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Arnaud Guertin, Etienne Nigrón, Alexandre Rintaud, Maxence Rayer, Lucas Granger, et al.. Measurements of  $^{161}\text{Tb}$  Production Cross Section for Nuclear Data and Nuclear Medicine. *Advances in Radioactive Isotope Science* 2023, Jun 2023, Avignon, France. hal-04143053

**HAL Id: hal-04143053**

**<https://hal.science/hal-04143053>**

Submitted on 27 Jun 2023

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# Measurements Of $^{161}\text{Tb}$ Production Cross Section For Nuclear Data And Nuclear Medicine

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## $^{161}\text{Tb}$ «ID card»

$^{161}\text{Tb}$  decays to  $^{161}\text{Dy}$  (stable) by  $\beta^-$  emission at 100 %.  
 $T_{1/2} = 6.89$  days [1].  
 Main  $\beta^-$  and gamma emissions (intensity > 1%).  
 $E_{\beta^-} = 138$  keV 461 (26%),  $E_{\beta^-} = 157$  keV 518 (64%),  
 $E_{\beta^-} = 175$  keV 567 (5%),  $E_{\beta^-} = 184$  keV 593 (5%).  
 $E_{\gamma} = 25.6$  keV (23.2 %),  $E_{\gamma} = 48.9$  keV (17.0 %),  
 $E_{\gamma} = 57.2$  keV (1.8 %),  $E_{\gamma} = 25.6$  keV (23.2 %).

## $^{161}\text{Tb}$ medical interest

- Several terbium isotopes identified as promising for medical use [2,3]:
  - $^{152}\text{Tb}$  PET imaging
  - $^{155}\text{Tb}$  SPECT imaging
  - $^{149}\text{Tb}$   $\alpha$  therapy and control by PET
  - $^{161}\text{Tb}$   $\beta^-$  therapy
- An alternative to the clinically-applied  $^{177}\text{Lu}$  [4]:
  - Similar decay characteristics  $T_{1/2} = 6.7$  days  $E_{\beta_{\text{av}}} = 134$  keV
  - Similar coordination chemistry
- May show an increased therapeutic efficacy per decay:
  - ~ 12 e- vs ~ 1 e-  $\Rightarrow$  Larger number of conversion and Auger electrons
  - ~ 36 keV vs ~ 1.0 keV  $\Rightarrow$  Favorable energy range

**Motivation** Measure  $^{161,160}\text{Tb}$  production cross section via  $^{\text{nat}}\text{Gd}(d,x)$  as disparities exist between the published data [5, 6, 7]. Calculate yields and purity of the final product to explore a potential medical use

