

THE FRENCH PARTITIONING-TRANSMUTATION PROGRAMME,  
ASSETS AND PROSPECTS

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ABSTRACT

Partitioning-transmutation studies are covered by the 1991 French law concerning radioactive waste management.

The programme is progressing with a dual approach:

- What can be done in partitioning-transmutation? At what cost? In what timescale?
- How can long-term gains and short-term disadvantages be qualified and quantified?

The first approach concerns technical know-how. The studies based on today's technologies are continuing (reactors, fuels and targets, separation of radionuclides by solvents).

The second approach involves an assessment activity, based firstly on studies of scenarios. Pertinent assessment criteria must be brought out.

## INTRODUCTION

The French law of December 1991 on radioactive waste management requires this management to comply with the protection of nature, environment and health, taking the rights of future generations into consideration. It explicitly indicates that solutions must be found to enable the partitioning and transmutation of the long-lived radionuclides present in these wastes.

In 2006, the French Parliament will have to come to a decision as to the construction of an underground disposal and the continuation of other research paths.

The French Assessment Commission consisting of twelve members <sup>(1)</sup>, set up in 1994, is in charge of assessing the studies. It published two progress reports in June 1995 and June 1996.

Its principal recommendation, to set up the scientific and technical coordination and a research plan, was followed by a letter from the Ministry (December 27, 1995) organising the management of the R&D and by the publication of a research programme.

Among these technical recommendations, the Commission requested that thought concerning the order of precedence to be assigned to the long-lived radionuclides to be separated and transmuted be continued and that quantified goals be defined. It also requested that the studies and research be organised so as distinguish between the short and medium-term options concerning already industrial systems, or those undergoing industrialisation, and the longer-term options which are based on the overall foreseeable innovative systems. Lastly, it considered scenario studies and their contribution in the acquisition of highly diversified data bearing on radionuclide inventories, flows of material, economics, safety, etc. These studies are necessary to assess the partitioning-transmutation systems that result in particularly complex schemes.

Deputy Christian Bataille (Member of Parliament) published a report on the "evolution of research on the management of high level nuclear waste", on behalf of the French Office of Scientific and Technological Choices. He recalled the genesis and the content of the 1991 law, underlining its beneficial effect in calming down the discussion, indicated that the research on the transmutation of radionuclides, the underground disposal of waste and the long-duration interim storage of wastes, is progressing most satisfactorily. In conclusion, he noted that no domain, even technical in appearance, is outside the realm of democracy and that today, the law-maker's will is done. However, the change in the European economic context has modified the picture and he recommends adapting to the postponed reprocessing strategy by promoting new research on the possibilities of long-term surface interim storage as well as on the possibilities of direct disposal of non-reprocessed assemblies.

The exposé below gives the state-of-the-art on the research programme concerning partitioning-transmutation carried out by CEA in collaboration with those "directly concerned by the law" (EDF, COGEMA, CNRS, ANDRA, ...), and replies to two questions:

- What can be done in partitioning-transmutation? At what cost? With what timescale?
- How can long-term gains be qualified and quantified? Are there short-term disadvantages?

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<sup>(1)</sup> The Commission consists of six people (including at least two international experts) appointed by the French National Assembly and by the Senate, and proposed by the French Office for Parliamentary Scientific and Technological Choices, two people appointed by the Government and proposed by the Conseil Supérieur de la Sûreté et de l'Information Nucléaire (Higher Council for Nuclear Safety and Information), four scientific experts appointed by the Government and proposed by the French Academy of Sciences.

## THE ASSETS AND LIMITATIONS OF PARTITIONING-TRANSMUTATION

Partitioning-transmutation fulfills the desire to transform long-lived radioisotopes (>31 years) into short-lived radioisotopes or stable isotopes which could then be managed by confinement and natural decay over periods of some hundreds of years.

It is not planned for short-lived radionuclides (< 31 years) for which confinement pending decay is clearly preferable and already implemented, for instance, in the Aube Storage Centre (CSA).

Both operations, partitioning and transmutation, call upon different types of techniques the limitations of which should be clearly understood.

### 1. Assets and Limits of partitioning-transmutation

#### 1.1. Partitioning: Assets and Limits

Radionuclides are found in non-reprocessed spent fuels, in type B wastes and in glass (table 1, diagram 1).

To achieve transmutations or fissions, the radionuclides must be submitted to a sustained neutronic flux. These conditions lead to the use of ceramic-type materials able to withstand high temperatures, thermal flux and mechanical constraints. It is therefore necessary to have concentrated and purified radionuclides. (The ideal would be an isotopic purity). With the removal of the long-lived radionuclides from the wastes as a goal, the partitioning must be performed with the highest possible efficiency before proceeding to the purification, concentration and production of the ceramics.

The type B wastes represent large volumes in which the radionuclides are diluted. They must be decontaminated to a point where they can be stored on the surface. The feasibility of such operations depends on the type of waste (concrete, metals, etc.) and on the nature of the contamination (labile, fixed etc.). The performance required is beyond our present know-how. On the other hand, the quantities of radionuclides recovered would be small and easy to manage with those from the bulk of the spent fuel.

The spent fuel, when reprocessed, is quasi-totally dissolved. The valuable materials, U and Pu, are separated and purified (with a recovery yield of 99.9%). Iodine and other fission gases (krypton, ...) are discharged. The fission products and minor actinides (Np, Am and Cm) are contained in a so-called "high level effluent" (which contains 98% of the  $\beta\gamma$  activity and the  $\alpha$  activity exclusive of plutonium). The glass is made from the high level effluent. (Figure 1).

The high level effluent containing most of the radioactivity is the subject of long-lived radionuclide separation studies.

