





# Advances in the Gd-160 capture cross section data analysis

**M. Mastromarco**, A. Mazzone, A. Manna, S. Amaducci, F.G. Infantes, A. Mengoni, S. Cristallo, G. Tagliente, C. Massimi, U. Koester and N. Colonna

#### **Motivations**

#### <sup>161</sup>Tb is a clinically interesting isotope for theranostics!!!

Dy 154 3.0 · 10 <sup>6</sup> a	Dy 155 10.0 h	Dy 156 0.056	Dy 157 8.1 h	Dy 158 Dy 159 0.095 144.4 d		Dy 160 2.329	Dy 161 18.889	Dy 162 25.475	Dy 163 24.896	Dy 164 28.260	Dy 165	
α 2.87	ε β <sup>+</sup> 0.9; 1.1 γ 227	σ 33 σ <sub>n, α</sub> <0.009	¢ γ 326	σ33 σ <sub>n. α</sub> <0.006	€ γ 58; e <sup>−</sup> σ 8000	σ 60 σ <sub>n, α</sub> <0.0003	σ 600 σ <sub>n, α</sub> <1E-6	σ 170	σ 120 σ <sub>n, α</sub> <2E-5	or 1610 + 1040	η 106; e   β     β <sup>-</sup> 0.9;   1.3     1.0   γ 95;     γ 515   (362)     σ 2000   σ 3500	
Tb 153 2.34 d	Tb 154 23 h   9.0 h   21 h	Tb 155 5.32 d	Tb 156	Tb 157 99 a	Tb 158	Tb 159 100	Tb 160 72.3 d	Tb 161 6.90 d	Tb 162 7.76 m	Tb 163 19.5 m	Tb 164 3.0 m	
$\substack{\substack{\varepsilon\\\beta^{+},\\\gamma212;170;\\110;102;83}}$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	ε γ 87; 105; 180; 262	Fy 88   €     0"   y 534;     4   199;     1y 50   β*     0"   222     0"   7	е γ(54) е⊤	by (110) e <sup>-</sup> 962; 80	σ 23.2	β <sup></sup> 0.6; 1.7 γ 879; 299; 966 σ 570	β <sup></sup> 0.5; 0.6 γ 26; 49; 75 e <sup></sup>	β <sup></sup> 1.4; 2.4 γ 260; 808; 888	β <sup></sup> 0.8; 1.3 γ 351; 390; 494	β <sup></sup> 1.7; 3.0 γ 169; 755; 215; 688; 611	
Gd 152 0.20	Gd 153 239.47 d	Gd 154 2.18	Gd 155 14.80	Gd 156 20.47	Gd 157 15.65	Gd 158 24.84	Gd 159 18.48 h	Gd 160 21.86	Gd 161 3.56 m	Gd 162 8.2 m	Gd 163 68 s	
1.1 · 10 <sup>14</sup> a α 2.14; σ 700 σ <sub>n, α</sub> <0.007	ε γ97; 103; 70 σ20000 σ <sub>n, α</sub> 0.03	or 60	σ 61000 σ <sub>n, α</sub> 0.00008	σ~2.0	σ 254000 σ <sub>n, α</sub> <0.05	or 2.3	β <sup>=</sup> 1.0 γ364; 58	or 1.5	γ 361; 315;   β <sup>-</sup> 1.0     102   β <sup>-</sup> 1.0     σ 20000   γ 442; 403		β <sup></sup> γ288; 214; 1562; 1685	
Eu 151 47.81	Eu 152 96 m   9.3 h   13.33 a	Eu 153 52.19	Eu 154 46.0 m 8.8 a	Eu 155 4.761 a	Eu 156 15.2 d	Eu 157 15.18 h	Eu 158 46 m	Eu 159 18.1 m	Eu 160 42 s	Eu 161 26 s	Eu 162 10.6 s	
or 4 + 3150 + 6000	1y 90 963 344 e11000	σ 300 σ <sub>n, α</sub> 1E-6	p 0.6, 13 ς γ 123 1274; 723; 105 101 σ 1500	β <sup>+-</sup> 0.17; 0.25 γ 87; 105 σ 3900	β <sup></sup> 0.5; 2.4 γ812; 89; 1231	β <sup></sup> 1.3 γ64; 411; 371; 619	β <sup></sup> 2.4; 3.4 γ 944; 977; 80; 898	β <sup></sup> 2.6 γ 68; 71; 79; 96; 103	β <sup></sup> 4.1 γ 173; 515; 412; 822	β <sup>-</sup> γ72-314	β <sup></sup> γ71; 165	
Sm 150 7.38	Sm 151 93 a	Sm 152 26.75	Sm 153 46.27 h	Sm 154 22.75	Sm 155 22.4 m	Sm 156 9.4 h	Sm 157 8.11 m	Sm 158 5.51 m	Sm 159 11.4 s	Sm 160 9.6 s	Sm 161 4.8 s	
σ 102	β <sup>-</sup> 0.1 γ (22); e <sup>-</sup> σ 15200	or 206	β <sup>-</sup> 0.7; 0.8 γ 103; 70 σ 420	or 7.5	β <sup></sup> 1.5 γ 104; 246; 141	β <sup>-</sup> 0.7 γ204; 88; 166 e <sup>-</sup>	β <sup>-</sup> 2.4 γ 198; 196; 394	β <sup></sup> γ 189; 364; 325	β <sup></sup> γ 190; 862; 254; 797; 179	β <sup></sup> γ 110	β <sup></sup> γ 264	

November Valencia (FS)

