Nuclear Development

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

A Comparative Study

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Annex C

HISTORY OF P&T STUDIES IN OECD/NEA MEMBER COUNTRIES AND INTERNATIONAL ORGANISATIONS

1. *First generation systems studies* on P&T as a new waste management issue were initiated in the 1970s in different OECD/NEA Member countries:

   - In 1973, the Japan Atomic Energy Industry Forum published a report titled "A closed system for radioactivity" [1]. This report pointed out the importance of R&D for P&T of long-lived nuclides as long-term efforts. JAERI started the development of the partitioning process for high-level liquid waste and the design study of a transmutation system in mid 1970s.

   - In the United States, many individual researchers and small groups were conducting studies related to P&T since Steinberg's seminal work in 1964 [2]. Oak Ridge National Laboratory investigated P&T during the 1970s from a theoretical and assessment perspective [3-4]. Claiborne [5] demonstrated in 1972 the neutron-physical feasibility of transmuting "by-product actinides" in LWRs. Argonne National Laboratory (ANL) performed very interesting work on closing the fuel cycle with Pu-recycling and having potential for P&T. Specifically the pyrochemical reprocessing methods were initially developed in ANL and these methods remain of high value in future P&T-schemes. This work by ANL was however almost exclusively based on own funding without specific governmental support.

   - Simultaneously, the German Research Centre of Karlsruhe, the CEA in France and the European Commission at the Joint Research Centre of Ispra [6-7] started a comprehensive theoretical and experimental R&D programme. In France, the Castaing Commission [8] conducted a general investigation in 1981-82 on the different approaches possible in the fuel cycle and included the P&T option as a mandatory route for further R&D. The studies were conducted during about ten years and were summarised in overview reports which showed the complexity of the issue and the discrepancy between the waste management "risk" approach on long-term disposal and the P&T-approach aiming at the reduction of the radiotoxic inventory by recycling long-lived nuclides into fission reactors.

2. Three major "final assessment" reports were published in the late 1970s and early 1980s, which led to following conclusions:

   - The conclusions of the EC programmes on P&T in 1977 and 1983 [6-7] were that the impossibility of total actinide recycling and the impact of the process flowsheets complexity on waste streams were the main limitation of the potential benefits from the proposed P&T scenarios for long-term hazard reduction. Partitioning would become worthwhile as a HLW management scheme if advanced fuel cycles such as recycling of plutonium and MAs through FBRs and LWRs were implemented, provided that the loss factors for fuel isotopes could be kept very low ($<5 \times 10\text{-}4$). Transmutation of MAs was considered theoretically feasible from the point of view of neutron physics and fuel cycle technology but it was not obvious whether the potential long-term risk reduction for the waste disposal site compensates the increase in short-term risks for the workers and the environment.

   - Taking into account the potential long-term hazard associated with the disposal of spent fuel, the Castaing report (France) in 1982 concluded that it was worthwhile to investigate the benefits of advanced reprocessing techniques with separation and conditioning of Pu and MAs for intermediate storage and tentatively for destruction by neutron irradiation. This

long-term programme is to be conducted simultaneously with investigations of the waste disposal technology in experimental underground facilities.

- The ORNL studies in 1977 and 1980 [3-4] concluded that there were no cost or safety incentives P&T of actinides in High-Level Waste (HLW) for waste management purposes since the long-term risk is mainly associated with long-lived fission products ^{99}Tc and ^{129}I and not with the actinides. The reduction of the radiotoxic inventory of waste is theoretically possible but needs the development of advanced partitioning methods and the use of other types of reactors than the available LWRs.

3. The period of active investigation on P&T starting in early 1970s was terminated around 1982-1983 as no international consensus was obtained on the benefits of P&T as an alternative or complementary waste management option.

4. During the 1980s, a growing awareness of the inherent difficulties in creating and licensing large nuclear waste repositories, and growing delays in the repository R&D projects, particularly in the development of underground pilot repository facilities, led the international community to reconsider the potential benefits of P&T as a complementary waste management option and these resulted in second generation system studies. This renewed interest was also based on technological developments in several fields making the P&T option seemingly more feasible.

5. In October 1988, the Japanese government by way of the Atomic Energy Commission (AEC) launched the ambitious "OMEGA" R&D programme [9]. The R&D programmes were stimulated by the collaborative efforts of JAERI and the former PNC (now JNC). In the public sector, CRIEPI has also been carrying out R&D on this subject. The "OMEGA" programme is proceeded in two steps: the phase-I was intended to cover a period up to about 1996, and the phase-II to about 2000. The basic studies and tests were to be conducted in the phase-I, and engineering tests of technologies or demonstration of concepts are planned in the phase II. The first check and review of the phase-I of the programme by the Atomic Energy Commission was started in February 1999. After 2000, pilot facilities would be built to demonstrate the P&T technology. Following items are being studied:

   - Physical and chemical properties of MAs and FPs.
   - Partitioning of radioactive elements from high-level liquid waste by reprocessing process and recovery of useful metals.
   - Nuclear and fuel property data of MAs.
   - System design studies.
   - Reactor fuel and accelerator target.
   - Development of high power accelerator for transmutation.