*In a first stage, the partitioning-transmutation applies to spent fuels only. It does not apply to type B wastes.*

Extraction by solvent techniques are extremely efficient (they are the ones that enable the industrial recovery of uranium and plutonium), on condition that a good solvent is used. The latter must extract the desired element with very high affinity (recovery yield) and good selectivity (without extraction of unwanted species), allow the subsequent recovery of the element (back extraction) and enable the implementation of operations under industrial conditions without generating new waste.

Partitioning is first of all a question of molecular chemistry (discover the functionalities of the molecules of the solvent and tailor the molecule to the extraction conditions), then of chemistry and of chemical engineering (operating conditions).

For neptunium, zirconium and technetium, the research pertains to implementation, as the solvent is well-known (TBP).

For caesium, the calixarenes functionalised by etheroxide chains have been discovered. The development of a molecule for the solvent and process implementation remain to be achieved.

For the co-extraction of actinides and lanthanides, a molecule has just been developed (DMDBTDMA) and the Diamex process is to be defined (chemistry and implementation).

For americium and curium, unsatisfactory solutions exist (very tricky implementation and large secondary wastes) and interesting functionalities are under study (TPTZ and picolinamides). It is hoped that they will be suitable and, if so, the molecules will have to be tailored to the extraction conditions and the implementation made.

Table 2 gives the research status for the partitioning of actinides and fission products.

*Concerning partitioning, once the feasibilities have been acquired, performances will be excellent and a preliminary calculation may be made by assuming losses of long-lived radionuclides from 0.1% to 1% in the high level effluent sent to vitrification.*

## 1.2. Assets and limits of transmutation for actinides

Incineration-transmutation (1) is seen by an overlapping of phenomena with the disappearance and the creation of nuclei: the limits of the process therefore have to be clearly defined.

Chemical separation leads to radioisotope mixes. Each one interacts with neutrons in a specific way, which is the only interaction possible today to transmute on a large industrial scale.

Actinides may undergo fissions generating radioactive fission products as well as neutronic captures which produce other actinides. The radioactive decay of actinides spans a very long time and belongs to one of four main families of decay which end with stable isotopes of lead or bismuth.

### a) Physical feasibility

Studies to date have shown that it would be possible theoretically, and exclusive of any industrial and economic feasibility studies, to very appreciably reduce the final production of radiotoxic heavy nuclei (plutonium and minor actinides) resulting from the supply of electricity, using fission reactors in a park of reactors that produce and consume these heavy nuclei. Such a park is said to be balanced (in mass and isotopic composition) when it reaches a steady state in which all the radiotoxic heavy nuclei it produced are fissioned.

Various scenarios of multiple recyclings of plutonium alone or with minor actinides in parks consisting of PWRs, RMAs (AMRs?) or FBRs have been studied to strike a balance between production and consumption of actinides, hence a final zero production within the park. (Diagram 2).

These studies tend to show that there are neither outstanding nor even significantly different scenarios for the recycling of plutonium alone (Table 3). They all result in balanced Pu inventories in the cycle, of the same order of magnitude (a few hundred tons). They also show that the in-cycle plutonium inventory is higher for these scenarios than for a PWR open cycle that produces the same amount of energy but discards the plutonium for waste. On the other hand, the amount of plutonium sent to waste in these scenarios depends only on the separate performances of the cycle knowing, moreover, that the production of minor actinides is considerably increased.

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(1) The term transmutation is used when the atomic nucleus captures a neutron, and incineration when it fissions.

These studies also indicate that the dynamics of the systems is very slow (about 100 years to reach equilibrium) and that a controlled phasing out of nuclear power must also be provided for to progressively eliminate the plutonium inventory in the cycle. (1% may be reached in more than 100 years).

The same theoretical studies began with the recycling, besides plutonium, of the minor actinides. They started with the study of the reactivity of various reactor cores and the verification of the main safety parameters. Thus the acceptable limit in minor actinides was set at 5% in FBRs and 1 to 2% in PWRs when the minor actinide is homogeneously distributed within the UO<sub>2</sub>-PUO<sub>2</sub> mixture in the ceramic fuel. These cores result in actinide incineration performances of 18 to 27% in FBRs and from 6 to 9% in PWRs at standard burn-ups and allow a positive balance in the consumption versus the production of minor actinides (Table 4). Multiple recycling scenarios are under study. It seems that the same type of results would be obtained as with the recycling of Pu alone, slightly more contrasted depending on the reactors. The study with CAPRA reactors is partly completed (Table 5).

The management of curium is difficult owing to its strong neutron and gamma emission. Interim storage may be envisaged (100 years) and then transmute the plutonium from decay or accept to send it to waste pending very strongly reduced production. This could be obtained by separating the americium and by its single-recycling once only in targets. (Then an americium destruction rate by fission higher than 90% is required).

The manufacture of plutonium fuels has already reached the industrial level, and their in-reactor performances mastered. The fuels also containing neptunium raise little problem (an experimental assembly was produced for SPX). On the other hand, the americium targets require further fundamental research on the chemical nature of the americium combination (AmO<sub>2</sub>, AmO<sub>2-x</sub>, Am<sub>2</sub>O<sub>3</sub>), and of the inert matrix able to behave properly under irradiation (choice of the material, Al<sub>2</sub>O<sub>3</sub>? MgO?...). It is also necessary to improve the behaviour of the cladding under long irradiation and very great deformation of the ceramics. Table 6 recapitulates the status of the research in progress.

Furthermore, innovative options for transmutation such as hybrid systems based on accelerators are being considered. Their potentialities remain to be analysed.

#### b) Technical and technological feasibility

Several scenarios should be selected, chosen for their technical and industrial credibility and the broad range of choices offered to decision-makers, and technical work should be performed on the feasibility of reactors, the feasibility of the cycle, the dynamics of the systems, the inventories per cycle and the wastes, and the consequences on the risks and costs. Unsteady state periods will deserve special attention.