# (Medical Motivations: terbium-161 production)

• Chemically similar to lutetium-177 (used in the ranostic as  $\gamma$  and  $\beta^{-}$  emitter)

• Similar half-life  $T_{1/2}$  = 6.9 d (against 6.7 d of Lu-177)

In addiction to being a γ and β<sup>-</sup> emitter (like Lu-177), Tb-161 is also an emitter of Auger and conversion electrons;

*The higher LET (compared to Lu-177) can be effective in reducing the survival probability of tumors cells.* 

#### **Motivations**

#### ...and influences the abundance of Dy in stars!!!

Dy 154 3.0 · 10⁵ a	Dy 155 10.0 h	Dy 156 0.056	Dy 157 8.1 h	Dy 158 0.095	Dy 159 144.4 d	Dy 160 2.329	Dy 161 18.899	Dy 162 25.475	Dy 163 24.896	Dy 164 28.260	Dy 165 1.3 m 2.35 h hy 108; e <sup>-</sup> B <sup>-</sup>
α 2.87	ε β <sup>+</sup> 0.9; 1.1 γ 227	σ 33 σ <sub>n, α</sub> <0.009	ε γ 326	σ33 σ <sub>n, α</sub> <0.006	€ γ 58; e <sup>−</sup> σ 8000	σ 60 σ <sub>n, α</sub> <0.0003	σ 600 σ <sub>n, α</sub> <1E-6	x 170	σ 120 σ <sub>n, α</sub> <2E-5	σ 1610 + 1040	β <sup>++</sup> 0.9; 1.3 γ 515 γ 95; γ 515 (362) σ 2000 σ 3500
Tb 153 2.34 d	Tb 154 23 h 9.0 h 21 h	Tb 155 5.32 d	Tb 156	Tb 157 99 a	Tb 158 10.5 s 180 a	Tb 159 100	Tb 160 72.3 d	າ <u>້າ</u> 161 6.80 d	Tb 162 7.76 m	Tb 163 19.5 m	Tb 164 3.0 m
ε β+ γ 212; 170; 110; 102; 83	ε: hγ   ε   ε     γ248:   hγ   β*     347:   γ123;   γ123;     1420:   248;   1274     123   540	ε γ 87; 105; 180; 262	<sup>1</sup> γ 88 ε e <sup></sup> γ 534; ε 199; lγ 50 β <sup>+</sup> 1222 e <sup></sup> β <sup>-</sup> ?	ε γ(54) e <sup>-</sup>	6 β <sup>+</sup> 0.9 γ 944; θ <sup>-</sup> 962; 80	σ 23.2	β <sup>-</sup> 0.6; 1.7 γ 879; 299; 966 σ 570	β <sup>=</sup> 0.5; 0.6 γ 26; 49; 75 e <sup>-</sup>	β <sup>=</sup> 1.4; 2.4 γ 260; 808; 888	β <sup>+-</sup> 0.8; 1.3 γ 351; 390; 494	β <sup></sup> 1.7; 3.0 γ 169; 755; 215; 688; 611
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σ 4 + 3150 + 6000	r 8* 8*07:15 7541: 1122 963	σ 300 σ <sub>n, α</sub> 1E-6	ε; γ 123 1274; 723; 1005 101 σ 1500	β <sup>+-</sup> 0.17; 0.25 γ87; 105 σ3900	β <sup>+-</sup> 0.5; 2.4 γ812; 89; 1231	β <sup></sup> 1.3 γ64; 411; 371; 619	β <sup></sup> 2.4; 3.4 γ 944; 977; 80; 898	β <sup></sup> 2.6 γ68; 71; 79; 96; 103	β <sup></sup> 4.1 γ 173; 515; 412; 822	β <sup>-</sup> γ72-314	β <sup></sup> γ71; 165
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σ 102	β <sup>-</sup> 0.1 γ (22); e <sup>-</sup> σ 15200	or 206	β <sup></sup> 0.7; 0.8 γ 103; 70 σ 420	σ7.5	β <sup></sup> 1.5 γ 104; 246; 141	β <sup></sup> 0.7 γ 204; 88; 166 e <sup></sup>	β <sup></sup> 2.4 γ 198; 196; 394	β <sup></sup> γ 189; 364; 325	β <sup></sup> γ 190; 862; 254; 797; 179	β <sup></sup> γ 110	β <sup></sup> γ 264

wano wastromarco @ n\_ror General weeting, 22-24

### Motivations: Model Calculations against Observations



#### Motivations: State of the Art

#### **Exp. Data and Main Evaluations**

#### Incident neutron data / / Gd160 / / Capture Reaction



was meanwhile improved.

**Type:** The letters and numbers in the column labelled 'type' give information on how the cross section has been obtained:

- c Directly quoted from the reference itself
- Mario Mastron b Calculated from smooth cross sections with model fit: ln(sigma) = a + a1 ln(E) + a2 ln^2(E)
  - e Evaluated value taken directly from the reference
  - t Theoretical value

#### Motivations:

Unsatisfactory situation triggered the n\_TOF Collaboration to perform a new measurement of the <sup>160</sup>Gd(n, γ) reaction from thermal up to 300 keV at n\_TOF facility (CERN)

## Samples: Gd sample and Dummy

(Sample available in the form of powdred Gd oxide!!!)

Step by step samples preparation...





