

**OECD-NEA Specialists' Meeting on Accelerator-Based Transmutation
24-26 March, 1992, Paul Scherrer Institute, Würenlingen/Villigen, Switzerland**

**THE INFLUENCE OF DIFFERENT RECYCLING SCHEMES ON
TOXICITY REDUCTION FOR TRANSMUTATION SYSTEMS
USING HIGH-ENERGY SPALLATION REACTIONS**

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ABSTRACT

The minor **actinides** in the high-level waste from **LWR** spent fuel are contributors to the long-term radiological risk. In the present study a theoretical transmutation system for minor **actinides** is investigated which **relies** on the direct use of high-energy fission and **spallation** reactions alone.

The advantages of **utilising** the high-energy reactions themselves **as** transmutation **pro-**cesses are the high fission probability and the tendency to directly **reduce** the mass of the bombarded nuclei (no build-up of undesirable higher reaction products).

The purpose of the study is to find the theoretically achievable reduction of the **long-**term risk by assuming different recycling and partitioning schemes. The transmutation system is simulated by a quasi-infinite minor **actinide** target irradiated by 1 **GeV** protons.

It is shown that the reduction of the radiological toxicity is highest for a system in which all **spallation** products are recycled. Beyond 200 years the overall toxicity decreases by 3 orders of magnitude and reaches 5 orders of magnitude at 1000 years compared with the direct decay of the original minor **actinide** mixture from **LWR** spent fuel.

The disadvantages of the above theoretical transmutation system are a poor energy balance and the necessity of a powerful proton accelerator. However, the system provides a very intense neutron source which can be used to breed **fissile** material for high-conversion reactors or to transmute fission products with very low capture **cross-**section.

Introduction

In many countries vitrification and geological disposal techniques are being investigated or applied for the safe storage of long-lived high-level waste from nuclear power and reprocessing plants. The residual long-term radiological hazard of such waste comes from **actinides** and fission products with half-lives of millions of years. In the **longer-term** future, technical progress may make it practicable to transmute such **nuclides** to products with half-lives of hundreds of years. This does not render geological repositories unnecessary, but the consequent reduced long-term risk should have a positive influence on their design requirements.

The transmutation methods being investigated at present may be split between those considering incineration in fast (burner) reactors (this is outside the scope of the meeting and not considered here) and accelerator based methods.

The accelerator-based methods may be further subdivided between those that use **high-energy** particle induced **spallation** and fission reactions directly ([1],[2],[3],[4]) or **neutrons** generated by such processes to produce intense thermal neutron fields ([5],[6]) or to drive subcritical fast assemblies ([7], [8]). Presently, no one of these possibilities stands out as a ‘best’ transmutation concept: all of them are based on a considerable extrapolation beyond present technology and/or involve the combination of several complex systems.

Purpose of the study

The present study investigates the theoretically achievable reduction of the long term radiological risk of minor **actinides** (MA) **from** the combined use of (i) direct irradiation with high-energy protons and (ii) selected recycling and partitioning schemes. This is an essential **first** step in an investigation of a ‘direct irradiation’ transmutation system, a schematic diagram of such a facility is shown in Figure 1.

High energy particle-nucleus interactions result in secondary particles (neutrons, protons, pions with a wide band energy spectrum reaching close to that of the incident particle), evaporation products (fast neutrons, protons, α -particles etc.) and residual nuclei spread over a wide range of mass and charge but which are mainly below that of the struck nucleus. For nuclei in the actinide region there is a high (about 80%) probability of fission occurring. In a thick target, the secondary particles in the high energy region go on to make further (and similar) interactions and this carries on through successive

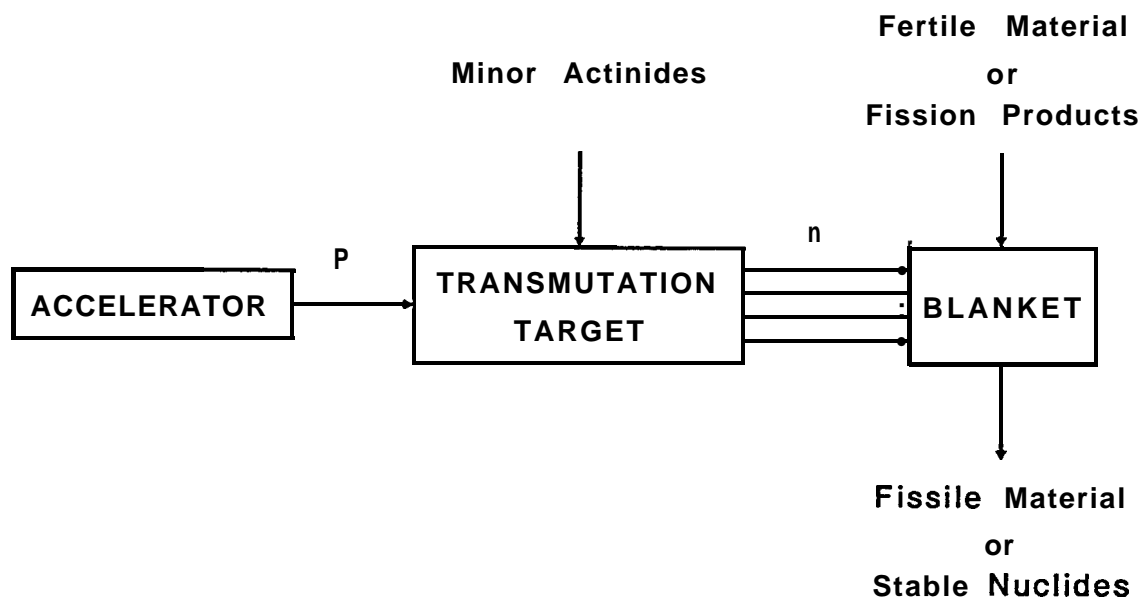


Figure 1: High-energy reaction transmutation system. The minor **actinides** are part of the target. The blanket is used for breeding and/or incinerating fission products.

generations.

That is: the primary protons induce particle cascades through the material resulting in the removal of several **actinide** nuclei per proton incident on the target and replacing them with products spread over a very wide mass and charge range created by interactions induced by a range of particle types and energies.

Table 1 gives a summary of the results for the irradiation of three quasi-infinite **actinide** targets by 1 **GeV** protons. About 5 actinide nuclei are removed per proton with about 80% undergoing fission. The large fast neutron production gives the strong possibility of making such a transmutation target system part of an energy-efficient assembly (e.g. by using them to produce an intense neutron source for breeding or transmuting fission products).

Assumptions and calculational methods

The system **modelled** in the calculation consists of a quasi-infinite cylindrical target containing a typical minor **actinide** (MA) mixture from LWR spent fuel and **irradiated** by 1 **GeV** protons.

Target	Pure Np-237	Minor actinide mixture	Actinide mixture
No. of spallation products	1.1	1.0	1.0
No. of high-energy fissions	4.2	4.0	4.1
No. of transmuted nuclei	5.3	5.0	5.1
No. of neutrons below 15 MeV	30.9	30.5	31.0
Total energy deposited (GeV)	1.60	1.56	1.58

Table 1: Efficiency of high-energy reactions in a **quasi-infinite** target (per incident 1 **GeV** proton)

A sample of cascades induced by the protons has been calculated using the Monte-Carlo programme HETC [9] in a version including a treatment of high-energy particle induced fission [10]. A lower energy cut-off of 15 **MeV** is used the dimensions of the system are such that the majority of the cascades are terminated by particles **reaching** the cut-off energy rather than escaping. The residual nuclei (which represent all possible products created by all generations of particles above 15 MeV) are collected and used to give the **nuclide** distribution for a chain-yield analysis, and hence **time-dependant** toxicities, with the program **ORIHET** (this is a modified version of the ORNL code **ORIGEN** [11] for use with **HETC**).

The contribution of the neutrons below 15 **MeV** is not included as it is only meaningful in the case of a finite target when the majority will leak from the surface after inducing **(n,xn)** and fission events.

Nuclide	Weight (%)	Nuclide	Weight (%)	Nuclide	Weight (%)
Np-237	57.0	Am-241	29.5	Cm-243	0.04
		Am-242m	0.1	Cm-244	2.26
		Am-243	11.0	Cm-245	0.09
				Cm-246	0.01

Table 2: Minor **actinide** composition of of high level waste **from** an LWR reprocessing plant, 4 years after discharge of the fuel ([12],[13])

The composition of the initial MA mixture is given in Table 2. This is modified by the irradiation/recycling strategy and an equilibrium mixture has been obtained from

an iterative calculation which was **terminated** when the individual change of the 10 most abundant **nuclides** in the transmutation target was less than **0.1% by weight** (Note: HETC only allows a maximum of 10 different **nuclides** in a material). The composition of this ‘equilibrium’ transmutation target is shown in Table 3.

Nuclide	Weight (%)	Nuclide	Weight (%)	Nuclide	Weight (%)	Nuclide	Weight (%)	Nuclide	Weight (%)
U-232	1.3	Np-237	52.5	Pu-239	0.5	Am-241	27.2	Cm-244	2.1
U-235	1.5			Pu-240	2.0	Am-242m	0.7		
u-236	2.2					Am-243	10.0		

Table 3: ‘Equilibrium’ composition of transmutation target consisting of the 10 most abundant nuclides

Different recycling schemes

The time evolution of the activities and the related toxicities of the waste depends strongly on the recycling and partitioning scheme. Two recycling strategies are **considered**:

1. After transmutation, the newly generated MAs are separated and recycled (Figure 2). Three cases are then distinguished:
 - (a) Only the MAs are partitioned. All other **spallation** and fission products (including uranium and plutonium) are part of the waste.
 - (b) Plutonium as well as the MAs are partitioned. The waste consists of the remaining **spallation** and fission products.
 - (c) In addition to plutonium of case (b) also uranium is partitioned. The waste contains neither MAs nor plutonium and uranium, but the rest of the **spallation** and the fission products.
2. All **spallation** products are separated and recycled after irradiation (Figure 3). The waste only contains high-energy fission products.

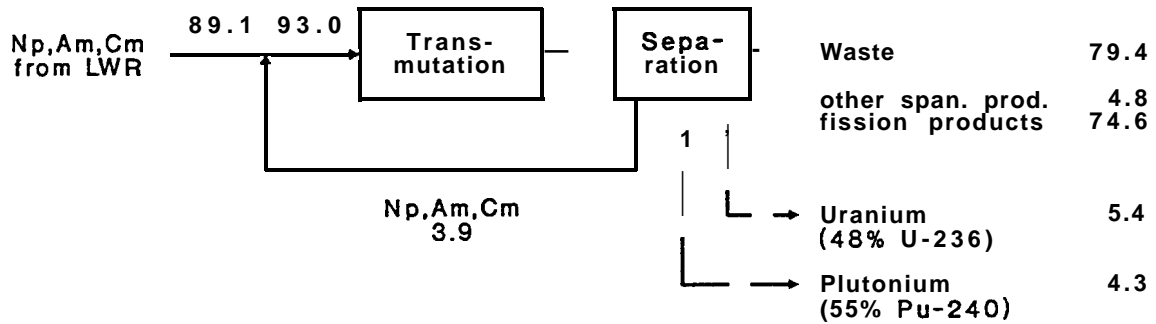


Figure 2: Different schemes for minor **actinide** recycling. **Pu and U** partitioning belongs to case (c), **Pu** partitioning alone to case (b), and no further partitioning to case (a) above. The mass balance (in kg/year) holds for a 300MW proton beam and a load factor of 0.8.

