Format Changes for High Energy File

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Objective

➢ To provide a format frame for high energy activation-transmutation files, where it is necessary to completely specify the reaction mechanism in particular for the emitted particles and the residual.

➢ The number of open channels increases with energy as the number of combinations of the emitted particles increases.

➢ However, the MT's description has many advantages and proven performance and reliability when carrying out activation-transmutation calculations.

Current status

➢ Reaction types (MT) are identified by an integer number from 1 through 999 with the addition of the (LR) flag to describe simple, complex or breakup reactions and decay modes of the residual nucleus.

➢ Appendix B of ENDF-102 Formats and Procedures defines the assigned reaction types. Traditionally, 39 MT's have been defined from number 2 to 117 that have been judged to be important for fission reactor type transport calculations below 20 MeV.

➢ MT numbers 152 to 200 are unassigned.

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Proposal

➢ Calculation with nuclear reaction model code, such as TALYS, indicate that the addition of 50 more defined MT numbers would make any reaction description complete (+/- 10 mb) up to an incident energy of 60 MeV, for all foreseeable light and heavy target nuclides.

➢ Some of those MT numbers are by no mean more exotic than some already defined. As an example, the (n,dα) (official ENDF format: MT-117) has been judged as deserving its own MT number, there should be no reason to stop there.

➢ These new MT numbers are proposed as a practical way to enhance the current and near term activation files. Above about 60 MeV we would need to define so many new MTs that this approach is not feasible and so we must change to total and yields. But use of MTs until 60 MeV seems a better practical approach than making the change at 20 MeV.

Advantages

➢ A huge advantage of the MT description is that it allows full covariance information to be given in the file (MF-33).

➢ We really do need an MT for the higher (n,xn) reactions since (n,5n),(n,7n) data are available in EXFOR but at present are ignored in the V&V systems.

➢ Exclusive definition of reactions and MTs gives us a good way to keep track of the different gas productions, the standard example is (n,np) and (n,d) producing H and D respectively.

➢ Some experiments count products rather than determining the amount of the daughter so it is best to still think about exclusive reactions.

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Format frame

```
----------------------------------------------------------------
MF              Description    for energy  < 60 MeV)
----------------------------------------------------------------
1               General information, comments
2               Resonance parameter, scattering radius
3               Total reaction channels
8               Flag, file pointer, dictionary (pendf only)
9               Isomeric branching ratio, for non threshold reaction
10              Split threshold reaction channels
33              Covariance of neutron cross sections
40              Covariance for production of radioactive nuclei
----------------------------------------------------------------


----------------------------------------------------------------
MF              Description     for energy > 60 MeV
----------------------------------------------------------------
6               Activation yields for MT-5
40              Covariance for radionuclides production yields
----------------------------------------------------------------
```

Grey areas

➤ MF-8, Flag, file pointer, dictionary applied only to the pendf formatted file.

➤ Branched positive Q values (n,alpha), (n.p) and (n,h) channels are in MF-10, thus not allowed in MF-2.

➤ Nothing stops anybody to ignore those new MT, backward compatibility.

Simple particles reactions

MT	Particles	MT	Particles	MT	Particles	MT	Particles
2	n	45	npα	159	2npα	182	dt
4	n′	102	g	160	7n	183	n′pd
5	anything	103	p	161	8n	184	n′pt
11	2nd	104	d	162	5np	185	n′dt
16	2n	105	t	163	6np	186	n′ph
17	3n	106	^{3}He	164	7np	187	n′dh
18	fission	107	α	165	4nα	188	n′th
22	nα	108	2α	166	5nα	189	n′tα
23	n3α	109	3α	167	6nα	190	2n2p
24	2nα	111	2p	168	7nα	191	ph
25	3nα	112	pα	169	4nd	192	dh
28	np	113	t2α	170	5nd	193	hα
29	n2α	114	d2α	171	6nd	194	4n2p
30	2n2α	115	pd	172	3nt	195	4n2α
32	nd	116	pt	173	4nt	196	4npα
33	nt	117	dα	174	5nt	197	3p
34	n^{3}He	152	5n	175	6nt	198	n′3p
35	nd2α	153	6n	176	2nh	199	3n2pα
36	nt2α	154	2nt	177	3nh	200	5n2p
37	4n	155	tα	178	4nh		
41	2np	156	4np	179	3n2p		
42	3np	157	3nd	180	3n2α		
44	n2p	158	n′dα	181	3npα		

Actual MT black (29)
New MT green (48)

ENDF Summation rules

Table 14: ENDF sum rules for cross sections

MT	Sum	MT Meaning
1	2, 3	Total cross sections (incident neutrons only)
3	4-5, 11, 16-18, 22-37, 41-42, 44-45, 152-154, 156-181, 183-190, 194-196, 198-200	Non-elastic
4	50-91	Total of neutron level cross sections (z,n)
18	19-21, 38	Total fission
27	18, 101,	Total absorption
101	102-117, 155,182, 191-193, 197	Neutron disappearance
103	600-649	Total of proton level cross sections (z,p)
104	650-699	Total of deuteron level cross sections (z,d)
105	700-749	Total of triton level cross sections (z,t)
106	750-799	Total of 3He level cross sections (z,3He)
107	800-849	Total of alpha level cross sections (z,α)

Résumé

➢ Here we purposely frame the formats to provide all the necessary data needed not only at the ENDF level but also during the data file processing, verification and validation processes.

➢ Detailed ENDF-102 document changes have been proposed.

➢ Expected modifications for processing codes are minimal if not non-existent for most type of processing.