# Samples: Gd sample and Gd<sub>2</sub>O<sub>3</sub> Composition

	mass [mg]
Gd oxide container total mass	1459
Gd oxide container after oxide removal	1141
Gd <sub>2</sub> O <sub>3</sub>	318
PEEK capsule	795
kapton	17
glue	114
dummy (capsule + glue + kapton)	926
Gd <sub>2</sub> O <sub>3</sub>	317
Gd oxide sample (oxide + PEEK)	1243
Gd mass (oxide is Gd <sub>2</sub> O <sub>3</sub> )	276
Gd-160 mass (98.1 % enrichment)	270

In the past the  ${}^{160}$ Gd(n,  $\gamma$ ) measurement was hampered by the natural isotopic presence of  ${}^{155}$ Gd and  ${}^{157}$ Gd

# Samples: Gd sample and Gd<sub>2</sub>O<sub>3</sub> Composition

	mass [mg]
Gd oxide container total mass	1459
Gd oxide container after oxide removal	1141
Gd <sub>2</sub> O <sub>3</sub>	318
PEEK capsule	795
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dummy (capsule + glue + kapton)	926
Gd <sub>2</sub> O <sub>3</sub>	317
Gd oxide sample (oxide + PEEK)	1243
Gd mass (oxide is Gd <sub>2</sub> O <sub>3</sub> )	276
Gd-160 mass (98.1 % enrichment)	270

#### But this time...

Sample irradiated for 55 days at the thermal reactor of ILL: <sup>155</sup>Gd and <sup>157</sup>Gd burned out!!!

Gd-160 enrichment:	
Isotope	[%]
Gd-152	3.80E-05
Gd-153	3.90E-10
Gd-154	0.02
Gd-155	3.30E-05
Gd-156	0.59
Gd-157	4.20E-06
Gd-158	1.29
Gd-160	98.1

### Samples: Gd sample, X-ray Spectroscopy



Average thickness ~ 2.10 +/- 0.01 mm

## Experimental Setup @ EAR1 and EAR2

#### Liquid scintillation detectors with **deutered benzene**: (C<sub>6</sub>D<sub>6</sub> & sTED)

- Low neutron sensitivity
- Low γ-ray detection efficiency

The **total energy detection principle** by combining the detection system with the so-called **Pulse Height Weighting Technique (PHWT).** 

For details see: <u>P. Schillebeeckx *et al.*, Nucl. Data Sheets **113**, 3054 (2012) <u>A. Borella, G. Aerts, F. Gunsing *et al.*, Nucl. Instr. Meth. A **577**, 626 (2007)</u></u>

#### EAR1

- Flight Path: **185 m**
- Flux: 10<sup>6</sup>/cm<sup>2</sup>/Proton Bunch
- Very High Resolution: < 10<sup>-3</sup>

# Experimental Setup @ EAR1 and EAR2

Liquid scintillation detectors with **deutered benzene:** (C<sub>6</sub>D<sub>6</sub> & sTED)

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#### EAR1: $4 C_6 D_6$



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# Experimental Setup @ EAR1 and EAR2

Liquid scintillation detectors with **deutered benzene**: (C<sub>6</sub>D<sub>6</sub> & sTED)

- Low neutron sensitivity
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The **total energy detection principle** by combining the detection system with the so-called **Pulse Height Weighting Technique (PHWT).** 

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# EAR1

#### (Resolved and Unresolved Resonances Region)









# Low Thresholds: after pulse rejection and dead-time

C6D61 2D





Sn\_Au = 6.5 MeV Sn\_Gd = 5.6 MeV



Sn\_Au = 6.5 MeV Sn\_Gd = 5.6 MeV





#### **Evaluated Flux**



27

## Au-197: normalization factors



#### Au-197: TOF – neutron energy check (transport code and SAMMY) Au-197



#### Au-197: TOF – neutron energy check (transport code and SAMMY) Au-197



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#### *Au-197: TOF – neutron energy check* (transport code and SAMMY) Au-197



#### Gd-160: normalization factors



#### Gd-160: normalization factors



<sup>160</sup>Gd

#### Yields...



#### Yields...



RSA by SAMMY code

1 2 3 4 5 6 7	Gd160 dummy case Gd 160 151.920066 5   TWENTY USE NEW SPIN GROUP FORMAT NUMBER   REICH-MOORE FORMALISM IS WANTED PRINT ALL INPUT PARAmeters   BROADENING IS WANTED USE FORM COMPLEXE FOR PROADENING		0.9 RADIUS PARAMETERS FOLLOW 7.4763380 7.4763380 0 0 1 7.4763380 7.4763380 0 0 2 3 7.8000000 7.8000000 0 0 4 7.8000000 7.8000000 0 0 5 6
9	DOUBLE		7.9000000 $7.9000000$ $0$ $0$ $7$ $8$
10	NORMALIZE AS YIELD Rather than cross section		7.9000000 7.9000000 0 0 9
11	eV		7.9000000 7.9000000 0 01011
12	PUBLISH		7.9000000 7.9000000 0 01213
13			7.4000000 7.4000000 0 014
14	294.15 183.9252 0.007 7.4763380 3.3100e_4 0.00000		8.5000000 8.5000000 0 01516
16	CAPTIIRF		8.0000000 8.0000000 0 017
17	1 1 0 0.5 1.0 0.0	#qd160	
18	1 1 0 0 0.5	2	NUCLIDE MASSES AND ABUNDANCES FOLLOW
19	2 1 0 -0.5 1.0 0.0		159.926848 .98086900 0. 0 1 2 3
20	1 1 0 1 0.5		157.923640 1.290E-02 0. 0 4 5 6
21			156.924053 4.200E-08 0. 0 7 8
22	4 1 0 0 5 1 0 0 0	#ad158	155.922449 5.900E-03 0. 0 91011
24		#gu130	154 922862 3 300E-07 0 01213
25	5 1 0 -0.5 1.0 0.0		153 921257 3 3025E-4 0 014
26	1 1 0 1 0.5		152 921671 3 900E-12 0 01516
27	6 1 0 -1.5 1.0 0.0		152.521071 5.5000 12 0. 01510
28		# 11 F C	151.920000 5.0000-07 0. 017
29	9 1 0 0.5 1.0 0.0	#ga156	
30			T 4762800 204 15000 0002200 0 0 0 0 0 0 0 0 0 0 0 0 0 0
32			
33	11 1 0 -1.5 1.0 0.0		
34	1 1 0 1 0.5		MISCEllaneous parameters follow
35	14 1 0 0.5 1.0 0.0	#gd154	TZERO 0 0 .00000000 .00000000 .99999999 .00000000
36	1 1 0 0 0.5		
37 38 39	2.100e-1 1.00 0.0 0.0		NORMAlization and "constant" background follow 1.00000000 1.89773-8 0. 0. 0. 0. 0. 0. 0 1 0 0 0 0
40	USER-DEFINED RESOLUTION FUNCTION		$.005000000 \ 1.00000 \ 9 \ 1.00000 \ 8 \ 0.$ 0. 0.
41	FILE=RF EAR1 v2 CORR.txt		

