NEUTRON PHYSICAL ANALYSIS OF SIX ENERGETIC FAST REACTORS

Peter Vertes
Hungarian Academy of Sciences, Centre for Energy Research

ABSTRACT

Numerous fast reactor constructions have been appeared world-wide in pages of institutes' reports. Most of them are benchmark exercise with complicated features. We shall examine 6 constructions: 5 sodium cooled and 1 lead cooled. Critical and dynamic parameters as well as their burnup are calculated and compared with each other. The computational tool is composed from NJOY, TRANSX, KENO and TIBSO programs.

Introduction

The basic composition of any fuel from the six cores is a typical composition of an LWR spent fuel, that is the main fissionable isotope in each reactor is the Pu239. Thus the main goals of our investigation are:

- To know whether a reactor can be operated with such composition
- To know whether the U238 left in the fuel can breed enough fissionables to maintain the criticality
- To know whether these systems are applicable to incineration of higher actinides.

The examined six reactors are the following:

1. Sodium cooled fast breeder with thorium blanket (FBR) [1]
2. Lead cooled fast reactor (Pb) [2]
3. Large carbide sodium cooled reactor (big-na) [3]
4. Large oxide sodium cooled reactor (big-ox) [3]
5. Medium metal sodium cooled reactor (midmet) [3]
6. Medium oxide sodium cooled reactor (mid-ox) [3]

Method of analysis

By means of the NJOY [4] and TRANSX [5] programs 80-group macroconstant libraries in GOXS format were prepared from ENDFB data files. Using a house made program this file is converted to AMPX working format from which library was made for KENOVI [6] Monte-Carlo critical code. The later code is a three-dimensional one, enabling the hexagonal geometry. Using this code no compromise in geometrical modeling is required.
Flux data are exhausted from the KENOVI results and burnup calculations are performed with TIBSO [7] code.

Core constructions, calculated parameters and burnup results

Any of the cores is composed from hexagonal assemblies. Pitch of assemblies differs from reactor to reactor and the dimension and number of fuel pins in assemblies are also different. The fuel compositions do not exhibit too much diversity. They are typical composition of spent LWR fuel. In some cases something of a sort of material is given in order to represent the fission products. In our calculation these were not always taken into account.
The vertical structure of fuel, control, shielding etc. assemblies is given in all cases. The whole reactor core with reflector and shielding are described in each case.
Details of the reactors follow.

Global parameters

reactor	power (MW_{th})	campaign (days)	Av. fuel temp.^{0}C	Moderator temp. °C	Amount of HM (kg)	Amount of Pu239 (kg)
FBR	1150	180	627	400	32066 (13446)*	1315
Pb	900	310	627	477	18153	957
big-na	3600	500	987	470	78464	6165
big-ox	3600	410	1227	432.5	76283	6615
midmet	1000	360	534	432.5	13130	1381
mid-ox	1000	360	1027	432.5	14765	1633

*with and without Th

Construction, dimensions (cm)

reactor	active length	assembly pitch	fuel radius	number of pins in ass.	number of fuel ass.
FBR	100	10.194	0,33	217	187
Pb	130.87	18.5026	0.44	204	192
big-na	100.56	20.9889	0.3319	469	487
big-ox	100.56	21.2205	0.4742	271	453
midmet	85.82	16.2471	0.3236	271	180
mid-ox	114.94	16.2471	0.3322	271	180

Results of criticality calculations

reactor	k_{eff}	β_{eff}(pcm)	Na void	doppler	control rod
FBR	1.1349	417	0.00725	-0.0031	9 rod 35cm in
Pb	0.9469	274	-------	-0.00147	320.837 inside
big-na	0.97672	448	0.0351	0.000876	withdrawn
big-ox	1.00419	289	0.0285	0.000972	withdrawn
midmet	0.97582	262	0.0282	0.000953	withdrawn
mid-ox	0.96976	308	0.0274	0.000200	withdrawn

Burnup steps (in days):
FBR – 18, Lead cooled: 15.5, large carbide: 25, large oxide: 20.5, medium metal and medium oxide: 16.25.

