SCENARIOS OF PLUTONIUM AND MINOR ACTINIDE MANAGEMENT AT EQUILIBRIUM

M. DELPECH, J.P. GROUILLER, M. SALVATORES, J. TOMMASI, A. ZAETTA
CEA - Nuclear Reactor Directorate - Cadarache

A. HARISLUR, H. MOUNEY, M. ROME
EdF - Direction de l'Equipement

ABSTRACT

Any strategy related to radioactive waste management has to provide first a consistent answer on the Plutonium management. In fact, Plutonium build-up with standard PWRs should be accounted for and, if reprocessing is adopted, long-term solutions have to be found to use Plutonium in an effective way, and to minimise the associated minor actinide build-up.

The present paper gives the results obtained for different scenarios related to a nuclear power park of 60 GWe.

These results are given to show main trends and features, but do not account for detailed, economic and technological feasibility aspects, that will be the aim of future work.

1. INTRODUCTION

Any strategy related to radioactive waste management has to provide first a consistent answer on the Plutonium management. In fact, Plutonium build-up with standard PWRs should be accounted for and, if reprocessing is adopted, long-term solutions have to be found to use Plutonium in an effective way, and to minimise the associated minor actinide build-up.

In the frame of the studies required by the French Parliament law of 1991 on Waste Management, and according to the requirements of the National Commission (CNE) in charge of Evaluating these studies, the CEA Nuclear Reactor Directorate has launched a wide range of assessments on different scenarios of Pu utilisation in different reactor types (PWRs, FRs) and on the consequent approaches to the residual minor actinide management, and in particular to specific options to transmute them. The goal is to help feasibility assessments, to quantify fuel cycle characteristics and eventual benefits for deep storage.

This type of far-reaching studies is the closest to what can be considered a full system study, related to Plutonium management and partitioning/transmutation, and are an essential part of the SPIN program.

The present paper will give results and present trends.

2. THE SCENARIOS CONSIDERED IN THIS STUDY

The following scenarios have been characterised :

- Open cycle scenario.
- Pu recycling in light water reactors. Two major options for PWRs are considered : a) 100 % MOX-PWRs with a high moderator-to-fuel ratio, RMA, b) PWRs with MOX fuel on a ^{235}U enriched support, with standard moderator-to-fuel ratio.
- Pu recycling in PWRs (RMAs) followed by FR (CAPRA-type) utilisation for Pu multirecycling. Two hypothesis are considered : a) Only one recycle of Plutonium in PWRs, b) Two recycles of Pu in PWRs. Both cases attempt to consider delays in the introduction of FRs in a nuclear power park.
- In two cases : a) Full Pu recycling in PWRs, b) One recycle of Pu in a standard PWR followed by multirecycling in FR ; the explicit management of separated Np, Am, and Cm is considered.

All PWRs have a burn-up of 55 GWd/t, with fuel reloading frequency equal to six. Fast Reactors are of the CAPRA type (140 GWd/t burn-up, frequency 3).

For each of these seven scenarios, mass flow (Pu, minor actinides) throughout reactors and in the fuel cycle installations (reprocessing, fabrication) has been obtained.

All scenarios are relative to the same installed power (60 GWe, producing 400 TWhe/y).

Moreover, the detail of the reactor core characteristics is also given (enrichments at equilibrium, Pu vectors, detailed minor actinide inventories).

Finally the full Plutonium inventory at equilibrium is explicitly given. In terms of benefits for waste management in the storage, potential radiotoxicity and its evolution in time is presented for the scenarios where minor actinide transmutation is studied.

3. RESULTS OF THE SCENARIOS STUDIES

The results for the seven scenarios indicated above, are summarized in figures 1-7. Some comments on each scenario is given below.

3.1 Open cycle (figure 1)

This is the standard reference scenario. To be noted the high burn-up which has been chosen (and which is applied to all PWRs, whatever the fuel loading, in all subsequent scenarios).

The figure shows both the Uranium resources needed (in terms of annual mass flow) and both the resulting depleted Uranium (U-235 enrichment : 0.25 %) and the "wastes", which, in that case, include Plutonium.

3.2 Pu recycling in high moderation PWRs ($R_{mod} = 4$) (Figure 2)

In this scenario, all Plutonium is multirecycled in PWRs with a high moderator-to-fuel ratio, HMR, ($R_{mod} = 4$), which previous studies [1] have indicated as a particularly interesting option. Since the multirecycling is shown at equilibrium, one has an unlikely high Pu content in the fuel (~ 18 %). This scenario implies a 190 t MOX fabrication capability (to be compared to the present MELOX plant potential).

The HMRs represent ~ 20 % of the reactor park.

As far as resources, this scenario allows a ~ 20 % reduction of natural Uranium requirements.

As far as wastes, the Am and Cm production goes up of a factor of 4, with respect to the open cycle scenario.

3.3 Pu recycling in standard MOX PWRs with enriched Uranium support (figure 3)

In order to avoid potential problems related to the increase of Pu content in MOX PWRs (and the consequent potential problems related to reactivity coefficients), one can envisage a mixed enriched U-235-MOX fuel.

An equilibrium park is obtained with only one type of PWR. The fuel Pu content is ~ 2 %, and the U-235 enrichment is 3.8 % (to be compared to the standard 4.5 % value, see figure 1).

Multirecycling seems then feasible from a physics point of view. However two main drawbacks should be noted : a) Fuel fabrication costs will probably grow significantly, and MOX fuel fabrication plants should account for the annual need of 880 tons (~ 7 MELOX plants) ; b) The Cm produced in this scenario goes up about a factor of 2.