RSA by SAMMY code

1	Gd160 dumm					
2	Gd 160	151 920066		5		0.9
3	TWENTY	191.920000		5		RADIUS PARAMETERS FOLLOW
4	USE NEW SP	IN GROUP FO	RMAT NUMBER			7.4763380 7.4763380 0 0 1
5	REICH MOOR	E FORMALISM	IS WANTED			7.4763380 7.4763380 0 0 2 3
6	PRINT ALL	INPUT PARAme	eters			7,8000000 7,8000000 0 0 4
7	BROADENING	IS WANTED				7 8000000 7 8000000 0 0 5 6
8	USE FREE G	AS MODEL OF	DOPPLER BROAD	DENING		
9	DOUBLE					
10	NORMALIZE	AS YIELD Ra	ther than cros	ss section		
11	eV					
12	PUBLISH					7.9000000 7.9000000 0 01213
13	204 15	102 0252		0.007		7.4000000 7.4000000 0 014
14	294.15	2 21000 4		0.007		8.5000000 8.5000000 0 01516
16		5.51096-4		0.00000		8,0000000 8,0000000 0 017
17	1 1	0 0.5	1.0 0.0	9	#ad160	
18	1 1	0 0	0.5	-	<i>"</i> ga200	NUCLIDE MASSES AND ABUNDANCES FOLLOW
19	2 1	0 -0.5	1.0 0.0	Ð		
20	1 1	0 1	0.5			
21	3 1	0 -1.5	1.0 0.0	9		
22	1 1	0 1	0.5			156.924053 4.2000-08 0. 0 7 8
23	4 1	0 0.5	1.0 0.0	9	#gd158	155.922449 5.900E-03 0. 0 91011
24	1 1	0 0	0.5	_		154.922862 3.300E-07 0. 01213
25	5 1	0 -0.5	1.0 0.0	Э		153.921257 3.3025E-4 0. 014
26		0 1	0.5	2		152.921671 3.900E-12 0. 01516
27	0 1	0 -1.5	1.0 0.0	9		151.920066 3.800E-07 0. 017
28			0.5	9	#ad156	
30	1 1	0 0.5	0.5	5	#gu150	BROADENTNG PARAMETERS FOLLOW
31	10 1	0 - 0 5	1.0 0.0	9		
32	1 1	0 1	0.5	0		7.4703800 294.13000 .0003309 0. 0. 0. 0. 0. 0.000 0 0
33	11 1	0 -1.5	1.0 0.0	9		
34	1 1	0 1	0.5			MISCEllaneous parameters tollow
35	14 1	0 0.5	1.0 0.0	9	#gd154	TZERO 0 0 .00000000 .00000000 .99999999 .00000000
36	1 1	0 0	0.5		-	
37						NORMAlization and "constant" background follow
38	2.100e-1	1.00	0.0	0.0		1.00000000 1.89773-8 0. 0. 0. 0. 0 1 0 0 0
39						.005000000 1.00000-9 1.00000-8 0. 0. 0.
40	USER-DEFIN	ED RESOLUTI	DN FUNCTION			
41	FILE=RF EA	RI VZ CORR.	txt			

