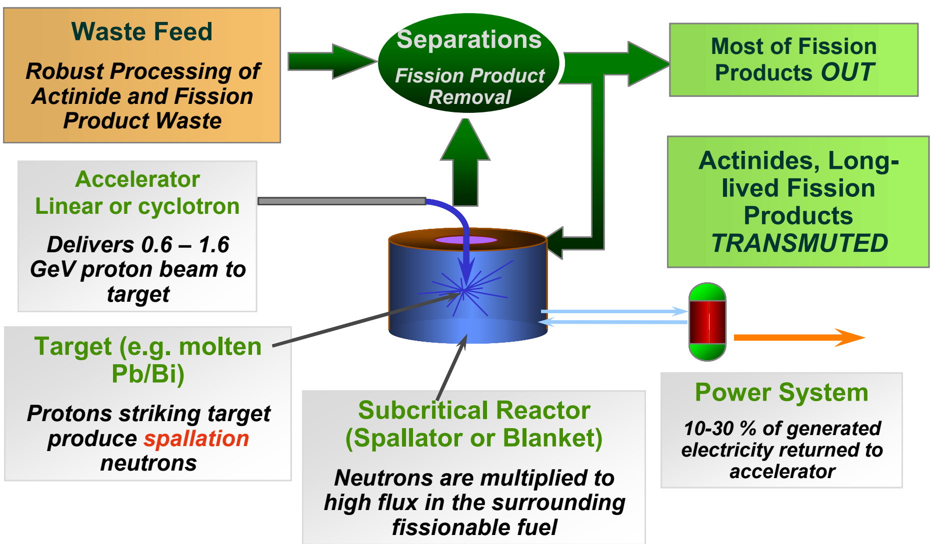
SKI Report 2003:19

Research

Nuclear Waste Separation and Transmutation Research with Special Focus on Russian Transmutation Projects Sponsored by ISTC



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SKI's perspective

Background

After the collapse of the Soviet Union a general international fear was that Russian scientists involved in the nuclear weapons programme would proliferate nuclear weapons technology to threshold states. In order to prevent this, USA, EU, Japan, Sweden and Finland helped in establishing the International Science and Technology Center, ISTC, in Moscow. The aim of the centre is to finance civilian projects using former nuclear weapons scientists. Part of the research funded by the ISTC concerns Accelerator Driven Transmutation techniques in order to burn weapons grade plutonium from decommissioned nuclear devices and transuranium elements, including plutonium, from spent nuclear fuel.

Aim

During a number of years SKI has supported a group that follows the research on nuclear waste separation and transmutation within the ISTC. The purpose is to see how far the research has progressed and how the ISTC fulfils its purpose to engage former nuclear weapons specialists in peaceful research.

Results

This report summarises the activities of the group during three years, 2000-2002. As an appendix, phase 3 (1999) is given. The overview gives a good description of the combined effort in the area of nuclear waste separation and transmutation world-wide.

Continued efforts in this area of research and effect on SKI's activities

The non-proliferation aspect of this research has decreased over the years and now the focus is on solving the fundamental problems of transmutation. Therefore, we now see that the non-proliferation motivation for SKI to fund the activities of the group has diminished. SKI has issued a contract for travel in order to make use of the reference group organised by the Swedish Nuclear Fuel and Waste Management Co (SKB) for continued coverage of these issues. This is in line with the strategic research plan (SKI Report 02:24) that was written in 2002.

Project information

Kåre Axell has been responsible for the project at SKI.

SKI ref. 14.10-000283/00068

Previous projects:

SKI Report 97:15 – Planning and Reporting of Russian Transmutation Research Projects within ISTC. Phase 1.

SKI Report 99:05 – Planning and Reporting of Russian Transmutation Research Projects within ISTC, Phase 2

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PREFACE

This is the final report of a project, supported by the Swedish Nuclear Power Inspectorate (SKI) to plan and report of Russian transmutation research projects financed by the International Science and Technology Center (ISTC) in Moscow. This Center was set up by USA, Russia, Japan and EU to engage former Soviet Union nuclear weapon experts in civilian research to reduce a know-how proliferation risk.

The SKI project started in 1995 and has been split on 4 phases reported separately. The phases 1 and 2 were reported to SKI in February 1997 (SKI Report 97:15) and in November 1998 (SKI Report 99:5), respectively. Phase 3 of the project, which was reported to SKI in May 2000, is given as an appendix to the present report, which otherwise summarises the research up till the end of year 2002, thus including the final phase (Phase 4) of the project.

In 2002 the SKI presented its future research strategy in a report (SKI Report 02:24) requested by the Government. In this report it is said that transmutation is not seen by SKI as a realistic option for treatment of Swedish nuclear waste. Furthermore, it is also stated in the same report that SKI thinks that the non-proliferation impact of the ISTC is of diminishing importance. Subsequently, the task to plan and report about ISTC transmutation projects was transferred to the Reference Group for Separation and Transmutation Research set up by the Swedish Nuclear Fuel and Waste Management Company (SKB) by January 1, 2003.

Summary

High-level nuclear reactor waste is made up of relatively few long-lived radioactive species, among them plutonium, that contribute to difficulties with its storage and disposal. Separation of these species from larger waste volumes mainly constituting of uranium (about 95 %) coupled with nuclear incineration to fission products of plutonium and the so called minor actinides (MA) (Neptunium - Np, Americium - Am, and Curium - Cm) and transmutation of some of the long lived fission products to short lived or stable isotopes represents a viable nuclear waste management strategy to drastically reduce the time and space requirements for a bed-rock repository of the remaining waste.

A remarkable increase in the international research and development on partitioning and transmutation has occurred during the recent years. The road-map report published in April 2001 by "The European Technical Working Group on ADS" for the development of a European demonstration facility for nuclear waste transmutation has high-lighted the ongoing European research and pointed out the need for further research. The road-map has given the different research activities a position in the ultimate goal of producing an ADS demonstrator and is guiding research planning on the national as well as on the EU level. The "Advanced Accelerator Application (3A)" program in the U.S, with the long term goals to enhance long term public safety, provide benefits for the repository, reduce proliferation risks and improve prospects for nuclear power has focused the research on nuclear waste transmutation. The reports on the 3A program indicates a change of the US former abandonment position towards reprocessing and fast reactors due to a strong incentive to eliminate the reactor plutonium and to lower the amount of high level reactor waste for the Yucca Mountain repository.

The SKB's proposed research and development program for the next 3 years (FUD01) was presented by SKB in September 2001. It is proposed that the research program for transmutation of long lived nuclear waste should be carried through on about the same level as present (5 MSEK/year). Support is also given for participation in international projects, primarily EU projects. The aim of the research is to provide knowledgeable experts in the field to assess the international research and development on transmutation.

Swedish transmutation research, in general fundamental research, are performed at three universities – CTH, KTH and Uppsala University – with the essential support from SKB, SKI and Swedish Nuclear Technology Centre (Svenskt Kärntekniskt Centrum). The same university groups are also participating in a number of international transmutation related research projects, in particular, the projects under the 5th Framework Programme of the European Commission.

One of the main issues of the International Science and Technology Center (ISTC) in Moscow, which is financially supported by USA, EU, Russia, Japan, South Korea and Norway, is to reduce the proliferation risk by engaging experts at the former Soviet Union nuclear weapon laboratories in civilian research. This issue has been more

pronounced since the terrorist attacks on September 11, 2001 and the following threats from the same group of terrorists. At a workshop in Saltsjöbaden in 1991 on Accelerator Based Radioactive Waste Transmutation it was concluded that research on incineration and transmutation of reactor- and weapons grade plutonium was a civilian research area well suited to occupy the former USSR weapon experts with support from ISTC.

The Expert Group on Transmutation/SKI Reference Group has chosen to initiate ISTC projects, which are dealing with fundamental technical issues for the accelerator driven transmutation concepts. The possibility of finding a Swedish research group as a counterpart to the Russian group has also played a role in the reference group's selection of projects. The Swedish research groups from CTH, KTH and UU are at present collaborating in 9 transmutation projects supported by ISTC and are continuously discussing new proposals from Russian laboratories for transmutation research.

As a consequence of SKI's research strategy reported to the Government in 2002 that transmutation is not a realistic option for the treatment of Swedish nuclear waste and that ISTC projects are of diminishing importance for non-proliferation the SKI withdrew the financial support to the Expert Group for planning and reporting ISTC transmutation projects. This latter task was transferred by January 1, 2003 to SKB. Several members of the Expert Group do not agree with the opinions of SKI.

Sammanfattning

Högaktivt reaktoravfall består av relativt få långlivade radioaktiva element, bland dem plutonium, som bidrager till svårigheterna vid förvaring och deponering av avfallet. Separation av dessa högaktiva element från det huvudsakliga innehållet i avfallet som utgörs av uran (omkring 95%) kopplat till en nukleär förbränning till fissionsprodukter av plutoniet och de s.k. mindre aktiniderna (MA) (neptunium-Np, americium-Am och curium-Cm) samt transmutation av några av de långlivade fissionsprodukterna till kortlivade eller stabila isotoper utgör en mycket intressant strategi för hantering av kärnavfall som drastiskt reducerar såväl tiden som utrymmet för slutförvaret.

En avsevärd ökning av den internationella forskningen och utvecklingen på separation och transmutation har skett under de senaste åren. En vägledande rapport för utvecklingen av en europeisk demonstrationsanläggning för transmutation av kärnavfall publicerades under 2001 av en europeisk arbetsgrupp. Rapporten belyser den pågående europeiska forskningen och pekar ut behovet av ytterligare forskningsarbeten. Rapporten placerar också in den pågående forskningen i relation till målsättningen att producera en demonstrationsanläggning och ger vägledning till kommande forskningsinsatser på såväl nationell som EU nivå. ”Advanced Accelerator Application (3A)” programmet i USA har målsättningen att långsiktigt öka säkerheten kring kärnkraften, minska tids- och utrymmesbehovet för slutförvaret (Yucca Mountain), minska spridningsrisken för kärnvapen och öka den publika acceptansen för kärnkraften. Forskningen i anslutning till detta program har fokuserats kring transmutation. Programmet indikerar en förändring i amerikansk attityd (Carter doktrinen) till ett accepterande av separation av kärnavfall och användning av snabba reaktorer i syftet att eliminera plutonium och förbränna reaktoravfall.

SKB’s förslag till program för forskning och utveckling för de närmaste 3 åren (FUD01) presenterades av SKB i september 2001. I rapporten föreslås att forskningsprogrammet för transmutation av långlivat reaktoravfall fortsättes att drivas på samma nivå som tidigare (5 MSEK/år). Stöd ges inom detta program till deltagande i internationella projekt, huvudsakligen EU projekt. Syftet med forskningsstödet är att skapa kunniga experter som kan bedöma den internationella forskningen och utvecklingen inom transmutation.

Svensk transmutationsforskning, i allmänhet grundläggande forskning, bedrivs vid tre universitet – CTH, KTH och Uppsala universitet – med huvudsakligt stöd från SKB, SKI och Svenskt kärntekniskt centrum. Samma universitetsgrupper deltager också i ett antal internationella transmutationsrelaterade forskningsprojekt, främst inom EU’s 5te ramprogram.

Ett av de huvudsakliga syftena med ”International Science and Technology Center (ISTC)” i Moskva som ekonomiskt stöda av USA, EU, Ryssland, Japan, Syd Korea och Norge, är att reducera spridningsrisken av kärnvapenkunnande genom att engagera experter från före detta kärnvapenlaboratorier i Sovjet unionen i civila forskningsuppdrag. Denna målsättning förstärktes ytterligare efter terroristattacken i New York den 11 september 2002. Vid ett arbetsmöte i Saltsjöbaden 1991 om accelerator baserad transmutation av radioaktivt avfall med deltagare från USA, Ryssland och Sverige konstaterades att förbränning av reaktor- och vapenplutonium var ett forskningsområde som passade väl in med ISTC målsättning att sysselsätta före detta kärnvapenvapenexperter från USSR med civila forskningsuppdrag.

Expertgruppen för transmutationsforskning/SKI's referensgrupp har valt att initiera ISTC projekt vilka berör fundamentala tekniska frågor i samband med accelerator driven transmutation. Möjligheten att finna en svensk forskningsgrupp som medverkar med den ryska gruppen har också spelat en roll vid referensgruppens val av projekt. Svenska forskningsgrupper från CTH, KTH och Uppsala universitet deltagare i 9 transmutationsprojekt med ekonomiskt stöd från ISTC och diskuterar kontinuerligt nya projekt från Ryska laboratorier gällande transmutationsforskning.

SKI's forskningsstrategi rapporterades till Regeringen under 2002. SKI säger i denna rapport att man inte bedömer att transmutation är ett realistiskt alternativ för kärnavfallet från de svenska reaktorerna och att ISTC projekten har en minskande betydelse för icke-spridningsproblematiken. Som en följd härav drar SKI in det finansiella stödet till Expertgruppen för rapporteringen och planeringen av ISTC stödda transmutationsprojekt. Denna uppgift överförs till SKB per den 1 januari 2003. Flera av Expertgruppens medlemmar har en avvikande mening från SKI ställningstagande i dessa frågor.

Swedish Nuclear Waste Handling Strategy

The nuclear power reactors in Sweden will up till 2010 produce about 8000 tons of spent nuclear fuel. According to the Swedish Act on Nuclear Activities, the companies licensed to operate nuclear power plants have full responsibility for safely managing all nuclear production waste and for waste resulting from the dismantling of the facility. The financing system is based on a fee charged per generated kilowatt-hour of electricity and is paid to the Government. There is a specific law – the Act on the Financing of Future Expenses for Spent Nuclear Fuel – regulating the way in which the expenses are calculated and how they should be met. The total estimated cost for the Swedish program for managing all nuclear waste and for dismantling nuclear power plants are about SEK 50 billions (~ $ 5 billions). The nuclear power utilities have formed a jointly owned company, the Swedish Nuclear Fuel and Waste Management Company (SKB) to fulfil the obligations of the power utilities regarding nuclear waste. The research and development (R&D) for waste management is carried out by SKB. The R&D program is evaluated each third year by the National Council for Nuclear Waste (KASAM), the Swedish Nuclear Power Inspectorate (SKI) and the Swedish Radiation Protection Institute (SSI) followed by a final decision taken by the Government The latest R&D program proposal was issued by SKB in September 2001 (FUD01). The final approval by the Government of the program is still pending.

The present Swedish program for managing nuclear waste contains the following steps. The spent nuclear fuel is shipped to an interim storage (CLAB) for a 40 years cooling down period. Subsequently, the spent fuel will be put in a deep geological repository. The Government has accepted, as the main alternative, that the spent fuel will be encapsulated in canisters of steel and copper, which are placed in crystalline bedrock, at a depth of 500 meters, surrounded by highly absorbent clay in the repository. A demonstration repository will be built. When 5-10 percent of the spent fuel has been lowered in the repository, an evaluation of the method will be made and a definite decision will be taken by the Government if the rest of the spent fuel can continue to be deposited in the repository.

As one of the alternative options to the direct deposition of the total nuclear waste in a repository, the Government has responded positively on the proposal by SKB to follow the international research on partitioning and transmutation (P&T) of the nuclear waste in combination with geological deposition of the remaining waste. This proposal has resulted in a limited support on P&T research from SKB to three different universities in Sweden, the Chalmers University of Technology, the Royal Institute of Technology and the Uppsala University. Furthermore, the same university research groups are also actively taking part in P&T research projects within the European 5th framework program.

On the request from the Government the SKI presented its future research strategy (SKI report 02:24) by June 30, 2002. The report covers research needs for SKI's nuclear safety inspection work, national competence needs and the possibilities for international cooperation. Concerning the partitioning and transmutation of nuclear waste the SKI states in the report that this techniques are not a realistic alternative for treatment of burned nuclear fuel from the Swedish reactors. However, it is also stated in the same report that SKI has to have enough competence to screen SKB's future proposed research programmes in the field of transmutation and also in a limited way to follow the international research on transmutation. Several members of the Expert Group do not agree with the opinions of SKI.

Nuclear Waste Partitioning and Transmutation

High-level nuclear reactor waste is made up of relatively few long-lived radioactive species (table I and fig. 1), among them plutonium, that contribute to difficulties with its storage and disposal. Separation of these species from larger waste volumes mainly constituting of uranium (<about 95 %) coupled with incineration of plutonium and the so-called minor actinides (MA) (Neptunium - Np, Americium - Am, and Curium - Cm) and transmutation of some of the long-lived fission products represents a viable nuclear waste management strategy.

Isotope	Half-life (years)	Mass (kg/year)
Plutonium and Minor Actinides (MA)		
^{237}Np	2,100,000	14.5
^{238}Pu	80	4.5
^{239}Pu	24,000	166.0
^{240}Pu	6,600	76.7
^{241}Pu	14	25.4
^{242}Pu	380,000	15.5
^{241}Am	430	16.6
^{243}Am	7,400	3.0
^{244}Cm	18	0.6
Long Lived Fission Products (LLFP)		
^{79}Se	65,000	0.2
^{90}Sr	29	13.4
^{93}Zr	1,500,000	23.2
^{99}Tc	210,000	24.7
^{107}Pd	6,500,000	7.3
^{126}Sn	100,000	1.0
^{129}I	17,000,000	5.8
^{135}Cs	3,000,000	9.4
^{137}Cs	30	31.8
^{153}Sm	90	0.4

Table I. Annual production of plutonium, minor actinides and fission products from a 3000 MWth pressurized light water reactor with fuel burned to 33,000 MWD/ton (After 10 years decay).

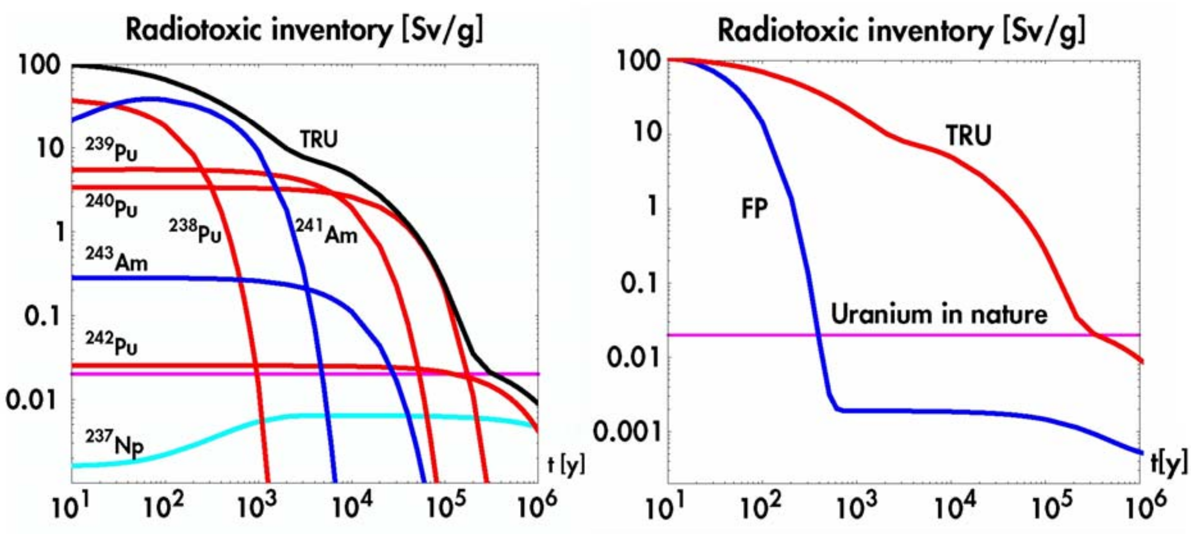

Figure 1: Time dependence of the specific radiotoxic inventory for the transuranium isotopes (left) and a comparison of the same quantity for fission products and transuranium elements.

The use of neutron induced incineration and transmutation processes to destroy these species involves two major reaction types. One is neutron capture, which is used with fission products and for most cases involves the creation of an intermediate short-lived isotope that may decay to a stable by-product. The other is the fission process that causes the actinides to split forming two fission products.

A renewed interest of partitioning and transmutation of nuclear waste was raised in the early 90-ties mainly due to the technical developments of large accelerators, which made the accelerator driven transmutation concepts more likely to be realised. The investigated transmutation systems include thermal and fast neutron critical reactors and accelerator driven subcritical thermal or fast neutron concepts and different combinations of all these facilities. The use of critical reactors in general suffer because of low transmutation rates and may also involve safety problems when burning minor actinides. The use of accelerator driven transmutation systems (ADS) have been proposed to overcome the drawbacks with the critical reactors for transmutation of reactor waste, in particular the minor actinides.

