission Safety" is to concentrate and co-ordinate different efforts from member states to create the European scientific and technological basis for eventual further projects aimed to develop safer nuclear fission energy source. Models, tools, validated routines and some new experimental data for a possible future experimental activity on a larger scale will be the final results.

The OECD/NEA has a comprehensive international work programme related to issues concerning transmutation and separation of fission products and actinides. The NEA Nuclear Development Committee set up an Expert Group to perform system studies on Actinide and Fission Product Partitioning and Transmutation (the first report has been published in 1999, the second phase of the group's work is on-going), whereas the NEA Nuclear Science Committee has a number of co-operative projects covering the scientific and physics aspects of different transmutation concepts.

As for the IAEA, besides its activities in safeguards and safety, the Agency has a promotional function "to encourage and assist research on, and development and practical application of, atomic energy for peaceful uses throughout the world..." In this context, the IAEA within the frame of its programme on "Utilization and Transmutation of Actinides and Long-lived Fission Products" can provide a forum for information exchange, the review and discussion of programmes and projects, as well as for collaborative R&D in the area of ADS. Specifically, the activities carried out by the IAEA within the frame of the programme mentioned above include preparation of status reports on advanced technologies development, conduct of technical information exchange meetings and Co-ordinated Research Programmes (CRPs). Some of the major ADS related activities are:

- Status Report on Accelerator Driven Systems;
- Status Report on Thorium-based Fuel Cycles;
- CRP on "Use of Th-based Fuel Cycle in ADS to Incinerate Pu and to Reduce Long-term Waste Toxicities";
- Technical Committee Meeting (TCM) on "Feasibility and Motivation for Hybrid Concepts for Nuclear Energy Generation and Transmutation" (Madrid, September 1997);
- Database on ADS related R&D (WWW-based);
- Advisory Group Meeting on "Review of National Accelerator Driven Systems (ADS) Programmes" (Taejon, Rep. of Korea, November 1999).

Trends, outlook

Many technical and engineering questions remain to be explored and answered before the potential of the ADS concept can be demonstrated. The work ahead will require enhanced international co-operation to pool expertise and resources.

In many respects, accelerators driven systems are worth pursuing: they may play an important role as part of a sustainable development of nuclear energy production. By producing electricity, they can contribute to the world's growing energy needs, and by incinerating plutonium and other actinides as well as long-lived fission products they can contribute to the goals of environmental protection and safe waste management.

Some types of ADS being developed can produce energy from the abundant element thorium in a safe, sub-critical blanket with a minimal nuclear waste-stream.

Beyond this, there is also the promise of systems with the goal to burn weapons plutonium and to incinerate spent nuclear fuel including its major long-lived fission products from commercial nuclear power plants. Wit regard to this latter issue, it must be stressed that, because of their neutronics properties, ADS are particularly adapted to incinerate actinides and reduce the long-term radio-toxicity risk of waste repositories to that of the uranium ore used for the energy production.

In recognition of this potential, presently a number of national and regional scientific institutes and laboratories around the world are engaged in R&D of ADS. At the global level, the IAEA's programmes in this field are helping to promote the exchange of information and collaborative research on specific topics. The work is indicative for the heightened interest in ADS technology as a practical tool for contributing to global energy and environmental goals.

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Suggested bibliography

- Proceedings of the IAEA Technical Committee Meeting on "Feasibility and Motivation for Hybrid Concepts for Nuclear Energy Generation and Transmutation (IAEA-TC-903.3), Madrid, Spain, September 1997;
- Proceedings of GLOBAL '97, Yokohama, Japan, October 1997;
- Accelerator Driven Systems: "Energy Generation and Transmutation of Nuclear Waste (Status Report)", IAEA-TECDOC-985, November 1997;
- Proceedings of the OECD/NEA – EC Fifth International Information Exchange Meeting (EUR 18898 EN), Mol, Belgium, November 1998;
- Proceedings of ADTTA '99, Praha, Czech Republic, June 1999
- "Actinide and Fission Product Partitioning and Transmutation (Status and Assessment Report)", OECD/NEA, 1999