

Analysis of Resonance Self-Shielding Effect of Gold Foils under Low Energy

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Abstract

In an albedo effect experiment, the reaction rates of gold foils predicted by simulations were a few times bigger than the measurements. Theoretical analyses showed that the main reason of the difference comes from the gold's resonance self-shielding effect on neutrons below 1 keV. Then, a new resonance self-shielding effect experiment was carried out and the experiment data agreed with the theoretical results. The thickness of the metal foil at low neutron's energies can be recommended by the analytic method.

Keywords: reaction rates, resonance self-shielding effect, low energy spectrum.

1. Introduction

In the experimental study of radiation chemistry and neutron physics, changes of some nuclides in the neutron irradiated (fission and activation) often need to be given in the high precision, to infer the properties of neutron nuclide properties or device from the result of the experiment. In the analysis of the activation rate, the influence of low energy neutron is one of the difficulties. Through the program simulation can be given some understanding of neutron energy effect, but the low energy region (resonance region of various materials) of the neutron flux spectrum is difficult to accurately calculate. The uncertainties of micro cross section data of various materials given by the theory might result in deviation of the activation rate.

To obtain quantitative data with high confidence, the neutron physics experiment can give more information. To calibrate results of the theoretical analysis, the method of neutron macroscopic laboratory experiment for quantitative analysis is proposed. Theory design and experimental measurement of albedo activation rate in the cement tank was carried out. The different of capture reaction activation of gold foils between the measured result and the theoretical expectation, were found in the experimental measurement.

This paper analyses the main reasons of the difference, and then carry out the verification experiment. In theory, the activation foils thickness requirements are clearly for the activation rate measurement under low energy neutron spectrum. The proposed method can be used to carry out experimental low-energy spectrum activation measurement.

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2. The albedo activation rate measurement experiments in the cement tank

In the neutron physics experimental of activation rate measurement, the capture reaction rates of ^{197}Au foils vary greatly, there appearing to be a systematic deviation.

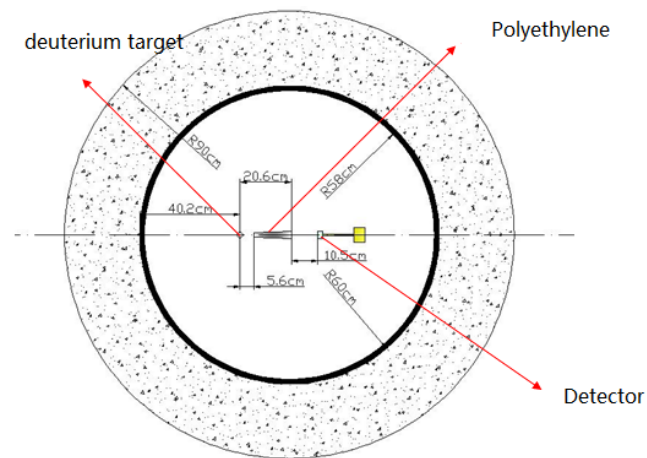


Figure 1 Schematic diagram of albedo experimental

Table 1 ratio of reaction rate between experimental and theoretical (B7.1)

Exp/Theory	Detector with 0.12mm polyethylene film	Bare detector
$^{197}\text{Au}(\text{n},\text{c})$ reaction rate	0.220	0.228

After the analysis of a variety of possible effects, the absorption effect of activation foil itself may be the main reason. There existing the activation foil or not, the difference of reaction rate are given in Table 1, and the flux spectrum in low energy in Figure 2.