RSA by SAMMY code

1 2 3 4 5 6 7 8 9 10 11 12	Gd160 dum Gd 160 TWENTY USE NEW SI REICH MOO PRINT ALL BROADENING USE FREE DOUBLE NORMALIZE eV PUBLISH	ny case 151.920066 PIN GROUP FOF RE FORMALISM INPUT PARAme G IS WANTED GAS MODEL OF AS YIELD Rat	RMAT NUMBER IS WANTED eters DOPPLER BROADENING ther than cross sectio	5	0.9 RADIUS PARAMETERS FOLLOW 7.4763380 7.4763380 0 0 1 7.4763380 7.4763380 0 0 2 3 7.8000000 7.8000000 0 0 4 7.8000000 7.8000000 0 0 5 6 7.9000000 7.9000000 0 0 7 8 7.9000000 7.9000000 0 0 9 7.9000000 7.9000000 0 0 9
13	TODEISH				7.4000000 7.4000000 0.01215
14	294.15	183.9252		0.007	
15	7.4763380	3.3109e-4		0.00000	
16	CAPTURE		1 0 0 0	#= 11CO	
10	1		1.0 0.0	#ga160	NUCLTRE MASSES AND ABUNDANCES FOLLOW
19	2	1 0 0	1000		NUCLIDE MASSES AND ADUNDANCES FULLOW
20	- 1	1 0 1	0.5		159.926848 .98086900 0. 0 1 2 3
21	3	1 0 - 1.5	1.0 0.0		157.923640 1.290E-02 0. 0 4 5 6
22	1	1 0 1	0.5		156.924053 4.200E-08 0. 0 7 8
23	4	1 0 0.5	1.0 0.0	#gd158	155.922449 5.900E-03 0. 0 91011
24	1	1 0 0	0.5	-	154.922862 3.300E-07 0. 01213
25	5	1 0-0.5	1.0 0.0		153,921257 3,3025E-4 0. 014
26	1	1 0 1	0.5		152 921671 3 900E-12 0 01516
27	6	1 0 -1.5	1.0 0.0		
28	1	1 0 1	0.5	<b>"</b> 1150	151.520000 5.0002-07 0. 017
29	9		1.0 0.0	#ga156	PROADENING DADAMETERS FOLLOW
20	10	1 0 0			BRUADENTING PARAMETERS FOLLOW
32	10	1 0 0.5	0.5		
33	11	1 0 - 1 . 5	1.0 0.0		
34	1	1 0 1	0.5		MISCEllaneous parameters follow
35	14	1 0 0.5	1.0 0.0	#gd154	TZERO 0 0 .00000000 .00000000 .99999999 .00000000
36	1	1 0 0	0.5	2	
37					NORMAlization and "constant" background follow
38	2.100e-	1 1.00	0.0 0.0	•	
39					.005000000 1.00000-9 1.00000-8 0. 0. 0.
40	USER-DEFI	NED RESOLUTIO	JN FUNCTION		
41	FILE=KF E	AKI VZ CURR.1	LXL		

RSA by SAMMY code

1 2 3 4 5 6 7 8 9 10 11 12	Gd160 dumr Gd 160 TWENTY USE NEW SP REICH MOOI PRINT ALL BROADENING USE FREE O DOUBLE NORMALIZE eV PUBLISH	ny case 151.920066 PIN GROUP FOR RE FORMALISM INPUT PARAme G IS WANTED GAS MODEL OF AS YIELD Rat	MAT NUMBER <del>IS WANTED</del> ters DOPPLER BROADENI <del>her than cross s</del>	5 NG		0.9 RADIUS PARAMETERS FOLLOW 7.4763380 7.4763380 0 0 1 7.4763380 7.4763380 0 0 2 3 7.8000000 7.8000000 0 0 4 7.8000000 7.8000000 0 0 5 6 7.9000000 7.9000000 0 0 7 8 7.9000000 7.9000000 0 0 9 7.9000000 7.9000000 0 01011 7.9000000 7.9000000 0 01213
13 14 15 16	294.15 7.4763380 CAPTURE	183.9252 3.3109e-4		0.007 0.00000		7.4000000 7.4000000 0 014 8.5000000 8.5000000 0 01516 8.0000000 8.0000000 0 017
17 18 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34	1 1 2 1 3 1 4 1 5 1 6 1 9 1 10 1 1 1 1 1 1 1 1 1 1 1 1 1	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$		#gd160 #gd158 #gd156	NUCLIDE MASSES AND ABUNDANCES FOLLOW   159.926848 .98086900 0. 0 1 2 3   157.923640 1.290E-02 0. 0 4 5 6   156.924053 4.200E-08 0. 0 7 8   155.922449 5.900E-03 0. 0 91011   154.922862 3.300E-07 0. 01213   153.921257 3.3025E-4 0. 014   152.921671 3.900E-12 0. 01516   151.920066 3.800E-07 0. 017   BROADENING PARAMETERS FOLLOW 0. 0. 0 0 0 0 0 0   MISCEllaneous parameters follow 0. 0. 0 0 0 0 0 0
35 36 37 38	14 1 1 2.100e-1	L 0 0.5 D 0 0	1.0 0.0 0.5 0.0 0	0.0	#gd154	TZER0 0 0 .00000000 .00000000 .99999999 .00000000 183.9252   NORMAlization and "constant" background follow 1.00000000 1.89773-8 0.
39 40 41	USER-DEFIN FILE=RF E/	NED RESOLUTIO AR1 v2 CORR.t	N FUNCTION xt			.005000000 1.00000-9 1.00000-8 0. 0. 0.

#### RSA up to 10 keV



41

## Main <sup>160</sup>Gd capture resonance



42

*RSA*...







