Nuclear Development

Accelerator-driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles

A Comparative Study

NUCLEAR ENERGY AGENCY
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Annex E

COMPARISON OF MA TRANSMUTATION EFFECTIVENESS IN DIFFERENT FUELS AND COOLANT SYSTEMS

The MA transmutation characteristics (in terms of transmutation effectiveness) in conventional MOX-type fuel, sodium-cooled fast reactor cores were described in detail in the OECD/NEA P&T Phase 1 report "Status and Assessment Report of Actinide and Fission Product Partitioning and Transmutation" (1999) [1]. Recently, a feasibility study for different fuels and coolant systems was performed in Japan. The objective of the feasibility study was to establish FR and related fuel cycle technologies with the following targets:

- Economic competitiveness as an energy production system.
- Effective utilisation of uranium resources.
- Reduction of radioactive waste.
- Security of non-against proliferation.

In this addendum, the MA transmutation effectiveness in FRs with different types of fuels and coolants is compared quantitatively.

E.1 Fuel-types

Three types of FR fuel, oxide, nitride and metal were considered. In this kind of comparison, it is desirable to make a consistent and fair evaluation. Since MA transmutation in power FRs is assumed here, the performance as power generation system should be made equivalent for each fuel-type core. The core parameters fixed here were: reactor thermal power, operation cycle length, refuelling batch number, spent fuel burn-up, core height and blanket thickness. The design criteria which must be satisfied from a realistic viewpoint are: reactivity at the end of equilibrium cycle, positive burn-up reactivity loss, maximum linear heat rating of fuel pin, and pressure drop at fuel bundle.

Figure E.1 shows the 1 000 MWe-class MOX-fuelled FR core as the reference of the study. Fuel-types changed were $(U,Pu)O_{1.98}$ as oxide, $(U, Pu)^{15}N$ as nitride, and U-Pu-10Zr as metal fuel. The core specifications of each fuel-type core are summarised in Table E.1.

The MA composition to be loaded is assumed to come from the reprocessing of LWR-spent fuel, 35 GWd/t, after 5-year cooling, i.e.:

$$^{237}Np/^{241}Am/^{242m}Am/^{243}Am/^{243}Cm/^{244}Cm/^{245}Cm = 49.1\%/30.0\%/0.08\%/15.5\%/0.05\%/5.0\%/0.26\%$$

Table E.2 shows the evaluated MA transmutation effectiveness of each fuel-type core where MA was loaded at 5 weight% of total fuel. The total transmutation effectiveness of nitride and metal-fuelled cores is 9.9% and 9.7% per year, respectively, both a little better than that of oxide-fuelled core. The difference can be attributed to the harder neutron spectrum of the new fuel-type cores. Figure E.2 shows the dependence of MA transmutation on loading with MA for each fuel-type core. The slight superiority of nitride and metal fuel to oxide can be seen again, but the difference is rather insignificant, compared with the dependencey to on MA loadinged.

