Differential cross section measurements of the $^{6}Li\,(d, n\gamma_{1\text{-}0})^{7}Be$, $^{6}Li\,(d, p\gamma_{1\text{-}0})^{7}Li$, $^{7}Li\,(d, d\gamma_{1\text{-}0})^{7}Li$ and $^{19}F\,(d, p\gamma_{1\text{-}0})^{20}F$ reactions suitable for d-PIGE applications

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Motivation

Light elements such as lithium and fluorine, are widely used in industry.

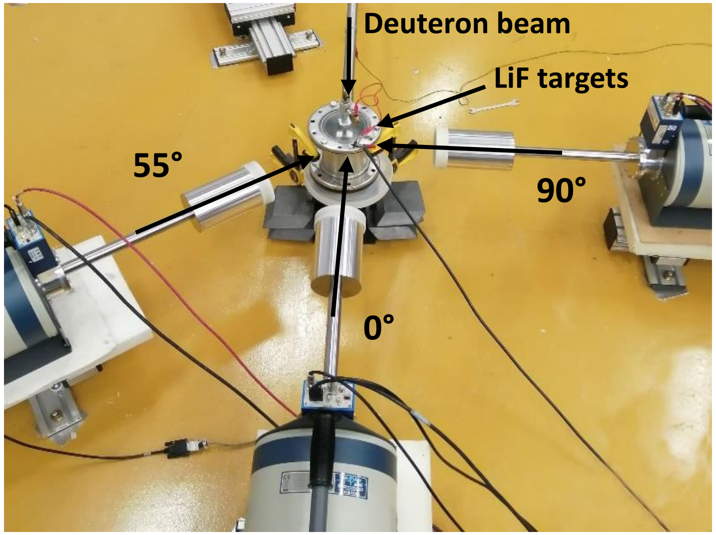
As a result, their detection and accurate quantification is of great importance. Despite the fact that proton beams are ideal for quantifying ^{7}Li and ^{19}F, they fail for the case of ^{6}Li due to the lack of an appropriate gamma – ray. In that case, deuteron beams were proposed as a more appropriate approach.

However, a survey of the existing literature proves that there is a lack of datasets in higher energies and a rather narrow range of angles covered.

In the present work, a thorough study of the reactions $^{6}Li\,(d, n\gamma_{1\text{-}0})^{7}Be$, $^{6}Li\,(d, p\gamma_{1\text{-}0})^{7}Li$, $^{7}Li\,(d, d\gamma_{1\text{-}0})^{7}Li$ and $^{19}F\,(d, p\gamma_{1\text{-}0})^{20}F$ is carried out, followed by a benchmarking procedure, necessary for the results' validation.

Experimental Setup

5.5MV Tandem Van de Graaff accelerator of NCSR "Demokritos"



- **Deuteron energy range**: from 1000 keV up to 2200 keV with a 20 keV step.
- **Beam energy**: Via Nuclear Magnetic Resonance. 0.04 keV offset, calculated with the use of the resonance at 991.89 ± 0.1 keV originating from the $^{27}Al(p,\gamma)^{28}Si$ reaction. Ripple estimated at 1.6 keV.
- **Targets**: The first was a layer of ^{nat}LiF evaporated on a thick ^{nat}Ta layer while the second one consisted of a ^{nat}C substrate on top of which a thin ^{6}LiF (95% ^{6}Li, 5% ^{7}Li) layer was created via the same technique, with a top layer of Au. The third, used for the benchmarking procedure, was a ^{nat}LiF thick target.
- **Detectors**: 3 High Purity Germanium Detectors of 80% relative efficiency, placed at 0°, 55° and 90° to the beam axis, at a ~20cm distance from the targets and a ~11° angular uncertainty.

