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Determination of Neutron Capture Cross-Sections of ^{141}Pr with Am-Be Neutron source

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Introduction

- Neutron capture cross-sections of isotopes have a wide range of applications in nuclear science.
- Neutron capture cross-section plays a vital role in reactor physics and the Nucleosynthesis of elements in stellar environments.
- In this work, we estimated the neutron capture cross-section of ^{141}Pr in two groups with the help of neutron activation analysis (NAA) and offline gamma spectrometry.
- The isotope ^{141}Pr has the magic neutron number and is also the uranium fission product in reactors. The cross-section of this isotope is of utmost importance in reactor physics and stellar Nucleosynthesis of heavy elements.

Objective

- To measure the Neutron Capture Cross Section of ^{141}Pr and its uncertainty.
- To calculate the Maxwellian Averaged Cross-Section of ^{141}Pr using TALYS and compare it with KADoNiS database.

Material and Method

- The resonance absorption feature of cadmium allows for the splitting of neutron spectra into two energy groups.
- For lower neutron energies, the cross-section of Cadmium is considerable, but it rapidly shrinks over 0.5 eV as the energy of neutrons rises.
- Therefore, cadmium allows the epi-cadmium neutrons to pass through and irradiate cadmium-covered samples while simultaneously absorbing all thermal neutrons up to 0.5 eV.
- The measured -spectra of gold and praseodymium using the HPGe detector are used to derive absolute activity.
- Folding the neutron energy flux distribution with the cross sections will give the experimental epi-cadmium to thermal (up to 0.5 eV) flux weighted capture cross sections of Praseodymium and gold.
- Neutron flux profile is needed for this purpose and is obtained from earlier findings by Subbaiah et al.
- The measured counts using HPGe detector are given in terms of flux weighted cross sections and other parameters as given in the activation equation below taken from Robert R et al.

$$C=\phi_{th}\sigma_{th}\frac{N_{Av}\theta m_x}{M_a}\left(1-e^{-\lambda t_i}\right)e^{-\lambda t_d}\frac{\left(1-e^{-\lambda t_m}\right)}{\lambda}\Gamma\varepsilon \quad (1)$$

where,

- C — Net counts in the γ-ray peak area at energy Eγ
- N_{Av} — Avogadro's number, mol^{-1}
- θ — Isotopic abundance of the target isotope considered for capture reaction
- m_x — Mass of the irradiated sample, g
- M_a — Atomic mass, g mol^{-1}
- Γ — γ-ray abundance
- ε — Full energy photo peak efficiency of the detector at energy Eγ in the measured spectrum
- t_i — Irradiation time
- t_d — Cooling (decay) time
- t_m — Counting (measurement) time

References

- Subbaiah K. V et al (2013), Neutron Flux and Dose rate mapping around the experimental 16 Ci AmBe source facility at Manipal University, Proceedings of the DAE Symposium on Nuclear Physics, Page 924 – 925.
- D.A. Brown et al (2018), ENDF/B-VIII.0: The 8th Major Release of the Nuclear Reaction Data Library with CIELO-project Cross Sections, New Standards and Thermal Scattering Data, Nuclear Data Sheets, Volume 148, Pages 1-142.
- Robert R. Greenberg et al (2011), Neutron activation analysis: A primary method of measurement, Spectrochimica Acta Part B 66 (2011) 193–241.

Experimental Setup

- The neutron source of MCNS consists of a 16 Ci 20 cm long 5 cm diameter cylindrical Am-Be neutron source housed inside a concrete bunker.
- There are two types of gold foils: 0.1246 gm (with Cd cover) and 0.1254 gm (without Cd cover). The indium foils used weigh 0.1234 g (without Cd cover) and 0.1216 g (with Cd cover). Use is made of praseodymium foils weighing 0.6618 g (with Cd cover) and 0.4127 g (without Cd cover)
- The foils were irradiated for a period of 142.5 hours.
- γ-spectra of the irradiated samples are counted using the HPGe detector and the sample spectra of gold and indium are shown in Fig 3.
- The efficiency of the HPGe detector is obtained by ^{152}Eu count spectra of known activity, which is 6.65 kBq, kept at a distance of 5 mm from the detector.
- The efficiency determination has been carried out using coincidence summing effect and fitting the experimental efficiency log-log data by a polynomial required for interpolation at desired sample γ-energies.
- Maxwellian Averaged Cross-Section and reaction rate of ^{141}Pr using Nuclear Reaction Modular Code TALYS.
- The output is then compared with KADoNiS database.

