2. R&D PROGRAMS ON PARTITIONING AND/OR TRANSMUTATION

2.1 R&D Programs and Their Principal Objectives

(1) French SPIN program [1]

In order to respond to the public concern about wastes and in particular the long-lived high level ones, a French law issued on December 30,1991 identified the major objectives of research for the next fifteen years, before a new debate and possibly a decision on final wastes disposal in Parliament. To comply with the requirements of the management of long-lived high level wastes, the CEA has launched an important and long term R&D program. A part of this program called SPIN is devoted to separation and incineration of these wastes and it includes two sub-programs:

a) In short and mid term perspectives (1991-2000), PURETEX aiming primarily at reducing the volume of wastes from reprocessing from $1.5m^3$ to $0.5m^3$ per ton of reprocessed heavy metal. This result will be obtained by modifying the PUREX process in order to be able to eliminate bitumen and by improving the conditioning of solid wastes.

b) In a long term perspective, ACTINEX devoted to the separation and transmutation of long-lived elements in view of reducing wastes toxicity by a factor 100 and then 1000 compared to direct disposal within 20 and 40 years respectively. With regard to transmutation, the feasibility of actinide incineration by PWR and fast reactor are investigated. In parallel the possibilities of advanced systems such as specific nuclear reactors and accelerators are also investigated.

The objective of this program is to limit volume and potential radiotoxicity of minor actinides in deep storage and also the quantities of long-lived fission-products for the outcome of deep storage.

(2) Japanese OMEGA program [2]

The Japan's Atomic Energy Commission launched in October 1988 a comprehensive basic research program (OMEGA) to explore the feasibility of utilizing HLW as useful resources and widening future options for waste management by releasing the report entitled "Long-Term Program for Research and Development on Nuclide Partitioning and Transmutation". In the partitioning technology development, following scopes are to be studied;

- Partitioning from HLW or in main reprocessing process.
- Recovery of useful metals from insoluble residue.
- Technology to make use of separated nuclides.

The development of transmutation technology falls into following two major R&D categories;

- Application of nuclear fission reactors.
- Application of high-intensity accelerators.

Fission reactors include fast breeder reactor power plants ,and specially designed actinide burner reactors,which would be a very effective mean to transmute long-lived TRU. High-intensity accelerator aims at transmuting TRU and other long-lived FP.

The program is planned to be carried out in two phases. The first phase (1988-1996) will be dedicated in general for basic studies and testings to examine feasibilities, to develop fundamental technologies, and to conduct overall assessment for various candidate concepts. In the second phase, engineering scale tests will be conducted to verify the systems and technologies evolved by that time. Because of the exploring nature of the program, several potential methods or concepts are being investigated in parallel in both partitioning and transmutation areas by the Japan Atomic Energy Research Institute (JAERI), the Power Reactor and Nuclear Fuel Development Corporation (PNC), and the Central Research Institute of Electric Power Industry (CRIEPI).

The objective of the program is to significantly reduce the source term of the long-term potential hazard which arises from HLW.

(3) ALMR Actinide Recycle Program [3]

The Advanced Liquid Metal Reactor (ALMR) Actinide Recycle System is being developed in the United States for application early in the 21st century. The system is expected to have the ability to fulfill multiple missions including: (1) the conversion of excess Pu to produce power, (2) utilizing the tremendous energy potential associated with spent LWR fuel, (3) providing long-term energy security, and (4) achieving a significant reduction in the heat load and time constant associated with processed waste. The ALMR is a fast reactor design, and its plant design and development program is a national program involving wide participation by US industry as well as national laboratories, universities,and international organizations. The ALMR utilizes the metal fuel cycle being developed by Argonne National Laboratory (ANL) which inherently recycles actinides to the reactor in the reference breakeven/breeder and burner designs.

The objectives of the program include potential reduction of major long-lived toxic actinides and removal of heat-producing radionuclides .

(4) Los Alamos ATW Program [4]

The Accelerator Transmutation of nuclear Waste (ATW)is being developed by the Los Alamos National Laboratory (LANL) in the US. The ultimate goals of the ATW development effort concern creation of a system that can destroy long-lived migratory fission-products and high toxicity actinides associated with high-level waste storage, and creation of an advanced energy production concept that can rectify major obstacles facing nuclear power.

Application of an ATW system to HLW management programs can have a significant impact. An ATW system applied to cleanup of Long-.Lived defense HLW at a DOE site could provide management options that minimize or eliminate HLW leaving the site. Long-lived nuclide destruction could also aid creation of more robust on-site waste storage forms . The impact of an ATW system on geologic repository storage could be significant. It could delay or potentially avoid altogether the need for a second geologic repository. It could also reduce the performance required of a geologic repository, e.g. reduce the waste isolation period from 10000 years to a period of around 500 years.

ATW application development involves a staged approach. Specific technology development allows components to be developed for a next application stage. A relevant example is that of defense waste application. The ATW system components developed for it share a high degree of commonality with that could be applicable to destruction of commercial high level waste.

(5) R&D Program at BNL [5,6,7]

Brookhaven National Laboratory (BNL) in the US has proceeded research programs on transmutation by using large proton linear accelerator (PHOENIX program), small power accelerator and high-flux thermal reactor. The objective is to substantially reduce some of the most significant challenges in building a waste repository, by transmuting key elements, such as Pu, minor actinides and a few of the long-lived fission products.

(6) R&D Program at ENEA [8]

A research program on accelerator-driven transmutation is being proceeded at ENEA under the close collaboration with LANL in the US. The objective of transmutation is the radiotoxicity reduction of minor actinides potentially introduced into the biological sphere with a not very significant increase of the KWh cost, and in the case of Pu, straight forward reduction of its stockpiles as a solution of Pu problem.

(7) RAS Program at Netherlands Energy Research Foundation ECN [9]

In 1991 the ECN at Petten has defined a program on recycling and transmutation of long-lived nuclear waste. This program is known under the Dutch acronym RAS of which general objective is to contribute to international research on recycling and transmutation of nuclear residues and to indicate possibilities to include this option in an acceptable waste management strategy. After reviewing the program by a committee installed by the Dutch government , a follow-on program for the RAS has recently been defined for 1994-1997. It is aimed to evaluate by the end of the program the technical feasibility and the risks of P-T and to present a proposal for its implementation in an acceptable waste management strategy.

