Present Status of Karlsruhe Cross Sections

(B. Pritychenko, 2019-10-23, Memo CP-C/472)

In the last 30 years nuclear astrophysics calculations often relied on the results of Karlsruhe cross section measurements and data compilations [1], and the Karlsruhe Astrophysical Database of Nucleosynthesis in Stars (KADoNiS) library [2] has been a golden standard in the field. Many of these data have been produced by neutron activation technique that relied on two gold foils in front and behind the target for neutron flux measurements [3]. The Karlsruhe group used its own ^{197}Au(n,γ) cross section value [4] for the neutron flux determination and, essentially, created a potential point of failure in the KADoNiS library.

Recent analysis showed that the aforementioned gold activation Maxwellian-averaged cross section (MACS) 582±9 mb disagrees with the international evaluation of neutron cross section standard value of 620±11 mb [5,6]. The KADoNiS gold value has been re-evaluated in 2018 with Monte Carlo simulations, extensive analysis of neutron time-of-flight, and activation experiments [7]. The comprehensive analysis of gold neutron capture cross sections showed an impact of neutron backing material scattering, while ENDF libraries are essentially based on the TOF measurements and not affected by this issue. The revised ^{197}Au(n,γ) activation MACS value of 612±6 mb is consistent with the standard value, and the KADoNiS cross sections have been updated for 63 target nuclides from ^{103}Rh to ^{197}Au [7]. As of today, graphic representations of the corrected reaction rates are publicly available [7], while numeric cross section values will be disseminated later.

This development creates issues for the EXFOR database users because many Karlsruhe results have been compiled in the EXFOR Area #2 and added to the database. These systematically lower values have been occasionally used in ENDF evaluations and could impact the overall quality of ENDF libraries and other derived products. As of today, there is no information available about possible Karlsruhe group corrigendum that would correct all affected results. In light of this disclosure the NRDC network should clearly identify and mark all Karlsruhe compilations with comments where deficient gold capture cross section or spectrum were used.

To estimate the scale of required updates all the measurements for 1988-2018 timespan were re-analyzed with the NSR and EXFOR database Web Interfaces [8,9]. The analysis revealed that gold activation cross sections were employed across the whole nuclear chart, not just within the previously discussed Z=45-79 target range [7], and multiple compilation centers are affected.

1. <u>Z=45-79 range:</u>

Target	EXFOR Accession #		NSR KeyNumber
103Rh		22195	1990WI14
	V0102		2000Ba79
110Cd		22813	2002WI11
	V0102		2000Ba79
111Cd		22813	2002WI11

	V0102		2000Ba79
112Cd		22813	2002WI11
	V0102		2000Ba79
113Cd		22813	2002WI11
	V0102		2000Ba79
114Cd		22813	2002WI11
	V0102		2000Ba79
116Cd		22813	2002WI11
	V0102		2000Ba79
114Sn		22377	1996WI14,1990WI17,1992WI05,1993WI12
	V0102		2000Ba79
115Sn		22377	1996WI14,1990WI17,1992WI05,1993WI12
	V0102		2000Ba79
116Sn		22377	1996WI14,1990WI17,1992WI05,1993WI12
	V0102		2000Ba79
117Sn		22377	1996WI14,1990WI17,1992WI05,1993WI12
	V0102		2000Ba79
118Sn		22377	1996WI14,1990WI17,1992WI05,1993WI12
	V0102		2000Ba79
120Sn		22377	1996WI14,1990WI17,1992WI05,1993WI12
		22387	1996WI20,1996WI14,1996WI17
	V0102		2000Ba79
122Te		22275	1992XI01
		22285	1991WIZX
		22372	1992WI05
		22373	1992XI01,1992WI05,1990WI17
	V0102		2000Ba79
123Te		22275	1992XI01
		22285	1991WIZX
		22372	1992WI05
		22373	1992XI01,1992WI05,1990WI17
	V0102		2000Ba79
124Te		22275	1992XI01
		22285	1991WIZX
		22372	1992WI05
		22373	1992XI01,1992WI05,1990WI17
	V0102		2000Ba79
125Te		22285	1991WIZX
		22373	1992XI01,1992WI05,1990WI17
	V0102		2000Ba79
126Te		22285	1991WIZX
		22372	1992WI05