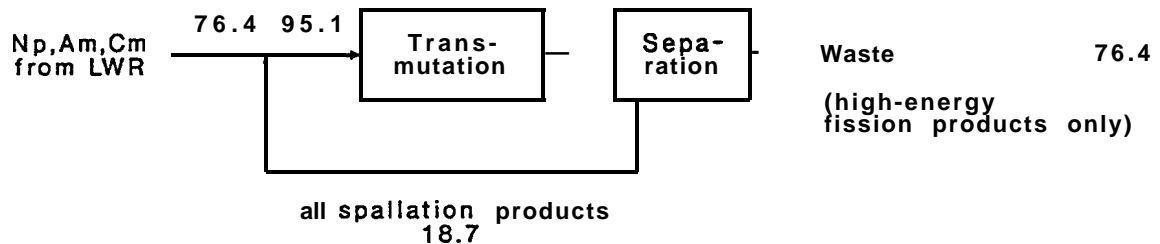


Figure 3: Scheme with recycling of **all spallation** products. The mass balance (in kg/year) holds for a 300 MW proton beam and a load factor of 0.8.

Toxicity and activity of the minor actinide transmutation products

The evolution of activity and toxicity for the different recycling schemes was evaluated for the mass yields in the quasi-infinite geometry. The decay time was assumed to begin after a short irradiation **period**, during which no radioactive decay and build-up was considered. All results are normalized to 1 kg of fully transmuted MA mixture. Mass yield and activity over a period of 10⁷ years were calculated for all decay products, and the activities were then multiplied by dose conversion factors for ingestion compiled from **ICRP-30** [14] with recommendations of **ICRP-48** [15]. The dose factors taken into account are summarized in Table 4.

Toxicity

The differences between various recycling schemes **are** more pronounced in terms of radiological toxicities than in terms of activities (**This** is a consequence of the larger dose conversion factors related with α -decay of the long-lived **spallation** products).

Figure 4 shows the **spallation** product toxicities (doses for ingestion) in the waste stream of recycling scheme 1.(a) [MA recycling, no partitioning]. Between 500 and $5 \cdot 10^4$ years the total toxicity is dominated by plutonium. The main contributors between 10^5 and 10^6 years are Ra-226 and **Pb-210**, and above 10^7 years Pa-231 and Ac-227 (these are decay products of U-234 and U-235, respectively).

Additional **Pu partitioning** besides MA separation and recycling [recycling scheme 1.(b)] reduces the overall toxicity between a few hundred and a few tenthousand years (Figure 5). The maximum reduction of a factor > 30 at 10^3 years decreases to 13 at 10^4 years.

By partitioning of uranium in addition to plutonium [recycling scheme 1.(c)] the **spallation** product toxicity can be reduced below 10^3 and above 10^4 years (Figure 6). Below 200 and above $2.5 \cdot 10^5$ years, however, the overall toxicity of the remaining waste is dominated by fission products.

In recycling strategy 2 [recycling of all **spallation** products] the waste stream contains only high-energy fission products. Their total toxicity is shown in Figure 7. Below 300 years it is dominated by **Sr-90** and **Cs-137**, between 300 and $2 \cdot 10^5$ years by **Sn-126**, and above $2 \cdot 10^5$ years by **I-129**.

In Figure 8 a comparison of the total toxicity of the remaining waste is made between the different recycling schemes. Figure 8 also contains the decay product toxicity of the original MA **mixture** under the assumption that the reference amount of 1 kg of MA mixture simply decays. (The individual components of the decay product toxicity are given in Figure 9).

Some observations can be made:

- The total transmutation product toxicity is lower than the decay product toxicity for all **recycling** schemes and over the whole time range.
- The larger toxicity of recycling scheme 1.(a) [**MA recycling** without further partitioning] between 500 and $5 \cdot 10^4$ years is caused by *plutonium spallation products*. *These should therefore always be separated from the waste stream.*

- From the viewpoint of toxicity reduction, recycling scheme 2 with recycling of all **spallation** products has the greatest potential. Beyond 200 years it reduces the overall toxicity by 3 orders of magnitude and reaches 5 orders of magnitude at 1000 years.

Activity

The **results** for the different recycling schemes are given in Tables 5 to 9. Figure 10 compares the overall activities with the total activity of the original MA mixture and its decay products.

- Below ~ 100 years the transmutation product activity is larger than that of the original MA mixture for all recycling schemes.
- The previous observation that **Pu spallation** products should always be separated from the waste stream is already obvious if the activities are compared. Except for recycling scheme 1.(a) [MA recycling without additional partitioning the **reduction** in activity is comparable for the other schemes.
- Above a few hundred years the reduction in activity is 1 to 2 orders of magnitude compared with the direct decay of the MA mixture for all recycling schemes with **Pu** partitioning.

Mass and energy balance

With a **300 MW** proton beam and a load factor of $\sim 0.8,75$ to 90 kg (depending on the recycling strategy) of minor **actinides** per year (i.e. the yearly production **from 3.0–3.5 LWRs**) could be transmuted by high-energy reactions alone.

However, with the calculated energy multiplication factor of 1.6, a thermal efficiency of 33%, and an estimated maximum efficiency of 50% for converting the electric power into beam power, this (hypothetical) transmutation system would have a self-sufficiency of only about 25%, i.e. **450 MW** – or 13-15 % of the power produced by the **LWRs** – would have to be supplied externally. It is clear that a better overall energy balance is desirable, and this could be achieved by using the 31 **free** neutrons below 15 **MeV** to generate additional fission power in a surrounding blanket **from** fertile material (in addition to the thermal power, about 1 t of new **fissile** material could be recovered from an appropriately optimised breeding blanket).

Conclusions

HETC calculations for a quasi-infinite minor **actinide** target bombarded by 1 **GeV** protons show:

- A **theoretical** high-energy reaction transmutation system for minor **actinides** has a favorable fission to **spallation** ratio of ~ 4 ($\sigma_{\text{fiss}} \sim 1.3$ b for 1 **GeV** protons, $\sigma_{\text{tot,inel}} \sim 1.9$ b).
- The potential toxicity reduction strongly depends on the recycling and partitioning scheme.
- For **recycling** schemes without uranium separation, the residual toxicity beyond 10^7 years is **about** the same as that of **natural U_3O_8** . Its time **behaviour** is governed by the U-235 decay ($T_{1/2} = 7 \cdot 10^8$ y). For recycling schemes with uranium separation, the **residual** toxicity is about 1/3 of that of natural **U_3O_8** . Its time **behaviour** follows that of I-129 ($T_{1/2} = 1.59 \cdot 10^7$ y).
- A maximum toxicity reduction is achieved *with a system in which all actinides and spallation products are recycled*.
- The toxicity reduction in this best system is **better than 3** orders of magnitude beyond 200 years and reaches 5 orders of magnitude at around 1000 years compared with the direct decay of the original minor **actinide mixture**.
- A practicable high-energy reaction transmutation system **needs** a powerful proton accelerator.

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Table 4: Dose conversion factors (**mrem/Ci**) for ingestion (from **ICRP-30** [14]) and half lives (years)

Nuclide	Toxicity	Half life	Nuclide	Toxicity	Half life
Mn-53	9.8 E4	3.74 E6	Fe-60	1.6 E8	3 E5
CO-60	1.0 E7	5.27	Ni-59	2.0 E5	7.50 E4
Se-79	8.5 E6	6.50 E4	Sr-90	1.3 E8	2.81 E1
Zr-93	1.6 E6	9.49 E5	Nb-93m ¹	5.3 E5	1.20 E1
Nb-94	5.2 E6	2.00 E4	Mo-93	1.3 E6	3.7 E3
Tc-99	1.3 E6	2.1 E5	Pd-107	1.4 E5	6.5 E6
Sn-126	2.7 E7 ²	9.99 E4	1-129	2.7 E8	1.59 E7
Cs-135	7.0 E6	2.3 E6	Cs-137	5.0 E7	3.01 E1
Sm-151	3.4 E5	9.29 E1	Gd-148	2.1 E8	9.75 E1
Tb-157	1.0 E5	1.50 E2	Tb-158	4.0 E6	1.50 E2
Pt-193	1.1 E5	5.0 E1	Hg-194	6.0 E6	2.60 E2
Pb-202	3.9 E7	3 E5	Pb-210	5.0 E9	2.23 E1
Ra-226	8.2 E9 ²	1.60 E3	Ac-227	1.5 E10 ²	2.18 E1
Th-229	3.9 E9 ²	7.34 E3	Th-230	5.6 E8	8.0 E4
Pa-231	1.1 E10	3.28 E4	U-232	1.3 E9	7.17 E1
U-233	2.7 E8	1.6 E5	U-234	2.6 E8	2.4 E5
U-235	2.5 E8	7 E8	U-236	2.5 E8	2.34 E7
U-238	2.5 E8 ²	4.47 E9	Np-237	4.1 E9	2.14 E6
Pu-238	3.1 E9	8.77 E1	Pu-239	3.6 E9	2.41 E4
Pu-240	3.6 E9	6.57 E3	Pu-241	6.7 E7	1.44 E1
Pu-242	3.3 E9	3.8 E5	Pu-244	3.3 E9	8.1 E7
Am-241	3.6 E9	4.32 E2	Am-242m ¹	3.6 E9	1.52 E2
Am-243	3.6 E9	7.37 E3	Cm-243	2.5 E9	2.85 E1
Cm-244	2.0 E9	1.81 E1	Cm-245	3.7 E9	8.5 E3