(8) R&D Program at Toshiba Corporation [10]

Future contribution to overall energy production by nuclear power depends on the development of efficient transuranic elements recovery system for spent fuel reprocessing. The system is expected to lead to optimum resource utilization and substantial reduction in HLW associated with large scale energy production.

The objective of transmutation is:

a) Substantial reduction in volume and long-term radiotoxicity of HLW in fuel recycling system,and

b) Simplification of future TRU-recycling technology in LWR and FBR aiming at total cost competitiveness, including reactor, reprocessing and storage in the total nuclear energy system.

(9) R&D Program at Royal Institute of Technology [11]

A research program on accelerator-driven transmutation is going on at the Royal Institute of Technology in Sweden, under the collaboration with LANL.

The objective of transmutation is:

a) Reduction of radiotoxicity in the geological storage, drastic reduction of the duration of radiotoxicity,

b) Combination of transmutation of waste with energy production, i.e.effective fissioning of transuranic isotopes,and

c) Opening a new "subcritical nuclear option" for energy production.

(10) R&D Program at IPPE [12]

A research of transmutation with fast reactors is being conducted at the Institute of Physics and Power Engineering (IPPE) in Russia. The objective is reduction of radiotoxicity in the deep storage,and finally reduction of health and environmental risks. Recycling of Pu in fast reactors could reduce the long term radiotoxicity of TRU up to 10 times. And recycling of Pu,Np, and Am would reduce it up to 100 times. The reduction of health and environmental risks is still uncertain.

(11) R&D Program at ITEP [13]

A research of accelerator-driven transmutation is being conducted at the Institute of Theoretical and Experimental Physics (ITEP) in Russia. The objective is the radiotoxicity and mass reduction of HLW before deep (underground) storage and the energy production in the blanket of an accelerator-driven transmutation system.

2.2 Nuclear Fuel Cycle Consideration on Partitioning and Transmutation

The nuclides to be transmuted have to be recycled many times to incinerate them sufficiently, since the considered transmutation cross-sections may be relatively low and the highest achievable neutron flux is limited. This means that the transmutation technology has a strong correlation with the partitioning technology and also with nuclear fuel cycle. If the transmutation efficiency in one cycle is low, the partitioning efficiency must be high to achieve the overall required reduction factor during several cycles. This may give large influence to the overall nuclear fuel cycle concepts. In this context,the proposed nuclear fuel cycle concepts with the P-T technology are illustrated here, although it is out of scope of the present discussion.

(1) SPIN Program

The SPIN program consists of two major projects: PURETEX and ACTINEX, as mentioned above. The ACTINEX project aims at separating Pu, Np, Am, Cm as well as long-lived fission products in an advanced reprocessing system,and furthermore at incinerating them by using thermal or fast reactor, or accelerator. The nuclear fuel cycle concept with the P-T technology considering in the SPIN program is illustrated in Fig.2.1.

(2) OMEGA Program

The OMEGA program is composed of two major R&D areas: the transmutation technology development and the partitioning technology development. Since several potential methods or concepts in both R&D areas are being investigated in parallel by the JAERI ,PNC and CRIEPI as seen in Fig.2.2, these organizations propose their own nuclear fuel cycle concepts.

1) JAERI

The JAERI aims to develop a partitioning process of TRU and long-lived fission products from HLW and their subsequent transmutation system based on a specially designed fast burner reactor or an intense proton linear accelerator. A double strata nuclear fuel cycle concept is proposed as shown in Fig.2.3, in which the first cycle is the conventional fuel cycle and the second is the P-T cycle. Another concept under investigation is concerned with TRU recycling in LWR as seen in Fig.2.4.

2) PNC

The PNC's approach is to develop a partitioning process as a part of advanced reprocessing system where the improved PUREX process is closely combined with TRUEX-like TRU separation process with emphasis on TRU recycling in a MOX fueled FBR system. The nuclear fuel cycle concept is given in Fig.2.5.

3) CRIEPI

The CRIEPI aims at a concept to separate TRU from HLW by dry process with pyrometallurgical methods and then to transform them to the nuclides with shorter half-lives in a metallic fuel FBR. The nuclear fuel cycle concept is shown in Fig.2.6.

(3) ALMR Actinide Recycle (IFR) Program

The IFR is the entire reactor system consisting of reactor, fuel cycle and waste process. In the IFR pyroprocessing, minor actinides accompany the plutonium stream and therefore actinide recycling occurs naturally in a metallic fuel LMR. The schematic picture of the IFR concept is given in Fig.2.7.

(4) LANL ATW Program

The feed to the ATW system is the separated actinides,Np,Pu, Am and Cm plus the long-lived fission products (LLFP’s),Tc-99 and 1-129. Chemical separation capacity is assumed to allow the LWR spent fuel to be partitioned into various streams before ATW is feasible. The ATW target/blanket converts the LLFP’s to stable species by neutron capture and the actinides to fission products by capture and fission. There is a small chemical facility to remove any LLFP’s created by fission for recycle, and to continuously recycle the actinides. Material flow in the ATW is shown in Fig.2.8.

(5) BNL Program

While not tied to a specific fuel reprocessing/recycling technology, much of the PHOENIX concept is based on the clean use of reactor energy (CURE) approach proposed by the Westinghouse Hanford [14], which is a waste partitioning process based on the well-known Purex process and the newer Truex process. The waste partitioning and transmutation system shown in Fig.2.9 is common in all the transmutation concepts including the PHOENIX concept proposed by BNL.

(6) Consideration at ENEA

The present fuel cycle will be completed adding, after the reprocessing, two new steps : partitioning (recovery of minor actinides from HLW) and transmutation (destruction of TRU). This last step can be carried out in different ways: Pu burning separated from minor actinide burning or the two together. The first strategy can be developed using the IFR for Pu burning and the ATW system for minor actinide burning or the two tasks can be performed by means of the latter strategy.