		22815	2002RE30
	V0102		2000Ba79
128Xe		22816	2002RE32
129Xe		22816	2002RE32
130Xe		22816	2002RE32
134Ba		22307	1994VO18
		22337	1994WI18
	V0102		2000Ba79
135Ba		22307	1994VO18
		22337	1994WI18
	V0102		2000Ba79
136Ba		22307	1994VO18
		22337	1994WI18
		22385	1995VO06,1994VO18
	V0102		2000Ba79
137Ba		22307	1994VO18
		22337	1994WI18
	V0102		2000Ba79
141Pr		22498	1999VO02
	V0102		2000Ba79
142Nd		22388	1998WI04
		22389	1998WI18
	V0102		2000Ba79
143Nd		22388	1998WI04
	V0102		2000Ba79
144Nd		22388	1998WI04
		22389	1998WI18
	V0102		2000Ba79
145Nd		22388	1998WI04
	V0102		2000Ba79
146Nd		22305	1995TO01
		22388	1998WI04
	V0102		2000Ba79
148Nd		22305	1995TO01
		22388	1998WI04
	V0102		2000Ba79
148Sm		22374	1993WI12
	V0102		2000Ba79
149Sm		22374	1993WI12
	V0102		2000Ba79
150Sm		22374	1993WI12
	V0102		2000Ba79

151Sm		22893	2006MA18,2005MA73,2004AB22
		22916	2006WI01
152Sm		22374	1993WI12
		22670	2001BE33
	V0102		2000Ba79
152Gd		22386	1995WI25
	V0102		2000Ba79
154Gd		22386	1995WI25
	V0102		2000Ba79
155Gd		22386	1995WI25
	V0102		2000Ba79
156Gd		22386	1995WI25
	V0102		2000Ba79
157Gd		22386	1995WI25
	V0102		2000Ba79
158Gd		22386	1995WI25
	V0102		2000Ba79
160Dy		22498	1999VO02
	V0102		2000Ba79
161Dy		22498	1999VO02
	V0102		2000Ba79
162Dy		22498	1999VO02
	V0102		2000Ba79
163Dy		22498	1999VO02
	V0102		2000Ba79
164Dy		22498	1999VO02
	V0102		2000Ba79
170Yb		22499	2000WI08
	V0102		2000Ba79
171Yb		22499	2000WI08
	V0102		2000Ba79
172Yb		22499	2000WI08
	V0102		2000Ba79
173Yb		22499	2000WI08
	V0102		2000Ba79
174Yb		22499	2000WI08
		23267	2014MA95
	V0102		2000Ba79
176Yb		22499	2000WI08
		23267	2014MA95
	V0102		2000Ba79

175Lu		22267	1991KL02
		22917	2006WI02
		23046	2007WIZW
	V0102		2000Ba79
176Lu		22917	2006WI02
176Hf		22926	2006WI11
177Hf		22926	2006WI11
178Hf		22926	2006WI11
179Hf		22926	2006WI11
180Hf		22926	2006WI11
		22963	2007VO02
		23022	2008VO04
180Ta		22801	2001WI22, 2004WI07
181Ta		22195	1990WI14
		22801	2001WI22, 2004WI07
	V0102		2000Ba79
197Au		22099	1988RA05
	V0102		2000Ba79
		22195	1990WI14
		22275	1992XI01
		22285	1991WIZX
		22307	1994VO18
		22372	1992WI05
		22373	1992XI01,1992WI05,1990WI17
		22374	1993WI12
		22377	1996WI14,1990WI17,1992WI05,1993WI12
		22386	1995WI25
		22388	1998WI04
		22459	1995JA07
		22498	1999VO02
		22499	2000WI08
		22654	2001WI03,1990WI,1990WI14,1992WI05,1993WI12
		22801	2004WI07,2001WI22
		22813	2002WI11
		22816	2002RE32
		22916	2006WI01
		22917	2006WI02
		22926	2006WI11
		23170	2014WA17,2011CH57,2011WA35

