Modelling Incineration of Minor Actinides in the Experimental ADS MYRRHA

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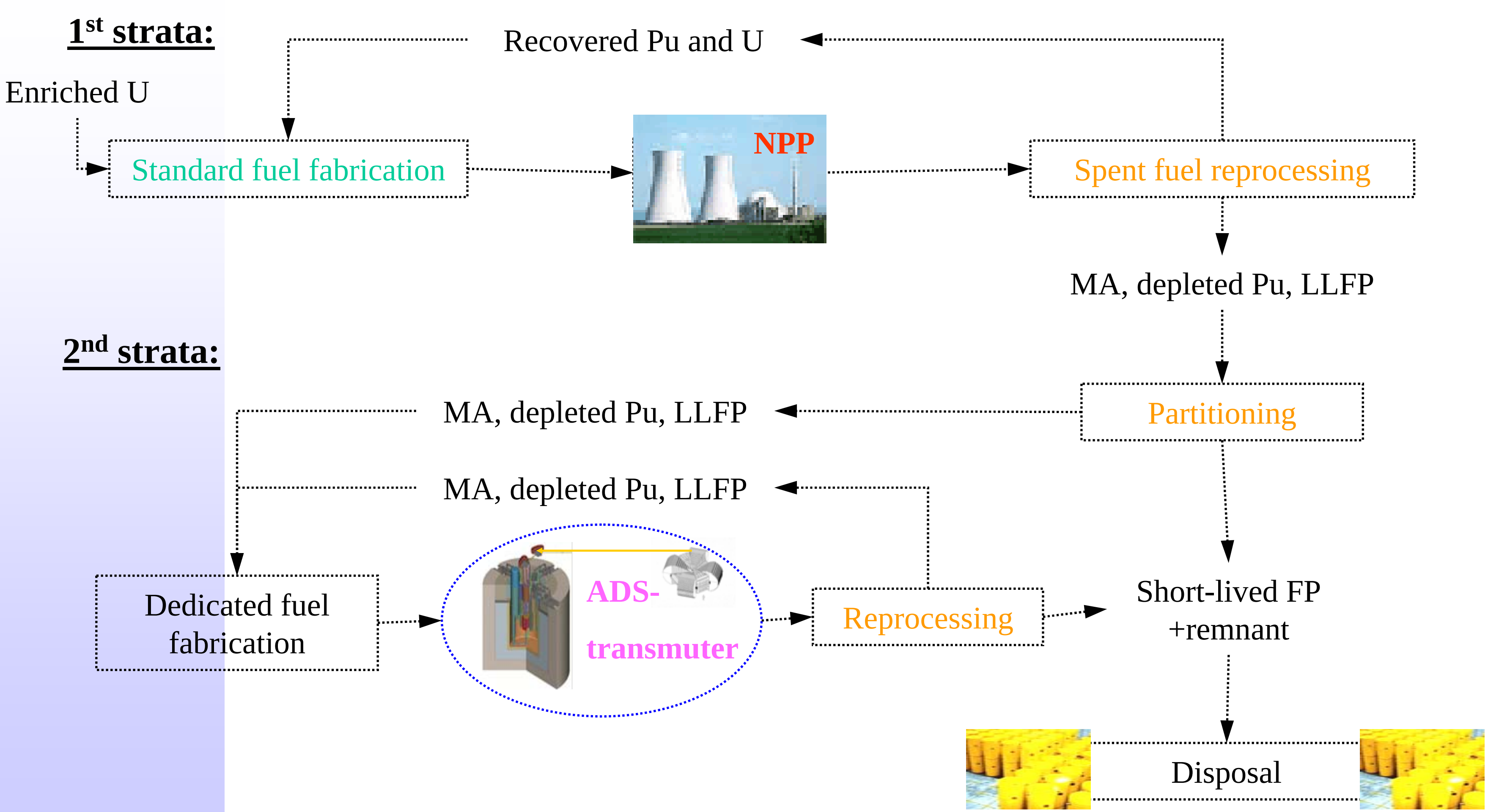
Contents

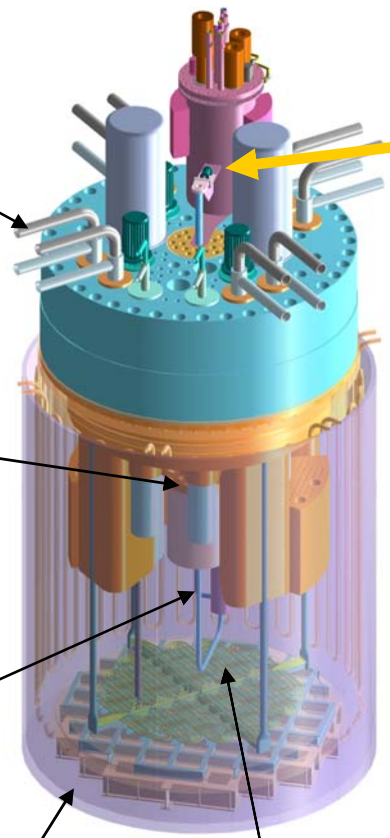
1.1. Introduction

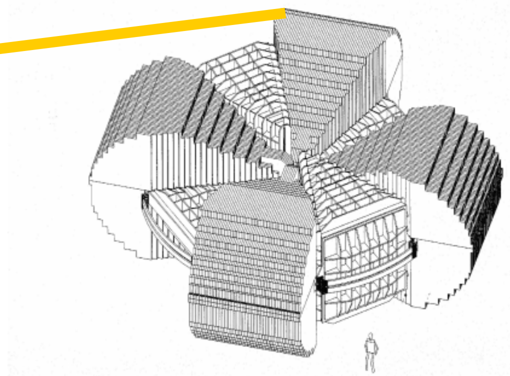
- High level radioactive waste (HLW) is the problem of a high importance in countries using nuclear energy. About 10^5 t of HLW are into intermediate storages. 2000 t are produced every year in USA and 2500 t in EU(15).
- Pu, MA (Np, Am, Cm) and some LLFP give major contribution to the long term radiotoxicity. Spent fuel -> 10 kg/t Pu, 1.4 kg/t MA, 1.2 kg/t LLFP.
- P&T allows to reduce significantly the amount and radiotoxicity of HLW going to geological disposal.
- Subcritical ADS can be an effective and safe solution for transmutation of MA and Pu burning.
- **The Belgian nuclear research Centre SCK·CEN in collaboration with other countries is developing an experimental ADS (MYRRHA) for MA and LLFP transmutation studies and demonstration.**

