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(Dictionary 236 (Quantities))

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May 14 – 17, 2024
NRDC 2024, IAEA Headquarter, Vienna

KAERI Korea Atomic Energy Research Institute

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Proposal

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Date: 5 February 2024
To: Distribution
From: S.C. Yang, N. Otsuka

Subject: **Dictionary 236 (Quantities) – M+,SIG,,RAB and question on RAB**

The following new quantity code is proposed for compilation of 30856.003. This entry relates the cross section of Zr isotopes with the fast neutron. Zr-89 has both a short-lived metastable state Zr-89m ($t_{1/2}$=4.161 m) and a ground state Zr-89g ($t_{1/2}$=78.41 h). The Zr-89m decays to the unstable Zr-89g through IT process with the branching ratio of 93.77%. According to the current rule, M+ is used when there is no contribution from another nuclide and partial feeding via IT is not 100%. However, its combination with RAB is absent in the current Dictionary 236.

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History

- Entry number: 30856

Eur. Phys. J. A (2021) 57:267
https://doi.org/10.1140/epja/s10050-021-00568-8

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article - Experimental Physics

Measurement of cross sections of Zr-isotopes with the fast neutrons based on the ^{9}Be(p, n) reaction

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REFERENCE   (J,EPJ/A,57,2674,2021)
FACILITY    (CYCLO,3KORKRM) MC-50 cyclotron (KIRAMS)
INC-SOURCE  (P-BE) The neutron beam was produced from the 9Be(p,n)
             reaction by impinging 25, 35 and 45 MeV proton beams
             on a 5 mm thick Be target.
INC-SPECT   (EN-RSL-HW) The neutron spectrum was characterized by
             MCNPX 2.6.0.
SAMPLE      natural Zr foil
             - purity: >99.99%
             - thickness: 0.05 mm
             - Size: 0.8-1 cm x 1cm
             - weight: 71.6, 103.8, 75.3 mg
METHOD      (ACTIV) Irradiation for 1 hour
            (GSPEC) Started after the cooling time (1.86-2.78 h)
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History

Table 4 Flux-weighted average cross sections of the ^{96}Zr(n, 2n)^{95}Zr and ^{90}Zr(n, xn)^{89,88}Zr reactions from this work, literature values and calculated values from the TALYS-1.9 [62] at different flux-weighted average neutron energies.

Reactions	Flux-weighted average neutron energy ($\langle E_n \rangle_{i,j}^{k}$) (MeV)	Reference [Ref.]	Average reaction cross-section ($< \sigma >$) (mb)			
			m-state	g-state	Total (m+g)	
			TALYS	TALYS	Measured	TALYS
^{96}Zr(n, 2n)^{95}Zr	**13.80**	**Present**	–	–	**1489.3 ± 196.4**	**1479.6**
	13.74	Filatenkov et al.[26]			1614.0± 161.4	
	13.96	Filatenkov et al.[26]			1594.0± 91.8	
	18.91	**Present**	–	–	**960.7 ± 75.0**	**940.8**
	25.81	**Present**	–	–	**446.4 ± 92.9**	**336.7**
^{90}Zr(n, 2n)^{89}Zr	**16.11**	**Present**	**221.7**	**762.0**	**983.3 ± 51.3**	**983.7**
	15.92	Abboud et al. [41]			1053.6 ± 11.1	
	16.02	Wenrong et al. [53]			1033.0± 42.0	
	16.23	Bayhurst et al. [46]			994.0± 42.0	
	16.28	Abboud et al. [41]			1024.6 ± 15.4	
	16.30	Semkova et al. [61]			1090.0± 60.0	
	20.92	**Present**	**196.2**	**927.3**	**1190.7 ± 80.0**	**1123.5**
	20.60	Semkova et al. [61]			1200.0± 80.0	
	19.90	Semkova et al. [61]			1200.0± 70.0	
	19.98	Bayhurst et al. [46]			1225.0± 52.0	
	19.76	Prestwood et al. [38]			1169.0± 58.0	
	28.74	**Present**	**85.3**	**592.9**	**642.8 ± 33.2**	**678.2**
	27.99	Bayhurst et al. [46]			750.0	
^{90}Zr(n, 3n)^{88}Zr	**25.37**	**Present**	–	–	**118.0 ± 12.6**	**131.7**
	31.33	**Present**	–	–	**503.2 ± 38.1**	**508.4**

Bold values indicate present data

- Report of isotopic cross sections under use of a natural sample could be stressed.