(7) RAS Program at ECN Petten

It will be investigated in the RAS program whether it is feasible to reduce the actinide production itself,e.g.by application of the thorium cycle or by replacing U-238 by inert matrix material. The “evolutionary rout’’(the current fuel cycle) should lead to a reduction of Pu losses during reprocessing and in a latter phase to a separation of the minor actinides and some long lived fission products. Investigations will be also made on methods to deal with the reprocessed and partitioned products.

(8) Consideration at Royal Institute of Technology

The transmutation strategy is aimed to propose an energy producing transmutation system based on thorium fuel cycle. The Institute would try to design a proliferation safe system which will minimize chemistry requirements, possibly only one to the end-of-life stage.

(9) Program at Toshiba Corporation

An integrated nuclear energy production system should be developed to minimize impact on the global environment in future. The recovered minor actinides will be used as fuel together with Pu in LWRS and FBRs. The considered nuclear fuel cycle is shown in Fig.2.11.

(10) Program at IPPE

The considered nuclear fuel cycle includes followings:

- Closed fuel cycle with recycling of Pu mainly in fast reactors with breeding ratio of nearly unity,
- Partitioning of minor actinides, and recycling of Am and Np-237 together with Pu in fast reactors with breeding ratio of nearly unity ,

- Long-term storage of Cm, and recycling of accumulated Pu-240, and
- Burning of excess of Pu and minor actinides in special burner reactors including one cycle of Pu in thermal reactors.

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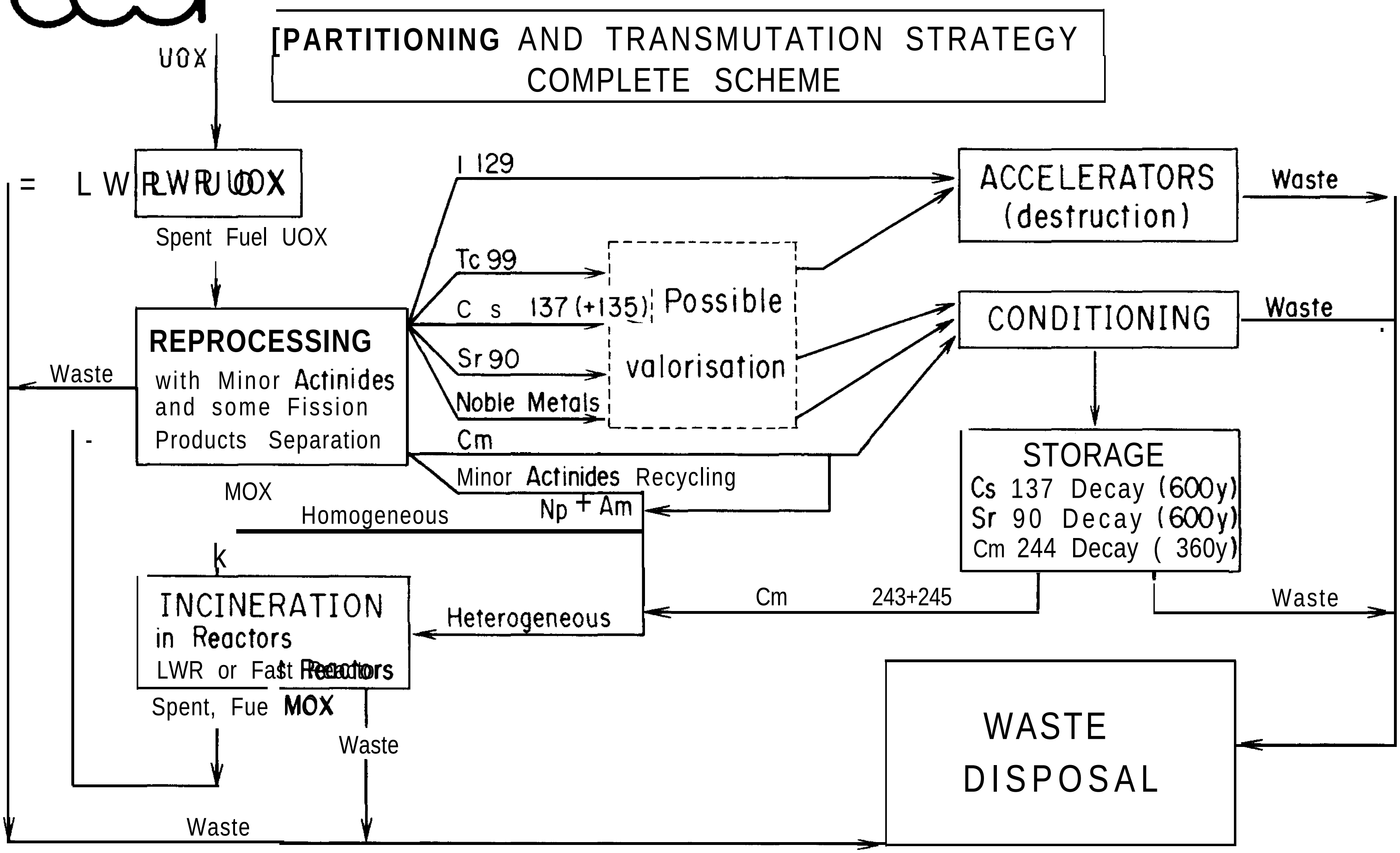