2. Extended range (Outside Z=45-79):

Target	EXFOR Accession #	NSR KeyNumber
69,71Ga		2017GOZY
23Na	23337	2017UB01
63Cu	14467	2017WE02
41K,45Sc	23306	2016HE06
235,238U	23170	2014WA17
197Au		2012LE13
64,68,70Zn	23166	2012RE05
186,187,188Os		2011KA43
102Pd,120Te,130,132Ba,156Dy,197Au	22939	2010DI01
168Yb,180W,194Os,190Pt,196Hg	23094	2010MA50
74,76Ge	14237	2009MA35
184,186W	14218	2009MA48
60Fe	14228	2009UB01
209Bi	23051	2008BIZV
102Pd,120Te,130,132Ba,156Dy		2008DIZT
58Fe,59Co,64Ni,63,65Cu	22996	2008HE01
79,81Br,85,87Rb	23035	2008HE10
175Lu		2008HE17
76Ge	23043	2008MA08
14C	22995	2008RE01
209Bi		2007BIZY
79Se		2007DIZY
19F	22968	2007UB01
19F		2007UBZZ
176Lu		2007WIZZ
74Se,84Sr	22982	2006DI02
58Ni,78Se		2006RUZX
139La		2006WI20
74Se,84Sr	22892	2005DI15
18O	22885	2005HE04
18O	23303	2005HE19
14C	22895	2005RE22
175,176Lu,176,177,178,179,180Hf	22907	2005WIZZ
62Ni		2004NA39
62Ni		2004NAZX
135Cs	22846	2004PA06
208Pb,209Bi	22883	2004RA29
208Pb	22852	2003BE49
139La	22879	2003OB03

147Pm	22829	2003RE39
186W	G0030	2003SO05
96Ru,98,102,104Ru	22685	2002RA36
22Ne, 40Ar, 78,80,84,86Kr	22808	2002BE37
30Si	22804	2002BE70
197Au,232Th	22654	2001WI03
34S	22424	2000RE01
46Ca	22500	1999MO16
50Ti	22485	1999SE16
179Ta	22940	1999SC26
26Mg	22419	1998MO17
106,108,114,116Cd		1998TH10
135Cs	22448	1997JA08
153Eu		1997BA52
141Pr,142,143,144,15,146,148Nd,160,161,162,163,164Dy,164,170Er		1997KAZR
48Ca,197Au	22416	1997MO17
142,143,144,15,146,148Nd		1997WI13
87Rb	22477	1996JA07
136,140,142,138Ce	23420	1996KA03
18O	22781	1996ME01
15N		1996ME03
48Ca	22371	1996BE53
18O	22781	1996ME01
36S	22445	1995BE55
107,109Ag, 22Ne, 14C, 18O, 15N		1994BE29
107,109Ag	22306	1994BE41
14C	22254	1992BE05
76Se	22256	1992BE10
176Lu		1991ZH12
78,80,84,86Kr, 124,126,128,132,134,136Xe	22253	1991BE35
176Lu		1991KL03
94,96Zr	22182	1990TO02
88Sr, 89Y	22177	1990KA13
Sn		1989BE53

Neutron activation measurements strongly rely on nuclear data inputs: $T_{1/2}$, branching ratios, γ-ray intensities. Incorrect nuclear data inputs may result in erroneous findings [10,11]. The overall quality of nuclear data restricts precision of nuclear astrophysics cross sections and reaction rates. For instance, A=177 mass chain evaluation was used in Karlsruhe measurements of 177Hf [12,13], and it renders these measurements as imprecise. Fortunately, the original Karlsruhe report [12] had the details of the nuclear data inputs that are missing in the final publication [13]. Further

analysis of the Karlsruhe BaF_2 detector [14] shows that the total registration of gamma cascades would minimize the impact of erroneous nuclear data inputs; however, such inputs could still affect the efficiency calculations using the Monte Carlo methods.

This example demonstrates that incorrect nuclear data inputs can introduce additional systematic errors in nuclear reaction measurements that are often difficult to estimate (known unknowns). It is absolutely essential in any activation measurements to record the complete list of nuclear data inputs in order to estimate their validities.

EXFOR Compilation:

Target	EXFOR Accession #	NSR KeyNumber
177Hf	22926	2006WI11

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