¹nuclide with metastable state

²including contribution of **short-lived** daughter **nuclides**

NUCLIDE RADIOACTIVITY, CURIES
BASIS = 1 KG FULLY TRANSMUTED MA MIXTURE

	TIME UNIT-YRS										
	INITIAL	1.00E+01	1.00E+02	5.00E+02	1.00E+03	5.00E+03	1.00E+04	5.00E+04	1.00E+05	1.00E+06	1.00E+07
TL207	8.98E+04	6.53E-03	2.29E-02	2.37E-02	2.35E-02	2.16E-02	1.94E-02	8.36E-03	2.94E-03	5.28E-05	5.23E-05
TL208	2.36E-05	8.90E+01	4.81E+01	1.01E+00	8.05E-03	4.22E-09	4.46E-09	6.89E-09	1.00E-08	6.59E-08	5.50E-07
TL209	1.61E-08	1.41E-03	1.41E-03	1.37E-03	1.32E-03	1.02E-03	7.72E-04	3.28E-04	2.64E-04	3.73E-05	1.65E-06
PB205	2.20E-05	1.27E-04	1.90E-04	2.61E-04	2.65E-04	2.66E-04	2.66E-04	2.65E-04	2.64E-04	2.53E-04	1.64E-04
PB207M	2.26E+00	3.44E+01	6.68E+00	4.55E-03	5.00E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PB209	4.38E+03	6.43E-02	6.39E-02	6.22E-02	6.01E-02	4.64E-02	3.51E-02	1.49E-02	1.20E-02	1.70E-03	7.52E-05
PB210	6.81E-06	5.68E+00	3.45E-01	3.63E-04	6.85E-04	2.52E-03	4.17E-03	1.42E-02	2.06E-02	3.51E-03	5.98E-07
PB211	0.00E+00	6.55E-03	2.30E-02	2.3SE-02	2.35E-02	2.16E-02	1.95E-02	8.38E-03	2.95E-03	5.30E-05	5.25E-05
PB212	8.07E-09	2.47E+02	1.34E+02	2.80E+00	2.24E-02	1.17E-08	1.24E-08	1.91E-08	2.79E-08	1.83E-07	1.53E-06
PB214	0.00E+00	7.71E-06	7.61E-05	3.62E-04	6.85E-04	2.52E-03	4.17E-03	1.42E-02	2.06E-02	3.51E-03	5.98E-07
BI207	8.29E+00	4.14E+01	8.02E+00	5.46E-03	6.00E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BI208	1.15E-03	1.80E-03	1.80E-03	1.80E-03	1.79E-03	1.78E-03	1.76E-03	1.64E-03	1.49E-03	2.74E-04	1.20E-11
BI210	1.27E+04	5.68E+00	3.45E-01	3.63E-04	6.85E-04	2.52E-03	4.17E-03	1.42E-02	2.06E-02	3.51E-03	5.98E-07
BI211	7.48E+07	6.55E-03	2.30E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8.38E-03	2.95E-03	5.30E-05	5.25E-05
BI212	6.92E-02	2.47E+02	1.34E+02	2.80E+00	2.24E-02	1.17E-08	1.24E-08	1.91E-08	2.79E-08	1.83E-07	1.53E-06
BI213	5.57E-04	6.43E-02	6.39E-02	6.22E-02	6.01E-02	4.64E-02	3.51E-02	1.49E-02	1.20E-02	1.70E-03	7.52E-05
BI214	0.00E+00	7.71E-06	7.61E-05	3.62E-04	6.85E-04	2.52E-03	4.17E-03	1.42E-02	2.06E-02	3.51E-03	5.98E-07
PO208	1.09E+02	6.33E+01	2.87E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO209	1.22E+01	1.95E+01	1.06E+01	6.99E-01	2.34E-02	3.72E-14	6.65E-29	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO210	1.62E+03	5.68E+00	3.45E-01	3.63E-04	6.85E-04	2.52E-03	4.17E-03	1.42E-02	2.06E-02	3.51E-03	5.98E-07
PO211	1.57E+10	1.97E-05	6.90E-05	7.14E-05	7.06E-05	6.49E-05	5.84E-05	2.52E-05	8.84E-06	1.59E-07	1.57E-07
PO212	7.17E+09	1.58E+02	8.56E+01	1.79E+00	1.43E-02	7.50E-09	7.94E-09	1.22E-08	1.78E-08	1.17E-07	9.78E-07
PO213	1.64E+08	6.29E-02	6.25E-02	6.08E-02	5.88E-02	4.54E-02	3.43E-02	1.46E-02	1.18E-02	1.66E-03	7.35E-05
PO214	2.43E+04	7.71E-06	7.61E-05	3.62E-04	6.85E-04	2.52E-03	4.17E-03	1.42E-02	2.06E-02	3.51E-03	5.98E-07
PO215	0.00E+00	6.55E-03	2.30E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8.38E-03	2.95E-03	5.30E-05	5.25E-05
PO216	2.22E-03	2.47E+02	1.34E+02	2.80E+00	2.24E-02	1.17E-08	1.24E-08	1.91E-08	2.79E-08	1.83E-07	1.53E-06
PO218	0.00E+00	7.71E-06	7.61E-05	3.62E-04	6.85E-04	2.52E-03	4.17E-03	1.42E-02	2.06E-02	3.51E-03	5.98E-07
AT217	6.92E+00	6.43E-02	6.39E-02	6.22E-02	6.01E-02	4.64E-02	3.51E-02	1.49E-02	1.20E-02	1.70E-03	7.52E-05
RN219	0.00E+00	6.55E-03	2.30E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8.38E-03	2.95E-03	5.30E-05	5.25E-05
RN220	3.88E-03	2.47E+02	1.34E+02	2.80E+00	2.24E-02	1.17E-08	1.24E-08	1.91E-08	2.79E-08	1.83E-07	1.53E-06
RN222	0.00E+00	7.71E-06	7.61E-05	3.62E-04	6.85E-04	2.52E-03	4.17E-03	1.42E-02	2.06E-02	3.51E-03	5.98E-07
FR221	6.92E+00	6.43E-02	6.39E-02	6.22E-02	6.01E-02	4.64E-02	3.51E-02	1.49E-02	1.20E-02	1.70E-03	7.52E-05
FR223	0.00E+00	9.17E-05	3.22E-04	3.33E-04	3.30E-04	3.03E-04	2.73E-04	1.17E-04	4.12E-05	7.41E-07	7.35E-07
RA223	0.00E+00	6.55E-03	2.30E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8.38E-03	2.95E-03	5.30E-05	5.25E-05
RA224	9.36E-01	2.47E+02	1.34E+02	2.80E+00	2.24E-02	1.17E-08	1.24E-08	1.91E-08	2.79E-08	1.83E-07	1.53E-06
RA225	5.81E-09	6.43E-02	6.39E-02	6.22E-02	6.01E-02	4.64E-02	3.51E-02	1.49E-02	1.20E-02	1.70E-03	7.52E-05
RA226	1.85E-21	7.71E-06	7.61E-05	3.62E-04	6.85E-04	2.52E-03	4.17E-03	1.42E-02	2.06E-02	3.51E-03	5.98E-07
RA228	2.13E-17	7.81E-09	1.12E-08	1.12E-08	1.13E-08	1.17E-08	1.24E-08	1.91E-08	2.79E-08	1.83E-07	1.53E-06
AC225	5.75E+03	6.43E-02	6.39E-02	6.22E-02	6.01E-02	4.64E-02	3.51E-02	1.49E-02	1.20E-02	1.70E-03	7.52E-05
AC227	4.85E-12	6.55E-03	2.30E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8.38E-03	2.95E-03	5.30E-05	5.25E-05
AC228	0.00E+00	7.81E-09	1.12E-08	1.12E-08	1.13E-08	1.17E-08	1.24E-08	1.91E-08	2.79E-08	1.83E-07	1.53E-06
TH227	0.00E+00	6.46E-03	2.27E-02	2.35E-02	2.32E-02	2.13E-02	1.92E-02	8.27E-03	2.90E-03	5.22E-05	5.18E-05
TH228	1.26E-08	2.47E+02	1.34E+02	2.80E+00	2.24E-02	1.17E-08	1.24E-08	1.91E-08	2.79E-08	1.83E-07	1.53E-06
TH229	2.15E-02	6.43E-02	6.39E-02	6.22E-02	6.01E-02	4.64E-02	3.51E-02	1.49E-02	1.20E-02	1.70E-03	7.52E-05
TH230	4.04E-10	1.78E-03	1.81E-03	1.93E-03	2.10E-03	3.37E-03	4.88E-03	1.41E-02	2.05E-02	3.51E-03	5.98E-07
TH231	3.21E-11	3.60E-05	3.61E-05	3.63E-05	3.65E-05	3.83E-05	4.03E-05	4.90E-05	5.20E-05	5.30E-05	5.25E-05
TH232	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.13E-08	1.17E-08	1.24E-08	1.91E-08	2.79E-08	1.83E-07	1.53E-06
PA231	9.61E-03	2.40E-02	2.40E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8.38E-03	2.94E-03	5.30E-05	5.25E-05
PA233	3.84E+03	6.31E-06	2.28E-04	1.03E-03	1.52E-03	1.91E-03	1.91E-03	1.88E-03	1.85E-03	1.39E-03	7.52E-05
U232	2.20E+00	2.81E+02	1.30E+02	2.73E+00	2.18E-02	3.57E-19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U233	8.91E-03	1.68E-02	1.68E-02	1.68E-02	1.68E-02	1.65E-02	1.62E-02	1.39E-02	1.15E-02	1.69E-03	7.52E-05
U234	1.67E-02	3.03E-02	3.52E-02	3.96E-02	3.98E-02	3.93E-02	3.88E-02	3.46E-02	3.01E-02	2.36E-03	5.98E-07
U235	8.50E-06	3.60E-05	3.61E-05	3.63E-05	3.65E-05	3.83E-05	4.03E-05	4.90E-05	5.20E-05	5.30E-05	5.25E-05
U236	8.94E-04	1.85E-03	1.87E-03	1.94E-03	2.02E-03	2.56E-03	2.97E-03	3.55E-03	3.56E-03	3.46E-03	2.65E-03
NP235	1.71E+04	2.91E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NP237	2.48E-23	6.31E-06	2.28E-04	1.03E-03	1.52E-03	1.91E-03	1.91E-03	1.88E-03	1.85E-03	1.39E-03	7.52E-05
PU236	1.66E+02	7.13E+02	2.27E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PU238	1.08E+01	2.66E+01	1.31E+01	5.54E-01	1.07E-02	2.03E-16	1.43E-33	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PU239	1.44E-01	4.96E-01	4.94E-01	4.89E-01	4.82E-01	4.30E-01	3.72E-01	1.18E-01	2.81E-02	1.69E-13	0.00E+00
PU240	2.08E+00	6.10E+00	6.05E+00	5.80E+00	5.50E+00	3.61E+00	3.14E+00	3.14E-02	1.61E-04	0.00E+00	0.00E+00
PU241	2.85E+02	1.76E+02	2.29E+00	9.53E-09	3.19E-19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PU242	7.12E-03	7.12E-03	7.12E-03	7.11E-03	7.11E-03	7.05E-03	6.99E-03	6.49E-03	5.92E-03	1.13E-03	7.09E-11
AM241	7.25E-09	3.60E+00	8.27E+00	4.40E+00	1.97E+00	3.23E-03	1.06E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CM242	1.77E+03	3.11E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TOTAL	3.14E+11	3.14E+03	1.12E+03	3.51E+01	8.94E+00	4.70E+00	3.07E+00	5.51E-01	4.14E-01	6.12E-02	4.25E-03

Table 5: Spallation product activities for recycling scheme 1.(a)
[minor actinide recycling without further partitioning].