In fact, the U-235 dominated core spectrum with a high thermalisation, favours the Cm production (the reduced Am production is an extra source of Cm build-up).

3.4 Scenarios with fast reactors for Pu recycling (figures 4 and 5)

Both scenarios of figures 4 and 5 account for the use of CAPRA-type fast reactors [2]. This seems to be still the most promising option, in view of the difficulties encountered in both the full-PWRs scenarios described above. For both scenarios, it has been considered realistic to envisage one or two recyclings of Plutonium in standard MOX-PWRs. The difference between the two scenarios is then represented by the delay in introducing fast reactors into the reactor park and the relative proportion of reactor types in the park (the fast reactor share is never higher than ~ 18 %). In fact, two recyclings of Pu in PWRs is envisaged in the scenario of fig. 5.

As far as resources, both scenarios allow a 30 % decrease of the natural Uranium supply requirement. In terms of MOX fabrication for both PWRs and FRs, one MELOX-type should be enough for the scenario of fig. 4. More fabrication capability is obviously required, if two recycling have to be foreseen in MOX-PWRs (fig. 5).

The waste production in these types of reactor parks, is close to that of the reactor park with HMRs (see figure 2). In fact, the potential benefits of using fast reactors, are reduced by the limited amount of these

reactors in the park and by the fact that the Pu recycled in fast reactor has already been degraded by one (or two) recycling(s) in PWRs.

Finally, it should be noted that the Pu content at equilibrium in the CAPRA-type reactors is close to 50 %, which is slightly higher of what is suggested in the CAPRA feasibility studies, but which can be easily adjusted to the required value (~ 45 %).

3.5 Scenarios with Minor Actinide (MA) recycling (figs. 6 and 7)

Minor actinides are recycled according to two scenarios which have been presented previously, namely a full PWRs scenario, with only one type of fuel loading (mixed enriched-U-235 and MOX fuel, shown in figure 3) and a MOX-PWR (one recycling) plus CAPRA-type reactors (shown in figure 4).

The mixed enriched-U/MOX PWRs have been chosen, since the MA recycling in PWRs generally worsens the core parameters [3], and, if an homogeneous MA recycling is chosen, one has to take that general trend into account. However, even in that case, the equilibrium composition (shown in fig. 6 : 4.1 % U-235, 2.6 % Plutonium, 1 % MA) can give rise to feasibility problems. As expected, the Cm production (see fig. 6) is very relevant with negative consequences on the physics parameters of the fuel cycle. Once more, it seems that the only reasonable way out to envisage a MA recycling in PWRs is the heterogeneous mode, and a specific scenario has to be envisaged, possibly with a temporary, long-term out-of-pile storage of Cm, or with a very long irradiation of MA targets, in order to fission them at a very high degree.

The scenario of figure 7 implies the use of FRs of the CAPRA-type. The relative fractions of the different reactor types are very close to those of fig. 4 (i.e. no MA recycling). The minor actinide recycling is of the homogeneous type for Np-237, and of the heterogeneous type for Am. Cm is separated and left to decay out-of-pile into Pu, and successively recycled [4].

This scenario does not present feasibility problems from the physics point of view. It has to be noticed that all the features of the specific, MA-burner CAPRA cores, are presently being experimentally studied in SUPERPHENIX [5] (high-Pu content fuel S/A in the CAPRA 1 and 2 irradiations, Np-bearing fuel in the homogeneous mode in the NACRE experiment. Am targets are foreseen to be introduced in SUPERPHENIX early 1998 : ECRIN experiment).

To optimise this scenario, the option of a once-through irradiation of Am targets is also being studied.

Finally, it is of interest to notice the overall amount of Am targets to be fabricated annually ($\simeq$ 5 tons).

4. THE POTENTIAL RADIOTOXICITY SOURCE IN THE STORAGE

It is easy, starting from the mass balances obtained in the studies described above, to evaluate the potential radiotoxicity source in a deep geological storage.

This parameter (when normalized to the energy which is produced), even if not to be taken as an absolute reference, is a simple way to characterize the activity inventory in a storage and its evolution with time. The Scenarios described in figs. 6 and 7 show a potential reduction of the radiotoxicity source term with respect to the open cycle scenario, of a factor which varies between 50 and 100, according to the time scale, when a decontamination factor of 0.1 % is applied to the Plutonium reprocessing and of 1 % to the MA partitioning (see fig. 8).

This factor is reduced to approximately 3 for all the scenarios, where only Pu is recycled, and MA are sent directly to the wastes (see fig. 8).

5. MASSES INVENTORY

All the previous discussion has been based on annual mass flows. However, an interesting point is to consider the total isotope masses which are present in the fuel cycle. These quantities will help to understand the implications of the equilibrium scenarios, in the case, for example, of the need to reduce drastically a nuclear power park.

Fuel cycle inventory is defined as the total isotope masses present in Reactors and in the different fuel cycle plants (reprocessing, storage, fabrication). We consider five years for cooling time before reprocessing and two years for fabrication operations.

For the different scenarios, masses inventories are given in the following table :

	Pu Inventory (tons)	Minor Actinides Inventory (tons)
Pu recycling in HMR (fig. 2)	430	/
Pu recycling in PWR with U235 support (fig. 3)	230	/
Pu recycling in CAPRA (once in PWR (fig. 4))	370	/
Pu recycling in CAPRA (twice in PWR (fig. 5))	380	/
Pu + M.A recycling in PWR with U235 support (fig. 6)	300	95
Pu + M.A recycling in CAPRA Pu once in PWR (fig. 7)	440	90

Scenarios with Pu recycling in dedicated Reactors (PWR or FR) show a quite similar amount of Pu inventory (around 400 tons).

