DRN PROGRAM ON LONG-LIVED WASTE TRANSMUTATION STUDIES : TRANSMUTATION POTENTIAL OF CURRENT AND INNOVATIVE SYSTEMS

M. Salvatores, A. Zaetta, C. Girard, M. Delpech,
I. Slessarev, J. Tommasi
(CEA/DRN, CEA/DRN/DER/SPRC)

DRN PROGRAM ON LONG - LIVED WASTE TRANSMUTATION STUDIES : TRANSMUTATION POTENTIAL OF CURRENT AND INNOVATIVE SYSTEMS

M. Salvatores*, A. Zaetta**, C. Girard**, M. Delpech**, 1. Slessarev**, J. Tommasi**
• CEA/DRN ** CEA/DRN/DER/SPRC

1. INTRODUCTION

The DRN program on nuclear waste transmutation is a part of the SPIN program [Ref. 1] aimed at comparing feasibility and performances of long - lived waste transmutation in reactors and innovative systems. This program includes researches to improve and validate data and codes, to evaluate the transmutation potential of different systems, to develop fuels and targets devoted to transmutation.

The goal of transmutation is to reduce the risk due to nuclear waste, risk characterized here by the potential radiotoxicity which is based on well - known parameters (mass, activities) and less precise hazardous factors.

Two main transmutation issues will be addressed, namely :

- a theoretical evaluation of the transmutation potential related to the neutron balance,
- parametric studies of the transmutation efficiency taking in account other constraints (safety, fuel cycle, partitioning performances, realistic scenarios).

il. TRANSMUTATION POTENTIAL

Transmutation potential refers to the full transmutation of transuranians and long - lived fission products in stable or short - lived nuclei. Transmutation of one isotope in a neutron field has to be associated to the transmutation of the whole isotope family. To evaluate the transmutation potential, the number of neutrons needed for the full transmutation is compared to the number of neutrons available for this purpose in the system.

The neutron consumption D_A for the full transmutation of a nucleus A could be represented by and algorithm taking into account all the transmutation and decay reactions for the A family [Ref. 2, 3]. A negative value of D_A means that A has a surplus of neutrons to support (partially or fully) the own needs of the installation or to transmute other nuclei as needed.

Calculations of D for U and TRU with different neutron flux and neutron spectra show that the best way to decrease D is by hardening the neutron spectrum, see figure 1. D is negative for all isotopes in fast reactor spectra but positive for many of them in LWR spectra, (see table 1). Most of the nuclei tend to have a decreased D when ϕ increases with different slopes that are more pronounced for thermal spectra.

For long - lived fission products, the neutron consumption is high even with isotopic separation.

The neutron surplus G available in a reactor is equal to (-D fuel -De), Dc being required for parasitic absorption and leakage (Dc ≈ 0,3 n/fission). The transmutation potential for A is shown by the number of A transmutations per fission $r_A = \frac{G}{DA}$. The transmutation rate is proportional to r_A and to the power.

For an hybrid system an additional neutron source μ is added to the neutron surplus in the subcritical system as defined here. A high value of μ will be achieved with a high subcriticality and an intense proton current. In this case the transmutation potential will be shown by $\frac{G + \mu}{DA}$.

A small surplus of neutrons (G ≈ 0,1 n/fission) is obtained in LWRS only if the fuel enrichment is increased ; furthermore the transmutation rate is small. G is higher in FRs (G ≈ 0,32 n/fission) for a standard oxide type reactor with a breeding ratio for TRU ≈ 1 and increases for the metallic fuel (G ≈ 0,45) and when the BR is close to O (G ≈ 1 n/fission). For hybrids G is higher the maximum value being obtained in fast neutron spectra. Table 2 gives G values for different characteristics of the hybrid system.

III. PARAMETRIC STUDIES

Parametric studies on transmutation of Pu, minor actinides and fission products are mncemed by an evaluation of the radiotoxicity reduction which can be obtained taking into accounts “realistic” scenarios.

Multirecycling of Pu is needed which gives a striking advantage to fast neutron reactors (with 3 recycles in the same conditions the radiotoxicity is divided by 2 in LWRS, by 7 in FRs) and makes the gain very sensitive to losses (for a one - through LWR radiotoxicity would be divided by 4).

To obtain the best results minor actinides have to be recycled in fast reactors and in different ways (homogeneously in the core for Np, in the blanket for Am and ^{245}Cm, the other isotopes being left to decay on Pu isotopes and then recycled in the Pu flux).

These strategies applied to a nuclear park (see figure 2) gives a benefit on the radiotoxicity source comprised between a factor of 40 and 80.