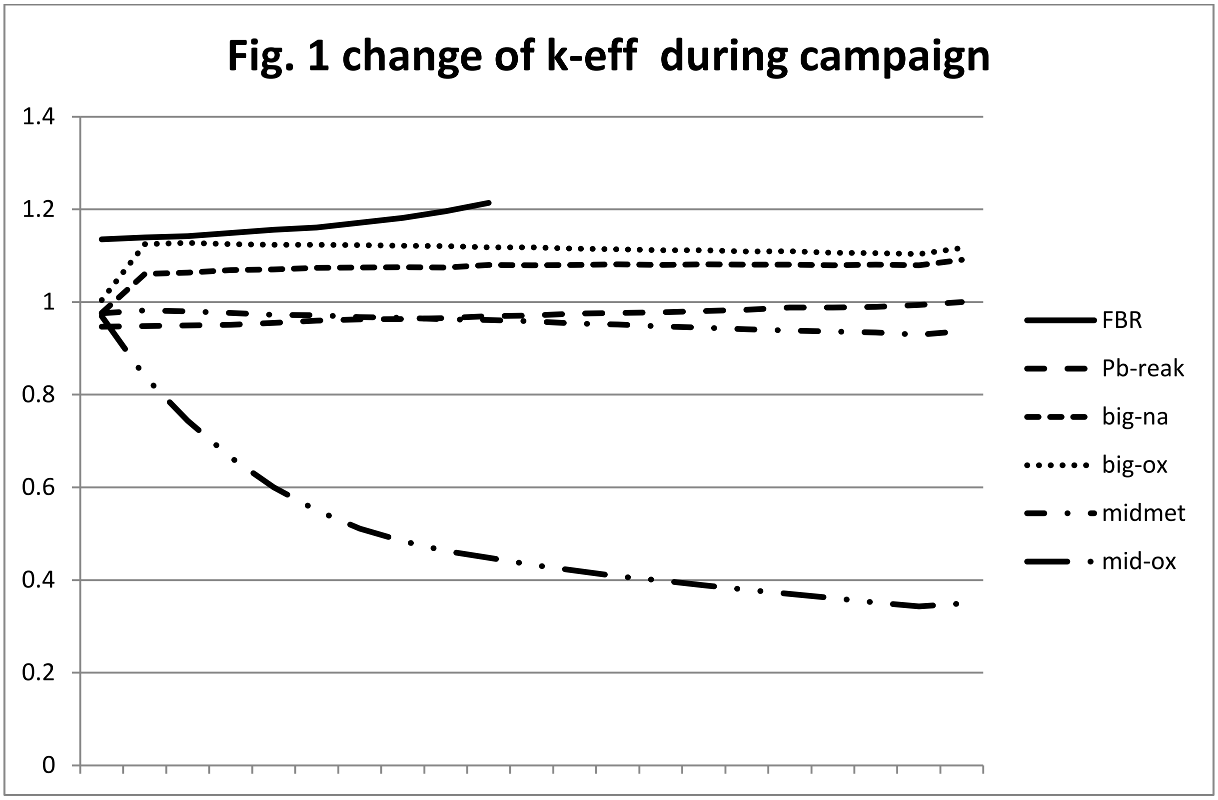


Fig. 1 change of k-eff during campaign

Fig. 2. Main fissionable during campaign

