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Nuclear Data Target Requirements for MA Burners

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G. Palmiotti
M. Salvatores

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Nuclear Data Target Accuracy Requirements for MA Burners, invited

G. Palmiotti, M. Salvatores[1, 2]

1-Idaho National Laboratory, 2525 Fremont Ave. P.O. Box 1625, Idaho Falls, ID 83415-3855 (USA, Giuseppe.Palmiotti@inl.gov

2- CEA-Cadarache

I. Nuclear Data Target Accuracy Assessment

Innovative fuel cycles, in particular those that require the introduction of TRU burners, present several potential feasibility issues, in particular in the field of the development of new fuels with a high MA content. Their definition, fabrication, performance under irradiation and reprocessing are crucial issues still under investigation. In this context, neutronics issues could seem to be of a lesser importance. However, key feasibility issues can arise in terms of nuclear data uncertainty impact, since safety and operation constraints can jeopardize specific fuel choices (e.g. maximum MA content) of potential interest.

Nuclear data requirements for innovative systems have been initially assessed, using sensitivity and uncertainty analysis and preliminary covariance data. Previous work was performed and preliminary indications were obtained [1]. The availability of more realistic uncertainty data allows a better target accuracy assessment. The present work improves previous evaluations in two respects: the method used is a more general one since it accounts for energy correlations in the definition of target accuracies [2] and it is based on a very recent release of new covariance data The AFCI 2.0 [3].

The present analysis is related to two typical TRU burner systems [1]. The first system, called SFR, is a Na-cooled, metal fuelled fast reactor loaded with TRU fuel of a composition as discharged by standard PWRs (i.e. Pu/MA ratio ~10). This is the typical composition of a TRU burner reactor when all TRUs are considered a potential waste.

The second system, called ADMAB, is a Pb-cooled nitride fuelled fast spectrum ADS; the fuel composition has a Pu/MA ratio close to one. This is a typical MA burner in a so-called double strata fuel cycle strategy where most of the Pu is considered a resource and recycled in LWRs (or FRs) and MA are loaded in the burner ADS together with some Pu that is needed to create a fuel such that the reactivity loss during the cycle stays approximately close to zero (and consequently, the accelerator proton current stays ~constant).

In Table I the uncertainty on k_{eff} of both SFR and ADMAB systems are shown together with the major components (i.e. isotope, reaction) of the overall uncertainty. These uncertainties are much higher than the expected design requirement (±0.3 %Δk/k). For both systems the uncertainties have a significant impact. As an example to account for the present uncertainty on the k_{eff} for the sub-critical system ADMAB (~±1.7 % Δk/k), it would be needed to increase the nominal design value of the sub-criticality level, with a significant penalty on the proton beam power requirements.

In order to meet the design requirement, the required cross section target accuracies obtained with the method of Reference 2, are given in tables II and III. A 7 group energy structure has been used with the following upper energy in eV: $1.96x10^7$, $2.23x10^6$, $4.98x10^5$, $6.74x10^4$, $2.03x10^3$, $1.49x10^2$, and $5.40x10^{-1}$. The requirements are shown according (rank) to their overall original contribution to the total uncertainty on k_{eff}.

II. Fuel Cycle Nuclear Data Uncertainty Impact

As for integral parameters more related to the fuel cycle (as decay heat, neutron sources at fuel fabrication or radiotoxicity in a geological disposal), their uncertainty is due to both the out-of-pile decay (and related decay constants uncertainties) and to the uncertainty of the isotope composition at the end of the in-pile irradiation. Since uncertainties on decay constants are relatively small, the major effect can be associated to the isotope composition uncertainty at the end of irradiation (N_F):

$$\delta N_F/N_F = \delta (N_0+\Delta N)/N_F = \delta (\Delta N)/N_F = (\delta (\Delta N)/ \Delta N) \times \Delta N /N_F$$

where $\Delta N=N_F-N_0$ is the difference between the final and initial densities of any isotope.

For example in the case of decay heat of fuels with a high content of MA, the major contribution to decay heat is due to Pu-238, Am-241 and Cm-244 (see e.g. References 1 and 4).