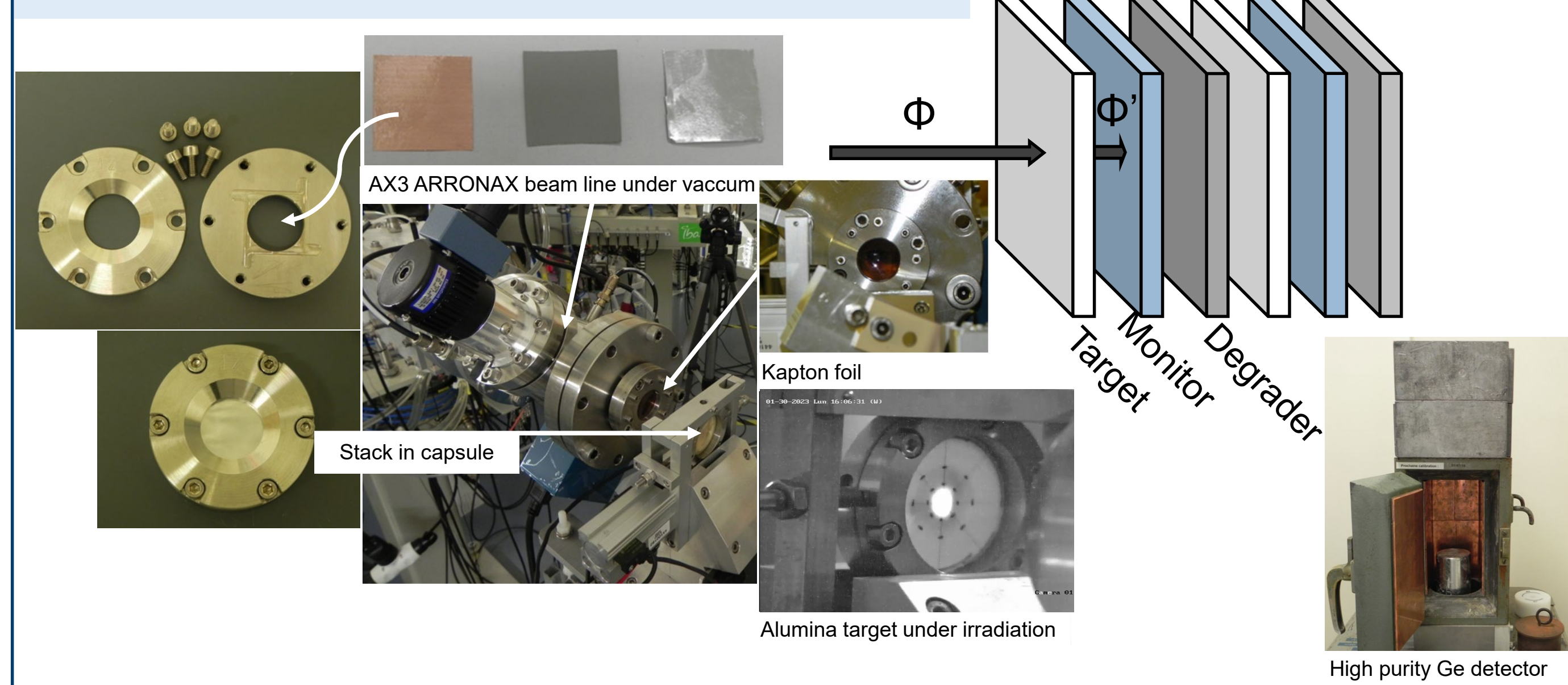
## $^{161}\text{Tb}$ production routes

- Neutron capture on  $^{160}\text{Gd}$  in reactor:  $^{161}\text{Gd}$  decaying to  $^{161}\text{Tb}$ , actual production route
- Proton induced reaction: no interest, too low cross section
- Alpha particle beam: possible but scarce availability and low production yield of the  $^{\text{nat}}\text{Gd}(\alpha,x)^{161}\text{Tb}$  reaction
- Deuteron beam:  $^{\text{nat}}\text{Gd}(d,x)^{161}\text{Tb} + ^{\text{nat}}\text{Gd}(d,p)^{161}\text{Gd}$ , **this work**.