FUEL CYCLE DIRECTION — WE WORK FOR THE FUTURE

Fig. 2. 1 Partitioning and Transmutation Strategy of French SPIN Program

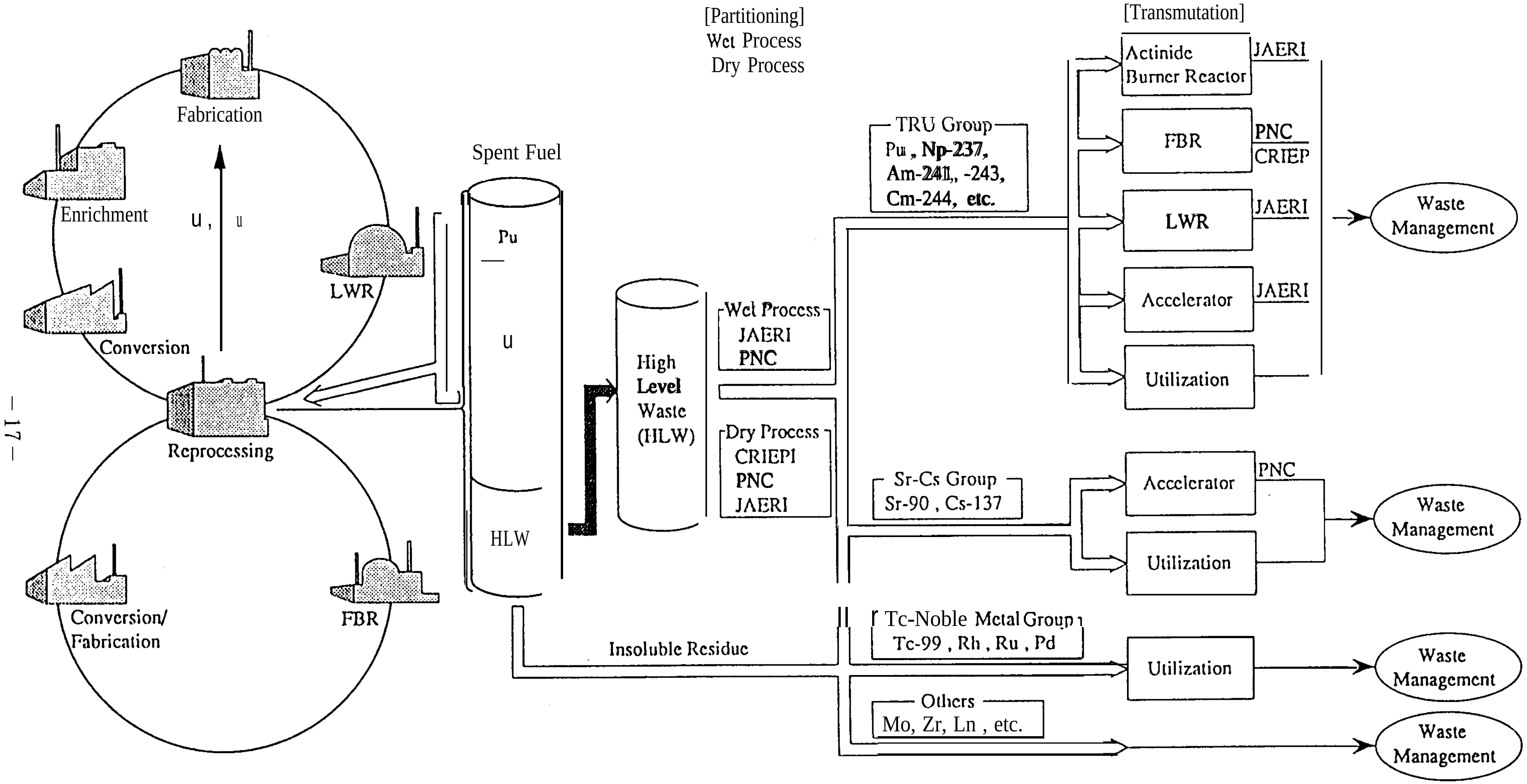

Fig. 2.2 R&D Activities under OMEGA Program on Partitioning and Transmutation (Japan)