For the scenario with Pu recycling in standard PWR with U235 support, Pu inventory is rather smaller about 200 tons. This is mainly due to the fact that in these case, the fissile isotope inventory necessary to reach Reactor's criticality is partially provided by the U235 support.

When Minor Actinides are recycled, the Pu inventory is increased by about 20 % to 30 % and Minor actinides inventory is slightly smaller than 100 tons for both scenarios.

REFERENCES

1. M. Salvatores et al. "Nuclear Waste Transmutation : physics issues and potential in Neutron fields, ENS Conf. Tel-Aviv, January 1994.

2. J. Rouault et al. "The CAPRA feasibility study", Proc. 3rd Int. CAPRA Seminar, Lancaster, 1995.

3. M. Delpech et al. "PWRs potential for Pu and Minor Actinide burning", ENC'94, Lyon, Oct. 1994.

4. J. Tommasi et al, Nuclear Technology, 111, 133 (1995).

5. P. Anzieu, R. Del Beccaro, "Pu burning and Actinide Transmutation in SUPERPHENIX", GLOBAL'95, Versailles, Sept. 1995.

FIGURE 1
PARK OF PWRs (60 GWe) - 400 TWhe/year
Burn-up = 55 GWD/t Frequency = 6

1. OPEN CYCLE

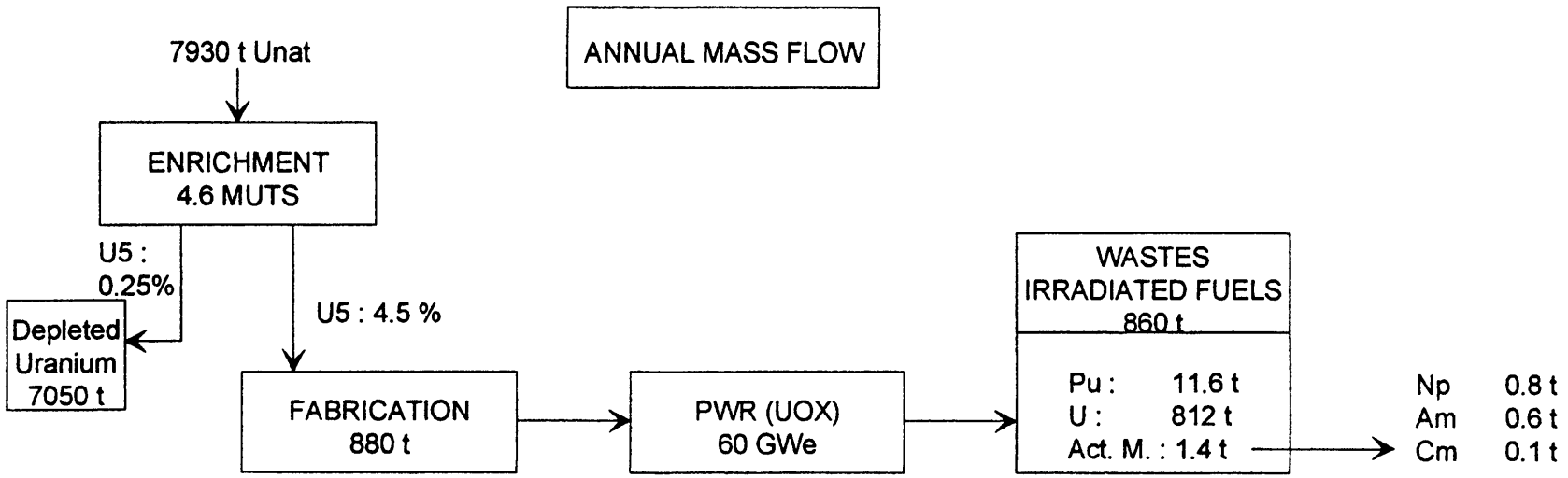


FIGURE 2
PARK OF PWRs (60 GWe - 400 TWhe/year)
EQUILIBRIUM STATE
BURN-UP : 55 GWD/t Frequency = 6