Figure E.1. **1 000 MWe MOX-fuelled FR core**

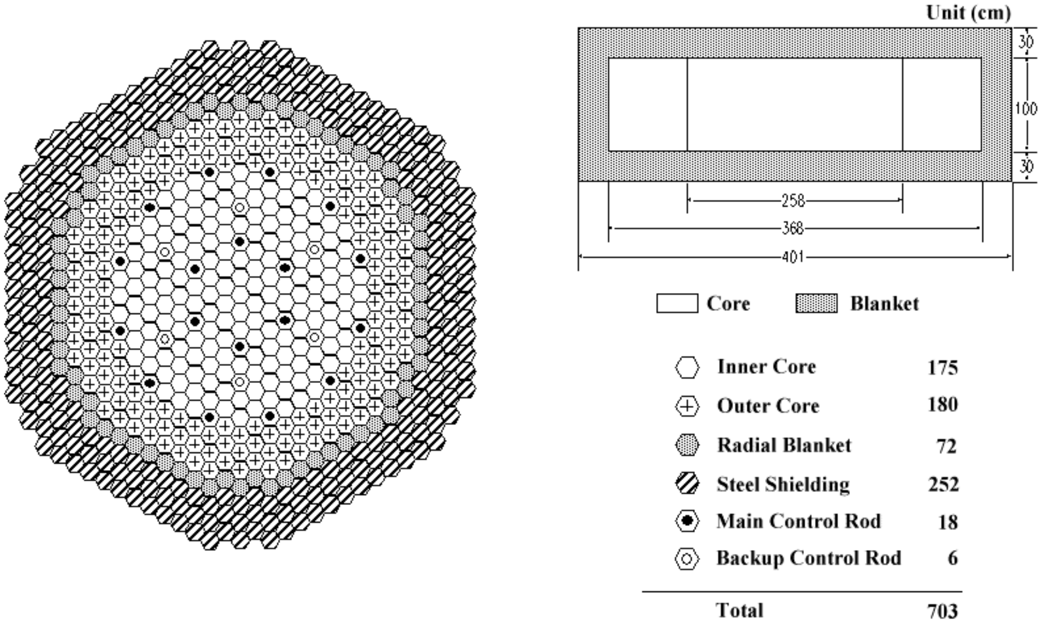


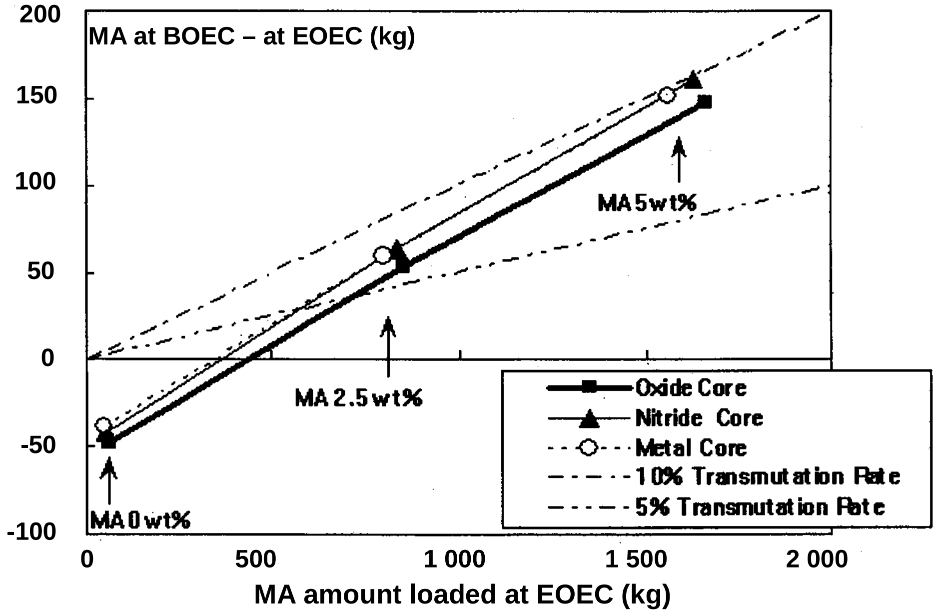
Table E.1. **Major specifications of different fuel-type cores**

Item	Specification		
	Oxide core	Nitride core	Metal core
Thermal out-put	2 600 MWth	2 600 MWth	2 600 MWth
Operation cycle length	12 EFPM	12 EFPM	12 EFPM
Refuelling batch number	3 batches	3 batches	3 batches
Core height	100 cm	100 cm	100 cm
Core equivalent diameter	368 cm	346 cm	348 cm
A/B thickness (upper/lower)	30 cm/30 cm	30 cm/30 cm	30 cm/30 cm
Fuel type	$(U, Pu)O_{1.98}$	$(U, Pu)^{15}N$	U-Pu-10Zr
Fuel smear density	87.6%TD	80%TD	75%TD
Fuel pin outer diameter	8.3 mm	8.7 mm	8.5 mm
Cladding thickness	0.4 mm	0.42 mm	0.41 mm
Number of fuel pins per fuel sub-assembly	271	271	271
Fuel sub-assembly pitch	179.8 mm	197.0 mm	198.2 mm
Number of fuel subassembly (inner/outer)	175/180	126/130	126/130
Pu enrichment (inner/outer)	15.3%/19.0%	12.3%/16.2%	12.2%/16.5%
Spent fuel average burn-up rate	73.6 GWd/t	73.2 GWd/t	75.4 GWd/t
Burn-up reactivity loss per cycle	1.96%dk/kk’	0.31%dk/kk’	0.57%dk/kk’
Peak linear heat rate (without 3-dim. Effect)	381 W/cm	530 W/cm	508 W/cm
Breeding ratio	1.22	1.35	1.34
Pressure drop at fuel bundle	3.4 kg/cm^2	2.3 kg/cm^2	2.4 kg/cm^2