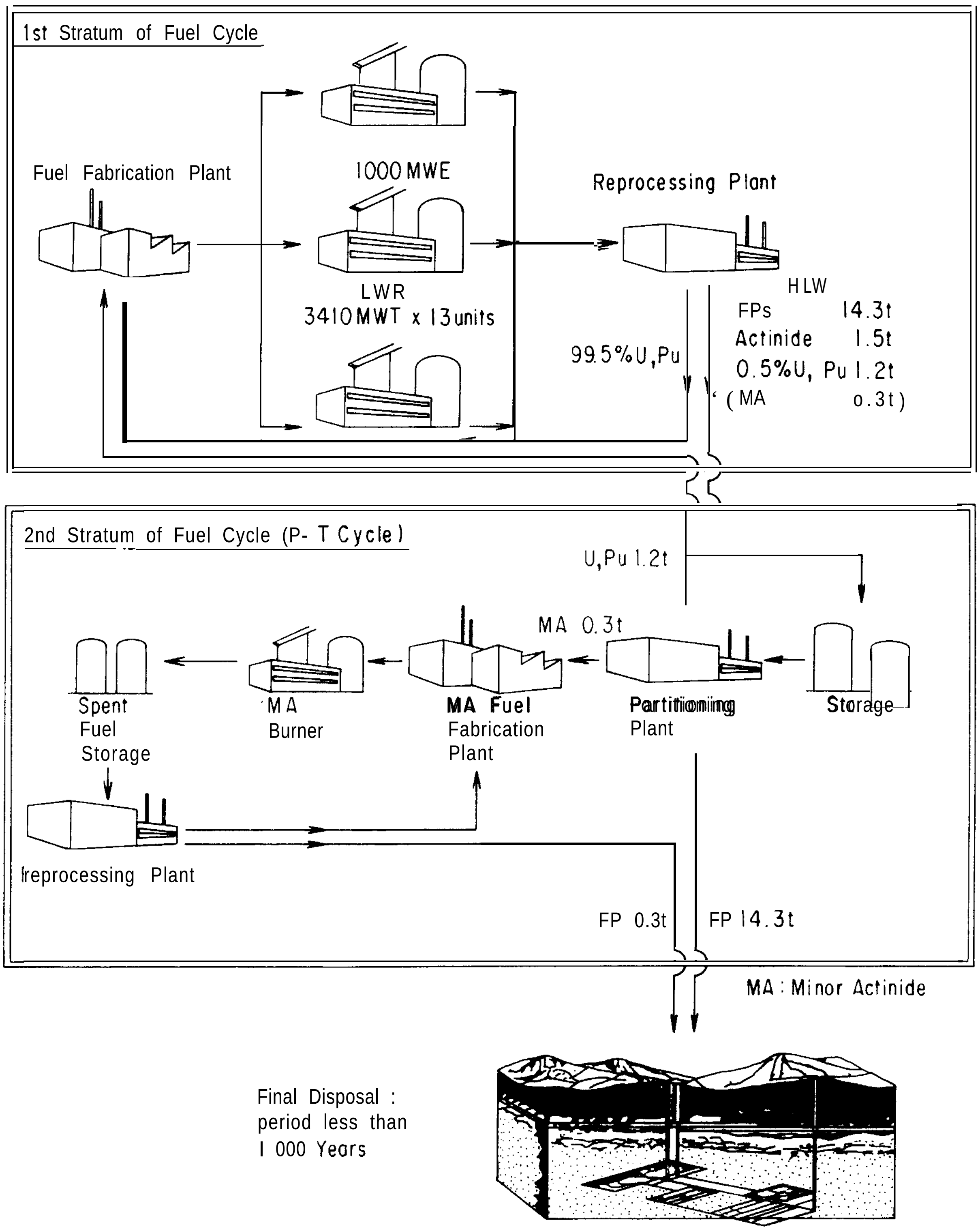

Fig. 2.3 Flow of High-level Radioactive Waste per Year Through Double Strata Fuel Cycle Combined with Partitioning and Transmutation (JAERI)

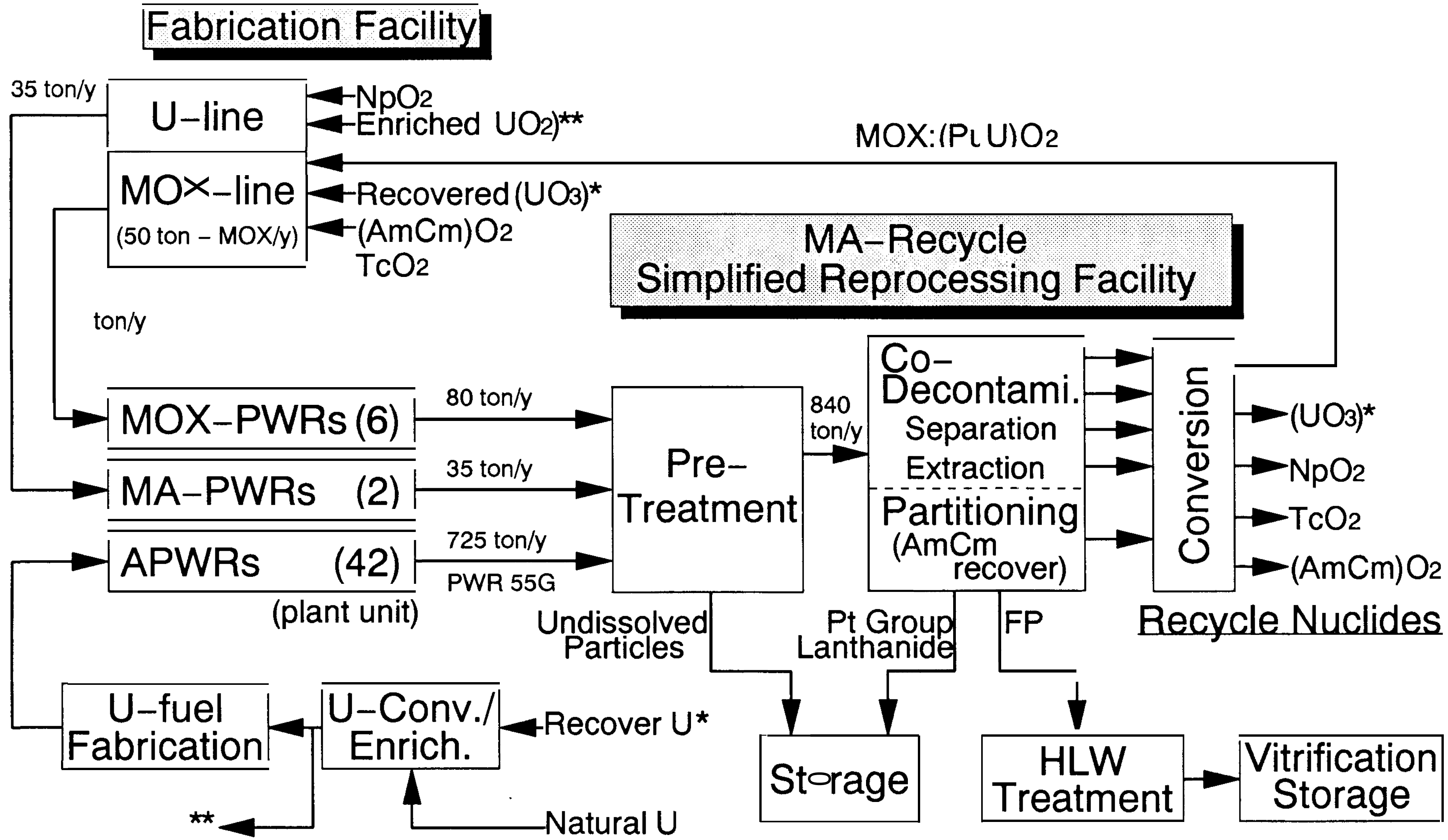

Fig. 2.4 A Concept of Pu and MA Fuel Cycle in LWRs (JAERI)