An excess of neutrons has to be available for transmutation purposes in each step of the chain reaction for a critical reactor and in each neutron generation step for ADS. The ADS concepts have in general a larger excess of neutrons per fission for transmutation than the critical reactors, in particular, than the thermal critical reactor. The neutron excess per fission (G) can be expressed as:

$G = -\sum e_J D_J - (CM + L)$ for a critical thermal or fast reactor

and

$G = S_{ext} - \sum e_J D_j - (CM + L)$ for a subcritical accelerator driven system with an external source.

The (CM + L) is the number of neutrons per fission lost in parasitic captures, absorption in construction materials and leakage. D_J is the number of neutrons per fission needed to transmute isotope J down to fission products (can be positive or negative) and e_J is the fraction of isotope J in the fuel of the system.

The (CM + L) term is for all realistic power reactors about 0.3 neutrons per fission. A positive G means that transmutation can be achieved, while if negative, there is a lack of neutrons.

Physics analysis show that the transmutation of the minor actinides and long-lived fission products can be made in standard critical reactors. However, for light water reactors one has to increase the enrichment to high values (about 10 %) to transmute the minor actinides while if one uses fast critical reactors one has to conceive a nuclear power park with a very large fraction of this type of reactors.

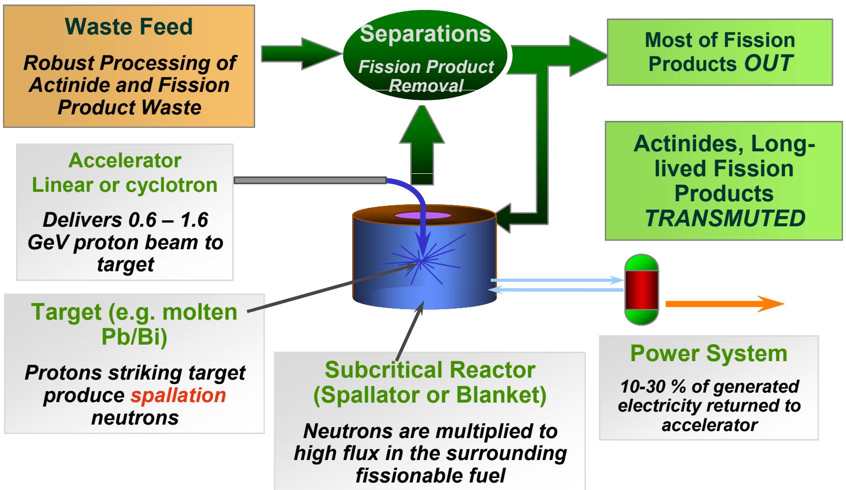

Figure 2: Outline of an accelerator-driven transmutation system.

An accelerator driven transmutation system (fig. 2) consists of an intense neutron source, which is driven by a high power proton accelerator (1-2 GeV, 20-150 mA). The protons are stopped in a heavy metal (e.g. molten Pb/Bi) in which a large number of neutrons are produced by each proton through so-called spallation reactions. The spallation neutron source is surrounded by a subcritical blanket containing the nuclear waste to be incinerated and transmuted Different blanket system have been proposed with fast or thermal neutron spectrum or with a combination of these spectra by having different zones of the blanket with different spectrum. The waste might be housed in solid nuclear fuel pins put into a blanket of molten lead or lead/bismuth or dissolved in e.g molten salt (mixture of lithium (Li)- and beryllium (Be)-fluorides or of sodium (Na)- and zirconium (Zr)-fluorides) . Special proliferation resistant processes have been proposed to prepare the fuel. About 99 % reduction of the amount of transuranium actinides can be obtained by transmutation with realistic assumptions in relation to present separation techniques.

Two different types of processes can be applied to the separation of long-lived radionuclides: hydrochemical ("wet") and pyrochemical ("dry") processes.

The PUREX process is the most important hydrochemical reprocessing technique to separate uranium and plutonium from spent fuel and is based on the dissolution of the fuel in nitric acid. For the extraction of minor actinides, the process should be modified/extended for which extensive research is being currently performed.

An alternative to hydrochemical processes are pyrochemical processes in which refining is carried out in molten salt. In nuclear technology, they are often based on electrorefining or on distribution between non-miscible molten salt-metal phases. The major advantages of pyrochemical techniques to reprocess advanced fuels, in comparison to hydrochemical techniques, is a higher compactness of equipment and the possibility to form an integrated system between irradiation and reprocessing facility, thus reducing considerably transport of nuclear materials. In particular, for advanced oxide fuel (mixed transuranium, inert matrix or composite) and metal fuels, but also nitride or thorium based fuels, pyrochemistry is to be preferred. In addition, the radiation stability of the salt in the pyrochemical process compared to the organic solvent in the hydrochemical process offers an important advantage when dealing with highly active spent minor actinide fuel. Shorter cooling times reduce storage costs.

The separation techniques for the minor actinides and the long-lived fission products are on a laboratory research level for both the wet and dry techniques. The goal is to obtain a separation efficiency of > 99,9% for the actinides and > 95 % for the fission products to minimize the amount of waste from the reprocessing.

Two different incineration routes of the actinides can be followed the “single strata” and the “double strata” (American “single-tier” and “dual-tier”)-. In the “single strata” route the plutonium, minor actinides and long lived fission products are transmuted together. A number of studies focused on the ”single strata” route are in progress. They include studies on thermal or fast accelerator driven systems including systems with molten salt as fuel and coolant.

In the “double strata” scenario, uranium and plutonium are first extracted from the spent fuel and the remaining minor actinides and long-lived fission products are sent to an independent partitioning and transmutation facility. The plutonium is mixed with uranium, both as oxides, to form the so-called MOX fuel, which is burned in thermal and/or fast reactors. The process is repeated several times (2 – 3 times). The remaining plutonium and the minor actinides are burned in a dedicated reactor or accelerator driven system. Several different sub-critical fast reactors for the accelerator driven system are being studied with either liquid lead or eutectic liquid lead-bismuth, liquid sodium or helium gas as coolant and solid metallic, oxide, nitride or carbide fuel. Furthermore, most of the sub-critical fast reactors are designed to contain a special thermal/epithermal zone for the transmutation of the long-lived fission products ^{99}Tc and ^{129}I.

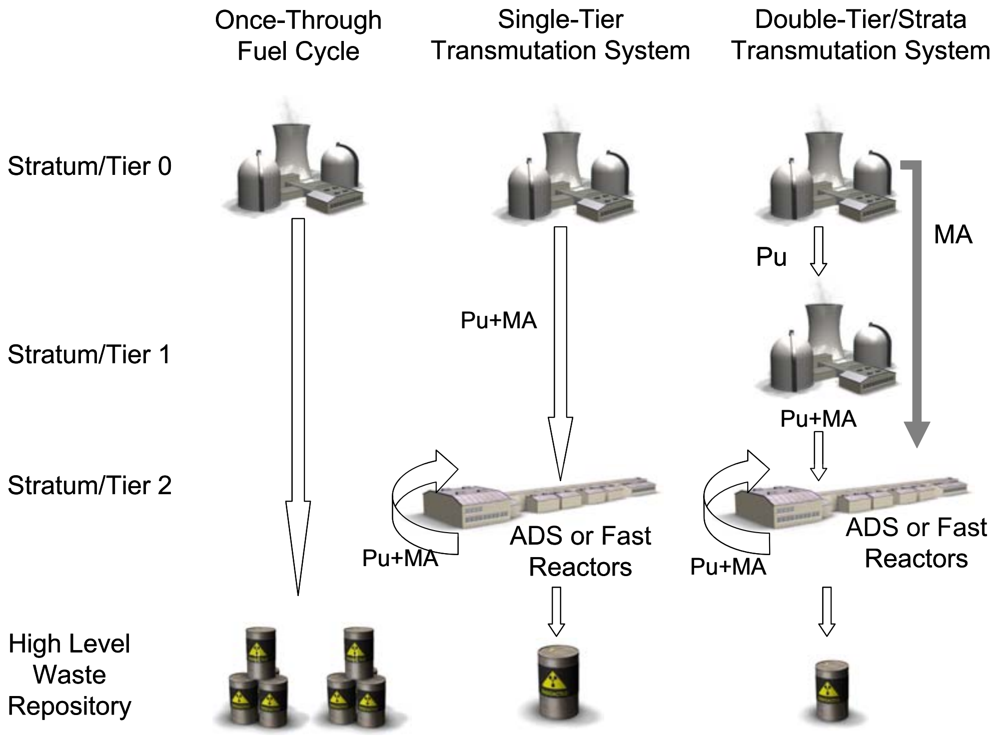

Figure 3: Once-trough fuel cycle, single-tier and dual-tier transmutation systems.

The present report gives information on the status of the international as well as of the Swedish research on transmutation. Mayor research programs on partitioning and transmutation are in progress in many countries (USA, France, Italy, Belgium, Czech Rep., Russia, Japan, South Korea, China etc.) and are run by international organisations (EU, OECD/NEA, IAEA).

International research and development in partitioning and transmutation

The international research and development on partitioning and transmutation has increased considerably during the time period from 1995 to 2002. The reason for this increase differs from country to country but is linked to the on-going and planned nuclear power programs and in many cases the difficulties in getting public acceptance for direct disposal of the waste in geological repositories. Thus, the early started Japanese research program OMEGA is aiming to make optimal use of the waste both for energy and isotope production. The US program will primarily reduce the waste volume for the Yucca mountain repository which otherwise will be filled by waste already when it is put in operation. The French option for treating nuclear waste will be decided by the French parliament in 2006 after thorough investigations of different options for waste handling. The EU is supporting basic studies of partitioning and transmutation in its member countries to meet design studies of a demonstration facility for accelerator-driven transmutation. The Russian studies are focused on the use of the molten lead/bismuth fast reactor (Russian type of sub-marine reactor) to reduce the waste volume besides the wide scope of basic studies for partitioning and transmutation supported by ISTC. The Republic of South Korea has a very ambitious program for developing an accelerator-driven system for waste transmutation etc. The international organisations OECD/Nuclear Energy Agency (OECD/NEA) and the International Atomic Energy Agency (IAEA) are promoting general studies of different transmutation systems and are compiling basic data needed for component and system analysis.

Europe

Studies in Europe of partitioning and transmutaion of nuclear waste are done both under national programs and jointly under an EU supported program. A European Working Group chaired by C. Rubbia has pointed out the direction for the European research on transmutation to reach the goal of a demonstration facility for accelerator-driven transmutation in 2012. The group produced a report "A European Roadmap for Developing Accelerator Driven System (ADS) for Nuclear Waste Incineration" (April 2001, ENEA) which links scientifically the ongoing research projects both on the national level and under the 5th EU Framework Program. It also discusses the research to be done under the 6th and 7th EU Framework Programs. The report has been an inofficial guide for research planning on transmutation in Europe.

Technical Working Group (TWG)

A Technical Working Group (TWG) chaired by C. Rubbia was established by the Advisory Group (MAG), which in turn was appointed by the Research Ministries of France, Italy and Spain to identify the critical technical issues for a demonstration program to be performed within 12 years. The working group was enlarged and named the European Technical Working Group (ETWG). It included 10 partners representing Austria, Belgium, Finland, France, Germany, Italy, Portugal, Spain, Sweden and EURATOM Joint Research Centres. A roadmap document was published by ETWG in April 2001 which identifies the steps necessary to start the construction of an experimental accelerator driven system towards the end of the decade. The report also identifies the ongoing projects in Europe, which constitutes a broad R&D program of the basic principles of an accelerator driven system for nuclear waste transmutation.

The following steps are required for the development and deployment of accelerator driven systems according to ETWG:

A comprehensive mid- and long term R&D program, to develop the single elements and components of the system. This program is already on its way with support from several project of the 5th EU framework program and is planned to continue under the 6th and 7th framework programs. Following a first phase of R&D on basic principles the program should focus on practical demonstrations of the key issues, which are a high intensity proton accelerator, spallation target of high power and its coupling with a subcritical core and the development of advanced fuel fabrication and reprocessing technologies.

Planning, design, construction and operation of an Experimental Accelerator Driven System (XADS) for the demonstration of the concept. In the next few years (2-3 years) a broad system analysis will be performed on the two concepts under consideration the Pb/ Bi cooled system and the He cooled concept (Preliminary Design Study of XADS (PDS-XADS)). After a decision on the most suitable concept, to be made prior to 2004, a detailed design of the ADS could be started. XADS is planned to be in operation about 2012,

Planning, design, construction and operation of a large size prototype accelerator driven system (Accelerator Driven Transmuter ADT). Around 2030 construction of a prototype could be started. It could be deployed on a large and industrial scale starting around 2040.

The ongoing projects which, constitute a broad R&D program for nuclear waste transmutation with ADS are the following split on relevant research areas:

- Neutron Data
  CERN neutron time of flight (nTOF) project
  EU project on High and intermediate energy nuclear data for ADS (HINDAS)
- Accelerators
  SCK/CEN-Mol experiment on the vaccum interface compatibility (VICE)
  ENEA/INFN TRASCO (Transmutazione Scorie) project
  CEA IPHI (Injecteur de proton haute intensité) project
  CEA/IN2P3 ASH (Accélérateur superconducteur pour hybrid) project
- Spallation target
  The megawatt pilot experiment of a spallation source at the Paul Scherrer Institue, Switzerland (MEGAPIE)
- Sub-critical system
  MUSE experiment at CEA-Cadarache
  TRIGA project at ENEA Casaccia (TRADE)
  SCK/CEN project on a multipurpose accelerator driven system for R&D (MYRRHA)
- Material studies
  EU project on Technologies, materials and thermal hydraulics for lead alloys (TECLA)
  Karlsruhe lead laboratory (KALLA)
  ENEA/Brasimone lead corrosion loop (LECOR)
  ENEA/Brasimone chemical and operational loop (CHEOPE-III)
  EU project on Spallation and irradiation effects (SPIRE)
- Advanced fuel and fuel processing studies
  Institute for transuranium elements (ITU), Karlsruhe
  Experimental feasibility of targets for transmutation (EFTTRA). A network of research organisations in France (CEA, EdF), Germany (FZK), Netherlands (NRG), and the Joint Research Centres in Ispra (IAM) and Karlsruhe (ITU)
  EU collaboration project on oxide & nitride fuel irradiation & modelling (CONFIRM)
  EU project on fuel for transmutation of transuranium elements (FUTURE)
  EU project on pyrometallurgical processing (PYROREP)

- Preliminary design study of an XADS
- Possible transmutation strategies based on pebble bed ADS reactors for a nuclear fuel cycle without Pu recycling in critical reactors (study made by research groups in Spain)

The EU programme

EU is supporting 12 projects under the Projects on Advanced Options for Partitioning and Transmutation (ADOPT) of the 5th Framework programme. The projects are organised under 4 clusters serving the project on a Preliminary Design Study of an Experimental ADS (PDS-ADS).

The clusters are (fig. 4):

- PARTITION Cluster (partitioning)
  Pyrometallurgical processes for separation of Minor Actindes (MA) from Lanthanides (PYROREP)
  Develop solvent extraction processes of MA from HLLW (PARTNEW)
  Direct extraction of MA from HLLW by functionalized organic compounds such as Calixarene (CALIXPART)

- FUERTA Cluster (fuel)
  Uranium-free nitride fuel irradiation and modeling (CONFIRM)
  Irradiation behavior of the Thorium-Plutonium oxide fuel at high burn-up (THORIUM CYCLE)
  Study of Oxide compounds (Pu, Am)O_2, (Th, Pu, Am)O_2, (Pu, Am, Zr)O_2 (FUTURE)

- BASTRA Cluster (nuclear data)
  Experiments for sub-critical neutronics validation (MUSE)
  Nuclear data in the 20-200 MeV energy region and beyond for ADS engineering design of an ADS measure at different European accelerator facilities (HINDAS)
  Nuclear data for transmutation in the 1 eV – 250 MeV energy range measured at CERN and IRMM and other Labs (n-TOF-ND-ADS)

- TESTRA Cluster (material)
  Neutron/proton irradiation effects on structural steel (SPIRE)
  Assesment of heavy liquid metal lead alloys as spallation target and coolant for ADS (TECLA)
  Design, develop and perform experiment on liquid Pb-Bi spallation target with p-beam at 1 MW level (MEGAPIE-TEST)
  Assess fluid dynamics commercial and research codes for heavy liquid metals and validate against experiments (ASCHLIM)

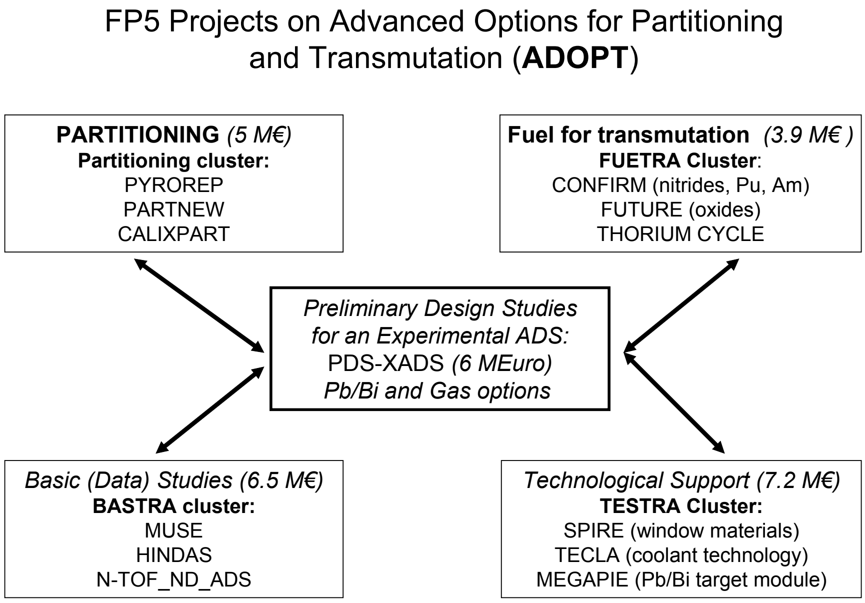

Figure 4: EU partitioning and transmutation programme within the 5th Framework programme.

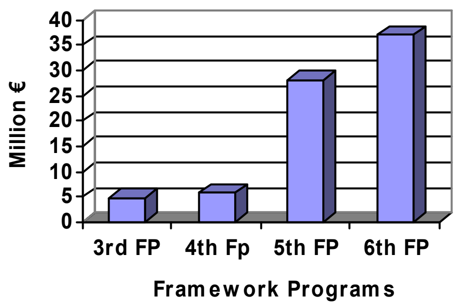

Figure 5: The growth of the EURATOM P&T budget.

These projects involve more than 50 organisations with a EU budget of 28 M€ over the years 1998-2002 financed by EU. The budget for the 6th Framework Programme (2002-2006) (FP&) on partitioning and transmutation will be around 37 M€. The work-programme for FP6 is ready and calls for proposals are underway.

MEGAPIE project

The MEGAPIE (Megawatt pilot experiment) project which is a joint initiative by Paul Scherrer Institute (PSI), Villigen, Switzerland, CEA Cadarache, SUBATECH France, Forschungszentrum Karlsruhe (FZK), Germany, ENEA (Bologna and Brasimone) Italy, CRS4 (Sardinia), JAERI Japan, KAERI South-Korea and the US-DOE to design, build, and test a liquid lead-bismuth spallation target (fig. 6) at the SINQ facility at PSI. The SINQ is a neutron scattering facility driven by a proton beam from the SINQ 600 MeV cyclotron with a power of 0.7 MW.

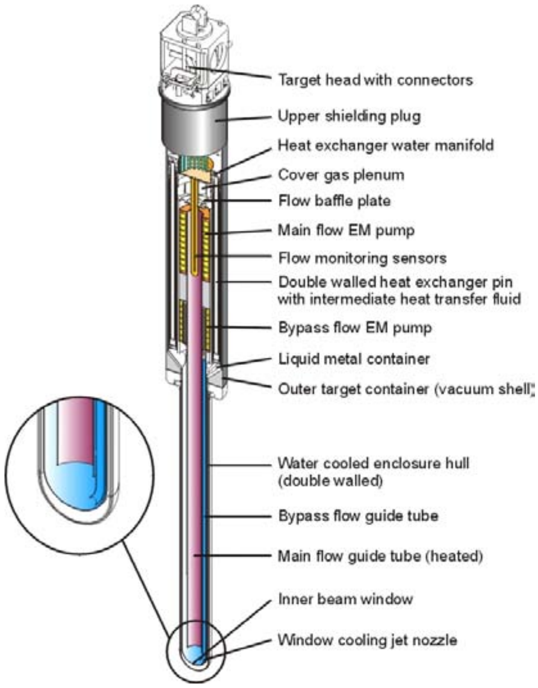

Figure 6: Outline of the MEGAPIE spallation target.

As part of the design process, Computational Fluid Dynamics (CFD), is being used to optimise the thermal-hydraulic behaviour of the target. Results obtained so far indicate that it should be possible to remove the 0.7 MW of heat, without the window temperature rising above 420ºC. Further design refinement is required in order to improve the temperature distribution and minimise stress levels in the structure. The spallation target was originally planned to be set up at the PSI cyclotron in the year 2004 but will most probably be delayed with one to two years.