Table E.2. **MA transmutation performance of different fuel-type cores (Loaded MA: 5 weight% of total fuel)**

Element	**Oxide core**			**Nitride core**			**Metal core**		
	Transmutation			Transmutation			Transmutation		
	Initial amount at BOEC (kg)	Amount (kg)	Effectiveness (%)	Initial amount at BOEC (kg)	Amount (kg)	Effectiveness (%)	Initial amount at BOEC (kg)	Amount (kg)	Effectiveness (%)
Np	764	112	14.7	756	114	15.1	728	105	14.4
Am	746	72	9.7	728	83	11.4	695	78	11.3
Cm	150	-38	-25.4	148	-36	-24.4	139	-32	-23.1
MA total	1 659	147	8.8	1 631	161	9.9	1 562	151	9.7

Figure E.2. **MA transmutation effectiveness**



E.2 Coolant types

Three types of coolant (sodium, lead and gas) were compared with respect to their impact on MA transmutation effectiveness. Since it is quite difficult to make the parametric comparison strictly due to their different characteristics of density and thermal conductivity, existing typical reactor designs with these coolants were considered in the survey: a sodium-cooled fast reactor of commercial size, a lead-cooled reactor of BREST-300 type [2] and a CO_2 gas-cooled reactor of ETGBR-type [3]. Major design specifications of these cores are summarised in Table E.3. Although there are many differences in design parameters including thermal power, operation cycle length and fuel-type etc. besides coolant type, a rough evaluation of MA transmutation characteristics may be possible by normalising the results with respect to thermal power and operating period. MA composition loaded in this survey is the same as in the fuel-type survey above. Figure E.3 is the comparison of neutron spectrum among these different coolant-type cores. On the whole, all cores have a fast reactor spectrum with a peak energy around several hundred keVs, where some differences can be found caused by coolant-type. The gas-cooled reactor has the hardest spectrum among the three coolants, because of its very low moderating capability. On the other hand, the lead-coolant core shows special features. Above 1 MeV, the neutron flux reduces owing to the large inelastic cross-section of lead. Below 100 keV, the neutron spectrum is also smaller than that of sodium, as lead shows a lower moderating capability due to the heavy atomic mass. From the comparison of neutron spectrum, a gas-cooled core might be more favourable from a MA transmutation viewpoint, and sodium and lead-cooled cores might be equivalent.

Table E.3 summarises the MA transmutation effectiveness of each coolant-type core. After normalisation, the MA transmutation effectiveness of these cores is almost identical with a value of 7.5-7.7% per year. Figure E.4 shows the dependence of MA transmutation effectiveness on MA loading for each coolant- type after normalisation. The ratio of transmuted MA to loading is a little worse in the case of lead-coolant, but the difference is rather small compared with the dependency to other core parameters like core-fuel inventory which is not directly connected with coolant-types. As a conclusion, the effect of coolant choice in FR design will be negligible from the viewpoint of the MA transmutation.