NUCLIDE RADIOACTIVITY, CURIES
BASIS . 1 KG FULLY TRANSMUTED MA MIXTURE

	TIME UNIT=YRS										
	INITIAL	1.00E+01	1.00E+02	5.00E+02	1.00E+03	5.00E+03	1.00E+04	5.00E+04	1.00E+05	1.00E+06	1.00E+07
TL207	8. 98E+04	6.53E-03	2.29E-02	2.37E-02	2.35E-02	2.16E-02	1. 94E-02	8.35E-03	2.93E-03	3.59E-05	3.56E-05
TL208	2.36E-05	5.44E+01	2.35E+01	4. 93E-01	3. 93E-03	4.18E-09	4.35E-09	5.66E-09	7.30E-09	3.64E-08	2.88E-07
TL209	1.61E-08	1.41E-03	1.41E-03	1.37E-03	1.32E-03	1.02E-03	7.72E-04	3.21E-04	2.51E-04	4.98E-06	4.64E-23
PB205	2.20E-05	1.27E-04	1. 90E-04	2. 61E-04	2. 65E-04	2.66E-04	2. 66E-04	2.65E-04	2.64E-04	2. 53E-04	1.64E-04
PB207M	2.26E+00	3.44E+01	6. 68E+00	4. 55E-03	5.00E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PB209	4.38E+03	6.43E-02	6.39E-02	6.22E-02	6. 01E-02	4.64E-02	3.51E-02	1.46E-02	1.14E-02	2.26E-04	2.11E-21
PB210	6. 81E-06	5.68E+00	3.45E-01	3. 60E-04	6.72E-04	2.27E-03	3.53E-03	1.09E-02	1.55E-02	2. 60E-03	2.32E-14
PB211	0.00E+00	6.55E-03	2.30E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8.38E-03	2.93E-03	3.60E-05	3.57E-05
PB212	8.87E-09	1.51E+02	6. 53E+01	1.37E+00	1.09E-02	1.16E-08	1.21E-08	1.57E-08	2.03E-08	1. 01E-07	8.00E-07
PB214	0. 00E+00	7.71E-06	7. 60E-05	3.59E-04	6.72E-04	2.27E-03	3.53E-03	1.09E-02	1.55E-02	2. 60E-03	2.32E-14
BI207	8.29E+00	4.14E+01	8.02E+00	5. 46E-03	6.00E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BI208	1.19E-03	1.80E-03	1.80E-03	1. 80E-03	1. 79E-03	1.78E-03	1.76E-03	1.64E-03	1.49E-03	2.74E-04	1.20E-11
BI210	1.27E+04	5.68E+00	3.45E-01	3. 60E-04	6.72E-04	2.27E-03	3.53E-03	1.09E-02	1.55E-02	2. 60E-03	2.32E-14
BI211	7.48E+07	6.55E-03	2.30E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8.38E-03	2.93E-03	3.60E-05	3.57E-05
BI212	6. 92E-02	1.51E+02	6. 53E+01	1.37E+00	1.09E-02	1.16E-08	1.21E-08	1.57E-08	2.03E-08	1. 01E-07	8.00E-07
BI213	5.57E+04	6.43E-02	6.39E-02	6.22E-02	6. 01E-02	4.64E-02	3.51E-02	1.46E-02	1.14E-02	2. 26E-04	2.11E-21
BI214	0.00E+00	7.71E-06	7.60E-05	3.59E-04	6.72E-04	2.27E-03	3.53E-03	1.09E-02	1.55E-02	2. 60E-03	2.32E-14
PO208	1.09E+02	6.33E+01	2.87E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO209	1.22E+01	1.95E+01	1.06E+01	6.99E-01	2.34E-02	3.72E-14	6. 65E-29	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO210	1. 62E+03	5.68E+00	3.45E-01	3. 60E-04	6. 72E-04	2. 27E-03	3.53E-03	1.09E-02	1.55E-02	2. 60E-03	2.32E-14
PO211	1.57E+10	1.97E-05	6. 90E-05	7.14E-05	7.06E-05	6.49E-05	5.84E-05	2.51E-05	8.80E-06	1.08E-07	1. 07E-07
PO212	7.17E+09	9.67E+01	4.18E+01	8.76E-01	6. 99E-03	7.44E-09	7.73E-09	1. 01E-08	1.30E-08	6. 46E-08	5.12E-07
PO213	1.64E+08	6.29E-02	6.25E-02	6.08E-02	5.88E-02	4.54E-02	3.43E-02	1.43E-02	1.12E-02	2.21E-04	2.06E-21
PO214	2.43E+04	7.71E-06	7.60E-05	3.59E-04	6.72E-04	2.27E-03	3.53E-03	1.09E-02	1.55E-02	2. 60E-03	2.32E-14
PO215	0.00E+00	6.55E-03	2.30E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8.38E-03	2.93E-03	3. 60E-05	3.57E-05
PO216	2.22E-03	1.51E+02	6.53E+01	1.37E+00	1.09E-02	1.16E-08	1.21E-08	1.57E-08	2.03E-08	1. 01E-07	8.00E-07
PO218	0.00E+00	7.71E-06	7. 60E-05	3.59E-04	6. 72E-04	2.27E-03	3.53E-03	1.09E-02	1.55E-02	2. 60E-03	2.32E-14
AT217	6. 92E+00	6.43E-02	6.39E-02	6.22E-02	6. 01E-02	4.64E-02	3.51E-02	1.46E-02	1.14E-02	2.26E-04	2.11E-21
RN219	0.00E+00	6.55E-03	2.30E-02	2.3 8E-02	2.35E-02	2.16E-02	1.95E-02	8.38E-03	2. 93E-03	3.60E-05	3.57E-05
RN220	3.88E-03	1.51E+02	6.53E+01	1.37E+00	1.09E-02	1.16E-08	1.21E-08	1.57E-08	2.03E-08	1. 01E-07	8.00E-07
RN222	0.00E+00	7.71E-06	7.60E-05	3. 59E-04	6.72E-04	2. 27E-03	3.53E-03	1.09E-02	1.55E-02	2. 60E-03	2.32E-14
FR221	6. 92E+00	6.43E-02	6.39E-02	6.22E-02	6. 01E-02	4.64E-02	3.51E-02	1.46E-02	1.14E-02	2. 26E-04	2.11E-21
FR223	0.00E+00	9.17E-05	3.22E-04	3.33E-04	3.30E-04	3.03E-04	2.73E-04	1.17E-04	4.11E-05	5. 04E-07	4.99E-07
RA223	0.00E+00	6.55E-03	2.30E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8.38E-03	2.93E-03	3. 60E-05	3.57E-05
RA224	9.36E-01	1.51E+02	6. 53E+01	1.37E+00	1.09E-02	1.16E-08	1.21E-08	1.57E-08	2.03E-08	1. 01E-07	8.00E-07
RA225	5.81E-09	6.43E-02	6. 39E-02	6.22E-02	6. 01E-02	4.64E-02	3.51E-02	1.46E-02	1.14E-02	2.26E-04	2.11E-21
RA226	1.85E-21	7.71E-06	7.60E-05	3. 59E-04	6. 72E-04	2. 27E-03	3.53E-03	1.09E-02	1. 55E-02	2. 60E-03	2.32E-14
RA228	2.13E-17	7.81E-09	1.12E-08	1.12E-08	1.13E-08	1.16E-08	1.21E-08	1.57E-08	2.03E-08	1. 01E-07	8. 00E-07
AC225	5.75E+03	6.43E-02	6.39E-02	6.22E-02	6. 01E-02	4.64E-02	3.51E-02	1.46E-02	1.14E-02	2.26E-04	2.11E-21
AC227	4.85E-12	6.55E-03	2. 30E-02	2. 38E-02	2.35E-02	2.16E-02	1.95E-02	8.38E-03	2. 93E-03	3.60E-05	3.57E-05
AC228	0.00E+00	7.81E-09	1.12E-08	1.12E-08	1.13E-08	1.16E-08	1.21E-08	1.57E-08	2.03E-08	1. 01E-07	8.00E-07
TH227	0.00E+00	6.46E-03	2.27E-02	2.35E-02	2.32E-02	2.13E-02	1.92E-02	8.26E-03	2.89E-03	3.55E-05	3.52E-05
TH228	9.33E-07	1.51E+02	6.53E+01	1. 37E+00	1.09E-02	1.16E-08	1.21E-08	1.57E-08	2.03E-08	1. 01E-07	8.00E-07
TH229	2.15E-02	6.43E-02	6.39E-02	6. 22E-02	6. 01E-02	4.64E-02	3.51E-02	1.46E-02	1.14E-02	2.26E-04	2.11E-21
TH230	4. 04E-10	1.78E-03	1.81E-03	1. 90E-03	2.02E-03	2.95E-03	4.05E-03	1.08E-02	1.54E-02	2. 60E-03	2.30E-14
TH231	3.21E-11	3. 60E-05	3.60E-05	3.60E-05	3.60E-05	3. 60E-05	3.60E-05	3.60E-05	3.60E-05	3.60E-05	3.57E-05
TH232	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.13E-08	1.16E-08	1.21E-08	1.57E-08	2.03E-08	1. 01E-07	8.00E-07
PA231	9.61E-03	2.40E-02	2.40E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8.37E-03	2. 93E-03	3. 60E-05	3.57E-05
U232	1.63E+02	1.52E+02	6.35E+01	1.33E+00	1.06E-02	1.74E-19	0.00E+00	0.00E+00	0.00E+00	0. 00E+00	0.00E+00
U233	8.91E-03	1. 68E-02	1.68E-02	1.68E-02	1.68E-02	1. 65E-02	1. 61E-02	1.35E-02	1.09E-02	2.16E-04	2. 01E-21
U234	1. 67E-02	2.96E-02	2.96E-02	2.95E-02	2. 95E-02	2.92E-02	2.87E-02	2.57E-02	2.23E-02	1. 75E-03	1.55E-14
U235	8.50E-06	3.60E-05	3.60E-05	3.60E-05	3. 60E-05	3.60E-05	3.60E-05	3.60E-05	3.60E-05	3. 60E-05	3. 57E-05
U236	1.86E-03	1.86E-03	1.86E-03	1.86E-03	1.86E-03	1. 86E-03	1.86E-03	1.85E-03	1.85E-03	1. 80E-03	1.38E-03
NP235	1.71E+04	2.91E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TOTAL	3.14E+11	1.41E+03	5.47E+02	1.24E+01	8.61E-01	6.39E-01	5.40E-01	3.44E-01	3.1 0E-01	3.25E-02	1. 94E-03

Table 6: Spallation product activities for recycling scheme I.(b)
[minor actinide recycling with additional plutonium partitioning].