2. RECYCLE OF PU IN HIGH MODERATED REACTOR (Rmod = 4)

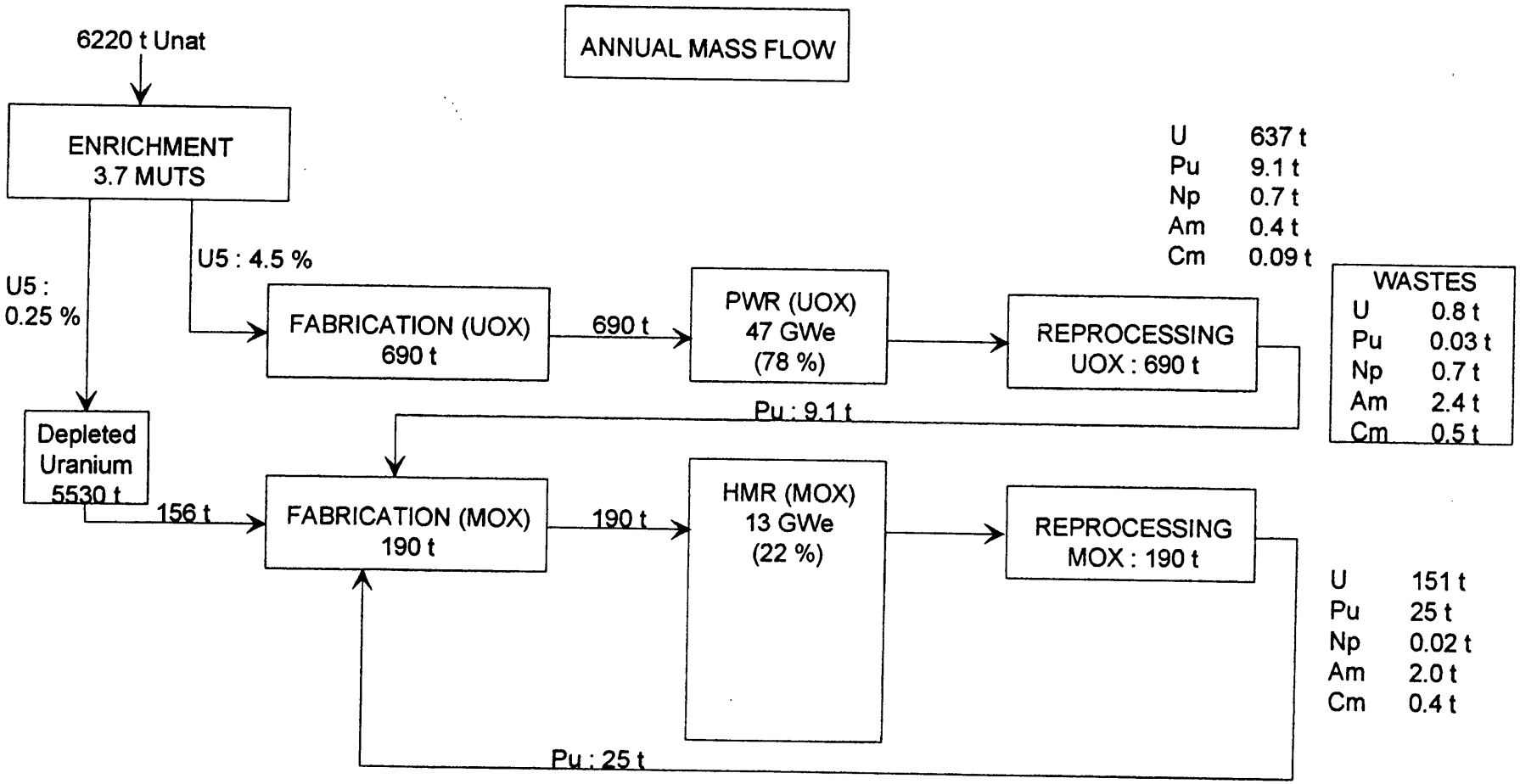


FIGURE 3
PARK OF PWRs (60 GWe - 400 TWhe/year)
EQUILIBRIUM STATE
BURN-UP : 55 GWD/t Frequency = 6