1.2. Introduction:
ADS in double strata



1.3. Introduction:
MYRRHA ADS

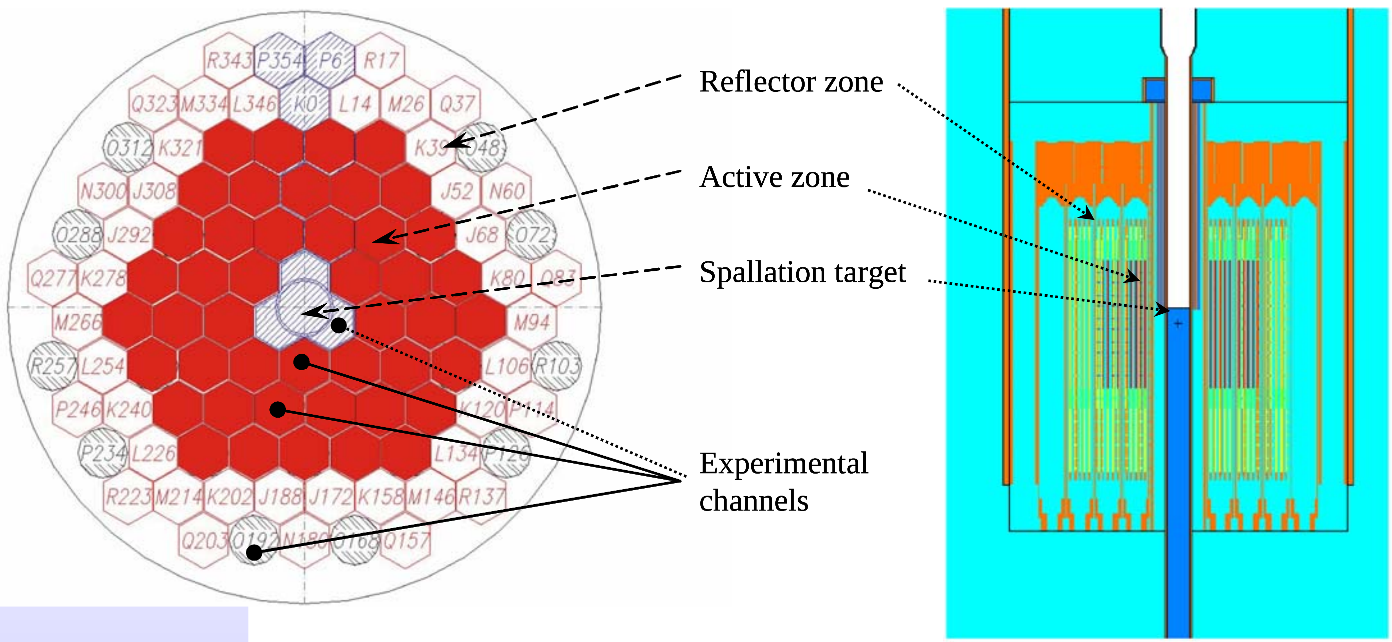


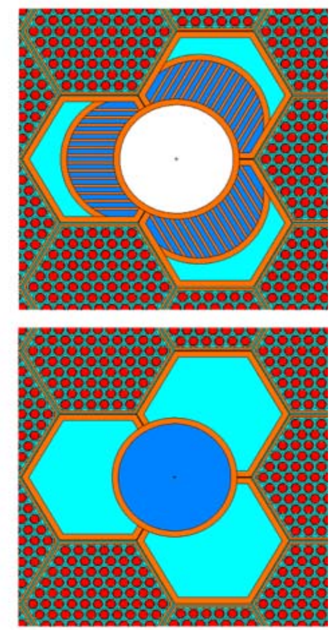


Main performances:

- Proton source: E_p~350 MeV, I_p~ 5 mA
- Liquid Pb-Bi spallation source and coolant
- Highly enriched MOX in the sub-critical core
- k_{eff} limited to ~ 0.95
- Total power ~ 50 MW(th)
- Maximal fast neutron flux ~ 10^{15} $n.cm^{-2}s^{-1}$

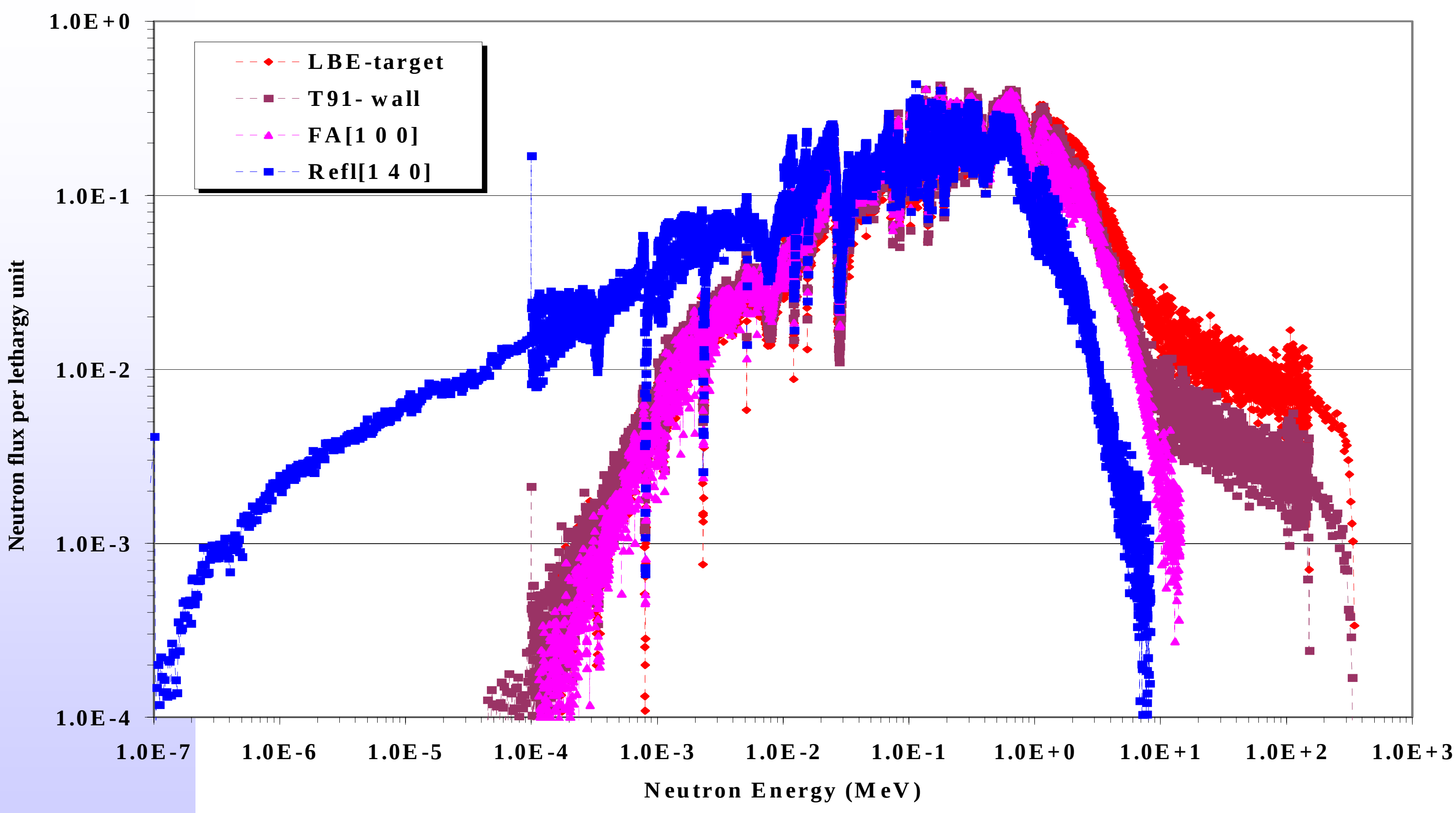
1.4. Introduction:
MYRRHA ADS core



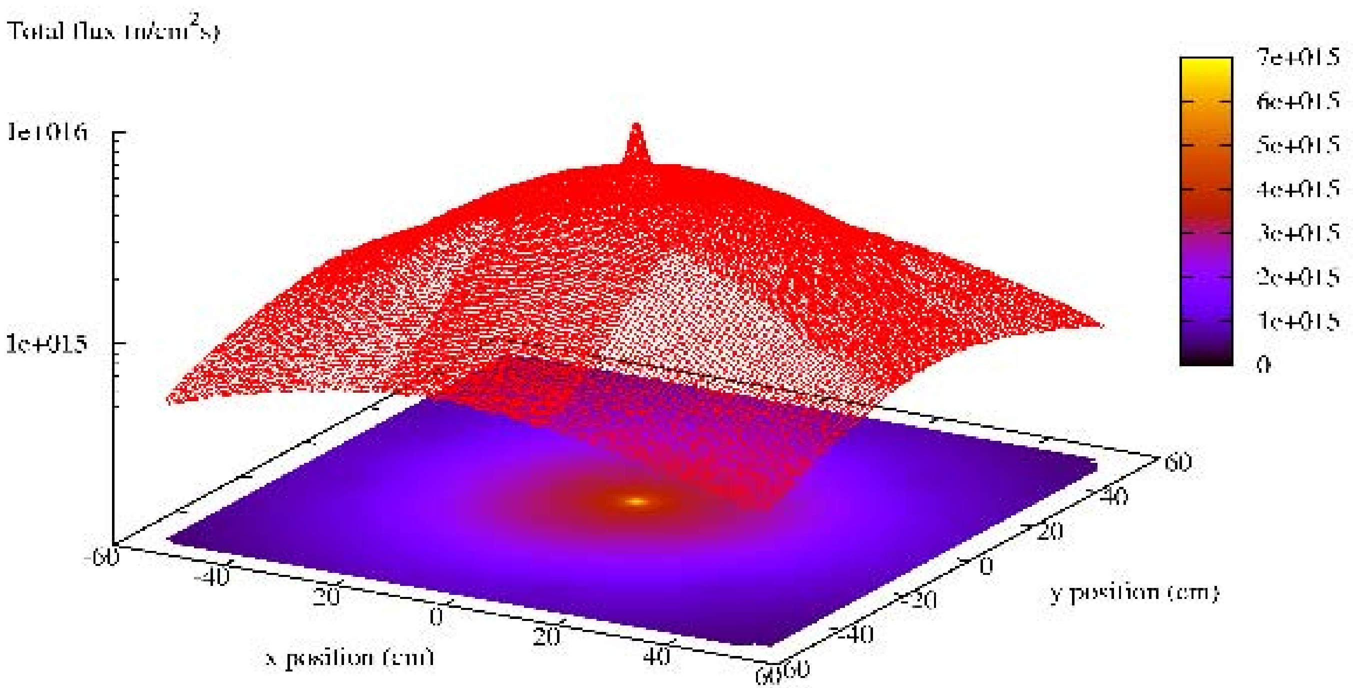


- 99 + 3 hexagonal cells ("macro-cells")
- Target-block hole is made by 3 removed FA in the central region
- Surrounding active zone composed of 45 (or more) FA
- Outer reflector zone composed of 54 (or less) reflector assemblies