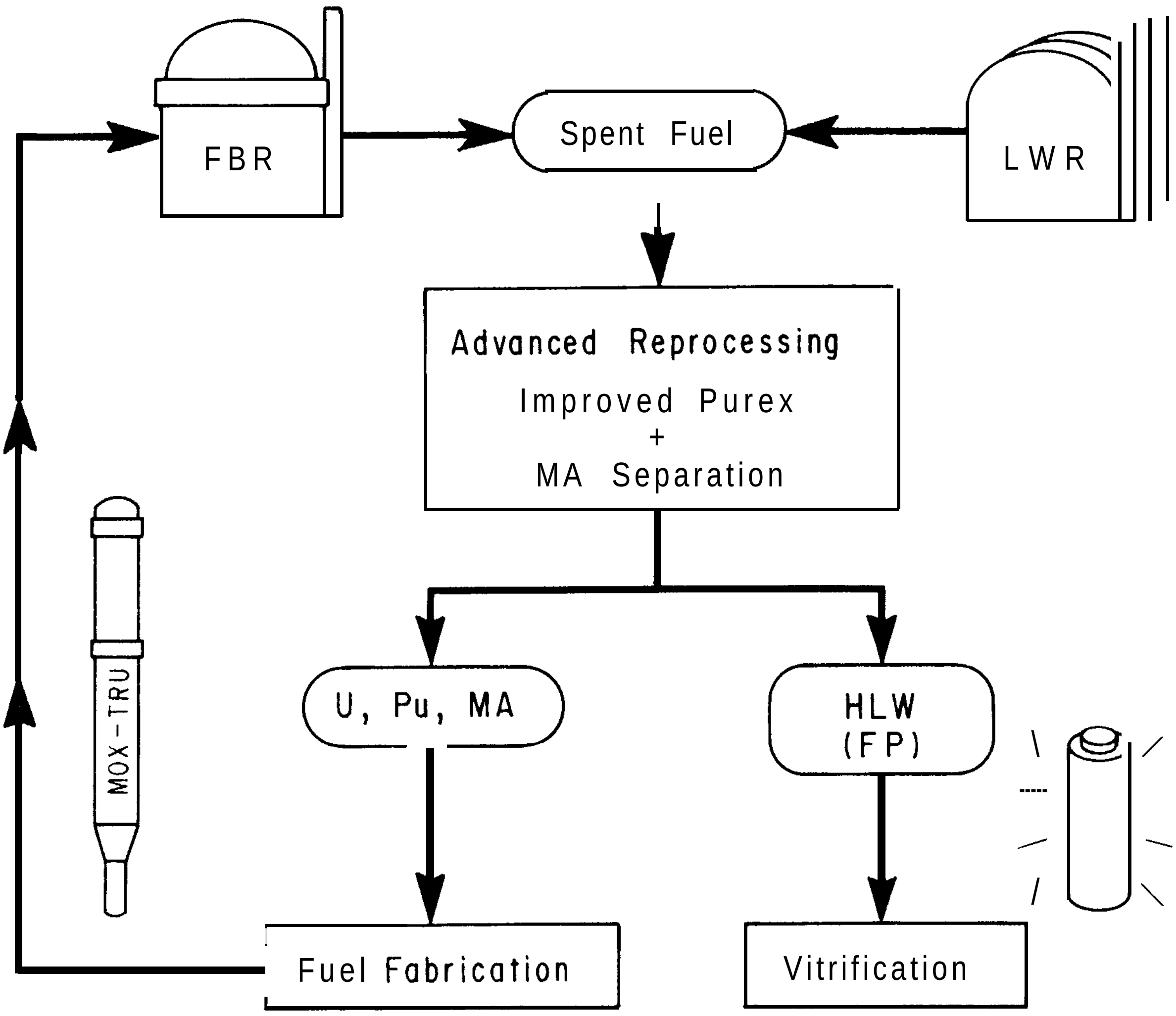

Fig. 2.5 Minor Actinide (MA) Separation and Recycle in FBR System (P NC)

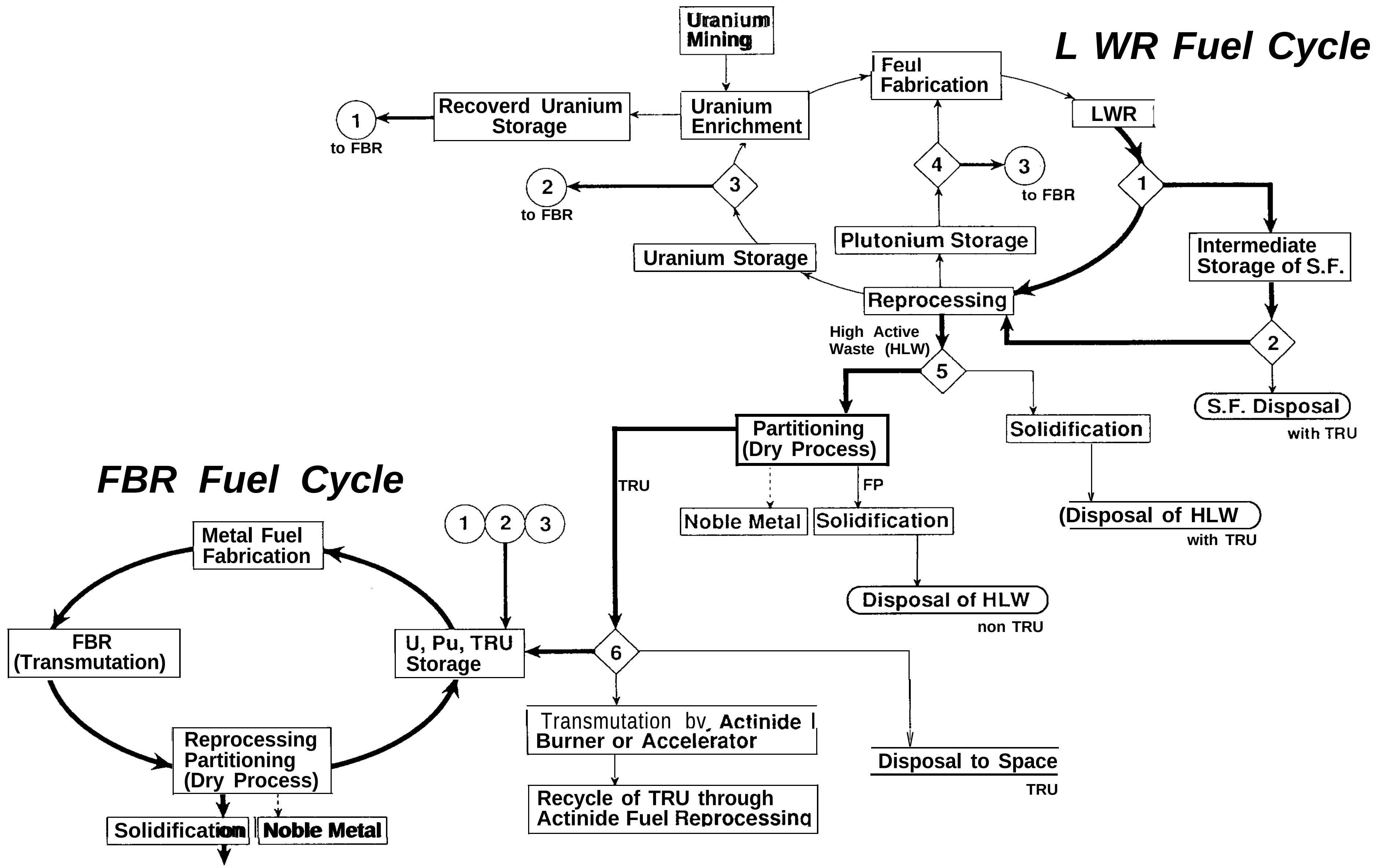

Fig.2-6 Partitioning and transmutation concept of transuranium elements(CRIEPI). TRU produced in LWR and FBR cycles are confined in the FBR cycle.