Fig 2: Components used and experimental setup.

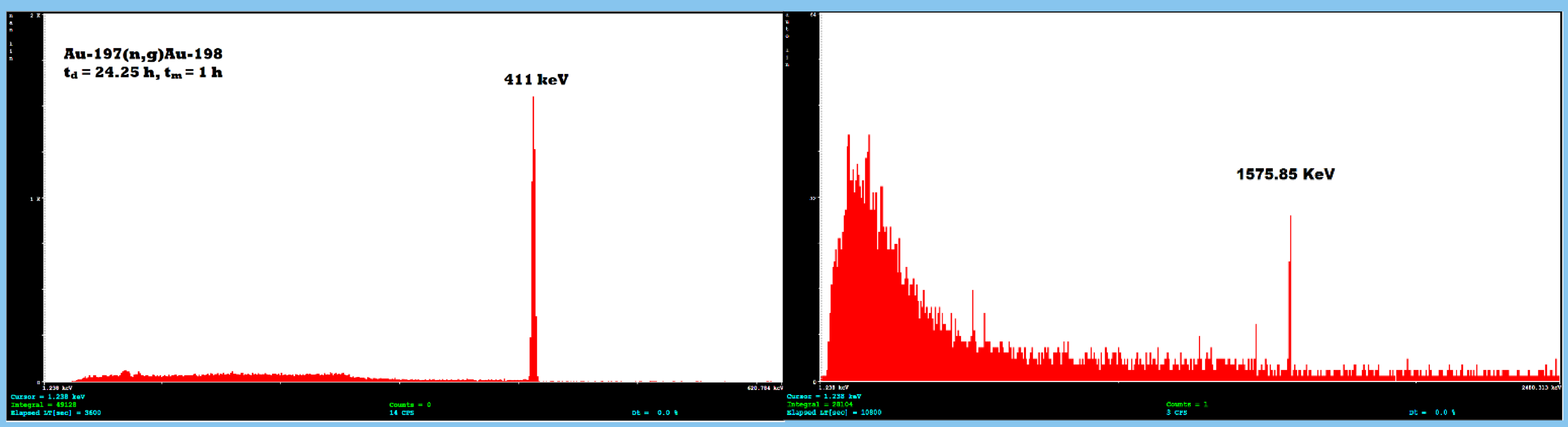

Fig 3: Measured γ-spectra of gold and praseodymium.

Results

Flux monitors	Gamma line used (keV)
^{197}Au (n,g) ^{198}Au	411.8
^{115}In(n,g) ^{116m}In	138.29, 416.9, 818.68,1097.28, 1293.56, 1507.67, 2112
^{141}Pr(n,g) ^{142}Pr	1575.85

Table 1: Ratio result with γ-lines used.

Sample	Extended thermal group (upto 0.5 eV)	epi-cadmium (0.5 eV and above)
^{197}Au (n,g) ^{198}Au (monitor)	(2.33 ± 0.033)x 10^3 n cm^{-2} s^{-1} **(flux)**	(1.72 ± 0.084)x 10^3 n cm^{-2} s^{-1} **(flux)**
^{115} In(n,g) ^{116m}In	(152.9 ± 5.22) barns	(92.1 ± 7.82) barns
^{141}Pr(n,g) ^{142}Pr	(4.14 ± 0.35) barns	(3.26 ± 0.23) barns

Table 2: Fluxes as measured by gold and estimated Indium and Praseodymium cross section.

	TEMPERATURE	ENERGY	REACTION RATE(cm^3/mole/s)	MACS (mbans)
TALYS	0.348 GK	30 KeV	1.70638×10^7	117.897
KADoNiS	0.348 GK	30 KeV	1.71×10^7	117.7±1.6

Table 5 MACS of Pr-141

Conclusion

- The neutron-capture cross-section of ^{141}Pr in the energy region of epi-cadmium (0.5 eV above) and extended thermal (thermal and upto 0.5 eV) region are estimated using the NAA with the use of Am-Be neutron source and the uncertainty in the cross-section is calculated which is improved compared to previous works.
- The MACS and Reaction Rate of Praseodymium-141 is calculate using TALYS- Nuclear Reaction Modular Code which is then compared with KADoNiS database.
- It is found that the theoretically calculated MACS data has an excellent agreement with the KADoNiS database.

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