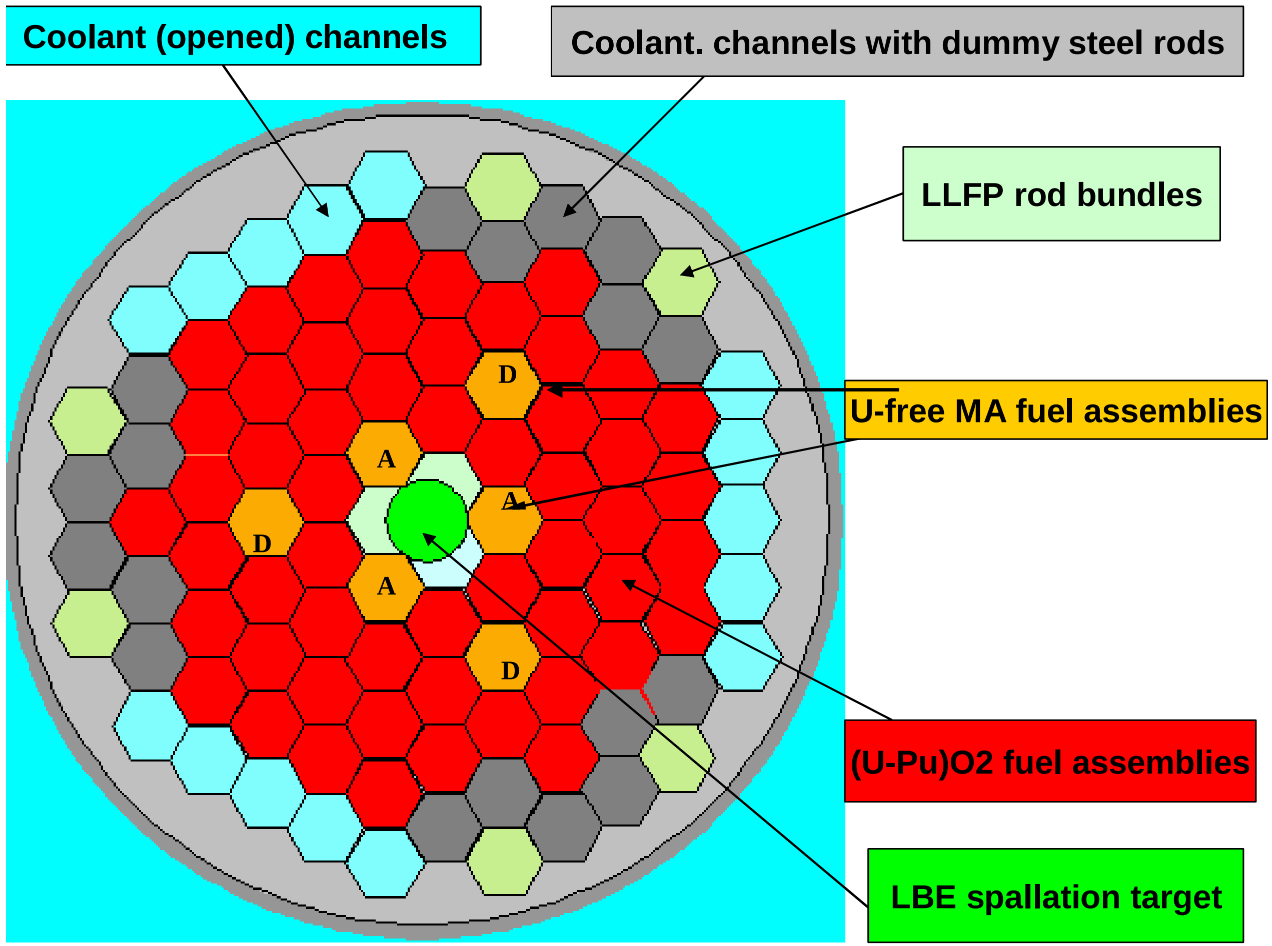
1.5. Introduction: MYRRHA ADS spectrum



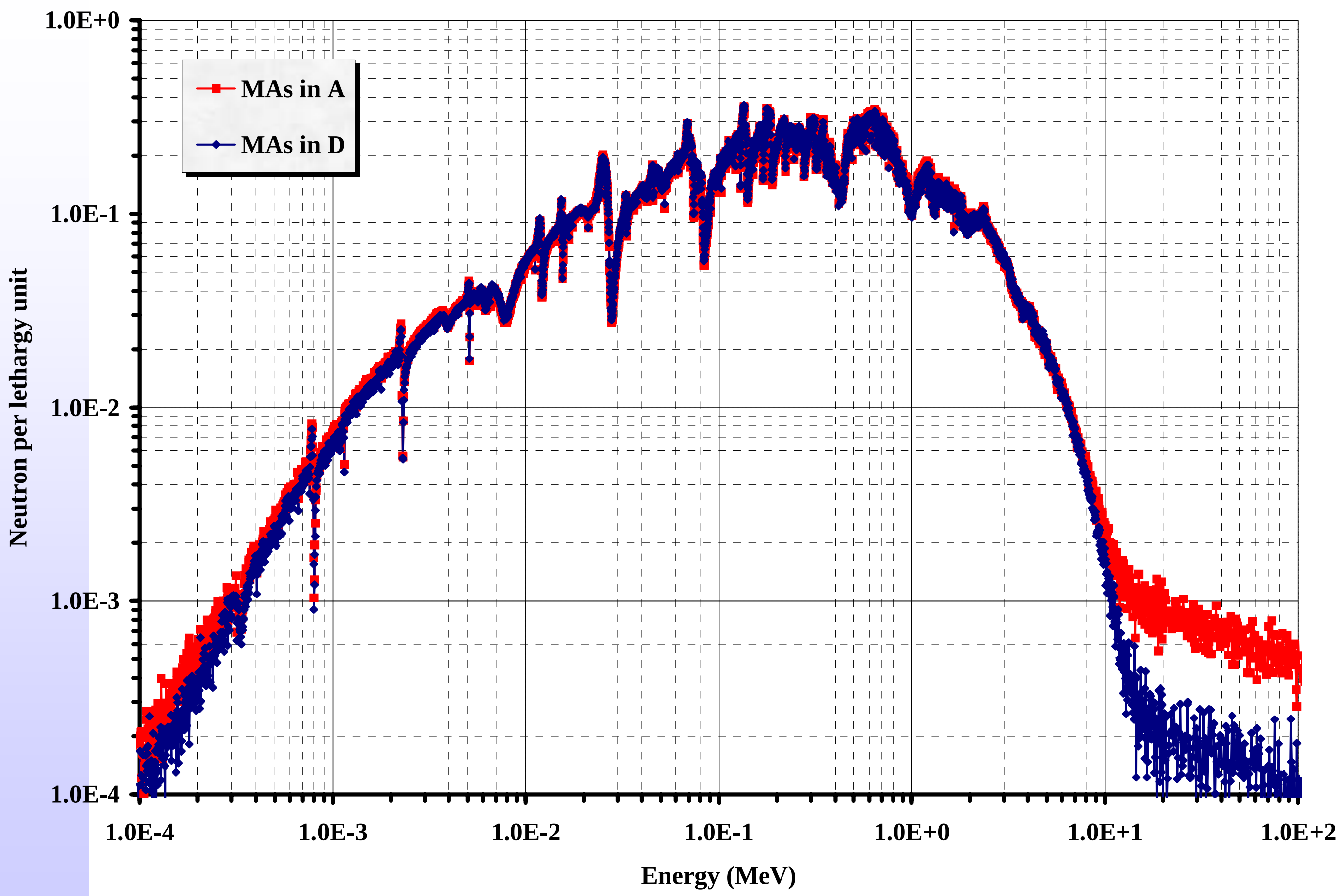
1.6. Introduction:
MYRRHA ADS flux



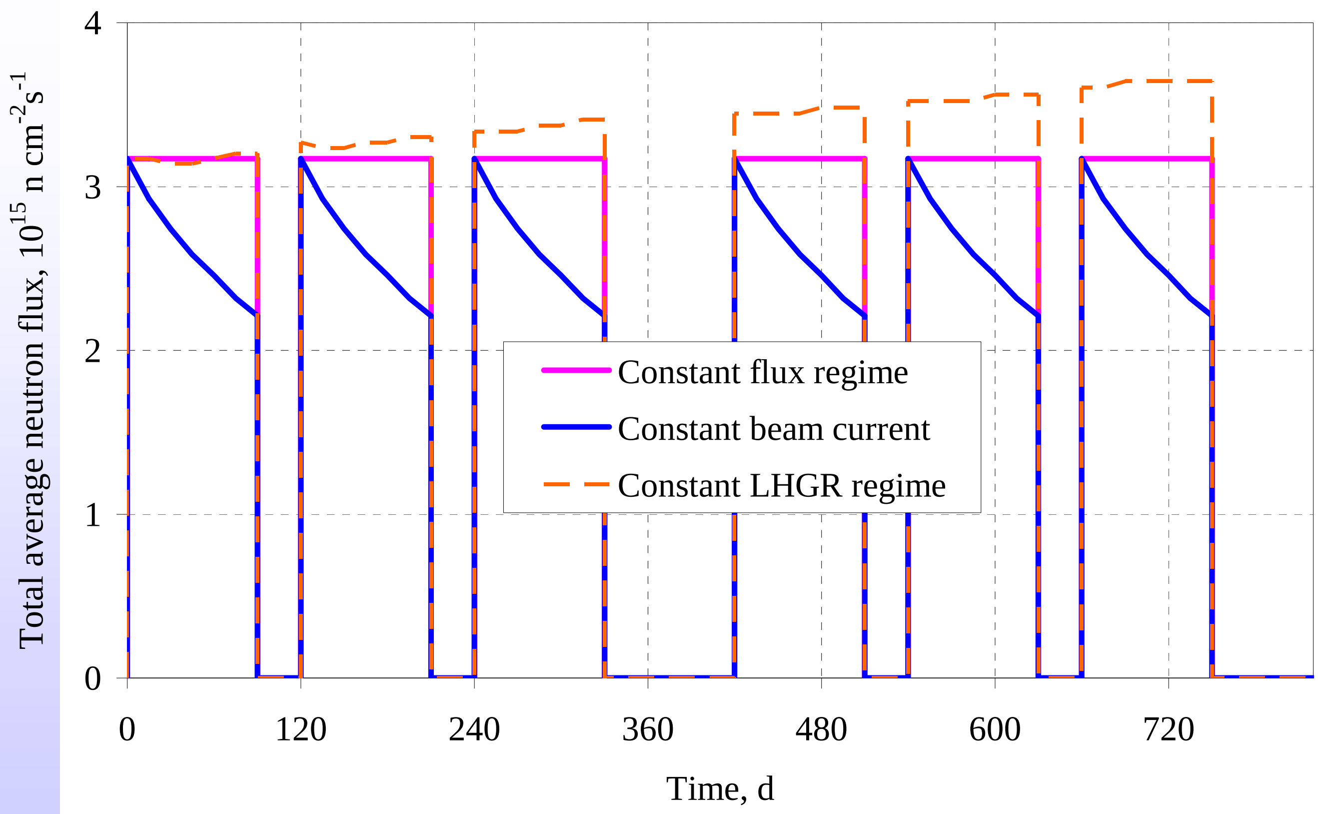
2.1. Irradiation conditions:
Transmutation core option



2.2. Irradiation conditions : Neutron spectrum in A and D



2.3. Irradiation conditions:
Flux regime



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3. Fuel targets:

MYRRHA

- Composition:
  40 vol.% $(Cm_{0.1}Am_{0.5},Pu_{0.4})O_{1.88}$ + 60 vol.% MgO
- Density 90 % TD
- Fuel column diameter x height: 5.35 x 40.0 mm