### 1.3. Assets and limitations of transmutation for fission products

Long-lived fission products can be transmuted by neutron capture only. Therefore, a system must be used that produces a large available excess of neutrons. This is why fission reactors (in the theoretical parks mentioned above) are not very efficient for transmuting long-lived fission products.

Each fission product must be studied individually to assess the technical feasibility of its transmutation in reactors or in innovative dedicated systems. Sensitive points appear: the making of thermally stable iodine targets able to withstand the irradiation, the isotopic separation of caesium (without this separation, caesium 133 and 134 generate more caesium 135 than is transmuted, without mentioning the occurrence of the highly radioactive caesium 137), the recovery of carbon 14 which is an activation product of nitrogen 15 and oxygen 17 (can it be separated?)... One case is favourable: that of technetium 99. The others have not yet been studied.

## 2. Conclusion and prospects

Partitioning-transmutation can be considered from the technical point of view, in a dual approach at the medium and long-term.

At medium term, it is theoretically possible to design nuclear reactor parks that fission all the transuranic heavy nuclei they produce.

The main sensitive points identified today are actinide-lanthanide separation, making americium targets and managing curium.

Major technical changes are necessary, in reactors, reprocessing and fuel fabrication.

These points make up the essential part of the technical research programme.

This management of materials should be performed on a large scale and on an extended timescale. It will not eliminate the "high level and long-lived" wastes as the long-lived fission products and the actinide losses from the cycle (~ 0.1%) will remain in the glass. Type B wastes could be increased in proportion to the flows processed. Furthermore, the controlled phasing out of nuclear must be taken into account.

Several studies of complete scenarios over time, inventory of material, wastes, risks and costs according to the service rendered will be useful to the 2006 decisions and are included in the research programme.

For the long-term, innovative techniques may be required. They could include new hybrid reactor systems allowing to incinerate the capturing only isotopes as well. Their potentiality and the whole of the associated cycle remain to be studied.

A rather fundamental assessment-oriented research programme has been launched.

In any case, type B wastes will remain. Endeavours to rationalise and reduce the volumes are being made in the framework of current reprocessing (Pu partitioning).

The Puretex research programme deals with this subject.

#### HOW CAN THE ADVANTAGES AND DISADVANTAGES OF PARTITIONING-TRANSMUTATION BE QUALIFIED AND QUANTIFIED?

Transmutation is a complex operation, easier to contemplate today for plutonium than for minor actinides or fission products. It meets the desire to get rid of wastes by destroying them, but it does have limitations. Since it concerns only separated radionuclides and refined products, it cannot deal with type B wastes.

It does, however, enable the composition of future "high level and long-lived" wastes to be changed by modifying the inventory of the long-lived radionuclides they contain. So it is a technical step in the management of wastes, upstream from their production, and which cannot be assessed independently.

#### 1. Can partitioning-transmutation complement geological disposal?

Projects for disposing of radioactive wastes in geological formations aim at isolating the radionuclides from man and the environment for a long enough time for their impact to have decreased below the regulatory limit of 0.25 mSv/year. The performance of the multibarrier confinement system (package, engineered barrier and geological formation) is assessed by means of safety models taking into account:

- the behaviour of the waste packages,
- the transfer rate of the various radionuclides through the engineered barrier,
- the transfer rate of the various radionuclides in the geosphere,
- the transfer paths and times of the various radionuclides within the biosphere,
- the effects of the various radionuclides on man.

The different confinement barriers allow to limit the flux of radionuclides at the outlet and hence their impact on man. The safety assessment allows this impact to be assessed for each radionuclide versus time, and hence to identify and classify the radionuclides that are important for safety. In particular, it allows to identify those that would be at the origin of a relatively greater impact, linked either to their properties, or to the uncertainty concerning their behaviour. These calculations are performed right from the design phase, taking the conditions offered by the site into account.

In the event the impact of some radionuclides from storage in a given site were too great in view of regulatory requirements, means must be found to reduce it. If their management involved technical conditions that are difficult to achieve, other processes must be considered. Several paths may then be envisaged, including:

- a reduction at the source of the wastes disposed of, corresponding to a reduction in the radionuclide inventory. This is the partitioning followed by transmutation system,
- partitioning for special conditioning,
- adapting the performance of the engineered barrier to meet the safety requirement,
- adding an extra barrier, of the over-packing type or similar.

Each of these systems must be examined and assessed with respect to the safety objectives and the technical means to reach them.

Some orientations may already be provided based on generic type exercises, including the international exercises. They indicate that, in a normal evolution scenario:

- the actinides are well contained by the multibarrier system. Owing to their very low solubility in a reducing medium, they are immobilised by precipitation either in the barriers or within the natural system,
- the only significantly predominant impact could be due to mobile fission products. Iodine is often mentioned, and to a lesser extent caesium. Elements for which the data on behaviour in a natural medium are still uncertain are also mentioned: technetium, palladium, niobium and selenium.

A specific request concerning partitioning and transmutation originating from disposal studies can therefore not be considered before the end of 1997, namely in the framework of the first choice of concept, once the inventory per radionuclide has been specified, the long-term behaviour of the packages described and the specifications laid down.

## **2. What does partitioning-transmutation contribute as a way to reduce the inventory of long-lived radionuclides in waste?**

It may first be considered that P&T fits into a simple rationale to reduce the inventory of long-lived radionuclides sent to waste to potentially reduce the dangers that future generations may be subjected to. In that case, it results only from a subjective need to reduce "potential" dangers independently of any waste management scenario.

