Neutron activation cross-section measurements for Chlorine using 14.77 MeV Neutron generator

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Introduction

In nuclear reactors, chlorine isotopes are studied for their neutron capture properties, which help in controlling reactor operations and preventing excessive neutron flux [1]. Understanding how chlorine interacts with neutrons at high energy levels, like 14.77 MeV, is critical for calculations related to nuclear transmutation and for managing problems caused by radiation. Very few labs have studied the behavior of chlorine isotopes when exposed to 14 MeV neutrons before 2000 [2] and there are still some inconsistencies in their results. In this study, we aim to improve this understanding by measuring the reaction of ^{34m}Cl when it interacts with neutrons at 14.77 MeV energy, using a method called offline gamma spectroscopy. This will help provide more accurate data on how chlorine behaves in nuclear reactions.

Experimental details

A 0.5-gram sample of $PdCl_2$, in powdered form with 99.9% purity and natural isotopic abundance, was used for the experiments. To measure neutron flux, the sample was wrapped in 0.167 grams of aluminium foil. Neutron irradiation was done with a 14 MeV neutron generator at the Department of Physics, Savitribai Phule Pune University, Pune. The sample was placed at a 0-degree angle to the incoming deuterium beam, where the neutron energy was 14.77 ± 0.17 MeV. The irradiation lasted for 3600 seconds. After irradiation, the sample was moved to the gamma spectrometry area. The sample was allowed to cool for 30 seconds, and gamma ray measurement was done for 3600 seconds using a high-purity germanium (HPGe) detector, which has an energy resolution of 1.5 keV at 1.33 MeV gamma energy. The data was collected with an Ortec Easy MCA 8k device connected to a PC running Maestro software.

Table 1: Nuclear spectroscopic data for reaction products.

Product Nuclei	Half-life	Eγ (keV)	Iγ (%)
^{34m}Cl	31.99 ± 0.02 min	146.36	38.3
^{27}Mg	9.458 ± 0.012 min	843.76	71.8

Data Analysis

The cross section was determined using the neutron activation equation:

$$\sigma_S = \sigma_m \frac{F_S C_S M_m a_m A_S \epsilon_m I_{\gamma m} f_{\lambda S}}{F_m C_m M_S a_S A_m \epsilon_S I_{\gamma S} f_{\lambda m}} \qquad (1)$$

the parameters of the sample reaction, denoted as subscript 's', and those of the monitor reaction, indicated as subscript 'm'. The parameters are ε for detector efficiency, C for photo peak counts, ‘a’ for isotopic abundance, A for atomic mass, M for mass, Iγ for the branching ratio of γ-ray as obtained from Ref. [3], and ‘f’ for the timing factor. The timing factor 'f' is determined by the following formula:

$$f_\lambda = \frac{\lambda}{(1-e^{-\lambda t_1}) e^{-\lambda t_2} (1-e^{-\lambda t_3})} \qquad (2)$$

λ representing the decay constant, t_1 as the irradiation time, t_2 for the cooling period, and t_3 denoting the counting duration. The correction factor (F), resulting from factors like coincidence summing effects (f_c) and gamma ray self-attenuation (f_a), is expressed as $F = f_c \times f_a$. Detailed information concerning HPGe detector calibration, detection efficiency curve along with its uncertainty, as well as insights into coincidence summing effects and self-attenuation, can be found in our prior research. The cross-section data is adopted from IRDFF-II library [4]. The uncertainty in the measured cross sections was estimated following the procedure described in literature [5,6]. Fractional uncertainties (%) due to various parameters are given in Table 2. The error $\Delta\sigma$ in the measured cross section σ can be obtained by quadratic summation of attributes of Eq.1

Table 2: Fractional uncertainties (%) due to various parameters for neutron-induced reaction cross-sections.

Parameter	**Fractional uncertainty (%)**
σ_m	1.46
C_s	2.38
C_m	0.83
$I_{\gamma s}$	0.13
$I_{\gamma m}$	0.02
M_s	0.28
M_m	0.01
a_s	0.02
$\eta_{m,S}$	0.02
$f_{\lambda s}$	0.39
$f_{\lambda m}$	0.19
Total	**2.95**

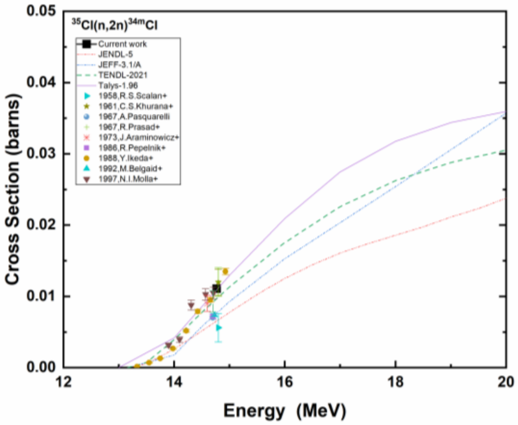

Fig.1 Comparison of present ^{35}Cl(n,2n)^{34m}Cl reaction cross-section with literature and evaluated data.

Results and discussion

In Table 2, the measured cross-sections of the neutron induced reactions for ^{34m}Cl are provided. The fig. 1 shows the measured cross-section for ^{35}Cl(n,2n)^{34m}Cl at 14.77±0.17 MeV neutron energy along with the literature data from the EXFOR database.

Table 3: Measured Neutron induced nuclear reaction cross-sections for ^{34m}Cl

Reaction	Cross-section (mb)	Talys 1.96 (mb)
^{35}Cl(n,2n)^{34m}Cl	11.07±0.33	10.9

The curve of TALYS-1.96 is in good agreement with the present cross-sections while TENDL-2021, JEFF-3.3 and JENDL-5 evaluations have underestimated the values.

Conclusion

In this study, we have documented the cross-sections for Chlorine activation caused by neutron exposure. The measured cross-section is in good agreement with existing literature and theoretical predictions. Theoretical calculations of cross-sections are executed using the TALYS-1.96 nuclear model code with optimized parameters, revealing consistent agreement with the earlier reported values.

References

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