The project has also been supported by EU in the second call of the P&T sub-programme of the 5th framework programme. A number of projects are in progress closely related to the technical issues of the MEGAPIE project, like the lead loop experiments at the Karlsruhe Lead Laboratory and at PSI, and the Riga Mercury Loop experiment. Furthermore, corrosion and quality control for molten lead bismuth system are being studied within the EU TECLA program and studies of irradiation effects in structural materials are being made under the EU SPIRE program.

Members of the Expert Group/Reference Group have argued for a Swedish participation in the project, which deals with one of the key issues of the ADS, in discussions during 2001 with KASAM, SKB and SKI. So far, no Swedish participation in the project is foreseen.

CERN

A neutron time-of-flight facility (n-TOF) is set up at the 20 GeV/c proton synchrotron (PS) to measure neutron cross sections relevant for the nuclear waste transmutation, ADS design and the development of the thorium fuel cycle. The project is organised as a shared cost action (SCA) within the 5th framework programme of the EU with wide participation from many EU countries.

Belgium

SCK-CEN is at the present time finalising the pre-design of the MYRRHA ADS prototype (fig. 7). A final design is scheduled for 2003. The accelerator part of the device will deliver a 350 MeV, 5 mA proton beam. The spallation target will be a window-less Pb/Bi source with a neutron/proton yield of 3. The sub-critical core (k_{eff} = 0.95) will contain high Pu content MOX fuel and have fast and thermal irradiation zones. The fast as well as the thermal flux will be of the order of 10^{15} n/cm^{2}s. The total power of MYRRHA will not exceed 25 MW.

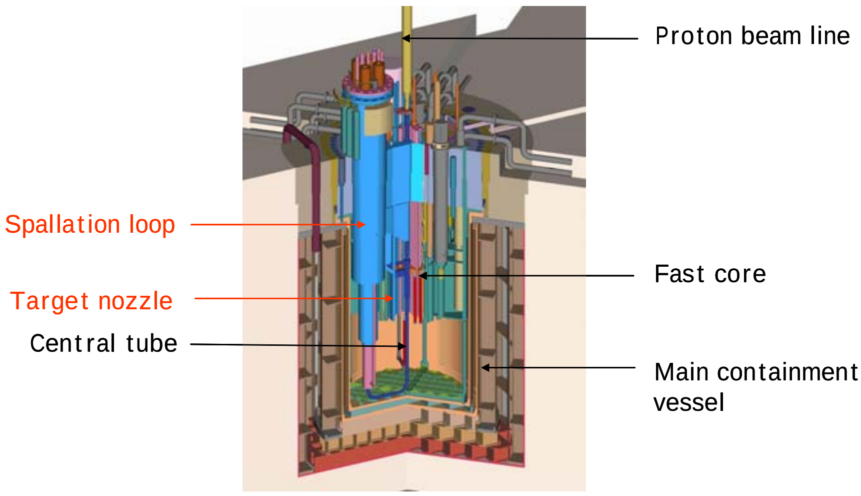

Figure 7: Outline of the MYRRHA facility.

An accompanying research activity (VICE – Vacuum Interface Compatibility Experiment) of SCK-CEN at Mol is underway to answer problems occurring from the direct coupling of an accelerator to the liquid Pb-Bi eutectic target in their windowless design for the spallation source of MYRRHA.

The MYRRHA facility will serve the European transmutation research and development program.

France

The national program in France includes three studies as specified by the French law of December 30, 1991 which stipulates that a final evaluation report on these studies should be given to the Parliament by 2006.The first study focus on methods to substantially reduce the quantity and toxicity of the remaining waste for a given energy production The second study focus on the geological storage of the waste without human intervention while the third study envisages interim storage, requesting permanent surveillance by society, in surface or near-surface installations. CEA is managing the first and third studies and Andra the second study. All studies are made in cooperation with industrial partners (EdF, Cogema and Framatome).

The first study includes investigations of partitioning, transmutation potential of long-lived waste in appropriate reactor configurations relying on current technologies as well as on innovative reactors (e.g. ADS). A large program on fuel development is also underway. The main focus is put on the so called double strata option where the plutonium is burned as MOX fuel in critical thermal and fast reactors and the minor actinides (MA) and some long lived fission products (LLFP) are incinerated in dedicated accelerator driven subcritical reactors.

In particular, two different projects IPHI (Injecteur de Proton Haute Intensité) and ASH (Accelerateur Superconducteur pour Hybrid) are in progress by CEA-CNRS in close cooperation with the ENEA TRASCO project to develop the injector and the high energy part of a high power linac for transmutation. Furthermore, the neutronics of a subcritical system driven by an external source is studied in the MUSE experiment at Cadarache. An accelerator based on the (D,D) and (D,T) well-known reactions drives a sub-critical assembly (MASURCA) in which different fast multiplying media in form of fuel and coolant can be loaded (fig. 8).

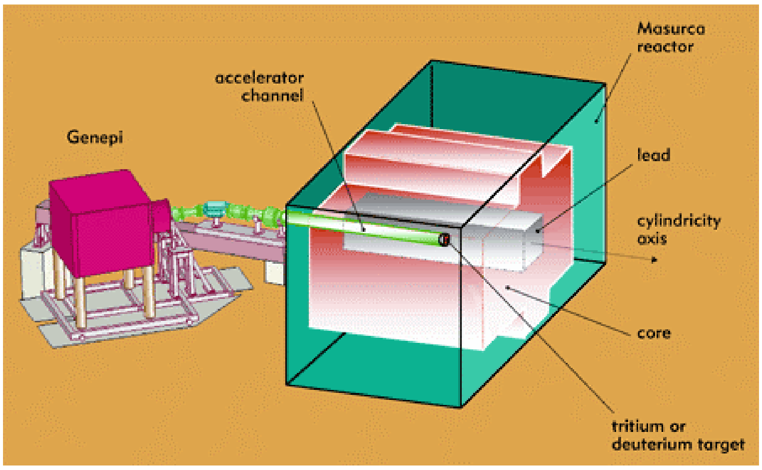

Figure 8: The MASURCA installation for the MUSE programme.

Germany

The Karlsruhe Lead Laboratory (KALLA, see Fig. 9) has 3 lead loops and one of those is devoted to corrosion tests of flowing lead-bismuth. Main objectives for KALLA are:

1) Development of the Pb-Bi technology:
- KArlsruhe Oxygen Control System (OCS)
- Instrumentation(e.g. Ultrasonic Doppler Velocimetry)
- Heattransfer, turbulence and two-phase flow

2) Corrosion studies:
- Corrosion mechanism
- Corrosion protection through advanced surface treatment with pulsed electron beam GESA)

3) Thermal hydraulics

- ADS component testing (spallation target design, fuel elements etc)

4) International User Laboratory
5) Staff exchange and training on the site.

In the Institute for Transuranium Elements (ITU), JRC Karlsruhe two unique facilities will be available for study of advanced fuel cycles namely a laboratory for the fabrication of minor actinide fuels and targets (MA laboratory) and an installation for pyrochemical reprocessing studies.

Figure 9: The Karlsuhe Lead Laboratory – KALLA. A part of the Pb-Bi loop.

Italy

A research program of ADS has been approved by ENEA and INFN with a yearly budget of 10 M€. The program includes the following studies:

A basic R&D program (TRASCO) aiming at study the physics and developing the technologies needed to design an ADS for nuclear waste transmutation. The objective of the first part of the research program is to make a conceptual design of a 1 GeV proton linear accelerator. Close cooperation with the IPHI project in France.

Large-scale tests of the Pb-Bi eutectic in the CIRCE test facility. The CIRCE facility (Fig. 10), at present mechanically complete and commissioned, is located at the Brasimone ENEA facility near Bologna. It basically consists of a reduced diameter (1:5 the XADS vessel diameter), full-height, cylindrical vessel (Main Vessel S100) filled with about 90 tons molten Lead-Bismuth Eutectic (LBE) with argon cover gas and recirculation system (the set of volumetric compressors is located on the top near the local control panel and the gas-chromatograph), LBE heating and cooling systems, and several test sections welded to, and hung from, bolted vessel heads for separate-effect and integral testing, and auxiliary equipment for eutectic circulation and oxygen activity control in the melt for corrosion protection of the austenitic stainless steel structures. Moreover, two flowing Pb-Bi loops, the LECOR (lead corrosion loop) and CHEUPE (chemical and operational loop) at ENEA Brasimone, have been designed and constructed to study corrosion related problems under different operative conditions.

A feasibility study is carried out by an ENEA-CEA working group of using the TRIGA reactor at ENEA Cassacia Centre (TRADE) in an experiment of the coupling of an upgraded commercial cyclotron (110 MeV) with a tungsten target (max. power about 70 kW) surrounded by the TRIGA reactor scrammed to under criticality. ENEA has opened for international cooperation of the 60 M€ project and discuss support from EU.

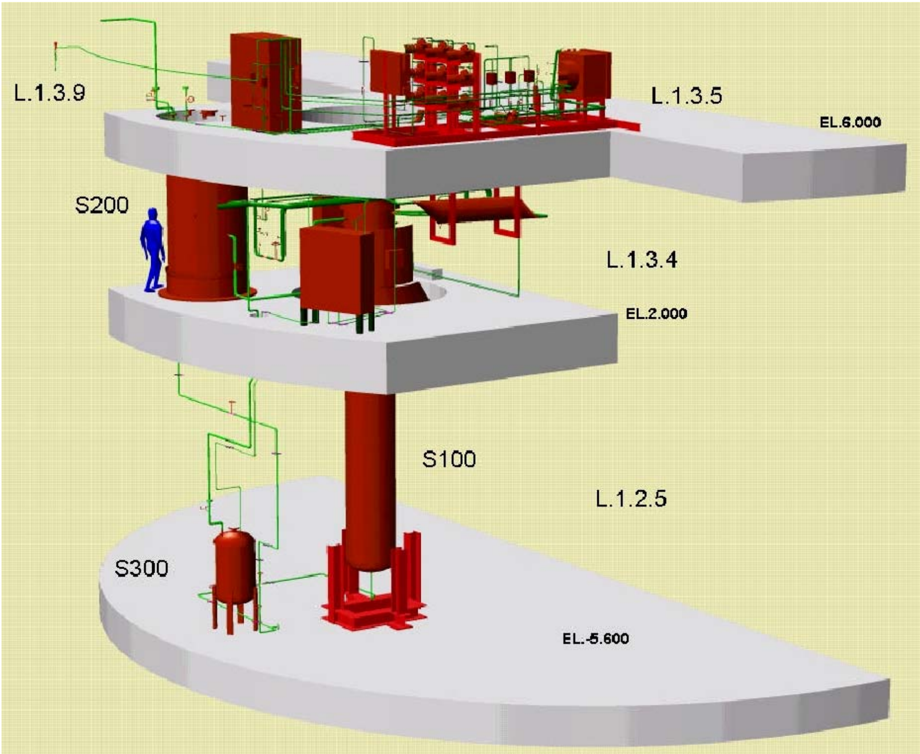

Figure 10: The Circe facility in Brasimone (Italy)

Spain

E.T.S.I. Industriales, LAESA, Universidad Politécnica de Madrid and Valencia have in collaboration with ORNL, USA and Soreq, Israel studied different accelerator-driven concepts for transmutation using subcritical pebble-bed reactors. In particular, a gas-cooled concept based on resonance enhanced transmutation has been investigated.

USA

Nuclear Reactor Programmes

The US energy secretary, Spencer Abraham, announced at the Global Nuclear Energy Summit in Washington DC on February 14, 2002 plans for a new US nuclear power plant to be built and brought on line no later than 2010. The new initiative – Nuclear Power 2010 – would be a joint venture involving the Department of Energy (DOE) and the US electricity utility industry.

An expert study concluded in the report "A Roadmap to Deploy New Nuclear Power Plants in the United States by 2010" that the General Electric ABWR can be deployed by 2010 while the Westinghouse AP600 and AP1000 and the Exelon PBMR can probably be deployed and the Framatom SWR1000, the General Electric ESBWR and the General Atomics GT-MHR can possibly be deployed by 2010.

Furthermore, the Nuclear Energy Research Initiative (NERI) was established in the fiscal year 1999 to sponsor research and development on key issues for future use of nuclear energy. Some of the key-issues are "Proliferation resistent reactor and fuel cycles", "Advanced reactor systems", Hydrogen production from nuclear reactors" and "Fundamental nuclear sciences". In 2002 bilateral agreements were signed with France/CEA and South Korea (KAERI) to collaborate on research and development on a cost-shared basis. Negotiations of research collaborations are underway with United Kingdom, South Africa and Japan

The US Department of Energy is also leading the so called Generation-IV Reactor International Forum (GEN-IV) with members from 10 different countries (U.S.A., United Kingdom, Switzerland, South Korea, South Africa, Japan, France, Canada, Brazil and Argentina). The GEN-IV Technology Roadmap will identify 6 to 8 promising technologies, establish clear research and development plans and enable deployment of GEN-IV systems after 2010 but before 2030.

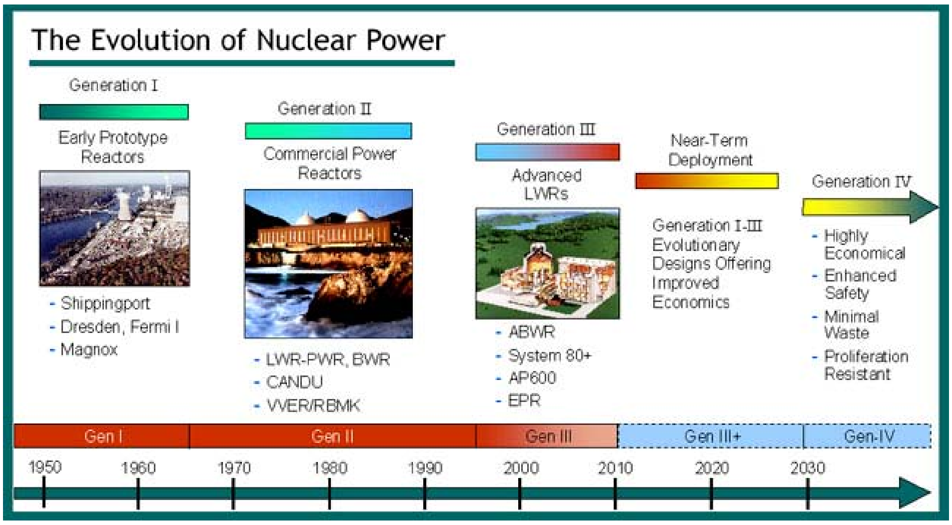

Figure 11: Generation – IV reactor development ideology.

Nuclear Waste Transmutation

In Fiscal Year 1999, Congress directed the Department of Energy (DOE) to develop a "Roadmap" to determine the feasibility and life-cycle cost of an Accelerator Transmutation of Waste Technology (ATW) system to manage the civilian nuclear spent fuel from U.S. reactors. The results of this study were published in a report to the Congress, "A Roadmap for Developing Accelerator Transmutation of Waste Technology", October 1999 (DOE/RW-0519). The report addressed issues associated with the question of whether the ATW concept could benefit the waste management system associated with disposing spent fuel from all existing U.S. nuclear plants during their anticipated lifetimes.

As a result of this study the Congress authorized DOE to begin an ATW research programme in the Fiscal Year 2000. Independent of the ATW research, DOE is also responsible for insuring adequate future tritium production needs of the nation. Although a reactor based option has been chosen as the primary technology to meet the needs, an Accelerator Production of Tritium (APT) back-up option existed at that time which had demonstrated impressive technology which appeared to be of direct value to demonstrate the ATW objectives of benefiting nuclear waste management.

The potential synergistic value of ATW and APT, as well as the possibility of supporting the nation's nuclear energy-related education and research infrastructure with an integrated accelerator applications facility, the DOE Office of Nuclear Energy, Science and Technology under Congressional guidance established a new Advanced Accelerator Applications (AAA) Program Office and initiated in the Fiscal Year 2001 an AAA program whose primary objective was to conduct scientific and engineering research, development and demonstration to ascertain if cost effective and beneficial transmutation of civilian spent nuclear fuel is possible..

The AAA Program addresses the following objectives:

- Demonstrate the practical performance of an accelerator-driven subcritical multiplier
- Demonstrate the viability of transmutation for waste and spent fuel management
- Enhance the Nation's nuclear science and advanced technology education infrastructure
- Provide a more robust backup tritium production capability for national security.

Existing facilities supports the completion of the program objectives, but a new, dedicated facility is required for fully reaching the goals, which includes demonstration of the safe and efficient coupling of an accelerator, spallation target and subcritical multiplier.

Research within the AAA program includes:

- Advanced fuels: High Zirconium/Actinide, Nitride, Mixed oxide, and Carbon Matrix fuels research and development
- Spent fuel separation research and development (oxide and metal)
- Coolant compatibility and heat transfer (Gas, Sodium and Lead/lead-Bismuth)
- Spallation target design, cooling, and the science of coupling spallation neutrons with nuclear fuel assemblies
- Research and development of new materials which can withstand high energy, high neutron flux levels, high temperatures, and be compatible with the reference fuel and coolant
- High energy accelerator reliability.

During 2002 DOE has delivered a report to the Congress outlining the complete AAA program with costs, schedule and deliverables. At the same time the Office for Nuclear Energy, Science and Technology has proposed a new budget structure for which the earlier "Nuclear Facilities Management" and "Advanced Accelerator Applications (AAA)" programs form a new program "Spent Fuel Pyroprocessing & Transmutation" with a budget of 77 M$ for 2002. The merged program goal is to develop and demonstrate an advanced, proliferation-resistance technology to reduce the quantity and toxity of U.S. commercial spent nuclear fuel while simultaneously enabling the U.S. to vastly increase the efficient use of its nuclear fuel resources.

The planned accomplishments for the Fiscal year 2003 of the Spent Fuel Pyroprocessing and Transmutation are.

- Treat a minimum of 0.5 metric tons of heavy metal of EBR-II spent nuclear fuels
- Initiate laboratory-scale demonstration of proprocessing technology
- Begin testing of advanced transmutation non-fertile fuel.

Furthermore the Fast Flux Test Facility (FFTF) project will conduct surveillance and maintenance activities to maintain the FFTF in full compliance with applicable Federal and State health, safety and environmental assessments. This project has a budget for 2002 of 36 M$.

Partners in the programs are Los Alamos National Laboratory (LANL), Argonne National Laboratory (ANL), Savannah River Laboratory (SRL), Lawrence Livermore National Laboratory (LLNL), Brookhaven National Laboratory (BNL), Oak Ridge

National Laboratory (ORNL), the universities Michigan, UC Berkeley, Texas, Nevada and as industrial partners Burns and Roe and General Atomics.

Los Alamos National Laboratory (LANL)

Since the early 90-ties LANL has studied different accelerator driven systems for waste transmutation (ATW). The laboratory has also later on been in charge of the accelerator production of tritium (APT) project.

The APT project was terminated in 1999 but before that had resulted in the design and construction of the technically most difficult low energy part of a high power accelerator, which difficulties are due to space charge effects created by the large low-energy ion-beam in that part of the accelerator. The low energy proton linear accelerator (3.7 MeV) with 100 mA beam current (Low Energy Demonstration Accelerator (LEDA) – see Fig. 12) is now a part of the 3A project. The future of LEDA is, however, not very clear due to the changed research priorities of the Los Alamos National Laboratory. Discussions are under way to move LEDA to the University of Nevada Las Vegas.

Figure 12: Low Energy Demonstration Accelerator – LEDA – at Los Alamos National Laboratory.

A special hardenable superalloy (Alloy 718, γ(Ni,(Al,Ti)) - γ(Ni,Nb)) with attractive strength and corrosion resistance has been studied as window material in proton irradiation with a maximum dose of 20 dpa at LANSCE in a collaborative experiment with Battelle Pacific Northwest National Laboratory and Forschungszentrum Jülich, Germany.

Most of the experiments related to the Pb-Bi technology have been transferred from Los Alamos to the University of Nevada, Las Vegas (UNLV), including facilitation of the 1 MW spallation target manufactured at IPPE in Obninsk in the frame of the ISTC project

#559 – Fig. 13. Department of Energy is now proposing a University consortium for conducting ADS research with a particular emphasis on Pb-Bi technology. UNLV, with its crucial location in the Nevada State (close to the Yucca Mountain) is supposed to play a central role in this consortium.

A large volume molten Pb-Bi test loop has been built for studies of corrosion problems and ways to control the oxide layer which protects the inside the loop from corrosion. The US experts participating in the MEGAPIE project at PSI, Switzerland are from LANL.

Figure 13: Unpacking the 1 MW spallation target at the University of Nevada Las Vegas, July 2002.