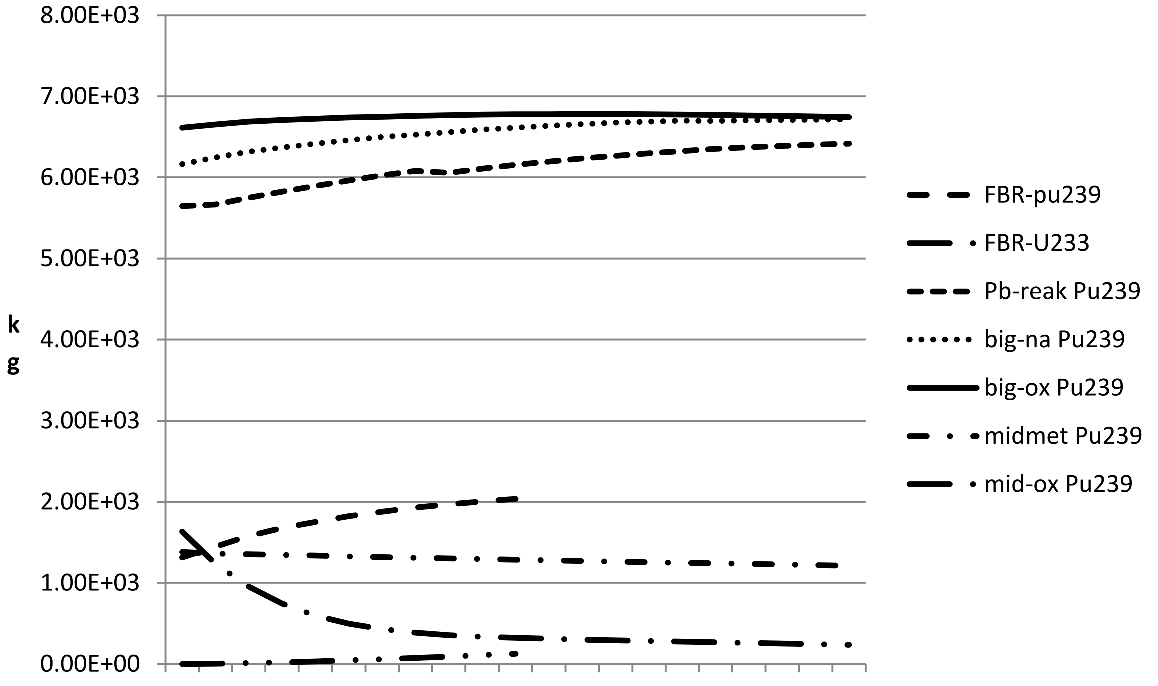


Fig. 3 Amount of plutonium during campaign

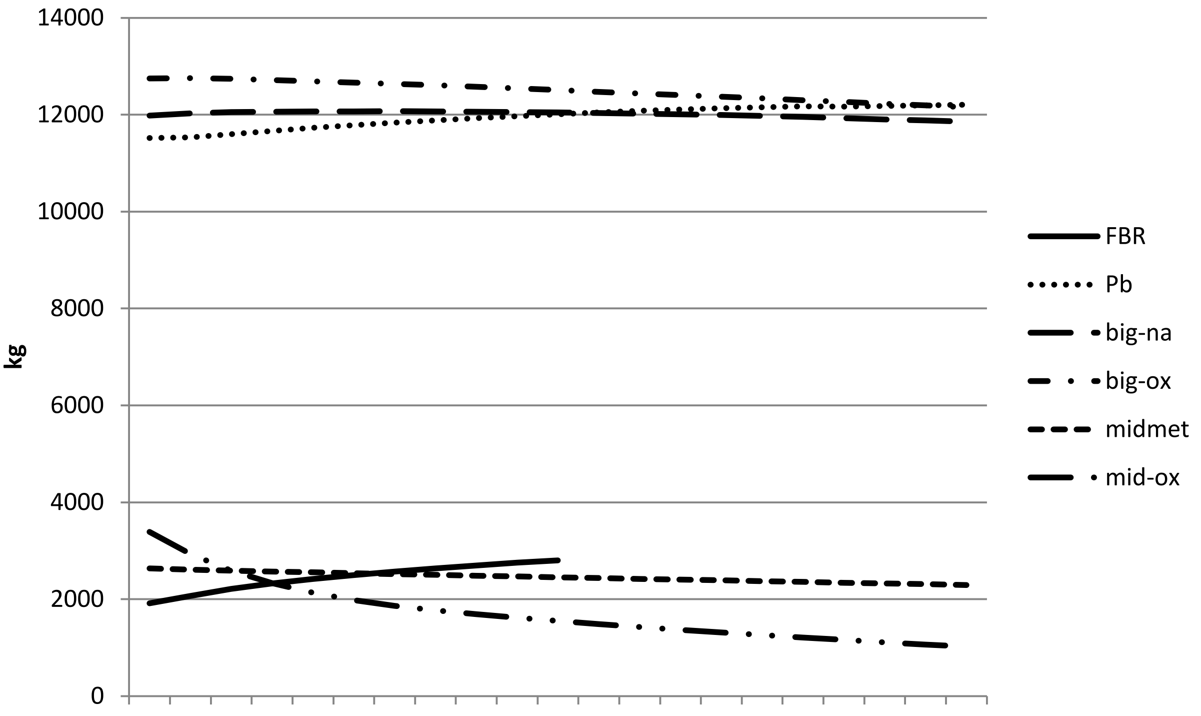


