

Unclassified

NEA/RWM/IGSC(2003)2

Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development

31-Jan-2003

English - Or. English

**NUCLEAR ENERGY AGENCY
RADIOACTIVE WASTE MANAGEMENT COMMITTEE**

Integration Group for the Safety Case (IGSC)

TOPICAL SESSION PROCEEDINGS OF THE 4TH IGSC MEETING ON:

**THE POTENTIAL IMPACTS ON REPOSITORY SAFETY FROM POTENTIAL PARTITIONING
AND TRANSMUTATION PROGRAMME**

Held on 6th November 2002 in Paris, France.

JT00138539

Document complet disponible sur OLIS dans son format d'origine
Complete document available on OLIS in its original format

**NEA/RWM/IGSC(2003)2
Unclassified**

English - Or. English

FOREWORD

Partitioning and Transmutation (P&T) is debated in many countries creating and possessing spent fuel and high level radioactive waste. Important projects are carried out by OECD/NEA countries, notably France, Japan and the USA. Within the Nuclear Fission Programme of the European Commission several projects are being supported. Agreement exists that P&T will not make geological disposal superfluous, for some waste streams P&T has the potential to reduce the volumes of high-level wastes and the time over which the wastes remain radiologically toxic.

In order to strengthen the interaction between the P&T and the RWM (Radioactive Waste Management) communities, at the 3rd plenary meeting of IGSC (Integration Group for the Safety Case) it was proposed to hold a Topical Session on “Potential Impacts of Partitioning and Transmutation on Long-term Waste Management and Disposal” at the next plenary meeting of the IGSC [see meeting minutes: NEA/RWM/IGSC(2001)8]. The proposal was given support by the RWMC.

The P&T Topical Session was organised into the framework of the 4th meeting of the IGSC. The Topical Session was held in Paris, France on 6 November 2002.

53 IGSC participants took part in the Topical Session. They represented several national waste management organisations, regulatory authorities, and research institutions from 16 OECD member countries, IAEA and EC. Two representatives of the P&T community were invited and took part. Two are part of the NEA’s Committee for Technical and Economic Studies on Nuclear Energy and Fuel Cycle known as Nuclear Development Committee (NDC) organisation. They took part in the NDC’s Phase 2 P&T systems study. Another invited P&T community guest presented the work performed in the Euratom Framework Programmes and co-sponsored by the European Commission. Their presence and presentations resulted in a useful dialogue between the P&T and disposal communities. The French, Japanese and US strategies for P&T were also presented, showing there is already some degree of coordination between the P&T and RWM communities within those nations.

It was emphasised that the Topical Session did not have the goal to present or discuss the technical details of potential future fuel cycles nor did it seek to elaborate on the details of geological disposal. The aim was to gain a balanced picture of the potential impact of future fuel cycles on geological disposal, on its pillars of safety in short and long-term performance, and to discuss in what directions future coordination-work could go.

The programme of the topical session had presentations addressing the following points:

- General aims of P&T.
- Present status of P&T and its projected impacts on inventories and geological disposal.
- Overview of EC activities and presentation of the new NEA/NDC studies.
- Main factors in recent safety evaluations of geological disposal and relevant open questions (in view of waste forms and inventories from P&T) such as potential impact on

performance assessment indicators, parameter values, and uncertainties. The adequacy of current performance assessment methods to address these potential P&T waste forms was also briefly discussed.

The presentations gave the necessary background for a discussion that was organised as a platform in order to provide IGSC messages on this topic that would then be delivered to the RWMC (Radioactive Waste Management Committee).

This report presents a synthesis of the various oral presentations and the discussions and exchanges during the Session as well as a compilation of the written contributions. It is intended to provide a state of the art overview of the different aspects of P&T strategies on repository long-term performance and safety.

ACKNOWLEDGEMENTS

The NEA would like to express its gratitude to:

- Jörg Hadermann (PSI, Switzerland) who chaired the Topical Session;
- Jürgen Wollrath (BfS, Germany) who co-chaired the Topical Session as a rapporteur;
- The speakers for their interesting and stimulating presentations as well as for their written contributions;
- The IGSC participants for their constructive participation.

These proceedings were prepared by Jürgen Wollrath with the collaboration of Sylvie Voinis (NEA secretariat) and reviewed by the speakers, Jörg Hadermann and Abe van Luik (Chairman of the IGSC).

TABLE OF CONTENTS

Agenda of the Topical Session	6
-------------------------------------	---

PART A SYNTHESIS

1. Introduction	13
2. Background	15
3. Summary of presentations	17
4. Discussion and Conclusions	21

PART B COMPILATION OF PAPERS / PRESENTATIONS

Plutonium Management, Minor Actinides Partitioning and Transmutation R & D in France

Jean-Marc CAVEDON and Charles COURTOIS (CEA, France)	25
--	----

Radioactive Wastes Generated From JAERI Partitioning – Transmutation Fuel Cycle

Shinichi NAKAYAMA, Yasuji MORITA and Kenji NISHIHARA (JAERI, Japan)	43
---	----

“ORIENT-Cycle” – An Evolutional Recycle Concept with Fast Reactor for Minimising High Level Waste

Naoyuki TAKAKI, Yoshihiko SHINODA, Masayuki WATANABE, Kazuo YOSHIDA (JNC, Japan)	51
--	----

Research and Development of Technologies for Partitioning and Transmutation of Long-lived Nuclides in Japan – Status and Evaluation

Sanae AOKI (STA, Japan)	53
-------------------------------	----

The U.S. Department of Energy’s Advanced Fuel Cycle Initiative is evaluating potential costs and benefits of partitioning and transmutation

Abe VAN LUIK (U.S. DOE, USA) 65

Radioactive waste partitioning and transmutation in the EURATOM framework programmes

Michel HUGON, Ved P. BHATNAGAR and Sylvie CASALTA, (EC) 75

Accelerator-driven systems (ADS) and fast reactors (FR) in advanced nuclear fuel cycles – a comparative study

Extract from OECD/NEA Publication ISBN 92-64-184882-1 87

List of Participants 97

AGENDA OF THE TOPICAL SESSION ON P&T

Extract of the NEA/RWM/IGSC(2002)10

Wednesday 6 November 2002**Introduction**

Chairman:	Jörg Hadermann,	PSI, Switzerland
-----------	-----------------	------------------

Part A: National Strategies

French strategies:	Jean-Marc Cavedon,	CEA, France
Japanese strategies:	Hideo Kimura	JAERI, Japan
	Hiroyuki Umeki	NUMO, Japan
US strategies:	Abe van Luik	U.S. DOE, USA

Part B: Technical Bases

EC projects:	Michel Hugon	EC
NEA/NDC project:	Peter Wydler	PSI, Switzerland

Round-up Discussion

Chairman:	Jörg Hadermann,	PSI, Switzerland
-----------	-----------------	------------------

Messages to be delivered

Rapporteur:	Jürgen Wollrath,	BfS, Germany
-------------	------------------	--------------

PART A

SYNTHESIS

1. INTRODUCTION

The bulk of radioactive waste results mainly from energy production in nuclear power plants. At present, this waste is safely stored near reactor sites, in dedicated storage facilities, and low-level wastes in some countries are disposed of in near surface disposal facilities. The stored wastes are accumulating, and the generally agreed-to solution is to dispose of vitrified waste or spent fuel in deep geological disposal facilities. The main concern in the disposal of radioactive waste is related to long-lived radionuclides – some of them will remain hazardous for tens of thousands of years and longer.

To demonstrate the safety of geological disposal of radioactive waste a safety case has to be developed for a specific concept of disposal at a given site. This safety case is a collection of arguments at a given stage of repository development in support of the long-term safety of the repository. The safety case comprises the findings of a safety assessment and a statement of confidence in these findings. The type of waste to be disposed of is an important component of the disposal concept.

At present, novel fuel cycles are under investigation at national and international levels including research in partitioning and transmutation (P&T) technologies. Comprehensive projects are carried out in OECD countries, notably France, Japan and the USA. Within the Nuclear Fission Safety programme the European Commission (EC) is supporting several projects and it is anticipated that the contribution of the EC will increase within the 6th Framework Programme¹. In addition the Nuclear Energy Agency has recently published a report comparing fuel cycles for accelerator driven systems and fast reactors (referenced in synopsis of NEA/NDC presentation, below). By using P&T it might be possible to reduce the long-lived component of the radioactive waste, thus easing the waste management problem. A safety case for a repository for wastes from P&T fuel cycles would be different from a safety case that deals with spent fuel and/or vitrified high-level waste.

Thus, a Topical Session that focused on the **“The potential impacts on repository safety from a potential P&T programme”** was organised in the framework of the 4th plenary meeting [NEA/RWM/IGSC(2002)10] of the IGSC (Integration Group for the Safety Case). This session was held in Paris, France on 6 November 2002. This Topical Session sought to create IGSC awareness regarding potential issues involving P&T, other potential fuel cycle changes, and a repository safety case. The Topical Session focused on the recent scientific developments in potential national P&T strategies, and on international research on P&T and the potential impacts of P&T deployment on repository long-term performance and safety.

53 participants represented several national waste management organisations, regulatory authorities, and research institutions from 16 OECD member countries, IAEA and EC.

1. Overview of the EU research projects on partitioning and transmutation of long-lived radionuclides. EC project report EUR 19614 EN, Brussels: EC, 2000, ISBN 92-894-0439-6.
Evaluation of possible partitioning and transmutation strategies and of means for implementing them. EC project report EUR 19128 EN, Brussels: EC, 2000, ISBN 92-828-3018-7.

The Topical Session was split in three parts:

- Part A was related to national P&T strategies (e.g. which radionuclide are affected by P&T; implication on step-wise decision-making, what are the changes in potential doses...)
- Part B consisted of EC and NEA/NDC presentations on the technical bases of P&T; (e.g. what is the resulting inventory of P&T, what is the schedule regarding developing and deploying P&T processes ?) and
- Based on background provided by the previous presentations, Part C was aimed at discussing the impact of P&T strategies on IGSC-related issues, and agreeing to key messages to be delivered to the RWMC.

The chairman of this Topical Session was Jörg Hadermann (PSI, Switzerland). The rapporteur was Jürgen Wollrath (BfS, Germany).

The current synthesis presented in part A of this document is aimed at briefly reflecting the material presented at the Topical Session and providing a short overview of the main outcomes of its discussions. The written contributions are compiled as-received without further elaboration, either as presentations or papers, in part B of the document. Part C gives the list of participants at this Topical Session.

2. BACKGROUND

The operation of nuclear fission reactors to produce electricity gives rise to radioactive waste as a by-product that contains a whole range of radionuclides from short-lived to long-lived. The radionuclides which are considered as a potential risk to future generations are mainly the long-lived actinides and fission products, thus requiring very long time periods to be considered for their geological disposal as they will remain hazardous for tens of thousands of years. P&T aims to reduce the inventories of these long-lived radionuclides in radioactive waste by transmuting them into radionuclides with a shorter half-life.

To achieve this goal, these long-lived radionuclides are to be transmuted by neutron irradiation in fission reactors or other facilities. Transmutation is possible only after reprocessing the spent fuel to separate the radionuclides intended for such treatment. Partitioning is the set of chemical processes necessary to separate from the high-level waste the long-lived radionuclides to be transmuted. This separation must be very selective to achieve an efficient transmutation of the long-lived radiotoxic elements. Long-lived radionuclides could be transmuted into stable or short-lived nuclides in dedicated burners [critical nuclear fast reactors (FR) and sub-critical accelerator-driven systems (ADS)]. However, this fuel-cycle management approach will be fully effective only if it is pursued consistently for many decades, perhaps a hundred years or more.

If successfully achieved, P&T will produce high-level waste with smaller inventories of radiotoxic nuclides than the current once-through fuel cycle. This has sometimes led to the over-enthusiastic assumption that P&T is an alternative to a geological repository. However, wastes will still have half-lives in the multiple hundred of years, meaning that geological isolation is still required, just not for the extremely long time periods currently necessary. Also, as the efficiency of P&T is not 100 %, also some radiotoxic actinides will remain in the waste, again making the use of a deep geological repository a prudent approach to assuring public safety. Additionally, the P&T processes produce additional radioactive waste which may not require geological disposal, but still has to be managed safely.

The IGSC learned that novel fuel cycles including P&T are under investigation at national and international levels, notably in the USA, in Japan, in France, and in the EC. These investigations have led to significant technological progress in the last decades. Nevertheless, the application of P&T on an industrial scale requires further efforts. Furthermore, this technology creates novel waste types influencing the waste disposal concepts developed so far for geological disposal of radioactive waste. As the safety case is specific for a specific disposal concept, which includes the waste type, and site, the P&T issue is clearly an NEA-level (both RWMC and NDC) concern. Therefore, the IGSC sought, through this Topical Session, to become aware of the technical issues potentially affecting the safety case.

It should be emphasised that the Topical Session did not have the goal to present or discuss the technical details of potential future fuel cycles nor those of geological disposal. The aim was to strengthen the awareness of the potential impact of future fuel cycles on geological disposal and on its pillars of safety in short- and long-term performance. Its theme was thus the interface between the P&T and waste management communities. The presentations gave the necessary background for a

discussion that was organised as a platform in order to provide messages to be delivered to the RWMC, including potential decisions on possible future work in this area. A need for a continued relationship between the two communities concerned seemed indicated.

3. SUMMARY OF PRESENTATIONS

Jörg Hadermann (PSI, Switzerland) opened the Topical Session by introducing the frame for the Session from the point of view of radioactive waste management. He reminded attendees that a safety case is specific for a specific concept of disposal at a given site for a repository and that the type of waste is an important component of the disposal concept. Because novel fuel cycles are under investigation at national and international levels and funding for research into P&T strategies is a reality, the potential impact of such strategies on radioactive waste management has to be considered. He pointed out considerable progress has been made over the past decades in the field of P&T. One of the aims of new nuclear energy systems (e.g. Generation IV) is to reduce waste toxicity and volumes. However, it is also recognised that the new systems and fuel cycles require a geological repository. Therefore, the aim of the Topical Session is to become aware of the technical issues of a P&T strategy that may affect a repository safety case.

Jean-Marc Cavedon (CEA, France) then presented the developments concerning Plutonium management and minor actinides P&T research and development in France. By the 1991 law on high-level long-lived radioactive waste a research programme was launched in the areas: (i) geological disposal, (ii) conditioning and long-term storage, and (iii) radiotoxicity reduction by P&T. The results of the work in these areas will be presented to the French Government and Parliament in 2006. The control of Plutonium stocks generated by the French PWRs is proposed to increase Plutonium consumption in reactors and minimise radioactive waste production, and requires the recycling of actinides, especially Plutonium. In the long term, CEA intends to develop a new technology based on gas cooled reactors and their associated fuel cycle, including multiple recycling of Plutonium. The advantages of this development consist in the optimisation of the use of natural resources and the concentration of Plutonium in limited quantities of fuel rods. If needed, the minor actinides could also be recycled. The planned CEA developments depend on new fuel types and will lead to novel waste types (light glasses) with a reduction of long-term radiotoxicity. Radiotoxicity reductions by a factor of 3 to 5 are expected for Plutonium recycling scenarios, and by up to a factor of a few hundreds for Plutonium and minor actinides recycling scenarios. This gain is nearly independent on the reactor type used, but needs about 100 years of application to become effective in terms of making a difference in the total waste inventory to be disposed of.

Hiroyuki Umeki (NUMO, Japan) and Hideo Kimura (JAERI, Japan) reported about the Japanese OMEGA (options making extra gains from actinides and fission products) project. This project is documented in an AEC progress report² and aims at the evaluation of three different P&T concepts, and the demonstration of their feasibility by performing engineering experiments. The emphasis of JNC's work under this project is on the development of a fast reactor technique to minimise high-level waste. The concept is based on the pure recovery of so-called necessary elements for new fuel production, and the rough removal of unnecessary elements leading to novel types of radioactive waste. This ORIENT (optimisation by removing impedimental elements) cycle³, which is based on the latter concept, produces about 1/10th the waste volume per unit energy, or 1/3rd the per

2. See the paper in the compilation list: S. Aoki (2001).

3. See the paper in the compilation list: N. Takaki, *et al.* (2002).

unit-energy fuel mass of high-level waste of the conventional cycle applied in Japan. The CRIEPI Pyro-Process Fuel Cycle consists of an effective coupling of current or future LWR and fast reactor cycles and aims at excellent economy, enhanced safety, proliferation resistance, and environment-friendliness. Two major waste streams are generated consisting of salt waste on the one hand and metal waste on the other. The JAERI research⁴ is based on a double strata fuel cycle in which the current Japanese reprocessing fuel cycle is the first layer and an accelerator-driven P&T system would be the second layer. JAERI has begun to identify the chemical composition and to quantify the amount of radioactively contaminated wastes that may be generated by each of the processes involved in the P&T cycle. The introduction of the P&T system into the current fuel cycle decreases both short- and long-term radioactivity of high-level waste, but it also produces various additional forms of lower-level radioactive waste. Long-lived radionuclides are added to the existing inventory of these wastes that are generated in the current fuel cycle. The chemical toxicity of some heavy metals contained in the waste may be of more concern than the radiological toxicity.

Abe van Luik (DOE, USA) stated that the U.S. Department of Energy is interested in P&T to the extent that transmutation is technically feasible and will reduce the toxicity of the waste to a point that makes it technically and economically justified. Therefore, research on P&T strategies incorporates the evaluation of its potential costs and benefits. A progress report to Congress (in preparation) will likely state that system studies in the USA and in Europe indicate a preference for reactor based transmutation rather than accelerator-driven systems. DOE proposes isolation of Cs and Sr, the recycling of Pu and Np in LWRs, and later the recycling of minor actinides in fast reactors. The report identifies the high-level waste volume reduction, the easier management of short-term heat load, the reduction of long-term heat load and radiotoxicity, and therefore long-term dose reduction as potential benefits. The goal of ongoing work is to quantify these benefits in order to allow an assessment of which alternatives can be economically useful in increasing the repository capacity, reducing the potential hazard from the repository and reducing uncertainties associated with the performance of the repository. This may, depending on the national nuclear power scenario, delay or avoid the need for a second repository for high-level waste in the USA. Furthermore DOE has received and is evaluating a proposal for simulation-based engineering to integrate all aspects of nuclear energy including reactor technology and waste disposal.

Representing the EC, Michel Hugon gave an overview of the research activities on P&T carried out during the EURATOM 5th Framework Programme lasting from 1998 to 2002. The aim of the research work on P&T is to provide a basis for evaluating the practicability of P&T on an industrial scale for reducing the amount of long-lived radionuclides to be disposed of. The research projects are grouped in five clusters co-ordinated by the ADOPT (ADvanced Options for P&T) network: (i) hydrometallurgical and pyrochemical partitioning processes, (ii) basic studies on transmutation (nuclear data and neutronics), (iii) technological support for transmutation, (iv) fuel for transmutation and (v) preliminary design for an accelerator driven system (ADS). The transmutation part of the programme is focused on ADS development although many topics investigated are useful for critical burners also. The results of the 5th Framework Programme projects will be presented in an International Workshop on P&T and ADS Development to be held in Mol, Belgium 6-8 October 2003. The 6th Framework Programme (2002-2006) and its specific programmes have been adopted by the European Council and Parliament in 2002. The objective of the research in the P&T sub-area is to determine practical ways of reducing the amount and/or hazard of the long-term component of the radioactive waste to be disposed of in geological repositories by P&T and to evaluate their practicability on an industrial scale. One of the research area of this programme will be a fundamental assessment of the overall concept of P&T and in particular its impact on waste management and geological disposal.

4. See the paper in the compilation list: S. Nakayama *et al.* (2001).

Peter Wydler presented the results of the “second phase” P&T study performed by an expert group of the NEA’s Committee for Technical and Economic Studies on Nuclear Energy Fuel Cycle known as Nuclear Development Committee (NDC)⁵. The study complements an earlier (first phase) study, carried out from 1996 to 1998, which reviewed progress in the P&T area with emphasis on partitioning technologies, actinide and fission product transmutation in dedicated reactor systems, and benefits for waste management. During the second phase (1999-2002) the roles of the ADS and the FR in P&T strategies have been clarified. The sustainability characteristics of transmutation strategies as well as the development status of the ADS with respect to reactor and fuel cycle technology, safety, and R&D needs have been assessed. The study came to the general conclusions that:

- (i) P&T must be considered as a long-term endeavour because it will be an important element of a future sustainable nuclear energy system and directly influence the choices of new technologies;
- (ii) P&T addresses primarily the radiotoxicity of the high-level waste and the benefit for waste management requires further investigation, especially regarding the new waste forms arising from the pyro-reprocessing;
- (iii) a considerable amount of R&D will be needed before the new reactor and fuel cycle technologies could be deployed and;
- (iv) due to long time constants for the introduction and phase-out of the technology, the full potential of a transmutation system can be exploited only if the system is utilised for at least hundred years.

Reprocessing strategies, with or without P&T, generally reduce the mass of the high-level waste compared with the once-through strategy. Additionally, P&T allows to practically eliminate all radiotoxic actinides from the high-level waste. Due to the high decay heat of dedicated transmutation fuels, P&T requires pyrochemical reprocessing models. These, generates new waste forms for which a sufficient understanding under repository conditions has not yet been developed.

5. Accelerator-driven systems (ADS) and fast reactors (FR) in advanced nuclear fuel cycles - a comparative study. Paris: OECD/NEA, 2002, ISBN 92-64-18482-1.

4. DISCUSSION AND CONCLUSIONS

The Topical Session on the **“The potential impacts on repository safety from a potential P&T programme”** gave a rough overview of the technical issues concerning P&T strategies and their influence on radioactive waste management. The implications of P&T on radioactive waste management are diverse and the Topical Session could not tackle all perspectives. Nevertheless, it brought together a number of important issues from the viewpoint of radioactive waste management.

Each presentation was followed by a discussion. Discussions tended to cover many topics such as research needs and schedules and potential obstacles to P&T deployment. These were of interest to allow the IGSC participants to place what they learnt into a time perspective. Some of the discussion was directly focused on the need for a working interface between the two communities, of course. That discussion was captured and made into a list of items the IGSC wished to communicate to the RWMC. The list is a summary of discussions as well as a communications tool:

- P&T will not eliminate the need for geological disposal of radioactive waste but has the potential to reduce volume, radiotoxicity and long-term heat production of the highest activity waste.

The P&T technology reduces the initial radioactivity of high-level waste through its separation process and reduces the amount of long-lived minor actinides contained in the high-level waste through its transmutation process. To achieve a radiotoxicity reduction of the high-level waste by a factor of 100 the ambitious goal for 99,9 % recovery of all actinides has to be set.

This reduction of the waste volume may lead to a better use of a repository site. However, the comparison of the amount of waste generated by different fuel cycle options per unit of energy produced does not take into account that P&T strategies may increase the overall nuclear programme considerably.

- P&T shows potential only if nuclear energy production is continued beyond the middle of this century and a commitment to reprocessing of spent nuclear fuel is made.

P&T strategies make only slightly better use of the mined Uranium and therefore may lead to a more sustainable energy production in other respects. Due to the long time constants for the introduction and phase-out of this technology, its full potential can be exploited only if it is utilised for at least a hundred years. P&T must be considered therefore as a long-term endeavour.

- Design studies and small-scale experiments have led to progress in P&T. The Topical Session could give only a rough overview. For example, the potential increase, and the radiological consequences, of new LLW and ILW streams have not been specifically addressed.

Besides the reduction of the initial radioactivity of high-level waste, the P&T technology produces various types of low-level waste through its physical and chemical processes. This applies especially to the pyrochemical reprocessing methods, which generate new waste forms for which a sufficient understanding of their behaviour under repository conditions has not yet been developed.

- From the IGSC point of view, on the one hand no showstoppers for the new reactor concepts appeared even if there is not sufficient information on new waste types, on their characterisation, and especially on their long-term behaviour and in-situ performance. Therefore, characterisation programmes should be started in due time as necessary.

On the other hand, from the IGSC point of view the development of P&T strategies is no argument to delay repository developments because repositories are needed also for waste that exists to-day and that will be generated until the possible deployment of this new technology.

- Few, if any, full system studies have been performed to get the larger potential impacts picture including costs. From the IGSC point of view it is necessary to perform comprehensive systems studies and not to restrict the considerations to inventories and heat production of the highest activity waste. If a society is to understand the implications of introducing this technology in the future, it must also be informed by studies of all aspects of the endeavour important to society, such as cost, land and resource commitment, and worker and public safety.