Data Analysis

Absolute measurement

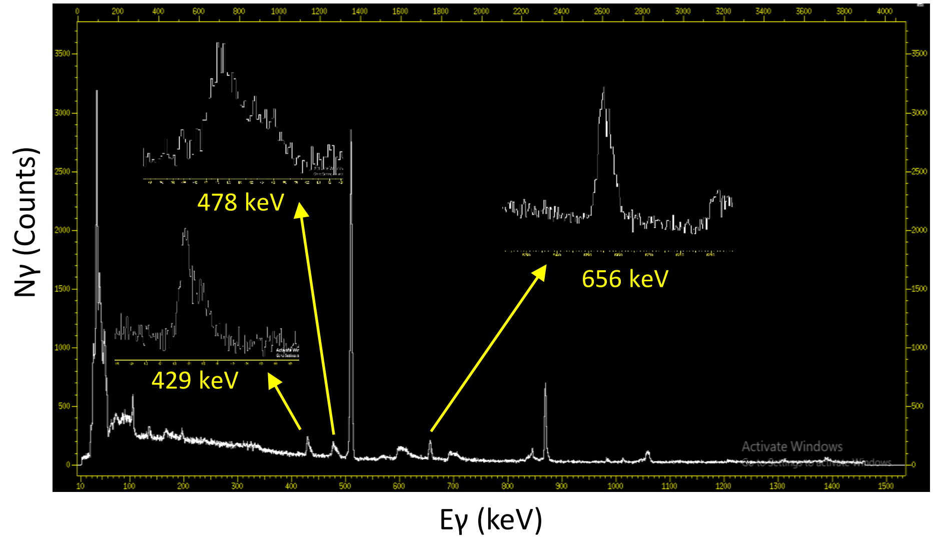
$$\frac{\mathrm{d}\sigma(E,\theta)}{\mathrm{d}\Omega} = \frac{Y(E,\theta)}{N_p \cdot N_t \cdot 4\pi \cdot \varepsilon_{abs}} [\text{barn/sr}]$$

where,

- **Y(E,θ)**: experimental yield, determined by integrating the peak of interest of each spectrum
- **N_p**: number of incident deuterons
- **N_t**: target thickness (atoms/cm^2)
- **ε_{abs}**: detector absolute efficiency

Total systematic uncertainty: ~9.6% due to target thickness, current integrator and detector efficiencies.

Spectrum



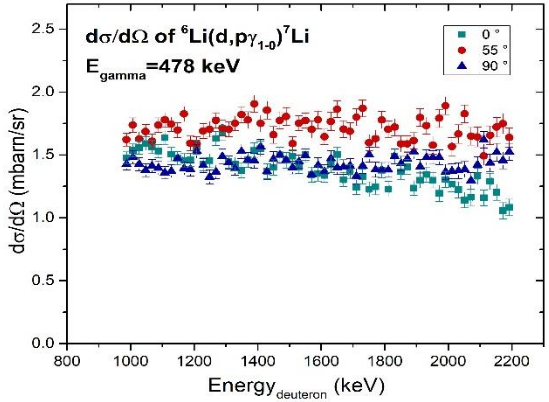
A typical experimental spectrum of ^{6}LiF target for E_d= 2000 keV at 0°.

Doppler shifted peaks of interest due to:

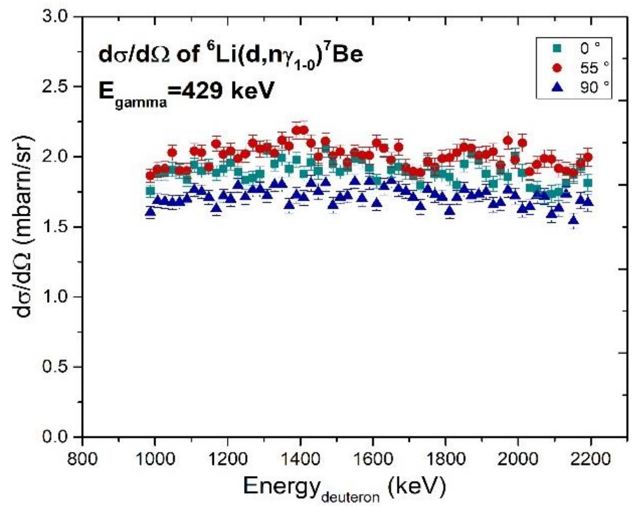
- the detector solid angle
- the increase of the compound nucleus velocity with the increase of the deuteron energy

The peaks of interest were integrated via the Tv code, with a statistical error ~ 3%.