Argonne National Laboratory (ANL)

The research program at ANL is focusing on the development of pyrochemistry to separate the TRU elements but also some long-lived fission products. The goal of the project is to reach >99.9% recovery of actinide elements and >95% recovery of Tc and I. So far, the uranium separation has been made on an industrial level (100 kg) while the plutonium separation is only made on a laboratory scale.

Furthermore, an ATW fuel development program is underway with 4 primary tasks:

- Fabrication development
- Measurement of properties
- Irradiation testing
- Fuel performance modeling.

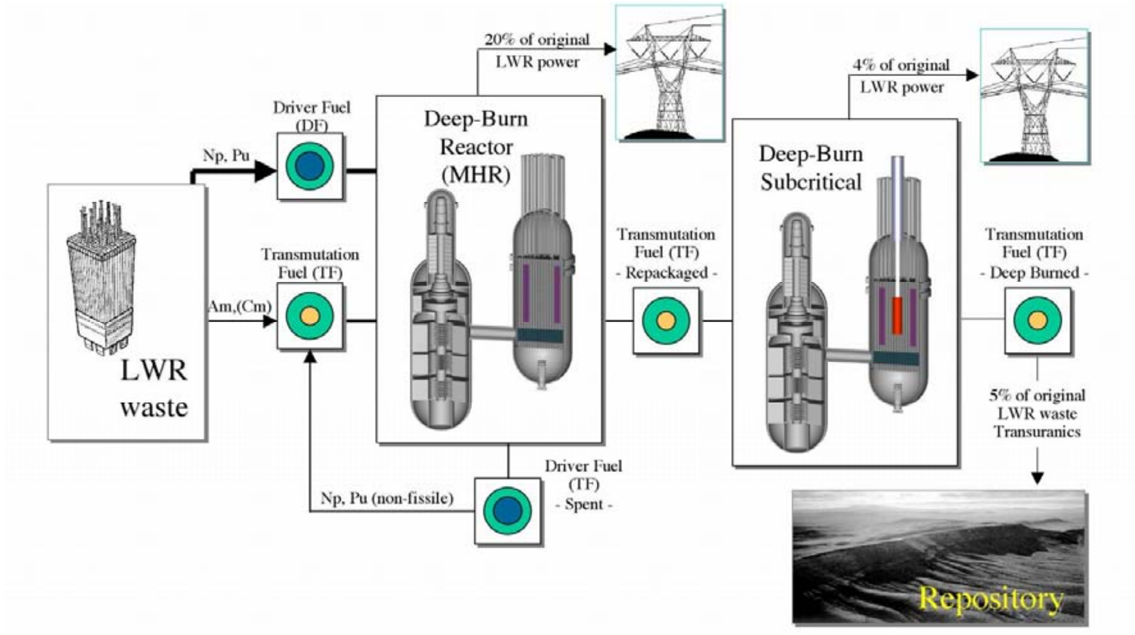

Figure 14: Deep-Burn Transmutation of Nuclear Waste concept.

General Atomic

Two different concepts for transmutation using helium-cooled reactor technologies have been investigated by General Atomics. Both concepts make use of thermal and fast neutron energy spectra. One concept uses a single type of transmuter to eliminate essentially all weapons-useful material in the waste and achieve a significant reduction in total toxicity. The other concept uses a two strata option to achieve deeper levels of transmutation. In this system, the thermally fissile isotopes are destroyed in a critical reactor operation in the passively safe Gas-Turbine Modular Helium Reactor (GT-MHR), followed by a deep burnup phase in an accelerator-driven GT-MHR. Deep Burn Transmutation is based on the use of thermalized neutrons and high burnup fuels in Modular Helium Reactor systems (MHRs). The concept addresses the destruction of plutonium and the other transuranic actinides in spent fuel. An essential feature is the use of ceramic-coated fuel (TRISO) particles that are strong and highly resistant to irradiation, with very extensive destruction levels in one pass ("Deep-Burn"). TRISO fuel also provides a robust and attractive residual waste form. The destruction of waste transuranics is carried through one burn-up cycle, achieving virtually complete destruction of weapons-usable materials, and up to 95% destruction of all transuranics. Passively safe up to 600 MW per module, the Deep-Burn MHR operates at high temperatures, resulting in electric power produced at close to 50% efficiency.

Japan

The OMEGA project with the aim to study different means to make optimal use of the reactor waste has run since 1988. The aim of the first phase of the project, which was to evaluate different concepts and make R&D on key technologies, has been achieved.

The second phase is underway which include engineering experiments on key technologies and demonstrations. A “double strata” concept with ADS is studied by JAERI while JNC and CRIEPE studies transmutation in FBR and also partitioning by wet processes (JNC) and dry processes (CRIEPE). Some key questions for the research are “Reduction of Minor Actinides (MA) and Long Lived Fission Products (LLFP) and the time requested”, “Generation of secondary waste”, “Increase in radiation dose” and “Economy”. The R&D will be summarized in 2005.

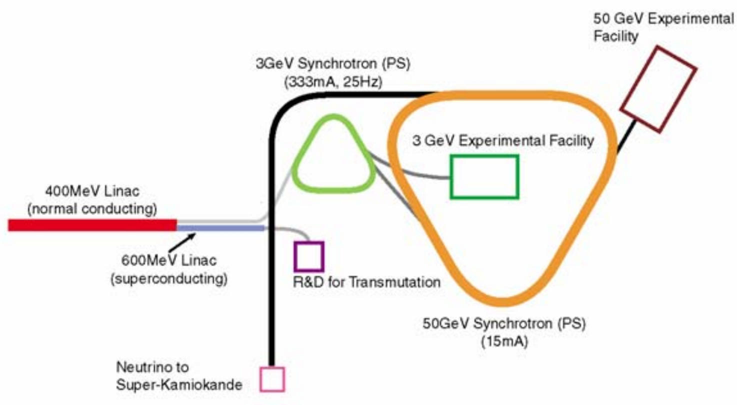

Figure 15: A general layout of the Joint KEK-JAERI, J-PARC, accelerator-ADS project.

A 600 MeV proton accelerator in a complex of advanced accelerator systems, will be built by KEK and JAERI in collaboration for studies of neutrino-oscillations by KEK and transmutation processes by JAERI. The name of the project is J-PARC. The cost is estimated to 1.8 B$ and the start for experiments to 2008.

Two transmutation experimental facilities are to be built under the J-PARC project.

(1) Accelerator Material Irradiation Facility,
(2) ADS Physics Experimental Facility.

The first facility is aiming at evaluating soundness of the materials, which are exposed by extremely severe proton and neutron irradiation under a high temperature lead-bismuth flow. The proton beam of 600 MeV and 0.33mA (200 kW) will be used. The second facility is for research of the basic sub-critical reactor physics, e.g., sub-criticality, reactivity, power profile, etc. and reactor power control with the beam power, with a low power proton beam of up to 10 W.

A law for implementing geological disposal of the remaining reactor waste was passed in the Japanese Parliament in May 2000. The time to start the operation of the repository is scheduled to between 2030 and the mid-2040 at the latest.

South Korea

The Korea Atomic Energy Research Institute (KAERI) is developing a Hybrid Power Extraction Reactor (HYPER) for the transmutation of nuclear waste and energy production through the transmutation process. The system is being designed to utilise fast neutrons (Pb/Bi as target and cooling system) for the transmutation of TRU and has 4 thermal target regions for the transmutation of fission products (^{99}Tc and ^{129}I (NaI)). KAERI is planning to finish the design and construction of the 1000 MW_{th} HYPER concept by 2007.

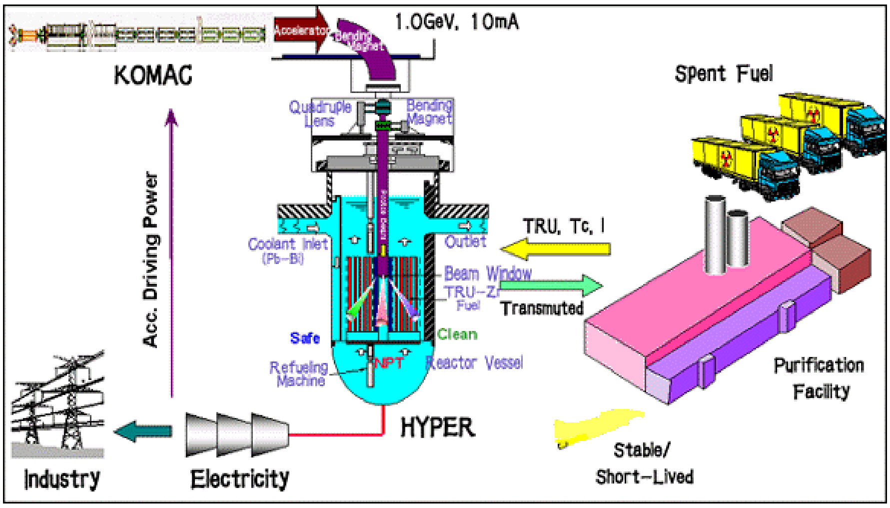

Figure 16: Outline of the HYPER concept.

The HYPER reactor will be driven by the linear proton accelerator (1 GeV, 20 mA, 20 MW) KOMAC, which is under construction.

In parallel the development of pyroprocessing technology is underway and is focused on the partitioning of long-lived radionuclides for transmutation. The pyroprocessing will be developed as a proper recycling technology on the basis of proliferation resistance and safeguardability.

International Organisations

OECD-NEA

OECD Nuclear Energy Agency has launched new studies under the auspices of its Nuclear Development and Nuclear Science Committees. Both Committees have, together with the NEA Data Bank, developed several well co-ordinated activities, covering a diverse set of issues related to partitioning and transmutation, such as nuclear data and benchmarks, partitioning techniques and also more strategic system studies.

An expert group under the OECD/NEA Nuclear Development Committee (NEA-NDC) has made a study of “Accelerator-driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles. A Comparative Study”. The expert group contained 37 members from 15 countries. The report was published by NDC in the spring of 2002 (ISBN 92-64-18482-1)

In particular, the arrangement of a series of information exchange meetings on Actinide and Fission Product Partitioning and Transmutation. The 7th meeting in this serie was arranged at Jeju in South Korea on 14-16 October 2002. The work within a task force on shielding aspects of accelerators, targets and irradiation facilities (SATIF) but also the work on model codes for spallation neutron sources (SARE) can be mentioned.

International Atomic Energy Agency (IAEA)

IAEA has initiated a number of Coordinated Research Programmes (CRPs) linked to the ADS research.

Recent accomplished CRPs:

- CRP on the Potential of Thorium-based Fuel Cycles to Constrain Pu and Reduce Long Term Waste Toxicities
- CRP on the Use of Th based Fuel Cycles in ADS to Incinerate Plutonium and to Reduce Long-term Waste Toxicities.

On-going CRP:

- CRP on Studies on Advanced Reactor Technology Options for Effective Incineration of Radioactive Waste.

Furthermore, an international database on ADS related research and development program has been established.

An international conference on “Innovative Technologies for Nuclear Fuel Cycles and Nuclear Power” will be held in Vienna, 23-26 June 2003.

Swedish Research on Partitioning and Transmutation

The SKB’s proposed research and development program for the next 3 years (FUD01) was presented by SKB in September 2001 (SKB report FUD-program 2001). It is proposed that the research program for transmutation of long lived nuclear waste should be persued on about the same level as present (5 MSEK/year). Support is also given for participation in international projects, primarily EU projects. The aim of the research is to provide knowledgeable experts in the field to assess the international R&D on transmutation. Several motivations are presented by SKB for not initiating any bigger Swedish development program on transmutation. They are, as SKB sees it, on the one hand political, abandonment of nuclear energy and the prohibition of reprocessing, and on the other hand technical and economical, the development is long term and costly. Furthermore, it is said that the radiation risk to individuals involved in the different steps of the transmutation technology is large compared to a hypothetical radiation risk to the population in a distant future.

Swedish transmutation research, in general basic research, is performed at some universities (CTH, KTH and Uppsala University) with the essential support from SKB, SKI and the Swedish Nuclear Technology Center (Svenskt Kärntekniskt Centrum). The same university groups are also participating in a number of international ADS related research projects, in particular, the projects under the 5th Framework Programme of the European Commission.

Chalmers University of Technology

The Department of Nuclear Chemistry, CTH participates in the project PARTNEW within the EU 5th framework programme. The project is a continuation of NEWPART (4th EU FP) to study the extraction of lathanides and actinides using pyridins or similar nitrogen-based molecules. The work to be carried out concerns the design of solvent extraction processes of Am(III) and Cm(III) that are contained within the acidic high active rafinates (HARs) or concentrates (HACs) from the reprocessing of spent nuclear fuels. The work to be done is sorted out in eight Work Packages (WPs) corresponding to 3 research domains:

- The actinides (III) (AN(III)) + lanthanides (III) (LN(III)) co-extraction from acidic HARs or HACs (DIAMEX processes)
- The An(III)/Ln(III) group separation from acidic feeds (SANEX processes)
- The Am(III)/Cm(III) separation system.

For each domain, basic research and limited flowsheet developments will be carried out.

Royal Institute of Technology

The Royal Institute of Technology (KTH) has decided during 2001 to organise a centre for education and research in nuclear energy technology including the departments of nuclear and reactor physics, reactor technology, reactor safety and nuclear chemistry. This centre, called CEKERT, started its operation at the beginning of 2002 assured reappointment of the nuclear technology related professorships at KTH after retirements of the present professors.

The Department of Nuclear and Reactor Physics at the Royal Institute of Technology, Stockholm participates in a number of projects under the 5th Framework Programme of the European Commission. The group coordinates the CONFIRM project aiming to manufacture and test nitride fuel. Irradiation tests will be made at the R2 reactor at Studsvik. The group also participates in the SPIRE and MUSE projects, in which studies are made of radiation damage effects in martensitic steels in the mixed proton-neutron beams and at the subcritical assembly MASURCA in CEA/Cadarache, respectively.

Moreover, the Department participates very actively in the PDS-XADS project, the biggest transmutation project in the 5th FP, sharing important tasks with the Department of Nuclear Safety at KTH.

KTH has also constructed and is now taking into operation at the Dep. Of Nuclear Safety a test Pb-Bi loop, particularly suitable for a natural circulation studies. This work is being done in the frame of the EU's Tecla project.

The aspects of severe accidents in transmutation systems have been studied together with a group at JRC-ISPRA, Italy and the use of Pb-Bi eutectic as the coolant of an accelerator-driven system together with a group at ETSII e IT, Bilbao, Spain.

The group is also actively taking part in several ISTC transmutation research projects as projects #559 (W. Gudowski chairman of the International Advisory group for #559), #B-70, #B-404, #1372, #1606, #1653, #2002 and #2267.

Extended studies have been made of a Pb/Bi cooled ADS concept (Sing-Sing – Fig. 17) for transmutation of the nuclear waste from the Swedish reactors. The sub-critical yields low activity losses for fuel with a high fraction of plutonium by use of burnable poisons in conjunction with core enlargement.

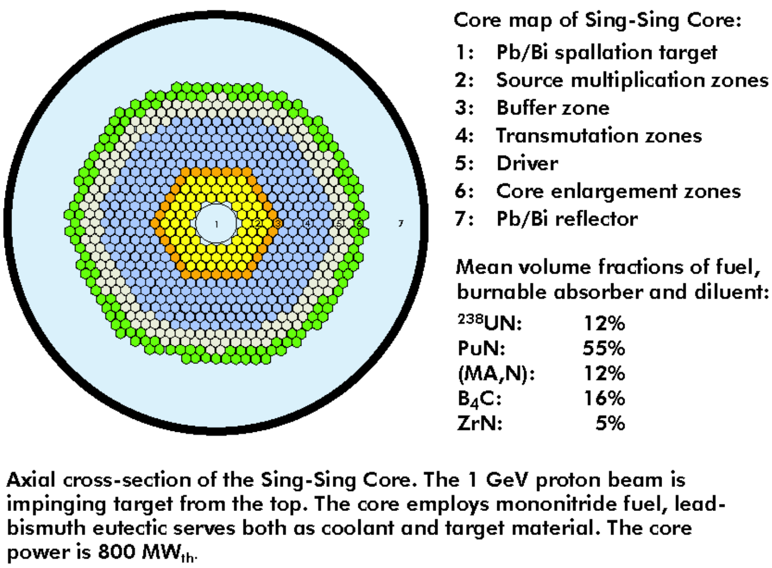

Figure 17: Lay-out of the ADS concept Sing-Sing.

An extended cost benefit analysis has been made of accelerator driven systems. The main purpose of the study has been to identify cost drivers for partitioning and transmutation strategies and estimation of the cost of electricity generated in a nuclear park with ADS transmuters.

Figure 18: Tecla Pb-Bi loop at KTH.

Uppsala University

The activities at Uppsala University are dominated by nuclear data measurements. Such data are crucial for improvement of existing nuclear models, which in turn are used for design and safety assessment of spallation targets and transmutation cores.

During 1998-2002, a project financed by SKB, SKI, Vattenfall AB, Barsebäck Kraft AB and FOA has been run at the Department for neutron research (INF) on elastic scattering measurements for transmutation applications. Within this project, two PhD students have been educated. Both of them have obtained licentiate degrees, and are at present close to dissertation. July 1, 2002, a new four-year project started, continuing these studies. The project, which is supported by SKB, SKI, FOI and Ringhalsverket/Barsebäck Kraft AB, involves two new PhD students.

INF is involved in the EU project HINDAS (High and Intermediate energy Nuclear Data for Accelerator-driven Systems), in which 16 laboratories or institutes in seven countries are involved. Within HINDAS, experimental groups from France and Germany are running major experiment series in Uppsala in collaboration with INF. These experiments are devoted to gas production (hydrogen and helium) and measurements of residual radioactivity.

Within ISTC, a group from Khlopin Radium Institute has been active for about a decade in fission cross section measurements (ISTC projects 540, 1309 and 2213). In addition, part of the approved ISTC project 2405 will be devoted to experimental studies in Uppsala, carried out in a collaboration between institute for Theoretical and Experimental Physics, Moscow, Russia, and INF. Finally, an application for a new ISTC project on fission studies in Uppsala by Petersburg Nuclear Physics Institute, Gatchina, Russia, has recently been submitted. A first test experiment has, however, already been performed.

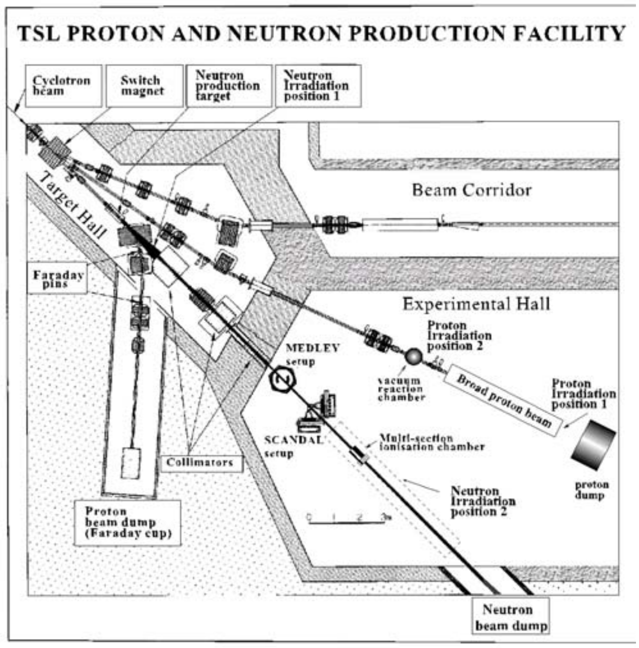

Figure 19: Experimental facilities with proton and neutron beams (20-200 MeV) at the cyclotron of the The Svedberg Laboratory, Uppsala.

Personnel from the Department of Radiation Sciences have participated in a sensitivity analysis on a spallation-driven core, managed by the Emerging Energy Technologies group at CERN.

International Science and Technology Center (ISTC), Moscow

General information

A large number of technical and scientific experts on nuclear weapons were working at classified nuclear weapons laboratories in the USSR. Most of these experts have experienced severe economical and social problems as a result of drastically reduced governmental funding of the weapons laboratories following the break up of the Soviet Union. Under such circumstances there is an obvious risk of proliferation of the nuclear know how to countries which could be aiming towards the development of nuclear weapons. This issue has been more pronounced since the terrorist attacks on September 11, 2001 and the following threats from the same group of terrorists.

To counteract this risk USA, EU, Russia and Japan decided to finance an international science and technology center (ISTC) in Moscow. The objective of the center is to financially support research projects of civilian interest, which will occupy the nuclear weapon experts in Russia and other former republics of the USSR.