There is the need for a comparison of risk for the different components associated with a nuclear energy strategy that includes P&T versus the current no-P&T strategy. In terms of the repository, for example, P&T strategies may reduce the potential dose in the far future, but may increase the risk of doses to workers.

- Suggested interaction between RWMC and NDC is highly recommended, especially on the last two points.

PART B

**COMPILATION
OF
PAPERS / PRESENTATIONS**



Plutonium management, minor actinides partitioning and transmutation R and D in France

Nuclear Energy Division, CEA
Waste Management Research Program Direction


Jean-Marc Cavedon, Charles Courtois

Presentation lay out



- **Introduction**
- **Plutonium management**
 - The french plutonium strategy
 - Pu inventory ; scenarios and cycle performances
- **High Level Long Lived Waste management**
 - Partitioning
 - Transmutation
- **Conclusion**

Introduction (1)



Multiple recycling of plutonium in PWR for minimising long-lived radioactive waste and proliferation risks

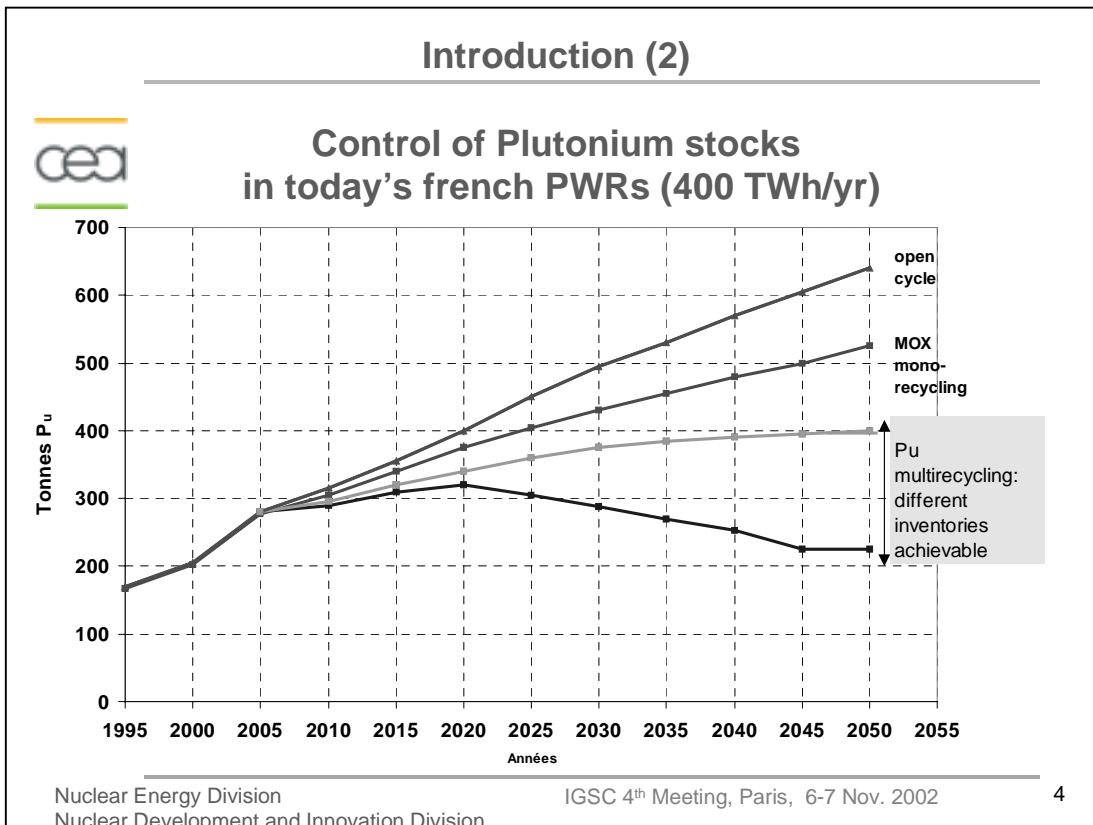
Two main objectives :

Control of plutonium stocks generated by operating french PWRs

- ✓ Pu consumption and waste minimisation

➔ Recycling of actinides (Plutonium, Minor Actinides)

Nuclear Energy Division IGSC 4th Meeting, Paris, 6-7 Nov. 2002 3
 Nuclear Development and Innovation Division



Introduction (3)



The R&D needs for multiple recycling of plutonium in PWRs :

→ Development of fuels

- at acceptable economic conditions
- with the possibility of simultaneous recycling of Minor Actinides

→ Advanced fuels and appropriate fuel fabrication and reprocessing technologies

Introduction (4)



1991 : A french law on HLLL* radioactive waste

- The rights of future generations are recognised
- A 15 years moratorium on any geological disposal until a new law is issued
- A research programme is launched :
 - Geological disposal
 - Conditioning and long term storage
 - Radiotoxicity reduction by Partitioning and Transmutation
- Public consultation must be implemented

* High level long lived

The French plutonium strategy (1)



- Initially, plutonium extracted from irradiated fuel in PWR was meant for LMFBRs.

A fast neutron spectrum was and still is, indeed, the most efficient option for:

- Economics of neutrons
- Use of natural resources
- Reduce the quantity of actinides in final waste

The French plutonium strategy (4)



- In the long term, to achieve a sustainable energy development

- Safe
- Competitive
- Non proliferating
- Making best use of natural resources
- And minimizing the ultimate waste

(mass, volume, decay heat and radio toxicity as a function of time)

- CEA is developing a new technological range based on gas cooled reactors and the associated fuel cycle

The French plutonium strategy (5)



- The main periods:
 - Before 1975: the “heroic” period
 - 1975 – 1985: toward an industrial recycling
 - 1985 – 2000: confirming the first options
 - 2000 – 2015: improving the single recycling
 - After 2015: toward a multi recycling
CORAIL
 - After 2025: improving plutonium cycle
APA


Conclusion on Pu management


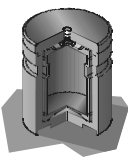



- Pu multirecycling in PWR with advanced fuels has multiple advantages
 - Optimisation of use of natural resources and energy extracted
 - Control of Plutonium inventory
 - Almost no Plutonium out of cycle
 - Concentration of Plutonium in a limited quantities of fuel rods (APA)
- The CEA, in very close cooperation with the concerned industries (Framatome-ANP, EdF, COGEMA), is carrying out active R & D to improve cycle management performances through
 - continuation of existing technologies (**CORAIL**)
 - the use of more innovative solutions (**APA**)
- Isotopic degradation of Plutonium – and increased production of MA – due to multirecycling limit risks of proliferation
- If needed, MA could also be recycled in PWR as well as Pu, in order to minimise radiotoxicity impact and also proliferation risk

High Level Long Lived Waste management (1)

Existing radioactive waste in France




<p>Short-lived low and medium activity ~ 1 million m³</p> <p style="text-align: right; font-size: small;">For the current nuclear power plant park</p> <p>~ 90 % of the total volume of waste produced in France, <1% of the radioactivity.</p> <p style="text-align: center;">Are subject to final disposal under current regulations</p>	
<p>Intermediate level long lived waste ~ 50 000 m³ in 2020</p> <p>< 10 % of the total volume of waste, <10% of radioactivity</p>	
<p>High level long lived waste ~ 5 000 m³ in 2020</p> <p>~ 1 % of the volume of waste, >90% of the radioactivity</p>	


Nuclear Energy Division
Nuclear Development and Innovation Division
IGSC 4th Meeting, Paris, 6-7 Nov. 2002
11

Partitioning and transmutation (1)

Two strategies for managing toxic products

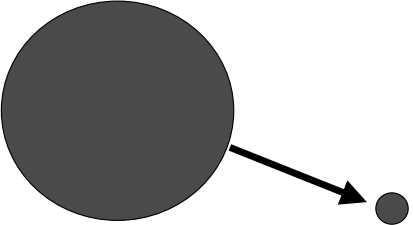


=> Two criteria for risk assessment



Confinement and careful storage

Effective risk




Reduce inventory

Potential toxicity = danger


Nuclear Energy Division
Nuclear Development and Innovation Division
IGSC 4th Meeting, Paris, 6-7 Nov. 2002
12

Partitioning and transmutation (2)

Reducing quantity (radiotoxicity)



Potential radiotoxicity after 1000 years




Category	Potential radiotoxicity after 1000 years
Plutonium	High
Minor actinides	Medium-Low
Fission products	Very Low

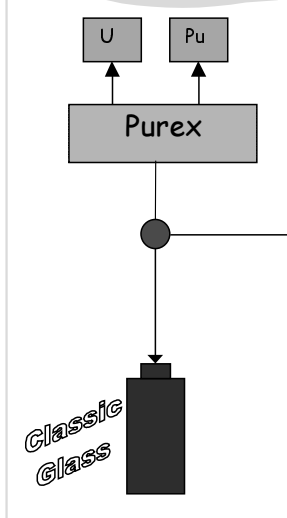
- Partitioning
- Transmutation *or* specific conditioning

Nuclear Energy Division IGSC 4th Meeting, Paris, 6-7 Nov. 2002
 Nuclear Development and Innovation Division 13

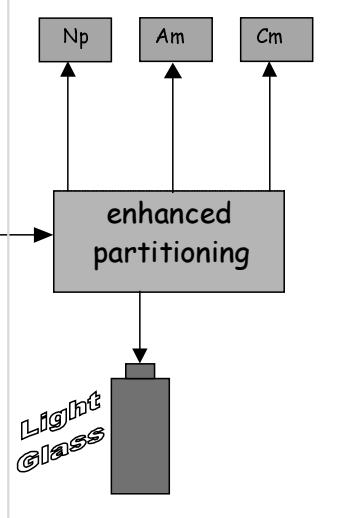
Partitioning and transmutation (3)




La Hague today



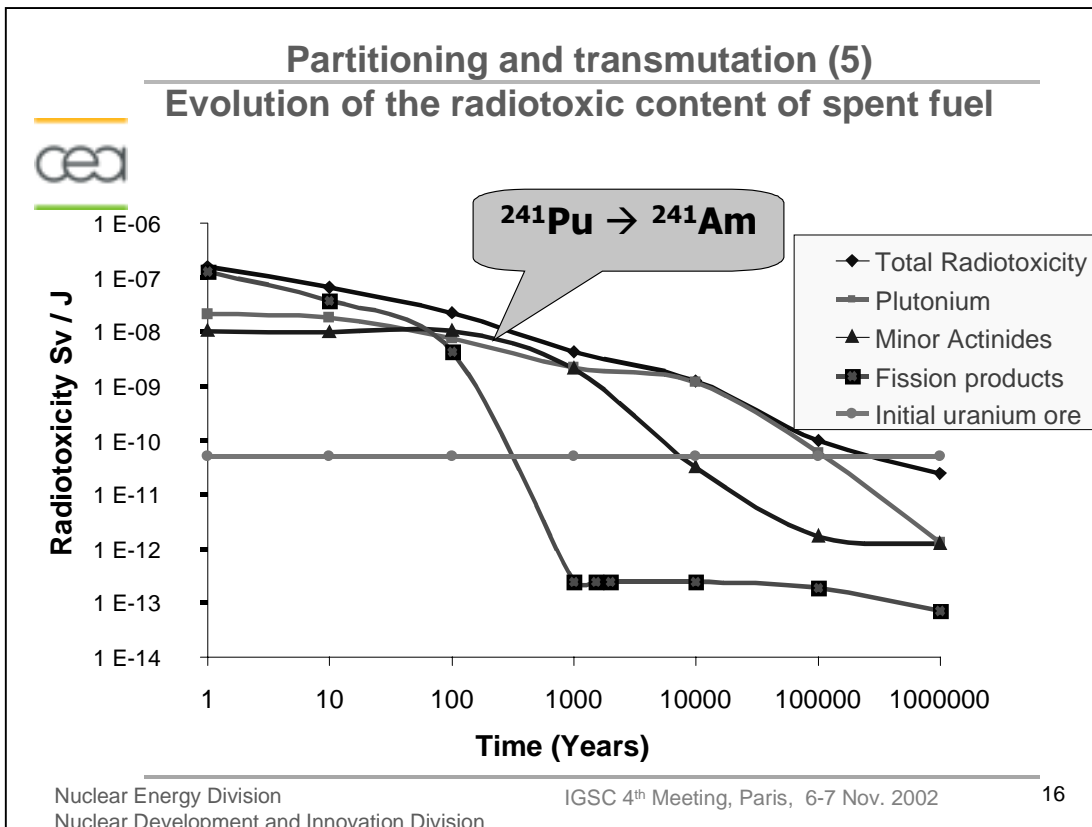
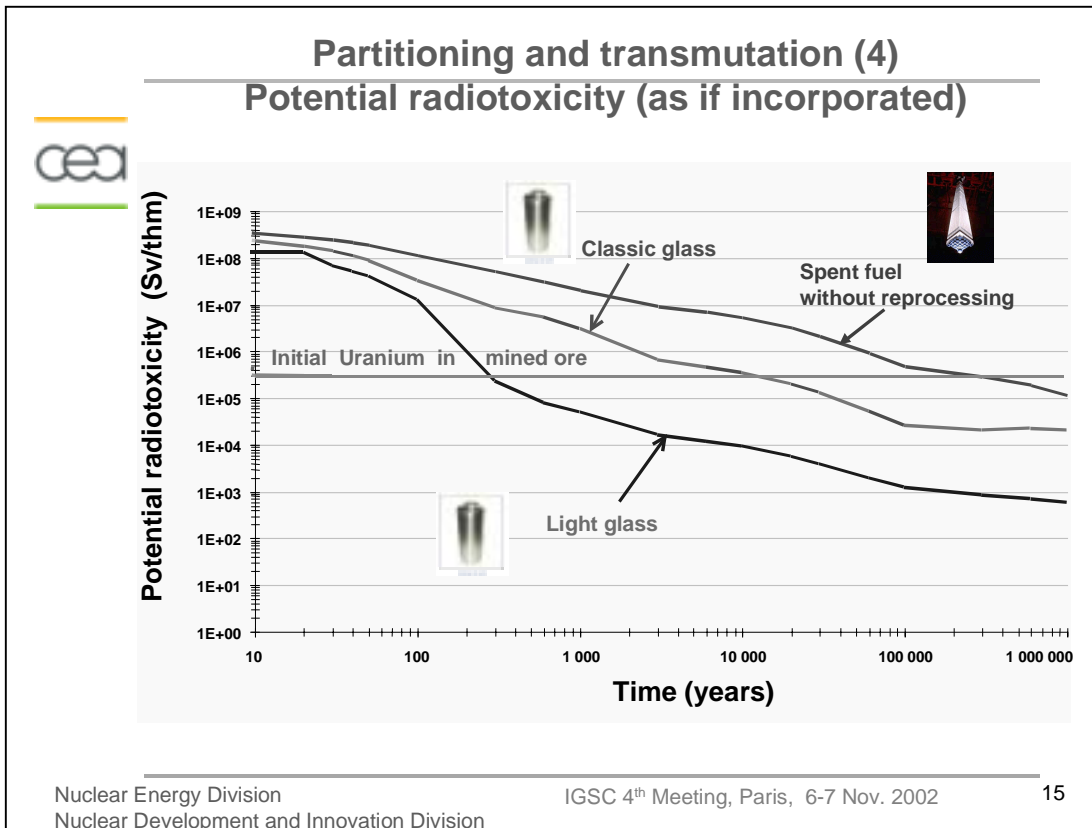
New possibilities

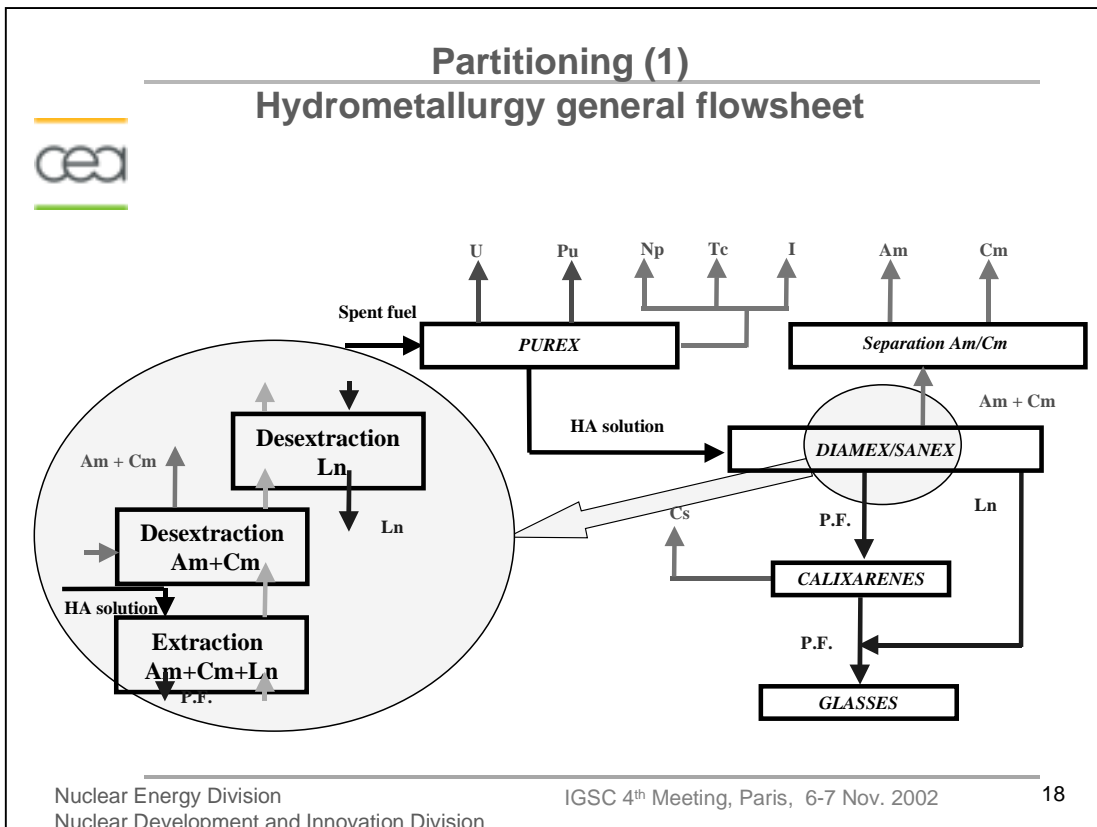
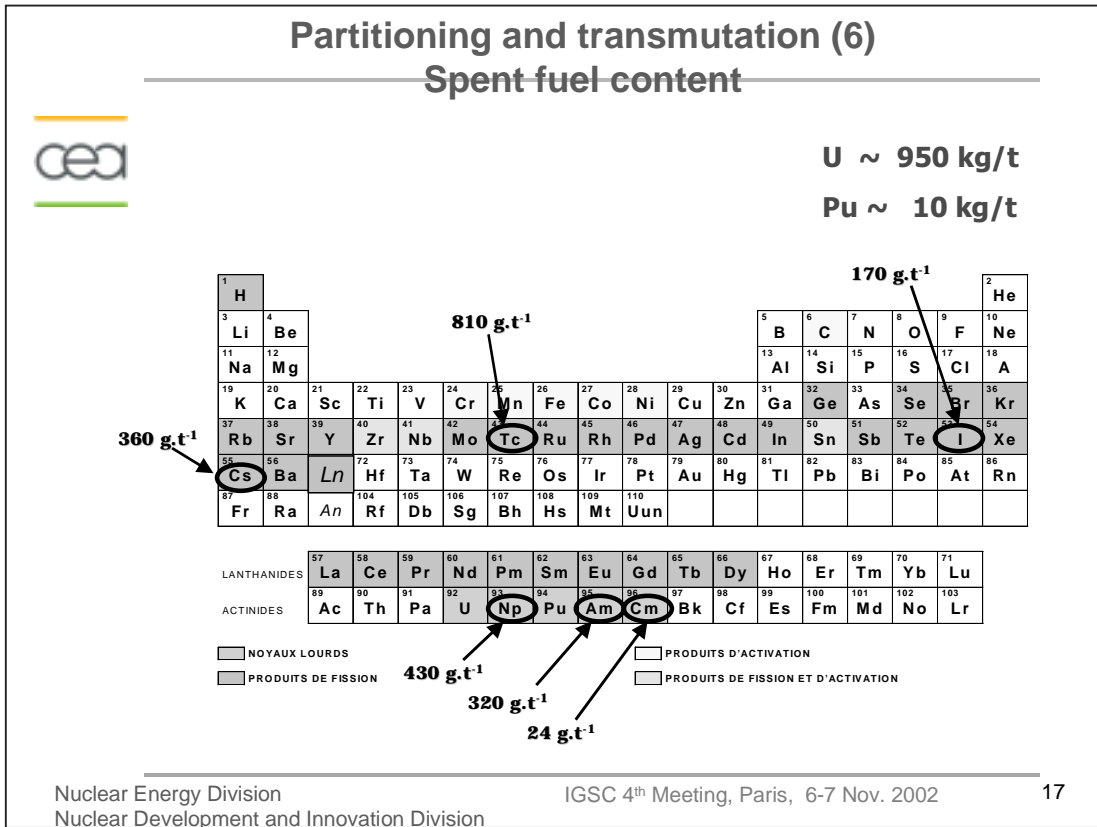




ATALANTE


Nuclear Energy Division IGSC 4th Meeting, Paris, 6-7 Nov. 2002
 Nuclear Development and Innovation Division 14

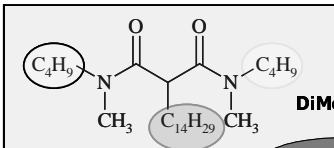




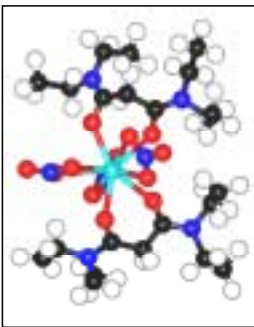
Partitioning (2)


Diamex extracting molecule

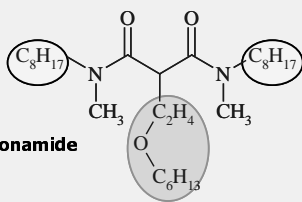




DMDBTMA
DiMéthyl DiButyl TétraDécyl MALonamide








DMDOHEMA
DiMéthyl DiOctyl Hexyl Ethoxy MALonamide

Nuclear Energy Division
Nuclear Development and Innovation Division
IGSC 4th Meeting, Paris, 6-7 Nov. 2002
19

Partitioning (3)

Enhanced separation : main hot tests recent results



*ATALANTE facility, genuine fuels, laboratory scale :
scientific feasibility is achieved*

- DIAMEX (1999 and 2000) : > 99.9% An+Ln
Reference molecule : DMDOHEMA
- SANEX (2000 and 2001) : up to > 99.9% An
Ln : from 0.01% to 0.1%
3 distinct routes explored ; nPrBTP
- CCCEX (2001) : > 99.9% Cs
1, 3 alternate calixcrown

Nuclear Energy Division
Nuclear Development and Innovation Division
IGSC 4th Meeting, Paris, 6-7 Nov. 2002
20

Partitioning (4)

Criteria and main milestones from now



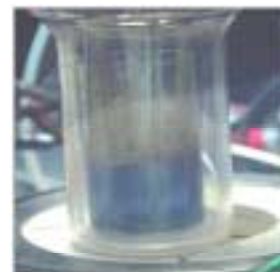
- **Criteria :**
 - selective recovery efficiency
 - stability (medium effects)
 - industrialisation, secondary waste minimisation
- **Milestones from now by 2004 :**
 - processes and technologies optimisation
 - “representative” hot runs (a few kg of spent fuel)
 - global evaluation processes
 - technical feasibility

Partitioning (5)