Some results were obtained for fission products recycled in a moderated subassembly at the periphery of a standard fast reactor [4]. Studies were done also with and hybrid system with a molten salt subcritical core using $[\{TRU_{UOX-LWR}\} Cl_3 + Pb\, Cl_3]$ both as spallation source and

TABLE 1

Neutron Consumption Values for LWR Discharge at Standard Burnup

TRu Content	Fuel Component Fraction	Fast Reactor (Oxide Fuel) Spectrum		Standard LWR Thermal Spectrum	
		Flux. 4 (n/cm²·s)			
		10^{15}	10^{17}	10^{14}	$10^{’6}$
^{238}Pu	0.025	-1.36	-1.49	0.17	0.042
^{239}Pu	0.476	-1.46	-1.51	-0.67	-0.79
^{240}Pu	0.214	-o.%	-1.18	0.44	0.035
^{241}Pu	0.107	-1.24	-1.60	-0.56.--	-0.91
^{242}Pu	0.069	-0.44	-0.7s	1.76	1.10
^{237}Np	0.054	-0.59	-0.72	1.12	0.53
^{241}Am	0.033	-0.62	-0.78	1.12	0.076
^{242}Am	0.047	-1.36	-1.54	0.15	-0.88
241 Am	0.016	-0.60	-1.07	0.s2	0.16
^{243}Cm	0.049	-2.13	-2.26	-1.9	-2.04
^{244}Cm	0.006	-1.39	-1.92	-0.15	-0.53
^{245}Cm	---	-2.51	-2.50	-1.48	-1.46
D_{TRU}		-1.17	-1.33	-0.0s0	-0.35
$D_{TRPu+Np}$		-0.70	-0.9	1.1	0.3
D_{Pu}		-1.1	-1.2	-0.20	-0.40

Table 2: G Values for hybrids

	Fast Spectrum ($\Phi = 10^{15}$ n/cm^2·s)			
	Fuel: Metallic TRU, No ^{238}U	**Fuel: Metallic** ^{238}U	Fuel: Oxide **TRPu,** *No* ^{238}U	**Fuel: Metallic** ^{238}U
Fuel cycle type	**Open**	closed	**Open**	*closed*
G	1.3	0.75	0.73	1.4
k_{eff}	0.90	0.93	0.90	0.75
f	0.25	0.25	0.25	0.70
I (A)/ *W* [GW(thermal)]	0.003	0.003	0.003	**0.09**
For **reference**	H3	H4	**H5**	H6

Fig. 1. Neutron consumption as a function of neutron flux level in typical spectra : ^{237}Np

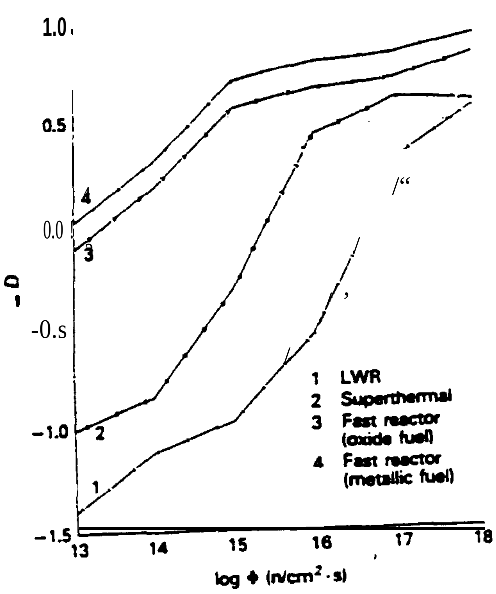
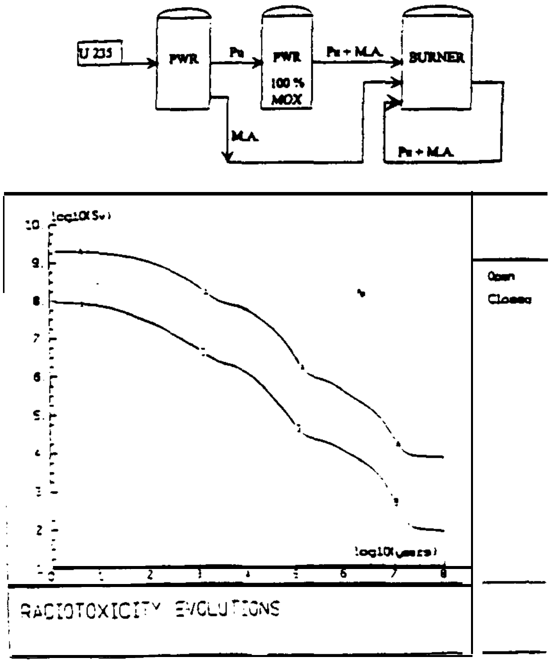


Fig. 2. (Pu + Np + Am + Cm) BALANCED SCENARIO



multiplying medium. For a core power of 3 000 MWth, Keff = 0,95, proton beam current I = 75 mA, Ep = 1,6 GeV and f (fraction of energy used to feed the accelerator) = 0,2, a transmutation rate of Tc 99 (introduced as targets in the core) of 0.7 tons/year has been found. More studies are underway to further detail the potential of hybrid systems for a larger range of long - lived fission products.

REFERENCES

1/ M. Salvatores et al. "The SPIN program at CEA : Transmutation aspects" Proc. GLOBAL'93 Conference, Vol 1, p 548 (1993).

2/ M. Salvatores, 1. Slessarev, M. Uenatsu. 'A global physics approach to radioactive nuclei transmutation" Nucl. Sci. Eng., January (1994).

3/ 1. Slessarev et al. "Transmutation potential of current and innovative nuclear power system". GLOBAL'93 Conference, Vol 2, p 1044 (1993).

4/ J. Tommasi, P. Coulon. "PHENIX experiment facilities for fission product destruction and actinide burning". GLOBAL'93 Conference, Vol 1, p 475 (1993).