- Initial fuel isotopic vectors: 2nd strata option.

PLUTONIUM

Isotope	Content wt.%
^{238}Pu	5.06
^{239}Pu	37.91
^{240}Pu	30.31
^{241}Pu	13.21
^{242}Pu	13.51

AMERICIUM

Isotope	Content wt.%
^{241}Am	66.67
^{243}Am	33.33

CURIUM

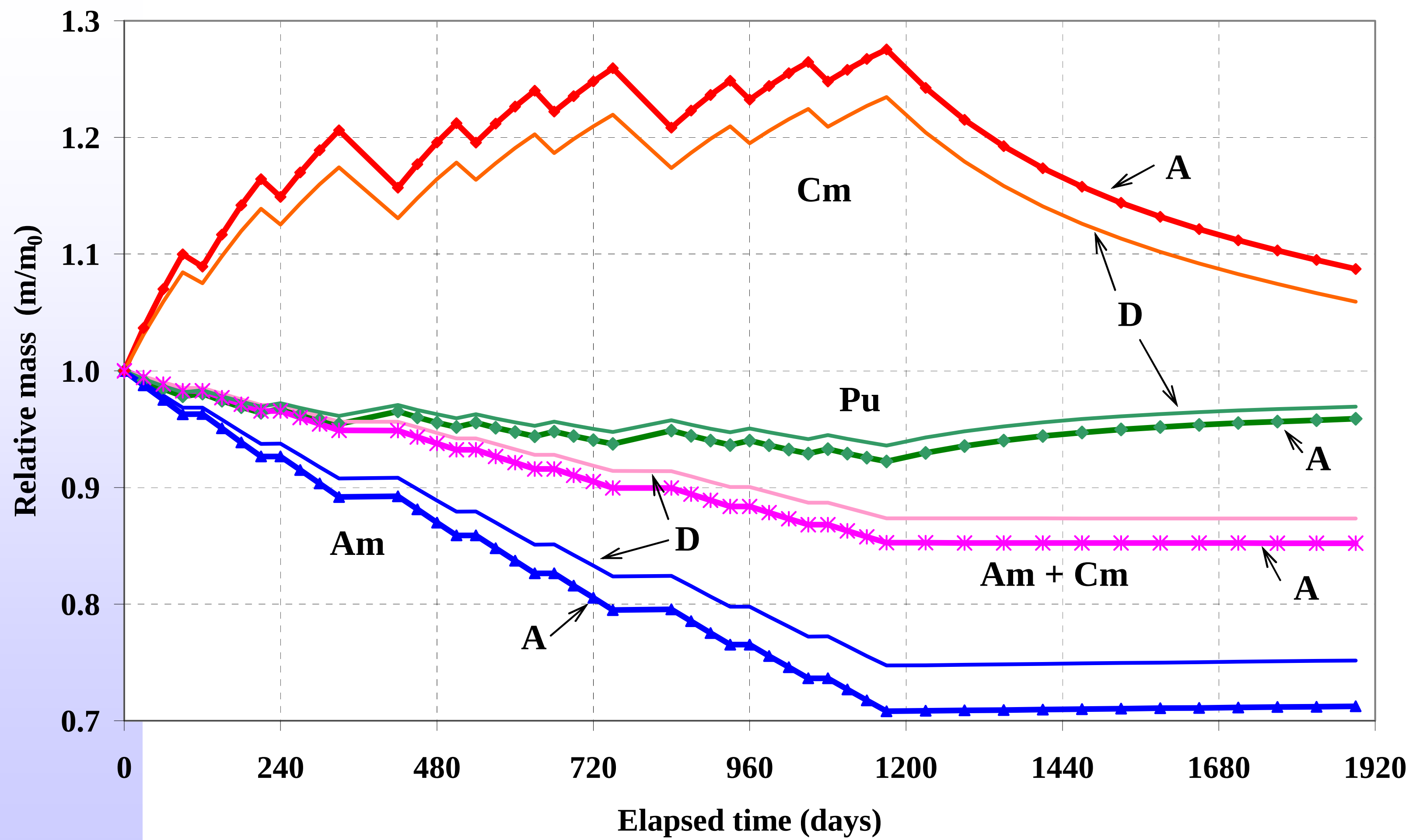
Isotope	Content wt.%
^{244}Cm	90.00
^{245}Cm	10.00

4.1. Results of modelling:

- ALEPH code system:

  MCNPX + NJOY + ORIGEN + JEF 2.2 (mod SCK)
- Calculated features:
  - Neutron flux distribution
  - Neutron spectrum
  - Effective cross-sections
  - Fuel isotopic composition evolution
  - Power density evolution