The analysis of the concentration of radioisotopes in a spent fuel, of their specific radioactivity and of their dose factor when ingested or inhaled has shown that the "radiotoxic inventory" after 1000 years was linked only to the actinides a thousandfold to ten thousandfold more than to the long-lived fission products. Plutonium represents 90% of the inventory, minor actinides 10%. Plutonium and minor actinides are therefore the priority challenge (Figure 2).

Let us recall that the "radiotoxic inventory" is only a global indicator. It is obtained by weighing each element in the inventory (its concentration) by a coefficient which is strictly valid only in the event of inhalation or ingestion in small doses.

Reducing the inventory of plutonium and minor actinides in wastes obliges global scenarios to be taken into account when they are recycled in a reactor park.

These theoretical scenarios compared with the once-through scenario where the spent fuel is considered a waste, brings out the following conclusions:

In the case of multirecycling plutonium alone, the radiotoxic inventory of the wastes is only reduced by a factor less than 10 (from 2 to 5 depending on the reactor type), since 10% of the plutonium is transmuted into americium and curium (Figure 3 and 4 give an example for Pu recycling in PWRs).

In the case of multirecycling of plutonium and minor actinides, the inventory gain in wastes will then practically depend only on the partitioning performances.

a P&T strategy in a reactor park really makes sense only if it is mastered from beginning to end: reaching a steady state in the park, operating this balanced park over the desired period of time, programmed phasing out necessary to eliminate the inventory in the cycle and putting an end to the nuclear programme. Any brusque interruption in the sequencing of these phases would heavily penalise, or even annihilate the expected gains in the tonnage to be disposed of.

the establishment, operating and programmed phase-out times for nuclear in a P&T strategy is counted in centuries. The problem of the availability of the foreseeable uranium resource in a PWR park will then be acutely felt for carrying out such a strategy. In this regard, the position of FBRs is much more favourable in all respects: sufficient uranium resources, proven physical feasibility of multirecycling, lower production of minor actinides, etc.

The inventory of fission products in wastes can hardly be reduced using fission reactors and dedicated, potentially more efficient, innovative systems must be considered. However their feasibility remains to be proven.

## CONCLUSION

Partitioning-transmutation applied to the management of materials is an operation that could modify the composition of the wastes and act on the long-lived radionuclide inventory (especially actinides). We do not know today how to assess the gain of such operations, or the disadvantages resulting from a service rendered, namely the TWh of electricity produced.

This step will have to be included in nuclear power evolution and waste management scenarios to bring out more significant parameters of the pros and cons, for example the short-term radiologic impact on the workers, the impact that could be produced in the future by geological disposal, the costs, the consumption of raw material resources, etc.

Typical scenarios could perhaps suffice to bring out easier to use assessment criteria by showing "classes" of radionuclides (fissile materials,  $\gamma$  n emitters, mobile elements, very low radioactive  $\beta$  emitters, etc.).

However, the difficulty in short-term and long-term risk intercomparisons will remain.

## Acknowledgments:

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May they all be thanked.



TABLE 1

**LONG LIVED NUCLIDE INVENTORY IN 2010,  
ACCORDING TO EDF'S PLAN (GLOBAL 1995)**

FUELS:			WASTES:		
PWR operation buffer (UOX)	=	8 500 mtHM	GLASSES	=	2 800 m <sup>3</sup>
PWR in storage (UOX)	=	3 440 mtHM	Type B	=	70 000 m <sup>3</sup>
PWR in storage (MOX)	=	1 900 mtHM			

**ACTINIDES (metric tons)**

	Pu	Np	Am	Cm
In glass and type B waste	0.15	7.6	7.1	0.9
In stored fuels and operation buffer	223 (1)	6.9	17	2.3

**LONG LIVED FISSION PRODUCTS (metric tons)**

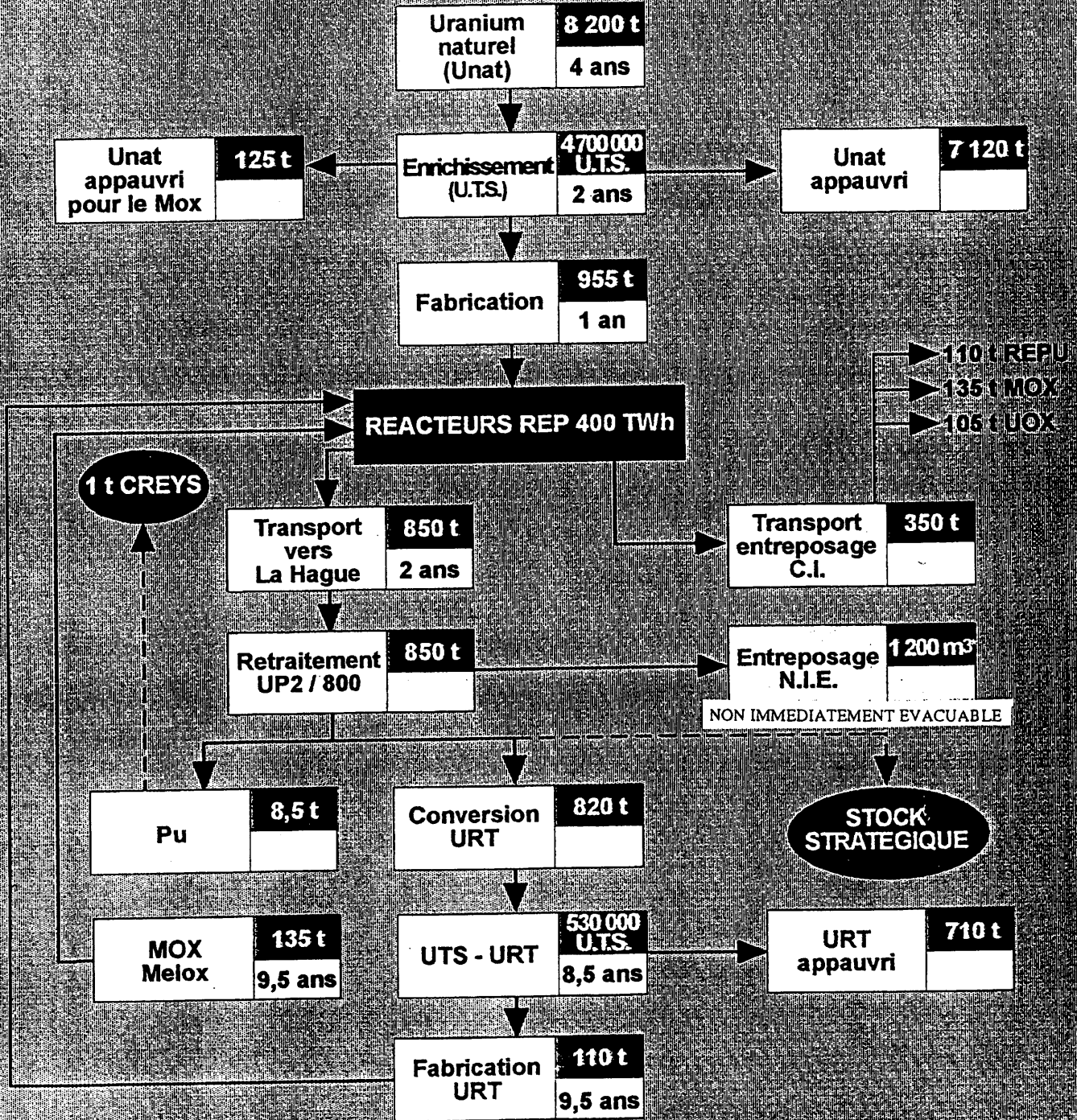
	<sup>79</sup> Se	<sup>93</sup> Zr	<sup>99</sup> Tc	<sup>107</sup> Pd	<sup>126</sup> Sn	<sup>129</sup> I	<sup>135</sup> Cs
In glass and type B waste	0.01	9.7	13.7	3.7	0.4	---	6.3(2)
In stored fuels and operation buffer	0.01	11	13.8	4.4	0.4	3	7.2