Alternative process by pyrochemistry




- One step process
- Can be integrated on reactor sites



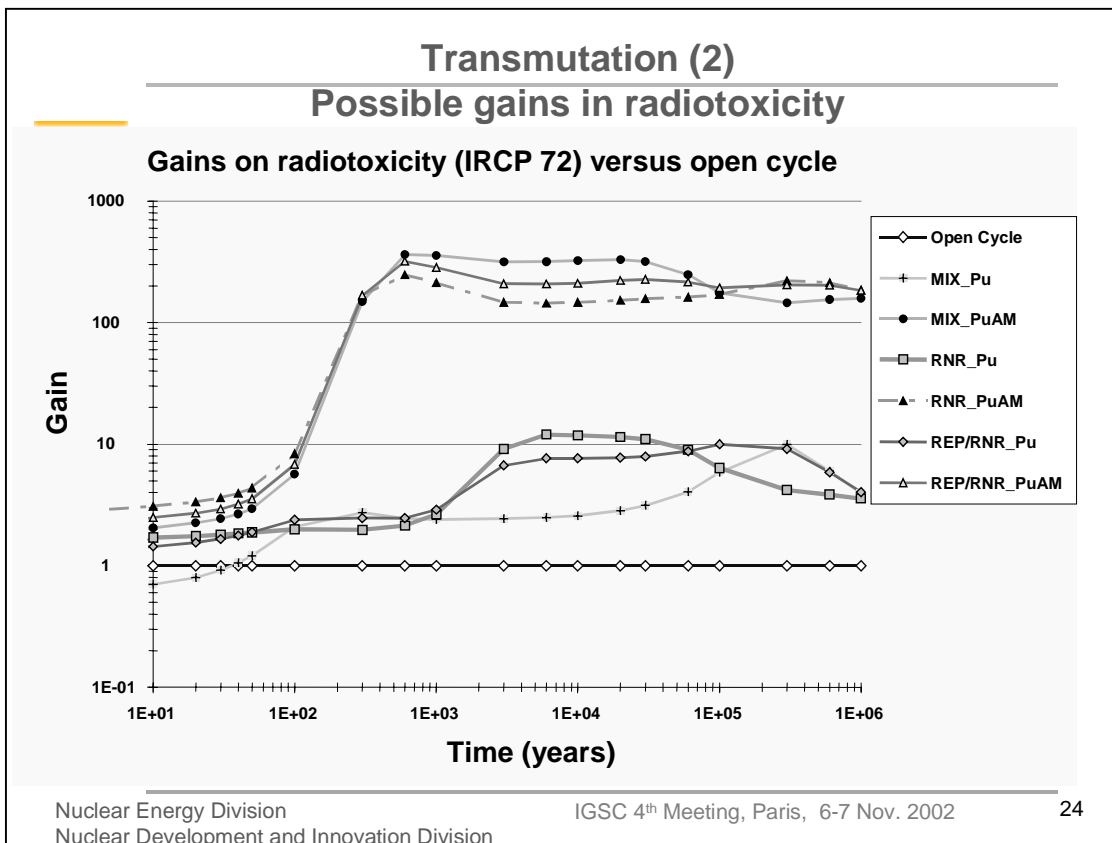
Transmutation (1)

~~Scenarios based on reactor core physics~~



- Plutonium , MA (Am, Cm, Np) and optional LLFP (Tc, I, Cs) management scenarios established for :
 - homogeneous recycling Pu/MA in PWR and FR
 - homogeneous recycling Pu/Np + heterogeneous Am/Cm in FR
- Scenarios to be established for :
 - PWR (Pu) + dedicated system (MA)
 - PWR then HTR-GCFR (Pu+AM) + dedicated systems ?
- Reduction of long term radiotoxicity :
 - a factor 3 to 5 for Pu recycling scenarios
 - up to a few hundreds for (Pu+MA) recycling scenarios

Nuclear Energy Division IGSC 4th Meeting, Paris, 6-7 Nov. 2002 23
 Nuclear Development and Innovation Division



Transmutation (3)

Transmutation with present technology



Fast
neutrons
reactors



Light
water
reactors

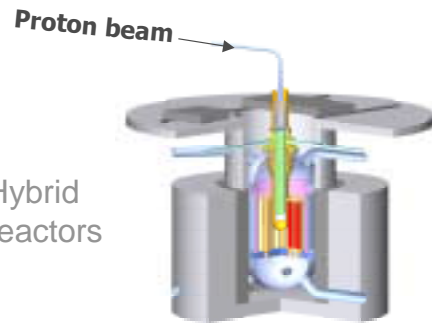


New perspectives.....

Advanced
gas cooled
reactors



Hybrid
reactors

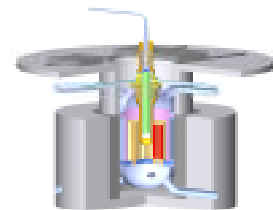


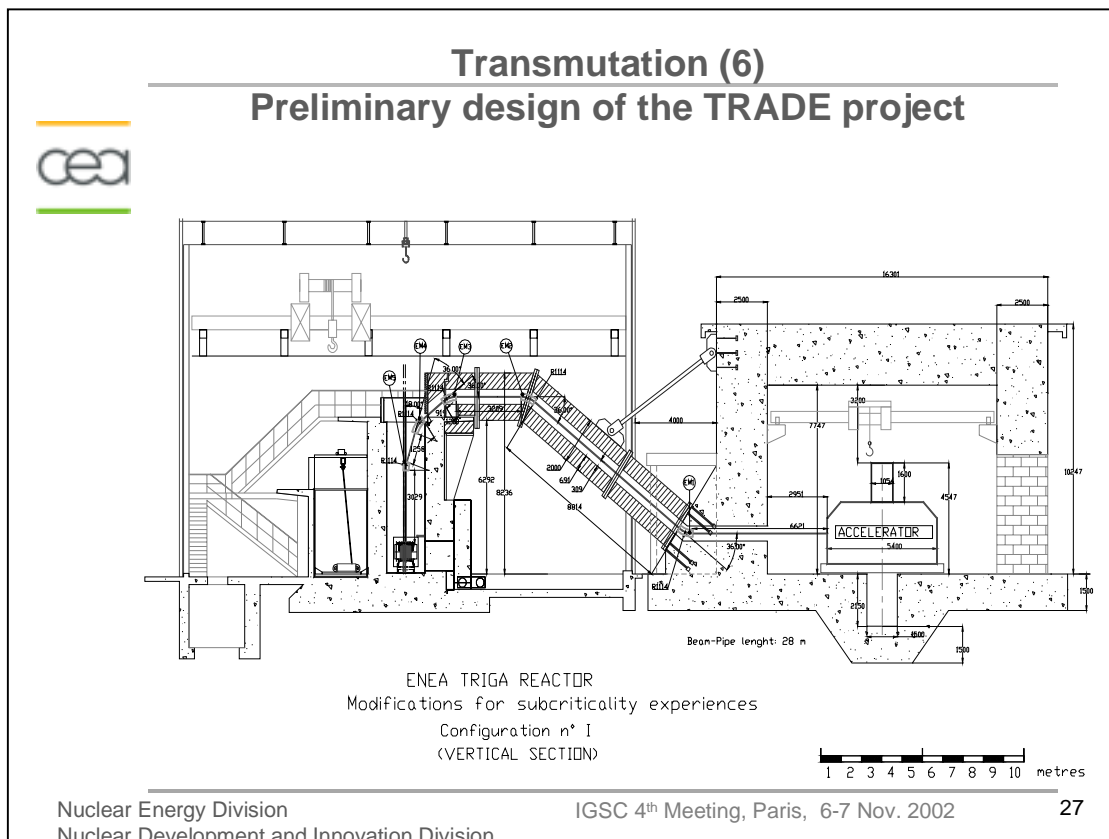
Transmutation (4)

R & D on Accelerator Driven Systems



- Nuclear data, neutronics of coupling (MUSE in MASURCA)
- High intensity accelerator research (IPHI, *with CNRS*)
- Materials (window), technology (Pb/Bi), irradiation behaviour (MEGAPIE target project)
- Mid power (few hundreds kW) ADS demonstrator TRADE project
- Preliminary engineering design of experimental european ADS (PDS-XADS project)
- Europe, US, Japan collaborations





Transmutation (7)

Targets and fuels for Transmutation

- Uranium-free fuels : solid solutions, ceramic inclusions in ceramic, ceramic inclusions in metal
- Specific requirements :
 - strong interactions with neutrons, FP, alpha particles (large production >> usual one of FR)
 - thermal / mechanical / chemical properties
- Ongoing irradiations in experimental reactors
 - Actinide compounds (MAO_x , MAZrYO_x ,...)
 - Matrices (Al_2O_3 , MgAl_2O_4 , MgO ,...)
 - Composites

28

Nuclear Energy Division IGSC 4th Meeting, Paris, 6-7 Nov. 2002
Nuclear Development and Innovation Division

Transmutation (8)

First results on targets and fuels for Transmutation

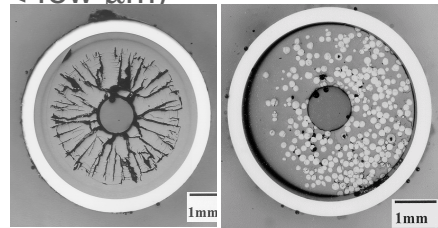
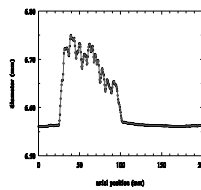


• **Matrices :**

- Al_2O_3 : high swelling under irradiation
- $MgAl_2O_4$: swelling, complex behaviour under irradiation
- MgO : good behaviour under irradiation, present reference

• **Microstructures :**

- Microdispersed fuel (fissile particles < few μm)
- Macromasses (> 100 μm)



A : Diameter change of Efttra T4

B: Microdispersed fuel

C: Macromasses

Transmutation (9)

Planned irradiation tests in the fast Phénix reactor



Experiment	Time EFPD	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		R&D - Conception - Fabrication					Irradiation			ND Exams		D Exams
ECRIX B	670											
ECRIX H	340											
METAPHIX 1-2	360											
METAPHIX 3	600											
PROFIL - R	240											
ANTICORP1	500											
PROFIL - M	240											
MATINA 2 - 3	360											
CAMIX COCHIX	340											
FUTURIX	240											
		Full power PHENIX										

Conclusion on HLLW waste management (1)



Solutions do exist, that could be implemented in a progressive manner.

Several scenarios might be considered and combined :

- Full Pu consumption
- Deep geological disposal of existing vitrified waste and "B" waste
- Long term storage of any waste (up to 300 y)
- Spent fuel direct disposal
- Partitioning and transmutation of Minor Actinides and LL Fission Products

Conclusion on HLLW waste management (2)



Partitioning and Transmutation :

- MA (and some LLFPs) could be efficiently recovered from PUREX HLLW
 - DIAMEX/SANEX/SESAME hot runs : up to 99.9% recovered
 - These results open the way to a possible specific management of LLRN
- Advances in dedicated fuel development, but further work is needed
(Phénix experiments planned from beginning of 2003)
- ADS appear well suited for high consumption of MA in dedicated strata ;
CEA and CNRS contribute to the international work in this field

Conclusion on HLLW waste management (3)



- Future nuclear power production systems designed to minimise waste
- French law 1991-2006
 - Solutions will be available for presentation to the French government and the Parliament in 2006, for open debate and choice of options for the long-term management of HLLW in France
- International cooperation :
an essential need for the future !!

Radioactive Wastes Generated from JAERI Partitioning-Transmutation Fuel Cycle

Shinichi NAKAYAMA, Yasuji MORITA and Kenji NISHIHARA
Japan Atomic Energy Research Institute, Japan

Abstract

Production of lower-level radioactive wastes, as well as the reduction in radioactivity of HLW, is an important performance indicator in assessing the viability of a partitioning-transmutation system. We have begun to identify the chemical compositions and to quantify the amounts of radioactive wastes that may be generated by JAERI's processes. Long-lived radionuclides such as ^{14}C and ^{59}Ni and spallation products of Pb-Bi coolants are added to the existing inventory of these nuclides that are generated in the current fuel cycle. Spent salts of KCl-LiCl, which is not generated from the current fuel cycle, will be introduced as a waste.

Keywords: partitioning-transmutation system, long-lived activation and spallation products, spent KCl-LiCl salt, Pb-Bi coolant and target

1. INTRODUCTION

Separation of short-lived fission products through partitioning reduces the initial radioactivity of high-level radioactive waste (HLW). Transmutation of long-lived minor actinides such as ^{237}Np reduces the radioactivity of HLW over tens of thousands of years. The partitioning-transmutation technology accordingly helps reduce the potential hazard of HLW[1].

The physical and chemical processes used during the application of partitioning-transmutation technology, however, generate other, lower-level, radioactive wastes. Although the lower-level radioactivity does not represent a significant increase in potential hazard after disposal of the waste, the technological feasibility of waste disposal, including radiological safety, is assessed based on the quantity and chemical compositions of the wastes, besides radioactivity contained. The type of solidifying matrix material is chosen depending on the chemical compositions of the wastes, and the volume of waste forms is determined both by that of the employed matrix material and the quantity of loaded raw wastes, as well as the radioactivity. The chemical compositions and the amount of the wastes affect the treatment, the total volume, and therefore the cost for final waste disposal.

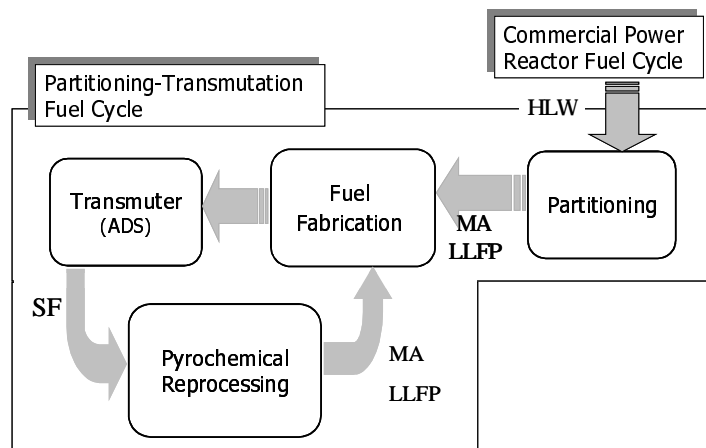
Waste management technologies have been developed for radioactive wastes generated from the current nuclear fuel cycle. The technologies may not be applicable and different technologies may be required for wastes arising from partitioning-transmutation fuel cycle.

We have begun to identify the chemical compositions and to quantify the amounts of radioactively contaminated wastes that may be generated by each of the partitioning-transmutation processes. There are two general sources of the wastes – process losses, and wastes arising from the maintenance and decommissioning of the plants. The process losses can be estimated from the material balance calculations for each process, and so, in principle, the types and amounts of wastes generated can be assessed quantitatively. By using industrial experiences and expertise, the types and amounts of maintenance and decommissioning wastes can be estimated on at least a semi-quantitative basis. This paper presents the results of estimates of process losses obtained so far by material flow analyses of the partitioning, transmutation, and nitride fuel reprocessing processes of the partitioning-transmutation system proposed by Japan Atomic Energy Research Institute, JAERI. The analysis for the nitride fuel fabrication process has not been examined yet.

2. JAERI'S PARTITIONING AND TRANSMUTATION SYSTEM

JAERI has proposed to have a “double strata” nuclear fuel cycle, in which the current Japanese reprocessing fuel cycle would be the first stratum, or layer, of the cycle, and a partitioning-transmutation system would be the second layer. This cycle is shown schematically in Figure 1. The partitioning-transmutation cycle system is composed of four processes -- partitioning of elements into groups, fabrication of nitride fuel, accelerator-driven transmutation of the nitride fuel, and pyrochemical reprocessing of the nitride fuel after transmutation. This system is featured to be independent from the commercial power reactor fuel cycle.

Figure 1: **JAERI's “double strata” fuel cycle system. The commercial power reactor fuel cycle is the first stratum, and the partitioning-transmutation fuel cycle is the second. HLW: High Level Waste, MA: Minor Actinide, LLFP: Long-Lived Fission Product, SF: Spent Fuel. ADS: Accelerator-Driven subcritical System.**

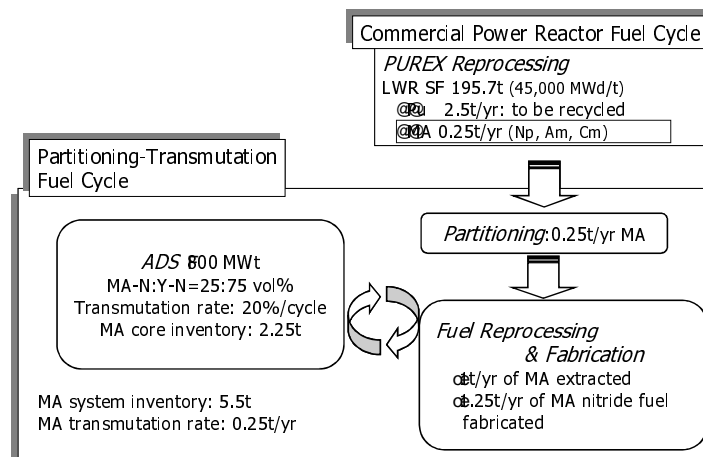


The

partitioning-transmutation layer of the double strata cycle begins when high-level liquid waste, discharged from the fuel reprocessing plants of the first layer of the cycle, is received at the partitioning plant. Minor actinides and a long-lived fission product, ^{99}Tc , extracted at this partitioning will be converted into fuel for transmutation.

Material flow in the partitioning-transmutation system is summarized in Figure 2. One and one-fourth tons of minor actinides per year (the sum of 0.25 tons from the PUREX reprocessing plant and 1.00 ton from the pyrochemical reprocessing) are loaded into the ADS, accelerator-driven subcritical system. Twenty percent of the 1.25 tons is transmuted and the rest, 1.0 tons, is discharged to be pyrochemically reprocessed. The system-wide inventory of minor actinides is 5.5 tons. The 0.25 tons of minor actinides supplied from the PUREX reprocessing is the quantity of minor actinides produced by 195.7 tons of 45,000 MWd/t burnup spent nuclear fuel from light water reactors. Consequently, the following estimates are based on reprocessing and applying partitioning-transmutation technology to 195.7 tons of spent light water reactor fuel per year.

Figure 2: **System-wide material flow in JAERI's partitioning-transmutation cycle system**



The accelerator-driven subcritical system, ADS, is currently designed to be 800 MWt with the lead(Pb)-bismuth(Bi) eutectic coolant and to transmute 20 wt% of the loaded minor actinides, 0.25 tons, during the system cycle period of 600 days[2]. The fuel composite is a homogeneous mixture of minor actinide nitrides and an yttrium (Y) nitride in the volume ratio of 1 to 3. The yttrium nitride is an inert diluent to control the power density. Titanium and zirconium are alternative diluents to be considered in the future design study for optimization. Zirconium(Zr) is used for vibropacked fuel element with Zr-N and minor actinide nitride microspheres. Our analysis here in this study is on the yttrium option.

The irradiated nitride fuels are submitted to molten-salts electrorefining to remove fission products. This pyrochemical separation yields actinide metals, and the metals are converted into nitride fuel by nitridation.

3. EVALUATION OF GENERATED WASTES

3.1 Partitioning

Radionuclides in the high-level liquid waste are separated into four groups by the partitioning process: transuranium elements (TRU; Np, Pu, Am, Cm), Tc-platinum group metals (^{99}Tc , Ru, Rh, Pd), the elements Sr and Cs, and "other elements" (Zr, Mo, Fe and rare earth elements). Material flow for the partitioning process is fairly well established in the partitioning-transmutation system, with the assumption of 0.1 wt% of process loss [3]. Products and wastes generated by the partitioning process are estimated in Table 1.

Table 1. **Products and Wastes generated from Four-group Partitioning Process**
(Based on data given in Ref.[4] for 195.7 tons of LWR spent fuels producing 0.25 tons of minor actinides)

(a) Partitioned products				
Group	Major nuclides or elements	Chemical form	Volume (m ³)	Treatment after partitioned
TRU	Np, Am, Cm	oxides	0.024	transmuted
Tc-platinum group metal	^{99}Tc , Ru, Rh, Pd	metal	0.104	Utilization <i>or</i> disposal Tc: transmuted
Sr-Cs	^{90}Sr , ^{137}Cs	calcined products	3.5	interim storage <i>or</i> utilized as heat source, followed by disposal
Others	Zr, Mo, Fe, rare earths	vitrified form (30 wt% of oxides loaded)	8.6	storage, followed by disposal
Total			12.1	
Non-partitioned option		vitrified form (12 wt% of oxides loaded)	40	interim storage followed by final disposal

(b) Secondary wastes			
Waste	Composition	Treatment/Waste form	α radioactivity
Spent solvent	DIDPA-TBP-dodecane	Thermal decomposition into 1.55 tons of $\text{Ca}_2\text{P}_2\text{O}_7$ yielding 9.2 m ³ of cemented form (10 wt% of $\text{Ca}_2\text{P}_2\text{O}_7$ loaded)	0.013 GBq/t
Washing liquid	NaNO_3 , Na_2CO_3	Neutralization into 56.6 tons of liquid NaNO_3 , yielding 56.6 m ³ of cemented form (50 wt% of palletized NaNO_3 loaded)	0.2 GBq/t
Others	DTPA, oxalic acid	Decomposed in H_2O and CO_2	

Partitioned transuranium elements (284 kg, in oxides, per year) and technetium (206 kg, in metal, per year) will be converted into nitride fuel for transmutation. Platinum group metals (1,094 kg per year) may be retained for later use as noble metals. (Chemical treatments for purification of

platinum group metals are not designed in the current partitioning process and the secondary wastes arising from the treatments are therefore not counted in the material flow analysis.)

Strontium and cesium are solidified by calcinations of the loaded zeolites and titanic acid into 3.5 m³ of waste, and the remaining group of elements is solidified into 8.6 m³ of vitrified waste. These last two groups are the primary wastes from partitioning, totaling 12.1 m³. This is much less than the 40 m³ of vitrified waste that would be produced by solidifying an equivalent quantity of non-partitioned high-level waste. This reduction in volume results from the removal of short-lived fission products ⁹⁰Sr and ¹³⁷Cs. The loading of high-level waste liquid into glass is limited by the temperature rise by decay heat. Removal of ⁹⁰Sr and ¹³⁷Cs allows the increased loading into glass, and accordingly the number of glass waste forms is expected to decrease. The secondary wastes that would result from the partitioning process include spent solvent (DIDPA-TBP-dodecane) and sodium salt solutions (sodium carbonate and sodium nitrate). The spent solvent yields 9.1 m³ of calcium phosphate and the sodium salts result in 56.6 m³ of cementitious waste.

The calcined products with zeolites and titanic acid are wastes that are not generated from the current fuel cycle, but will be generated from the partitioning-transmutation system.

3.2 ADS

Radionuclides produced by the ADS include short-lived fission products produced in nitride fuels, activation products and spallation products generated in fuel pins, and the Pb-Bi eutectic target and coolant.

Nitrogen-15, enriched from natural nitrogen, is used for the nitride fuel. Carbon-14 (5,730 yr) is produced through activation of the remaining ¹⁴N during the transmutation process. The amount of ¹⁴C produced is proportional to that of ¹⁴N. A 90% enrichment of ¹⁵N yields 20 TBq (110 g) of ¹⁴C per year. Activation products of SUS316 fuel cladding include radionuclides of various lifetimes. Twenty thousand TBq of ⁵⁸Co (71 d) dominate the initial radioactivity of the discharged fuel, and 0.4 TBq of ⁵⁹Ni will dominate 10,000 years after fuel discharge from the ADS.

Some of the yttrium in the yttrium nitride in the fuel is activated during transmutation to produce 1x10¹⁸ Bq of ⁹⁰Y (64 hr). This isotope quickly decays to a stable isotope of ⁹⁰Zr. About 2.4 tons of Y and 5.6 kg of ⁹⁰Zr will remain, affecting the subsequent partitioning-transmutation processes, and finally will be disposed of as a waste.

About 7,000 tons of the Pb-Bi eutectic metal (target and coolant) of the ADS are a source of spallation and activation products. An example of calculation of radioactivities of the spallation and activation products for an 800 MWt ADS is shown in Table 2[5]. Polonium-210 (138 d; 8x10¹⁷ Bq) is one of the main radioactivity-dominating radionuclides that will be present at the end of 50-year operation of the ADS. A long-lived spallation product of ²⁰²Pb/²⁰²Tl and an activation product of ^{210m}Bi/²⁰⁶Ti will contribute 50 TBq of radioactivity at 10,000 years after the 50-year operation. This radioactively contaminated Pb-Bi metal is discharged in decommissioning the ADS facility. This is a decade-long generating waste: waste that will be generated once in decades of years. This radioactively contaminated Pb-Bi waste does not exist in the current fuel cycle, but will be generated from the partitioning-transmutation system. The chemical toxicity of these metals may dominate the risk of groundwater contamination when the waste is disposed of into the underground.