#### *RSA... unricognized structures*



#### *RSA... unricognized structures*



#### Unsigned structures above 10 keV



#### structure @ 635 eV





48 rows	IECC									
Search	Incident particle	Evaluation	n Material	E						
NEA	Incident neutron data	JEFF-3.3	As72	635.0613						
NEA	Incident neutron data	JEFF-3.3	As74	637.2687	<b>20</b>					
NEA	Incident neutron data	JEFF-3.3	As74	637.3422	7.7.7	PV				
NEA	Incident neutron data	JEFF-3.3	Sr84	635						
NEA	Incident neutron data	JEFF-3.3	Sr89	636.8112						
NEA	Incident neutron data	JEFF-3.3	Ru99	636.2						
NEA	Incident neutron data	JEFF-3.3	Pd108	636.2						
NEA	Incident neutron data	JEFF-3.3	Pd110	636.5						
	Incident neutron data	JEFF-3.3	Ag108	635.36	07					
	Incident neutron data	JEFF-3.3	Ag109	637 1204	27 rows		ENDF			
	Incident neutron data	JEFF-3.3	Ag110	637.4988	Search	Incident particle	Evaluation	Matorial	E	
NEA	Incident neutron data	JEFF-3.3	Cd106	635.087	NEA	Incident particle		Material	L .	1
NEA	Incident neutron data	JEFF-3.3	In114	634.3417	INEA	Incident neutron data	ENDF/B-VIII.0	AS73	637.6	
NEA	Incident neutron data	JEFF-3.3	In114	637.0182	NEA	Incident neutron data	ENDF/B-VIII.0	RD86	636	
NEA	Incident neutron data	JEFF-3.3	Sb126	634.5823	NEA	Incident neutron data	ENDF/B-VIII.0	Sr84	635	
NEA	Incident neutron data	JEFF-3.3	Te121	635.9277	NEA	Incident neutron data	ENDF/B-VIII.0	Ru99	636.2	
NEA	Incident neutron data	JEFF-3.3	1127	635.75	NEA	Incident neutron data	ENDF/B-VIII.0	Pd108	636.2	
	Incident neutron data	JEFF-3.3	Xe127	637.111	NFA	Incident neutron data	ENDE/B-VIII 0	Pd110	636.5	
	Incident neutron data	JEFF-3.3	Re129	630.8	NEA	Incident neutron data		10110	630.5	
	Incident neutron data	IEFE-3.3	Ba131	635 5911	NEA	Incident neutron data		Agrii	034.5	
NEA	Incident neutron data	JEFF-3.3	La138	635.7065	NEA	Incident neutron data	ENDF/B-VIII.0	Cd106	635.087	
NEA	Incident neutron data	JEFF-3.3	Ce137	636.527	NEA	Incident neutron data	ENDF/B-VIII.0	Xe129	636.8	
NEA	Incident neutron data	JEFF-3.3	Ce143	636.832	NEA	Incident neutron data	ENDF/B-VIII.0	Pr141	635.8	
NEA	Incident neutron data	JEFF-3.3	Pr141	635.8	NEA	Incident neutron data	ENDF/B-VIII.0	Nd142	636.4	
NEA	Incident neutron data	JEFF-3.3	Nd142	636.4	NFA	Incident neutron data	ENDE/B-VIII 0	Pm145	634 7093	1
NEA	Incident neutron data	JEFF-3.3	Gd149	635.845	NEA	Incident neutron data		Dv161	635.3	
	Incident neutron data	JEFF-3.3	1D159	637.6	NEA	Incident neutron data		Dutch	633.3	
	Incident neutron data	JEFF-3.3	Dy161	635.3	INEA	Incident neutron data	ENDF/B-VIII.0	Dy163	637.17	4 10
NFA	Incident neutron data	JEFF-3.3	Ho165	634.8	NEA	Incident neutron data	ENDF/B-VIII.0	Ho165	634.8	
NEA	Incident neutron data	JEFF-3.3	Er167	636.9	NEA	Incident neutron data	ENDF/B-VIII.0	Er167	636.9	
NEA	Incident neutron data	JEFF-3.3	Tm170	635.7607	NEA	Incident neutron data	ENDF/B-VIII.0	Re187	636	
NEA	Incident neutron data	JEFF-3.3	Yb168	636.2426	NEA	Incident neutron data	ENDF/B-VIII.0	Os186	634.7	1
NEA	Incident neutron data	JEFF-3.3	Hf177	634.32	NFA	Incident neutron data	ENDE/B-VIII 0	Os187	636.5	i A
NEA	Incident neutron data	JEFF-3.3	Ta181	636.29		Incident neutron data		lc104m	624 2605	
NEA	Incident neutron data	JEFF-3.3	Re187	636	NEA	Incident neutron data		11 194111	034.3005	
	Incident neutron data	JEFF-3.3	Re188	635.007	INEA	Incident neutron data	ENDF/B-VIII.0	0234	637	
	Incident neutron data	JEFF-3.3	Oc187	636.5	NEA	Incident neutron data	ENDF/B-VIII.0	U235	635.3727	
NEA	Incident neutron data	JEFF-3.3	U234	637	NEA	Incident neutron data	ENDF/B-VIII.0	U235	635.9863	
NEA	Incident neutron data	JEFF-3.3	U235	635.3746	NEA	Incident neutron data	ENDF/B-VIII.0	U235	636.5657	
NEA	Incident neutron data	JEFF-3.3	U235	635.9864	- NEA	Incident neutron data	ENDF/B-VIII.0	U238	636.5637	
NEA	Incident neutron data	JEFF-3.3	U235	636.5639	NFA	Incident neutron data	ENDE/B-VIII 0	Pu239	637 2534	900 950
NEA	Incident neutron data	JEFF-3.3	U238	636.5637	NEA	Incident neutron data		Du240	637 / 2/1	neutron energy [eV]
	Incident neutron data	JEFF-3.3	Pu239	637.2519	INEA	Incluent neutron data		PU240	037.4241	
INEA	incident neutron data	JEFF-3.3	PU240	037.56						