3. RECYCLE OF Pu IN STANDARD MOX WITH ENRICHED URANIUM SUPPORT

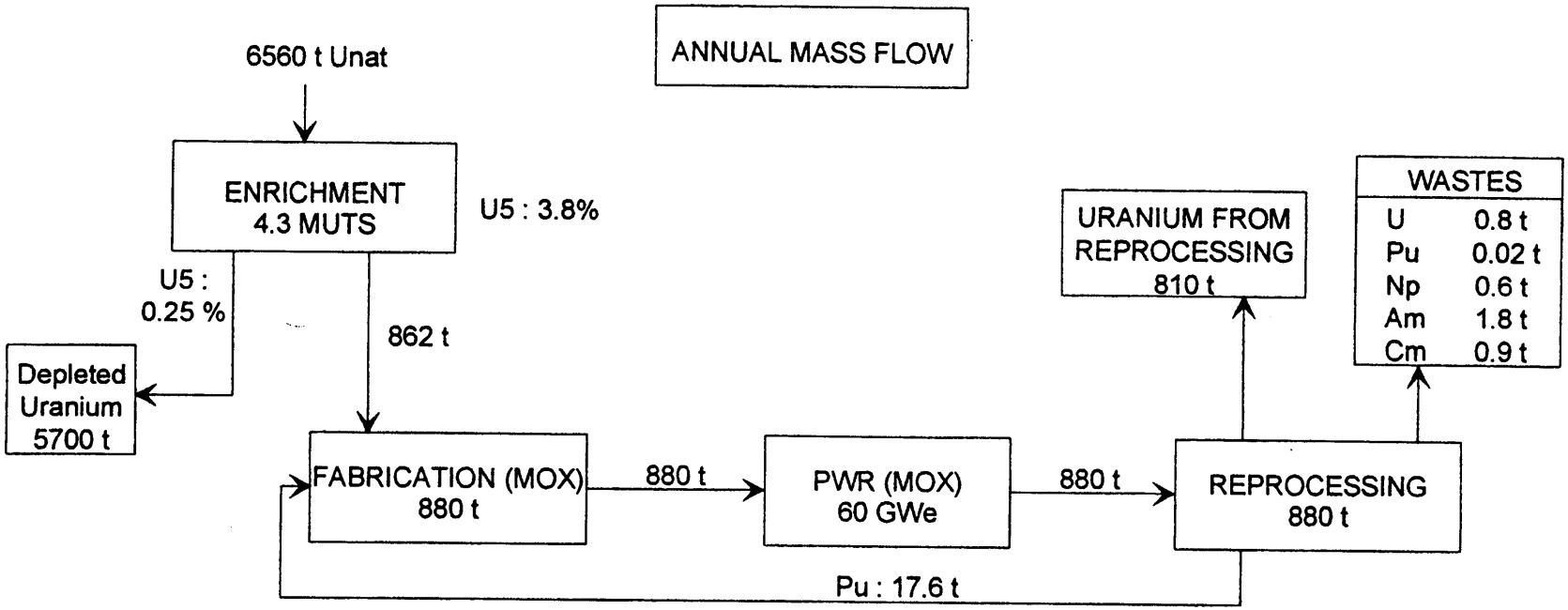


FIGURE 4
PARK PWR + CAPRA (60 GWe - 400 TWhe/year)
EQUILIBRIUM STATE
BURN-UP PWR = 55 GWD/t **Frequency 6**
BURN-UP CAPRA = 140 GWD/t **Frequency 3**