Table 2. **Radioactivity generated in the Pb-Bi target and coolant for 50 years of operation of the 800 MWt ADS**

	Nuclides	Half-life	0 ^(a)	1 yr	5yr	10yr	100 yr	1000 yr	10,000 yr
Spallation	TOTAL		8.7E+17 ^(b)	1.1E+17	8.6E+16	7.5E+16	1.2E+16	3.7E+14	4.5E+13
	²⁰¹ Pb+ ²⁰¹ Tl	3.038 d	<u>5.3E+16</u> ^(c)	0	0	0	0	0	0
	²⁰⁶ Bi	6.243 d	4.5E+16	1.7E+03	0	0	0	0	0
	²⁰³ Pb	2.16 d	4.2E+16	0	0	0	0	0	0
	²⁰⁷ Bi+ ^{207m} Pb	31.55 yr	8.1E+16	<u>8.0E+16</u>	<u>7.3E+16</u>	<u>6.5E+16</u>	<u>9.1E+15</u>	2.3E+07	0
	²⁰⁵ Bi+ ^{205,205m} Pb	1.53E+7 yr	3.6E+16	1.6E+11	1.6E+11	1.6E+11	1.6E+11	1.6E+11	1.6E+11
	¹⁹⁵ Au	186.1 d	1.2E+16	3.1E+15	1.3E+13	1.5E+10	0	0	0
	¹⁷² Hf+ ^{172,172m} L	1.87 yr	5.2E+15	3.5E+15	7.9E+14	1.2E+14	4.0E-01	0	0
	¹⁹³ Pt	50 yr	4.5E+15	4.4E+15	4.2E+15	3.9E+15	1.1E+15	4.3E+09	0
	²⁰⁴ Tl	3.78 yr	4.2E+15	3.5E+15	1.7E+15	6.8E+14	4.6E+07	0.0E+00	0
	¹⁹⁴ Hg+ ¹⁹⁴ Au	520 yr	2.5E+15	1.2E+15	1.2E+15	1.2E+15	1.0E+15	<u>3.1E+14</u>	1.9E+09
	²⁰² Pb+ ²⁰² Tl	5.25E+4 yr	4.3E+15	4.3E+13	4.3E+13	4.3E+13	4.3E+13	4.2E+13	<u>3.7E+13</u>
	²⁰⁹ Po	102 yr	4.5E+14	4.4E+14	4.3E+14	4.2E+14	2.3E+14	5.0E+11	0
	¹⁶³ Ho	4,570 yr	1.2E+13	1.2E+13	1.2E+13	1.2E+13	1.1E+13	1.0E+13	2.6E+12
	²⁰⁸ Bi	3.68E+5 yr	3.1E+12	3.1E+12	3.1E+12	3.1E+12	3.1E+12	3.1E+12	3.0E+12
	¹³⁷ La	6E+4 yr	7.1E+11	7.1E+11	7.1E+11	7.1E+11	7.1E+11	7.0E+11	6.4E+11
¹⁵⁴ Dy+ ¹⁵⁰ Gd	3E+6 yr	2.8E+10	2.8E+10	2.8E+10	2.8E+10	2.8E+10	2.8E+10	2.8E+10	
Neutron Capture	TOTAL		1.6E+18	1.3E+17	1.1E+14	2.3E+13	2.3E+13	2.3E+13	2.3E+13
	²¹⁰ Po	138.376 d	<u>7.6E+17</u>	<u>1.3E+17</u>	<u>8.4E+13</u>	3.5E+10	2.6E+10	2.6E+10	2.6E+10
	²⁰⁸ Bi	3.68E+5 yr	9.6E+12	9.6E+12	9.6E+12	9.6E+12	9.6E+12	9.6E+12	9.4E+12
	^{210m} Bi+ ²⁰⁶ Tl	3.04E+6 yr	3.4E+13	1.3E+13	1.3E+13	<u>1.3E+13</u>	<u>1.3E+13</u>	<u>1.3E+13</u>	<u>1.3E+13</u>

(a) At the end of 50-year operation

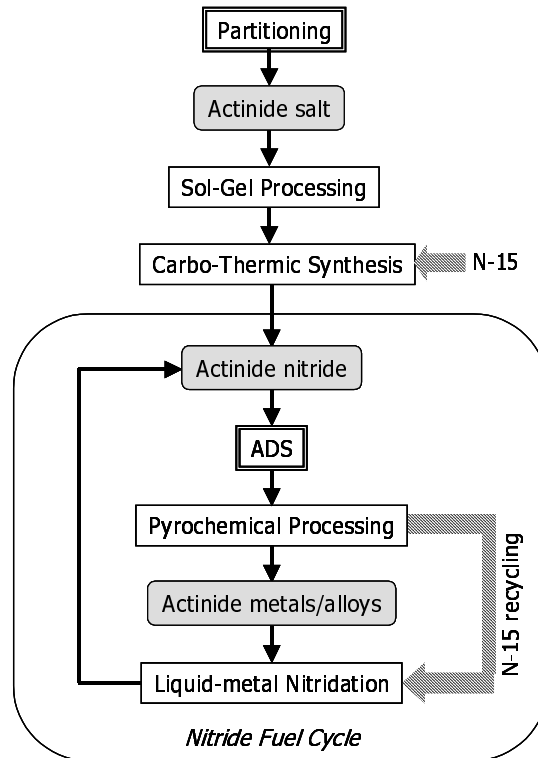
(b) Read as 8.7×10^{17}

(c) The underlined radionuclide dominates the total radioactivity at the time

3.3 Fuel fabrication

JAERI's partitioning-transmutation system needs two different fuel fabrication processes as schematically shown in Figure 3. One is a wet process: Actinides extracted in the partitioning process are fed into sol-gel process followed by conversion into nitride fuel through carbo-thermic synthesis. The other fabrication is a dry reprocessing of spent fuel. Spent nitride fuel is first subject to pyrochemical treatment using molten KCL-LiCl salt to separate actinides. The obtained actinide metal/alloys are converted into nitride fuel though nitridation with ¹⁵N.

Figure 3: **Fabrication process for the actinide nitride fuel in the JAERI's P & T cycle (modified from ref. [2].)**



Because the design of these fuel fabrication processes has not progressed as far as the designs of the partitioning and transmutation processes, engineering data are not yet available to quantify the material flow in the process. Data on the material losses therefore are much limited.

Typical wastes produced from the fuel reprocessing are hulls and fission product metals, and radioactively contaminated KCl-LiCl salt mixture. A semi-quantitative, preliminary evaluation with limited data indicates that the contaminated KCl-LiCl salt waste could amount to about 10^2 tons per year. The results of evaluation depend on the process performance: The amount of waste, 10^2 tons per year, was obtained under the assumptions that 1) the process losses for the above two fabrication processes are 0.05 wt% for each, and 2) Y, the fuel diluent is reprocessed with the decontamination factor of 3.0.

The assumed loss of 0.05 wt% was, for the wet process, based on the UK's pilot-scale experience to produce (U, Pu) O_2 microspheres for fast reactor fuel through the gel precipitation process[6]. The yield of >99.9% is reported. No loss data are currently available for nitride fuel reprocessing. The same number, 0.05wt% loss, was applied also for the reprocessing only as an input parameter without any technological feasibility.

4. DISCUSSIONS AND CONCLUSION

Introduction of the partitioning-transmutation system into the current nuclear fuel cycle decreases both short- and long-term radioactivity of HLW, but it also produces various additional forms of lower-level radioactive wastes. Long-lived radionuclides such as ^{14}C and ^{59}Ni and spallation products of Pb-Bi metal are added to the existing inventory of these wastes that are generated in the current fuel cycle. In addition, wastes such as spent salts of KCl-LiCl, which are not generated from the current fuel cycle, will be introduced by a partitioning-transmutation system.

Chlorine, Pb and N may be sources of groundwater contamination if disposed underground. The chemical toxicities may be of more concern than the radiological toxicity. These wastes should be treated and disposed of as safely as “radioactive wastes”. In this sense, the production of the additional lower-level radioactive wastes, as well as the reduction in radioactivity of HLW, are important performance indicators that should be quantitatively evaluated in assessing the viability of a partitioning-transmutation system.

Acknowledgements

The authors wish to thank H. Yamana of Research Reactor Institute, Kyoto University, M. Kurata of Central Research Institute for Electric Power Industry, M. Shiotsuki of Japan Nuclear Cycle Development Institute, T. Omori and T. Kobayashi of Toshiba Corporation, and H. Hayashi and S. Shirai for their advice and discussion, and J. McMurry of Atomic Energy of Canada Limited for her stylistic revisions.

REFERENCES

- [1] Japan Atomic Energy Commission's Advisory Committee on Nuclear Fuel Cycle Back-end Policy, “Research and Development of Technologies for Partitioning and Transmutation of Long-lived Nuclides - Status and Evaluation Report –”, March 31, 2000.
- [2] MUKAIYAMA, T., TAKIZUKA, T., MIZUMOTO, M., IKEDA, Y., OGAWA, T., HASEGAWA, A., TAKADA, H. and TAKANO, H., “Review of Research and Development of Accelerator-driven System in Japan for Transmutation of Long-lived Nuclides,” *Nucl. Energy*, 38, p.107 (2001).
- [3] MORITA, Y., YAMAGUCHI, I., KOIZUMI, H. and KUBOTA, M., “The First Test of 4-group Partitioning Process with Real High-level Liquid Waste”, *Proc. Fourth Int'l Conf. Future Nuclear Systems*, GLOBAL '99, August 29 – September 3, Jackson Hole (1999) (published in the form of CD-ROM).
- [4] KUBOTA, M. and MORITA, Y., “Preliminary Assessment on Four Group Partitioning Process Developed in JAERI”, *Proc. Third Int'l. Conf. on Future Nuclear Systems*, GLOBAL'97, Vol.1, p.458, October 5-10, 1997, Yokohama, Japan (1997).
- [5] NISHIHARA, K. and SASA, N., “Estimation of Activity and Toxicity for Spallation Product from the Target for Accelerator-driven Transmutation System”, JAERI-Research 2001-015, Japan Atomic Energy research Institute (2001).
- [6] PARKINSON, N., NELSON, R. L. and KENT, W. C. L., “Fast Reactor Fuel Fabrication Development”, *Nucl. Energy*, 20, p.55 (1981)

Submitted to the OECD/NEA Seventh Information Exchange Meeting
on Actinide and Fission Product Partitioning and Transmutation
October 14-16, 2002
Jeju, Korea (2002)

"ORIENT-CYCLE" **Evolutional Recycle Concept with Fast Reactor for Minimizing High-Level Waste**

Naoyuki TAKAKI, Yoshihiko SHINODA, Masayuki WATANABE, Kazuo YOSHIDA¹
Japan Nuclear Cycle Development Institute (JNC)

Abstract

JNC has proposed an evolutional concept of fast reactor recycle system for minimizing high-level waste (HLW) by adopting an unconventional recycling scheme based on the idea of “rough removal of unnecessary elements” instead of a conventional one as “pure recovery of necessary elements”. The concept was named "ORIENT-cycle" (Optimization by Removing Impedimental Elements). “Unnecessary elements” to be removed were listed up from various aspects such as core design, front end and back end of the fuel cycle. Stable fission products that amount to about 60 wt% of all FPs were identified as one category of key “unnecessary elements” from a neutronic aspect and also final disposal aspect because they were major parasitic neutron absorbers if recycled and were not required to be disposed in deep geological media. Adaptable separation schemes and the neutronic feasibility of the multi-recycling were discussed. The production rate of HLW was reduced by a factor of around 10 compared with a conventional cycle.

1. INTRODUCTION

In a past development of reprocessing technology, the fundamental principle had been “pure recovery of necessary elements” from spent fuels for further use in the fuel cycle. As generally known, fast reactors are less sensitive to impurities contained in a recycled fuel. It is considered that the insensitivity implies flexibility in structuring a fuel cycle scheme. To explore the flexibility and create a Japan-originated new recycle concept, the authors set up a fundamental principle of “rough removal of unnecessary elements”.

Assuming long-term use of nuclear power, the importance of back end of nuclear fuel cycle will increase more and more. Continuous use of fission reactors undoubtedly requires a series of repository constructions. Although transmutation technologies of long-lived nuclear waste by using fast reactors have been studied for several years among many research organisations, they are not necessarily linked to the reduction of HLW. Taking the political and sociological difficulties to find new repository sites into account, minimizing HLW production to prolong a need of new repository is of major concern when considering a new recycle concept.

1 . This paper is co-authored by: K. Wakasugi, M. Takeuchi, Y. Nagaoki, Y. Nakajima, T. Tsukada and H. Funasaka, Japan. Nuclear Cycle Development Institute (JNC).

The purpose of this study is to propose a new recycle concept, namely ORIENT-cycle, based on the principle of “rough removal of unnecessary elements”. The authors especially focused on the point what reduction can be attained in HLW generation by making the full use of distinctive neutronic feature of fast reactors. In forming a new recycle scheme, only element-wise separation technologies are assumed.

2. LISTING UNNECESSARY ELEMENTS

The meaning of “unnecessary” depends on the aspect we take. As an initial step, “unnecessary elements” were independently listed up from various viewpoints such as fuel fabrication, core design, waste conditioning and final disposal.

Front End Aspect

The heat generation of low decontamination fuel material containing 5 wt% of minor actinides and 2 wt% of FP is 7 times as high as that of standard MOX fuel. High fuel temperature causes changes in O/M ratio, fuel powder fluidity, etc. However the increased heat generation of fuel seems to be possible to cope with by controlling atmosphere in the fuel fabrication cell, installing cooling equipment and dividing the lot. The main contributor for heat generation of the low DF (decontamination factor) fuel is Cm.

The radiation dose of the low DF fuel is higher than MOX fuel by the order of 4. The increased radiation dose of the recycled fresh fuel brings difficulties in the operation and integrity of equipments. In terms of radiation dose for operators, Eu is a concerned element. The radiation damage for equipments are ascribed to Pm, Eu and Y. In order to overcome these adverse influences, following measures are required to be taken: remote controlled cell, lot dividing and use of radiation-resistant material.

The impact of contaminated FP except for volatile elements on the MOX fuel fabrication capability could be negligible up to 3% of FP contamination. As for metal fuel, the contamination of minor actinides (MA) and rare earth (RE) into U-Pu-Zr alloy could be limited to about 2% because of the appearance of deposited phase.

The corrosive elements (I, Cs) could be picked up as unnecessary elements from the aspect of integrities of fuel and cladding. Furthermore it is likely that La causes eutectic reaction by depositing with metal and also that platinum group metals (Ru, Rh, Pd etc.) causes cracks in cladding by depositing metal layer.

Core Design Aspect

In fast reactors, actinides are all fissionable and contribute to produce energy. On the contrary fission products are not, so that all of fission products can be basically regarded as unnecessary elements for recycling in terms of energy production.

The neutronic impact by contaminated fission products in fresh fuel recycled into fast reactors is generally small due to the hard neutron spectrum. There are, however, some dominant fission products on the reactivity deterioration. Recycling such parasitic neutron absorbers into cores must be especially avoided from a neutronic viewpoint.

Research and Development of Technologies for Partitioning and Transmutation of Long-lived Nuclides in Japan – Status and Evaluation –

Sanae AOKI

Radioactive Waste Policy Division, Science and Technology Agency (STA), Japan

1. CURRENT ACTIVITIES FOR RADIOACTIVE WASTE MANAGEMENT

Measures to treat and dispose of radioactive waste are one of the most important issues in the development and application of nuclear energy. The Atomic Energy Commission (AEC) has carefully considered how to classify radioactive waste properly and how to dispose of it according to these classifications.

Japanese basic policy regarding disposal of high-level radioactive waste (HLW) is to solidify it into stabilized form, to store it for 30-50 years to be cooled, and to dispose of it deep to the underground (geological disposal).

In April 1997, the Advisory Committee on Nuclear Fuel Cycle Back-end Policy, AEC, laid down the guidelines on future research and development of the disposal of HLW. In accordance with the report, the Japan Nuclear Cycle Development Institute (JNC) released the report on the outcome of R&D activities to elucidate technological reliability of the geological disposal, and to provide technical ground for selecting repository sites and for establishing safety requirement in the form of the second progress report in December 1999, with the co-operation of related institutions, such as the Japan Atomic Energy Research Institute (JAERI), the Central Research Institute (CRIEPI), the Geological Survey of Japan (GSJ), the National Research Institute for Earth Science and Disaster Prevention (NIED), and university researchers.

In parallel with the R&D programme, there has also been an effort to make a system for implementing HLW disposal. In the Special Committee on High-Level Radioactive Waste Disposal, AEC, and in the nuclear sub-committee of the Advisory Committee for Energy, Ministry of International Trade and Industry, various aspects of HLW disposal were considered, including social and economic aspects. A law¹ for implementing geological disposal was passed in the Diet in May 2000. Based on the law, an implementing entity² for HLW disposal was established in October 2000. The programme then moves from the generic into the site-specific phase. Thereafter we are looking to start operation of the repository between 2030 and the mid-2040s at the latest.

1 . Specified Radioactive Waste Final Disposal Act.

2 . Nuclear Waste Management Organisation of Japan (NUMO).

2. STATUS OF PARTITIONING AND TRANSMUTATION STUDY

At the same time, recognizing the nature of the radioactive nuclides contained in HLW, the aim since the early days of nuclear energy has been to develop technology either to separate useful elements and nuclides in order to re-use them effectively, or to transmute long-lived nuclides into short-lived or stable – i.e. non-radioactive – forms by irradiation.

In Japan, reference to P&T technology for long-lived and other nuclides first appeared in the *Long-term Programme for Nuclear Research, Development and Utilisation* (or “long-term nuclear programme”) back in 1972. That programme noted the need for research and development in order to ensure effective processing of radioactive waste.

In a 1976 interim report by the AEC’s Technical Advisory Committee on Radioactive Waste, the relationship between P&T technology and the disposal of radioactive waste was specifically pointed out. Specifically, if radioactive nuclides in waste could be appropriately separated into groups, waste management could become more flexible. This is because the amount of radioactive nuclides requiring strict control would be reduced, and treatment and disposal appropriate for the half-life of each group would become possible. In addition, if long-lived nuclides could be transmuted into short-lived ones by nuclear reaction, the burden of long-term waste management could also be reduced.

The long-term nuclear programme issued in 1987 stated that P&T technology was very important from the viewpoint of recycling HLW and enhancing disposal efficiency. It also stated that systematic R&D would be carried out jointly by JAERI, the then Power Reactor and Nuclear Fuel Development Corp. (PNC, now JNC) and others.

Under that programme, in 1988, the AEC’s Advisory Committee on Radioactive Waste Measures issued a report entitled, *Long-term Programme for Research and Development on Nuclide Partitioning and Transmutation Technology*³ This can be considered to have been the first systematic R&D programme on P&T technology in Japan. It presented a plan for R&D that ran from 1988 to 2000 and was divided into two phases: Phase I, covering the first four to nine years, which included evaluation of various concepts and R&D on key technologies; and Phase II, covering the next four to nine years, which included engineering experiments on key technologies and demonstrations.

The long-term nuclear programme issued in 1994 stated that each research institute would carry out basic studies on P&T technologies and evaluate each technology at some time in the mid-1990s to determine how to proceed thereafter.

Meanwhile, in 1998, the AEC’s Special Committee on the Disposal of High-Level Radioactive Waste released *Basic Concepts in the Disposal of High-level Radioactive Waste*. This stated that, in order to gain public understanding of disposal technology, “research on waste reduction with the aim of achieving safer and more efficient geological disposal, as well as more efficient use of waste, would be carried out on a regular basis”. It also said that it was “important to have mechanisms to respond flexibly to any dramatic progress in P&T technology”.

Under these circumstances, the AEC’s Advisory Committee on Nuclear Fuel Cycle Back-end Policy investigated and considered matters concerning P&T technology for long-lived and other nuclides, based on the evaluation schedule stated in the long-term nuclear programme issued in 1994.

3 . Called the “OMEGA Programme” – an acronym for Options Making Extra Gains from Actinides and Fission Products.

The Committee issued a report entitled, *Research and Development of Technologies for Partitioning and Transmutation of Long-lived Nuclide Status and Evaluation Report* in March 2000. The brief summary of this report is as follow.

3. RESULTS TO DATE AND ANALYSES OF CURRENT STATUS

3.1 Elements subject to P&T

Long-lived (i.e. long half-life). In particular:

- High radiotoxicity due to the emission of rays.
- Fast migration through geological formations via underground water, when disposed of geologically.

Relatively short-lived and heat-generating, producing most of the heat in HLW.

Rare and useful elements.

³Called the “OMEGA Programme” – an acronym for Options Making Extra Gains from Actinides and Fission Products.

3.2 Results to date and analyses of current status

3.2.1 *The partitioning process*

3.2.1.1 *JAERI*

JAERI is developing a four-group partitioning process, in which elements in concentrated highlevel liquid waste HLLW are separated into four groups: MAs, Tc-platinum group metals, Sr-Cs, and others. Basic experiments using simulated HLLW helped to establish the concept. Test runs with both simulated and actual HLLW on a scale 1/1000 that of an actual plant confirmed the expected capabilities of group partitioning. A recovery rate for MAs of 99.95% or better was achieved.

3.2.1.2 *JNC*

JNC is developing an improved PUREX process – an advanced version of the conventional reprocessing process – to recover Np. It is also developing a CMPO-TRUEX process to separate MAs from highly concentrated HLLW and an electrolytic extraction method to separate Tc-platinum group and other elements from aqueous reprocessing solutions. In the CMPO-TRUEX process research, it was demonstrated that Am and all nuclides can be recovered to a level of 99.9% or more under standard extraction conditions.

3.2.1.3 *CRIEPI*

CRIEPI is developing a reductive-extraction process using molten chlorides and liquid metal solvents. Basic data were obtained for the behavior of elements in this type of molten-salt-and-liquidmetal system. Experiments on the separation and recovery of TRUs were carried out using some 10 milligrams of TRUs and some 100 grams of chlorides, which confirmed recovery of more than 99% of the TRUs and adequate separation of TRUs from REs.

3.2.2 *The transmutation cycle*

JNC and CRIEPI are studying transmutation technology using fast breeder reactors (FBRs). This concept is centered on the use of fast reactors for electricity generation. In this scenario, FBR will take over the role of light-water reactor (LWR) in future, with power generation and the transmutation of MAs and other elements carried out simultaneously by the FBR. In contrast, JAERI's concept is the "double strata fuel cycle", where a dedicated system for transmuted MAs, such as an actinide burner fast reactor (ABR) or an accelerator-driven subcritical system (ADS) is at the centre of the transmutation cycle, allowing a commercial power generation cycle and a transmutation cycle to be developed and optimized independently for their individual purposes.

3.2.3 *The fuel production process*

3.2.3.1 *JAERI*

JAERI is developing MA-nitride fuel. The basic data on thermal properties of MA-nitrides necessary to design the fuel, as well as thermal properties of Tc alloys, were obtained. It was confirmed that the MA nitrides could be prepared by means of carbothermic synthesis and uranium nitrides microspheres can be produced via the sol-gel process. In addition, through irradiation tests of U-Pu mixed nitride fuel produced on a trial basis, it was ascertained that the fuel element was intact after a burn-up rate of 5.5% achieved.

3.2.3.2 *JNC*

JNC is developing fuel in which Np and/or Am is added to the MOX fuel that JNC has developed for FBRs. For the addition of Np to MOX fuel, a vibro-packing process is being developed in a joint international research effort. For the addition of Am to MOX fuel, in addition to irradiation experiments being carried out at the experimental fast reactor "Joyo", remote fuel fabrication facilities, including those to produce pellets and inspect fuel pins, were established and performance tests were carried out.

3.2.3.3 *CRIEPI*

CRIEPI is developing metallic fuel – an MA-content U-Pu-Zr ternary alloy under the international collaborations. Fuel pins have been made on a trial basis and physical characteristics and other basic data have been obtained. It has been determined that an MA content of about 5% does not affect the characteristics of the fuel, and it is expected that MAs can be mixed homogeneously during fabrication of the fuel.