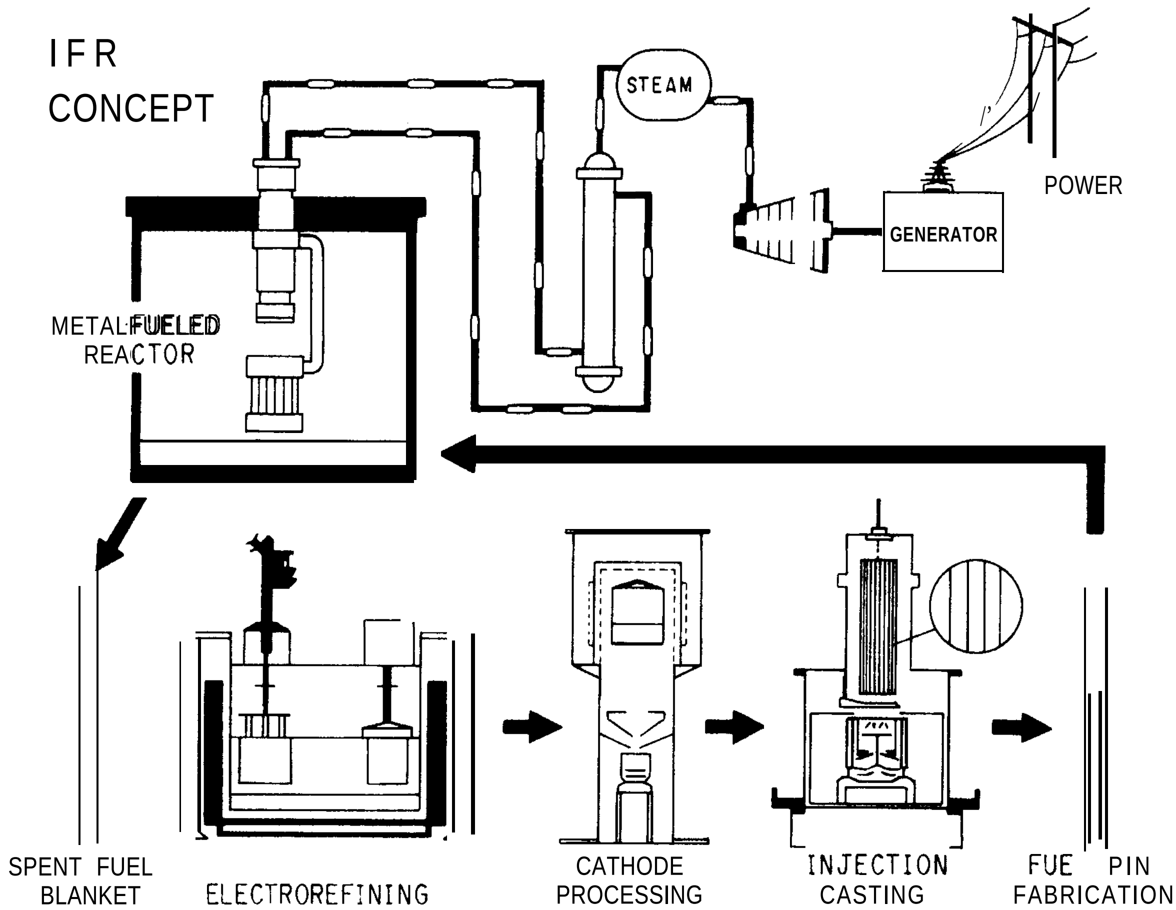

Fig. 2.7 A Schematic Picture of the IFR Concept (ANL)

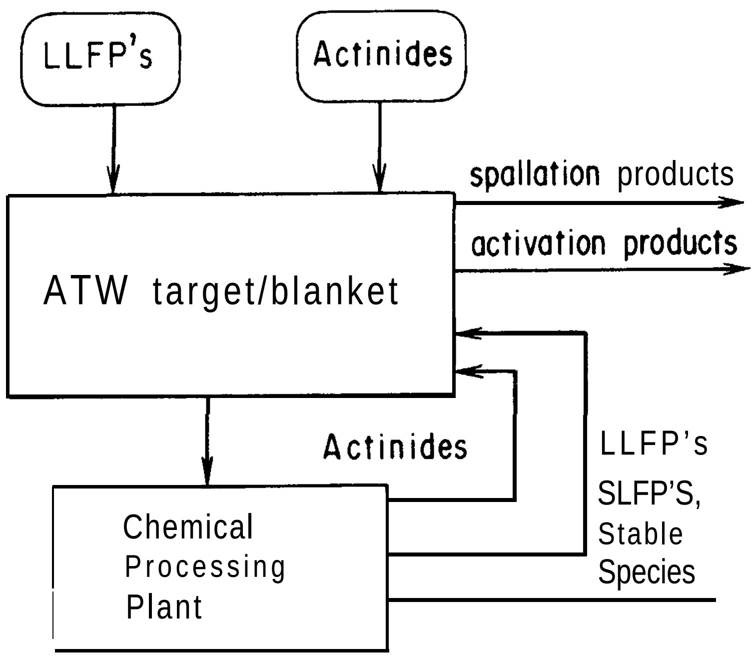

Fig. 2.8 General Concept of ATW System (LANL)