(1) Including 100 tons of Pu in MOX fuel assemblies

(2) <sup>135</sup>Cs = 6.3 tons for Cs total = 44 tons



# LES FLUX DANS LE CYCLE DU COMBUSTIBLE NUCLEAIRE

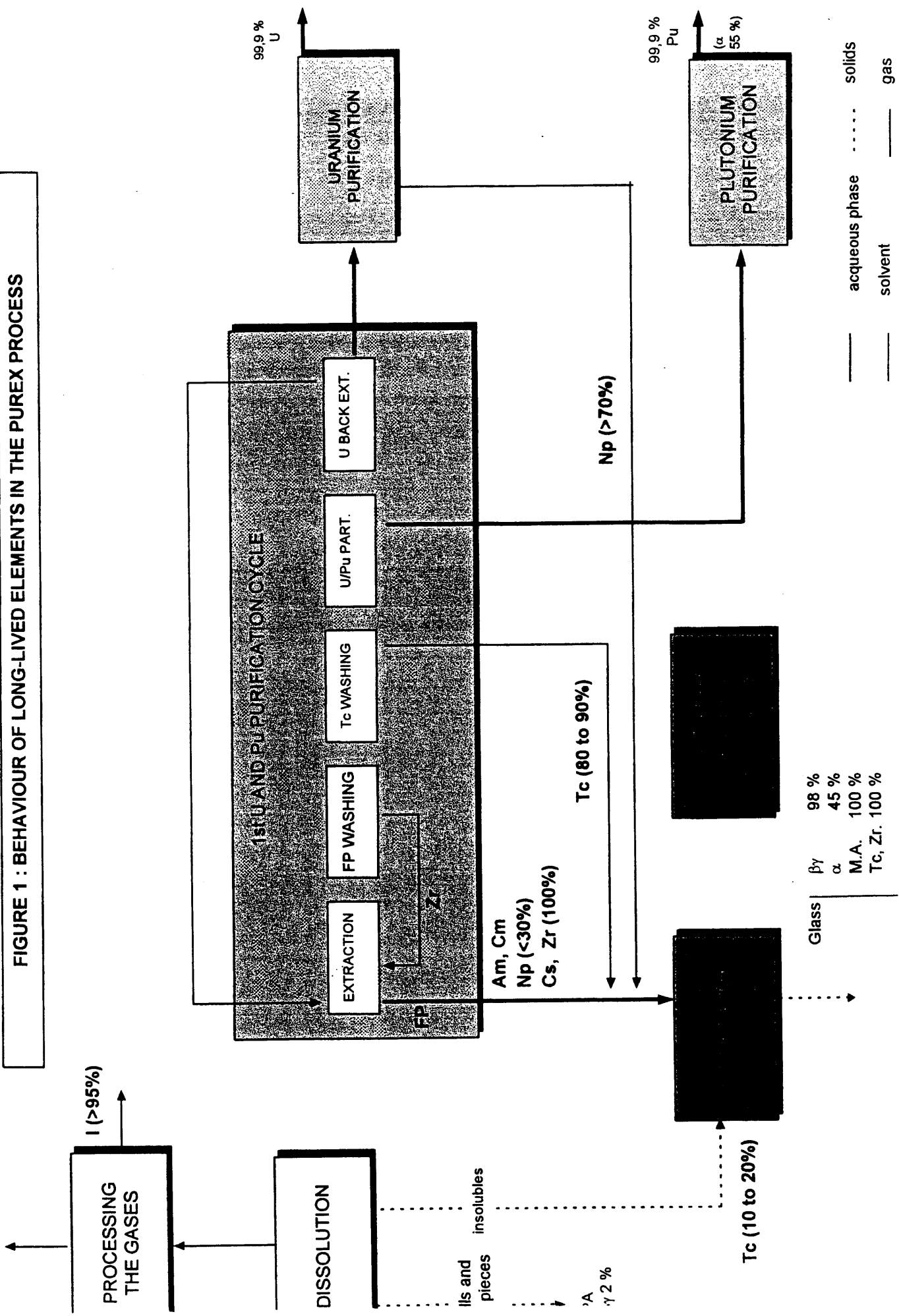


étape du cycle	flux de matière URT (t <sub>ML</sub> )	date de l'opération avant chargement ou après déchargement
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\* dans une hypothèse favorable de conditionnement pour entreposage à long terme, les 850 t d'assemblages irradiés occuperaient 1 700 m<sup>3</sup>.