3.2.4 *The transmutation process*

3.2.4.1 *JAERI*

JAERI is developing concepts for ADSs and ABRs. Nuclear data on MA nuclides were obtained through international co-operation and were verified while developing a database, carrying out integral experiments and analysing irradiated MA samples. In the development of a proton

accelerator for the ADS, major key technologies were developed, and the highest level performance has been demonstrated.

3.2.4.2 *JNC*

JNC is developing a MOX-fuelled FBR. The prototype reactor “Monju” already exists – i.e. construction of a “prototype plant” has been achieved – but the development of other key technologies will be required to add MAs to MOX fuel. Nuclear data on MA nuclides were obtained and evaluated via nuclear reactors and accelerators. Design studies were carried out on acceptable amounts of MAs and rare-earth elements, and on actual fuel loading.

3.2.4.3 *CRIEPI*

CRIEPI is developing the concept of metallic-fuelled FBRs. Regarding nuclear data on MA nuclides, analysis programmes for MA transmutation were developed and analyses were carried out.

3.2.5 *Fuel processing*

3.2.5.1 *JAERI*

JAERI is developing a pyrochemical process similar to dry reprocessing. Molten-salt electrolysis of U-nitride, Np-nitride and Pu-nitride on a gram scale were carried out to confirm that transuranic metals can be recovered. For the recovery and recycling of N-15, nitrogen (N₂) release in molten salts was studied, and it was confirmed that almost 100% of the nitrides can be released in the form of N₂.

3.2.5.2 *JNC*

JNC is considering the same method as for the partitioning process.

3.2.5.3 *CRIEPI*

CRIEPI is developing molten-salt electrorefining and reductive extraction, which is similar to the partitioning process. Electrorefining forms the main part of the pyro-reprocessing method. Feasibility was confirmed through an in-house study and international joint research, and the process is now at the stage of engineering experiments. Feasibility of the conversion of oxides of spent fuel to metal, and of the spent-salt treatment process, are still to be confirmed.

3.2.6 *Conclusion*

R&D at the three research institutes has resulted in establishment of processes for P&T technology with the expected performance. The aims of Phase I R&D have thus been achieved. R&D in Phase II has experienced some delays, the primary reasons being that Japan is redefining its entire FBR programme, and facilities to handle MAs and other materials have yet to be constructed. In carrying out further R&D, it is important to promote cooperation with domestic and foreign

organizations in order that experimental facilities – including those for engineering experiments – can be used efficiently.

3.3 Technical issues

The implementation of experiments to demonstrate processes using actual HLLW is an issue common to the three organizations. Also common to JAERI and JNC, which are developing aqueous partitioning processes, are development of a method to more efficiently separate MAs and rare-earth elements, and technologies to reduce the volume of secondary waste. At CRIEPI, where dry partitioning is being developed, the main technical issues in the handling of molten chlorides are material development and molten-salt transport technology. Common issues to the three organisations are preparation of a database on fuel irradiation behavior for performance analysis, and development of fuel fabrication technology.

4. EFFECTS AND SIGNIFICANCE OF PARTITIONING AND TRANSMUTATION TECHNOLOGY

4.1 Radioactive inventory in waste

It is a social imperative to minimise, as far as possible, the generation of hazardous waste produced by industrial activities. Reduction of long-term radioactive inventory through the removal of long-lived nuclides from HLW by P&T technology helps to meet this requirement. If, for example, 99% of MAs contained in spent fuel can be removed, the toxicity of the spent fuel after several hundred years following reprocessing will be equal to the toxicity of the same amount of natural uranium as used in the production of the original fuel.

4.2 Effects on geological disposal

4.2.1 Long-term safety

- Effects on the underground water migration scenario:

Maximum dose can be reduced by about two orders of magnitude by separating and removing 99% of the ^{135}Cs , and 99% or more of the Np and Am, which are parent nuclides of ^{229}Th .

- Effects on the human intrusion scenario:

Risks can be reduced by two orders of magnitude by separating and removing 99-99.99% of the actinide elements.

4.2.2 Impact on geological disposal site design

Approximately two-thirds of the heat from HLW is generated by Cs and Sr, and separation and removal of these elements would shorten the required storage period and reduce the size of the site. The HLW storage period could be reduced by separating and removing exothermic nuclides. In addition, disposal site design could be rationalized by, for example, disposing of the HLW in one large cavity rather than in several smaller ones.

4.3 Effective use of resources

Among the materials in HLW, some can be used effectively as resources. For example platinum group elements are widely used as catalysts to reduce nitrogen oxides in vehicle exhaust gases, and so on. However, prior to actual application, clearance level issues are to be solved.

4.4 Reduction of MA and LLFP inventory, and the times required

Even if P&T technology is employed, some MAs and LLFPs will remain in the waste, and final disposal of such waste will eventually be necessary. An oxide-fuelled or metallic-fuelled fast reactor can transmute MAs from more than five or six LWRs every year. While an ADS with one quarter of thermal output of a LWR can transmute MAs from more than ten LWRs (about 250 kg per year).

4.5 Generation of secondary waste

The aqueous partitioning process, like PUREX reprocessing, generates secondary waste. Compared with reprocessing, however, the volume of secondary waste is lower because P&T technology deals with the very limited quantities of HLLW generated by reprocessing. In the dry-type partitioning process, molten salts and liquid metals are used as solvents, and metallic Li is used as a reducer. These solvents and reducers are less susceptible to degradation by radiation, and may be recycled in the system. But there is almost no experience of using this process on an industrial scale. To evaluate the secondary waste volume, further investigations and experience using actual materials are needed.

4.6 Short-term increase in radiation dose

When P&T technology is employed in the nuclear fuel cycle, exposure dose could increase in the short term as new processes and facilities are introduced and as the volume of MAs and LLFPs to be dealt with in such processes increases. It will be possible, however, to keep exposure dose for workers and the public below the statutory standard, and as low as reasonably possible, by measures such as enhanced shielding.

4.7 Economy

R&D to date has focused on basic studies to obtain fundamental data for designing processes and systems, and no one is in a position to make a reliable cost estimate for the P&T technology. Nevertheless, very preliminary cost estimates of three organisations indicate a few percent of LWR electricity generation cost for PT implementation.

5. FUTURE RESEARCH AND DEVELOPMENT

Modern society demands maximum control of hazardous waste produced by industry, as well as recycling to preserve resources and protect the environment. It goes without saying that the nuclear industry, too, must take all effective measures. P&T technology applied to long-lived nuclides

can be useful in, for example, reducing the long-term radioactive inventory in nuclear waste, and it is appropriate that R&D should be carried out on an ongoing basis.

5.1 P&T technology and the nuclear fuel cycle

P&T technology is a part of the nuclear fuel cycle. The question of how and in what part of the nuclear fuel cycle P&T technology should be incorporated in order to optimize the cycle, should be considered. The purpose of R&D is to suggest scenarios for introducing P&T systems into the nuclear fuel cycle, and to develop designs and establish key technologies for such systems. Keeping the totality of the fuel cycle in mind, it is necessary to correctly evaluate issues of economy, energy security, and reduction of the radioactive inventory in waste, and to analyse the trade-off among those factors.

5.2 Research on system design and development of key technologies

R&D for P&T technology consists of research on system design with the aim of introducing this technology into the nuclear fuel cycle, and development of the key technologies necessary to realise the system. Development of key technologies takes time and should be carried out in a progressive fashion, while at the same time being properly integrated with research on system design.

5.3 How to proceed R&D in future

P&T technology based on the use of power-generating fast reactors, and P&T technology based on the double-strata fuel-cycle concept, on which R&D is being carried out in Japan, have their own distinctive features. These two concepts also provide new options for the fuel cycle and it is therefore appropriate at this stage to continue the development of both. The objectives of further R&D are to study scenarios, including a possible blending of these two concepts, in order to introduce a feasible P&T technology system into the nuclear fuel cycle, and to develop the necessary technologies. System design and P&T introduction scenarios will continue to be studied. According to the scenarios thus defined, and based on the results of R&D to date, small-scale experiments to demonstrate the feasibility of a series of processes will then be conducted. Following this, systems whose feasibility has been successfully demonstrated will be subjected to engineering tests in order to obtain data on their safety. It will be important at this stage to manage the R&D under a system of checks and reviews, and to update the scenarios on a regular basis.

5.4 Co-operation for R&D

Although there are differences in the concepts, reactor types and systems, many common issues exist in R&D on P&T technology. JAERI, JNC and CRIEPI should work together in an effort to resolve those common issues, strengthening their co-operation through the sharing of their R&D results. At the same time, it is important to carry out the R&D effectively by, for example, cooperating with other domestic organizations and using their existing facilities. In Western nations, the trend is toward international co-operation in various areas of P&T technology R&D, and the three organisations should actively join such cooperation frameworks and make use of research facilities available overseas. They are also encouraged to exchange information through the existing OECD/NEA framework.

5.5 R&D schedule and evaluation

P&T technology is inseparable from the nuclear fuel cycle, and it is therefore appropriate to conduct R&D in this area on a time schedule compatible with nuclear fuel cycle R&D. At present, feasibility study on commercialised FBRs and related fuel cycle system is being carried out under the collaborative efforts of JNC, electric utilities, CRIEPI and JAERI. In this study, R&D scenarios toward commercialization of fast reactor system will be reviewed by about 2005. Thus, around the year 2005 is deemed to be an appropriate time to reconsider all R&D scenarios of PT including the use of FBRs for transmutation together with power generation, and the double-strata fuel cycle. Thereafter, progress, results and R&D policy will be checked and reviewed every five years or so. Evaluations of P&T technology system concepts, and reviews of introduction scenarios, should also be conducted.

6. CONCLUDING REMARKS

P&T technology belongs to a world quite different from that of ordinary chemical reactions in the sense that, in P&T, materials are transformed at the atomic level. Its potential is not limited simply to transmutation. In addition, its development raises issues that will be difficult to resolve with existing technology alone, overcoming these difficulties could lead to other exciting technological breakthroughs. This, indeed, should be one reason for young engineers scientists to want to become involved in the field. Research on this kind of advanced technology can be expected to make a great contribution to revitalizing nuclear research generally. P&T technology research should be actively promoted in order to nurture the development of human resources in the nuclear field.

In doing this, however, it is important to create an environment in which innovative ideas can be adopted without “interference” from existing systems. P&T technology requires open-minded R&D.

Inspired by Japan’s OMEGA programme, many similar programmes have been established around the world – in France, other European countries, and the United States. It is expected for Japan to play an important on-going role in this area – and to do so as part of her international contribution, while conducting timely evaluation of R&D progress.

Annex 1

R&D scheme for partitioning and transmutation of long-lived radioactive waste in Japan

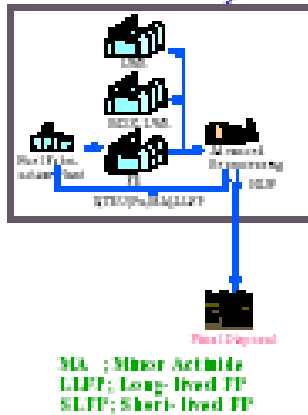
JNC, CRIEPI

- † **Advanced fuel cycle**
 - † Commercial FR for transmutation
 - † Oxide fuel, Metal fuel
 - † 2~5% MA content (homogeneous)

JAERI

- **Double-strata fuel cycle concept**
 - Combination of a power reactor fuel cycle & an independent P-T cycle
 - † Dedicated systems for P-T
 - † Accelerator-Driven System (ADS)

Advanced fuel cycle

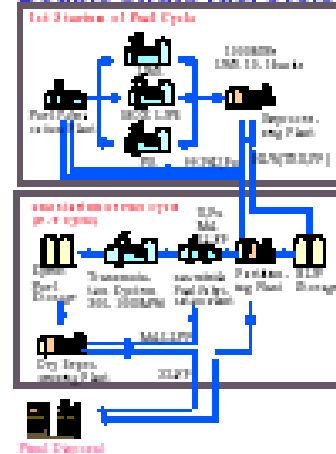


Common technologies

R&D items to be developed in collaboration

- † Separation chemistry
- † Reactor physics
- † Fuel basic property
- † Irradiation test
- † Nuclear data

Double strata fuel cycle



Annex 2

		JAERI	JNC	CRIEPI
Elements subject to P&T	Partitioning	MAAs (Np, Am, Cm), Pu, Tc Platinum group (Ru, Rh, Pd), Sr, Cs	MAAs (Np, Am, Cm), Pu, Tc Platinum group (Ru, Rh, Pd)	MAAs (Np, Am, Cm), Pu
	Transmutation	MAAs (Np, Am, Cm), Tc, I	MAAs (Np, Am, Cm), Pu, Tc, I	MAAs (Np, Am, Cm), Pu
Partitioning process		4-group partitioning process (wet process)	Advanced reprocessing nuclide partitioning system (wet process)	Dry process
	MA separation	DIDPA extraction	CMPOTRUEX process Improved PUREX process	Reductive extraction (molten salt/liquid metal)
	Tc-Platinum group	Precipitation by de-nitration	Electrolytic extraction	-
	Sr-Cs	Column absorption with inorganic ion exchangers	-	-
Transmutation cycle		Double strata fuel cycle	MOX fuelled FBR	Metallic-fuelled FBR
	Fuel type	MA-nitride fuel	MA-MOX fuel	U-Pu-Zr ternary alloy
	Transmutation process	Accelerator driven sub-critical system (ADS) Actinide burner fast reactor (ABR)	FBR	FBR
	Fuel processing	Molten-salt electrolysis (pyroprocess)	Wet process	Molten-salt electro-refining and reductive extraction

Annex 3

**Members of the Advisory Committee on Nuclear Fuel Cycle Back-end Policy
Atomic Energy Commission of Japan**

Yumi Akimoto	President, Mitsubishi Materials Corporation
Kenkichi Ishigure	Professor, Saitama Institute of Technology
Nobuo Ishizuka	Member of Board and Secretary General, Japan Atomic Industrial Forum, Inc.
Michiko Ichimasa	Professor, Ibaraki University
Yoichiro Ohmomo	Senior Executive Director, Institute for Environmental Sciences
Yoshiaki Oka	Professor, University of Tokyo
Takeki Kawahito	Chairman, Radioactive Waste Management Center
Keiji Kanda	Professor, Kyoto University
Tomoko Kusama	President, Oita University of Nursing and Health Sciences
Nobuaki Kumagai	Professor Emeritus, Osaka University
Keiji Kojima	Representative, Geospace Laboratory
Osamu Konishi	Editor, Nippon Hoso Kyokai (Japan Broadcasting Corporation)
Kisaburo Kodama	Director General, Geological Survey of Japan
Shinzo Saito	Vice President, Japan Atomic Energy Research Institute
Shiro Sasaki	Technical consultant, Japan Nuclear Fuel Limited
Atsuyuki Suzuki	Professor, University of Tokyo
Hiroshi Sekimoto	Professor, Tokyo Institute of Technology
Satoru Tanaka	Professor, University of Tokyo
Yasumasa Tanaka	Professor, Gakushuin University
Akira Tokuyama	President, Fuji Tokoha University
Hiroyuki Torii	Editorial Writer, Nihon Keizai Shimbun, Inc.
Yasuo Nakagami	Executive Vice President, Japan Nuclear Cycle Development Institute
Tadashi Nagakura	Senior Advisor Emeritus, Central Research Institute of the Electrical Power Industry
Kunio Higashi	Professor, Kyoto University
Junsuke Fujioka	Managing Director, Japan Radioisotope Association
Hajimu Maeda	Chairman, Nuclear Task Force, Federation of Electric Power Companies
Miyako Matsuda	Commentator on consumer and environmental affairs (Issues related to waste and recycling)
Hirotake Moriyama	Professor, Kyoto University
Yoshiaki Yamanouchi	Attorney at Law

**The U.S. Department of Energy's
Advanced Fuel Cycle Initiative is
Evaluating Potential Costs and Benefits of
Partitioning and Transmutation**

*Presented to the Integration Group for the Safety Case
by Abe Van Luik*

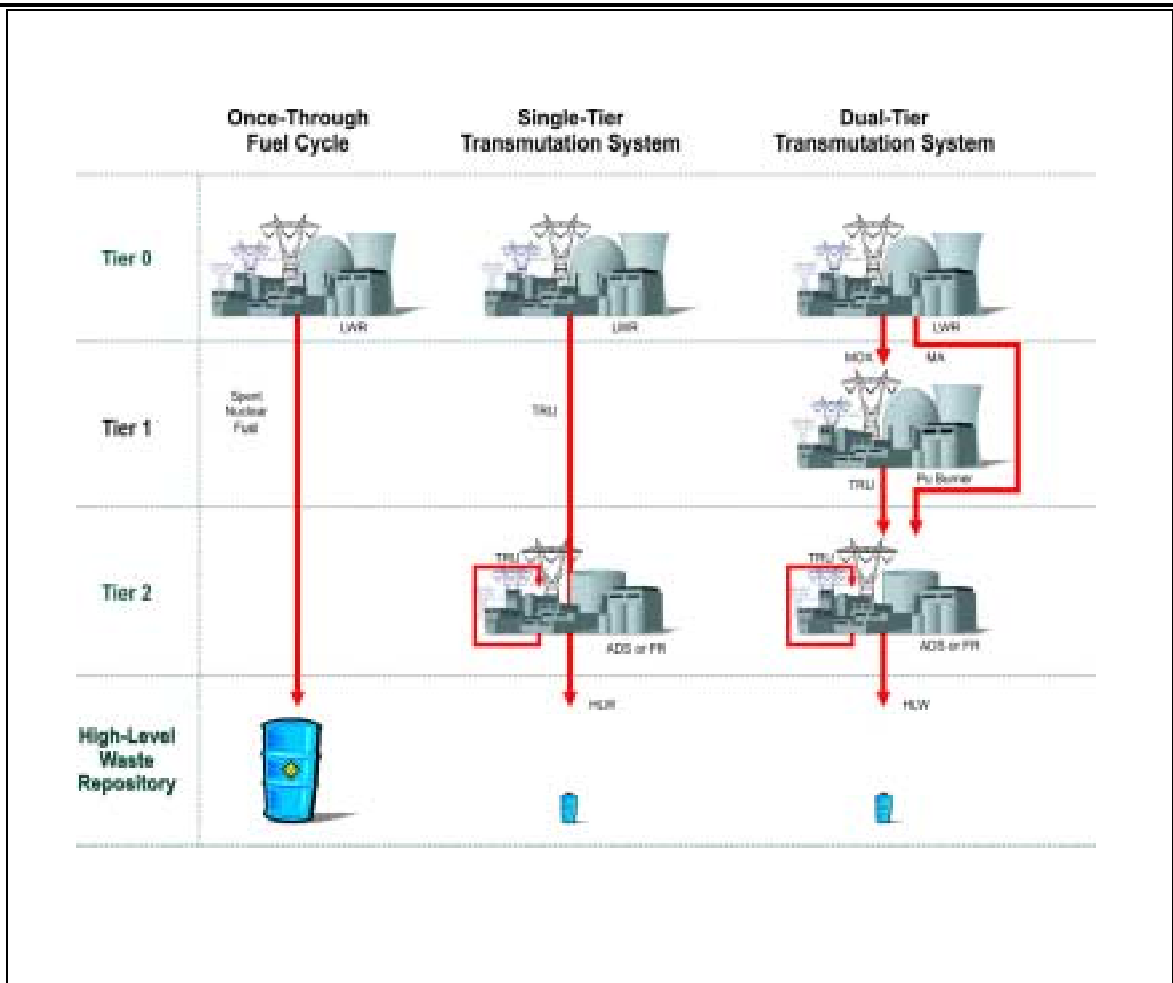
**Based on materials provided by P. J. Finck
Advanced Fuel Cycle Initiative Program Manager at
Argonne National Laboratory, and other sources**

INTRODUCTION

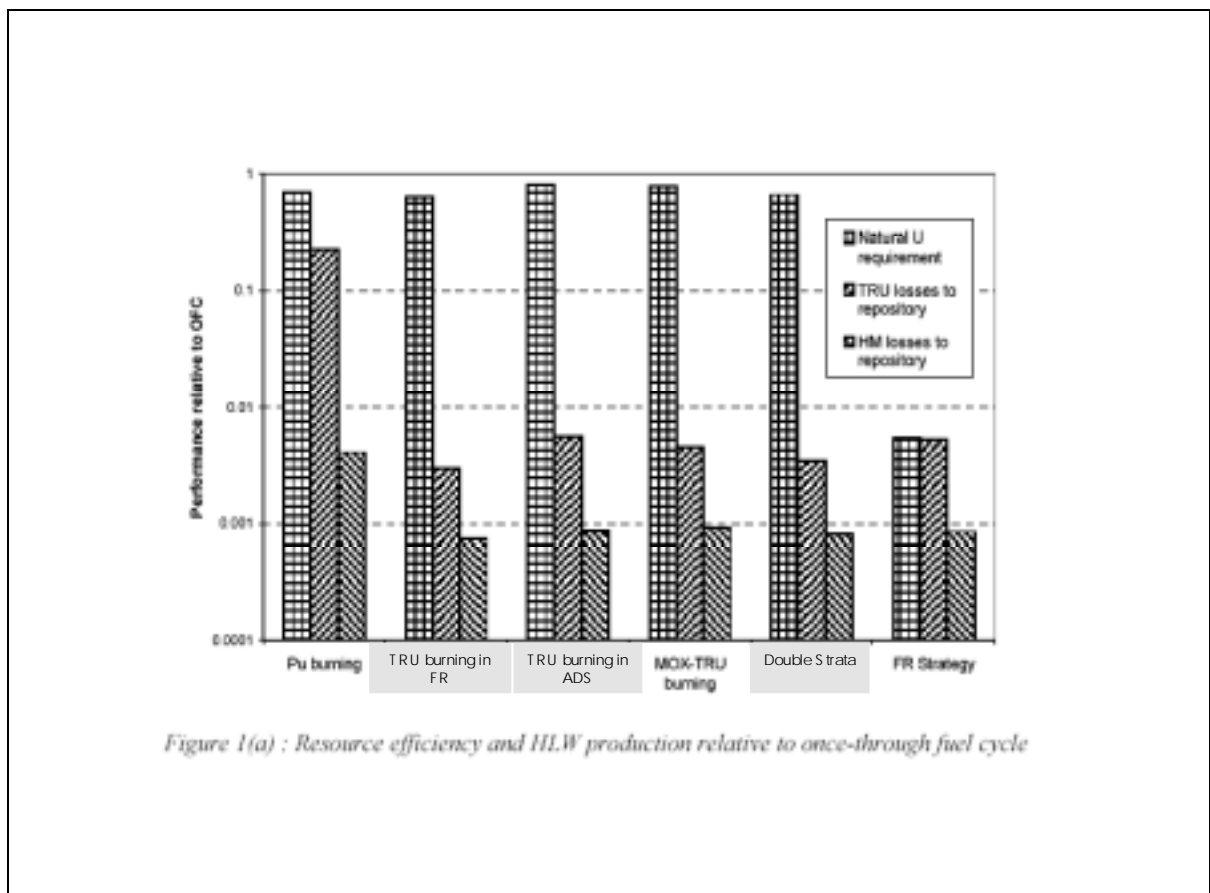
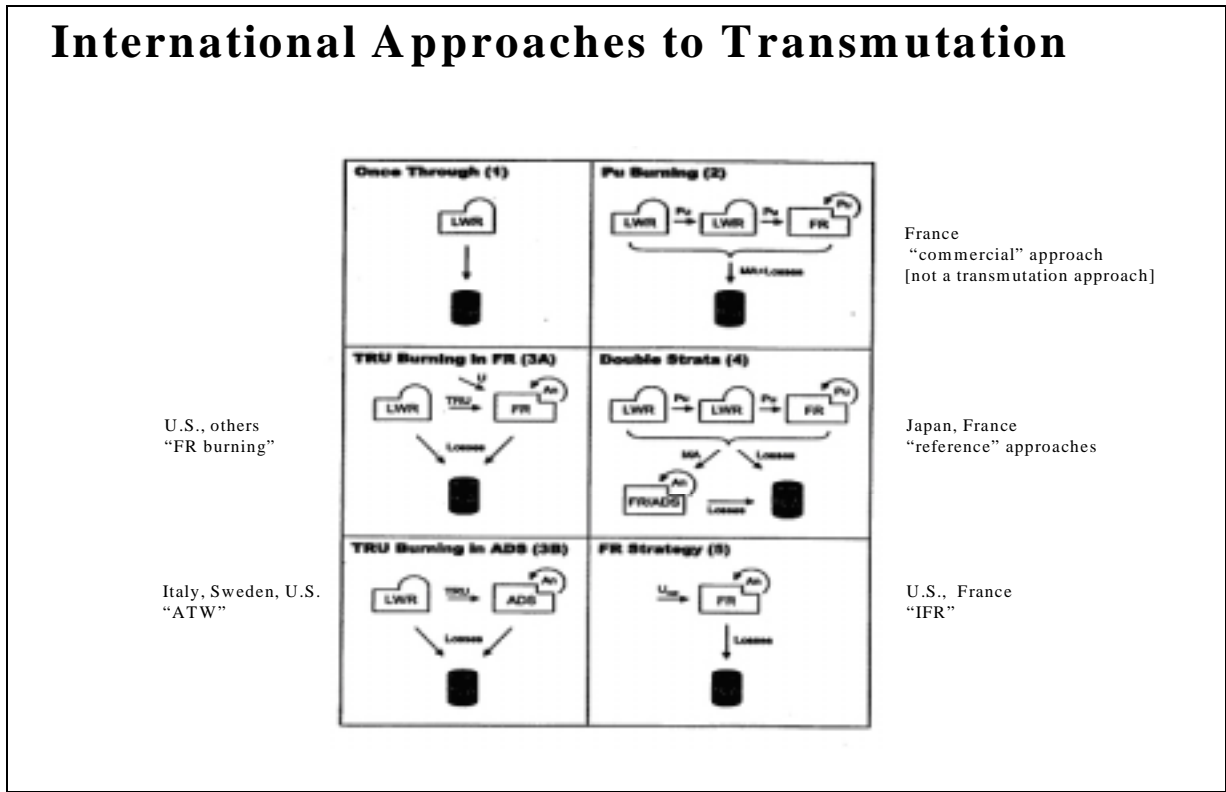
- **Policy Statement from Department of Energy
Undersecretary Card: the Department is interested in
partitioning and transmutation (P&T) to the extent that
“... transmutation is technically feasible and will reduce
the toxicity of the waste to a point that makes it technically
and economically justified ...”**
- **Therefore, making the case for P&T within the
Department requires an evaluation of its potential costs
and benefits**