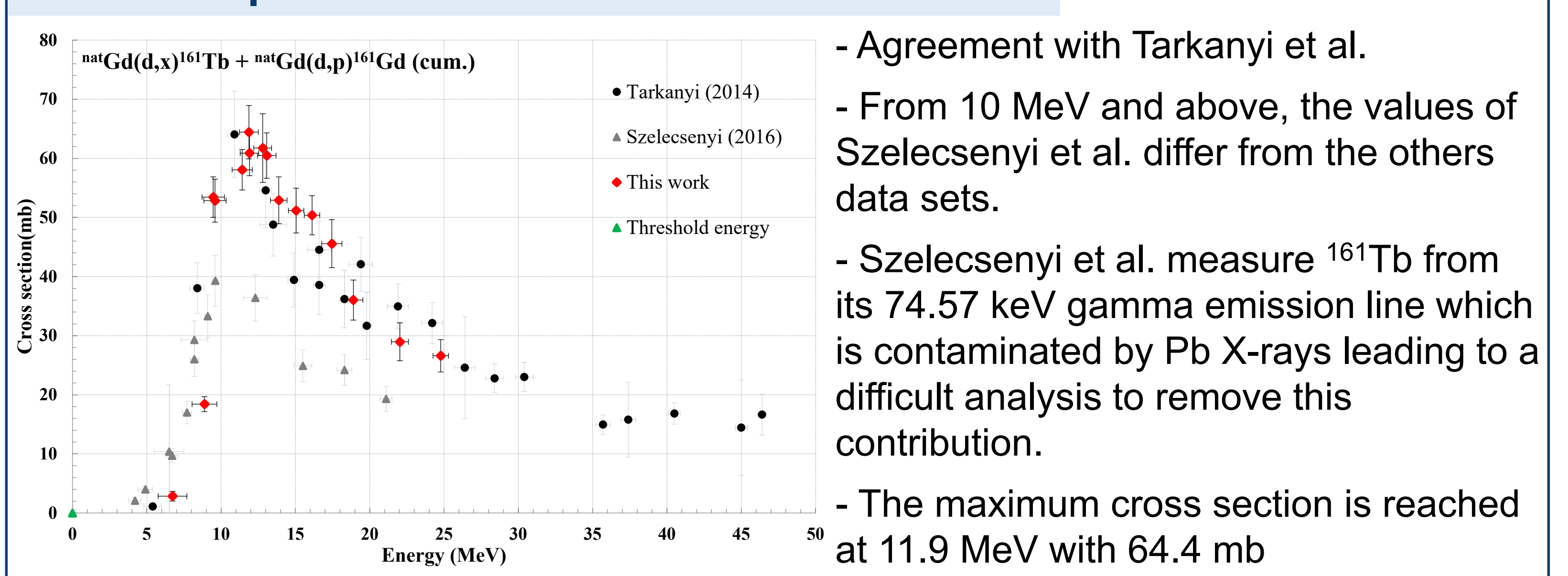
## Method

- Discrepancies between production cross section data series published [5,6,7].
- The 35 MeV deuteron beam delivered by the C70XP cyclotron at the GIP ARRONAX.
- A device devoted to production cross section measurements in the AX casemate.
- Stacked thin foils to make multiple cross section measurements in a single irradiation.
- Flux measured by monitor reaction  $^{\text{nat}}\text{Ti}(d,x)^{48}\text{V}$ , 10  $\mu\text{m}$  thick  $^{\text{nat}}\text{Ti}$  foil (99.6% elemental purity).
- gamma line used for activity measurement of  $^{161}\text{Tb}$  is 57.2 keV (1.8%).
- $^{161}\text{Gd}$ ,  $T_{1/2} = 3.7$  min, 1<sup>st</sup> measurement approximately 14 h after the EOB,  $^{161}\text{Gd}$  population is considered to have completely decayed to  $^{161}\text{Tb}$ .

## The stacked-foils method



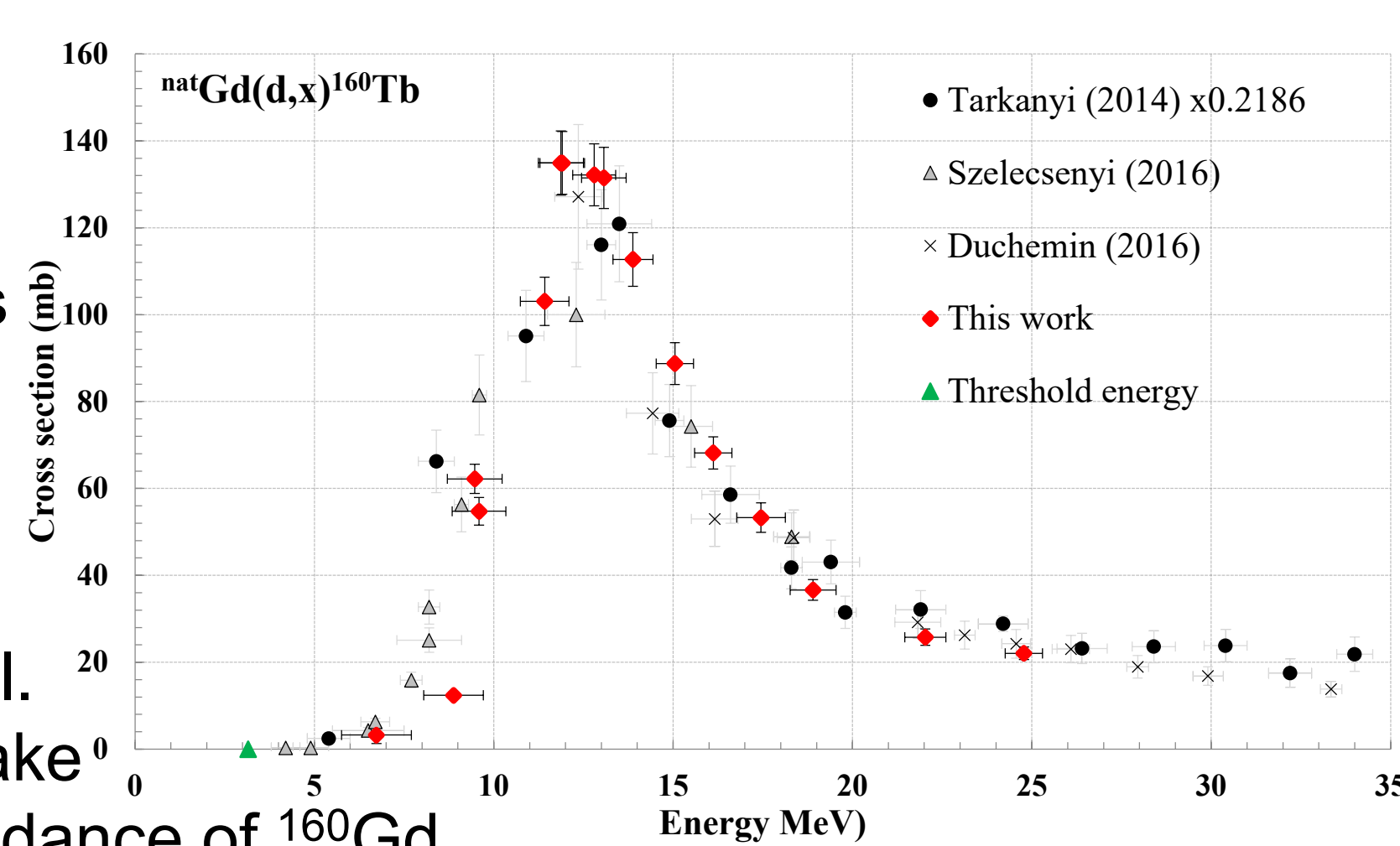
## $^{161}\text{Tb}$ production cross section