\*\* Pour les besoins de la présentation, on a retenu un flux de retraitement saturant la capacité nominale d'UP2 et l'égalité des flux de retraitement/MOX/URT sans prendre en compte les besoins de Creys.

FIGURE 1 : BEHAVIOUR OF LONG-LIVED ELEMENTS IN THE PUREX PROCESS



**TABLE 2**

**RESEARCH STATUS ON ACTINIDE AND F.P. PARTITIONING**

	<b>Basic R &amp; D</b>	<b>Process Development</b>	<b>Process Industrialisation</b>
U/Pu partitioning			
Np partitioning		X > 99 %	X 95 %
Am/Cm partitioning			
Diamex		X	
Ac/Ln	X		
Oxidised Am partitioning	X		
Tc partitioning	X insoluble fraction		X soluble fraction
I partitioning			X 95 %
Zr partitioning		X	
Cs partitioning	X		
Pd, Se, Sn partitioning			
X : Present status of research			

Once the feasibility is demonstrated, performances will be excellent and 99 to 99,9 % of the radionuclides should be separated.

SCENARIOS OF MULTIRECYCLING OF PLUTONIUM ALONE  
OR WITH MINOR ACTINIDES

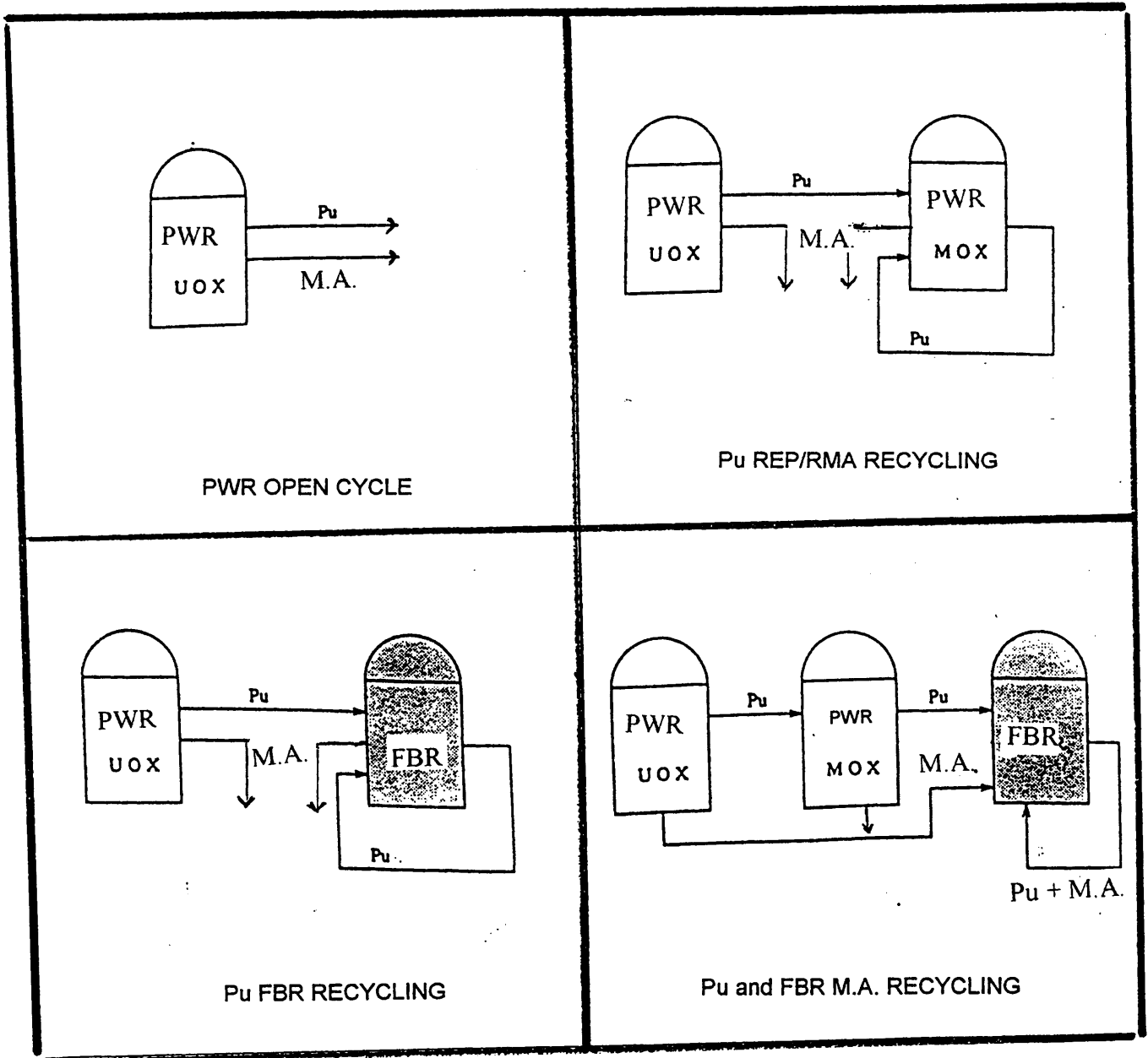


DIAGRAM 2

TABLE 3

MULTIRECYCLING OF PLUTONIUM ONLY  
 STEADY STATE CONDITIONS  
 60 GWe - 400 TWh

Reactor	N4 MOX heterogeneous	N4 MOX homogeneous	RMA heterogeneous	RMA homogeneous	CAPRA	N4 UOX
Moderation ratio	2	2	4	4	---	2
U, associated to Pu (%235U)	2.8%	3.8%	0.25%	3.8%	0.19%	4.5%
Pu concentration (%)	9.6%	2%	18%	1.2%	54%	0
Cycle inventory in tons of Pu	400	200	390	112	310	35
Pu in wastes (kg/year)	28	16	31	10	37	11600
MA in wastes (kg/year)	3600	3250	3450	2500	2800	1520

**TABLE 4**

**PHYSICAL FEASIBILITY OF RECYCLING MINOR ACTINIDES IN REACTOR**

	<b>Maximum concentration in M.A.</b>	<b>Transmutation ratio</b>