Preliminary calculations indicate that cross section uncertainties, both for the SFR and ADMAB systems, will increase the overall uncertainties on the N_F values of those isotopes of less than 5%. Consequently, rather acceptable (at least in initial design phases) uncertainties are expected on integral parameters as decay heat, neutron sources at fuel fabrication or radiotoxicity in a geological disposal.

III. Conclusions

Recent and improved evaluations of nuclear data uncertainties indicate a potential significant impact on the nominal performances of MA burner reactors. In particular, the uncertainty on the subcritical level can have an impact on the safety assessment of any type of subcritical source driven system, possibly resulting in the requirement to add control rods (up to now not foreseen in any conceptual designs) to the system. Fuel cycle related parameters are less affected by uncertainties. This preliminary indication should be carefully verified, in view of the very important feasibility issues related to advanced fuel cycles that make use of MA or TRU burner reactors as indicated in Reference 4. This is the case of decay heat of discharged fuel elements or targets, that can require long cooling times with potential impact on the reactor availability and, consequently, on the transmutation effectiveness. In that respect an uncertainty of 20% or more on that quantity, can induce significant penalties on the performance of the fuel handling design.

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TABLE I. Major components of K_{eff} uncertainty, expressed in pcm, for the two transmuter systems.

SFR						
Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	Total
PU240	192	258	447	12	129	565
FE56	162	0	0	401	289	521
CM245	7	434	48	0	3	437
CM244	166	142	110	1	8	245
U238	44	8	32	10	233	240
PU242	182	98	85	6	16	224
PU238	76	131	158	2	28	221
NA23	29	0	0	34	166	172
PU241	119	43	33	2	9	131
CM242	12	113	14	0	3	115
Total	382	563	498	403	428	1029
ADMAB						
Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	Total
AM241	207	125	173	3	119	321
PU241	92	41	32	0	14	106
CM245	12	1040	111	0	10	1046
CM244	555	642	505	1	60	989
AM243	316	430	93	3	267	604
NP237	166	162	63	2	102	261
BI209	54	0	0	64	180	198
PU240	52	91	149	1	73	197
N15	3	0	0	214	12	214
PU239	89	122	34	2	86	177
AM242M	11	133	10	0	5	134
Total	707	1328	578	223	380	1671

TABLE II. Nuclear data target accuracy requirements (first 20 major contributors) on a total uncertainty of 300 pcm on K_{eff} for the SFR system

Rank	Cross Sect.	Energy Range (eV)	Current (%)	Required (%)
1	^{56}Fe σ^{el} Gr. 3	$4.98x10^5$ to $6.74x10^4$	12.0	1.6
2	^{240}Pu ν Gr. 2	$2.23x10^6$ to $4.98x10^5$	3.2	0.8
3	^{245}Cm σ^{fis} Gr. 3	$4.98x10^5$ to $6.74x10^4$	47.0	3.1
4	^{56}Fe σ^{inel} Gr. 2	$2.23x10^6$ to $4.98x10^5$	11.4	1.8
5	^{240}Pu ν Gr. 3	$4.98x10^5$ to $6.74x10^4$	4.8	1.3
6	^{245}Cm σ^{fis} Gr. 2	$2.23x10^6$ to $4.98x10^5$	47.3	4.4
7	^{238}U σ^{inel} Gr. 2	$2.23x10^6$ to $4.98x10^5$	17.0	2.7
8	^{240}Pu σ^{fis} Gr. 2	$2.23x10^6$ to $4.98x10^5$	2.5	1.1
9	^{56}Fe σ^{el} Gr. 2	$2.23x10^6$ to $4.98x10^5$	6.3	2.0
10	^{240}Pu σ^{fis} Gr. 3	$4.98x10^5$ to $6.74x10^4$	6.4	1.7
11	^{56}Na σ^{inel} Gr. 2	$2.23x10^6$ to $4.98x10^5$	15.0	2.7
12	^{240}Pu ν Gr. 1	$1.96x10^7$ to $2.23x10^6$	2.5	1.4
13	^{245}Cm σ^{fis} Gr. 4	$6.74x10^4$ to $2.03x10^3$	16.1	3.7
14	^{238}U σ^{inel} Gr. 1	$1.96x10^7$ to $2.23x10^6$	19.4	3.5
15	^{56}Fe σ^{cap} Gr. 3	$4.98x10^5$ to $6.74x10^4$	12.3	2.7
16	^{244}Cm σ^{cap} Gr. 4	$6.74x10^4$ to $2.03x10^3$	68.7	6.6
17	^{242}Pu σ^{cap} Gr. 4	$6.74x10^4$ to $2.03x10^3$	20.2	3.8
18	^{240}Pu σ^{cap} Gr. 2	$2.23\ 10^6$ to $4.98\ 10^5$	28.2	3.7
19	^{244}Cm σ^{fis} Gr. 2	$2.23x10^6$ to $4.98x10^5$	14.5	3.1
20	^{242}Pu σ^{cap} Gr. 3	$4.98x10^5$ to $6.74x10^4$	28.2	4.5