4. RECYCLE OF Pu : once in PWR and after in CAPRA

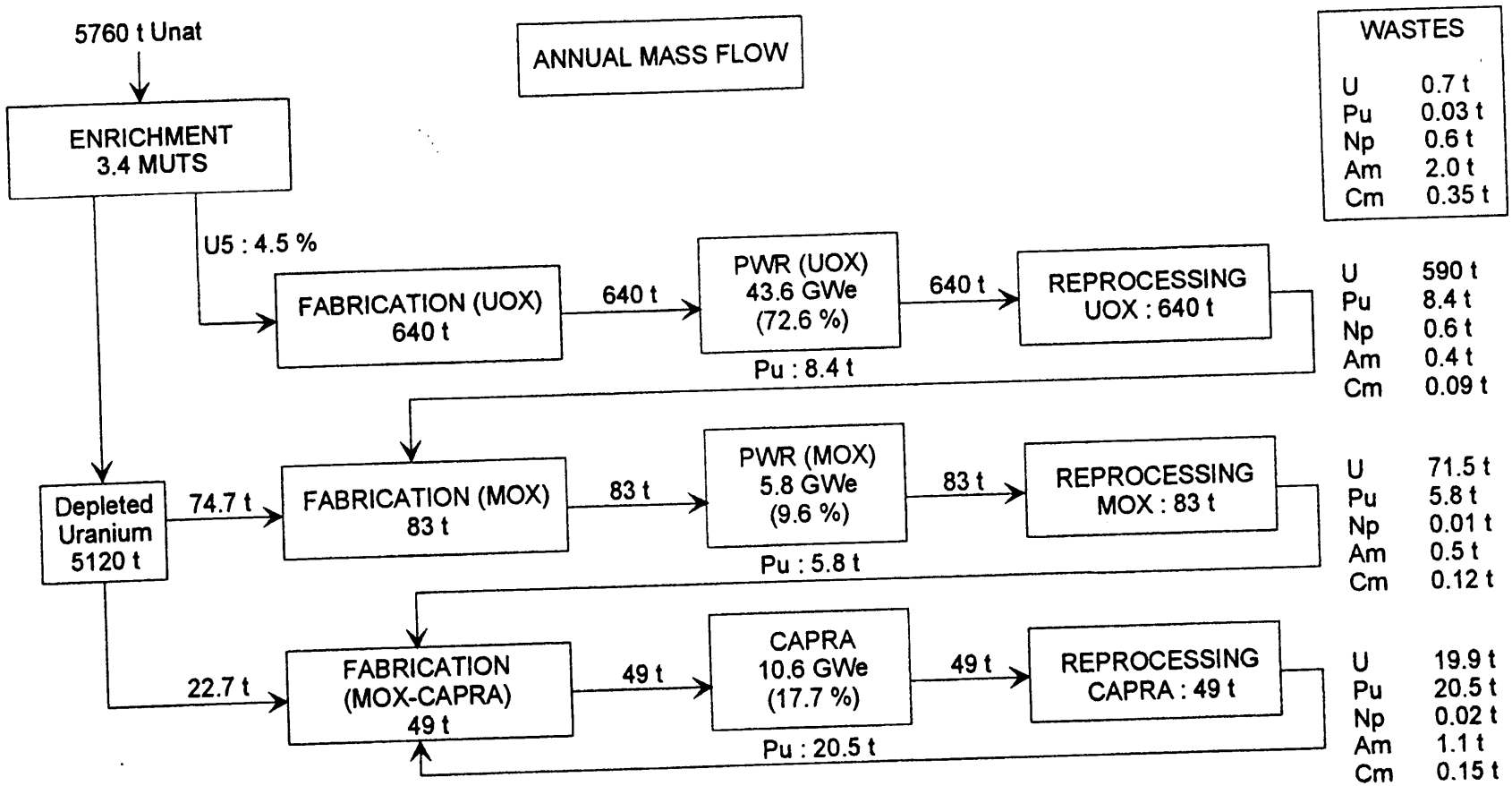


FIGURE 5
PARK PWR + CAPRA (60 GWe - 400 TWhe/year)
EQUILIBRIUM STATE

BURN-UP PWR = 55 GWD/t — **Frequency 6**

BURN-UP CAPRA = 140 GWD/t — **Frequency 3**

5. <u>RECYCLE OF Pu</u> : twice in PWR and after in CAPRA

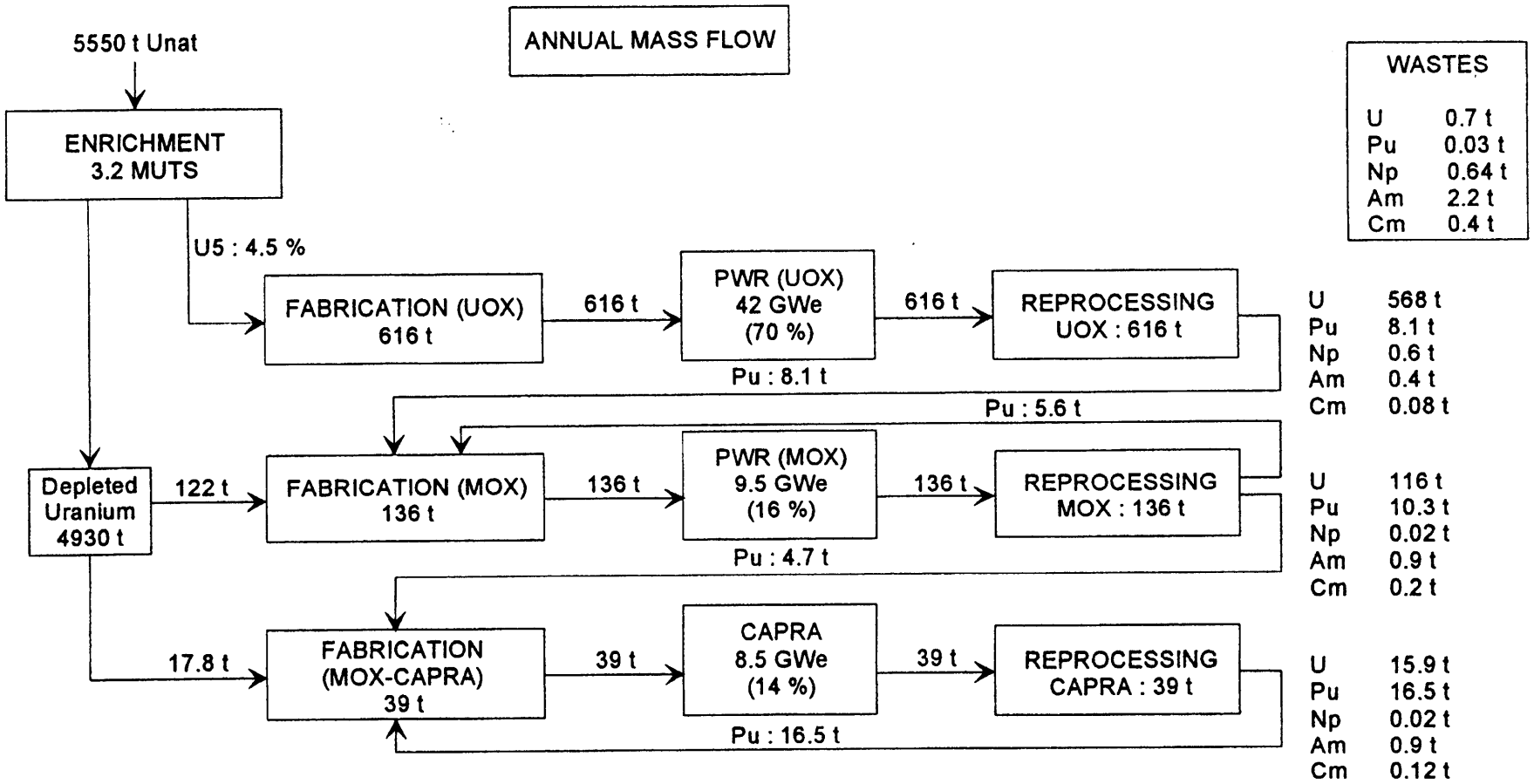


FIGURE 6
PARK OF PWRs (60 GWe - 400 TWhe/year)
(55 GWD/t, Frequency = 6)
EQUILIBRIUM STATE