4.2. Results of modeling:
Pu, Am and Cm content



4.3. Results of modeling: Cm, Pu and He generation

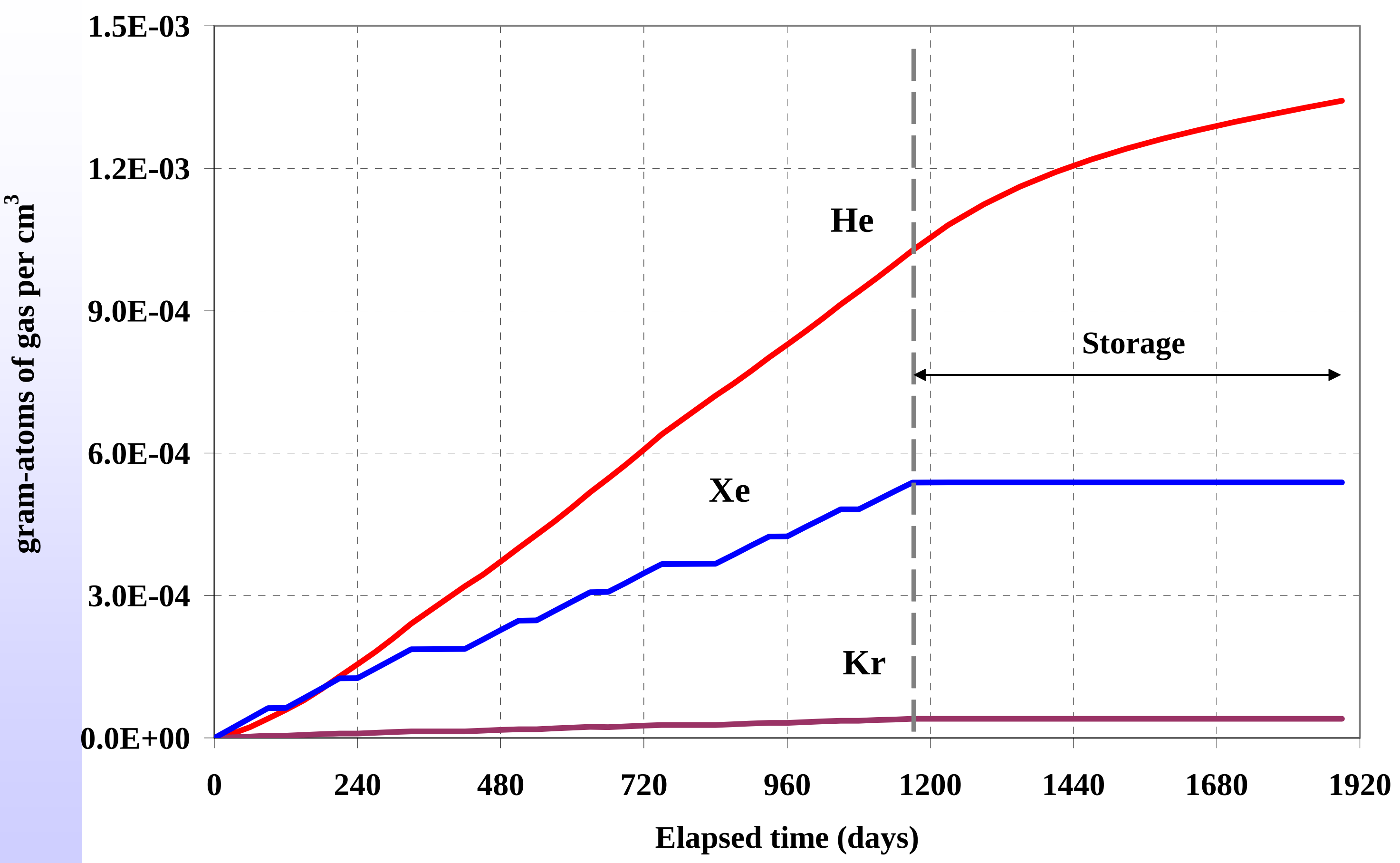
$$^{241}Am + n \rightarrow {}^{242}Am(90\%) \xrightarrow{(\tau=16h)} \beta^- + {}^{242}Cm \xrightarrow{(\tau=162d)} \alpha + {}^{238}Pu$$

$$\rightarrow {}^{242m}Am(10\%) \xrightarrow{(\tau=141y)}$$

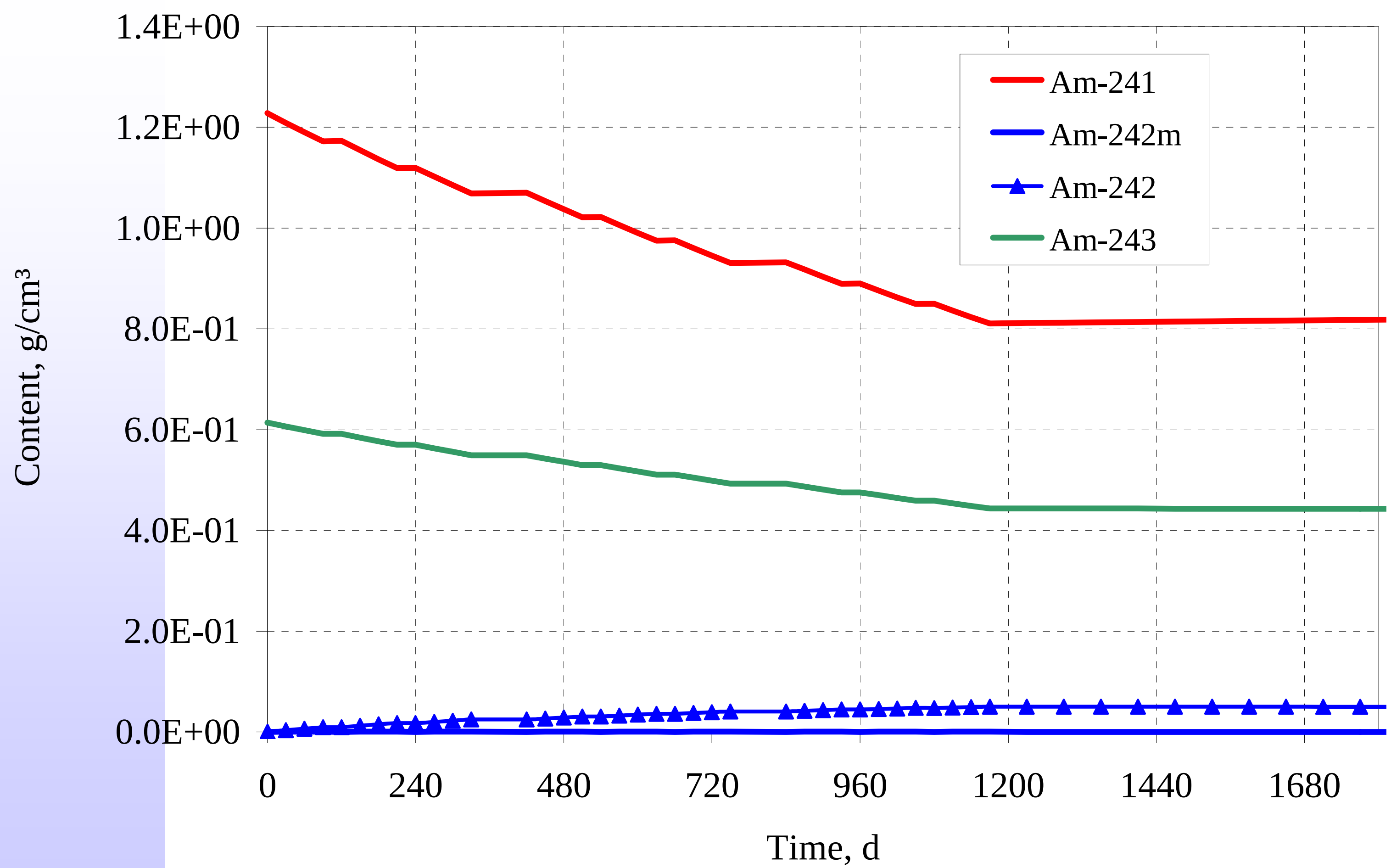
$$^{243}Am + n \rightarrow {}^{244}Am \xrightarrow{(\tau=10.1h)} \beta^- + {}^{244}Cm \xrightarrow{(\tau=18.1y)} \alpha + {}^{240}Pu$$

