Use of MT=900+ for primary gamma two-body channels, MT=102 being derived from these for backward compatibility

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Formats to specify primary capture gammas

Primary gammas:

- Each primary gamma can be its own two-body reaction (z,g) with the residual being left in the excitation state for that primary gamma
 - Primary gammas have energy that rises with incident projectile energy
- The residual is then decayed using transition probabilities to produce the correlated *secondary* (discrete) gammas on an event-by-event bases
 - e.g, n + O16 -> primary gamma + (O17_e3 -> O17 + transition gammas)
 - Secondary gammas have energies that are fixed, independent of projectile energy.
- ENDF format:
 - The ENDF format currently does not allow for correlated primary/secondary gammas.
 - MT=102 format is complicated as it must describe both primary and secondary gammas.



History: new specification for primary gammas

- History
 - MT=102 used traditionally in ENDF format for capture reactions.
 - Two-body reactions for particle products exist for n,p,d,t,h and a.
 But not for gammas (g) !
 - MT=102 different from other summing channels 4, 103, 104, 105, 106, 107 for n, p, d, t, h and a, as these are sums of two-body channels
- Proposal (more details later)
 - Use MT=900-998 for the first 99 discrete primary gammas needed
 - Use MT=999 as continuum channel for any further primaries
- I proposed this at MiniCSEWG meeting at LLNL in April 2023
 - Acceptance delayed so backward compatibility can be guaranteed.
 - Too late for ENDF/B-VIII.1
 - But still should be useful for experimentalists, evaluators and data users



Current ENDF/B-VIII.0 with primary *γ* **channels**

n-001_H_002.endf: n-003_Li_006_endf:	1 primary - only explicit two-body primary. 2 primaries	
n-003_Li_007.endf:	2	
n-005_B_010.endf:	6	
n-005_B_011.endf:	6	GRIN ENDF/B-VIII.1 candidates:
n-006_C_012.endf:	2	C13: 4 primaries
n-007_N_014.endf:	11 (rather old)	016: 2
n-014_Si_029.endf:	23	F19: 29
n-014_Si_030.endf:	8	Si28: 13
n-017_Cl_035.endf:	69	
n-017_Cl_037.endf:	22	

All of these are candidates for conversion to MT=900-999. Evaluations in red can be converted unambiguously More will be added from GRIN project. Much better to use in R-matrix fits rather than Reich-Moore sums



Proposal: MT=900-999 for primary capture gammas

- Use new MT numbers 900-999 to describe all primary gammas:
 - MT=102 becomes a summed-cross-section channel like 4, 103-107.
 - Can be reconstructed from 900-999 if present
- New MT Definitions for ENDF6 manual Appendix B:
 - MT=900: Production of a primary-γ particle leaving the residual nucleus in the ground state
 - MT=901-998 Production of a primary- γ particle, with residual in 1st to 98th excited state
 - MT=999: Production of a primary-γ particle in the continuum not included in the above discrete representation.
 - MT=102: Radiative capture: production of one or more gammas (photons) plus a residual.
 Redundant: sum of MT=900-999, if they are present.
- For backward compatibility:
 - In a PREPRO-like step before processing with older codes, make another file version by Reconstructing MT=102 <u>with</u> distributions and delete MT 900s. (See code MT900s2MT102.py later).





Consequences for Gamma Data

If using new MT numbers, then

- The secondary decay gammas must be specified either:
 - 1. by transition probability arrays with MF=12 data (preferred), or
 - 2. separately for each of discrete MT channels (900-998), or
 - 3. in a continuum distribution for MT channels 999.
- <u>All</u> the primary gammas MT=900-998 are 2-body channels.
 - Can use MT=999 :
 - for channels not covered by MT 900 to 998 [MT 91 for MT 50 to 90 for (n,n')]
 - if primary channels not known for a gamma
 - If data only gives continuum distribution of gamma production
- MT=102 can now be derived from the new channels if present
 - If 900-999 not present, just put inclusive data & distributions in MT=102 as now.



Code assistance

We give a FUDGE translation code gnds-capture.py that converts MT=102 to MT=900-998, 999 primary and secondary data Works well so far for ENDF/B-VIII.0 and VIII.1 versions of neutrons on Li6, Li7, B10, C12.

And a FUDGE code MT900s2MT102.py to reconstruct MT=102 from 900-999 & delete these, for backward compatibility. Like a PREPRO module making a intermediate version

Published ENDF evaluations should <u>not</u> have <u>distributions</u> with <u>both</u> MT=102 and 900-999, to avoid any double counting. That is, define like MT=103 – 107 for charged particles





Conclusion

- Proposal for explicit description of primary capture gammas from two-body reaction channels
 - No change needed for GNDS 2.0 (only for ENDF6 format)
 - Need relativistic kinematics or at least distinct treatment of photons.
- Resonance parameters should be specified for each channel: for each MT 900 to 998 as needed.

No longer for Reich-Moore 'absorption' to give summed capture gammas

- Codes (processing and transport) need to be updated to handle these MTs.
 - Demonstration files available for n + H2, Li6, Li7, B10, C12, C13, O16
- If gamma-then-particle emission, particle resonance width has to be assumed zero (discrete) if MT=900-998. MT=999 is ok.
 - For example the He5 resonance in $d + t \rightarrow gamma + (He5 \rightarrow He4 + n)$



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