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**Date:** October 23, 2019

**To:** Distribution

**From:** B. Pritychenko

**Subject:** **Present Status of Karlsruhe Cross Sections**

 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 197Au(n,) 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 197Au(n,) 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 103Rh to 197Au [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. Z=45-79 range:

|  |  |  |
| --- | --- | --- |
| 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: T1/2, branching ratios, -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 BaF2 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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