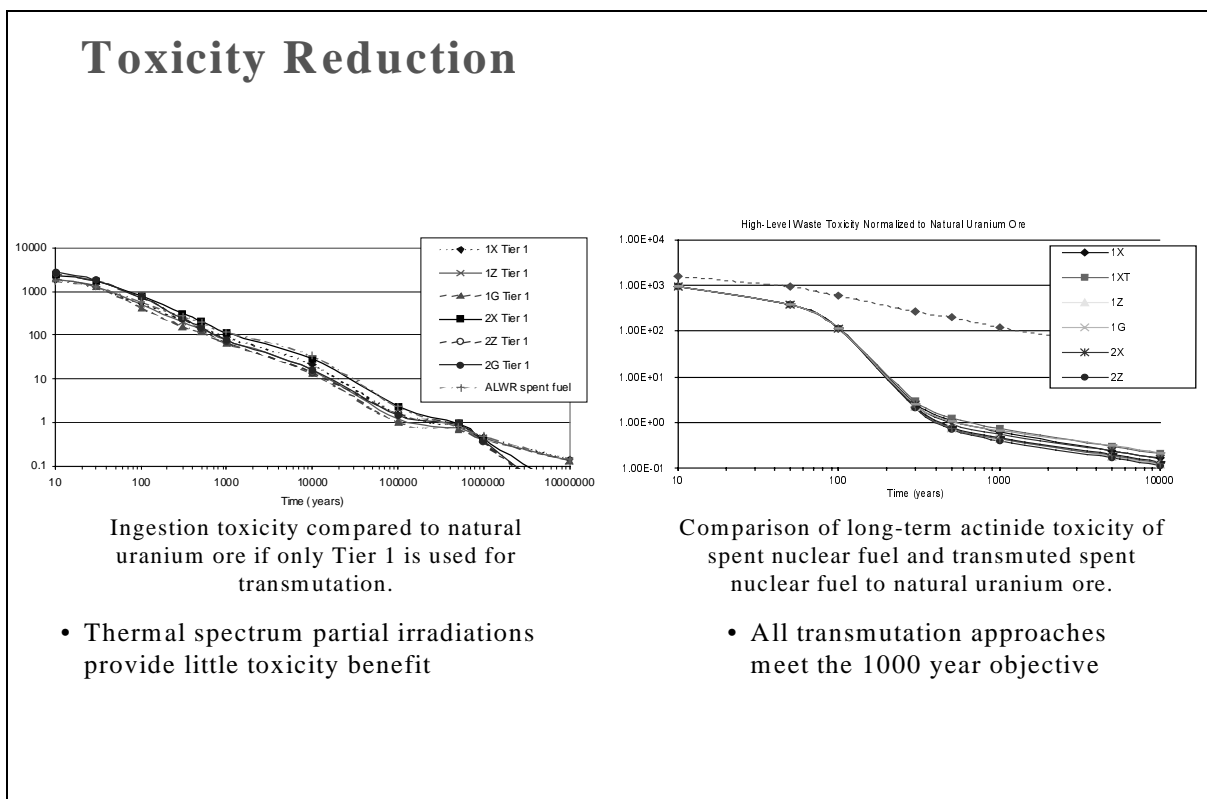
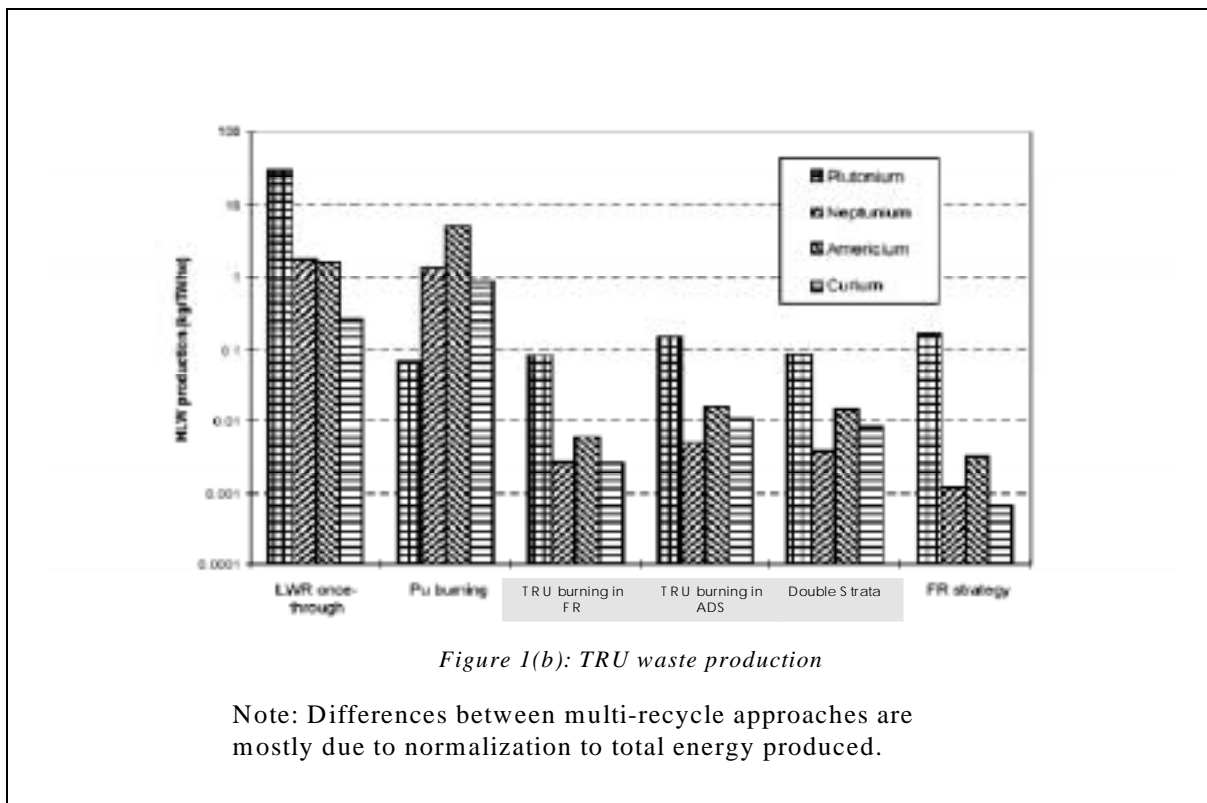
Background

- **Partitioning and Transmutation (P&T) strategies have been studied over the past 15 years as a way to:**
 - Reduce radiotoxicity (Long Lived Fission Products, Minor Actinides)
 - Reduce dose (I, Tc, Np)
 - Reduce proliferation potential
 - Reduce volume of high level waste
 - Reduce heat load
 - Provide a path for effective waste management
- **Summary of Studies**
- **AAA and AFCI programs**



International Approaches to Transmutation

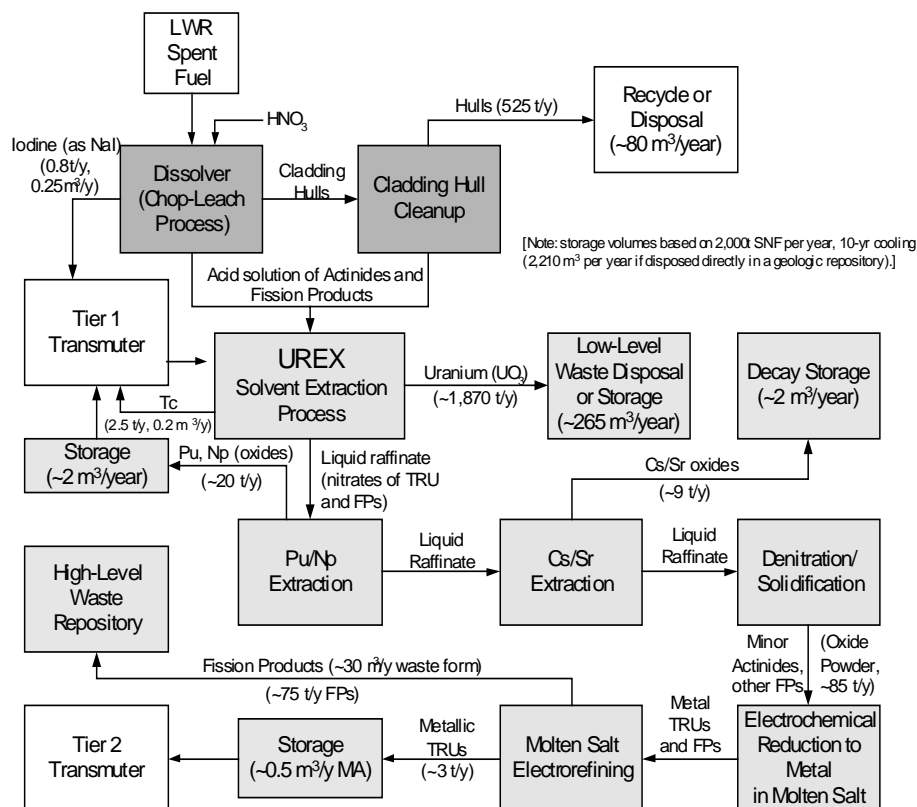




The U.S. Approach

- **1999: ATW Roadmap**
 - Accelerator based transmutation
 - R & D program was launched:
 - Separations
 - Fuels
 - Physics
 - Technology
 - System Studies
- **2002: Report to Congress (In Progress)**
 - System studies in U.S. and Europe indicate preference for reactor based transmutation
 - DOE-NE proposes: isolation of Cs/Sr, recycle of Pu and Np in LWR's, and later recycle of MA's in fast reactors
 - Depending on the national nuclear power scenario, it may delay or avoid need for second repository

Advanced Fuel Cycle System



Repository Benefit Analyses - Example: Effects of Spent Fuel Processing

- **The goal of ongoing work is to quantify the benefits to the repository from spent fuel processing, including**
 - effect of removal of contributors to the potential dose
 - effect of removal of contributors to the heat load
 - identify useful strategies for improving performance
 - **The results of the study will allow an assessment of which alternatives can be economically useful in**
 - increasing the repository capacity
 - reducing the potential hazard from the repository
 - reducing uncertainties associated with the performance of the repository
-

Repository Benefit Analysis - Example Effects of Spent Fuel Processing (continued)

Projects on quantifying the effects of actinide removal have been in place for several years

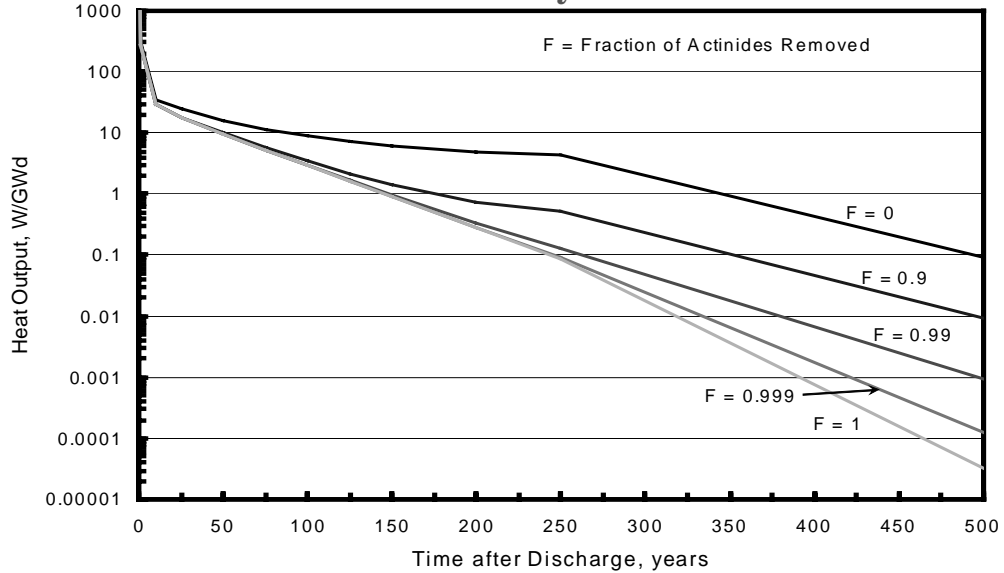
- **Scoping studies using the Yucca Mountain Project GoldSim models of the repository, along with thermal models of Yucca Mountain**

- **Initial results are promising concerning**

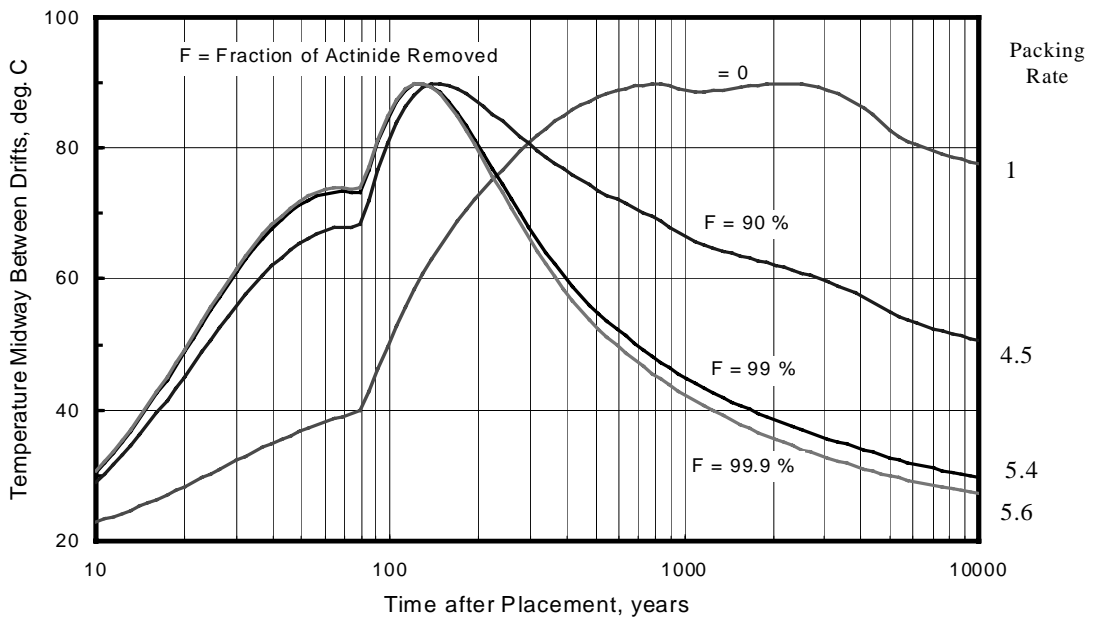
- *increased capacity*
- *shorter times at high temperatures*
- *increasing predictability of waste package performance*

Detailed analyses are planned that will allow better quantification of the impact, along with an economic assessment to determine if the approaches are viable

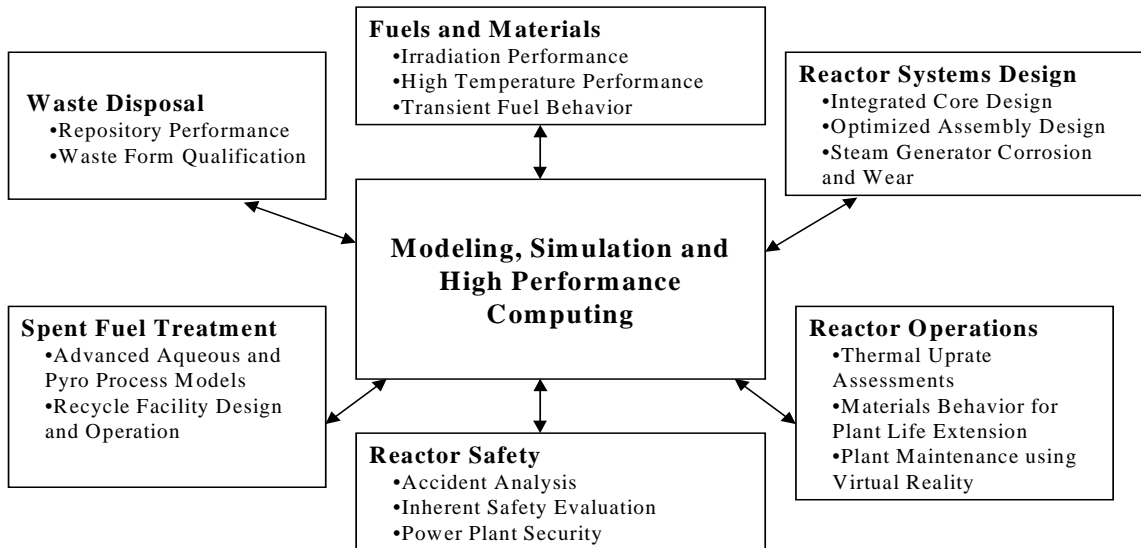
Repository Benefit Analysis - Example Actinide Removal and Decay Heat



Repository Benefit Analysis - Example Actinide Removal and Temperature



Example of Proposal: Simulation-Based Engineering to Integrate All Aspects of Nuclear Energy



Yucca Mountain Project FEIS on Potential Impacts of Separation & Transmutation

- **Section 9.1.3 of the *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada (DOE/EIS-0250)* addressed S&T**
- **Acknowledged that S&T could:**
 - **eliminate/reduce certain radionuclides in the inventory and thus add flexibility to the design of the repository, and**
 - **reduce uncertainties about repository performance**
- **DOE commits to incorporating information from future S&T studies in its decisions**
 - **during preparation of a Mitigation Action Plan for the EIS**
 - **during the repository licensing process, if necessary**

European Commission  Research


RADIOACTIVE WASTE PARTITIONING AND TRANSMUTATION IN THE EURATOM FRAMEWORK PROGRAMMES

Michel Hugon, Ved P. Bhatnagar and Sylvie Casalta
DG RTD-J-4
E-mail: michel.hugon@cec.eu.int

OECD/NEA, IGSC, November 6-8, 2002, Paris, F



EURATOM

uthor - D:\DATA\POWER\PI\ADTTA2001 08.11.2001 - Slide 1


European Commission  Research

EURATOM 5th Framework Programme 1998 - 2002

Key action Thermonuclear fusion	788 M
Key action Nuclear fission	142 M
Generic research Radiological Science	39 M
Support for infrastructures	10 M
Joint Research Center	281 M
Total	1 260 M


EURATOM


uthor - D:\DATA\POWER\PI\ADTTA2001 08.11.2001 - Slide 2

European Commission  Research

PARTITIONING AND TRANSMUTATION

OBJECTIVE OF FP5 (1998-2002)

Provide a basis for evaluating the practicability, on an industrial scale, of partitioning & transmutation for reducing the amount of long lived radionuclides to be disposed of


EURATOM

ufnr - D:\DATA\POWERPNT\ADTTA2001 08.11.2001 - S66e-3

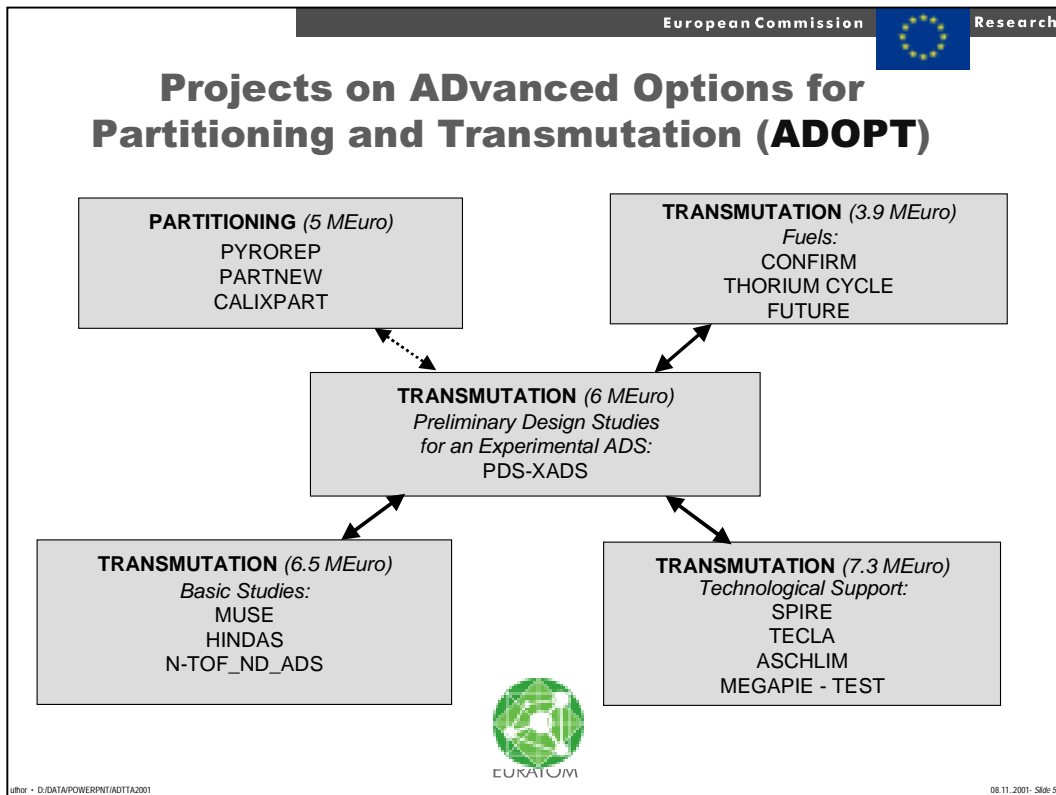
European Commission  Research


Organisations participating in EU research activities on P&T

AEA Technology (UK), ANSALDO (I), APC (GR), BNFL (UK), Catalunya University (E), CEA (F), CERN, Chalmers University (S), CIEMAT (E), CNR (I), CNRS (F), Coimbra University (P), CRIEPI (J), CRS4 (I), CSIC (E), Delft University (NL), Empresarios Agrupados (E), ENEA (I), Framatome-ANP GmbH (D), Framatome-ANP SAS (F), Frankfurt University (D), FZJ (D), FZK (D), FZR (D), Grenoble University (F), Groningen University (NL), GSI (D), Hannover University (D), IBA (B), INFN (I), Institut Quimic de Sarrià CETS (E), ITN Sacavém (P), JRC (EC), Krakov University (PL), KTH (S), KWO Obrigheim (D), LAESA (E), Liège University (B), Mainz University (D), Micromod (D), Nantes University (F), NNC (UK), NRG (NL), NRI (CZ), Parma University (I), Pavia University (I), Politecnico di Milano (I), PSI (CH), PTB (D), Reading University (UK), Santiago de Compostela University (E), SCK•CEN (B), Sevilla University (E), Strasbourg University (F), Studsvik Nuclear AB (S), Subatech (F), Swiss Fed. Inst. of Techn. Zürich (CH), Technische Universität Wien (A), Tractebel (B), Twente University (NL), Universidad Politecnico de Madrid (E), Université Catholique de Louvain (B), Uppsala University (S)