48 rows

48 rows	ICCC										1	17 гом	s TEN	וחו		
Search	Incident particle	Evaluation	Materia	I F								Search	Incident particle	Evaluation	Material	E
NFA	Incident peutrop data	IFFE-3 3	Δs72	635 0613							1	VEA	Incident neutron data	TENDL-2019	Mn50m	634.465
NFA	Incident neutron data	JEFE-3.3	As74	637,2687							Ī	IEA	Incident neutron data	TENDL-2019	Co62	634.6249
NFA	Incident neutron data	JEFE-3.3	As74	637.3422	<b>7</b> '	イフ	$\rho_V$				1	<b>IEA</b>	Incident neutron data	TENDL-2019	Cu76m	634.6431
NFA	Incident neutron data	JEFE-3.3	Sr84	635							1	VEA	Incident neutron data	TENDL-2019	Ga65	637.5577
NFA	Incident neutron data	JEFE-3.3	5189	636.8112							1	<b>NEA</b>	Incident neutron data	TENDL-2019	As73	637.4963
NEA	Incident neutron data	JEFF-3.3	Ru99	636.2							<u> </u>	IEA	Incident neutron data	TENDL-2019	Br79m	636.5836
NEA	Incident neutron data	JEFF-3.3	Pd108	636.2							<u> </u>	IEA	Incident neutron data	TENDL-2019	Rb86	635.5952
NEA	Incident neutron data	JEFF-3.3	Pd110	636.5								IEA	Incident neutron data	TENDL-2019	Sr84	635
NEA	Incident neutron data	JEFF-3.3	Aq108	635.36							-	VEA	Incident neutron data	TENDL-2019	Nb102m	637.2151
NEA	Incident neutron data	JEFF-3.3	Ag109	634.5		27 rows					- 4	VEA	Incident neutron data	TENDL-2019	ND106	635.9606
NEA	Incident neutron data	JEFF-3.3	Ag110	637.1204		2110103		LINDF					Incident neutron data	TENDL-2019	ND94	635.6213
NEA	Incident neutron data	JEFF-3.3	Ag110	637.4988		Search	Incident particle	Evaluation	Material	F			Incident neutron data	TENDL-2019	IND95	636.027
NEA	Incident neutron data	JEFF-3.3	Cd106	635.087		NEA	Incident neutron data		Ac73	637.6	l li		Incident neutron data	TENDL-2019	ND98	637.4332
NEA	Incident neutron data	JEFF-3.3	In114	634.3417			incident neutron data		AS7 5	037.0	l i		Incident neutron data	TENDL-2019	Mo102	635.5377
NEA	Incident neutron data	JEFF-3.3	In114	637.0182		NEA	Incident neutron data	ENDF/B-VIII.0	RD86	636			Incident neutron data	TENDL-2019	Tc95	637 2974
NEA	Incident neutron data	JEFF-3.3	Sb126	634.5823		NEA	Incident neutron data	ENDF/B-VIII.0	Sr84	635	l i		Incident neutron data	TENDL-2019	Tc95m	637 5628
NEA	Incident neutron data	JEFF-3.3	Te121	635.9277		NFA	Incident neutron data	ENDE/B-VIII.0	Ru99	636.2	l li		Incident neutron data	TENDI -2019	Rugg	635 7896
NEA	Incident neutron data	JEFF-3.3	127	635.75			Incident neutron data		Dd109	626.2	l li	JEA	Incident neutron data	TENDI -2019	Ru99	636.2
NEA	Incident neutron data	JEFF-3.3	Xe127	637.111		INEA	Incident neutron data		PUIVo	030.2	l i	JEA	Incident neutron data	TENDI -2019	Rh101	634,4981
NEA	Incident neutron data	JEFF-3.3	Xe129	636.8		NEA	Incident neutron data	ENDF/B-VIII.0	Pd110	636.5	i	VEA	Incident neutron data	TENDL-2019	Rh101	635.4865
NEA	Incident neutron data	JEFF-3.3	Ba131	634.9718		NEA	Incident neutron data	ENDF/B-VIII.0	Ag111	634.5	Ī	<b>IEA</b>	Incident neutron data	TENDL-2019	Rh111	635.7004
NEA	Incident neutron data	JEFF-3.3	Ba131	635.5911		NFA	Incident neutron data	ENDE/B-VIIL0	Cd106	635.087	Ī	IEA	Incident neutron data	TENDL-2019	Rh98m	636.0915
NEA	Incident neutron data	JEFF-3.3	La138	635.7065			Incident neutron data		Vo120	636.007	···· Ī	IEA	Incident neutron data	TENDL-2019	Rh99	636.2984
NEA	Incident neutron data	JEFF-3.3	Ce137	636.527		INEA	Incident neutron data		Ae129	030.0	Ī	IEA	Incident neutron data	TENDL-2019	Pd108	636.2
NEA	Incident neutron data	JEFF-3.3	Ce143	636.832		NEA	Incident neutron data	ENDF/B-VIII.0	Pr141	635.8	Ī	<b>IEA</b>	Incident neutron data	TENDL-2019	Pd110	636.5
NEA	Incident neutron data	JEFF-3.3	Pr141	635.8		NEA	Incident neutron data	ENDF/B-VIII.0	Nd142	636.4		<b>NEA</b>	Incident neutron data	TENDL-2019	Ag105	634.7806
NEA	Incident neutron data	JEFF-3.3	Nd142	636.4		NFA	Incident neutron data	ENDE/B-VIII 0	Pm145	634 7093	····	IEA	Incident neutron data	TENDL-2019	Ag105	635.3285
NEA	Incident neutron data	JEFF-3.3	Gd149	635.845			Incident neutron data		Dudea	(25.2	<u> </u>	IEA	Incident neutron data	TENDL-2019	Ag116	634.3221
NEA	Incident neutron data	JEFF-3.3	Tb159	637.6		INEA	incident neutron data	EINDF/B-VIII.0	Dy161	035.3		IEA	Incident neutron data	TENDL-2019	Cd99	635.2761
NEA	Incident neutron data	JEFF-3.3	Dy161	635.3		NEA	Incident neutron data	ENDF/B-VIII.0	Dy163	637.17	4	NEA .	Incident neutron data	TENDL-2019	Cd99	637.3324
NEA	Incident neutron data	JEFF-3.3	Dy163	637.17		NEA	Incident neutron data	ENDF/B-VIII.0	Ho165	634.8		VEA	Incident neutron data	TENDL-2019	In122	636.9546
NEA	Incident neutron data	JEFF-3.3	H0165	634.8		NFA	Incident neutron data	ENDE/B-VIII 0	Fr167	636.9			Incident neutron data	TENDL-2019	IN122	637.2724
NEA	Incident neutron data	JEFF-3.3	Er16/	636.9			Incident neutron data		De497	(2)			Incident neutron data	TENDL-2019	IN124	637.0118
	Incident neutron data	JEFF-3.3	1m1/0	635.7607		INEA	incident neutron data	EINDF/B-VIII.0	Re187	030	l i		Incident neutron data	TENDL-2019	In124m	635.2783
	Incident neutron data	JEFF-3.3	YD168	636.2426		NEA	Incident neutron data	ENDF/B-VIII.0	Os186	634.7			Incident neutron data	TENDL-2019	50110	636 6528
	Incident neutron data	JEFF-3.3	HF1//	634.32		NEA	Incident neutron data	ENDF/B-VIII.0	Os187	636.5	l li		Incident neutron data	TENDL-2019	50113	637 2378
	Incident neutron data	JEFF-3.3	1a181	636.29			Incident neutron data	ENDE/B-VIII 0	lr194m	634 3605	l i		Incident neutron data	TENDL-2019	1127	635.75
	Incident neutron data	JEFF-3.3	Re187	636			Incident neutron data		11224	607.0000	l li		Incident neutron data	TENDI -2019	Xe124	637,1186
	Incident neutron data	JEFF-3.3	Re188	635.007		INEA	Incident neutron data	ENDF/B-VIII.0	0234	637		JEA	Incident neutron data	TENDI -2019	Xe129	636.8
	Incident neutron data	JEFF-3.3	0c197	637.4905		NEA	Incident neutron data	ENDF/B-VIII.0	U235	635.3727		VEA	Incident neutron data	TENDL-2019	Cs135	636.1415
	Incident neutron data		11224	627		NEA	Incident neutron data	ENDF/B-VIII.0	U235	635.9863	i	VEA	Incident neutron data	TENDL-2019	La146	637.5143
	Incident neutron data	JEFF-3.3	11225	635 27/4	a 📩	NFA	Incident neutron data	ENDE/B-VIII 0	11235	636 5657	<b>k</b> 1	VEA	Incident neutron data	TENDL-2019	Ce138	635.8478
	Incident neutron data	JEFF-3.3	11225	635 0964	T Per				0233	636.3037	1	VEA	Incident neutron data	TENDL-2019	Ce141	635.3785
	Incident neutron data	JEFF-3.3	11235	636 5630	5	INEA	incident neutron data	ENDF/B-VIII.0	0238	636.5637	Ī	IEA	Incident neutron data	TENDL-2019	Ce141	636.4137
	Incident neutron data	JEFF-3.3	11238	636 5637	1	NEA	Incident neutron data	ENDF/B-VIII.0	Pu239	637.2534	Ī	VEA	Incident neutron data	TENDL-2019	Рг141	635.8
	Incident neutron data	IFFF-3.3	Du230	637 2519		NEA	Incident neutron data	ENDF/B-VIII.0	Pu240	637,4241	Ī	<b>IEA</b>	Incident neutron data	TENDL-2019	Рг143	635.162
	Incident neutron data	IFFF-3.3	Pu240	637.56								<b>IEA</b>	Incident neutron data	TENDL-2019	Рг147	636.7186
	inclucine neutron data	5011-5.5	p 0240	057.50							1	<b>IEA</b>	Incident neutron data	TENDL-2019	Pr154	635.4293