- Agreement with Tarkanyi et al.
- From 10 MeV and above, the values of Szelecsenyi et al. differ from the others data sets.
- Szelecsenyi et al. measure  $^{161}\text{Tb}$  from its 74.57 keV gamma emission line which is contaminated by Pb X-rays leading to a difficult analysis to remove this contribution.
- The maximum cross section is reached at 11.9 MeV with 64.4 mb

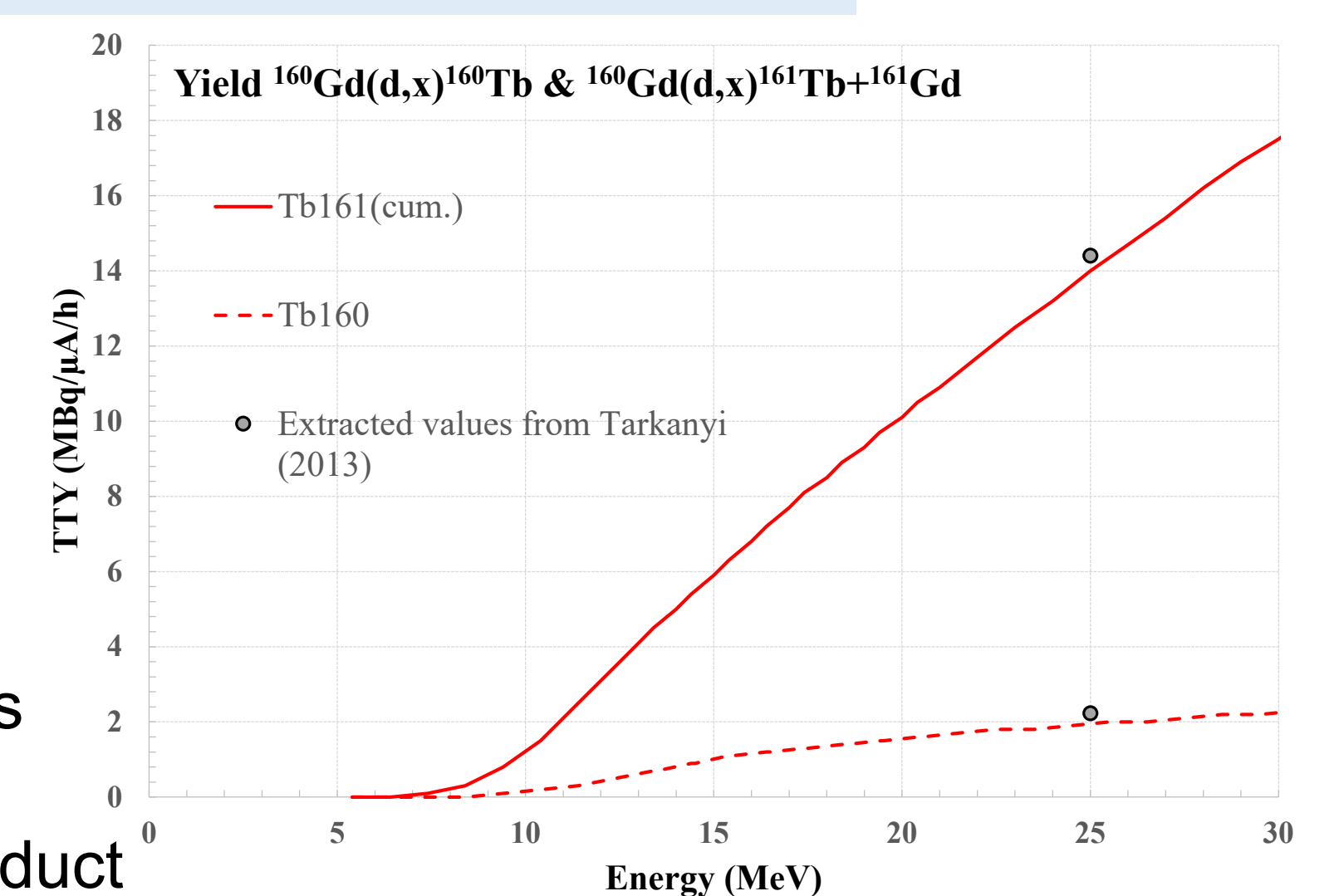
## $^{160}\text{Tb}$ production cross section