Fig. 4 Americium during campaign

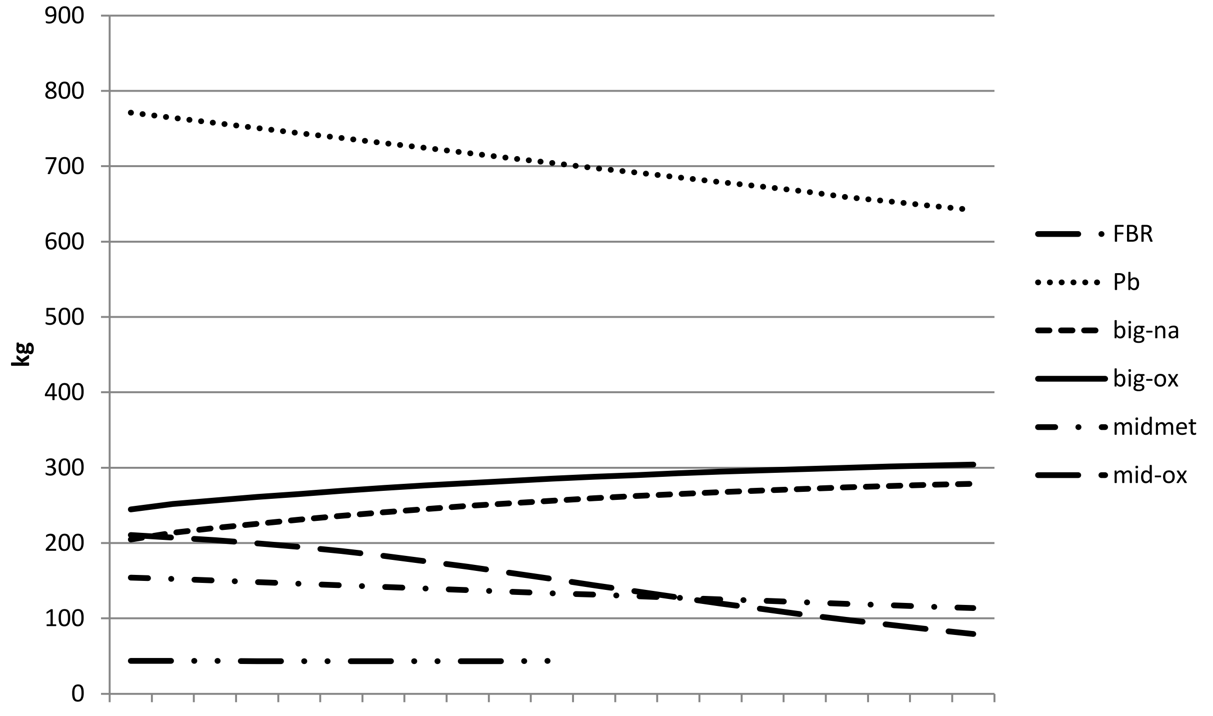
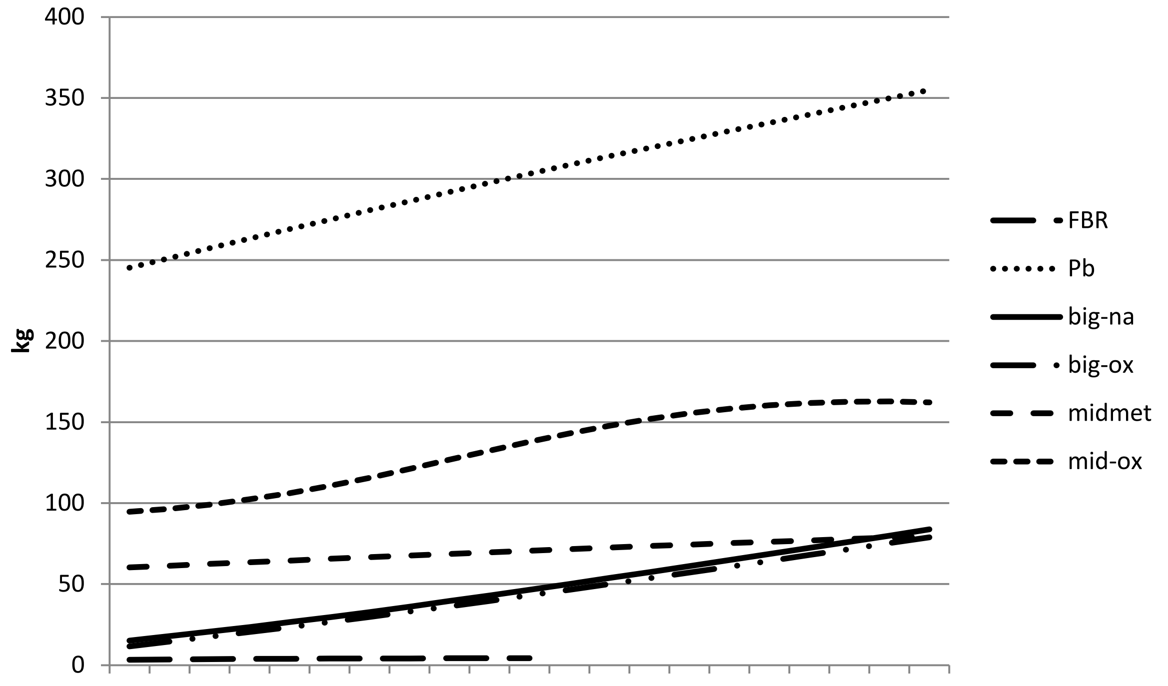