PWR N <sub>4</sub> or RMA (47 GWJt <sup>-1</sup> )	1 to 2 %	6 to 9 %
FBR ( EFR type) (120 GWJt <sup>-1</sup> )	5 %	18 to 27 %

Homogeneous recycling (minor actinide dispersed in a standard fuel).

Results : 3 to 15 kg/TWhe transformed depending upon reactor type and recycling conditions against 3 kg/TWhe produced in a PWR (UOX) at 33.000 MWdt<sup>-1</sup>

TABLE 5

EXAMPLES OF INVENTORY REDUCTION (Pu and M.A.)  
IN WASTES (Pu and M.A. RECYCLING)

400 TWhe/year

<u>PWR open cycle (UOX)</u>	<u>Steady state park with FBRs (CAPRA)</u>
<ul style="list-style-type: none"> <li>• Yearly uprisings: Pu 12 mt/year M.A. 1.3 mt/year</li> <li>• Yearly amounts to waste: Pu 12 mt/year M.A. 1.3 mt/year</li> <li>• In-cycle inventory~In-reactor inventory  Pu 34.8 mt M.A. 3.9 mt</li> </ul>	<ul style="list-style-type: none"> <li>• Yearly uprisings: Pu ~ 0 M.A. ~ 0</li> <li>• Yearly amounts to wastes: Pu ~ 0.1 mt/year M.A. ~ 0.1 mt/year depending upon separation efficiency</li> <li>• In-cycle inventory ~ In-reactor and in-plant inventory Pu ~ 460 mt (170 tons in reactors) M.A. ~ 120 mt (50 tons in reactors)</li> </ul>

A STEADY STATE FBR PARK VERSUS A PWR OPEN CYCLE

	Over 10 years	Over 100 years
Inventory in wastes	: 70	: 70
Total inventory (cycle and wastes)	X 3.5	: 2.2



TABLE 6

RESEARCH STATUS ON THE DEFINITION OF FUELS AND TARGETS FOR  
TRANSMUTATION

	Basic R&D	Process development	Process industrialisation
<b>FUELS</b>			
UO <sub>2</sub> or PuO <sub>2</sub> + Np + Am + Cm		X X	X
<b>TARGETS</b>			
Am targets Cm targets Tc targets	X	X	
X: Present status of research			