EURATOM

ufnr - D:\DATA\POWERPNT\ADTTA2001 08.11.2001 - S66e-4



European Commission  Research


ADOPT

OBJECTIVES


- ◆ **suggest actions suited to promote consistency between FP5 projects and national programmes**
- ◆ **review overall results**
- ◆ **identify gaps**
- ◆ **give rise to future research proposals**
- ◆ **international relations**

MEETINGS

- ◆ **6 December 2001: coupling with the cluster on basic studies**
- ◆ **14 March 2002: coupling with the cluster on partitioning**
- ◆ **24-25 September 2002: coupling with the cluster on fuels**

 EURATOM

uthor - D:/DATA/POWERPNT/ADITA2001 08.11.2001- Slide 6


European Commission  Research

PARTITIONING (1)


◆ Pyrochemical processes:

PYROREP

- Assessment of flow sheets for pyrometallurgical processes for separation of minor actinides (MA) from lanthanides
- 2 methods: salt/metal extraction and electrorefining
- Compatibility of materials with corrosive media



author - D:\DATA\POWERPNT\ADTTA2001 08.11.2001- Slide 7

European Commission  Research

PARTITIONING (2)


◆ Aqueous processes:
Development of solvent extraction processes of MA from HLLW (at present in 2 steps, tomorrow possibly in 1 step)

PARTNEW


- Closer to pilot plant demonstration
- BTP, dithiophosphinic acids

CALIXPART

- Synthesis of more innovative compounds (calixarenes)
- NMR, X-ray, molecular modeling



author - D:\DATA\POWERPNT\ADTTA2001 08.11.2001- Slide 8

European Commission  Research

TRANSMUTATION - Preliminary Design Studies

PDS-XADS


Preliminary design studies of an European experimental ADS addressing the critical points of the whole system:

- ◆ **accelerator (*cyclotron, linac*)**
- ◆ **liquid heavy metal spallation target (*window*)**
- ◆ **sub-critical core (*small core, larger core cooled by LBE or by gas*)**

Safety and licensing issues


Preliminary assessment of cost

Consolidating road-mapping



EURATOM

uthor - D:\DATA\POWERPNT\ADTTA2001 08.11.2001 - Slide 9

European Commission  Research

TRANSMUTATION - Technological Support (1)


SPIRE

- ◆ **Neutron/proton irradiation effects on structural steels (spallation products, mechanical properties)**
- ◆ **Irradiation in HFR, BR2, BOR60, SINQ**

TECLA


Assessment of lead alloys as spallation target and coolant for ADS:

- **corrosion and protection of structural materials**
- **thermo-hydraulic experiments**



EURATOM

uthor - D:\DATA\POWERPNT\ADTTA2001 08.11.2001 - Slide 10


European Commission  Research

TRANSMUTATION - Technological Support (2)

MEGAPIE-TEST


Design and operation of a heavy liquid metal (Pb-Bi) spallation target producing a high neutron flux

- ◆ **Separate tests for each component (*beam window, heat exchanger, corrosion control system*)**
- ◆ **Safety and reliability aspects**
- ◆ **coupling with the ≈ 1 MW proton beam of the PSI cyclotron in 2004**




EURATOM

author - D:\DATA\POWERPNT\ADTTA2001 08.11.2001 - Slide 17

European Commission  Research

TRANSMUTATION - Fuels

- ◆ **Uranium free nitride fuel: CONFIRM**
 - fabrication of (Am, Zr) N pellets
 - irradiation of (Pu, Zr) N pins in Studsvik
- ◆ **Thorium-plutonium oxide fuel: THORIUM CYCLE**
 - irradiation behaviour at high burn-up in HFR Petten and KWO Obrigheim
- ◆ **Innovative actinide-based oxide fuels: FUTURE**
 - synthesis, characterisation, fabrication tests
 - modeling of the fuel and safety performance



EURATOM

author - D:\DATA\POWERPNT\ADTTA2001 08.11.2001 - Slide 12



TRANSMUTATION - Basic Studies


- ◆ Analytical tools for sub-critical neutronics: **MUSE**
 - validation on MASURCA coupled to a neutron generator
 - code cross comparison, reactivity control techniques
- ◆ Nuclear cross sections:
 - above 20 MeV for ADS engineering design: **HINDAS**
 - measurements for 3 nuclides (Iron, Lead, Uranium) at different European facilities
 - for $1\text{eV} < E < 250\text{ MeV}$ for transmutation: **n-TOF-ND-ADS**
 - measurements at CERN and Geel for actinides and long-lived fission products



CONCLUSION - FP5


- ◆ Research activities on P&T under FP5 are in full operation
- ◆ All important aspects of P&T are covered by the R&D projects to fulfill the objective of FP5
- ◆ Results of FP5 projects will be presented in an International Workshop on P&T and ADS Development to be held in Mol (B) on September 16-19, 2003



European Commission  Research


EURATOM 6th Framework Programme 2002-2006 as adopted by Council on 3 June 2002

◆ Priority Thematic Areas of Research		
● Controlled Thermonuclear Fusion	750 M	
● Management of Radioactive Waste	90 M	
● Radiation Protection	50 M	
◆ Other activities in the field of nuclear technologies and safety		50 M
◆ Nuclear activities of the JRC		290 M
Total		1 230 M




EURATOM

author - D:\DATA\POWER\PI\ADTTA2001
08.11.2001 - Slide 75

European Commission  Research


SP on Nuclear Energy (2002-2006) as adopted by Council on 30/09/2002 *Extract*

◆ Management of Radioactive Waste		90 M
● Research on geological disposal		
● Partitioning and transmutation		
● Concepts to produce less waste		
◆ Other activities in the field of nuclear technologies and safety		50 M
● Innovative concepts to generate energy		
● Education and Training		
● Safety of existing nuclear installations		



EURATOM


author - D:\DATA\POWER\PI\ADTTA2001
08.11.2001 - Slide 76

European Commission  Research


PARTITIONING AND TRANSMUTATION (P&T)

Objective of FP6 (2002-2006)

Determine practical ways of reducing the amount and/or hazard of the long term component of the radioactive waste to be disposed of in geological repositories by P&T and to evaluate their practicability on an industrial scale.




uthor - D:\DATA\POWER\PI\ADTTA2001 08.11.2001 - S86e 17

European Commission  Research


PARTITIONING AND TRANSMUTATION (P&T)

Research areas:

- ◆ ***System assessment***
- ◆ ***Partitioning (chemical separation)***
- ◆ ***Transmutation (nuclear conversion)***




uthor - D:\DATA\POWER\PI\ADTTA2001 08.11.2001 - S86e 18

European Commission  Research


PARTITIONING AND TRANSMUTATION (P&T)

System assessment:

Fundamental assessment of the system and safety aspects of the overall concept of P&T and in particular its practicability on an industrial scale and its impact on waste management and geological disposal.




author - D:\DATA\POWERPNT\ADTTA2001 08.11.2001 - Slide 19

European Commission  Research


PARTITIONING AND TRANSMUTATION (P&T)

Partitioning:

Development of hydrometallurgical and pyrochemical processes for the chemical separation of radionuclides from the high-level radioactive waste with a view to the demonstration of the most promising processes.



author - D:\DATA\POWERPNT\ADTTA2001 08.11.2001 - Slide 20

European Commission  Research


PARTITIONING AND TRANSMUTATION (P&T)

Transmutation:


Development of basic knowledge and technologies for transmutation.

In the case of accelerator driven sub-critical systems (ADS), research on :

- ◆ **fuels for actinide transmutation,**
- ◆ **design and coupling of key elements of ADS,**
- ◆ **safety and licensing issues,**
- ◆ **structural material corrosion and irradiation behaviour,**
- ◆ **basic nuclear data.**



EURATOM

uthor - D:\DATA\POWERPNT\ADTTA2001 08.11.2001 - S86-27

European Commission  Research

FP6 STATUS

- ◆ **FP6 and specific programmes adopted by Council. Rules for participation very close to be approved**
- ◆ **Research Community submitted Eols to use the new instruments (IP, NoE) in FP6. Results of Eol analysis published on CORDIS**
- ◆ **Work programme developed by EC services**
- ◆ **First calls from December 2002**


EURATOM

uthor - D:\DATA\POWERPNT\ADTTA2001 08.11.2001 - S86-27

Accelerator-driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles – A Comparative Study

EXTRACT FROM OECD/NEA PUBLICATION IBSN 92-64-184882-1

EXECUTIVE SUMMARY

Scope of study and principal messages

The long-term hazard of radioactive wastes arising from nuclear energy production is a matter of continued discussion and public concern in many countries. By the use of partitioning and transmutation (P&T) of the actinides and some of the long-lived fission products, the radiotoxicity of the high-level waste (HLW) and, possibly, the safety requirements for its geological disposal can be reduced compared with the current once-through fuel cycle. To make the technologically complex enterprise worthwhile, a reduction in the HLW radiotoxicity by a factor of at least one hundred is desirable. This requires very effective reactor and fuel cycle strategies, including fast reactors (FRs) and/or accelerator-driven, sub-critical systems. The accelerator-driven system (ADS) has recently been receiving increased attention due to its potential to improve the flexibility and safety characteristics of transmutation systems.

The present study compares FR- and ADS-based actinide transmutation systems with respect to reactor properties, fuel cycle requirements, economic aspects, and R&D needs. The essential differences between the various systems are evaluated with the help of a number of representative “fuel cycle schemes”. The strategies investigated include an evolutionary transmutation strategy in which the ADS provides additional flexibility by enabling plutonium utilisation in conventional reactors and confining the minor actinides to a small part of the fuel cycle, and two innovative transuranics (TRU) burning strategies, with an FR or an ADS, in which plutonium and minor actinides are managed together to minimise the proliferation risk. A novelty in the present study is that the analyses are carried out in a consistent manner using reactor and fuel cycle parameters which have been agreed upon by international experts.

Principle messages from the study which could influence P&T policy development are:

- Fuel cycles with multiple recycling of the fuel and very low fuel losses are required to achieve the desired hundred-fold radiotoxicity reduction.
- All transmutation strategies with multiple recycling of the fuel can achieve similar radiotoxicity reductions, but the choice of the strategy strongly influences fuel cycle requirements.

- The ADS is particularly suited as a “dedicated” minor actinide burner in steady-state scenarios and provides flexibility in transient scenarios.
- The ADS-based evolutionary, and the FR-based innovative, approaches appear to be attractive transmutation strategies, from both technical and economic viewpoints.
- The full potential of a transmutation system can be exploited only if the system is utilised for a minimum time period of about a hundred years.
- A considerable amount of R&D on sub-critical reactors, advanced fuels, and materials would be needed before ADS-based transmutation technology could be deployed.

General context

The world-wide increasing energy demand in general, and electricity demand in particular, call for a re-evaluation of fission energy as a long-term energy source. In this context, a recent OECD/NEA publication has investigated the extent to which nuclear energy is compatible with the goals of sustainable development, and how it can best contribute to them [1]. Although present light water reactors (LWRs) are capable of covering the nuclear energy demand for many decades to come, there is a longer-term need for integrating advanced reactors, including fast reactors, into the nuclear energy system. Important development goals for such advanced systems are environmental friendliness, resource efficiency, and cost-effectiveness, while accounting for socio-political concerns such as proliferation.

In the early days of nuclear energy, electricity generation in LWRs as well as FRs was estimated to be economically competitive with other forms of electricity generation. At that time, uranium resources were assumed to be the limiting factor for nuclear deployment, while the limited amount of radioactive waste was seen as less of a concern than it is today. This early perspective called for a rapid introduction of conventional, uranium-plutonium mixed-oxide (MOX) fuelled fast reactors with a fuel cycle which is fully closed for plutonium, but not for the minor actinides neptunium, americium and curium, which are at least as radiotoxic as plutonium. A complete closure of the fuel cycle by recycling the minor actinides as well was already envisaged at that time, but not given much attention because the utilisation of the energy content of the minor actinides is not economically attractive.

Today, while uranium is still abundant but radioactive waste is giving increasing rise to public concern, an attempt to progress towards the ultimate goal of a fully closed, FR-based fuel cycle via the intermediate step of a transmutation system is appropriate. The partitioning and transmutation of actinides and fission products which are now put to waste would allow the “radiological cleanliness” of nuclear energy to be improved, and thus one of the most important requirements for an environmentally friendly nuclear energy system to be addressed. It is clear that not only the technical but also the economic feasibilities of such a system must be demonstrated.

Previous studies and adopted approach

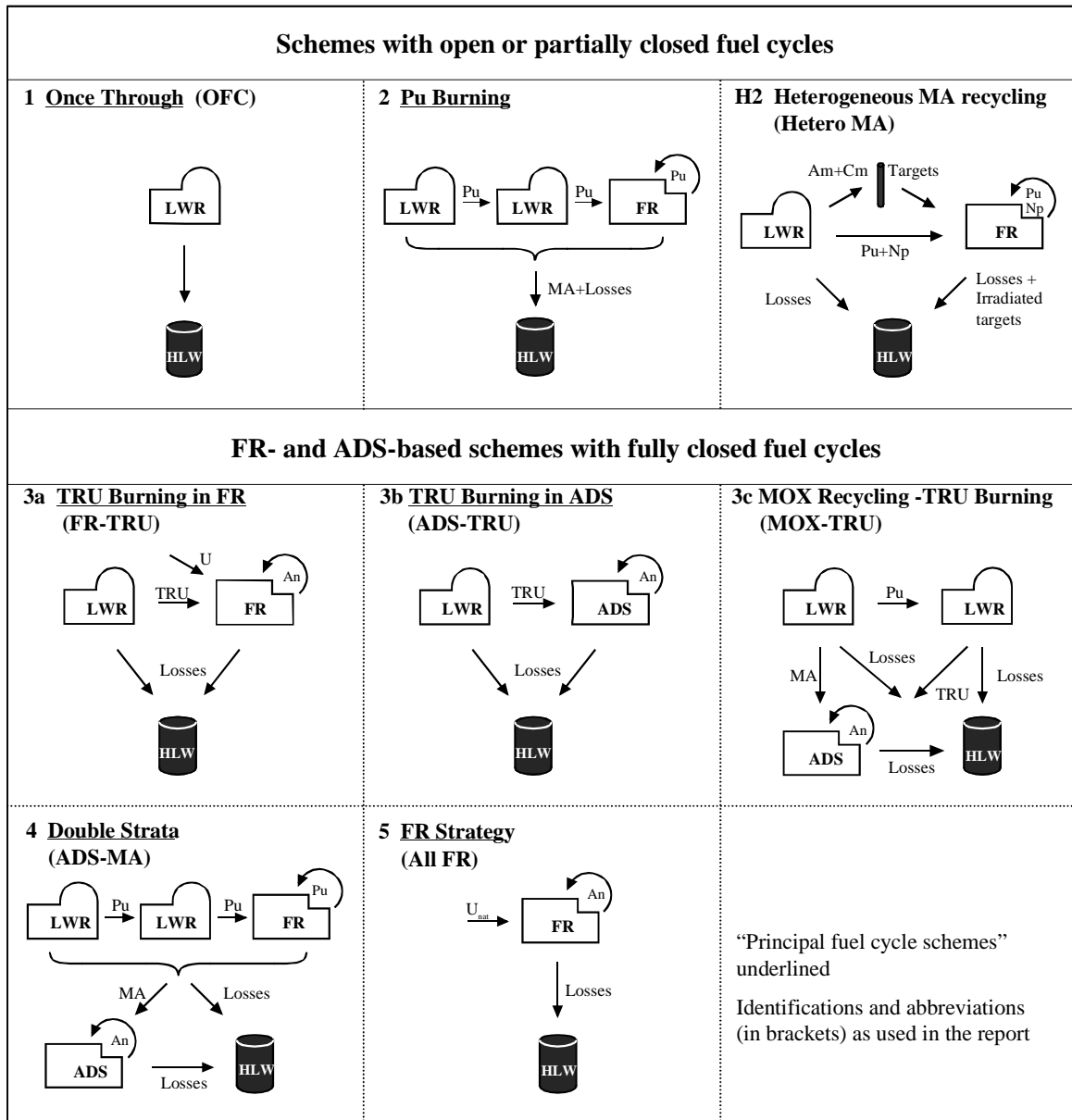
In response to the interest of Member countries, and recognising the activities pursued, the Nuclear Energy Agency initiated a long-term programme on P&T in 1989, addressing a wide range of technical and scientific issues. An International Exchange Programme was established to strengthen international collaboration, and a first P&T systems study was carried out from 1996 to 1998¹. This systems study focused on a review of the progress in P&T and the possible benefits for waste

1. Actinide and Fission Partitioning and Transmutation; Status and Assessment Report, OECD, 1999.

management. Specific fuel cycle strategies were discussed, covering plutonium recycling and the additional burning of minor actinides in dedicated reactor systems; however, the more effective transmutation strategies with fully closed fuel cycles and the specific role of the ADS in these fuel cycles were not addressed. The present, second P&T systems study tries to close this gap and thereby complements the first study. Specific aims of this second study are the clarification of the roles and relative merits of the FR and the fast-spectrum ADS in closed fuel cycles by means of comparative analysis, as well as the assessment of the development status of the ADS with emphasis on reactor and fuel cycle technology, safety, economics, and general feasibility.

To quantitatively assess the advantages and drawbacks of different plutonium and minor actinide (MA) burning strategies, seven “fuel cycle schemes”, shown in Figure 1, have been selected and compared with the current once-through fuel cycle (OFC). The schemes are generic and stand for groups of strategies with scope for variation according to national preferences. All reactors are assumed to be electricity producers.

Figure 1. Overview of analysed fuel cycle schemes



Note:

The “principal” fuel cycle schemes represent cornerstone strategies. Combinations of these are possible. For example, the MOX-TRU scheme combines elements of the ADS-TRU and plutonium burning schemes. The principal schemes were analysed using a single nuclear data library and a single reactor code system.

Schemes 3a, 3b, 3c and 4 allow the essential differences between FR- and ADS-based transmutation strategies with fully closed fuel cycles to be demonstrated. In addition, two schemes with partially closed fuel cycles are considered: scheme 2 is of interest because plutonium burning itself is an important issue and transmutation always involves plutonium burning as a preceding or simultaneous process. The heterogeneous recycling scheme H2 represents a possible alternative to the closed fuel cycle which, however, has an inferior transmutation potential. Finally, the all-FR strategy represents the long-term goal for nuclear development. Only “burner” reactors with solid fuels are considered, and these are optimised for a high burning efficiency so that they can support a large fraction of LWRs in the reactor park. The comparison is unique with regard to the use of consistent calculation methods, and reactor and fuel cycle parameters which have been evaluated specifically for this study.

Sustainability comparison

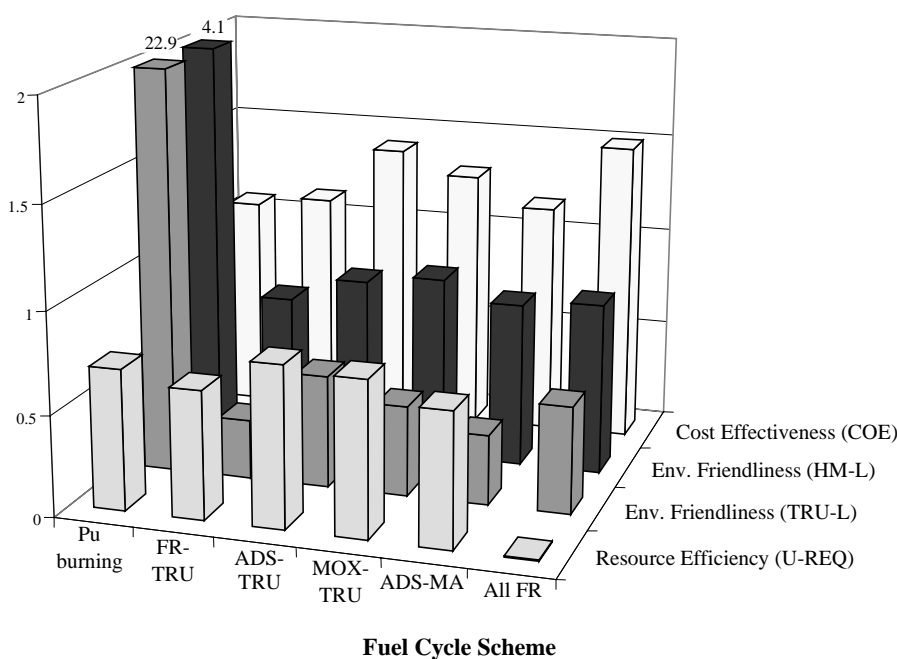
The comparison considers three axes of sustainability, namely resource efficiency, environmental friendliness, and cost-effectiveness. Key criteria along the second axis are the heavy metal and TRU losses, and the radiotoxicity of the losses, to repository. The principal results are illustrated in Figure 2 and can be summarised as follows:

- All transmutation strategies with fully closed fuel cycles can, in principle, achieve similar reductions in the actinide inventory and the long-term radiotoxicity of the high-level waste, and these are comparable with those of a pure fast reactor strategy. This implies that there are no distinct differences between the respective potentials of the FR and the ADS.
- With the assumed reactor and fuel cycle parameters, these strategies can achieve a more than hundred-fold reduction in the long-term waste radiotoxicity and even higher reductions in the heavy metal and TRU losses to repository, compared with the once-through fuel cycle. This applies for multiple recycling of the fuels, high fuel burn-ups, and very low reprocessing and fuel fabrication losses. For the latter, a value of 0.1% for all actinides is assumed, as already achieved for uranium and plutonium, though an ambitious target for the other actinides.
- Regarding actinide waste production and technological aspects, the FR-TRU and the ADS-MA scheme are similarly attractive. The first can gradually evolve to a pure fast reactor strategy, but requires higher initial investment in fast reactor and advanced fuel cycle technologies. The second confines the minor actinides to a small side-stream of the fuel cycle where, however, very innovative technology is needed. Here, the ADS has the advantage that it can burn pure minor actinides while avoiding a deterioration of the core safety characteristics.
- The economic analysis indicates that ADS-based transmutation technology can be made more competitive by burning as much plutonium as possible in conventional reactors, i.e. MOX-fuelled LWRs and FRs. This favours the ADS-MA scheme, which, together with the FR-TRU scheme, also features the lowest electricity costs of all transmutation schemes. In these cases, P&T is estimated to add a relatively modest 10-20% to the electricity costs of the once-through fuel cycle. Although such cost increases would be unacceptable to the market at present, they are limited and might be affordable in the future if price increases rendered fossil fuels less competitive or society placed a premium on reducing waste radiotoxicity.

The study also shows that plutonium burning alone is useful for the management of plutonium, but cannot qualify as a transmutation strategy because it reduces the long-term waste

radiotoxicity by only a factor of about five. Recycling americium and curium heterogeneously in special “target” pins which are disposed of after irradiation, as shown in the *hetero* MA scheme H2, is technically less demanding than a closed fuel cycle strategy, but is also about a factor of two less effective in reducing the radiotoxicity; this strategy is being explored as a near-term transmutation option.

Figure 2. Sustainability comparison



U-REQ: Natural uranium requirement relative to OFC.

TRU-L: Transuranics losses to repository (% of OFC).

HM-L: Heavy metal losses to repository (tenths of % of OFC).

COE: Cost of electricity relative to OFC (nominal case).

Note: For the Pu-burning scheme, TRU-L and HM-L are off-scale.

Regarding the utilisation period of transmutation systems, the study confirms that physical limitations associated with the production and destruction of in-pile and out-of-pile fuel inventories imply very long time constants for the introduction and final phase-out of such systems, and that P&T technology can, therefore, achieve its goal only if it is introduced with the intention of using it for at least a century. In particular, the full radiotoxicity reduction benefit can be realised only if the TRU inventory of the system is ultimately burnt and not put to waste.