TABLE III. Nuclear data target accuracy requirements (first 20 major contributors) on a total uncertainty of 300 pcm on K_{eff} for the ADMAB system

Rank	Cross Sect.	Energy Range (eV)	Current (%)	Required (%)
1	$^{245}Cm\ \sigma^{fis}$ Gr. 3	4.98×10^5 to 6.74×10^4	47.0	1.4
2	$^{244}Cm\ \sigma^{fis}$ Gr. 2	2.23×10^6 to 4.98×10^5	14.3	1.0
3	$^{245}Cm\ \sigma^{fis}$ Gr. 2	2.23×10^6 to 4.98×10^5	47.5	2.0
4	$^{244}Cm\ \nu$ Gr. 2	2.23×10^6 to 4.98×10^5	8.7	0.9
5	$^{244}Cm\ \sigma^{cap}$ Gr. 4	6.74×10^4 to 2.03×10^3	64.4	2.5
6	$^{243}Am\ \sigma^{fis}$ Gr. 2	2.23×10^6 to 4.98×10^5	8.8	1.0
7	$^{245}Cm\ \sigma^{fis}$ Gr. 4	6.74×10^4 to 2.03×10^3	14.7	1.5
8	$^{244}Cm\ \sigma^{cap}$ Gr. 3	4.98×10^5 to 6.74×10^4	48.6	2.6
9	$^{244}Cm\ \sigma^{fis}$ Gr. 1	1.96×10^7 to 2.23×10^6	19.7	1.7
10	$^{243}Am\ \sigma^{inel}$ Gr. 2	2.23×10^6 to 4.98×10^5	21.6	1.9
11	$^{243}Am\ \sigma^{cap}$ Gr. 2	2.23×10^6 to 4.98×10^5	6.8	1.1
12	$^{243}Am\ \sigma^{fis}$ Gr. 1	1.96×10^7 to 2.23×10^6	12.1	1.6
13	$^{243}Am\ \sigma^{cap}$ Gr. 3	4.98×10^5 to 6.74×10^4	8.2	1.3
14	$^{244}Cm\ \sigma^{cap}$ Gr. 2	2.23×10^6 to 4.98×10^5	77.9	4.2
15	$^{244}Cm\ \nu$ Gr. 1	1.96×10^7 to 2.23×10^6	10.1	1.7
16	$^{244}Cm\ \sigma^{fis}$ Gr. 3	4.98×10^5 to 6.74×10^4	10.0	1.9
17	$^{209}Bi\ \sigma^{inel}$ Gr. 2	2.23×10^6 to 4.98×10^5	14.0	1.9
18	$^{15}N\ \sigma^{elas}$ Gr. 2	2.23×10^6 to 4.98×10^5	2.9	0.9
19	$^{245}Cm\ \sigma^{fis}$ Gr. 1	1.96×10^7 to 2.23×10^6	38.0	4.0
20	$^{244}Cm\ \nu$ Gr. 3	4.98×10^5 to 6.74×10^4	10.0	1.9