NUCLIDE RADIOACTIVITY, CURIES
BASIS - 1 KG FULLY TRANSMUTED MA MIXTURE

	INITIAL	TIME UNIT=YRS									
		1.00E+01	1.00E+02	5.00E+02	1.00E+03	5.00E+03	1.00E+04	5.00E+04	1.00E+05	1.00E+06	1.00E+07
TL207	8. 98E+04	6.53E-03	2.29E-02	2.37E-02	2.35E-02	2.16E-02	1.94E-02	8.33E-03	2.89E-03	1.57E-11	0.00E+00
TL208	2.36E-05	2.26E-09	4.02E-09	4.02E-09	4.02E-09	4.02E-09	4.02E-09	4.02E-09	4.02E-09	4.02E-09	4.02E-09
TL209	1.61E-08	1.41E-03	1.40E-03	1.35E-03	1.29E-03	8.83E-04	5.51E-04	1.26E-05	1.13E-07	0.00E+00	0.00E+00
PB205	2.20E-05	1.27E-04	1. 90E-04	2. 61E-04	2.65E-04	2.66E-04	2.66E-04	2.65E-04	2.64E-04	2.53E-04	1.64E-04
PB207M	2.26E+00	3.44E+01	6. 68E+00	4.55E-03	5.00E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PB209	4.38E+03	6.43E-02	6. 38E-02	6.14E-02	5.86E-02	4. 01E-02	2.50E-02	5.74E-04	5.12E-06	0.00E+00	0.00E+00
PB210	6. 81E-06	5. 68E+00	3.45E-01	3.48E-04	6. 23E-04	1.53E-03	1.64E-03	1.18E-03	7.65E-04	3.15E-07	0.00E+00
PB211	0.00E+00	6.55E-03	2.30E-02	2.38E-02	2.35E-02	2.16E-02	1. 95E-02	8.35E-03	2. 90E-03	1.57E-11	0.00E+00
PB212	8.87E-09	6.29E-09	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08
PB214	0.00E+00	7.70E-06	7. 55E-05	3.46E-04	6.23E-04	1.53E-03	1.64E-03	1.18E-03	7. 65E-04	3. 15E-07	0.00E+00
BI207	8.29E+00	4.14E+01	8.02E+00	5.46E-03	6.00E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0. 00E+00	0.00E+00
BI208	1.19E-03	1. 80E-03	1.80E-03	1. 80E-03	1.79E-03	1.78E-03	1.76E-03	1.64E-03	1. 49E-03	2.74E-04	1.20E-11
BI210	1.27E+04	5.68E+00	3.45E-01	3.48E-04	6. 23E-04	1.53E-03	1.64E-03	1.18E-03	7. 65E-04	3.15E-07	0.00E+00
BI211	7.48E+07	6.55E-03	2.30E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8.35E-03	2. 90E-03	1.57E-11	0.00E+00
BI212	6. 92E-02	6.29E-09	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08
BI213	5. 57E-04	6.43E-02	6.38E-02	6. 14E-02	5.86E-02	4. 01E-02	2.50E-02	5.74E-04	5.12E-06	0.00E+00	0.00E+00
BI214	0.00E+00	7.70E-06	7.55E-05	3. 46E-04	6.23E-04	1.53E-03	1.64E-03	1.18E-03	7. 65E-04	3. 15E-07	0.00E+00
PO208	1.09E+02	6.33E+01	2.87E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO209	1.22E+01	1.95E+01	1.06E+01	6.99E-01	2.34E-02	3.72E-14	6. 65E-29	0.00E+00	0.00E+00	0.00E+00	0. 00E+00
PO210	1.62E+03	5.68E+00	3.45E-01	3.48E-04	6. 23E-04	1.53E-03	1.64E-03	1.18E-03	7.65E-04	3. 15E-07	0.00E+00
PO211	1. 57E+10	1.97E+05	6. 90E-05	7.14E-05	7.06E-05	6.49E-05	5.84E-05	2.51E-05	8.71E-06	4.72E-14	0. 00E+00
PO212	7.17E+09	4.02E-09	7.15E-09	7.15E-09	7.15E-09	7.15E-09	7.15E-09	7.15E-09	7.15E-09	7.15E-09	7.14E-09
PO213	1. 64E+08	6.29E-02	6.24E-02	6.00E-02	5.73E-02	3. 93E-02	2.45E-02	5.62E-04	5. 01E-06	0.00E+00	0.00E+00
PO214	2.43E+04	7.70E-06	7.55E-05	3.46E-04	6. 23E-04	1.53E-03	1.64E-03	1.18E-03	7.65E-04	3. 15E-07	0.00E+00
PO215	0.00E+00	6.55E-03	2.30E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8.35E-03	2.90E-03	1.57E-11	0.00E+00
PO216	2.22E-03	6.29E-09	1.12E-08	1. 12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1. 12E-08	1.12E-08
PO218	0.00E+00	7.70E-06	7.55E-05	3.46E-04	6.23E-04	1.53E-03	1.64E-03	1.18E-03	7. 65E-04	3.15E-07	0.00E+00
AT217	6. 92E+00	6.43E-02	6.38E-02	6.14E-02	5.86E-02	4. 01E-02	2.50E-02	5.74E-04	5.12E-06	0.00E+00	0.00E+00
RN219	0.00E+00	6.55E-03	2.30E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8.35E-03	2. 90E-03	1. 57E-11	0.00E+00
RN220	3.88E-03	6.29E-09	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08
RN222	0.00E+00	7.70E-06	7.55E-05	3.46E-04	6.23E-04	1.53E-03	1.64E-03	1.18E-03	7.65E-04	3.15E-07	0.00E+00
FR221	6. 92E+00	6.43E-02	6. 38E-02	6.14E-02	5.86E-02	4. 01E-02	2. 50E-02	5.74E-04	5.12E-06	0.00E+00	0.00E+00
FR223	0. 00E+00	9.17E-05	3.22E-04	3.33E-04	3.30E-04	3.03E-04	2.73E-04	1.17E-04	4.06E-05	2.20E-13	0.00E+00
RA223	0. 00E+00	6.55E-03	2.30E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8.35E-03	2. 90E-03	1.57E-11	0. 00E+00
RA224	9.36E-01	6.29E-09	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08
RA225	5.81E-09	6.43E-02	6.38E-02	6.14E-02	5.86E-02	4. 01E-02	2.50E-02	5.74E-04	5.12E-06	0.00E+00	0.00E+00
RA226	1.85E-21	7.70E-06	7.55E-05	3.46E-04	6. 23E-04	1.53E-03	1.64E-03	1.18E-03	7. 65E-04	3.15E-07	0.00E+00
RA228	2.13E-17	7.81E-09	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08
AC225	5.75E+03	6.43E-02	6.38E-02	6.14E-02	5.86E-02	4. 01E-02	2. 50E-02	5.74E-04	5.12E-06	0. 00E+00	0.00E+00
AC227	4.85E-12	6.55E-03	2.30E-02	2.38E-02	2.35E-02	2.16E-02	1.95E-02	8. 35E-03	2. 90E-03	1.57E-11	0.00E+00
AC228	0.00E+00	7.81E-09	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08
TH227	0.00E+00	6.46E-03	2.27E-02	2.35E-02	2.32E-02	2.13E-02	1.92E-02	8.24E-03	2.86E-03	1.55E-11	0.00E+00
TH228	0. 00E+00	6.29E-09	1.12E-08	1. 12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08
TH22 9	2.15E-02	6.43E-02	6. 38E-02	6.14E-02	5.86E-02	4. 01E-02	2.50E-02	5.74E-04	5.12E-06	0.00E+00	0.00E+00
TH230	4. 04E-10	1.78E-03	1.78E-03	1.77E-03	1.77E-03	1.71E-03	1.63E-03	1. 16E-03	7.49E-04	3. 09E-07	0.00E+00
TH232	1.12E-08	1.12E-08	1.12E-08	1. 12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08	1.12E-08
PA231	9. 61E-03	2.40E-02	2.40E-02	2. 38E-02	2.35E-02	2.16E-02	1.95E-02	8.35E-03	2. 90E-03	1.57E-11	0.00E+00
TOTAL	3.14E+11	1.76E+02	2.70E+01	1.42E+00	7.13E-01	5.33E-01	3.94E-01	9.34E-02	3.55E-02	5.30E-04	1.64E-04

Table 7: Spallation product activities for recycling scheme 1.(c)
[minor actinide recycling with additional plutonium and uranium partitioning].

NUCLIDE RADIOACTIVITY, CURIES
BASIS = 1 KG FULLY TRANSMUTED MA MIXTURE

	TIME UNIT-YRS										
	INITIAL	1.00E+01	1.00E+02	5.00E+02	1.00E+03	5.00E+03	1.00E+04	5.00E+04	1.00E+05	1.00E+06	1.00E+07
MN 53	4.50E-05	4.50E-05	4.50E-05	4.50E-05	4.49E-05	4.49E-05	4.49E-05	4.45E-05	4.41E-05	3.74E-05	7.05E-06
MN 54	3.93E+02	1.19E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FE 55	1.25E+02	1.42E+01	1.17E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FE 60	3.92E-03	3.92E-03	3.92E-03	3.92E-03	3.91E-03	3.88E-03	3.83E-03	3.50E-03	3.11E-03	3.90E-04	3.67E-13
co .57	6.78E+02	6.10E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CO 60	8.17E-12	2.87E-03	3.92E-03	3.92E-03	3.91E-03	3.88E-03	3.83E-03	3.50E-03	3.11E-03	3.90E-04	3.67E-13
NI 59	2.24E-03	2.24E-03	2.24E-03	2.23E-03	2.22E-03	2.14E-03	2.04E-03	1.41E-03	8.90E-04	2.18E-07	0.00E+00
NI 63	1.18E+01	1.57E+01	8.41E+00	5.28E-01	1.66E-02	1.57E-14	1.47E-29	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ZN 65	7.55E+02	2.37E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SE 75	1.56E+03	8.14E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SE 79	2.33E-02	8.28E-02	8.27E-02	8.24E-02	8.19E-02	7.85E-02	7.44E-02	4.86E-02	2.85E-02	1.93E-06	0.00E+00
KR 81	4.01E-03	7.21E-03	7.21E-03	7.20E-03	7.19E-03	7.09E-03	6.98E-03	6.11E-03	5.18E-03	2.66E-04	3.33E-17
KR 85	2.82E+02	2.15E+02	6.44E-01	3.92E-12	3.74E-26	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RB 83	6.41E+03	1.53E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RB 87	1.11E-07	3.65E-07	3.65E-07	3.65E-07	3.65E-07	3.65E-07	3.65E-07	3.65E-07	3.65E-07	3.65E-07	3.65E-07
SR 90	1.92E+02	5.45E+02	5.93E+01	3.09E-03	1.37E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y 88	5.76E+03	6.72E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y 90	5.06E+05	5.45E+02	5.93E+01	3.09E-03	1.37E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ZR 88	2.21E+03	1.47E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ZR 93	5.13E-03	3.35E-02	3.35E-02	3.35E-02	3.34E-02	3.33E-02	3.32E-02	3.23E-02	3.11E-02	1.61E-02	2.27E-05
NB 93M	4.47E-12	1.40E-02	3.17E-02	3.18E-02	3.18E-02	3.17E-02	3.16E-02	3.07E-02	2.96E-02	1.53E-02	2.15E-05
NB 94	1.51E-01	1.51E-01	1.51E-01	1.49E-01	1.46E-01	1.27E-01	1.07E-01	2.68E-02	4.73E-03	1.34E-16	0.00E+00
MO 93	1.36E-01	1.36E-01	1.34E-01	1.24E-01	1.13E-01	5.34E-02	2.10E-02	1.17E-05	1.01E-09	0.00E+00	0.00E+00
TC 97	1.10E-03	1.23E-03	1.23E-03	1.23E-03	1.23E-03	1.23E-03	1.23E-03	1.21E-03	1.20E-03	9.41E-04	8.56E-05
TC 98	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.76E-04	4.73E-04	4.07E-04	9.23E-05
TC 99	1.51E-02	2.07E-01	2.07E-01	2.06E-01	2.03E-01	2.03E-01	2.03E-01	1.76E-01	1.49E-01	7.88E-03	1.33E-15
RU106	9.39E+03	3.87E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RH101	2.55E+02	4.37E+01	2.72E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RH102	8.70E+02	4.98E+01	3.67E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RK106	4.56E+09	3.87E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PD107	4.40E-04	6.29E-03	6.29E-03	6.29E-03	6.29E-03	6.29E-03	6.28E-03	6.26E-03	6.22E-03	5.65E-03	2.17E-03
AG109M	3.63E+04	5.64E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AG110	5.36E+03	2.33E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CD109	1.08E+03	5.64E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CD113M	1.36E-04	2.06E+01	2.87E-01	1.62E-09	7.91E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SN113	3.20E+03	9.08E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SM119M	2.23E-01	5.34E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SN123	2.84E+04	1.71E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SN126	8.92E-02	1.87E-01	1.87E-01	1.86E-01	1.85E-01	1.80E-01	1.74E-01	1.32E-01	9.33E-02	1.82E-04	0.00E+00
SB125	3.14E+03	7.96E+02	9.60E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SB126	1.83E+05	2.61E-02	2.61E-02	2.60E-02	2.60E-02	2.52E-02	2.44E-02	1.85E-02	1.31E-02	2.55E-05	0.00E+00
SB126M	2.63E-05	1.87E-01	1.87E-01	1.86E-01	1.85E-01	1.80E-01	1.74E-01	1.32E-01	9.33E-02	1.82E-04	0.00E+00
TE123	3.22E-10	4.07E-10	4.07E-10	4.07E-10	4.07E-10	4.07E-10	4.07E-10	4.07E-10	4.07E-10	4.07E-10	4.07E-10
TE125M	5.00E-05	1.94E+02	2.34E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TE127	5.99E+06	1.02E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TE127M	4.00E-03	1.05E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1129	2.96E-04	2.01E-03	2.01E-03	2.01E-03	2.01E-03	2.01E-03	2.01E-03	2.01E-03	2.00E-03	1.92E-03	1.30E-03
CS134	2.94E+03	1.02E+02	7.30E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CS135	3.07E-03	1.70E-02	1.70E-02	1.70E-02	1.70E-02	1.70E-02	1.70E-02	1.68E-02	1.65E-02	1.26E-02	8.37E-04
CS137	3.36E+02	8.70E+02	1.10E+02	1.10E-02	1.11E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA133	2.37E+02	2.22E+02	6.41E-01	3.29E-12	2.54E-26	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA137M	7.18E-01	8.23E+02	1.04E+02	1.04E-02	1.05E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LA138	4.97E-08	4.97E-08	4.97E-08	4.97E-08	4.97E-08	4.97E-08	4.97E-08	4.97E-08	4.97E-08	4.97E-08	4.97E-08
CE13 9	4.92E+03	7.01E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CE14 2	3.53E-08	2.69E-07	2.69E-07	2.69E-07	2.69E-07	2.69E-07	2.69E-07	2.69E-07	2.69E-07	2.69E-07	2.69E-07
CE144	6.52E+03	3.51E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PR144	7.16E+07	3.51E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PR144M	6.26E-02	4.21E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PM14 3	3.03E-01	3.31E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PM14 4	3.52E+02	2.50E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PM14 5	6.65E+01	7.21E+01	2.13E+00	3.38E-07	1.07E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PM14 6	2.13E+02	6.08E+01	7.72E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PM147	5.13E+02	4.48E+02	2.13E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SM14 5	5.42E+02	4.25E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SM147	1.26E-08	1.57E-07	1.68E-07	1.68E-07	1.68E-07	1.68E-07	1.68E-07	1.68E-07	1.68E-07	1.68E-07	1.68E-07
SM151	9.05E+00	8.73E-01	4.46E+01	2.26E+00	5.45E-02	6.13E-15	4.00E-31	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EU149	2.64E+03	6.45E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EU150	1.41E+01	1.16E+01	2.03E+00	8.85E-04	5.55E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EU152	3.88E+01	2.28E+01	1.88E-01	1.02E-10	2.70E-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EU1 54	7.82E+01	3.49E+01	2.47E-02	2.45E-16	7.66E-34	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EU155	3.15E+02	2.07E+02	4.69E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
GD148	1.72E+00	1.61E+00	8.47E-01	4.94E-02	1.42E-03	6.42E-16	2.39E-31	0.00E+00	0.00E+00	0.00E+00	0.00E+00
GD150	9.45E-05	9.45E-05	9.45E-05	9.44E-05	9.44E-05	9.43E-05	9.41E-05	9.26E-05	9.09E-05	6.40E-05	1.93E-06
GD151	5.12E+02	7.14E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
GD153	1.02E+03	3.48E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TB157	1.12E+00	5.35E+00	3.53E+00	5.57E-01	5.53E-02	5.24E-10	4.90E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TB158	2.24E+00	2.14E+00	1.41E+00	2.23E-01	2.21E-02	2.10E-10	1.96E-20				