#### Extracted kernels



#### Extracted kernels

 $\Gamma_{\gamma 0} = 74.99 \pm 0.62 \ meV$ 

 $\Gamma_{n0} = 4.73 \pm 0.12 \ meV$ 



#### Extracted kernels



#### Kernels comparison



kernel ratio



URR





URR



# EAR2

#### (Thermal and Resolved Resonances Region)

#### sTED scintillators

Whole Energy Range



## Conclusions

#### **STEPS DONE & TO DO (EAR1)**

- *Kernel average uncertainty* ≤ 12.0 %
- Dummy background subtracted + in beam γ-rays
- *RRR analized by R-matrix SAMMY Code + unsigned structures + URR*

#### TO DO (EAR2)

- Implementation of the Setup geometry and energy loss (MC code) to get the WF for the PHWT
- Extract the Yield from Weighted Counts and normalize at @4.9 eV of Au
- Study of the reaction at low neutron energies and the RRR

# Thank You

# Conclusions (EAR2)

- The <sup>160</sup>Gd(n,γ) has been measured from thermal to a few hundreds of keV in both n\_TOF experimental area
- The preliminary results have a good S/B ratio in the thermal and in RRR

#### TO DO

- Implementation of the Setup geometry and energy loss (MC code) to get the WF for the PHWT
- Extract the Yield from Weighted Counts and normalize at @4.9 eV of Au
- Study of the reaction at low neutron energies and the RRR