- $T_{1/2} = 72.3$  days, main contaminant
- Produced by  $^{158}\text{Gd}(d,\gamma)$  and  $^{160}\text{Gd}(d,2n)$  reactions
- Agreement with
  - Szelecsenyi et al.
  - Duchemin et al.
- Data from Tarkanyi et al. need to be corrected to take into account natural abundance of  $^{160}\text{Gd}$ .



## $^{161}\text{Tb}$ and $^{160}\text{Tb}$ Thick Target Yield (TTY)

- At 25 MeV, we extract in [5]: 4.0 GBq/C for  $^{161}\text{Tb}$  and 0.62 GBq/C for  $^{160}\text{Tb}$ .
- In this study, we calculate: 14.1 MBq/ $\mu\text{A}/\text{h}$  or 3.9 GBq/C of  $^{161}\text{Tb}$  and 1.8 MBq/ $\mu\text{A}/\text{h}$  or 0.5 GBq/C of  $^{160}\text{Tb}$ .
- We agree with Tárkányi et al. with a difference in yield of 2% for  $^{161}\text{Tb}$  and 24% for  $^{160}\text{Tb}$ .
- Radionuclidic purity of  $^{161}\text{Tb}$  at the end of the irradiation in the 8 to 20 MeV range represents 86% of the terbium activity produced.
- Radionuclidic purity prevents the use of this product for medical applications without a further mass separation step to remove  $^{160}\text{Tb}$



## Conclusions

- Our new cross sections values for the  $^{\text{nat}}\text{Gd}(d,x)^{160}\text{Tb}$  and  $^{160}\text{Gd}(d,x)^{161}\text{Tb}$  (cum.) reactions help clarify some of the discrepancies in the data available in the literature.
- Corrections to the results from the publication [6] and the corresponding results in the EXFOR database should be carried out.
- Production yields of 14.1 MBq/ $\mu\text{A}/\text{h}$  for the  $^{161}\text{Tb}$  and 1.8 MBq/ $\mu\text{A}/\text{h}$  for the  $^{160}\text{Tb}$  were obtained at 25 MeV.
- The radionuclidic purity of  $^{161}\text{Tb}$  over the 8 MeV to 20 MeV energy range was determined to be 86%.
- The co-production of other terbium isotopes limits the interesting range of energy below 20 MeV.
- Considering the limited purity of  $^{161}\text{Tb}$  using this production route, it is not a suitable one for medical applications. This may have to be reconsidered if mass separation technique can be applied with high efficiency.

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