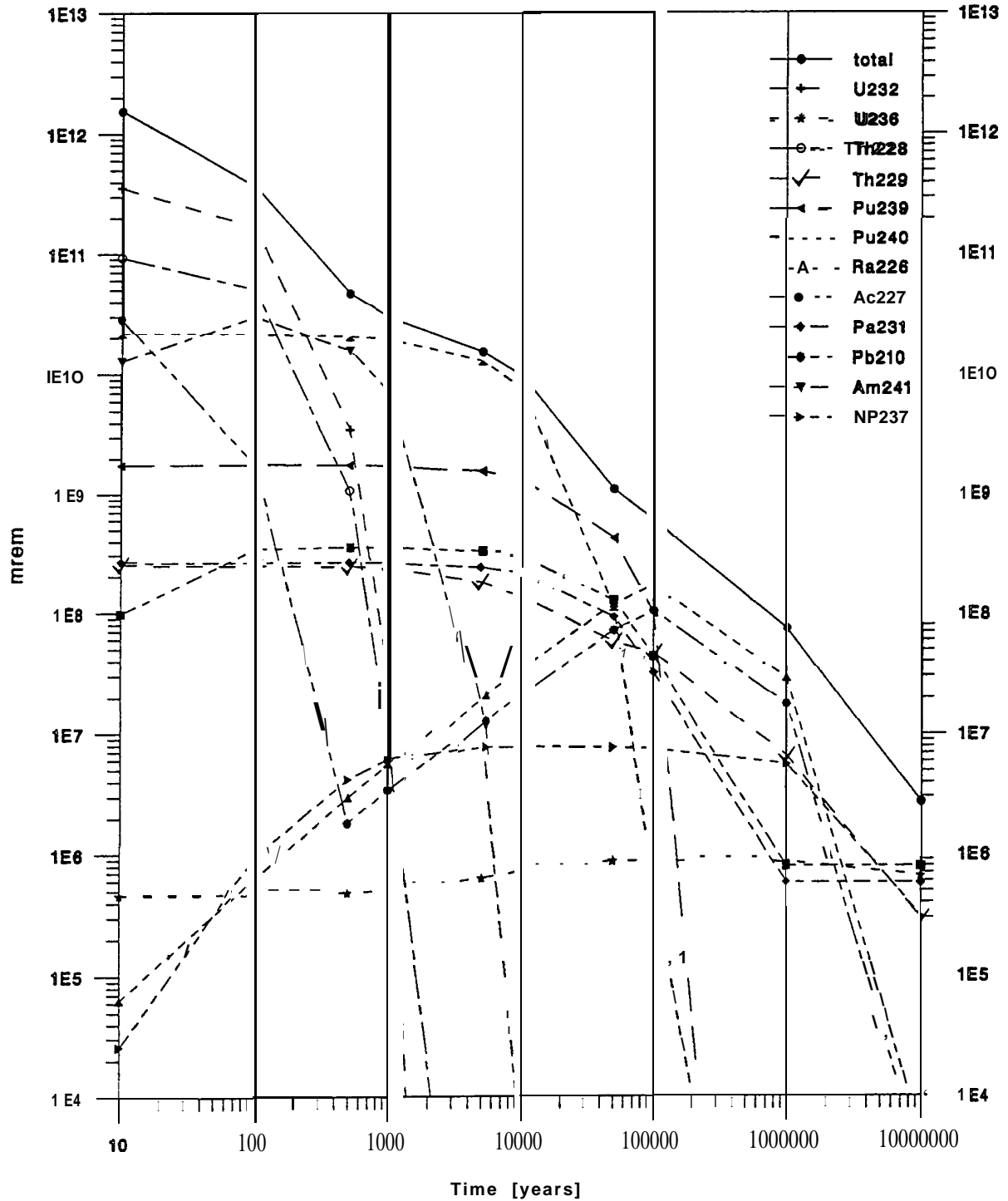
NUCLIDE RADIOACTIVITY, CURIES
BASIS - 1 KG DECAYING MA MIXTURE

	TIME UN][T=YRS										
	INITIAL	1.00E+01	1.00E+02	5.00E+02	1.00E+03	5.00E+03	1.00E+04	5.00E+04	1.00E+05	1.00E+06	1.00E+07
TL2 09	0.00E+00	1.8 0E-10	1.86E-08	4. 98E-07	2.1 0E-06	5.44E-05	1.95E-04	2.08E-03	4.22E-03	1.03E-02	5.25E-04
PB209	0.00E+00	8.19E-09	8.45E-07	2.26E-05	9.53E-05	2.47E-03	8.85E-03	9.43E-02	1.92E-01	4. 66E-01	2.38E-02
BI213	0.00E+00	8.19E-09	8.45E-07	2.26E-05	9. 53E-05	2.47E-03	8.85E-03	9.43E-02	1.92E-01	4. 66E-01	2.38E-02
PO213	0.00E+00	8. 01E-09	8.26E-07	2.21E-05	9.32E-05	2.42E-03	8.66E-03	9.23E-02	1.88E-01	4. 56E-01	2.33E-02
AT217	0.00E+00	8.19E-09	8.45E-07	2.26E-05	9. 53E-05	2.47E-03	8.85E-03	9.43E-02	1.92E-01	4.66E-01	2.3 SE-02
FR221	0.00E+00	8.19E-09	8.45E-07	2.26E-05	9.53E-05	2.47E-03	8.85E-03	9.43E-02	1.92E-01	4.66E-01	2.38E-02
RA225	0.00E+00	8.19E-09	8.45E-07	2.26E-05	9. 53E-05	2.47E-03	8.85E-03	9.43E-02	1.92E-01	4.66E-01	2.38E-02
AC225	0.00E+00	8.19E-09	8.45E-07	2.26E-05	9.53E-05	2.47E-03	8.85E-03	9.43E-02	1. 92E-01	4.66E-01	2.38E-02
TH229	0.00E+00	8.19E-09	8.45E-07	2.26E-05	9.53E-05	2.47E-03	8.85E-03	9.43E-02	1.92E-01	4.66E-01	2.38E-02
TH230	0.00E+00	3.1 0E-10	2.51E-07	1.15E-05	3.73E-05	2.58E-04	5.19E-04	2.13E-03	3.24E-03	5. 78E-04	5.11E-15
PA233	5.39E-08	4.05E-01	4.32E-01	5.15E-01	5.65E-01	6.06E-01	6. 05E-01	5.97E-01	5.88E-01	4. 39E-01	2.38E-02
U233	2.48E-21	1.74E-05	1.82E-04	1.01E-03	2.19E-03	1.25E-02	2.53E-02	1.17E-01	2.1 0E-01	4. 66E-01	2.38E-02
U234	0.00E+00	1.06E-05	7.86E-04	5.14E-03	6.39E-03	6. 47E-03	6.38E-03	5.70E-03	4.95E-03	3. 88E-04	3.44E-15
U236	9. 61E-25	2.53E-07	1.11E-05	6.94E-05	1.39E-04	5.80E-04	9.25E-04	1.41E-03	1.42E-03	1. 38E-03	1.06E-03
NP237	4.02E-01	4.05E-01	4.32E-01	5.15E-01	5.65E-01	6.06E-01	6. 05E-01	5.97E-01	5.88E-01	4. 39E-01	2.38E-02
NP238	1.00E-07	5.05E-02	3.35E-02	5.41E-03	5.54E-04	6.70E-12	8.50E-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NP239	3.74E-05	2.19E+01	2.17E+01	2.09E+01	1.99E+01	1.37E+01	8.56E+00	1.99E-01	1.81E-03	0.00E+00	0.00E+00
PU238	8.36E-18	7.35E-01	4.48E+00	2.08E+00	2. 53E-01	3.18E-09	4.03E-19	0.00E+00	0.00E+00	0.00E+00	0. 00E+00
PU239	1.08E-11	1.23E-02	8.80E-02	3.33E-01	6.19E-01	2.35E+00	3.49E+00	2.21E+00	5.47E-01	3.29E-12	0.00E+00
PU240	3.07E-09	1.61E+00	4.92E+00	4.82E+00	4.57E+00	3.00E+00	1.77E+00	2.61E-02	1.34E-04	0.00E+00	0.00E+00
PU241	1.16E-10	5.78E-02	1.49E-01	1.45E-01	1.40E-01	1. 01E-01	6.70E-02	2.57E-03	4.37E-05	0.00E+00	0.00E+00
AM241	1.01E+03	9.96E+02	8.63E+02	4.54E+02	2.04E+02	4.39E-01	6.71E-02	2.57E-03	4.37E-05	0. 00E+00	0.00E+00
AM242	6.33E-05	1. 01E+01	6. 67E+00	1.08E+00	1.1 0E-01	1.33E-09	1.69E-19	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AM24 2M	1.06E+01	1. 01E+01	6.70E+00	1.08E+00	1.11E-01	1.34E-09	1.70E-19	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AI1243	2.19E+01	2.19E+01	2.17E+01	2.09E+01	1.99E+01	1.37E+01	8.56E+00	1.99E-01	1.81E-03	0.00E+00	0.00E+00
CM242	1.04E-12	1. 01E+01	6.67E+00	1.08E+00	1.1 0E-01	1.34E-09	1.70E-19	0.00E+00	0.00E+00	0. 00E+00	0.00E+00
CM243	2.38E+01	1.86E+01	2.09E+00	1.25E-04	6.59E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CM244	1.84E+03	1.25E+03	4. 01E+01	9.07E-06	4.48E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CM245	1.51E-01	1.51E-01	1.50E-01	1.45E-01	1.39E-01	1. 01E-01	6.69E-02	2.57E-03	4.36E-05	0. 00E+00	0.00E+00
TOTAL	2.91E+03	2.35E+03	9.79E+02	5.08E+02	2.51E+02	3.46E+01	2.39E+01	4.74E+00	3.51E+00	5.08E+00	2. 66E-01

Table 9: Activities of the original minor actinide mixture and its decay products.