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Limitations

- Limitations of RAB

Ground and isomeric state information for $^{89}_{40}Zr$

E(level) (MeV)	Jπ	Mass Excess (keV)	$T_{1/2}$	Decay Modes
0.0	9/2+	-84878 *3*	78.41 h *12*	ε = 100.00%
0.5878	1/2-	-84290 *3*	4.161 min *10*	IT = 93.77% ε = 6.23%

- According to the current rule, M+ is used when there is no contribution from another nuclide and partial feeding via IT is not 100%.
- However, its combination with RAB is absent in the current Dictionary 236.

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REACTION sums within the current rule

- Use of RAB modifier

  : isotope production cross section for natural sample

- Subentries

```
SUBENT         30856002    20230711
BIB                   4           5
REACTION    (40-ZR-96(N,2N)40-ZR-95,,SIG,,SPA)
DECAY-DATA  (40-ZR-95,64.032D,DG,724.19,0.4427,
                           DG,756.73,0.5438)
SAMPLE      (40-ZR-96,NAT=0.0280)
```

```
SUBENT         30856003    20230711
BIB                   4           8
REACTION    ((40-ZR-90(N,2N)40-ZR-89-G,M+,SIG,,SPA)+
            (40-ZR-91(N,3N)40-ZR-89-G,M+,SIG,,RAB/SPA)+
            (40-ZR-92(N,4N)40-ZR-89-G,M+,SIG,,RAB/SPA))
DECAY-DATA  (40-ZR-89-G,78.41HR,DG,909.15,0.9904)
SAMPLE      (40-ZR-90,NAT=0.5145)
            (40-ZR-91,NAT=0.1122)
            (40-ZR-92,NAT=0.1715)
```

```
SUBENT         30856004    20230711
BIB                   4           6
REACTION    ((40-ZR-90(N,3N)40-ZR-88,,SIG,,SPA)+
            (40-ZR-91(N,4N)40-ZR-88,,SIG,,RAB/SPA))
DECAY-DATA  (40-ZR-88,83.4D,DG,392.87,0.9729)
SAMPLE      (40-ZR-90,NAT=0.5145)
            (40-ZR-91,NAT=0.1122)
```

- Chex result

```
** REACTION fields 5-8 not in dictionary                    30856003
          (40-ZR-91(N,3N)40-ZR-89-G,M+,SIG,,RAB/SPA)+      3085600300004
                          ^^^^^^^^^^^
** REACTION fields 5-8 not in dictionary                    30856003
          (40-ZR-92(N,4N)40-ZR-89-G,M+,SIG,,RAB/SPA))      3085600300005
                          ^^^^^^^^^^^
```

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Simplification

- Simplification of REACTION string without sum
- A REACTION string relevant to the RAB modifier becomes a REACTION sum.

```
REACTION    ((40-ZR-90(N,2N)40-ZR-89-G,M+,SIG,,SPA)+
             (40-ZR-91(N,3N)40-ZR-89-G,M+,SIG,,RAB/SPA)+
             (40-ZR-92(N,4N)40-ZR-89-G,M+,SIG,,RAB/SPA))
```

- Propose simplification of the REACTION sum to

```
REACTION    ((40-ZR-90(N,2N)40-ZR-89-G,M+,SIG,,OTH/SPA)
```

- OTH: presence of contribution from a Zr target isotope other than ^{90}Zr.
- Definition of OTH could be mentioned somewhere, e.g., “not corrected for contribution of other target isotopes”.