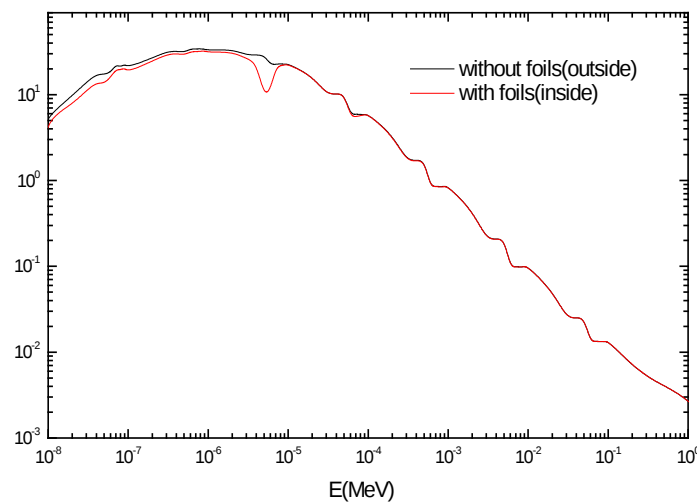


Figure 2 the flux spectrum in low energy inside and outside of the gold foils

Inferred from the simulation results, the main reason of the activation rate's deviation is the absorption and shielding of activation foils at the resonance peak. There is a significant decrease at the resonance peak of activation nuclei in the flux energy spectrum.

3. Activation foil self shielding effect experiment

Found in the resonance self shielding effect of the gold foils, analysis are carried out for further experimental research. In the shielding effect experiment, several different thickness of gold foils was used. The gold foils' thickness are 0.2 μm ~1000 μm , with diameter less than 18mm, and detection efficiency deviation less than 1%. Different gold foils were rotating at a constant speed by a small motor, to ensure the consistent of neutron irradiation. In order to improve the activation rate and enhance the ratio of low energy neutrons, gold foils were placed in the pure cement tank. DT neutron source was used and the neutrons was slow down behind lead bricks.

Ratio(Exp/Theory) of reaction rates of gold foils from the experiment are shown in table2. Gamma counting of gold foils with different thickness were shown by the relative ratio, with the combined uncertainty less than 2.1%.

Table 1 the relative ratio of activation rate of gold foils with different thickness

thickness / μm	the relative ratio (%)Exp/Theory
0.2	100
0.5	97.94
1	90.32
10	61.41
50	39.58
100	33.00
200	27.11
400	21.35
600	17.91
1000	13.74

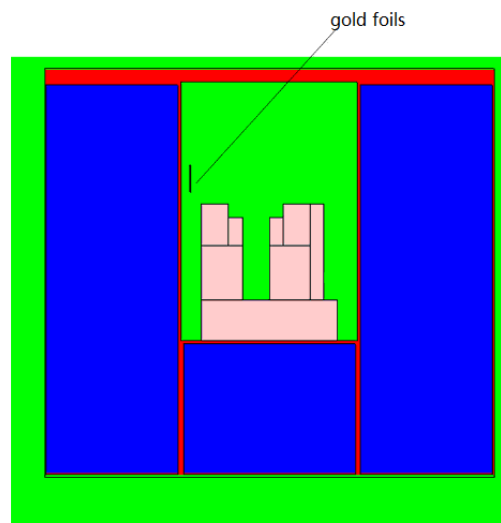


Figure 3 position of foils in the cement tank

Table 3 the reaction ratios of gold foils with different thickness

thickness / μ m	measured values (1E-24/neutron)	theory values (1E-24/neutron)	measured values / theory values
0.2	1.13E-02	9.70E-03	85.8%
0.5	1.11E-02	9.58E-03	86.3%
1	1.02E-02	9.27E-03	90.9%
10	6.97E-03	6.37E-03	91.3%
50	4.49E-03	4.33E-03	96.4%
100	3.74E-03	3.68E-03	98.5%
200	3.07E-03	3.13E-03	101.9%
400	2.42E-03	2.63E-03	108.5%
600	2.03E-03	2.34E-03	115.0%
1000	1.55E-03	1.97E-03	127.1%

From the calculation and experiment results, the activation ratio of the foils becomes smaller with the increase of the thickness, in the albedo neutron spectrum environment thick Au activation there is strong absorption peaks of shielding effect. These data suggest that under the albedo neutron spectrum environment, strong absorbing shielding effect exists in the thick gold foils. For the energy spectrum environment in this experiment, compared with the 0.2 micron foil, the activation rate of 200 micron foil is reduced by about 70%.