Table E.3. **Major specifications of different coolant-type cores**

Item	**Specification**		
	Sodium-cooled core (Commercial type)	Lead-cooled core (BREST-300 type)	CO_2 gas-cooled core (ETGBR type)
Thermal out-put	3 800 $\mathrm{MW_{th}}$	700 $\mathrm{MW_{th}}$	3 600 $\mathrm{MW_{th}}$
Operation cycle length	540 days	284 days	344 days
Refuelling batch number	5 batches	5 batches	5 batches
Core height	120 cm	110 cm	150 cm
Core equivalent diameter	457 cm	230 cm	456 cm
Fuel type	Oxide	Nitride	Oxide
Pu vector (^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu/^{241}Am/^{242m}Am/^{243}Am)	3/52/27/9.5/1/5/0/0	0.5/64/28/3.1/1.7/2.1/0.1/0.5	1.9/53/26/9.9/7.9 1.5/0/0
Fuel pin outer diameter (inner/middle/outer)	9.7/-/9.7 mm	9.1/9.6/10.4 mm	8.2/–/8.2 mm
Pu enrichment (inner/middle/outer)	17.8/–/19.8%	14.0/14.0/14.0%	18.7/–/26.7%
Number of fuel pins per fuel subassembly (F/S)	271	114	169
Fuel subassembly pitch	195.4 mm	149.6 mm	180.6 mm
Number of F/S (inner/middle/outer)	264/–/198	57/72/56	334/–/216
Spent fuel average burn-up rate	15.43 GWd/t	62.4 GWd/t	115.1 GWd/t
Burn-up reactivity loss per cycle	2.92%dk/kk'	0.04%dk/kk'	2.35%dk/kk'
Peak linear heat rate (without 3-dim. effect)	370 W/cm	313W/cm	320 W/cm
Breeding ratio	1.04	1.03	1.01
Pressure drop at fuel bundle	3 kg/cm^2	1 kg/cm^2	4 kg/cm^2

Table E.4. **MA transmutation performance of different coolant-type cores (Loaded MA: 5 weight% of total fuel)**

Element	**Sodium-cooled core (Commercial type)**			**Lead-cooled core (Brest-300 type)**			**CO_2 gas cooled core (ETGBR type)**		
	Transmutation			Transmutation			Transmutation		
	Initial amount at BOEC (kg)	Amount (kg)	Effectiveness (%)	Initial amount at BOEC (kg)	Amount (kg)	Effectiveness (%)	Initial amount at BOEC (kg)	Amount (kg)	Effectiveness (%)
Np	1 058	201	19.0	326	28	8.5	961	118	12.3
Am	1 262	148	11.7	364	25	6.8	1 176	81	6.9
Cm	321	–52	–16.2	64	–8	–12.1	228	–34	–15.0
MA total	2 641	297	11.3	754	45	5.9	2 366	165	7.0
Normalised MA transmutation	695 kg per GWth	53 kg per GWth per year	7.6% per year	1 077 kg per GWth	83 kg per GWth per year	7.7% per year	657 kg per GWth	49 kg per GWth per year	7.5% per year

Figure E.3. **Comparison of neutron spectrum among different coolant type cores**