Through April 2002 ISTC have funded 1600 projects valued at US$ 420 million, providing grant payments to over 30 000 individuals. The project proposals are sent by the laboratories to MINATOM for acceptance according to Russian regulations. If accepted, the proposals are forwarded to the secretariat of ISTC, which forward the proposals to the different parties supporting ISTC for classification. Finally, the ISTC board approves and decides about financial support. Each party has the right to decide about the use of its funding to ISTC but has also the possibility to veto support from the other parties for any good reasons.

When the ISTC was set up, Sweden not yet a member of EU, was approached with a question if our country could contribute with a grant to the Center fund. A decision was taken by the Swedish parliament to give a grant of US$ 4 million. Since Sweden joined EU the support is coming from Sweden through EU. The present partners of ISTC are USA, EU, Japan, South Korea and Norway.

A group of experts on partitioning and transmutation, Contact Expert Group (CEG), was set up on an initiative by W. Gudowski to advice the parties in ISTC on priorities of the proposed projects. The group members originally represented all parties. Today, each party in ISTC has its own CEG e.g. EU is adviced by the EU-CEG which thus is the body screening the project proposals of interest for Swedish experts.

Figure 20: Meeting of the ISTC Contact Expert Group in Brussels, January 2003.

The table below presents a project priority list agreed on the last meeting of the CEG in Brussels, January 2003.

Project Number	Shorttitle	Priority by CEG	Total cost k$	EU funds CEG's proposal k$	Project duration months	CEG/EU Collaborators	CEG/EU Monitors	Connections /links with EU Framework Programme
2680	Study of M inor Actinide Transmutation in Nitrides: modelling and measurements of out-of-pile properties .	18	**400**	400	24	Janne Wallenius	Marc Delpech	Confirm
2213	Fission Cross Sections of Tungsten Isotopes	17	**200**	200	30	J. Blomgren - UU, C. Broeders - FZK	W. Gudowski	Hindas
2405	Experimental Nuclear-Physics Data for Transmutation	16	**595**	200	24	Uppsala U., CEA (Ridikas), FZK, LANL, JAERI	E. Gonzales	Hindas
2578	Analysis of Radwaste Transmutation Data	to be discussed more and to be shared	**80**		9	FZK (Broeders), IAEA, Nevada Un., JAERI	Marc Delpech, Cornelis Broeders	
2253	Investigation of the delayed neutron characteristics	High if shared with US/Japan	**360**	150	24	CEA (Fioni), ENEA (d'Angelo), LANL	E. Gonzales, H. Abderrahim	
2524	Nuclear data lib. for heavy nuclei	medium	**204**		36	FZK (Broeders), Texas Un.	J. Blomgren	

Planning and Reporting of Russian Transmutation Research Projects supported by ISTC

An informal Expert Group on Partitioning and Transmutation (P&T) Research with members from Chalmers University of Technology (CTH), Royal Institute of Technology (KTH), Uppsala University and independent experts was formed in the early 90's to establish a forum for discussions on research strategies, means to find support for doing research, research coordination and collaboration, and information exchange.

At a Symposium on "Deposition of Nuclear Weapon Grade Plutonium "in 1990 a research group from the Los Alamos National Laboratory (LANL), USA presented a new concept of accelerator driven transmutation techniques (ATW) to incinerate and transmute reactor- and weapon-grade plutonium. This presentation was the starting point for a discussion on international cooperation on ATW research.

On the request from the LANL group, C Mileikowsky took the responsibility to arrange an international specialist meeting on "Accelerator-Driven Transmutation Technology for Radwaste and Other Applications" in Sweden. The specialist meeting was held in Saltsjöbaden on June 24-28, 1991 with participation of experts mainly from USA, Russia and Sweden.

One suggestion, as a result of the discussions at the meeting in Saltsjöbaden, was to occupy former Soviet Union nuclear weapon experts to do research on incineration of weapon grade plutonium and reactor waste financed by "International Science and Technology Center (ISTC)" grants. The frame of collaboration was discussed between the experts at the appropriate laboratories in each country. The proposal by the Expert Group on P&T Research to also use part of the Swedish grant to ISTC for supporting transmutation research projects at Russian former weapons laboratories was positively responded in discussions with the Swedish Ministry of Foreign Affairs, the Ministry of Environment and the Nuclear Power Inspectorate (SKI). Thus, the Expert Group was given financial support from the Swedish Nuclear Power Inspectorate (SKI) in 1995 to cover expenses for travelling in connection with discussions with Russian experts and project planning. A financial support from the SKI program budget for "non-proliferation" of 250,000 SEK annually for travelling has been given to the Expert Group during the 8 budget years from 1995 to 2002. The Expert Group has acted as a Reference Group to SKI for the ISTC projects and regularly reported to SKI on "Planning and Reporting of Russian Transmutation Research Projects supported by ISTC".

The expert group on transmutation research/ the SKI reference group has had 7 permanent members: H. Condé, (UU, chairman), J. Blomgren, (UU, meeting secretary), W. Gudowsky (KTH), J.-O. Liljenzin (CTH), C. Mileikovsky (Pully, Switzerland), N. Olsson (UU) and J. Wallenius (KTH). The group has invited observers from the Ministry of environment, KASAM, SKI and SKB.

According to the position that SKI has taken in its Research Strategy Report from 2002, the non-proliferation aspect of the ISTC projects is no longer dominant. Instead, SKI states that the ISTC projects on transmutation are to be looked upon as EU supported basic research. As a consequence of this changed classification SKI hands over the task of planning and reporting ISTC transmutation projects to SKB starting January 1, 2003.

International Science and Technology Centre (ISTC) transmutation projects

Project planning background

One of the main issues of the ISTC is to reduce the proliferation risk by engaging experts at the former Soviet Union nuclear weapon laboratories in civilian research. This issue has been more pronounced since the terrorist attacks on September 11, 2001 and the following threats from the same group of terrorists.

The Expert Group/Reference Group has chosen to initiate ISTC projects, which are dealing with fundamental technical issues for the accelerator driven transmutation concepts. The possibility of finding a Swedish research group as a counterpart to the Russian group has also played a role in the reference group's selection of projects.

Links between an ISTC project, which are supported by EU, and a possible EU framework research project dealing with the same research problems are encouraged.

In particular, a monograph on "Naturally Safe Lead-Cooled Fast Reactor for Large-Scale Nuclear Power" with the general editors E.O. Adamov and V.V. Orlov has recently been published supported by ISTC. The monograph sets forth the key principles of the strategy, which has been basic to the BREST concept, a fast reactor with high-density fuel (UN + PuN) of equilibrium composition and liquid Pb coolant, and sums up the results of the BREST studies and developments.

Projects in progress

"Measurements and comparison of proton- and neutron-induced fission cross-sections of Lead and neighbouring nuclei in the 20-200 MeV energy region".
Project leader: Vilen P. Eismont, V.G. Khlopin Radium Institute,
S:t Petersburg (ISTC project #1309)
The project is a follow-up of ISTC project #540. It focuses on measurements of proton- and neutron-induced fission cross sections in the lead region. The experiments are being made at the The Svedberg Laboratory and in collaboration with the Department of Neutron Research, Uppsala University, as also was the case for project #540. The produced database is partly unique and will through light on existing discrepancies between model calculations and experiments.

The project is paid by EU and has suffered a reduction of 25% of its budget in dollars because of the low value of the EURO compared to Dollar during 2001, which meant that the last year of the 3-years project was not funded. Discussions with the ISTC secretariat how to solve these problems resulted in a half-year reduction of the project time ending in May 2002. This fact has prompted the delivery of a new application to ISTC for measurements of fission cross sections of Tungsten (ISTC project #2213). The new project application has been forwarded to the ISTC secretariat by the Russian Authorities (MINATOM) and the reference group has decided to support the application through a supporting letter from the Dept. of Neutron Research, Uppsala University.

As a result of a recommendation by the officials of EU an information exchange has been established between the manager of the EU HINDAS project (J.-P. Meulders, Univ. Catholique de Louvain, Belgium) and the ISTC project # 1309.

"1 MWt lead-bismouth target for accelerator-based systems"
Project leader: M. Yefimov, Institute of Physics and Power Engineering,
Obninsk (ISTC projekt # 559)
The "reference group" took originally the initiative to this project, which also became strongly supported by USA and EU.

The purpose of the project was to develop a heavy metal flow target, which possesses the best features for producing neutrons at a high power proton accelerator. Thus, the technical key problems of a flowing lead-bismuth 20 MWth-power target should be investigated. Such a technical base was established by the design of a pilot lead-bismuth 1 MW_{th}-power target (TC-1). It was planned that the pilot target would be tested at the linear proton accelerator (800 MeV, 1.5 mA proton beam) LANSCE at Los Alamos National Laboratory.

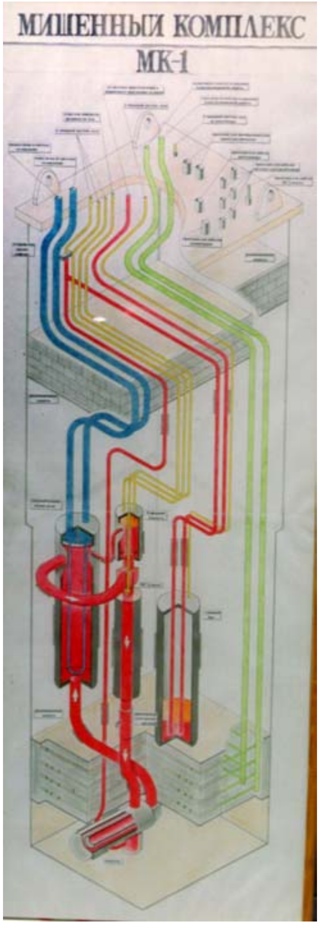

Figure 21: Schematic functional layout of the Pb/Bi spallation target TC-1.

The project benefited from the broad experience of specialists at IPPE and RDB "Gidropress", whose experience was developed by designing and operating the Russian nuclear submarines with lead-bismuth cooled reactors. The target design was a result of a close cooperation primarily between IPPE and LANL but had also been discussed at several technical meetings with the participation from Sweden (Swedish collaborator: the Department of Nuclear and Reactor Physics, Royal Institute of Technology, Stockholm) and France (EU collaborator: CEA/Cadarache).

During preliminary tests in early June 2000 it turned out that the Pb-Bi pump was defective.

Due to these reasons the project was prolonged 5 months, up till November the same year on a no-extra-cost basis. Restoration of some deficient level sensors for the molten lead was also made. Subsequently the TC-1 target was accepted by LANL, CEA and RIT after test runs at IPPE.

At a meeting of the Advisory Group of the IPPE TC-1 Molten Metal Target (Chairman W. Gudowski) in Reno, USA on November 12, 2001 with participation from USA (DOE and LANL), Russia (IPPE); EU (CEA/Cadarache) and Sweden (KTH, UU) the DOE representative (F. Goldner) reported the financial problems with the planned irradiation of the TC-1 target at LANSCE and proposed an alternative use of the target. The main obstacle for the irradiation test was the cost 20 M$ which could not be paid by the DOE/3A resources. The proposed alternative was to make instrumental tests to advance the molten lead-bismuth technology at the University of Nevada – Las Vegas – a University which had got financial support (4.5 M$) from the 3A project to built a molten lead laboratory (lead loop) and by that was able to finance the transport of the IPPE target and organise the research on the same target together with LANL and ANL. Experts or students from EU and in particular Sweden were welcome to make research using the target.

Even if the economical situation at LANL would change within a few years, the participants from LANL in the target meeting declared that it would be very unlikely that the target ever will be irradiated at LANSCE. The Russian delegates were very unhappy that the plan from the very beginning to irradiate the target at LANSCE was abolished. They accepted under protest the proposed changed program by the U.S. for the TC-1 target as a test facility for molten Pb/Bi at the newly set up laboratory at the University of Nevada, Las Vegas.

The target was shipped to the University of Nevada, Las Vegas in mid 2002 and a meeting was held at Las Vegas in August 2002 of the Advisory Group to discuss the research program for the target.

Figure 22: The Molten Metal Target (#559) Advisory Group meeting in Las Vegas, July 2002.

"Experimental Research of Transmutation of Fission Products and Minor Actinides in a Subcritical System Driven by a Neutron Generator".
Project leader: S. E. Chigrinov, Radiation Physics & Chemistry Institute, Minsk-Sosny 220109 (ISTC project B-70, Belarus)

Figure 23: The subcritical assembly Yalina in Minsk-Sosny Institute.

The Yalina facility consists of an accelerator driven 14 MeV neutron source surrounded by a sub-critical blanket. The planned experiments will yield information in the following fields:

- Physics of sub-critical systems driven by a neutron generator
- Transmutation rates of fission products and minor actinides
- Spatial kinetics of sub-critical systems with external neutron sources
- Experimental techniques for sub-criticality monitoring
- Dynamically characteristics of sub-critical systems with an external neutron source (pulse mode operation of the neutron generator).

The Department of Nuclear and Reactor Physics at the Royal Institute of Technology contributes to the project with the development of computer codes for simulation of the neutronics of the facility.

"Experimental Mock-up of Molten Salt Loop of Accelerator-Based Facility for Transmutation of Radioactive Waste and Conversion of Military Plutonium."
Stage 2: "Experimental Study of Molten Salt Technology for Safe, Low-Waste and Proliferation Resistant Treatment of Radioactive Waste and Plutonium in Accelerator-Driven and Critical Systems"
Project Manager: K.F. Grebyonkin; VNIITF, Snezhinsk, Chelyabinsk region
Project Scientific Leader: V.V. Ignatiev, Kurchatov Research Center, Moscow
(ISTC project # 1606)
The mission of the project is to perform an integral reevaluation of the molten salt nuclear fuel technology potential as applied to safe, low-waste and proliferation resistant treatment of radioactive waste and plutonium management as well as to develop a comprehensive program plan of the technology commercialisation

Besides the two laboratories "Russian Federal Nuclear Center – Institute of Technical Physics" (VNIITF) and "Russian Research Center – Kurchatov Institute" (RRC-KI) already mentioned, two more Russian laboratories participate in the project namely: "Institute of High Temperature Electrochemistry" (IVTEH), Ekaterinburg and "All-Russian Scientific & Research Institute of Chemical Technology" (VNIIHT), Moscow.

Figure 24: Project #1606 kick-off meeting in Snezhnisk-Chelyabinsk.

Foreign collaborators are: CEA/Cadarache, British Nuclear Fuels Ltd (BNFL), COGEMA, Research Center Rossendorf, Royal Institute of Technology (KTH) and Chalmers University of Technology (CTH). Furthermore, a close link will be established with the 5th European Framework Project on Molten Salt Reactors (MOST), with 12 participating European institutes.

A "Kick-off" meeting was held at the Russian Federal Nuclear Center – Institute of Technical Physics (VNIITF), Chelyabinsk on May 27, 2001.

Figure 25: Visiting the weapon laboratory at Snezhnisk-Chelyabinsk.

Actinide Nuclear Data Evaluation,
Project Manager: Maslov V M; Leading Institution: Institute of Radiation Physics and Chemistry Problems (Minsk, Sosny, Belarus); (ISTC project # B404, Belarus)
The project is closely linked to project B-70. Swedish collaborator is Department of Nuclear and Reactor Physics, Royal Institute of Technology.

Combined Radiochemical and Activation Analysis of Long-Lived Nuclear Waste Transmuted in Fast Reactors and High Energy Accelerators
Project manager: E. Ya. Smetanin, Institute of Physics and Power Engineering (IPPE), Obninsk (ISTC project # 1372)
The project will include radiochemical analysis and activation measurements of the isotopic composition changes of minor actinide samples irradiated in fast reactors and by the radiation field from a massive lead spallation neutron source. Comparative analysis of the radioactive isotope transmutation efficiency in fast neutron reactors and accelerator driven systems. The Department of Nuclear and Reactor Physics, Royal Institute of Technology will be the Swedish collaborator of the project.

Experimental and Theoretical Studies of the Yields of Residual Product Nuclei Produced in Thin Pb and Bi Targets Irradiated by 40-2600 MeV Protons
Project manager: Yu. E. Titarenko, Institute of Theoretical and Experimental Physics, (ITEP), Moscow (ISTC project #2002)
The project started on 1 January 2002 and is aimed at experimental and theoretical studies of the independent and cumulative yields of residual product nuclei in high energy proton irradiation of thin targets of highly enriched isotopes and natural Pb and natural Bi. The project is coupled to similar projects at Univ. of Hannover and GSI,

Darmstadt in progress within the EU-project HINDAS. European collaborators are besides the University of Hannover also CEA/Cadarache, CEA/Saclay, and KTH.

A report of the first quarter (1 January – 31 March 2002) has been published in which the first irradiation data for Bi and Pb isotopes are presented. The project research is reported to be on schedule.

Improvement of Corrosion Resistance of Constructional Steels in Liquid Pb and Pb-Bi Alloys by Means of their Surface Modification with the Help of Pulsed Electron Beams and Protective Coatings (ISTC project # 2048)
Project manager: V.I. Engelko, NIIEFA, S:t Petersburg
A "kick-off" meeting was held at the Efremov Institute, S.t Petersburg on 25-26 March 2002 with participation of the Russian partners of the project (NIIEFA, IPPE and CRISM) and the European collaborators (CEA/Saclay, CIEMAT-DFN, FZK and KTH).

The purpose of the project is to develop and ground an effective way to protect constructive steels from corrosion in liquid Pb and Pb-Bi melts at temperatures higher than 500ºC via modification of their surface properties with the help of pulsed intense electron beams.

The 640 000 US$ project is closely linked to the EU FP5 project TECLA.

Construction of a Subcritical Assembly Driven by Proton Accelerator in Dubna (SAD) (ISTC project # 2267)
Project manager: V. Shvetsov, JINR, Dubna
The purpose of the "SAD-project" is to develop and construct an experimental installation using the existing proton beam of 0.5 kW from the 660 MeV cyclotron at JINR and a sub-critical MOX fuel blanket (15 – 20 kW thermal power, k_{eff} = 0.95). Techniques for measurements of sub-criticality and neutronic properties will be developed and relevant computer codes, data libraries and dosimetry of high energy neutrons (above 20 MeV) will be validated. The SAD-project is complementary to the EU-project MUSE which uses a 14 MeV neutron source and a sub-critical facility of a few 100 W thermal power.

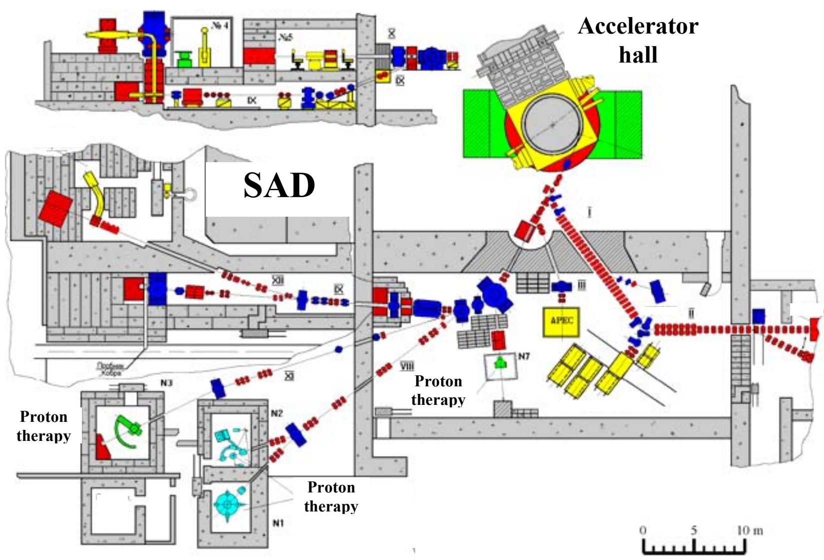

Figure 26: General plan view of the JINR "Phasotron" accelerator complex and SAD facility.

The project is scheduled for 3 years starting from January 2002. The total cost of the project is 1 750 000 US$ of which 1 200 000 US$ is granted by ISTC and the rest of the money will be provided by JINR.

The project is co-ordinated by JINR, Dubna with Russian participation also from NIKIET, Moscow, Mayak factory Ozersk, GSPI Moscow and VNIIM Moscow. European collaborators are FZK/Germany, CIEMAT/Spain, KTH/Sweden and CEA/Cadarache/France which group also financed a pre-ISTC project design study. A SAD Advisory Group has been formed with W. Gudowski as the Chairman. Research groups from the Czech Republic, Romania, Bulgaria and Poland have explained an interest to participate in the project.

Projects in the "pipe-line"

Experimental research of nuclear-physics characteristics of materials essential for the processes of weapon plutonium incineration and radioactive waste transmutation (New ISTC project # 2405)
Project manager: ITEP
The project is a follow-up of project #2002. Discussions are underway with the Dept. of Neutron Research, Uppsala University of using the neutron beam at the The Svedberg Laboratory for detector calibration.