$$^{238}Pu \xrightarrow{(\tau=87.7\,y)} \alpha + {}^{234}U$$

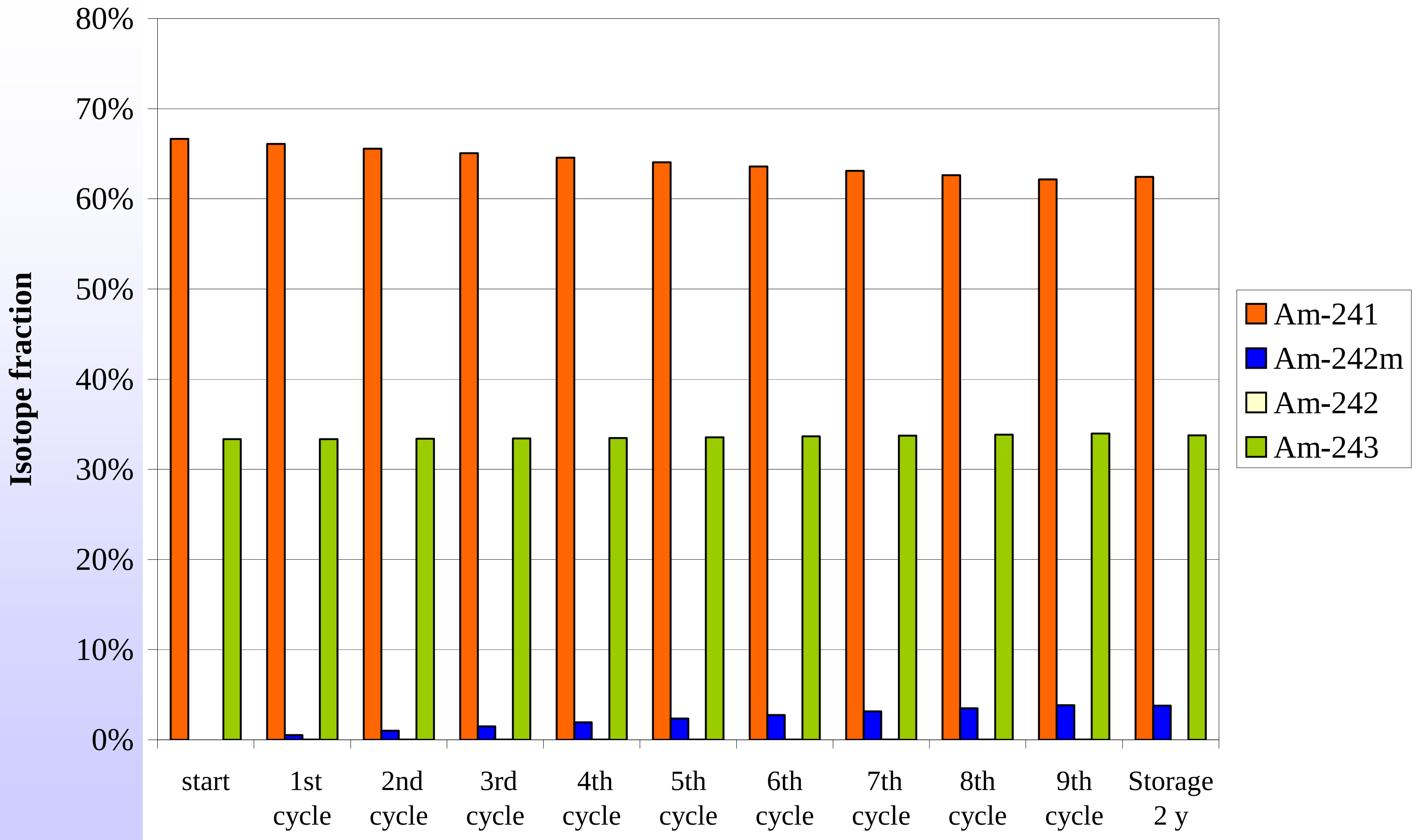
4.4. Results of modeling: He, Xe and Kr generation



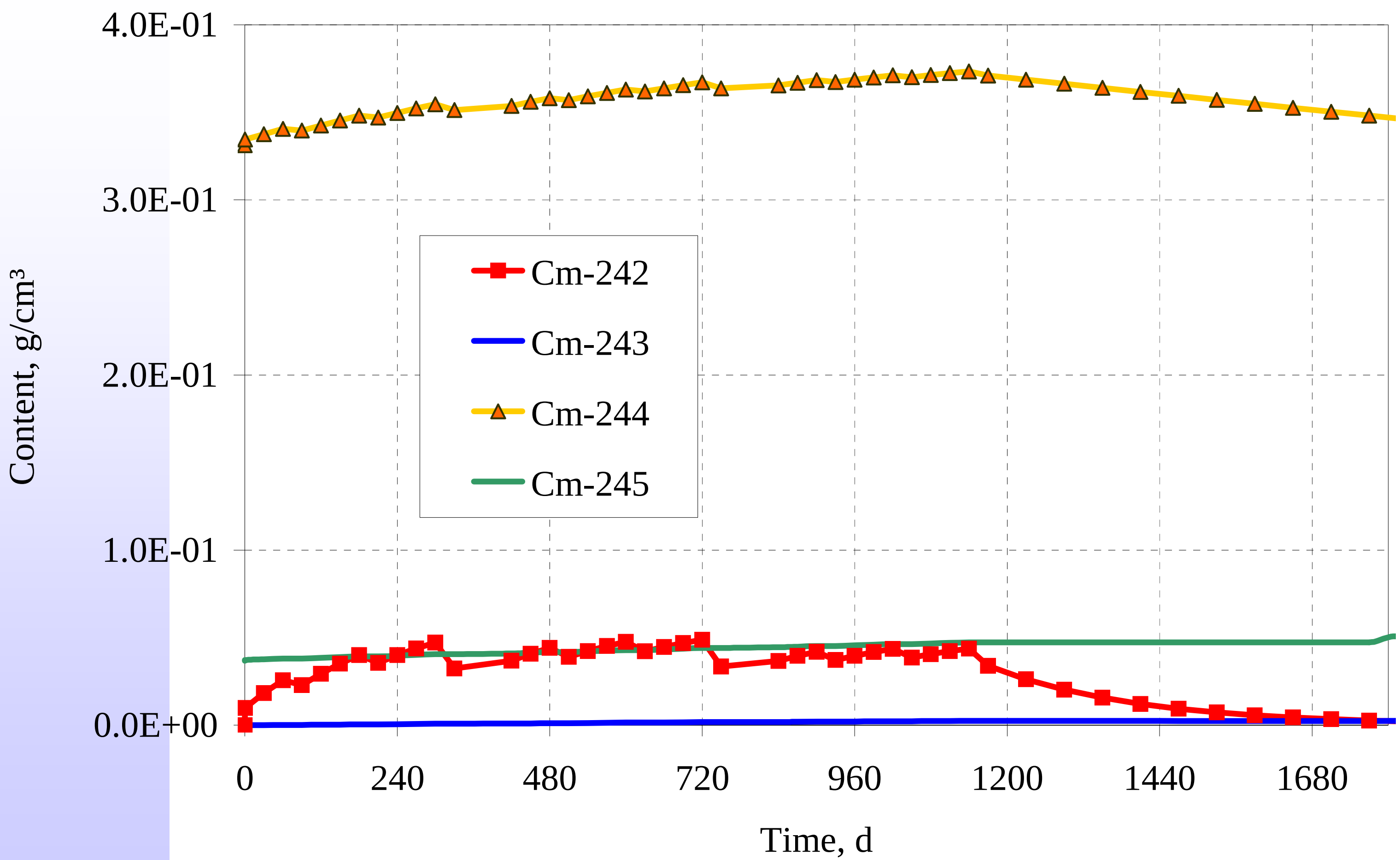
4.5. Results of modeling:
Am-isotopes content