**FIGURE 2 : Radiotoxic inventory of one ton of UOX1 fuel**

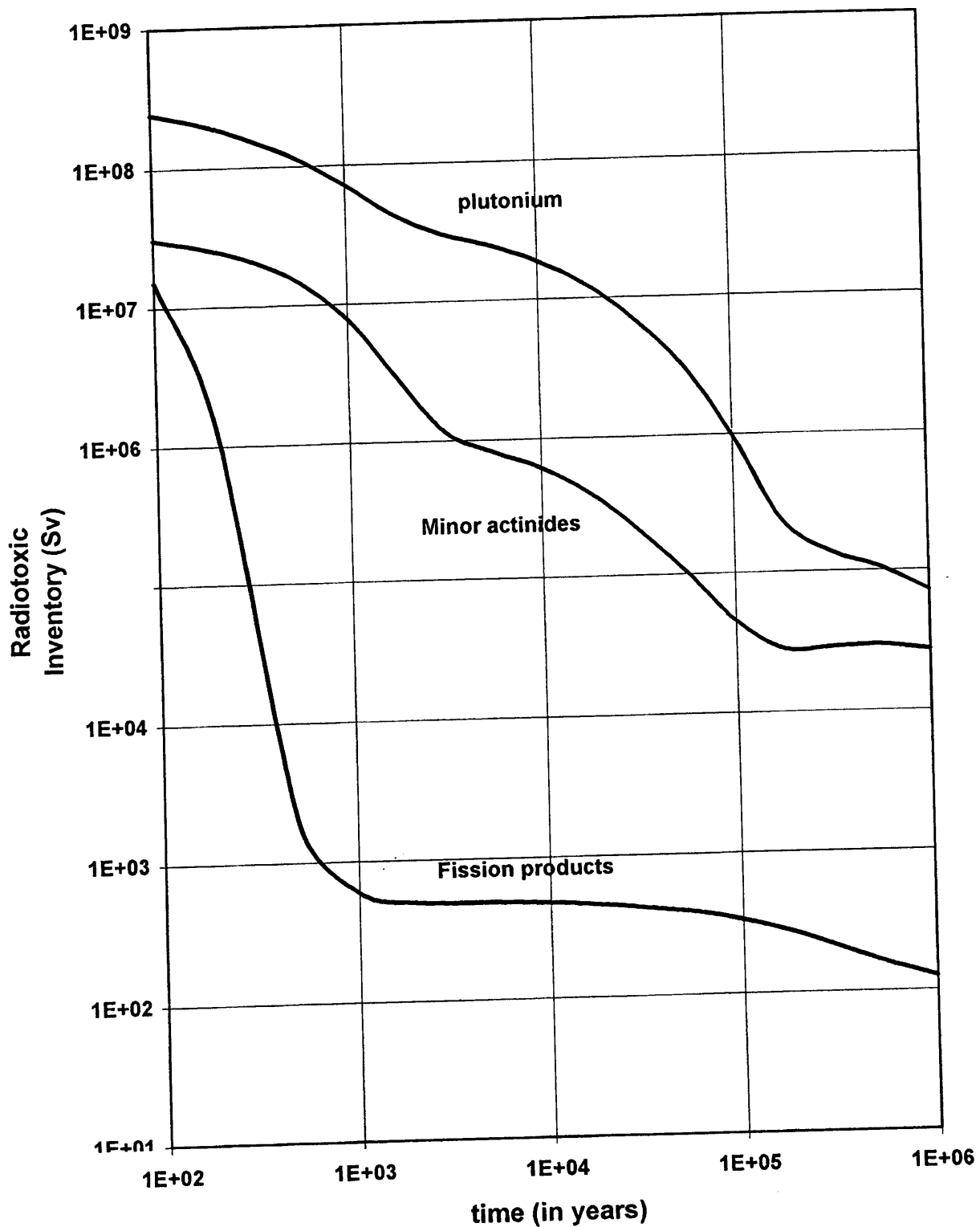


FIGURE 3: Contribution of the various initial actinides to the radiotoxic inventory of wastes  
(UOX1 fuel case)

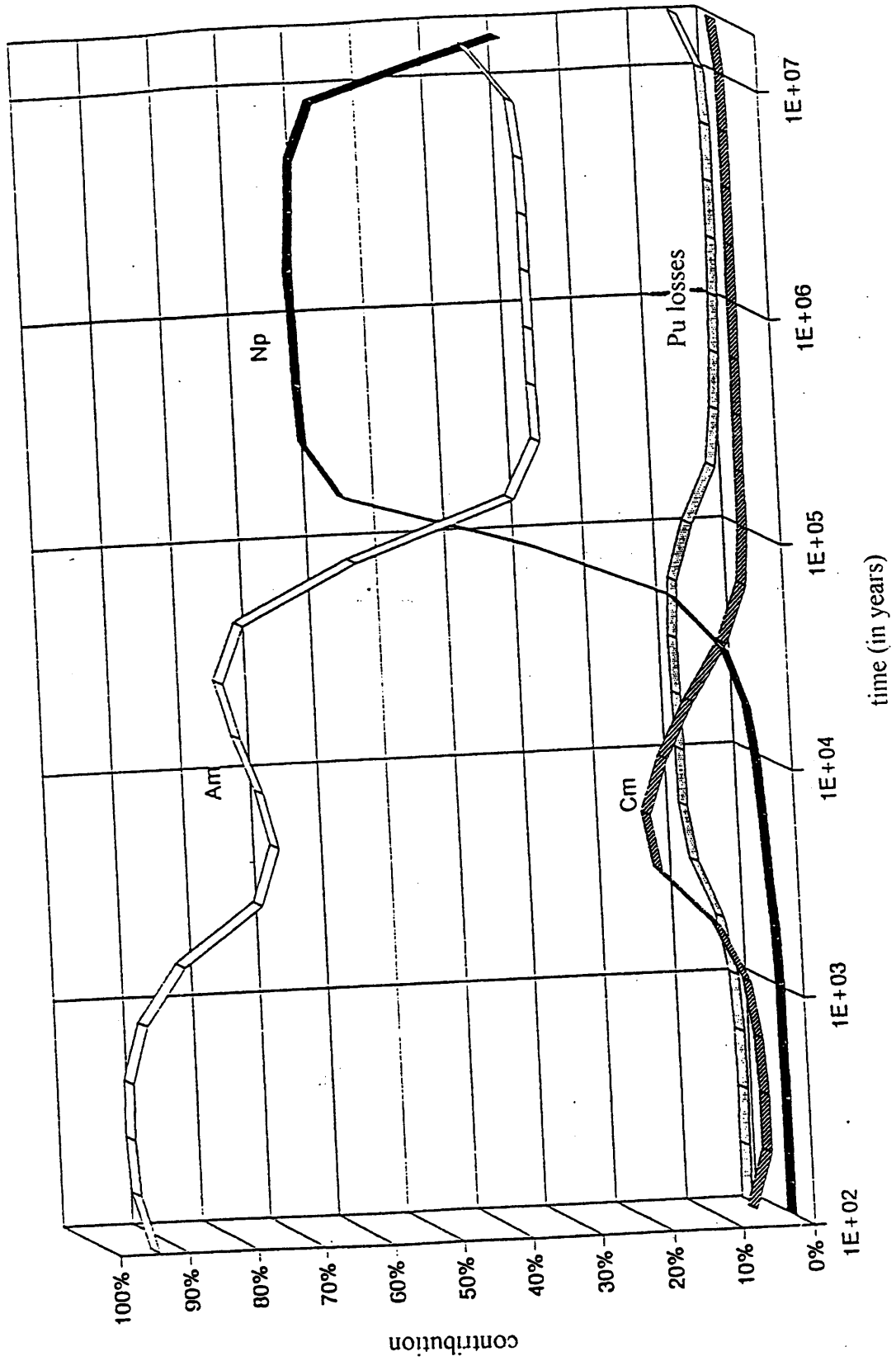


FIGURE 4: Contribution of the various initial actinides to the radiotoxic inventory of wastes (MOX fuel case)