6. RECYCLE OF Pu + Np + Am + Cm in MOX PWR with enriched uranium support :

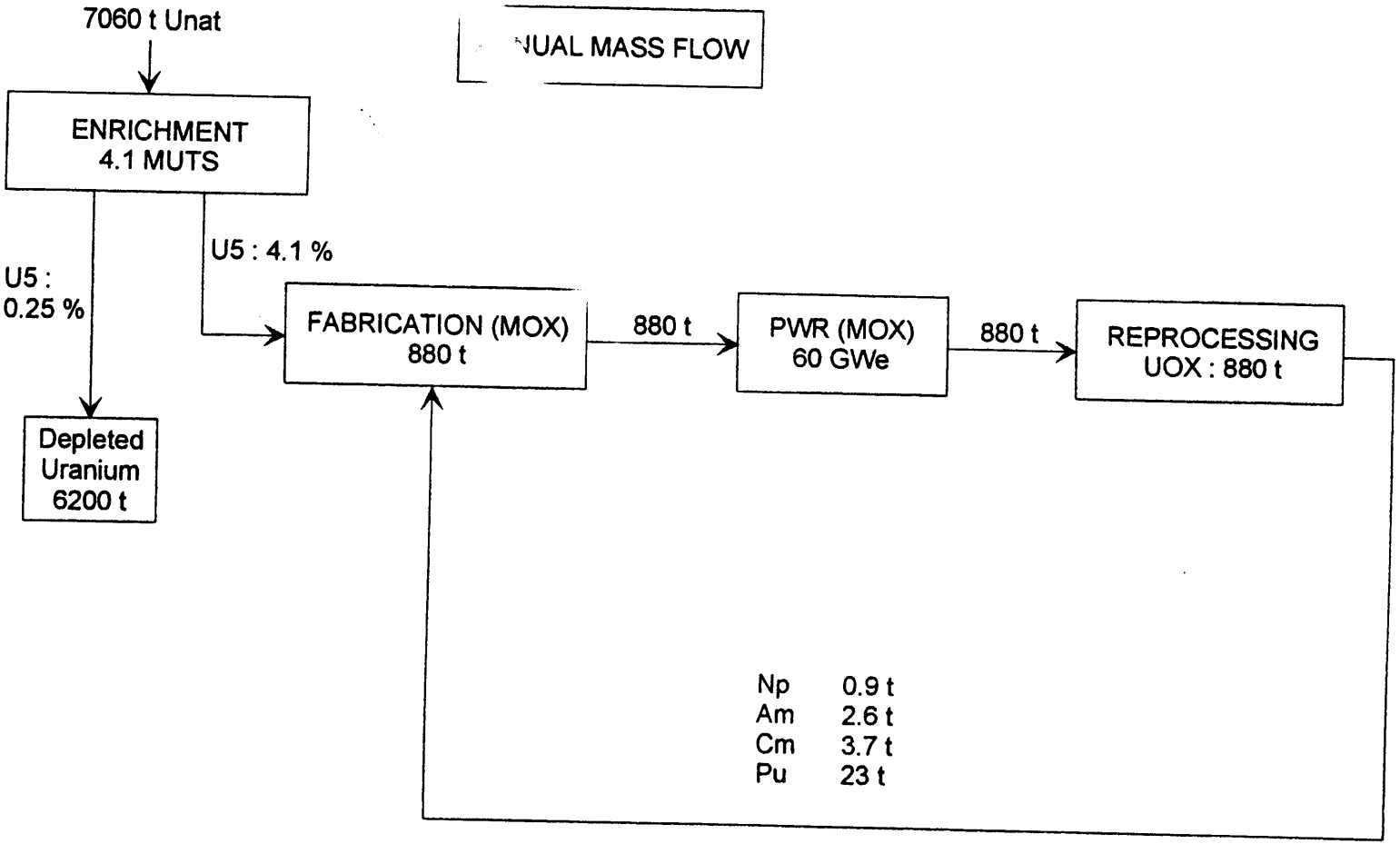


FIGURE 7
PARK PWR + CAPRA (60 GWe - 400 TWhe/year)
EQUILIBRIUM STATE

PWR = 55 GWD/t — Frequency 6
CAPRA = 140 GWD/t — Frequency 3

7. RECYCLE OF : once in Pu in PWR and after in CAPRA, Np + Am + Cm in CAPRA :