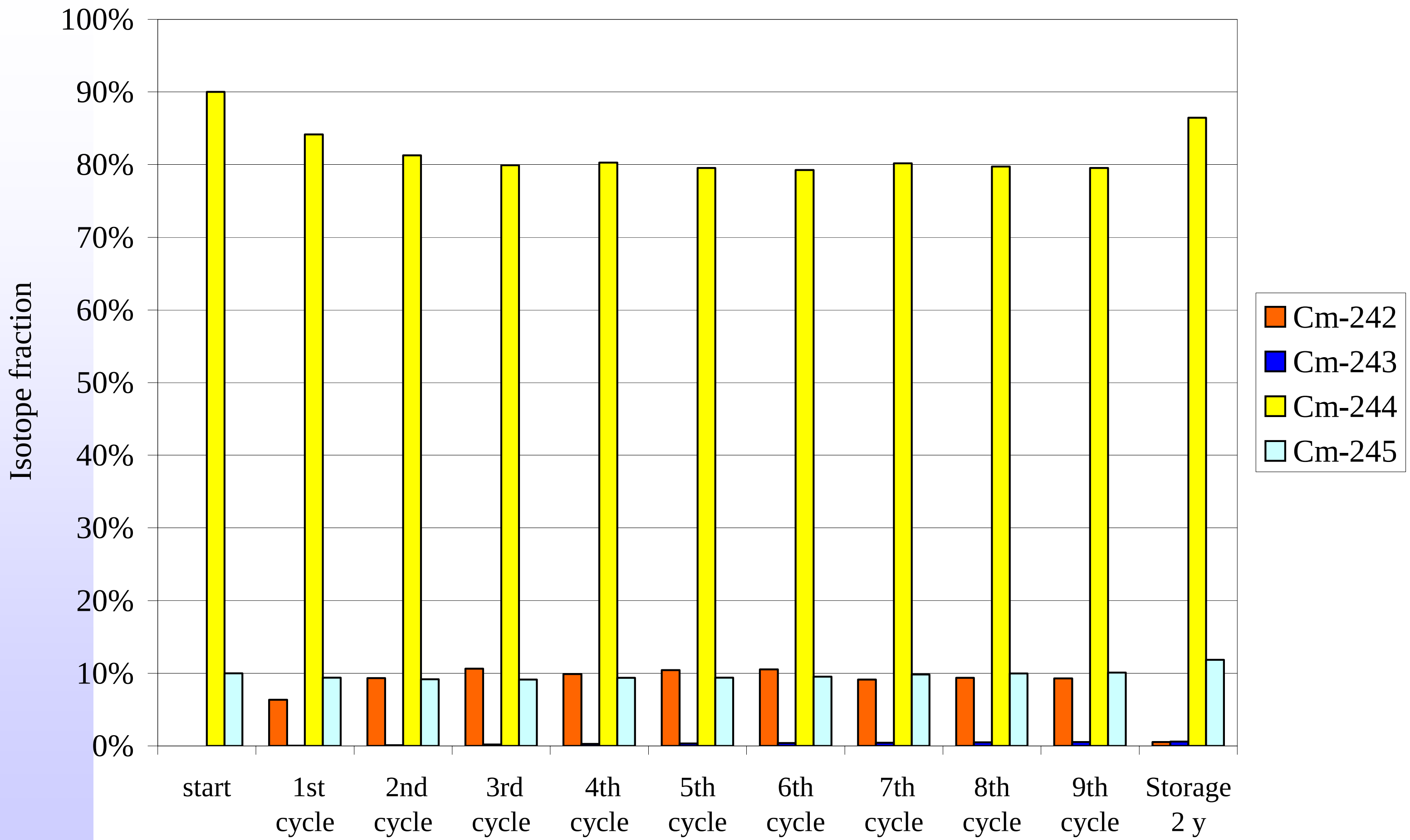
4.6. Results of modeling:
Am isotopic composition



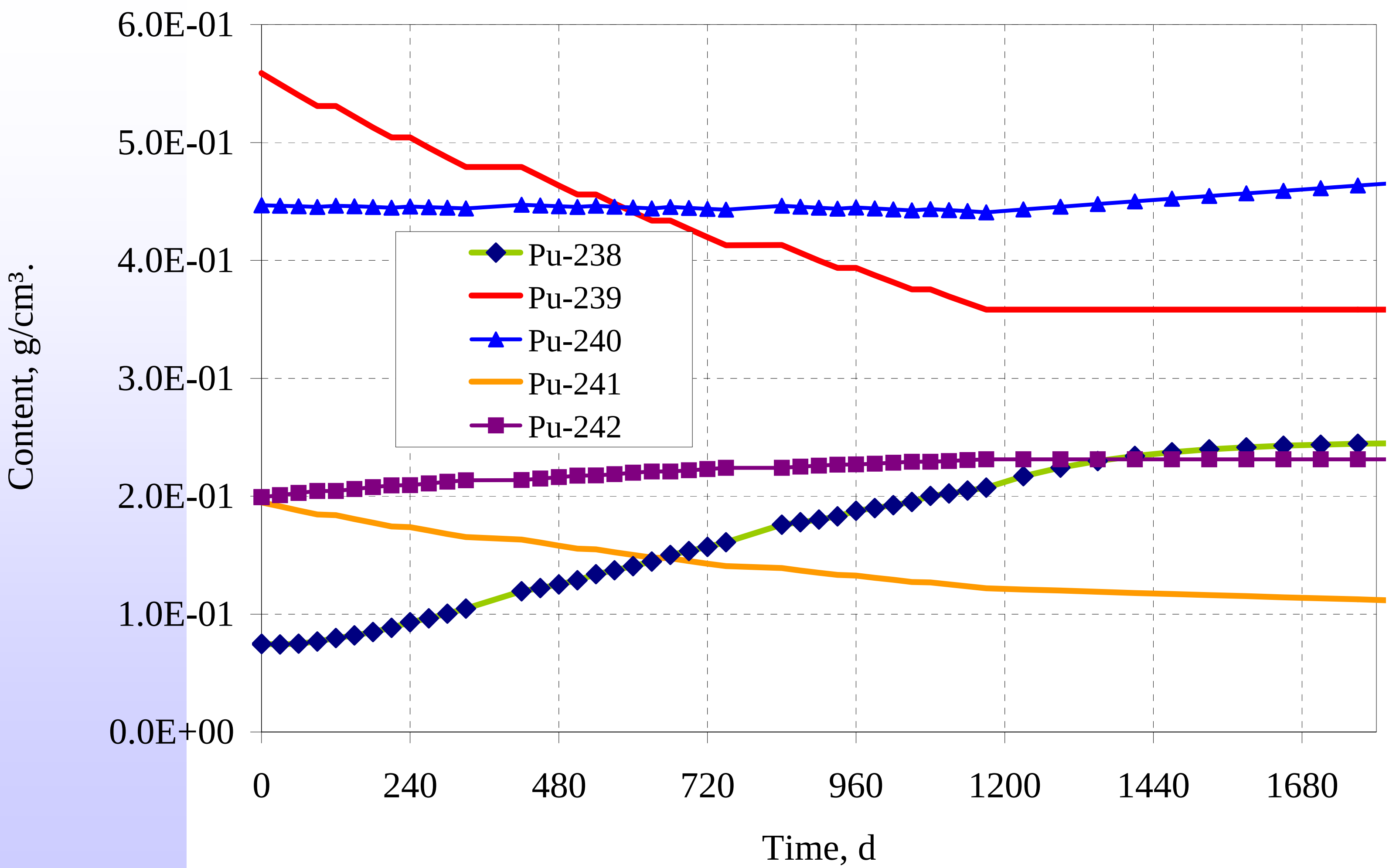
4.7. Results of modeling:
Cm-isotopes content



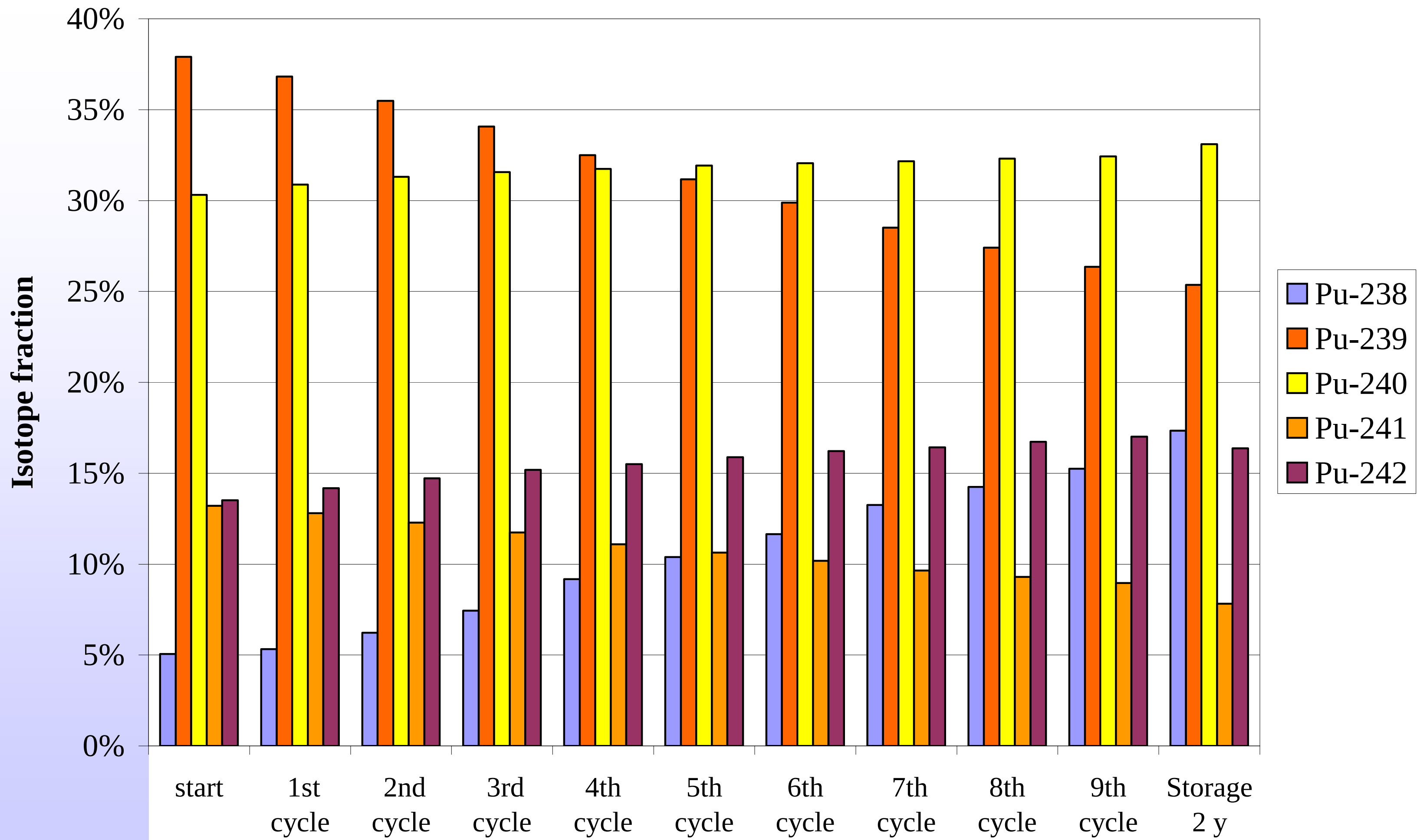
4.8. Results of modeling:
Cm isotopic composition