Spallation Product Toxicity

MA recycling without further partitioning

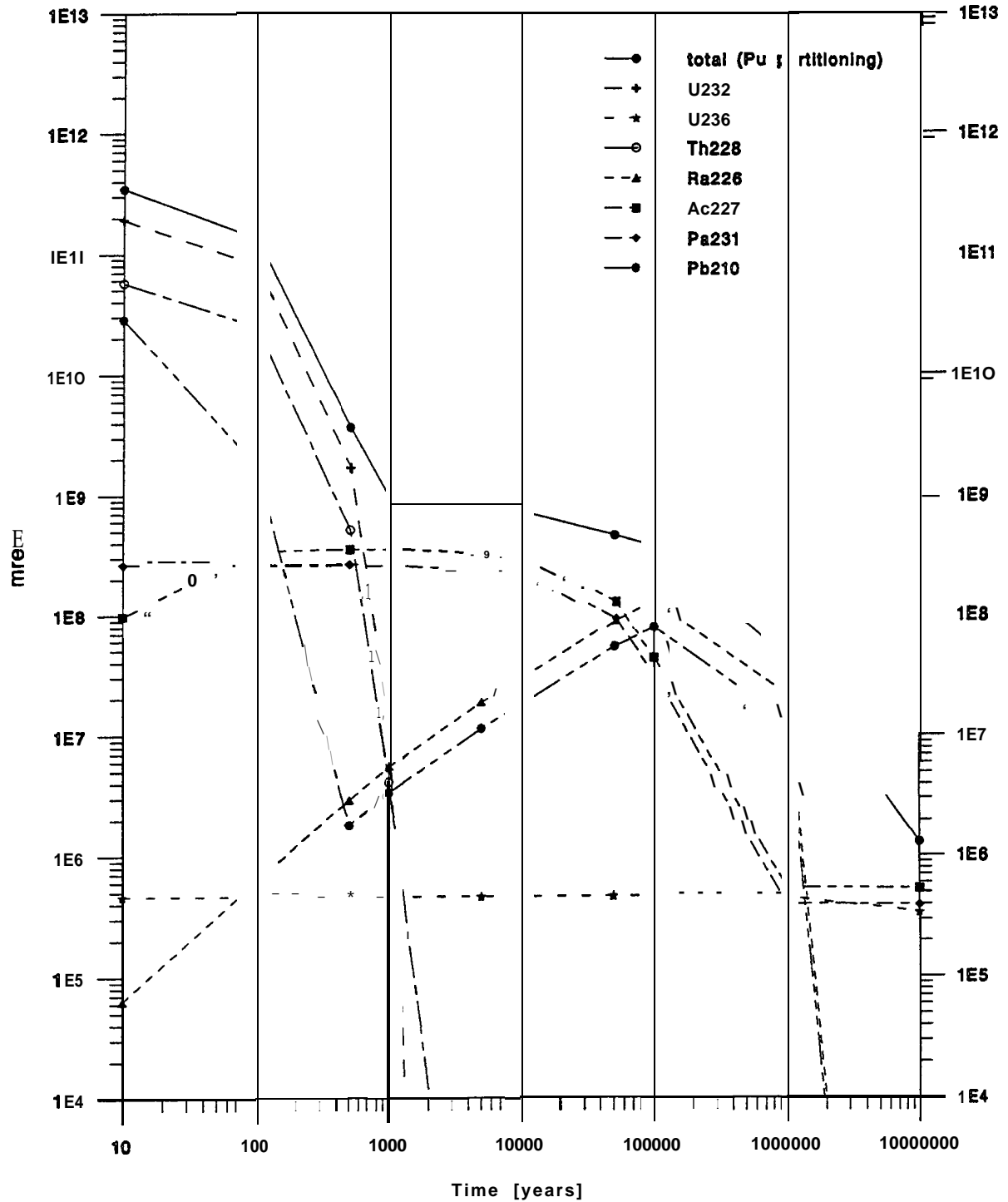


Recycling Scheme 1.(a)

Figure 4

Spallation Product Toxicity

MA recycling with additional Pu partitioning

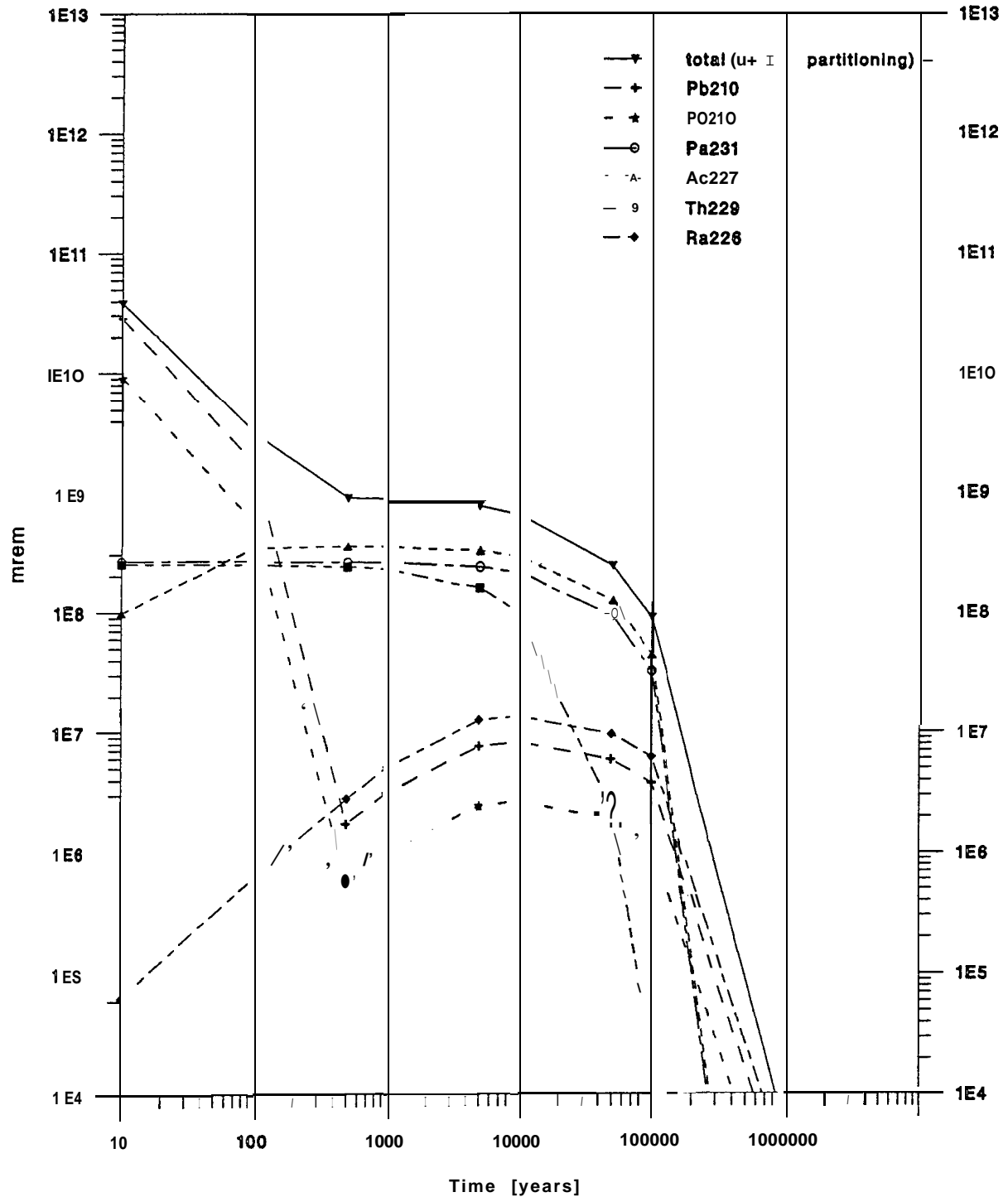


Recycling Scheme 1.(b)

Figure 5

Spallation Product Toxicity

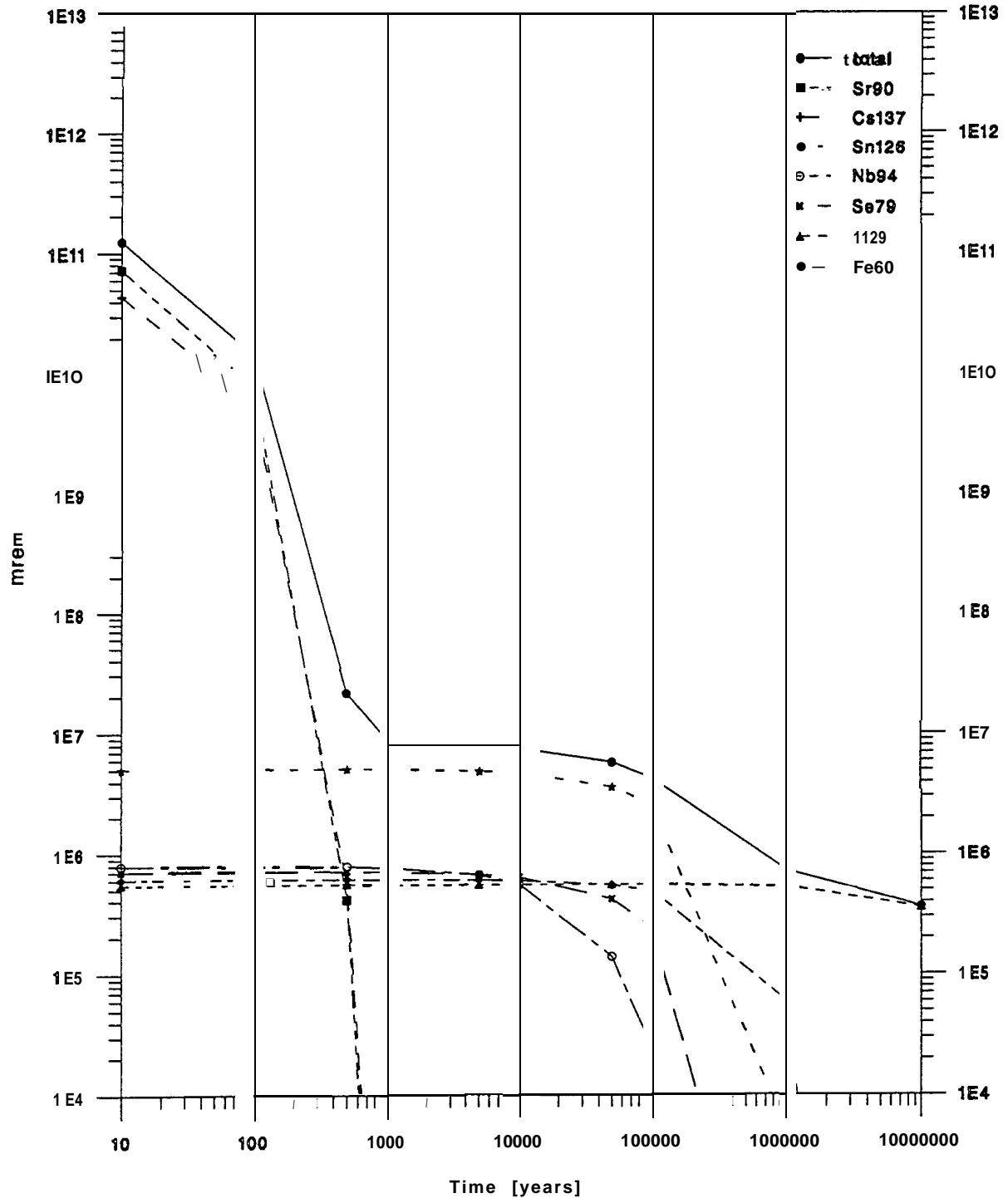
MA recycling with additional Pu/U partitioning



Recycling Scheme 1.(c)