Study of Minor Actinide Transmutation in Nitrides – modelling and measurements of out-of-pile properties (MATINÈ) (New ISTC project - #2680)
Project manager: IPPE
The project will be divided in four tasks with IPPE co-ordinating the work.

First task is a compilation of nitride fuel data from the literature. The task will be made by IPPE, RIAR and VNIINM.

The second task will cover fabrication and measurements of thermal characteristics of (Pu,Zr)N pellets. The task will be made by VNIINM.

The third task will involve modelling of the performance of (Pu,Am,Zr)N fuel under irradiation up to high burn-up in fast spectrum of ADS. The fuel form would be either pellets or vibropacked granulates/microspheres. The task will be performed by IPPE and RIAR.

The fourth task will be devoted to technical – economical assessments of the feasibility of fabricating nitride fuels with atomic fraction of ZrN inert matrix up to 60±10 % containing up to 10 atomic percent Cm. IPPE, RIAR and VNIINM will participate in this task.

The project is closely related to the EU-project CONFIRM. One difference is that the fuel fabrication proceeds from metals and oxides for the MATINÈ and CONFIRM projects, respectively. European collaborators are CEA/Cadarache and KTH.

SKI Report 2003:19
APPENDIX

Research

Planning and Reporting of Russian Transmutation Research Projects within ISTC
Phase 3

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Nils Olsson
Curt Mileikovsky
Jan Wallenius

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Summary

High level radioactive wastes from the present thermal nuclear power reactors and plutonium from dismantled nuclear weapons in USA and Russia constitute an environmental and proliferation risk. A technical concept, i.e. Accelerator Driven Transmutation of Nuclear Waste (ATW) has been proposed to incinerate and transmute long-lived radioactive nuclear waste to relax the amount of and the time needed to store waste in a geological repository. Likewise, the same method has also been proposed to incinerate weapon plutonium.

In the early 90's, after the disintegration of the former Soviet Union, USA, EU and Japan decided to set up an International Scientific and Technical Center (ISTC) in Moscow to fund research projects of civilian interest to counteract the risk of nuclear weapon proliferation by emigration of former USSR technical and scientific experts to countries which could be aiming towards the development of nuclear weapons. Countries outside this tripartite were also asked to support the ISTC. Sweden decided to join the effort with MUS$ 4. Nowadays, the Swedish support to ISTC is through EU.

A similar centre, the Scientific and Technical Centre of the Ukraine (STCU), has been set up in Kiev. Sweden has been active in promoting this Centre, which is supported by USA, Japan, Canada and recently also by EU.

The named Russian experts are knowledgeable and well equipped of doing research in the different technical fields of relevance for the transmutation concepts. Following discussions at a workshop in Saltsjöbaden 1991 on transmutation with participation mainly of US, Russian and Swedish experts, a positive respond was given in consultations with Swedish Authoroties to use part of the Swedish fund to ISTC for Russian ATW research projects.

The authors of the present report, representing a group of Swedish experts on transmutation, have initiated a number of ISTC projects to investigate different technical aspects of ATW engaging former Soviet Union weapon specialists. The projects, which have been initiated and still are in the ISTC "pipe-line", are presented in this report together with a review of the ongoing international research on transmutation. The group has had a financial support from the Swedish Nuclear Power Inspectorate (SKI) to cover mostly traveling expenditures which have been called for in fulfilling the objectives of the above described task. The report is mainly presenting the activities during the last phase (phase 3) of the three years SKI project. The phases 1 and 2 of the same project have been reported to SKI in February 1997 (SKI Report 97:15) and in November 1998 (SKI Report 99: 5).

Sammanfattning

Högaktivt radioaktivt avfall från de nuvarande kärnkraftsreaktorerna och plutonium från skrotade kärnvapen i USA och Ryssland utgör en risk för miljön och spridningen av kärnvapen. En teknisk metod kallad ”acceleratordriven transmutation av kärnavfall” (ATW) har föreslagits för att förbränna och transmutera långlivat radioaktivt avfall för att därigenom minska mängden avfall som behöver läggas i ett geologiskt förvar och även minska förvaringstiden för avfallet. Samma typ av metod har också föreslagits för förbränning av vapenplutonium.

I början på 1990-talet, efter sönderfallet av den forna Sovietunionen, beslöt USA, EU och Japan att sätta upp ett forskningscentrum i Moskva – det internationella vetenskapliga och tekniska centret (ISTC) – med uppgift att finansiera civila forskningsprojekt vid de ryska kärnvapenlaboratorierna. Syftet med centret är att engagera ryska kärnvapenexperter i dessa civila projekt, experter som annars skulle kunna tänkas emigrera till länder som önskar att utveckla kärnvapen. Andra länder inbjöds att ge stöd till ISTC. Sverige beslöt att stödja ISTC med 4 MUS$. Idag går det svenska stödet via EU.

Ett liknande centrum – det vetenskapliga och tekniska centret i Ukraina (STCU) – har satts upp i Kiev. Sverige har aktivt medverkat till bildandet av STCU, som också stöds av USA, Japan, Canada och sedan relativt nyligen också EU.

De ryska kärnvapenexperterna har både kunnande och utrustning för att bedriva forskning inom de olika vetenskapliga och tekniska områdena som är relevanta för forskning och utveckling av transmutationskoncept. Efter diskussioner i anslutning till en ”workshop” om transmutation som hölls i Saltsjöbaden 1991 med deltagare från främst USA, Ryssland och Sverige visade svenska myndigheter efter konsultationer en positiv attityd till att använda en del av det svenska bidraget till ISTC för forskningsprojekt med relevans för forskningen på ATW koncept.

Författarna till denna rapport, som utgör en grupp av svenska experter på transmutationsforskning, har initierat ett antal ISTC projekt med anknytning till olika forskningsproblem kring ATW och som engagerar kärnvapenexperter från det tidigare Sovietunionen. Projekten som är på gång eller under diskussion presenteras i denna rapport tillsammans med en översikt av den internationella forskningen på transmutation. Gruppen har haft ekonomiskt stöd från Statens kärnkraftsinspektion för i huvudsak resor som föranledes av arbetet att förbereda och följa ISTC projekten. Rapporten beskriver i huvudsak aktiviteterna under den sista etappen (etapp 3) av ett treårigt SKI projekt. Etapperna 1 och 2 av samma projekt har rapporterats till SKI i februari 1997 (SKI Report 97:15) och i november 1998 (SKI Report 99:5).

1. Nuclear Waste Transmutation

1.1 Introduction

A number of different methods have been discussed over the years to handle the problem of the nuclear waste. Studies have been made of geological, ice sheet, seabed and extraterrestrial disposal and nuclear transmutation. The geological disposal has become a major alternative for several countries, among them Sweden and USA. The main reason being the fact that the method to a large extent relies on existing technologies and that no "naked" plutonium, that could be a material for making nuclear explosives, becomes available during the handling process of the reactor waste. The main obstacle being the very long time a safe disposal (no exchange with the biosphere) has to be guaranteed (100 000 years or more) and the long term risk for plutonium material proliferation.

High-level nuclear waste is made up of relatively few rather longlived radioactive species, among them plutonium, that contribute to difficulties with its storage and disposal. Separation of these species from larger waste volumes coupled with incinaration of plutonium and the so called minor actinides (neptunium (Np), americium (Am), curium (Cm)) and by transmutation of the long lived fission products represents a viable nuclear waste management strategy.

The use of neutron-induced incineration and transmutation processes to destroy these species involves two major reaction types. One is neutron capture, which is used with fission products and for most cases involves the creation of an intermediate, short-lived isotope that may decay to a stable by-product. The other is the fission process that causes the actinides to split forming two fission products mostly short-lived otherwise converted by neutron capture to short-lived isotopes. For a few fission products, in particular for some of the Cs isotopes, there might be, on the contrary, a build-up of long-lived isotopes by neutron capture reactions. Different solutions to this problem have been proposed.

The investigated transmutation systems include thermal and fast neutron reactors and accelerator driven subcritical thermal or fast neutron concepts. The use of thermal reactors to transmute long-lived radio nuclides suffers from several problems. Because of relatively low neutron fluxes (10^{14} cm-^{2}s-^{1}) these systems have small transmutation rates for constituents having small thermal cross sections as e.g. some isotopes of the minor actinides such as ^{241}Am and ^{243}Am. Because of low fluxes large inventories of material are required to achieve a requested transmutation performance. The use of fast reactors have problems associated with the difficulty in transmuting fission products because of small capture cross sections for fast neutrons. Also in this case, large inventories are required to obtain reasonable transmutation performance and for the high flux reactor systems with hard neutron spectra there are also reactivity control concerns.

The use of Accelerator-Driven Transmutation Systems (ADS) have been proposed to overcome the drawbacks with the critical reactor based systems for transmutation of nuclear waste, and at the same time diminish the need for geological deposition. Studies at LANL, CERN and KTH have shown that to incinerate the long-lived transuranium actinides and transmute some of the long-lived fission products in the spent fuel from the lifetime of 10,000 MWe of LWR's (i.e. 30,000 MWth) one needs to build about 7,500 MWTh (25 %) of Accelerator-Driven Transmutation of Waste (ATW) plants and operate those plants during a normal reactor lifetime (35 to 40 years), thereby also treating their own nuclear waste. About 99% reduction of the amount of transuranium actinides can be obtained by transmutation with realistic assumptions in relation to present separation techniques.

In principle, the ATW concept consists of an intense neutron source, which is driven by a high power proton accelerator (1-2 GeV, 20-150 mA). The protons are stopped in a heavy metal (e.g. molten Pb/Bi) in which a large number of neutrons are produced by each proton through so-called spallation reactions. The spallation neutron source is surrounded by a subcritical blanket containing the nuclear waste to be transmuted. Different blanket concepts have been proposed with fast or thermal neutron spectrum. The waste might be housed in solid nuclear fuel pins put into a blanket with molten lead or dissolved in e.g. molten lead-bismuth or molten salt (mixture of lithium(Li)- and beryllium(Be)-fluorides or of natrium(Na)- and zirconium(Zr)-fluorides). Special proliferation resistant processes have been proposed to prepare the fuel for the Acceleration Transmutation of Waste (ATW) system from spent nuclear fuel or weapons plutonium and to remove the fission products (volatiles, transition metals and lanthanides) from the molten salt. The main proliferation resistant feature of the proposed pyrometallurgical separation processes is that separated ("naked") plutonium will not appear in any step, which contaminated plutonium also is acceptable for the feed to the ATW system because of its favourable neutronic properties for incineration and transmutation.

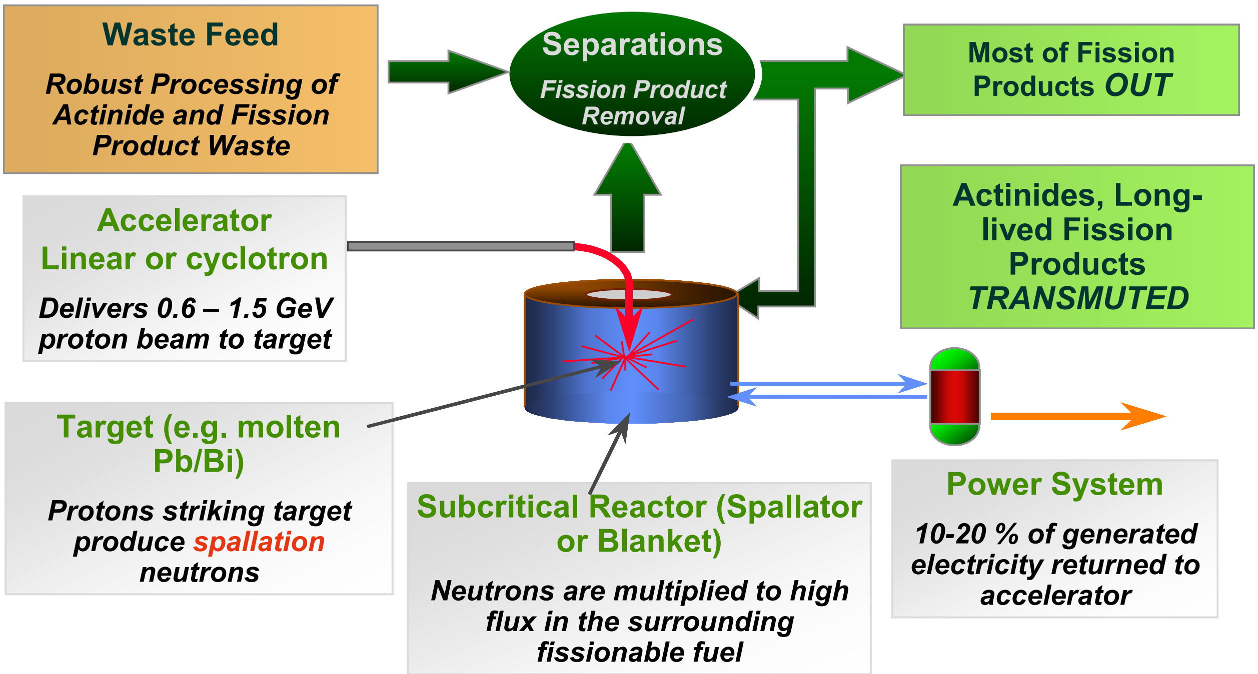

Figure A1: General lay-out of an ATW concept.

The present studies both in Europe and in USA focus on a fast neutron spectrum system with solid fuel pins and molten lead or lead/bismuth as moderator and coolant. This system is superior to a thermal neutron spectrum system (e.g. molten salt) what concern the incineration capabilities of heavier actinides like americium and curium. Improvements have been made in the development of water chemistry to separate plutonium and the minor actinides, for which the Department of Nuclear Chemistry at CTH has taken an active part. In particular, for countries, which already have water chemistry separation facilities, which produces MOX fuel for burning plutonium in thermal reactors this option has become of primary interest.

1.2 ATW research programs

Discussions have taken place all through the 90's about the organisation and financing of ATW research programs in both USA and Europe and have now reach a status with firm proposals. In addition, national research programs in Japan (the OMEGA program), The Republic of Korea and China have been initiated. A number of transmutation research projects are also in progress in the former Republics of the Soviet Union, in particular in Russia. Several of these projects are funded by ISTC and are thus reported under that heading in this report.

1.2.1 USA

1.2.1.1 The US – DOE ATW Program

DOE decided to make a close study (road-mapping) during the fiscal year starting October 1998 of all aspects of the accelerator based transmutation research program proposed by the Los Alamos National Laboratory (LANL). The road-mapping activity resulted in the proposal of a major US research program for transmutation of nuclear waste. A final open report of the investigation has been published by DOE. As a result of the road-mapping study, DOE requests 280 MUS$ for a 5 years basic research program on ATW from the Congress which will involve several national nuclear laboratories, universities and industries. Meanwhile, DOE has funded a one-year 9 MUS$ research program with a main part of the program placed at LANL.

The key phases of the recommended program for the development of the ATW techniques in the US were:

Government Supported Phase (2000-2027)

R&D Phase (2000-2008)
R&D Follow-up Phase (2008-2027)
Demonstration Phase (2000-2027).

Privatisation Phase (2023-2111)

FOAK (first-of-kind) Plant Privatisation (2023-2097)
NOAK (nth-of-a-kind) Plant Privatisation (2027-2111).

J Breese at the Office of Civilian Radioactive Waste Management was appointed as the DOE manager of the program. The road-mapping study engaged a large number of experts from US national laboratories, universities and private industries. It was coordinated by DOE which body also appointed an international advisory committee. The Swedish member of this committee was Waclaw Gudowski, KTH.

1.2.1.2 The LANL Program

The LANL was, before the DOE road-mapping exercise, in the forefront fighting for a national US ATW Program focused on studies to destroy plutonium and other actinides, as well as long-lived fission products in defence and commercial nuclear waste.

The long-term LANL program includes three phases. The first phase (about 5 years) includes studies of molten-Pb-loops, of a 1 MW Pb/Bi target at the 800 MeV, 1.5 mA proton linear accelerator at the Los Alamos Nuclear Science Laboratory (LANSCE) and of pyrometallurgical separation processes. The 1 MW Pb/Bi-target is being designed and produced by IPPE, Russia within the ISTC #559 project (see below). The second phase is the building and study of a 50 MW fuel blanket at LANSCE and the third phase is the building of a 1000 MW ATW prototype.

The LANL ATW concept uses a linear proton accelerator (about 0.8 to 1.5 GeV) which delivers a beam (about 20-100 mA) to a heavy metal (molten lead/bismuth) spallation target. The blanket consists of molten lead or lead/bismuth that contains solid fuel pins of actinides and other materials to be transmuted. The system also contains components used in the clean-up of the fuel by pyrochemical separation processes and for preparation of materials arising from the feed of spent nuclear fuel into the system. Fuel clean-up is a key issue to achieving a large destruction (factors of 100 to 1000) of long-lived radionuclides.

The molten salt LANL ATW concept, which was described in the Phase 1 report of the present project, is no longer a first priority option of the LANL ADS program. However, this concept was the leading concept when LANL a few years ago initiated several of the now on-going ISTC research projects on the incineration and transmutation of weapon plutonium and reactor waste. Thus, a majority of the Russian ATW/ISTC projects deals with different aspects of the molten salt concept of ATW.The molten salt envisioned for the ATW system is a mixture of lithium and beryllium fluorides or sodium and zirconium fluorides at a temperature of about 700 °C. The Li/Be mixture of molten salt was used as reactor fuel and as coolant in a four years study at the Oak Ridge National Laboratory in the US with the intent to develop a thermal breeder concept based on the thorium-uranium cycle. The experiences of the ORNL study was taken into account for the LANL/ATW blanket system. Molten fluoride salts are specifically suited to the versatile, proliferation-resistant front-end processes for the plutonium waste but is, because of its chemical and electrochemical stability, also providing a natural medium for reprocessing of spent nuclear fuel. Molten salts are low vapour pressure liquids even at high temperatures, and therefore add to the safety and performance of the system, allowing low pressure operations and high-efficiency power production.

The former head of the LANL ATW group, Dr C. Bowman, is the founder and the Chief Scientist of the ADNA (Accelerator-Driven Neutron Applications) Corporation. This corporation is pursuing research on molten salt thermal accelerator-driven transmutation systems, along the route of the former LANL project with molten salt. In particular, two systems Tier 1 and Tier 2, both with molten salt containing sodium and zirconium fluorides, are offered for in the first case (Tier 1) to eliminate weapon and reactor plutonium and in the second case (Tier 2) to transmute also other long lived species, minor actinides and long lived fission products. Both options can also burn thorium to produce energy.

1.2.2 EUROPE

1.2.2.1 ATW Related Research Projects within the EU Framework Programs

The support of ADS related research has increased going from the 4th to the 5th EU Framework program. Support to separation and ADS transmutation related research was given to 3 projects with a total cost of 2.5 MEURO under the 4th Framework Program while this number has increased to 7 projects already for the first phase of the 5th Framework Programme within a total budget of 17 MEURO. The next phase for the 5th Program is coming up in January 2001 and an additional support of 9 MEURO is expected.

The ADS related projects during the 4th Framework Program were:

IABAT – Impact of Accelerator Based Technologies on Nuclear Fission Safety with W. Gudowski, KTH as coordinator and 11 participating institutes among them 3 Swedish, Uppsala University, CTH and KTH. Three broad tasks were addressed in the project covering ADS-System and Fuel Cycle Studies, Nuclear and Material Data Development and Assessment of Accelerator Technology.

TARC – Test Assembly for Resonance Capture, with C Rubbia, CERN as coordinator and 14 participating institutes. Experimental study at the CERN PS accelerator of the phenomenology of spallation neutrons in a large lead block and in particular, of the resonance capture transmutation reaction in ^{99}Tc.

NEWPART – Partitioning: New Solvent Extraction Processes for Minor Actinides, Coordinator CEA, France and 7 participating institutes. The project has resulted in the preparation of reagents (triazinpyridines) with very high separation factors for the separation of Americium and the lanthanides.

The ATW related projects supported during the first phase of the 5th Framework Program (the research area, coordinator and budget) are:

Actinides, CEA, France, 2.2 MEURO.

TECLA – Corrosion, Quality Control in Lead-Bismuth and Associated Technology, CEA, France and ENEA, Italy, 2.5 MEURO.

HINDAS – High and Intermediate Nuclear Data for Accelerator-Driven Systems,
Université Catholique Louvain-la-Neuf, Belgium, 2.1 MEURO.

CONFIRM – Nitride Fuel Irradiation an Modelling Dept. of Neutron and Reactor Physics, KTH, 1.0 MEURO.

SPIRE – Effects in Martensitic Steels under Mixed Neutron and Proton Irradiation, CEA, France, 2.3 MEURO.

MUSE – Experiment for Subcritical Neutronics Validation CEA/Cadarache, 2.0 MEURO.