6. It was during this second era of P&T activities that the NEA became involved in studying this subject. In 1988, next to launching the "OMEGA" programme, the Japanese government also invited the international community, through the OECD/NEA, to participate in the assessment of a broad range of P&T developments. This initiative was the starting point of a world-wide renewal of interest and work in the P&T field. Large scale R&D programmes are still being conducted in Japan (JAERI, JNC, CRIEPI) and in France (CEA) in co-operation with several European countries under sponsorship of the European Commission. Important experimental programmes were conducted in the United States at the Argonne National Laboratory (ANL).

7. As a result of this increasing interest, the need was felt to re-examine the validity of the P&T option in the light of the more recent results. In France, a National Evaluation Commission was appointed in 1993 in order to supervise the R&D activities in the field of radioactive waste management. Reports were issued [10-12] in 1995, 1996 and 1997. In the field of P&T, the following recommendations were made:

   - Priority should be given to separation of Am-Cm from rare earths followed by Am/Cm separation.
   - Among the fission products priority should be given to Cs and Tc.
   - On the subject of transmutation a distinction should be made between short-term projects based on transmutation in present PWRs and long-term R&D on future reactor systems e.g. fast reactors and accelerator-driven transmutation.
   - Two options (partitioning-transmutation and partitioning-conditioning) should be studied at the same level of priority and a priority listing of the critical radionuclides should be made for each option.
   - The separation processes DIAMEX and SESAME should be demonstrated as soon as possible in the hot facility ATALANTE.
   - Accelerator-driven transmutation is a new venture, which should be studied on the national level within a co-ordinated CEA-CNRS-EDF R&D effort (GEDEON).

8. In Japan, the ongoing "OMEGA" project covered the activities on P&T where comparable national evaluation and assessment reports have not been openly published. However, the Japanese evaluations and assessments have been included in the OECD/NEA activities and publications as part of the NEA assessment studies.

9. A series of American reports was published in the meantime. On the basis of the ORNL retrospective assessment of P&T [13], the Electric Power Research Institute (EPRI) started a detailed evaluation programme [14] on the concept of transuranic burning using liquid metal reactors (LMR) and included, in their overview, the waste management consequences resulting from "alternative spent fuel separation processes". A study of the impact of P&T on the disposal of high-level waste was prepared by Lawrence Livermore National Laboratories [15] and the main conclusions of these US reports were:

   - The toxicity of high-level waste during the first thousand years cannot be reduced by transmutation since the cross-sections of the isotopes ^{90}Sr, ^{137}Cs, ^{3}H and ^{85}Kr are too small.
   - The cost of alternative reprocessing in order to reduce the actinide content to a level below 100 nCi/g (3 700 Bq/g) is very high and requires the construction of advanced aqueous reprocessing facilities and/or the development and construction of pyrochemical reprocessing units.
   - The use of LMRs for burning plutonium and actinides would require the construction of an aqueous reprocessing capacity of ~2 000 tHM/year and the deployment of 30 GWe LMR capacity creating a cost penalty of $0.5 billions to $2 billions per year.
   - The decentralised structure of the US electricity production, the absence of economic incentive for reprocessing and the changes in the regulatory requirements (NRC and EPA) for disposal facilities would make the acceptance of P&T as a waste management scenario very improbable under the then present economic conditions.

10. The most recent published and most comprehensive national assessment report on P&T was issued in 1996 by the National Academy of Science of the US under the chairmanship of N.C. Rasmussen [16]. The report covers all aspects of the problem from an American point of view. The principal recommendations listed in the report are:

    - None of the P&T system concepts reviewed eliminates the need for geological disposal.
    - The current policy of the "once-through-cycle" should be continued.
    - Fuel retrievability should be extended to ~100 years.
    - R&D should be conducted on selected topics of P&T.

11. Since the beginning of the 1990s, an emerging interest has been oriented towards renewed P&T technologies, e.g. accelerator-driven systems (ADS) and pyrochemical partitioning, which induced new R&D activities in several OECD/NEA Member countries. Especially ADS has been the attraction pole for many new researchers in the field and new international collaborations are being set-up in this domain. Those OECD/NEA Member countries conducted in addition studies on the P&T potential and giving overviews of national and international R&D activities in this field. This growing community of researchers in different OECD/NEA Member countries (in Europe about 250 researchers) published multiple reports on P&T during the past five years, where an overview of all these is out of the scope of this note.