Fig. 5 Curium during campaign



Comparison of results obtained from ENDFB-VI and ENDFB-VII libraries, respectively

In order to demonstrate the effect of different basic cross-section libraries on calculated reactor parameters, results from ENFB-VI and ENDFB-VII are presented:

reactor	k_{eff}	β_{eff}(pcm)	Na void	doppler
FBR VI	1.1472	202	0.00720	-0.00136
FBR VII	1.1349	417	0.00725	-0.0031
Pb VI	0.9593	344	-------	0.00480
Pb VII	0.9469	274	-------	-0.00147
big-na VI	0.99131	555	0.0354	-0.00029
big-na VII	0.97672	448	0.0351	0.000876
big-ox VI	1.01566	479	0.0292	0.000573
big-ox VII	1.00419	289	0.0285	0.000972
midmet VI	0.98879	414	0.0268	-0.00107
midmet VII	0.97582	262	0.0282	0.000953
mid-ox VI	0.97729	271	0.0292	-6.041E-05
mid-ox VII	0.96976	308	0.0274	0.000200

It can be seen that the k_{eff}, β_{eff} and doppler remarkably depend on the library. Investigating this closer it turned out that all effect is due to the difference in U238 data.

Discussion

The criticality factors, except for the medium oxide reactor, are near 1 and in some cases increase. This means that the breeding of plutonium from uranium can cover the consumption Pu. This depends on the construction of reactor core which consequently has effect on the neutron spectrum and further on the burnup. This marks out from the fact though in the medium oxide reactor at BOC there is more Pu239 and uranium than in the medium metal one, the k_{eff} in the previous dynamically decreases.

The incineration capabilty of these reactor is very doubtful. For instance while in the lead cooled reactor the amount of americium decreases at the same time the amount of curium increases. For large reactors the amount of americium inreases and for medium reactor decreases. The amount of curium generally increases.

References

[1] G. Pandikumar et. al.: FBR model for incineration of Long-lived MA, 3rd RCM, Chennai, India; January 15-19, 2007

[2] S. J. Kim, Y.Kim, Lead-Cooled Fast Reactor Core Benchmark Description, IAEA CRP Meeting in Rez, September 29, 2003.

[3] David BLANCHET et al.: Sodium Fast Reactor Core Definitions, September 19, 2011

[4] R. E. MacFarlane, D.W. Muir, NJOY Nuclear Data Processing System, LA-12740, 1994

[5] R. E. MacFarlane, TRANSX 2: A Code for Interfacing MATXS Cross-Section Libraries to Nuclear Transport Codes, LA-12312-MS (July 1992)
[6] D. F. Hollenbach, L. M. Petrie, N. F. Landers, KENO-VI: A general quadratic version of the KENO program, ORNL/TM-2005/39 Version 5.1
[7] Vértes P. Multinodal treatment of production, decay and spreading of radioactive isotopes, Nuclear Technology 1999;128:124-130