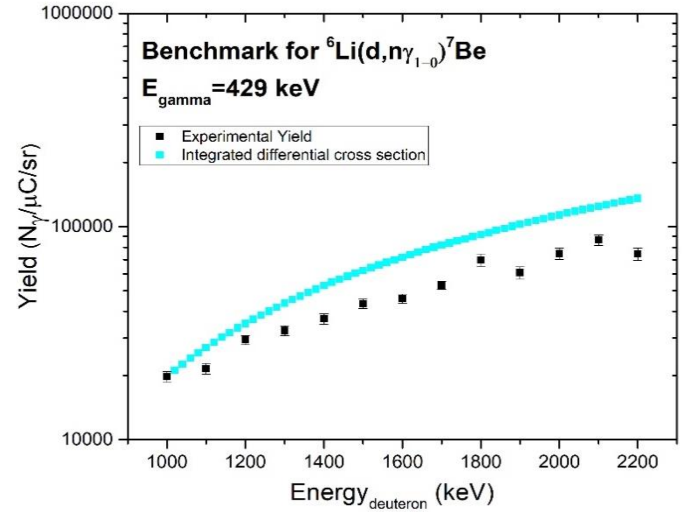
Results



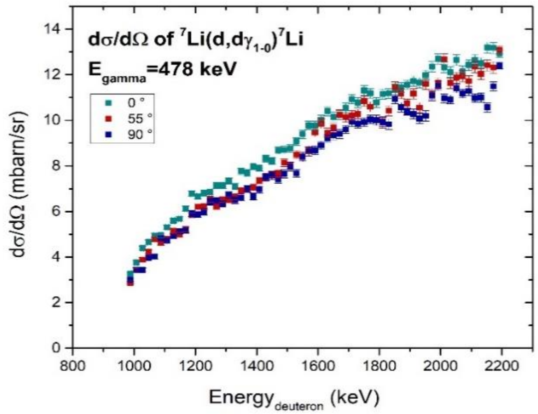
Graph 1



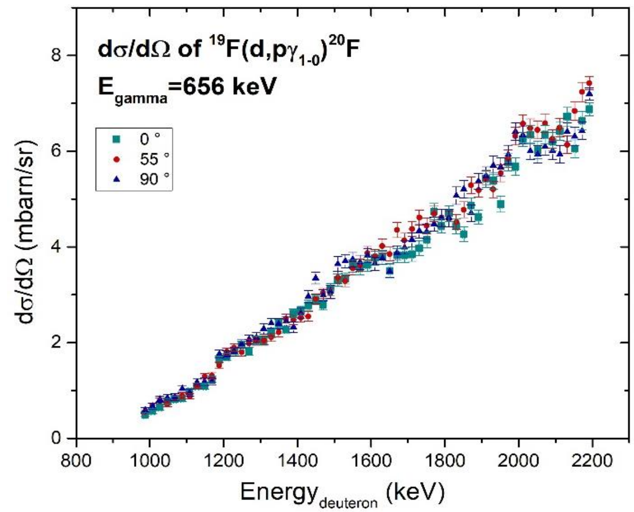
Graph 4



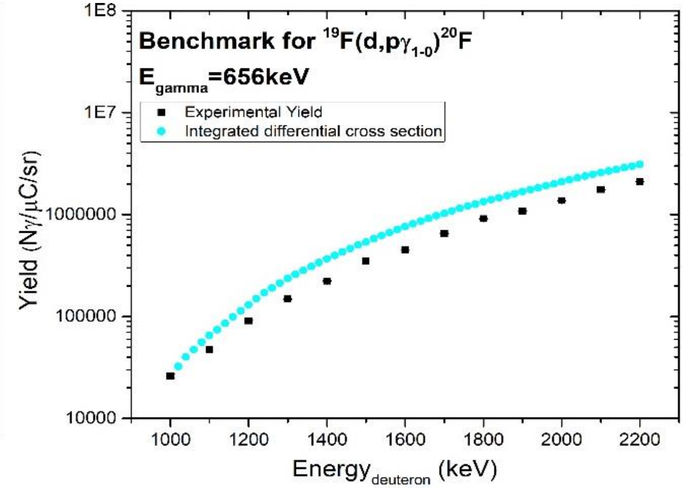
Graph 5



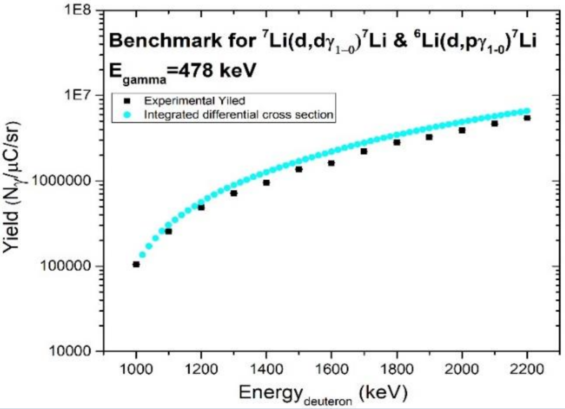
Graph 2



Graph 6

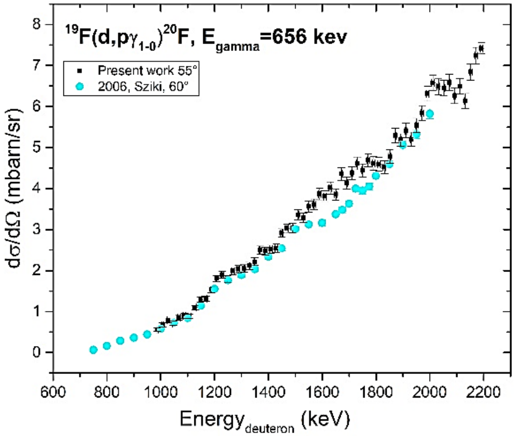


Graph 7

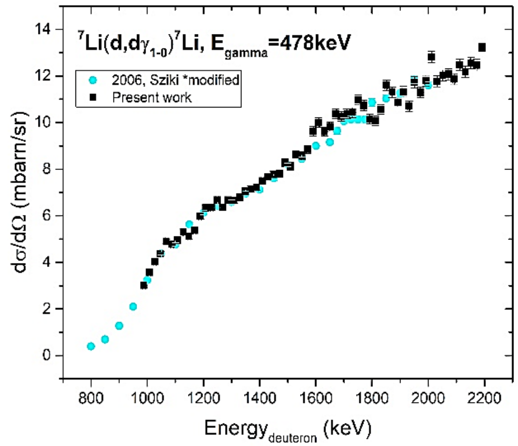


Graph 3

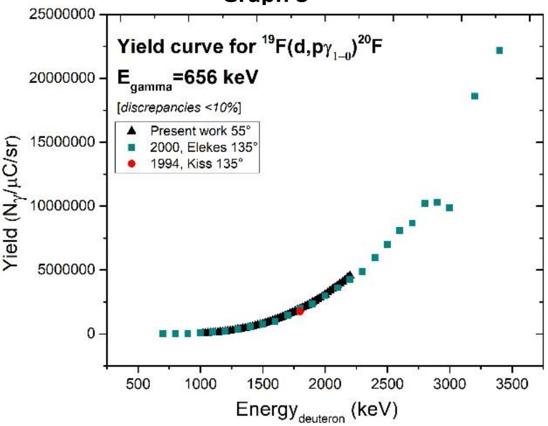
Discussion



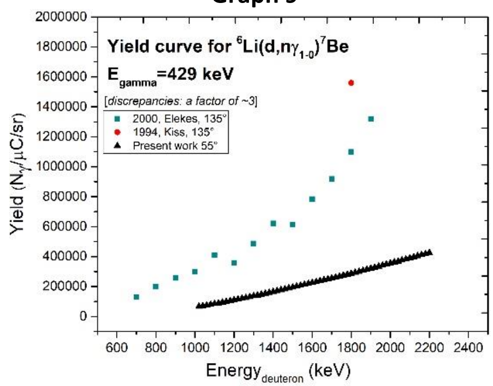
Graph 8



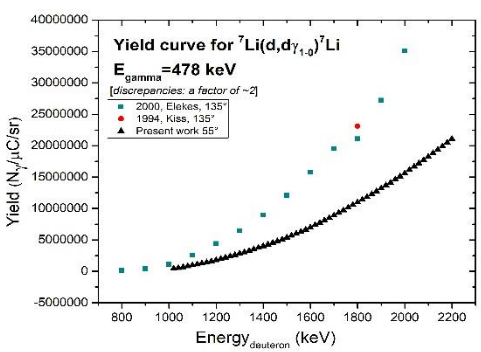
Graph 9



Graph 10



Graph 11



Graph 12

▪ Differential cross sections

Comparing present work's results with previous data from the literature, it is obvious that there is a good agreement for the case of ^{19}F (d, $p\gamma_{1-0}$)^{20}F. In Graph 9, although the 2 datasets agree, Sziki's have been modified. This modification is due to the fact that the initial data have been attributed to ^{6}Li (d, $p\gamma_{1-0}$)^{7}Li reaction. In fact, the peak at 478 keV is a contribution of both ^{6}Li (d, $p\gamma_{1-0}$)^{7}Li and ^{7}Li (d, $d\gamma_{1-0}$)^{7}Li reactions.

▪ Yields

Results for the peak at 656 keV of the present work agree with the existing datasets by Elekes and Kiss. On the other hand, remarkable discrepancies for both 429 keV and 478 peaks were found.