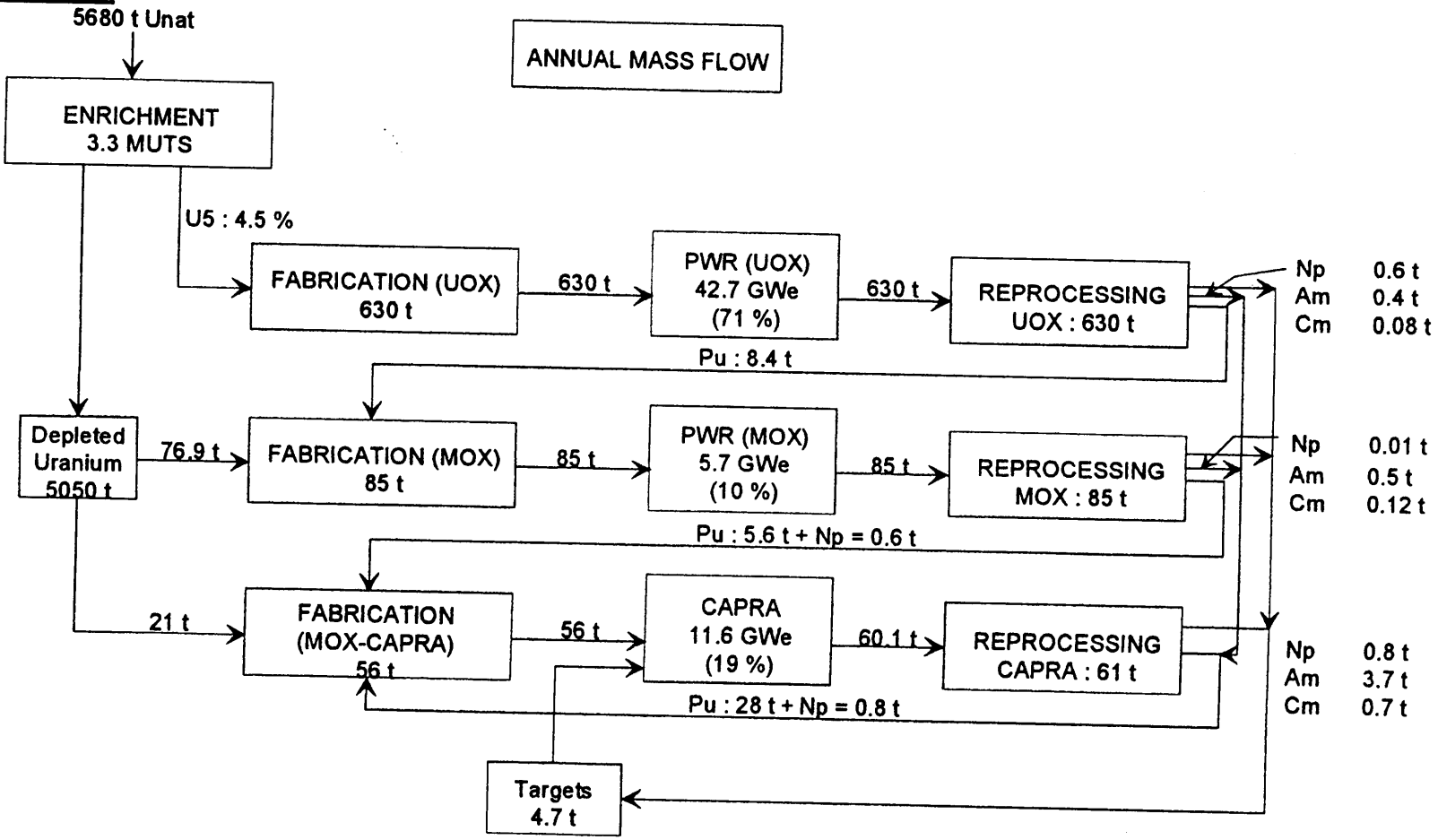
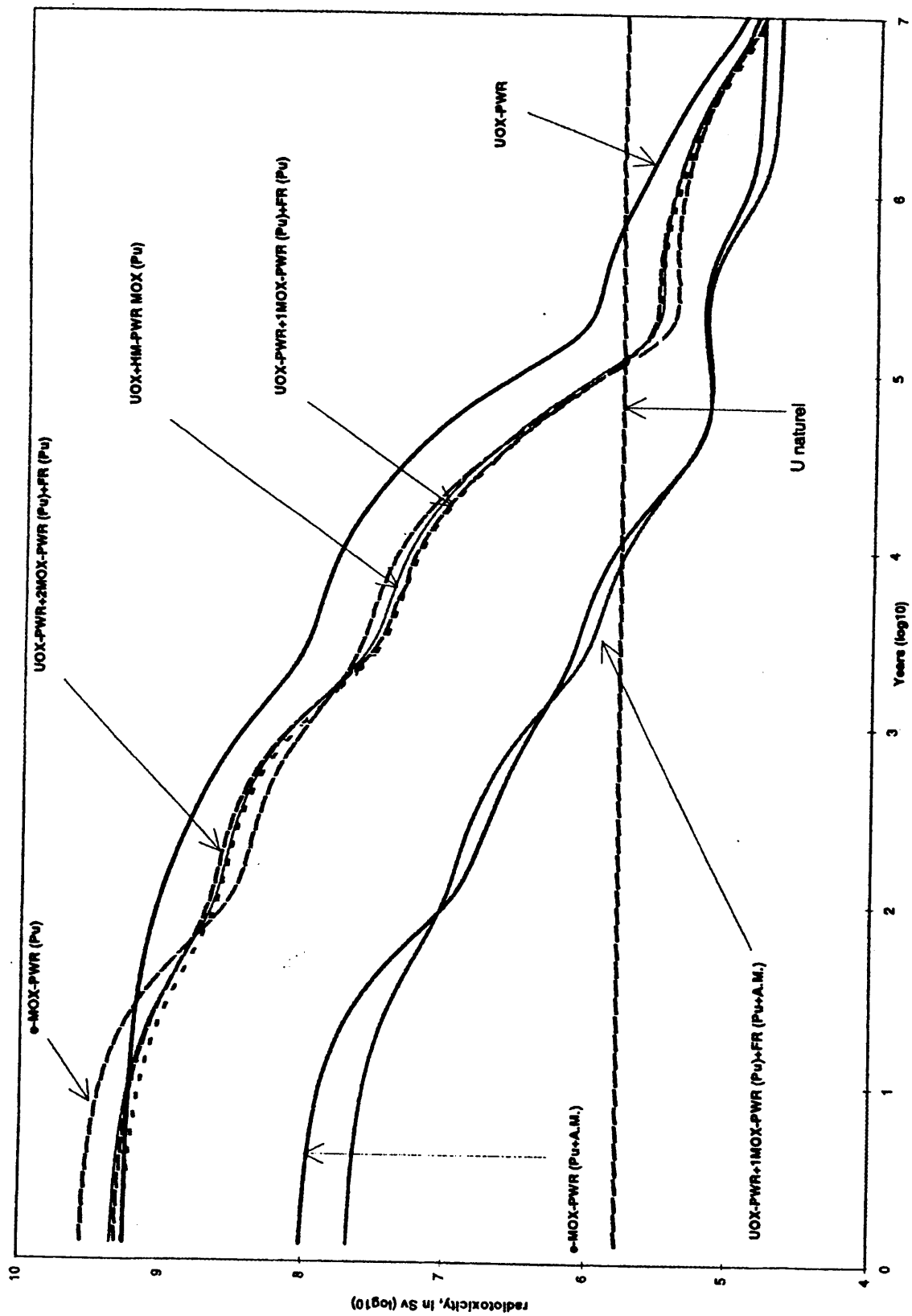


FIGURE 8


UOX-PWR+2MOX-PWR (Pu)+FR (Pu)
UOX+HM-PWR MOX (Pu)
UOX-PWR+1MOX-PWR (Pu)+FR (Pu)
UOX-PWR
U naturel
e-MOX-PWR (Pu)
e-MOX-PWR (Pu+A.M.)
UOX-PWR+1MOX-PWR (Pu)+FR (Pu+A.M.)
radiotoxicity, in Sv (log10)
Years (log10)
10
9
8
7
6
5
4
0
1
2
3
4
5
6
7