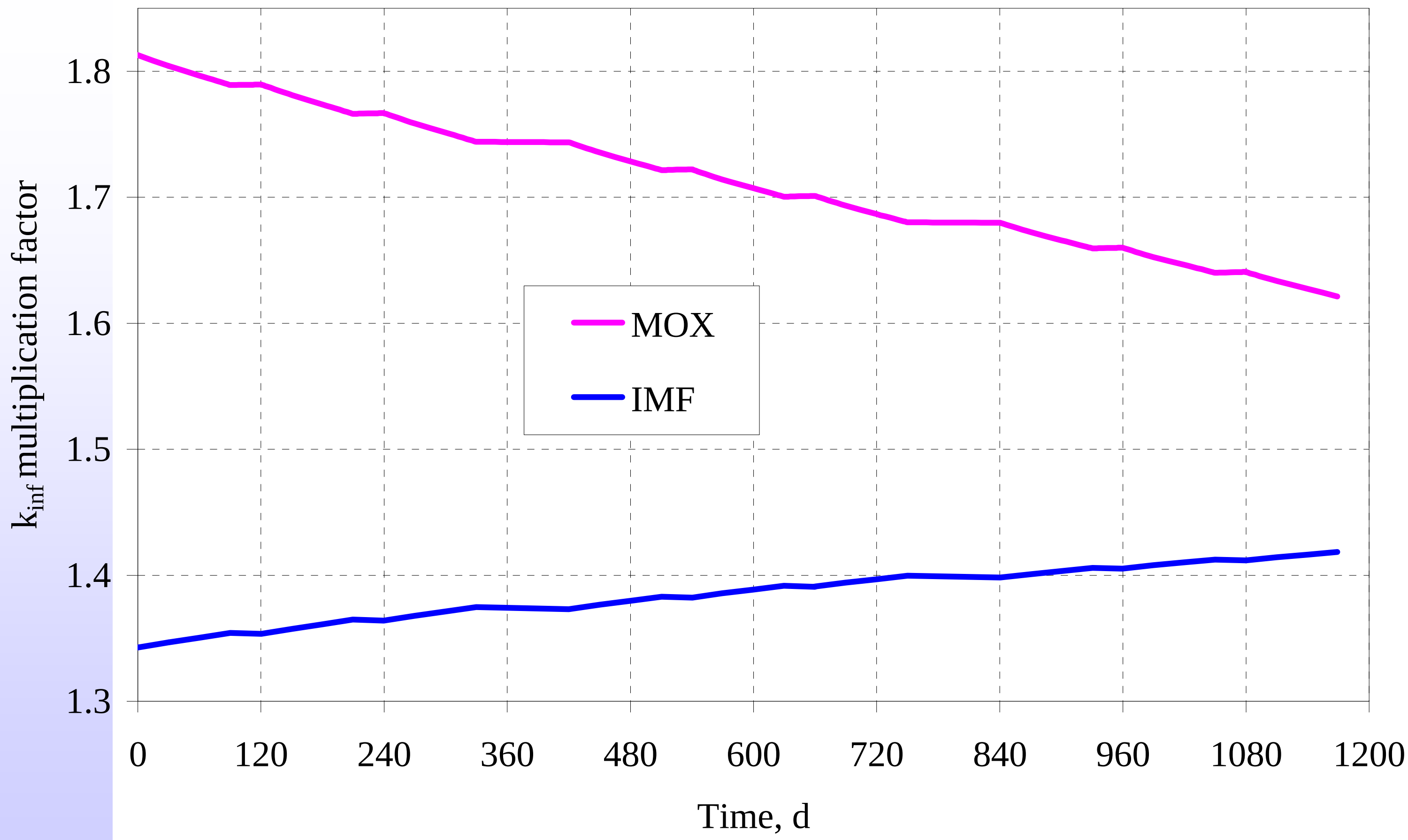
4.9. Results of modeling:
Pu-isotopes content



4.10. Results of modeling:
Pu isotopic composition



4.11. Results of modeling: k_{∞}



4.12. Results of modeling:
Actinide mass balance

Mass in grams

	$t_{1/2}$	m0(BOL) 3A+3D	Δm1=m1(EOI)-m(BOL) 3 A	Δm1=m1(EOI)-m(BOL) 3 D	Δm2=m2(EOS)-m1(EOI) 3 A	Δm2=m2(EOS)-m1(EOI) 3 D	(Δm1+Δm2)/m0(BOL) 3 A	(Δm1+Δm2)/m0(BOL) 3 D
Pu-238	**87.7 y**	366	326	333	93	92	229%	232%
Pu-239	**$2.4 \cdot 10^4$ y**	2744	-493	-479			-35.9%	-34.9%
Pu-240	**6550 y**	2194	-15	-14	66	63	4.7%	4.4%
Pu-241	**14.4 y**	956	-179	-174	-27	-29	-43.2%	-42.6%
Pu-242	**$3.76 \cdot 10^5$ y**	978	79	87			16.1%	17.8%
Pu		**7237**	**-282**	**-232**	**132**	**120**	**-4.1%**	**-3.1%**
Am-241	**433 y**	6030	-1025	-915	21	22	-33.3%	-29.6%
Am-242	**16 h; 141 y**		124	131	-2	-2	(122 g)	(129 g)
Am-243	**7370 y**	3014	-419	-359			-27.8%	-23.8%
Am		**9044**	**-1319**	**-1143**	**19**	**20**	**-28.8%**	**-24.8%**
Cm-242	**162.8 d**		107	104	-102	-99	(5.2 g)	(5.0 g)
Cm-243	**285 y**		6.1	5.9			(6.1 g)	(5.9 g)
Cm-244	**18.1 y**	1626	103.7	74.3	-68	-60	4.4%	1.8%
Cm-245	**8500 y**	180.7	25.9	22.2			28.6%	24.5%
Cm-246	**4730 y**		5.8	5.6			(5.8 g)	(5.6 g)
Cm		**1807**	**249**	**212**	**-170**	**-158**	**8.7%**	**5.9%**
All actinides		**18088**	**-1352**	**-1162**	**-19**	**-18**	**-15.2%**	**-13.1%**

5. Conclusions (I)

- Studies of possibilities of the MA transmutation in the subcritical ADS MYRRHA are under way at SCK·CEN.

- A code system ALEPH has been developed for the burnup-depletion calculations in the MYRRHA core, and is under validation and testing.

- The evolution of the composition of CERCER IMF with $Cm_{0.1}Am_{0.5}Pu_{0.4}O_{1.88}$ fuel and MgO matrix, placed into two different positions of the fast core for 9 operation cycles (810 EFPD) followed by 2 years storage, have been modelled with ALEPH.

5. Conclusions (II)

- The net actinide destruction is 2.55 kg over the initial amount of 18.1 kg. The mass decrease of 26.8 % is observed for Am, whereas a mass increase of 7.3 % for Cm.
- He generated in the MA fuels contributes significantly to the rare gas production during operation as well as in storage and can affect significantly fuel properties. The amount of the produced He is ~ 1.5 times higher than Xe+Kr at the end of irradiation and 2.2 times higher after the storage.
- A more detailed analysis aiming at optimisation of the design of the MA fuel targets and of the burning strategy is in progress.