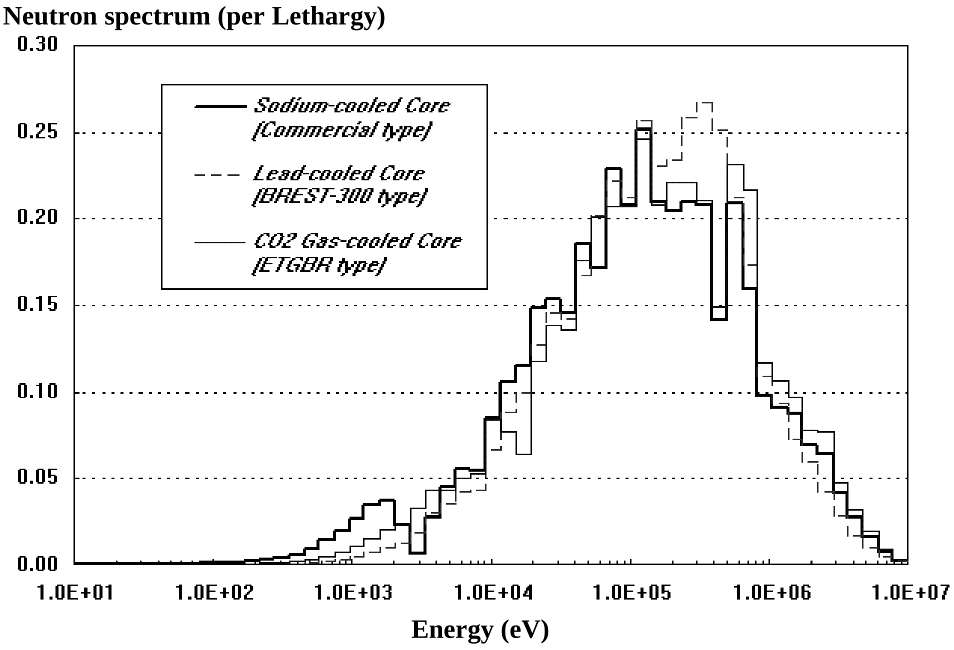
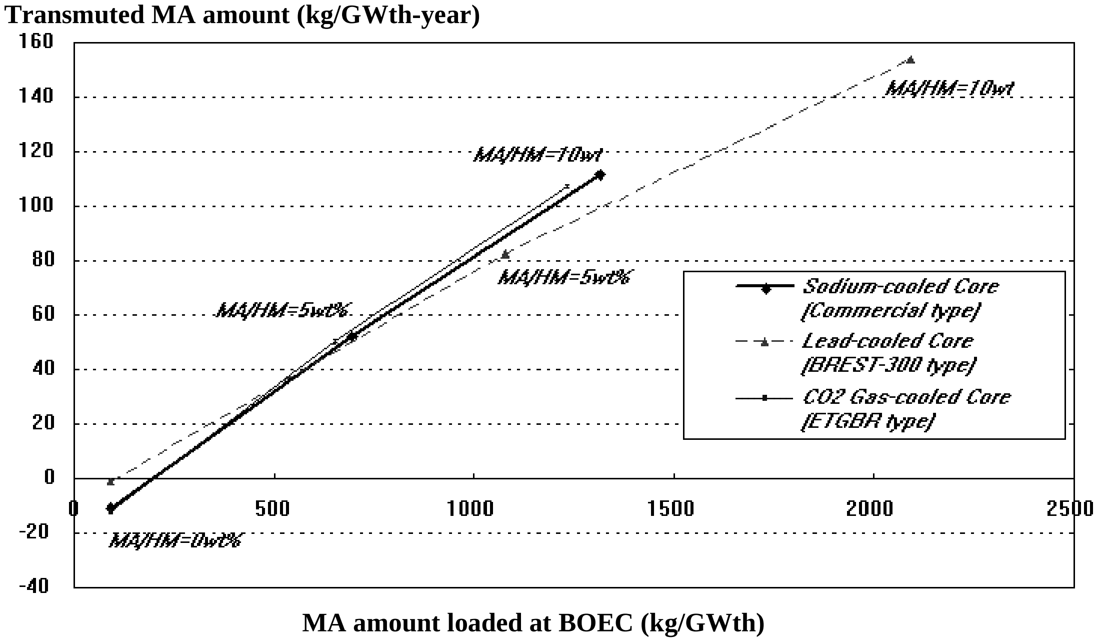


Figure E.4. **Dependence of MA transmutation effectiveness on MA loading for different coolants**



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[1] OECD/NEA, *Status and Assessment Report on Actinide and Fission Product Partitioning and Transmutation*, Paris, France, 1999.

[2] V.V. Orlov *et al.*, *Physical Characteristics of Lead Cooled Fast Reactor*, Proceedings of Topical Meeting on Advances in Reactor Physics, Vol. 1, Knoxville (USA), April 1994.

[3] R.B. Sunderland *et al.*, *A Gas-cooled Dedicated Minor Actinide Burning Fast Reactor: Initial Core Studies*, Proceedings of the International Conference on Future Nuclear Systems, Global'99, Jackson Hole (USA), September 1999.