Finally, it should be noted that all transmutation strategies including LWRs in the reactor mix require similar uranium resources and produce similarly large streams of residual uranium as the LWR once-through strategy. If the residual uranium is not considered as a resource for future fast reactors, its long-term radiological impact must also be assessed.

ADS technology and safety

Though the FR and the ADS perform similarly with respect to environmental friendliness criteria, they differ considerably from technology, operation, and safety viewpoints.

In this context, two advantages of the ADS are of particular interest:

- The sub-critical, ADS concept enables the design of reactor cores which would otherwise not have acceptable operating characteristics. In particular, the possibility of operating a sub-critical actinide burner with a uranium-free (or thorium-free) fuel supply allows burner effectiveness to be maximised and hence the fraction of specialised transmuters in the reactor park to be minimised.
- Moreover, the concept allows the adjustment, i.e. increase, of the reactivity margin to prompt criticality, thereby reducing the potential of the core for a power excursion. This is useful primarily for minor actinide burners, for which this margin is only about half of that of a normal fast reactor if the core is operated in a critical mode. TRU burner cores are less degraded in this respect.

The above-mentioned advantages of the ADS have to be balanced against the technological challenges arising from the coupling of a reactor and an accelerator, and the necessity to accommodate new types of operational and accidental transients. Regarding the former, the following problems require attention:

- Although the development of accelerators is well-advanced, with beam powers up to 10 MW for cyclotrons and 100 MW for linacs appearing feasible, beam losses and, most importantly, beam trip frequency must be further reduced to satisfy activation, fast temperature fluctuation and mechanical stress criteria for sensitive structures.
- Various problems related to accelerator-reactor coupling have still to be investigated. Thereby, special attention has to be given to the target and especially the beam window, as these components are subjected to complex stress, corrosion and irradiation conditions which are not encountered in normal reactors.

In the area of control and dynamic response, the following issues must be investigated:

- Controlling an ADS with beam power rather than an absorber-based reactivity compensation system reduces the potential of the core for reactivity-induced transients. For a sub-critical TRU burner, however, this advantage has to be balanced against the economic penalty arising from the high burn-up reactivity loss, which implies a higher beam current to maintain power at the end of the reactor cycle. The comparison is complicated because it also involves the balancing of safety-grade requirements for the two control systems.
- In contrast to the static behaviour of sub-critical cores, their response to reactivity and source transients is not yet well studied. The presence of an external neutron source which can vary very rapidly, in combination with very weak reactivity feedback, implies fast and (depending on the sub-criticality level) large responses to accelerator trips and control actions, which put additional demands on the control actuators, the fuel behaviour, and the heat removal processes. In particular, the fuel should be capable of buffering the respective heat balance disturbances.
- If a hypothetical core disruptive accident cannot be excluded deterministically, a prompt negative feedback mechanism must be developed to quench it.

Fuel cycle requirements

Important technological challenges also arise for the fuel cycle of a transmutation system. These are a direct consequence of the goal of transmutation, which implies the contamination of the fuel cycle by high concentrations of minor actinides. A central issue is the reprocessing of the fuel, but fuel fabrication and handling also pose new problems. The respective conclusions can be summarised as follows:

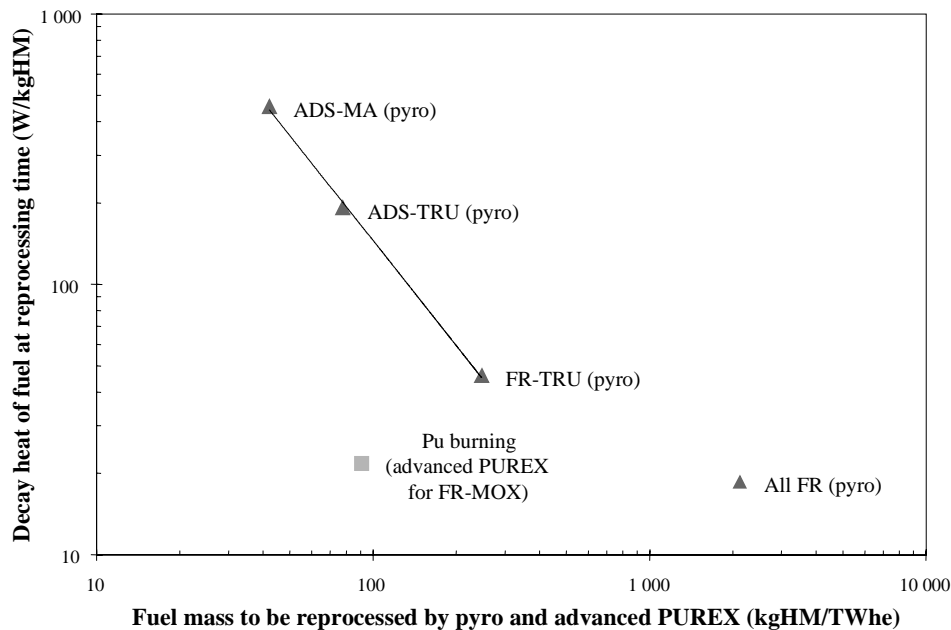
- Transmutation systems involve unusual fuels with high decay heat and neutron emission. A significant effort is required to demonstrate the manufacturability, burn-up behaviour, and reprocessability of these fuels. ADS fuels are particularly enriched in minor actinides and can probably be reprocessed only with the help of pyrochemical methods. These methods have to be further developed to tolerate from ten to more than twenty times higher decay heat levels than those encountered in the pyrochemical reprocessing of fast reactor fuels.
- The introduction of pyrochemical processing technologies at the industrial level will require the development of new process flowsheets and the use of potentially very corrosive reagents in hostile environments. These processes will generate chemical and radiological hazards which will have to be mitigated.
- PUREX aqueous reprocessing can be considered as valid for the FR-MOX fuel in the plutonium-burning and double strata schemes. Reprocessing of this fuel within short cooling times and with the required high recovery yields, however, will require the plutonium dissolution yield to be improved and the PUREX process to be modified.
- Due to the high radioactivity of FR-MOX fuel, its handling will require measures to be taken to reduce the radiation doses in the fabrication plant and during the transportation of the fuel assemblies. The increased requirements for shielding, and the preference for short transportation paths, of multiple recycled fuels also favour the pyrochemical reprocessing method at the reactor site.

During the past few years, many of these problems, especially in the separation area, have been addressed very successfully on a laboratory scale. The application of the processes on an industrial scale, however, still requires large extrapolations.

Figure 3 summarises the requirements of the different fuel cycle schemes for advanced aqueous reprocessing technology, as needed for the multiple recycled FR-MOX fuel, and for pyrochemical reprocessing technology. Regarding the pyrochemical reprocessing requirements of the transmutation schemes, there is some compensation for a high decay heat level by a low throughput, indicating that the reprocessing challenges are not very different (the trendline in the figure illustrates that the product of the two quantities is approximately constant).

A striking feature is that the pyroprocessing requirement of the all-FR scheme is much higher than that of the transmutation schemes. This is a consequence of accommodating the driver and the blanket fuel in the same fuel rod and blending the two components before processing. The blending has the advantage of reducing the decay heat of the fuel to be reprocessed and increasing the proliferation resistance of the system, but imposes high fuel throughput, and hence also economic, penalties on the scheme. These penalties could be reduced if the blanket were separated from the driver fuel and reprocessed using PUREX or UREX technology.

Figure 3. Advanced reprocessing requirements



Notes:

1. The ADS-MA scheme requires both pyro and advanced PUREX reprocessing. The requirements for the latter are very similar to those for the Pu-burning scheme.
2. Decay heats have to be compared with a “normal” decay heat of about 6 W/kgHM for LWR-MOX fuel.

Fission product transmutation

Fission product transmutation was already reviewed in the status and assessment report published in 1999 [2]. The present study indicates that, apart from its interesting potential as a powerful neutron source, the ADS does not open fundamentally new perspectives on this topic. Important general conclusions are:

- Excess neutrons produced by critical and sub-critical burners can, in principle, be utilised to transmute fission products. With the neutron fluxes available in these systems, it is theoretically possible to transmute the long-lived fission products; the transmutation of the more abundant short-lived fission products, however, is impracticable due to insufficient transmutation rates. This means that transmutation, in principle, allows the mitigation of the long-term risk from fission products in a geological repository, but cannot significantly reduce the heat generation and mass of the disposed fission products.
- Minimising the fraction of specialised transmuters in the reactor park can result in an insufficient neutronic potential for transmuting the long-lived fission products of the entire park. If the transmutation would be limited to ^{129}I and ^{99}Tc , all TRU burning strategies could, theoretically, accomplish the task.
- In practice, the necessity of isotopic separation, as well as difficulties in the preparation of targets, present difficult obstacles for fission product transmutation, which currently reduces the number of candidate nuclides to only one or two, i.e. ^{99}Tc and, possibly, ^{129}I .

(so far, the feasibility has been established only for ⁹⁹Tc). This means that, for the remaining long-lived fission products, partitioning followed by immobilisation in a specially stable matrix may remain the only realistic method for reducing their radiological impact.

R&D needs

Developing advanced reactors and fuel cycles to a point where they could be deployed in a technically satisfactory and cost-effective manner can be expected to require long lead-times. The study concludes that, in order to keep the P&T option open, focused R&D should be continued on critical and sub-critical fast reactors, reprocessing technologies, advanced fuels, structural and coolant materials, and irradiation targets containing transmutable elements.

Thereby, emphasis should be placed especially on:

- Basic R&D is needed for the new FR and ADS in the fields of nuclear data and neutronic calculations, fuel technologies, structural materials, liquid metals, reprocessing technologies, target materials and high power accelerators (the last two only for ADS).
- Experimentation on fuels, as no concept can be considered seriously if the appropriate fuels are not defined and proven, i.e. fabricated, irradiated, and reprocessed.
- The continued availability of fast-spectrum irradiation facilities.
- The demonstration at appropriate scale of the performance of pyrochemical processes, in order to assess in more detail the technical-economic viability of the respective fuel cycle options.
- A clarification of the advantages and disadvantages of different coolants for fast-spectrum systems.
- Improved modelling tools to simulate materials behaviour under mixed irradiation conditions and, possibly, high temperatures.
- Safety analyses of ADS.

In addition to this R&D, countries embarking on an ADS-based fuel cycle strategy should envisage a demonstration experiment which allows the ADS concept to be validated from operation and safety viewpoints.

Finally, it should be emphasised that a satisfactory answer to the crucial question as to whether the benefits from P&T can outweigh the necessary technological and financial investments will require a substantial strengthening of the effort in the area of performance assessment studies for geological repositories using a P&T source term.

LIST OF PARTICIPANTS

BELGIUM

DE PRETER, Peter
NIRAS-ONDRAF
Avenue des Arts, 14
B-1210 Bruxelles

Tel: +32 (0)2 212 1049
Fax: +32 (0)2 218 5165
Eml: p.depreter@nirond.be

LALIEUX, Philippe
Disposal Directorate
ONDRAF/NIRAS
Avenue des Arts, 14
B-1210 Brussels

Tel: +32 2 212 10 82
Fax: +32 2 218 51 65
Eml: p.lalieux@nirond.be

MARIVOET, Jan
Centre d'Etude de l'Energie
Nucleaire (CEN/SCK)
Boeretang 200
B-2400 MOL

Tel: +32 (0) 14 333242
Fax: +32 (0) 14 323553
Eml: jmarivoe@sckcen.be

CANADA

FLAVELLE, Peter
Senior Specialist
Wastes and Geosciences Division
Canadian Nuclear Safety Commission
P.O. Box 1046, Station B, 280 Slater St.
Ottawa, Ontario K1P 5S9

Tel: +1 613 995-3816
Fax: +1 613 995-5086
Eml: flavellep@cnsccsn.gc.ca

RUSSELL, Sean
Manager - Long-Term Waste Management Tech
Nuclear Waste Management Division
Ontario Power Generation Inc.
700 University Avenue, H16 D27
Toronto, Ontario M5G 1X6

Tel: +1 416 592-2854
Fax: +1 416 592-7336
Eml: sean.russell@opg.com

CZECH REPUBLIC

KONOPASKOVA, Sona
Radioactive Waste Repository Authority
Dlazdena 6
110 00 Praha 1

Tel: +420 2 21 42 1518
Fax: +420 2 21 42 1544
Eml: Konopaskova@rawra.cz

FINLAND

HAUTOJARVI, Aimo
POSIVA Oy
FIN-27160
Olkiluoto

Tel: +358 283723747
Fax: +358 28372 3709
Eml: aimo.hautojarvi@posiva.fi

PALTEMAA, Risto
Radiation and Nuclear Safety Authority
(STUK)
P.O. Box 14
FIN-00881 Helsinki

Tel: +358 9 759 88 313
Fax: +358 9 759 88 670
Eml: risto.paltemaa@stuk.fi

VIENO, Timo
VTT PROCESSES
P.O. Box 1608
FIN-02044 VTT

Tel: +358 9 456 5066
Fax: +358 9 456 6390
Eml: timo.vieno@vtt.fi

FRANCE

BRUNO, Gerard
IRSN
IRSN/DES/SESID - BP 17
92262 Fontenay-aux-Roses Cedex

Tel: +33 1 58 35 77 55
Fax: +33 1 58 35 77 27
Eml: gerard.bruno@irsn.fr

CAVEDON, Jean-Marc
CEA Saclay
DEN/DDIN
F-91191 Gif-sur-YVETTE

Tel: +33 1 69 08 44 93
Fax: +33 1 69 08 32 32
Eml: jean-marc.cavedon@cea.fr

GAY, Didier
IRSN/DES/SESID
BP 17
92262 Fontenay aux roses Cedex

Tel: +33 1 5835 91 58
Fax: +33 1 58 35 77 27
Eml: didier.gay@irsn.fr

GREVOZ, Arnaud
ANDRA
Directeur Sûreté Qualité Environnement
Parc de la Croix Blanche
1-7, rue Jean Monnet
F-92298 Chatenay-Malabry CEDEX

Tel: +33 1 46 11 80 35
Fax: +33 1 46 11 80 13
Eml: arnaud.grevoz@andra.fr

RAIMBAULT, Philippe
Direction Générale de la Sûreté Nucléaire
et de la Radioprotection (DGSNR)
10, Route du Panorama,
Robert Schumann - BP 83
F-92266 Fontenay-aux-Roses Cedex

Tel: +33 1 4319 7015
Fax: +33 1 4319 7166
Eml: philippe.raimbault@asn.minefi.gouv.fr

GERMANY

ROEHLIG, Klaus-Juergen
Gesellschaft für Anlagen- und
Reaktorsicherheit (GRS) mbH
Schwertnergasse 1
D-50667 Köln

Tel: +49 221 2068 796
Fax: +49 221 2068 939
Eml: rkj@grs.de

STORCK, Richard
Gesellschaft fuer Anlagen und
Reaktorsicherheit (GRS) mbH
Theodor-Heuss-Strasse 4
D-38122 BRAUNSCHWEIG

Tel: +49 531 8012 205
Fax: +49 531 8012 211
Eml: sto@grs.de

WALLNER, Manfred
Federal Institute for Geosciences and
Natural Resources (BGR)
Stilleweg 2
D-30655 Hannover

Tel: +49 511 643 2420
Fax: +49 511 643 3694
Eml: manfred.wallner@bgr.de

WOLLRATH, Jürgen
Bundesamt für Strahlenschutz(Bfs)
Federal Office for Radiation Protection
Postfach 10 01 49 - Willy-Brandt-Strasse
D-38201 Salzgitter

Tel: +49 1888 333 1964
Fax: +49 1888 333 1605
Eml: JWollrath@BfS.de

HUNGARY

BUDAY, Gabor
Director of Science and Technology
Public Agency for Radioactive Waste Management
H-7031 Paks
PO Box 12

Tel: +36 75 519 530
Fax: +36 75 519 569
Eml: gabor.buday@rhk.hu

ITALY

VENTURA, Giancarlo
ENEA - CR Casaccia
Via Anguillarese, 301
00060 S. Maria di Galeria
Rome - Italy

Tel: +39 06 30486542
Fax: +39 06 30486308
Eml: giancarlo.ventura@casaccia.enea.it

JAPAN

KIMURA, Hideo
Waste Disposal Safety Assessment Laboratory
JAERI
Tokai-mura, Naka-gun
Ibaraki-ken 319-11 95

Tel: +81-29-282-5941
Fax: +81-29-282-5842
Eml: hkimura@popsvr.tokai.jaeri.go.jp

UMEKI, Hiroyuki
Nuclear Waste Management Organization
(NUMO)
Mita NN Bldg., 1-23, Shiba 4-Chome, Minato-ku
Tokyo 108 0014

Tel: +81 3 4513 1503
Fax: +81 3 4513 1599
Eml: humeki@numo.or.jp

KOREA (REPUBLIC OF)

KANG, Chul-Hyung
Geological Disposal System Dev.
Korea Atomic Energy Research Institute (KAERI)
P.O. Box 105, Yusong
Daejeon 305-600

Tel: +82 42 868 2632
Fax: +82 42 868-2035
Eml: chkang@kaeri.re.kr

NETHERLANDS

O'SULLIVAN, Patrick J.
Team Co-ordinator - Radioactive Waste and
Nuclear Research and Consultancy Group (NRG)
Postbus 25
1755 ZG PETTEN

Tel: +31 224 564533
Fax: +31 224 568491
Eml: osullivan@nrg-nl.com

SPAIN

ALONSO, Jesus
ENRESA
Calle Emilio Vargas, 7
E-28043 Madrid

Tel: +34 91 566 8108
Fax: +34 91 566 8165
Eml: jald@enresa.es

SWEDEN

DVERSTORP, Björn
Department of Waste Management and
Environmental Protection
Swedish Radiation Protection Institute (SSI)
S-102 40 Stockholm

Tel: +46 8 7297 248
Fax: +46 8 7297 108
Eml: Bjorn.Dverstorp@ssi.se

HEDIN, Allan
Swedish Nuclear Fuel & Waste
Management Co. (SKB)
Box 5864
S-102 40 Stockholm

Tel: +46 8 459 85 84
Fax: +46 8 661 57 19
Eml: allan.hedin@skb.se

JENSEN, Mikael
Swedish Radiation Protection Institute (SSI)
S-171 16 Stockholm

Tel: +46 8 72 97 100
Fax: +46 8 72 97 162
Eml: mikael.jensen@ssi.se

SIMIC, Eva
SKI - Statens kärnkraftinspektion
Swedish Nuclear Power Inspectorate
S-106 58 Stockholm, Sweden

Tel: +46 8 698 84 86
Fax: +46 8 661 90 86
Eml: eva.simic@ski.se

SWITZERLAND

HADERMANN, Jörg
 Paul Scherrer Institute
 Waste Management Laboratory
 CH-5232 VILLIGEN PSI

Tel: +41 56 310 2415
 Fax: +41 56 310 2821
 Eml: joerg.hadermann@psi.ch

SCHNEIDER, Jürg
 NAGRA
 Hardstrasse 73
 CH-5430 Wettingen

Tel: +41 56 437 13 02
 Fax: +41 56 437 13 17
 Eml: schneider@nagra.ch

VIGFUSSON, Johannes O.
 Section for Transport and Waste Management
 HSK - Swiss Federal Nuclear Safety
 Inspectorate
 CH-5232 Villigen HSK

Tel: +41 56 310 3974
 Fax: +41 56 310 3907
 Eml: johannes.vigfusson@hsk.psi.ch

WYDLER, Peter
 Huttenacherstr. 12,
 CH-5452 Oberrohrdorf

Tel: +41 56 310 20 67
 Fax: +41 56 310 45 27
 Eml: peter.wydler@psi.ch

UNITED KINGDOM

HOOPER, Alan J.
 Chief Scientific Advisor
 United Kingdom Nirex Limited
 Curie Avenue
 Harwell, Didcot
 Oxfordshire OX11 0RH

Tel: +44 1235 825 401
 Fax: +44 1235 820 560
 Eml: alan.hooper@nirex.co.uk

SUMERLING, Trevor
 Safety Assessment Mngt. Ltd
 Beech Tree House
 Hardwick Road
 Whitchurch-on-Thames
 READING, RG8 7HW

Tel: +44 1189 844 410
 Fax: +44 1189 841 440
 Eml: sumerling@sam-ltd.com

THOMSON, Gavin
 Environmental Risk Assessments Team
 Research and Technology
 BNFL
 R202, Risley
 Warrington WA3 6AS, Cheshire

Tel: +44 1925 832654
 Fax: +44 1925 833561
 Eml: gavin.thomson@bnfl.com

WILMOT, Roger
 Galson Sciences Ltd
 5 Grosvenor House
 Melton Road
 Oakham
 Rutland LE15 6AX

Tel: +44 1572 770 649
 Fax: +44 1572 770 650
 Eml: rdw@galson-sciences.co.uk

YEARSLEY, Roger
Centre for Risk and forecasting
Environment Agency
Kings Meadow House
Kings Meadow Road
READING RG1 8DQ

Tel: +44 118 953 52 58
Fax: +44 118 953 5265
Eml: roger.yearsley@
environment-agency.gov.uk

UNITED STATES OF AMERICA

BEAUHEIM, Richard L.
Sandia National Laboratories
13255 W. Center Dr.
Lakewood,
CO 80228-2428

Tel: +1 303 980 8019
Fax: +1 505 234 0061
Eml: rlbeauh@sandia.gov

LEVICH, Robert A.
U.S. Department of Energy
1551 Hillshire Drive,
Las Vegas
NV 89134

Tel: +1 702 794 5449
Fax: +1 702 794 5431
Eml: bob_levich@ymp.gov

SAGAR, Budhi
CNWRA - Southwest Research
Institute, CNWRA
Post Office Drawer 28510
6220 Culebra Road
San Antonio, TX 78238

Tel: +1-210-522-5252
Fax: +1-210-522-5155
Eml: bsagar@swri.org

VAN LUIK, Abraham E.
U.S. Department of Energy
Office of Repository Development
1551 Hillshire Drive
Las Vegas, NV 89134

Tel: +1 702 794-1424
Fax: +1 702 794-1435
Eml: abe_vanluik@ymp.gov

International Organisations

METCALF, Phil
Head, Disposable Waste Unit
Waste Safety Section
International Atomic Energy Agency
Wagramer Strasse 5 P.O. Box 100
A-1400 Vienna

Tel: +43 1 2600 22676
Fax: +43 1 26007
Eml: P.Metcalf@iaea.org

HUGON, Michel
European Commission
DG Research J-4,
MO75 5/55
B-1049 Bruxelles

Tel: +32 2 296 57 19
Fax: +32 2 295 49 91
Eml: Michel.Hugon@cec.eu.int

VON MARAVIC, Henning
 European Commission
 DG RTD J-4
 MO75, 5/50
 B-1049 Bruxelles

Tel: +32 2 29 65273
 Fax: +32 2 29 54991
 Eml: henning.ritter-von-maravic@cec.eu.int

OECD Nuclear Energy Agency
 12, boulevard des Iles
 F-92130 Issy-les-Moulineaux
 Fax: +33 (0)1 45 24 11 10

HAAPALETHO Timo
 Nuclear Development

Tel: +33 (0)1 45 24 10 67
 Eml: timo.haapalehto@oecd.org

NORDBORG Claes
 Head, Nuclear Science

Tel: +33 (0)1 45 24 10 90
 Eml: nordborg@nea.fr

PESCATORE, Claudio
 Radiation Protection and Waste Management

Tel: +33 (0)1 45 24 10 48
 Eml: claudio.pescatore@oecd.org

RIOTTE, Hans
 Head, Radiation Protection and Waste Management

Tel: +33 (0)1 45 24 10 40
 Eml: hans.riotte@oecd.org

RUEGGER, Bertrand
 Radiation Protection and Waste Management

Tel: +33 (0)1 45 24 10 44
 Eml: ruegger@nea.fr

SHIMOMURA, Kazuo
 Deputy Director, Safety and Regulation

Tel: +33 (0)1 45 24 10 04
 Eml: kazuo.shimomura@oecd.org

VOINIS, Sylvie
 Radiation Protection and Waste Management

Tel: +33 (0)1 45 24 10 49
 Eml: ruegger@nea.fr

WILMER Peter
 Head, Nuclear development

Tel: +33 (0)1 45 24 10 60
 Eml: peter.wilmer@oecd.org