12. The IAEA assessment report on P&T in 1995 [17] investigated the technical feasibility and the radiological impact. Conclusions indicated that partitioning is indeed feasible but considerable R&D would be required to implement a realistic flowsheet operable at industrial scale. The reduction in long-term risks achievable by P&T of actinides is less than expected and long-lived FPs which are not amenable to any form of P&T, also contribute to the very long-term risk. All in all, the implementation of P&T would be an immense undertaking, involving a large proportion of a country's nuclear power program, but providing at best a rather small reduction in potential long-term radiological hazard. The IAEA undertook several complementary activities with respect to OECD/NEA's work:

    - A survey of research activities related to P&T in non-OECD countries was undertaken upon recommendation by a Technical Committee Meeting and the report was published in 1997 [18].
    - Participants of a Special Scientific Programme on "Use of High energy Accelerators for Transmutation of Actinides and Power Production" held in Vienna in 1994, in conjunction with the 38th IAEA General Conference recommended the IAEA to prepare a status report on ADS. The general purpose of the status report was to provide an overview of ongoing development activities, different concepts being developed and their status, as well as typical development trends in this area and to evaluate the potential of this system for power production, Pu burning and transmutation of minor actinides and fission products. The document [19] includes the individual contributions by experts from six countries and two international organisations.
    - Other activities involve Co-ordinated Research Projects (CRP) on the potential of Th-based fuel cycles to constrain Pu and to reduce long-term waste toxicities examining the different fuel cycle options in which Pu can be recycled with Th to get rid of the Pu, or replace the Pu with materials that are less unacceptable to the public.

- A Technical Committee Meeting was organised on the feasibility and motivation for hybrid concepts for nuclear energy generation and transmutation where programmes and concepts on ADS development were presented [20].

13. The European Commission was partly supporting research work on partitioning and transmutation of radioactive waste under the Fourth Framework Programme (1994-1998). This work included nine research projects. Five strategy studies were evaluating the capabilities of various burners and fuel cycles to limit the production and even destroy the stock of actinides (plutonium and minor actinides). Two experimental projects were aimed at developing techniques for the chemical separation of actinides and two others were dealing with the investigation of transmutation of americium and long-lived fission products. Within the Fifth Framework Programme (1998-2002), strategy studies on P&T are foreseen to investigate its benefits and compare different methods such as critical and sub-critical systems taking into account the whole fuel cycle. New efficient and selective processes will be developed for the separation of the critical long-lived radionuclides form high level and medium level waste. Basic nuclear data essential for transmutation and the development of ADS will be measured and computed. The radiation damage induced by spallation reactions in materials will be investigated. It is foreseen to develop and test fuels and targets for actinide and long-lived fission product incineration. The preliminary study of an ADS is also considered in the programme with supporting research work on sub-critical mock-ups, safety, coolants, the confinement of the accelerator/reactor window and high power accelerators. Finally, new specific matrices could be also developed for the conditioning of long-lived radionuclides, which cannot be transmuted.

14. The European Commission (EC) published in 1997 a report on the perspectives and the deemed costs of P&T [21]. Main conclusions in this report were the potential reduction of waste radiotoxicity by a factor of 40 to 100 compared with the open fuel cycle scenario and depending on the moment considered in the cooling period. Recycling the FPs was reported not to entail any gain on their radiotoxicity where neptunium recycling results in a gain after roughly one million years of decay. Nevertheless, in terms of residual radiotoxicity, recycling these elements may be an advantage because of their mobility in a geological repository environment. For the first level of P&T, based on technologies derived from existing techniques, the cost supplement over recycling plutonium alone was estimated at about one-third of the fuel cycle cost. Partitioning and fuel fabrication accounting roughly equal fractions of this cost supplement. At the second level, where P&T is implemented based on completely new technologies and aiming at complete separation of the MAs and some FPs, the partitioning involves an additional cost estimated at half the cost of the conventional fuel cycle operations.

15. Today, several national projects and bilateral or multilateral programmes are being undertaken. The most important projects involved are:

    - The Japanese “OMEGA” Programme is currently ongoing and the activities cover the development of a wet partitioning process, design study of an actinide burner reactor (ABR) and an ADS, the development of nitride fuel cycle technologies, and basic research such as nuclear data and fuel property data measurements. Development of a high-intensity proton linac has been carried out under the Neutron Science Project of JAERI which aims at construction of a superconducting proton linac of 8-MW for a 5-MW spallation neutron source for a neutron scattering facility and for an ADS experimental facility.
    - Besides the European countries own national projects and the EC Fifth Framework programme, a trilateral activity was launched by France, Italy and Spain. The Advisory Group and Technical Working Group on Accelerator-driven Systems, chaired by Prof. Rubbia, aims to investigate the potentialities of ADS for the transmutation of waste and to co-ordinate between governmental

agencies and industrial bodies. Their prime objective however is to construct a demo ADS-plant on a 10 years time schedule. Some other European countries joined this informal initiative in order to exchange information and create a European Network.

- The ATW-programme in the US has recently been reviewed by US-DOE and a roadmap for developing this technology has been published in October 1999 [22]. This roadmap proposes a six-year science-based R&D Programme to be established in order to reduce the technical risks and to assess the technical viability of the ATW technology. The total cost of this six-year R&D Programme amounts to $281 M
- The ISTC-framework has included specific projects related to ADS-technology and especially technological issues (Pb-Bi technology, …).

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