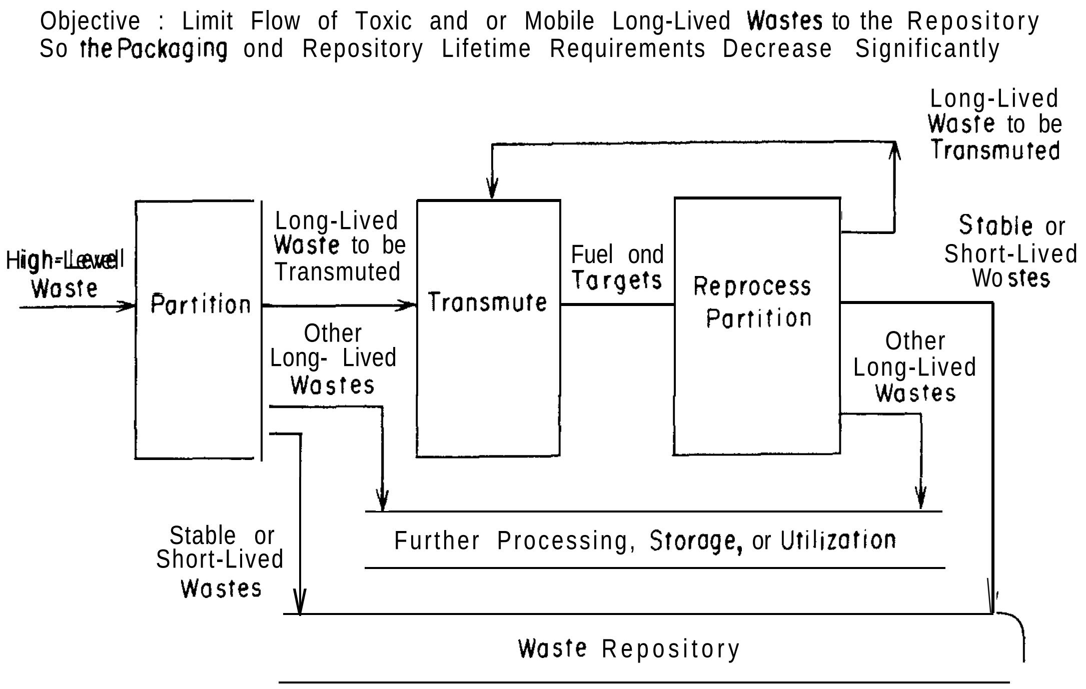

Fig. 2.9 Waste Component Flows through Partitioning and Transmutation System (BNL)

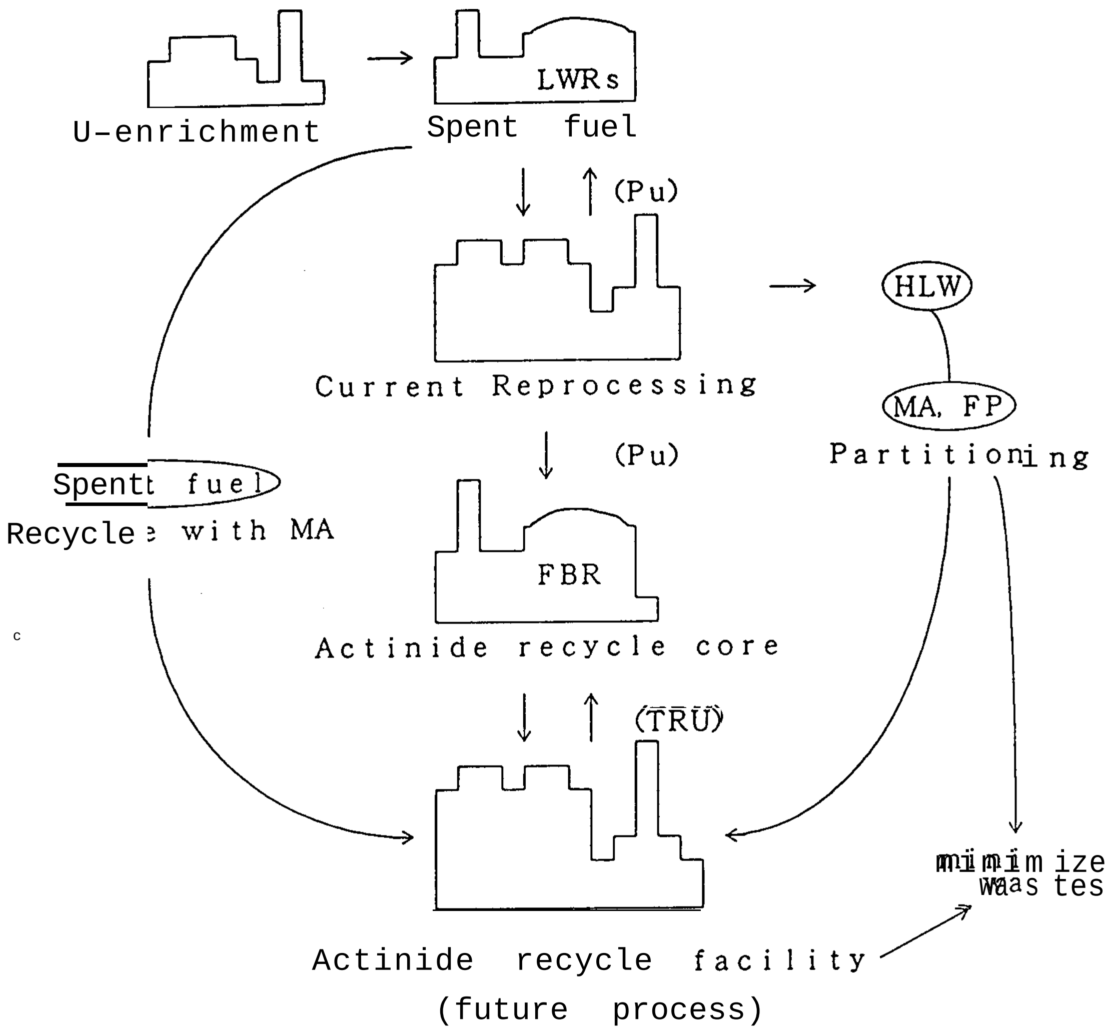

Fig. 2. 10 Fuel Cycle with Partitioning and Transmutation under Investigation (Toshiba Corporation)