NTOF – Neutron Time of Flight, CERN and NEDUFPA, Neutron Cross Section Data for Unstable Fission Products and Actinides, Forschungszentrum Karlsruhe, Germany 2.4 MEURO.

PYROREP, Pyrometallurgical reprocessing basic data acquisition, CEA France.

1.2.2.2 Multi-National European Programs

1.2.2.2.1 The CERN program

A major research activity on accelerator driven system was initiated by Prof Carlo Rubbia at CERN, Switzerland. The main emphasis of the group formed by Rubbia was to develop a safe, environmental clean and cost-effective energy source for industrial use, the so called Energy Amplifier (EA). The main components of the system are a 1 GeV accelerator, a cyclotron or linac, which delivers about 20-40 mA to a subcritical blanket. The blanket has molten lead as a coolant. The amount of lead is enough to take care of the produced heat in the core by forced circulation or by self-circulation. The fuel pins in the core contains ^{233}U and also natural thorium (^{232}Th) as a breeding material. The latter material converts to ^{233}Th by neutron capture which decays to ^{233}Pa and finally to ^{233}U via successive beta-decays. The use of the Th/^{233}U -cycle means that the production of plutonium and heavier actinides are much less than in an ordinary power reactor based on the U/Pu - cycle but it is a concern with the production via (n,2n)-reactions in ^{233}Th of the relatively long-lived and radiotoxid isotope ^{231}Pa.

The CERN group has argued that the EA-system also is efficient to burn plutonium and minor actinides as well as certain long lived fission products. Thus, during the last year, the CERN group has focused on the research of using the EA for waste burning.

Furthermore, a very powerful neutron spallation source to measure neutron cross section data for ATW (NTOF) is under construction at the CERN PS (24 GeV proton synchrotron) accelerator. A broad international user group has been formed. A Swedish detector development contribution to the effort is planned by Per Carlson, MSI. The collaboration has got a financial support, together with the NEDUFPA neutron cross section data program at KfK, of 2.4 MEURO from the EU 5th Framework Program.

C. Rubbia retired from CERN in 1998 and the present head of the "Emerging Energy Technology Group" at CERN, which houses the EA-studies, is Ernst Radermacher.

1.2.2.2.2 The Joined French, Italian and Spanish ADS programs

The Ministries of Research in France, Italy and Spain formed an Advisory Group (MAG) on the definition of a common R&D European platform on Accelerator Driven Sub-Critical Systems. Two of the recommendations of the Advisory Group were to work towards the construction of a demonstrator facility in Europe and to establish a Technical Working Group (TWG), which was charged to look into the technical details of the concept. The TWG, chaired by C. Rubbia, stressed the need for an ADS demonstrator facility to be built as soon as possible (ASAP-DEMONSTRATOR).

Following the recommendations by MAG "to enlarge the co-operation to other EU countries", "to seek support of ADS research within the 5th EU framework program" and "the realisation of an ASAP-DEMO" the Ministries of Italy, France and Spain invited representatives of other EU member states to discuss these matters at a meeting with MAG in Rome in April 1999. Sweden was represented by Per-Eric Ahlström from SKB. The main recommendation of the meeting was to enlarge the TWG with participants from other interested countries. The primary task for the enlarged group was to revise the interim report from TWG and co-ordinate with the already ongoing preparations of applications to the EU fifth framework programme (FP5). Carlo Rubbia continued as chairman of the enlarged TWG.

A second meeting with the (enlarged) MAG was held in Rome on September 17, 1999. A recommendation from P-E Ahlström after these two meetings was that Sweden should limit its involvement in ADS research on the European level to the basic research projects on transmutation which were being proposed to the European Commission for FP5. As many of these projects were also discussed in the TWG, W Gudowski was asked to attend the TWG meetings as an observer. He has participated in two such TWG meetings.

A third meeting with the (enlarged) MAG was held in Rome February 25, 2000. P-E Ahlström did not attend that meeting, but submitted written comments to the proposed document from TWG and from the meeting.

Two different ADS concepts are proposed to be studied by the TWG namely a molten lead or lead/bismuth cooled system with a likewise molten lead or lead/bismuth spallation neutron source and, as an alternative, a gas-cooled system with a solid tungsten spallation neutron source.

Each of the three countries has national ADS programmes, which are the initial input to the common R&D programme. The expenditure on transmutation research in France, Italy and Spain is 10 MEURO/year or more per country. The national programmes are in short as follows:

1.2.2.2.3 The MEGAPIE Neutron Spallation Source

MEGAPIE (**MEGA**watt **PI**lot **E**xperiment) is a joint initiative by CEA, France, Forschungszentrum Karlsruhe (KfK), Germany and Paul Scherrer Institute (PSI), Villigen, Switzerland to design, built, operate and explore liquid lead-bismuth spallation target for 1 MW of beam power, taking advantage of the existing spallation neutron facility, SINQ at PSI. The MEGAPIE experiment will be an important ingredient in defining and initiating the next step, a dedicated ADS-quality accelerator plus target plus (at a later substage) an irradiation oriented low power, subcritical blanket.

The MEGAPIE collaboration held its first meeting on May 19, 1999 at PSI with participation from: CEA, Cadarache/Saclay - SUBATECH/CNRS - KfK - PSI. JAERI, Tokai Establishment, Japan has expressed interest to participate actively in the effort and similarly, ENEA, Italy has expressed interest in the project and has sent an observer to the past meetings of the collaboration.

Although the collaboration is intended to be limited to members who actively participate in the project and make significant contributions to its funding it remains open for new members with an active interest in the topic.

Consideration is also given in the possibility of proposing the project for support within the 2nd phase of the 5th Framework Program of the European Union.

The initial MEGAPIE project phases are:

Phase 1	Nov 99 – Feb 00	Baselining
Phase 2	March 00 – May 00	Feasibility study
Phase 3	June 00 – Sept 00	Conceptual design

The goal is to have the target running at the 600 MeV PSI cyclotron in 2006.

A number of experiments are in progress closely related to the technical problems with the MEGAPIE spallation neutron source:

- The LISoR experiment – study of the question whether liquid metal - solid metal reactions are enhanced under irradiation in the presence of stress. Experiment at PSI's 72 MeV Philips cyclotron by CEA and CNRS.

- The TERM experiments - Experiments at the Riga Mercury Loop (TERM) to create a database for thermal hydraulic studies of heat transfer between the window and the fluid in geometries of the SINQ (PSI) and ESS (European Spallation source) spallation neutron sources.

- The PSI Lead-Bismuth loop – complimentary to the TERM experiments, testing of individual components as well as studies of flow configurations and heat transfer are being made at a lead-bismuth loop at PSI.

- KALLA – the Karlsruhe Lead Laboratory. The laboratory will comprise three different experimental molten lead or lead/bismuth loops, each emphasising on different specific activities namely: technology loop (oxygen control), thermal-hydraulic loop and corrosion loop.

- The TECLA Program – Corrosion, quality control in lead-bismuth and associated technology will be investigated and the SPIRE Program – studies of irradiation effects in structural materials under proton-neutron mixed irradiation. Both Programs have been funded by the EU 5th Framework Program with 2.5 MEURO and 2.3 MEURO, respectively.

1.2.2.3 France

The French parliament has imposed the nuclear authorities (CEA, CNRS, EDF) to produce basic data for a decision at year 2006 about the best way to treat the nuclear waste. A program (GEDEON) has been initiated by CEA; CNRS, EdF and FRAMATOME which includes a large experimental program, including the French participation in the MEGAPIE and associated experiments and a study of a neutron source driven undercritical facility (MUSE experiment), aiming towards a transmutation demo facility at CEA/Cadarache. The studies are mainly focused on the accelerator based incineration of the minor actinides (Am, Np, Cm) and likewise transmutation of some longlived fission products while plutonium, and possibly also Np, is thought to be recycled in thermal power reactors (MOX-fuel).

1.2.2.4 Italy

A research program based on the CERN concept of ADS has been approved by ENEA and INFN with a yearly budget of 10 MEURO.

The program will include studies of the following items:

- Linear proton accelerator, 1 GeV, 30 mA

- Subcritical blanket system

- Validation of the technology with molten Pb or Pb/Bi

- Final goal is to participate in an international collaboration on building an ADS prototype.

1.2.2.5 Spain

The CERN group investigated the possibility to incinerate and transmute the burned nuclear fuel from the present 9 power reactors in Spain. To eliminate the already existing and the further produced nuclear waste during the remaining drift-time for the reactors one needs to run 5 energy amplifier in 37 years of operating time according to the investigation. The treatment of nuclear waste would be profitable compared to a geological deposition, in particular, if the EA would be allowed to simultaneously produce fissile ^{233}U for energy production.

Following this investigation by the CERN group a Spanish company, LAESA, was formed in March 1997 to develop and built an EA for the Spanish needs. As a first task the company would build a 100 MWt prototype. The company run into both economical and technical problems. At present, the ADS research is coordinated with the same activities in France and Italy according to the agreement on research collaboration by the Ministries of Research in France, Italy and Spain.

1.2.2.6 ATW Research Activities in Belgium and the Czech Republic

1.2.2.6.1 Belgium

The Myrrha project within SCK/CEN nuclear research center in Mol intends to design, develop and possibly realise an accelerator-driven system. An intermediate goal is to base the research on a 300 MeV, 5-10 mA proton cyclotron driving a liquid lead/bismuth spallation source surrounded by a subcritical assembly. The use and specific design of this source is studied in the frame of multiple use (transmutation, radioisotope production, proton cancer therapy etc). In particular, the domain of medical applications, and more specifically the production of radioisotopes, is known as the ADONIS project. The currently proposed cyclotron is on 150 MeV with a proton current of 2 mA. Within a few years time it is intended to extend the energy and beam power to the above given figures.

1.2.2.6.2 The Czech Republic

The problem of finding an acceptable place for a geological repository in the Czech Republic has speeded the research on accelerator-driven transmutation systems. A national research program (LA-0) has been initiated with participation of several research institutes and the SKODA industries. In addition, many foreign institutes, mostly from Russia, participate in the research. Initially, the research has been focused on the physics, chemistry and material questions related to a blanket with the actinides and fission products dissolved in a molten salt (Li- and Be-fluorides). A test-loop for molten salt is under construction. The 3rd international conference on ADTT and Applications was held in Praha on 7-11 June, 1999.

1.2.2.7 ATW Research in Sweden

A number of basic research projects related to ATW is in progress in Sweden funded by SKB and EU. Besides those projects measurements are in progress by the Dept. of Radiation Science, Uppsala University in collaboration with the Inst. for Techniques and Natural Sciences, University of Örebro, ILL, Grenoble, France and IRMM, Geel, Belgium of fission and capture cross sections for ^{233}Pa.

1.2.2.7.1 SKB funded research

The SKB funded projects at the Dept. of Nuclear Chemistry, CTH deal with the development of water-based techniques for the separation of lathanides and actinides by using different Carbon-Hydrogen-Oxygen-Nitrogen extraction reagents in order to diminsh the amount of secondary wastes. Investigations how to include extraction of Neptunium, Technetium and Iodine in the standard PUREX process are also supported by SKB. The SKB funded studies at the Dept for Neutron and Reactor Physics, KTH involve optimisation calculations of subcritical core configurations with solid fuel and liquid metal cooling, development of Monte Carlo -based calculation methods for accelerator-driven systems, safety (reactor dynamical) studies of subcritical systems and participation in the MUSE program at Cadarache, France (see below). SKB is also funding together with SKI, Vattenfall, Barsebäck Kraft AB and FOA a project at the Dept. of Neutron Research, Uppsala University to measure neutron elastic cross sections at 100 MeV which data are requested for ATW research.

1.2.2.7.2 EU funded ATW research under the 4th and 5th Framework Programs

The Dept. of Nuclear Chemistry, CTH participated in several separation projects within the EU 4th Framework Program which covered studies of extraction properties and mechanisms of the separation process of lanthanides and actinides by carbon-nitrogen based reagents. The Swedish contribution to the IABAT project, which was supported by the same Framework Program, concerned model calculations, validations and measurements of nuclear transmutation reaction data, neutronic model developments for accelerator-driven subcritical systems and safety studies. In total 11 universities and institutions participated in the project including 3 Swedish research groups namely the Dept. of Neutron Research, Uppsala University, the Dept. of Neutron and Reactor Physics, KTH and the Department of Reactor Physics, CTH with W. Gudowski, Dept. of Neutron and Reactor Physics, KTH as coordinator. Furthermore, the Dept. of Neutron Research, Uppsala University participated in a so called “EU Concerted Action” with the title “Physical Aspects of Lead as a Neutron-Producing Target for Accelerator Transmutation Devices”. The Concerted Action included 16 European research groups from different Universities and Institutes.

The EU 5th Framework Program support to ADS related research activities at Swedish Universities amounts to about 1 MEURO for 6 different projects.

- High and Intermediate Nuclear Data for Accelerator-Driven Systems (HINDAS).
  Swedish participant Depts of Neutron Research (INF) and Radiation Science (ISV), Uppsala University

  Studies are made of neutron cross sections above 20 MeV of neutron energy. The project involves 16 laboratories of which 5-6 have their own experimental facilities among them INF with its neutron facility at the The Svedberg Laboratory, Uppsala. Development and validation will also be made of neutron cross section calculational models.The EU 5th Framework support is 2.1 MEURO in total of which 210 kEURO is directed to the Uppsala University.

- Collaboration on Nitride Fuel Irradiation and Modelling (CONFIRM)
  Swedish participant: Dept. of Neutron and Reactor Physics, KTH

  The project has 7 partners with Jan Wallenius, KTH as coordinator. EU has granted 1.0 MEURO in total of which 200 kEURO is directed to KTH.The actinides are proposed to be in the form of nitrides in a transmutation burner. Radiation effects will be studied in nitride fuel after irradiation of the fuel in the R2-reactor at Studsvik.

- Effects in Martensitic Steels under Mixed Neutron and Proton Irradiation (SPIRE)
  Swedish participant: Dept. of Neutron and Reactor Physics, KTH

  The project has 10 participating institutes and is supported with 2.3 MEURO by EU of which KTH will get about 110 kEURO. The aim of the project is to study radiation damage in the window between the accelerator and the reactor of an accelerator-driven system.

- Experiment for Subcritical Neutronics Validation (MUSE)
  Swedish participants: Dept. of Neutron and Reactor Physics, KTH and Dept. of Reactor Physics, CTH

  The support from EU is 2.0 MEURO of which KTH will get about 110 kEURO. Validation of subcritical neutronic calculations will be made from an experiment at CEA/Cadarache using a subcritical assembly (MASURCA) driven by a DT neutron source.

- Technologies, Materials and Thermal-hydraulics for Lead Alloys (TECLA)
  Swedish participants: Dept's of Nuclear Safety and Neutron and Reactor Physics, KTH

  The EU support to the project is 2.5 MEURO and 10 institutes are participating in the project. How much will be directed to KTH is not yet decided. Plans exist at KTH to build a lead-bismuth loop to study corrosion, circulation (pumping) and oxygen control problems. Bal Raj Sehgal, Dept. of Nuclear Safety will be in charge of the project at KTH.

- Partitioning: New Solvent Extraction Processes for Minor Actinides (PARTNEW)
  Swedish participant: Dept. of Nuclear Chemistry, CTH

EU support to the project is 2.2 MEURO of which about 250 kEURO is expected to be directed to the Dept. of Nuclear Chemistry, CTH. The project is a continuation of NEWPART (4th EU FP) to study the extraction of lanthanides and actinides using pyridines or similar nitrogen-based molecules.

1.2.3 Japan

The OMEGA-project will include design studies of a superconducting linac for ADS, a transmutation system with hardest possible spectrum containing nitrite fuel, Pb/Bi, Na or He as moderator and coolant. The transmutation system will have a capacity to convert about 250 kg/year of minor actinides with a thermal output of 820 MW.

The transmutation strategy which has been chosen by JAERI is the so called “double strata” scenario which include burning of Pu as MOX in light water reactors and transmutation of the minor actinides and possibly also the long lived fission products by ADS.

1.2.4 Korea

Korea has a very ambitious program in ADS, which reflects the lack of decision about a nuclear waste disposal program. This waste disposal program can shortly be labelled “Wait and See”. Korea has 16 reactors 12 PWRs and 4 CANDUs with a generation capacity of 13.7 GW_{el} covering 42 % of national electricity production. Spent fuel accumulation reaches 3 400 tons (1900 tons PWR and 1500 ton CANDU waste). All PWR spent fuel is stored in pools at the reactor sites, while CANDU spent fuel is stored both in pools and silos in a special site at Wolsong.

ADS research is concentrated at Korean Atomic Energy Research Institute (KAERI) having a broad research collaboration with universities and utility research institutes. The ADS program combines two major research projects: KOMAK and HYPER. KOMAC stands for KOrean Multipurpose Accelerator. The KOMAC is a multi-purpose superconducting, linear accelerator system when it is completed. It would deliver a proton beam of 10 to 20 MW-power to the ADS area as well as much lower power beams to particle-nuclear physics and medical science areas. The KOMAC accelerator is already under construction and a major part of the accelerator (260MeV, 20 mA) is scheduled to be ready by 2007. The final parameters of the accelerator are 1 GeV of proton energy and a current of 20 mA. HYPER stands for Hybrid Power Extraction Reactor.

The designing goals for HYPER are:

- maximise transmutation capability
- achieve economical competitiveness
- implement inherent safety features
- adopt a proper separation technology minimizing separation and maximising proliferation resistance

A targeted HYPER system configuration:

- Fast neutron system with Pb/Bi cooling
- Fertile-free TRU-Zr alloy fuel
- Pb/Bi spallation target integrated with cooling system
- Subcriticality level of 0.97
- Transmutation of ^{99}Tc and ^{129}I. using leaking neutrons and special thermalising fuel assemblies with Tc: CaH_2 and I: CaH_2
- Power of 1000 MW_{th} with 40% efficiency
- KOMAK beam power of about 6 MW (6 mA at 1 GeV)

An interesting and specific feature of KAERI ADS design is a continuous reloading of the fuel assemblies (1-2 assemblies/day) in order to compensate a reactivity decrease due to burnup of TRU-fuel.

1.2.5 China

China, which has an increasing number of nuclear power plants, has recognized ADS as a viable option of nuclear waste policy. Preliminary studies have been started at CIAE (China Institute of Atomic Energy), IHEP (Institute of High Energy Physics) and Peking University.

R&D studies of ADS are divided into 2 phases: the first one being a long-term program (about 10 years) to make feasibility studies of ADS and then a second phase of demonstration facility (5 to 10 years). The first phase is focused on a modest, small size accelerator facility of 150-200 MeV proton energy and 3-5 mA beam current to drive a light-water swimming-pool subcritical reactor

1.3 Non-Proliferation Aspects of ATW

In addition to technical, economical and radiation aspects of accelerator-driven systems, the fourth crucial issue is that of the proliferation risk. Different aspects of this risk were presented in the report of Phase 1 of the present project. The main objectives can be summarised as follows.

The proliferation risk presents in fact three distinct issues of opposite nature. One concerns the application of ADS for incineration of the plutonium in spent nuclear fuel which, if not burned, can be used to make “crude” nuclear bombs (Carson 1993). Another concern is the use of heavy water or lithium (enriched ^{6}Li) salts which leads to a possible production of large amounts of tritium (another nuclear weapons ingredient) in a short time. The third concerns the features, which are introduced into the ADS plant design in order to make the very system itself as proliferation resistant as possible what concern breeding of strategic actinide nuclear materials.

The spent fuel, produced by over 400 light water reactors in more than 30 countries, amounts to about 100,000 tons consisting mainly of uranium but contains also about 1,000 tons of fissile plutonium. It also contains radioactive fission products, some of them very long-lived, which are important as “poison” against proliferation as long as the plutonium remains mixed with them and is not chemically separated. If separation is carried out, less than 10 kg of civilian plutonium is sufficient material for a “crude” bomb capable of an explosion yield equivalent to 20-30 % of the Hiroshima bomb. Thus, the current world stockpile of spent fuel contains latent material for over 100,000 nuclear bombs. Furthermore, the amount of weapon-grade plutonium from dismantled nuclear weapons is about 200 tons of which half is in USA and half in Russia.

Most of the world’s spent fuel is being kept in temporary storage awaiting storage in deep repositories. An international panel selected by the American Nuclear Society recommended that the reactor plutonium should be burned i.e. with reprocessing and MOX. They also recommended that improvements should be made to reduce the proliferation risk in reprocessing by making sure that the plutonium is at no time “naked”, i.e. in its pure state, unmixed with highly radioactive products. This would make theft improbable.

The other concern about non-proliferation aspects of ADT plants is to make them intrinsically proliferation resistant, i.e. to prevent the production of bomb material, either plutonium or ^{233}U. However, with IAEA control and e.g. satellite surveillance in combination, an efficient control safeguard system can be achieved. The control is necessary as long as the accelerator is used and would cease when the machine is scrapped and the small amounts of residual radioactive materials are taken care of. A permanent repository has to be controlled for an indefinite time, which of course is practically impossible.