4. Theory analysis of the thickness of foils required for the albedo effect experiment

The experimental results verified the effect of the resonance self shielding effect, then further analysis was carried out theoretically.

For gold, in $E < 1\text{keV}$, there is a strong neutron absorption resonance peak,

$$^{197}\text{Au}: \sigma_0 = 27400b, E_0 = 4.89\text{eV}, \Gamma = (4.98 - 4.80) = 0.18\text{eV}$$

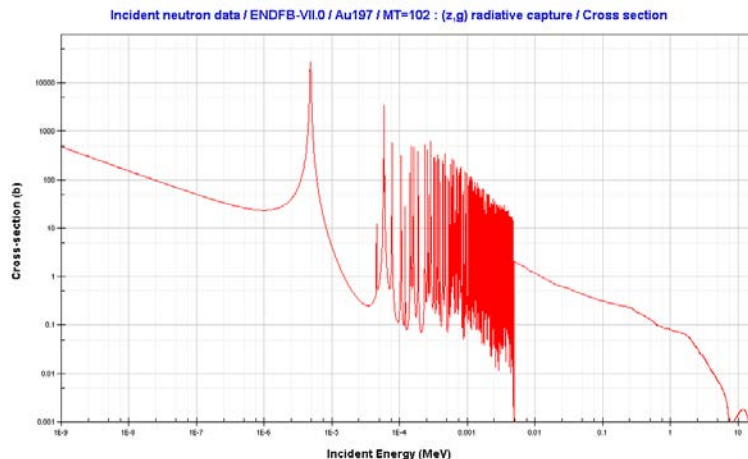


Figure 4 absorption cross section of ^{197}Au

The experimental results show that, if you want to obtain the required activation data under albedo energy spectrum, the effect of resonance self shielding need to be removed. The foils' thickness has certain requirements.

According to the reaction cross section data, the neutron mean free path of ^{197}Au in energy level width (i.e., the corresponding energy to $\sigma_0 / 2$ of resonance peaks on both sides) is about:

$$\lambda(E_0) = \frac{1.66A}{\sigma_0 \rho} (\text{cm}) = 0.0006 \text{cm} = 6 \mu\text{m} \quad (1)$$

When the activation foils' thickness d is much greater than $\lambda(E_0)$, the self shielding effect will be more serious. On the other hand, if the thickness is too small, the counting efficiency will be affected, and the measurement error becomes larger.

If the self shielding effect of the gold foil in the 4.80eV $\sim$ 4.98eV range is not more than 10%, there is

$$\delta(N) = \exp(d / \lambda(E_0)) / 2 = 10\% \quad (2)$$

The corresponding thickness of gold foil is

$$d = 0.2 \times \lambda(E_0) = 1 \mu\text{m} \quad (3)$$

If the count rate is sufficient, the decrease of the gold foils' thickness can further reduce the self shielding effect. Combined with the theoretical simulation results, in the experiment of measuring the low energy spectrum, the gold foils' thickness should be less than $1 \mu\text{m}$.

5. Conclusion

In the neutron physics experiments of neutron albedo affect measurement, the different of ^{197}Au activation rate between measurement and theoretical expectations and theoretical expectations was found. Preliminary analysis showed that the main reason for the different is resonance self-shielding effect of ^{197}Au in low energy region. Verification experiments show that in the low energy spectrum, resonance self shielding effect significantly influence the measurement result in the gold foil of 0.2mm thickness. Finally, through the theoretical analysis, the foils' thickness requirements of the low energy spectrum activation measurement was given. related experiments can be used as reference for the low-energy spectrum of activation measurement. the relevant activation measurement under low energy spectrum can refer to the results of this study.

6. References

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