Figure 6

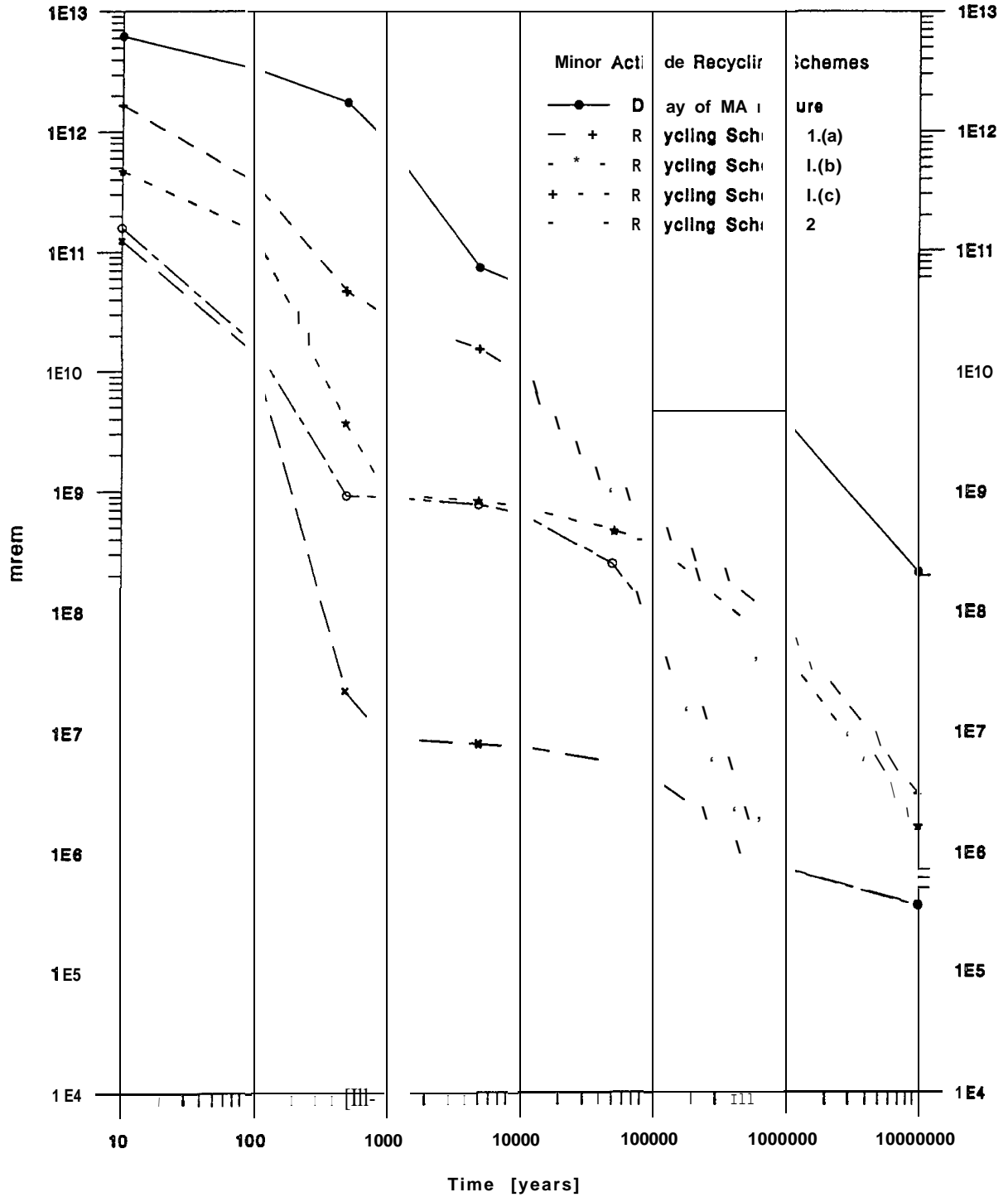
Fission Product Toxicity recycling of all spallation products



Recycling Scheme 2

Figure 7

Long-term Toxicity of Remaining Waste for different recycling schemes



Comparison with total toxicity of original MA mixture and its decay products

Figure 8

Toxicity of original MA mixture and its decay products

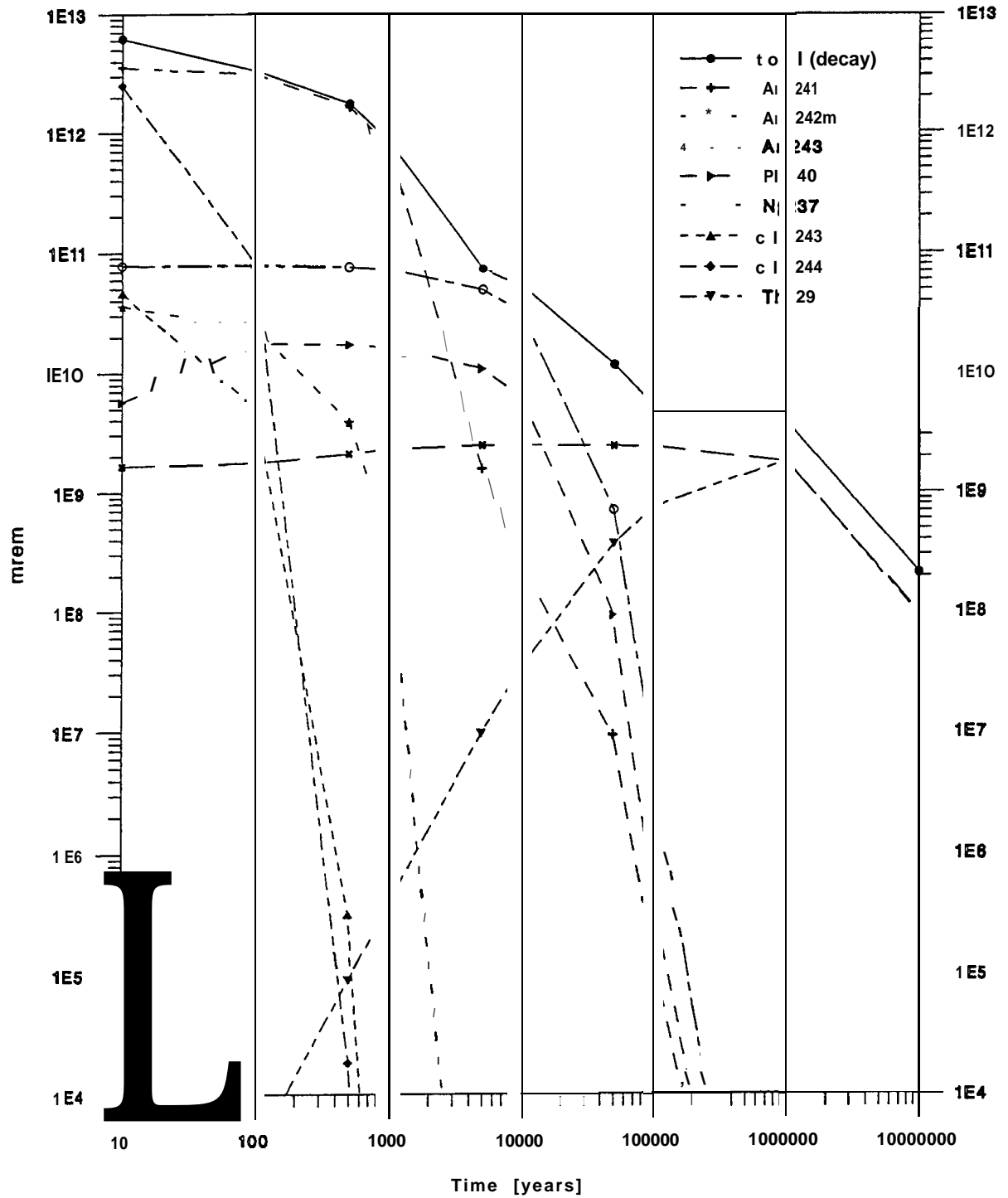
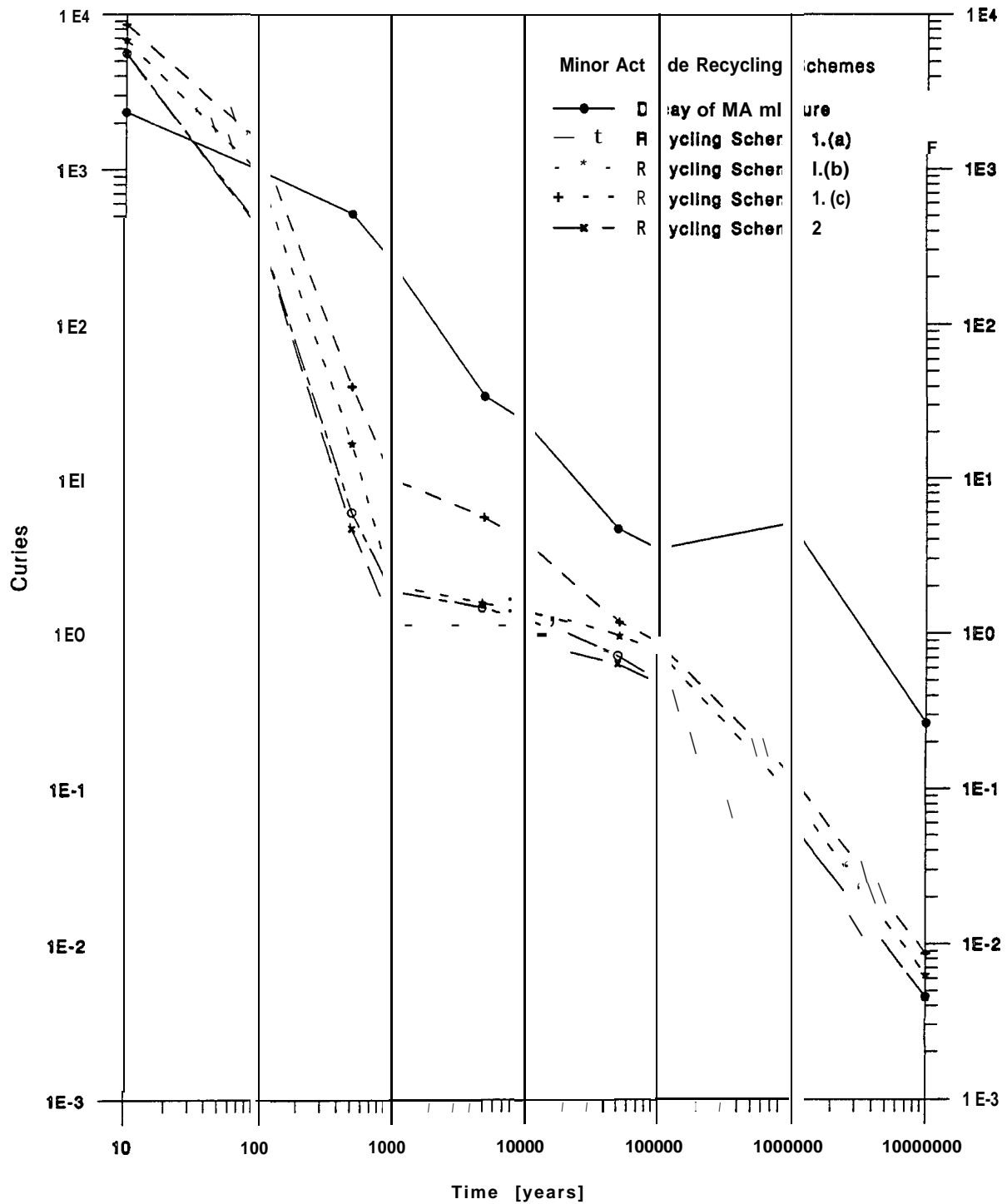


Figure 9

Overall Activities for different recycling schemes



Comparison with total activity of original MA mixture
and its decay products

Figure 10