2 International Scientific and Technical Center (ISTC), Moscow and the Scientific and Technical Center of the Ukraine (STCU), Kiev

2.1 Introduction

A large number of technical and scientific experts on nuclear weapons were working at classified nuclear weapon laboratories in the USSR. Most of these experts have got severe economical and social problems as a result of drastically reduced governmental funding of the weapon laboratories following the break-up of the Soviet Union. Under such circumstances it is an obvious risk of proliferation of the nuclear weapon know-how by emigration of former USSR technical and scientific experts to countries which could be aiming towards the development of nuclear weapons.

To counteract this risk USA, EU and Japan decided to finance an international scientific and technical centre (ISTC) in Moscow. The objective of the centre is to financially support research projects of civilian interest, which will occupy the nuclear weapon experts in the Russian Federation, and the following former republics of the USSR Armenia, Belarus, Georgia, Kazakstan and the Kyrgyz Republic.

The initial funding of ISTC starting 1994 was MUS$ 25, 17 and 25 from USA, EU and Japan, respectively. Countries outside this tripartite were also asked to support the ISTC. Sweden decided to join the effort with MUS$ 4. Since 1996 the Swedish support to ISTC is through EU. At present, the Republic of Korea and Norway are supporting ISTC besides the original contributors.

The ISTC project proposals are sent by the laboratories to the Russian authorities (MINATOM) for acceptance according to Russian regulations. If accepted, the proposals are forwarded to the board of ISTC for approval. The proposals are classified by each party in the Center according to scientific merits and the fulfilment of the objectives of ISTC.

An international expert group (CEG) was appointed in 1997 to screen the scientific merits of the projects dealing with research related to accelerator driven transmutation systems. About MUS$ 1 per year is anticipated as the budget frame for this category of projects and the maximum cost for a single project is limited to kUS$ 600. CEG has 12 members, 4 representing EU (one of whom is W. Gudowski, KTH), 4 USA, 2 Japan, 1 Norway and 1 the Republic of Korea.

Finally, the ISTC board approves and decides about the financial support. Each party has the right to decide about the use of its funding to ISTC but has also the possibility to veto support from the other parties for any good reasons.

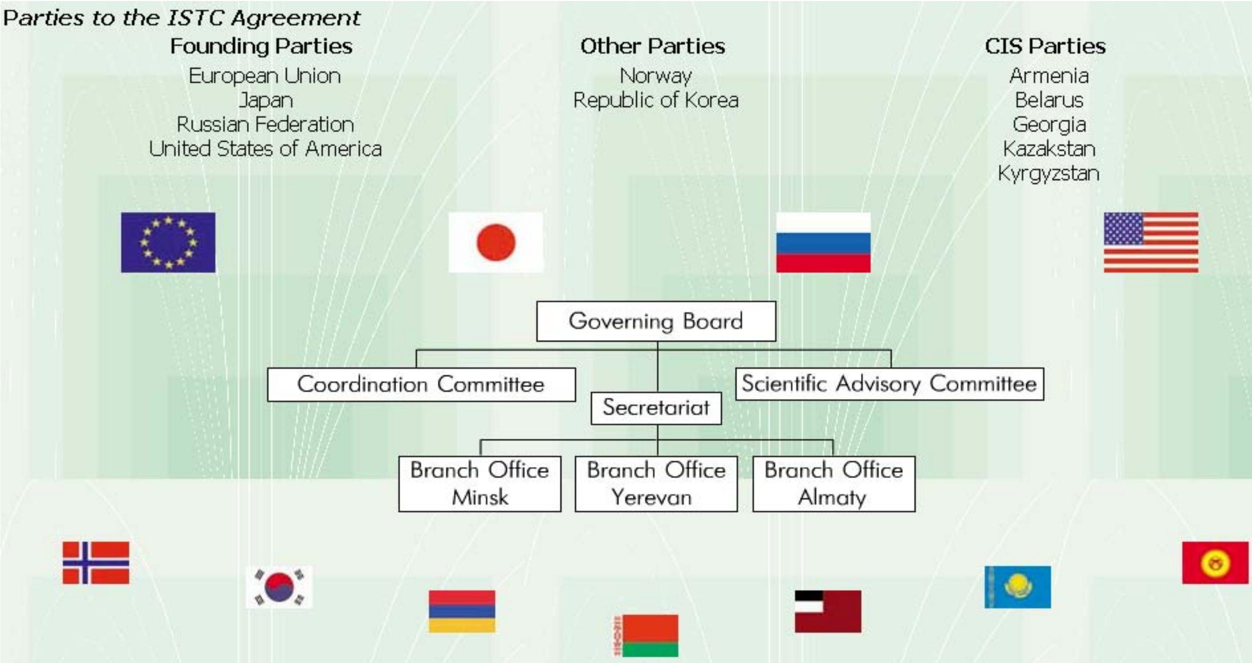

Figure A2: Organisation chart of ISTC.

The USA, Japan, Canada and Sweden also financed the organisation of a scientific and technical center (STCU) in Kiev on the same objectives and with a similar organisation and project handling as for the Moscow center. Recently, the EU has decided to support STCU and consequently Swedens national support is nowadays channeled through EU.

2.2 Background to – and Present Status of – the Swedish Activities in Planning of ATW Research at Russian Laboratories with Support from ISTC

At a Symposium on "Deposition of Nuclear Weapon Grade Plutonium" in 1990 a research group from the Los Alamos National Laboratory (LANL) presented a new concept of accelerator driven transmutation techniques to incinerate and transmute reactor- and weapon grade plutonium. This presentation was the starting point for a discussion on international research cooperation on ATW. On the request from the LANL group Dr C Mileikowsky took the responsibility to arrange an international workshop on "Accelerator Based Radioactive Waste Transmutation" in Sweden. The Workshop was held at Saltsjöbaden in July 1991 with participation of experts mainly from USA, Russia and Sweden.

One suggestion, as a result of the discussions, was to occupy former Russian nuclear weapon experts to do research on incineration of weapon grade plutonium and reactor waste transmutation financed by ISTC grants. The frame for the collaboration was discussed between the experts at the appropriate laboratories in each country. Informations of the discussions were also given to the Swedish Ministry of Foreign Affairs and the Ministry of Enviromental and Natural Resources as well as to the Nuclear Power Inspectorate (SKI).

An informal group of Swedish experts, who had taken part in the discussions with the Swedish Authoroties, started discussions with Russian laboratories concerning ISTC financed research projects on ATW in particular on the burning of weapons plutonium. The group kept a close correspondance with the LANL group and later on also with the group at CERN under Prof. Carlo Rubbia.

The first contacts with Russian institutes about ATW research from the Swedish side were established during 1993 with the Institute of Nuclear Research (INR), Troitsk, 70 km south of Moscow. The negotiations were directed to the use of the Troitsk linear accelerator to perform demonstration experiments showing the feasibility of the accelerator-driven plutonium incineration. It was soon realized that the integral demonstration experiment was not to be performed in Russia within the financial frame of ISTC. Thus, the attention was focused on experiments, which would have an important, if not decisive, impact on the future of ATW research.

An international conference on Accelerator-Driven Transmutation Technologies and Applications (ADTT96) was arranged by the expert group in Kalmar, Sweden in June 1996 as the second international conference in a serie of conferences on ADS which one has internationally decided among the experts to regularly arrange. About 60 Russian experts joined the Kalmar Conference and presented the on-going and planned ISTC-projects on ATW research. The first conference in the serie was arranged by LANL, USA and was held in Las Vegas, USA in 1994 (ADTT94). The third conference (ADTTA'99) in same serie was held in June 1999 at Pruhonice, Czech Republic.

In 1996, the Swedish expert group got a financial support from the Swedish Nuclear Power Inspectorate (SKI) through a project with the title “Planning and Reporting of Russian Transmutation Research Projects within ISTC”. The support was given to cover mostly traveling expenditures which had been called for in fulfilling the task aiming to initiate and report ISTC and STCU projects at former Soviet Union Nuclear Weapons Laboratories on R&D for transmutation of nuclear reactor waste and weapons plutonium. The SKI project was devided in 3 consecutive one-year long sub-projects. The first sub-project (Phase 1) lasted from April to December 1996, Phase 2 from September 1997 to October 1998 and Phase 3 from February 1999 to February 2000. The phases 1 and 2 of the project have been reported to SKI in February 1997 (SKI Report 97:15) and in November 1998 (SKI Report 99:5). The present report focuses on results of Phase 3 of the project.

2.3 ISTC Projects on ATW

The number of applications sent to ISTC for transmutation research from different Russian Laboratories is about 60. About 20 of these applications have been funded up-to-date.

The Swedish expert group has chosen to initiate projects, which are dealing with different fundamental technical issues of the ADS concepts. The possibility of finding a Swedish research group as a counterpart to the Russian group has also played a role in the expert group selection of projects.

So far, four of the projects have been approved by ISTC, one is given a development grant and two others are in the ISTC "pipe-line". Short statements are given below about the status of each of those projects.

2.3.1 Projects in progress

Measurements of Neutron Induced Fission Cross Sections in the Energy Region 20<En<160 MeV for basic and Applied Research (ISTC projekt # 540)

Project leader:	Vilen P. Eismont, V.G. Khlopin Radium Institute (KRI), S:t Petersburg
Status:	Approved by ISTC in 1996, duration 30 months
Financing grants in US$:	90 000 Sweden, 60 000 EU
Participation of scientists formerly connected with weapons development and production:	134 man-months

The measurements have been performed at the The Svedberg Laboratory, Uppsala in collaboration with the Department of Neutron Research at the Uppsala University. The project covers measurements of fission excitation functions for nuclei with mass number 200-240 in the intermediate energy range and comparison with theoretical models for fission cross section calculations. Results have been obtained of neutron fission cross sections for Au, Pb-isotopes, Bi, Th, U-isotopes, ^{237}Np, ^{239}Pu and Am-isotopes. The experimental arrangements include different types of detectors developed at KRI such as fast ionization chambers, thin film break downcounters, and double Frisch-grid ionization chambers.

Preliminary results have been presented at international conferences and workshops and for Pb and Bi in a paper to Phys Rev C. A final report is underway.

Measurements and comparison of proton- and neutron-induced fission cross-sections of Lead and neighbouring nuclei in the 20-200 MeV energy region (ISTC project #1309).

Project leader: Vilen P. Eismont, V.G. Khlopin Radium Institute, S:t Petersburg

Status: Approved by ISTC in 1999, duration 36 months

Financing grants in US$: 240 000 EU

Participation of scientists formerly connected with weapons development and production: 228 man-months

The project is a follow-up of ISTC project #540. It will focus on an observed difference, which is not theoretically predicted, between the proton- and neutron-induced fission cross sections for isotopes in the lead region. The experiments will be made at the The Svedberg Laboratory and in collaboration with the Department of Neutron Research, Uppsala University.

The new project (#1309) has been scientifically screened and given running time at the The Svedberg Laboratory by the International Program Advisory Committee of that laboratory.

Pilot flow lead-bismuth target of 1 MWth for accelerator-based systems (ISTC project # 559)

Project leader: Prof Boris F Gromov, Deputy Director of Russian Federation State Scientific Centre – Institute of Physics and Power Engineering (IPPE)

Status: Approved by ISTC in 1996, duration 30 months

Financing grants in US$: 500 000 USA, 250 000 Sweden, 250 000 EU

Participation of scientists formerly connected with weapons development and production: 925 man-months

The expert group took the initiative to this project, which also became strongly supported by USA and EU.

The purpose of the project is to develop a heavy metal flow target, which possesses the best features for producing neutrons at a high power proton accelerator. Thus, the technical key problems of a molten lead-bismuth 20 MWth-power target are being investigated. Such a technical base will, as far as it is technical possible, be established by the design of a pilot lead-bismuth 1 MWth-power target. It is decided that the pilot target will be tested at the LANL linear proton accelerator (800 MeV, 1.5 mA proton beam) at LANSCE.

The project benefits from the broad experience of specialists at IPPE and Research and Development Bureau (RDB) "Gidropress", whose experience was developed by designing and operating the Russian nuclear submarines with lead-bismuth cooled reactors. The target design is a result of a close cooperation primarily between IPPE and LANL but has also been discussed at several technical meetings with the participation from LANL – USA, CEA/Cadarache – France (representing EU), the expert group – Sweden (Swedish collaborator: the Department of Neutron and Reactor Physics, KTH, Stockholm) and IPPE and Gidropress – Russia.

The design phase will close in July 2000. A meeting was held in Cadarache on November 25, 1999 The status of the project was discussed and in particular the export problems of the target. A group was appointed, with W. Gudowski, KTH as Chairman, to advice the involved bodies and inform their respective "home teams" (authorities) on the different steps in the transfer, setting up, testing and experimental phases. It was decided to invite one representative each from EU and DOE ISTC offices to join the advisory group. The first meeting of this group will be held at DOE, Washington DC on March 27-28, 2000. A follow-up project to cover the installation and experimental phase of the spallation source is planned.

Experimental Research of Transmutation of Fission Products and Minor Actinides in a Subcritical System Driven by a Neutron Generator (ISTC project B-70, Belarus)

Project leader:	S. E. Chigrinov, Radiation Physics & Chemistry Problems Institute, Minsk-Sosny 220109
Status:	Approved by ISTC in 1999, duration 36 months
Financing grants in US$:	295 000 EU
Participation of scientists formerly connected with weapons development and production:	660 man-months

The project aims to experimentally determine the transmutation rates for a number of long-lived fission products (Sr-90, Zr-93, Tc-99, Sn-126, I-129, Cs-135, Cs-137 etc) and minor actinides (Np-237, Am-241, Am-243) in different neutron fields (thermal, resonance and fast neutrons). The irradiation of the fission products and the actinides is made in an undercritical reactor-configuration driven by a 14 MeV neutron source. The results will be compared with calculated data using well-known codes (MCNP and SYNTES-Q).

Collaborative western institutes are Los Alamos National Laboratory, USA and KTH, Stockholm.

2.3.2 Projects in the ISTC "Pipe-Line"

Molten Salt Technology, (ISTC project #1606)

Project leader:	Dr K. Grebyonkin, Russian Federal Nuclear Center, VNIITF (Chelyabinsk-70), Institute of Technical Physics, P.O. Box 245, 456770 Snezhinsk, Chelyabinsk Region
Status:	A project development grant (50 kUS$) is approved by ISTC, duration 9 months.
Financing grants in US$:	600 000 EU
Participation of scientists formerly connected with weapons development and production:	1500 man-months
Project duration:	30 months

The molten salt ADS concepts are less efficient for transmutation of the higher actindes (americium and curium) compared to molten lead or lead/bismuth concepts with a harder neutron spectrum. Thus, the present studies in USA and in Europe are mainly focused on the latter systems. However, the expert group believes that more information on the molten salt technology is needed and for that reason supports the ISTC project #1606.

The objective of the project is to construct and operate a realistic demonstration experiment to develop and test hardware and techniques to be used in the molten salt enviroment.

A facility will be constructed able to handle 100-200 kg of molten salt. The detailed design of a large-scale MS loop (up to 5 tons of molten salt) will also be developed. The constructed facility will include a heated reservoir, pumps, valves, circulation loop, experimental volumes, diagnostics, and a heat exchanger. The operating temperature will be between 500 and 700 °C. Salt preparation and melting procedures would be established. Salt mixing, heating, melting, circulation, drainage and sample removal will be demonstrated in a non-radioactive enviroment.

The following experimental tasks are envisioned:

- Molten salt corrosion tests
- Study of effects of contaminants and fission products on materials
- Diagnostics (flow and pressure detectors and thermocouples)
- Natural convection studies
- Design of hardware for use in high temperature molten salt enviroment.

The project #1606 has been awarded a development grant of 50 kUS$. The ISTC technical committe has recommended #1606 to be the main molten salt project comprising the earlier proposed ISTC projects #628, 698, 730 and 747 (see the report of Phase 2 of this project).

The Department of Nuclear Chemistry, Chalmers University of Technology is the Swedish collaborator of project #1606.

Feasibility study of accelerator-driven system with lead-bismuth coolant for transmutation of LWR spent fuel, (ISTC project)

Project leaders:	A. Dedoul, E. Yefimov, State Scientific Centre of Russian Federation Institute of Physics and Power Engineering (IPPE), I Bondarenko sq., Obninsk, Kaluga Region, Russia 249020
Status:	Screening in progress by MINATOM
Project duration:	30 months
Project cost:	US$ 500 000

The purpose of the project is to determine the main engineering characteristics of a full-scale subcritical system with lead-bismuth coolant for transmutation of LWR once through spent fuel. The main characteristics of the plant for fuel reprocessing will also be determined and a list of key problems and R&D efforts that should be carried out on possibly further development phases will be formulated. The project is presently being screened by MINATOM, Russia.

Participating institutions besides IPPE are the Research and Development Bureau "Gidropress", Podolsk and the Research Institute of Atomic Reactors, Dimitrograd.

Comparative analysis of the safety characteristics of a lead cooled critical reactor and a lead cooled sub-critical blanket during transmutation of long-lived actinides (ISTC project # 71.2)

Project leader:	Alexander Lopatkin, State Unitary Enterprise of Research and Development Institute of Power Engineering (SUE of RDIPE)
Status:	Recommended by CEG, screening in progress by MINATOM
Work duration:	300 man-hours
Project duration:	30 months

The concept of heavy metal (lead)-cooled fast power reactors BREST with nitride fuel has been developed by a group of Russian institutes lead by RDIPE. A broad range of experimental investigations of physical characteristics and technology of this reactor has been carried out. The development of lead-cooled reactors is based on Russian extensive experience in fast reactors and ship reactors with heavy metal (HM) cooling. Earlier research including substantiation of the HM technology, engineering developments, study of physical properties etc. show that broad-scale production of nuclear power can be based on BREST type reactors, meeting the requirements of:

- Deterministic safety of the BREST reactors with respect to severe accidents
- Maintaining the natural radiation balance in handling radioactive waste
- Non-proliferation of plutonium.

Preliminary estimates show that the lead-cooled reactor may be used not only for power production but also as burner of long-lived actinides. However, such a reorientation may lead to a considerable change of the neutronic characteristics – power distribution and reactivity effects determining nuclear safety. These effects will be studied and the amount of actinides allowed in the core will be substantiated.

A sub-critical blanket driven by an accelerated proton beam will be studied as an actinide burner in comparison with the critical BREST reactor using the already developed know-how concerning heavy metal technology and principles of reactor designs. The basic technical characteristics of the blanket (power density, temperature conditions, fuel type etc.) may be assumed the same as in the reactor to maintain the technological identity.

Two lines of actinide burning are being proposed for consideration. The design and physical essence of the process of transmutation will be very different depending on the chosen line:

- Transmutation of plutonium, neptunium, americium and curium

- Transmutation of neptunium, americium and curium (minor actinides).

2.3.3 Projects under discussion

Sub-Critical Assembly Dubna (SAD), Laboratory of Nuclear Problems (LNP) and The Energy and Transmutation Project, Joint Institute of Nuclear Research (JINR), Dubna

The aim of the first project is to study the coupling between a spallation target and a subcritical assembly. The experimental part of the project will be made at the 660 MeV phasotron of LNP with a proton beam of 1-2 microampere on targets of different materials (e.g. Pb-Bi). Different fuels of the subcritical assembly will be used (e.g. MOX). The aim of the second project is to study transmutation of transuranic samples by spallation neutrons produced by GeV protons from the new superconducting synchrophasatron at JINR.

The projects were discussed at a meeting in Dubna, July 31 - August 3, 1999.

3. General comments to ISTC supported ATW projects

The ATW research in USA and Europe is focused on solid fuel and molten lead or lead/bismuth accelerator driven systems. Thus, a recommendation from the International Technical Committee (CEG) is forwarded to the Russian laboratories to prepare and send in applications for ISTC projects on this type of systems.

In concord with this ambition from the Technical committee a monograph is being written by V. Orlov, ENTEK, about the Russian techniques with molten lead/bismuth reactors and a seminar was arranged in October 1998 at Obninsk covering the same subject.

Like the International Technical Committee recommends the support of ADS research projects which deals with main problems for the ATW concepts of general interest in the Western Countries, the SKI Reference Group, in addition, strives for initiating research activities which gain knowledge of special needs, if any, for nuclear burnimg of the Swedish nuclear reactor waste.

In general, the research projects related to the development of the ATW techniques are fulfilling the aims of ISTC namely to engage the former nuclear weapons expert in civilian research, coordinating research at Russian Institutes with Institutes in the Western hemisphere and that the research should have industrial applications.

The supporting mechanisms have worked very well for both ISTC and STCU and there is a consensus among the supporting countries that the ISTC and STCU should remain well beyond year 2005.