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Experimental determination of residual nuclei formation cross sections in 660 MeV proton reactions with ^{239}Pu and ^{nat}U

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Abstract. The paper gives an information about part of the investigations held in JINR Dubna within cooperation of several research institutions and universities. Experimental cross sections for proton induced reactions of an energy of 660 MeV with various fission products, minor actinides, and "major" actinides (plutonium, uranium, thorium) are studied. The paper describes ^{239}Pu and ^{nat}U experiments; other experiments have already been published or are planned for the time being. Cross section determination consist of three parts: experiment, data processing, and mathematical codes simulation of the problem. This paper deals only with experiment description and data processing methodology. Neither final results of processing, nor simulation of plutonium experiment are paper-ready at the moment. Uranium data have partially already been presented, final complete results are planned to be published with plutonium results together in reviewed journal.

1 Introduction

Plutonium and uranium investigations tied together with neptunium, americium, iodine, and other isotopes cross section measurements hold in Dubna in the end of nineteens [1]. Next step of investigations should be thorium 232 and plutonium 238 cross section measurements, but due to technical problems of accelerator complex and unpredictable financial situation at JINR Dubna, experiments are indeterminately postponed. All investigations would like to give a contribution to nuclear data for accelerator driven technologies development, whether transmutation, or non-transmutation systems. Many interesting investigations on this facility with the such conditions have already been performed by other groups, e.g., Sn isotopes irradiation [2], thick target studies [3,4].

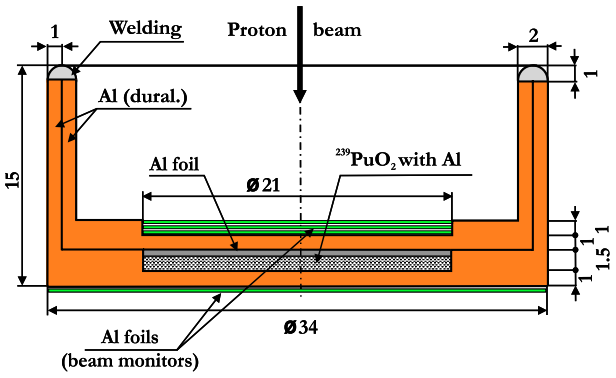

Fig. 1. Plutonium irradiation experimental setup.

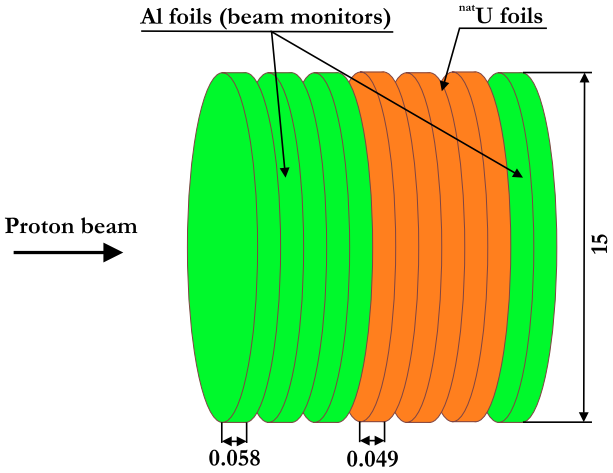

Fig. 2. Uranium irradiation experimental setup.

2 Experimental setup

All irradiations were performed on accelerator complex of Laboratory of Nuclear Problems, the oldest laboratory of Joint Institute for Nuclear Research at Dubna, using accelerator named "Phasotron". It is phasotron type accelerator with spatial variation of magnetic field. Accelerator is able to product protons with fixed energy of 660 MeV. That is why this energy was used for all experiments mentioned above. Paper deals with four irradiation experiments – two with natural uranium targets (see also [5,6]) and two with plutonium 239 isotopical targets. Schematic view of all experiments are given in figures 1 and 2. Each two experiments were identical, difference were only in irradiation time (and of course another samples were used). Uranium samples were in the thin foils form, plutonium were covered into aluminum (duralumin)

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container, hermetically closed by manufacturer. Plutonium samples inside container were in dioxide form, dispersed in aluminum powder and covered by thin aluminum foil. Materials were of very good purity – pure natural uranium (99.2% ^{238}U, rest ^{235,234}U and uranium chain isotopes); and pure plutonium isotopes mixture (99% of ^{239}Pu, rest ^{236,238,240,241,242}Pu and appropriate decay chains isotopes). Uranium samples consisted of three foils, due to reflected and impacted nuclei phenomena. For the measurement a foil placed in the middle of three was used. Because plutonium target was covered in the container that is why such phenomena was suppressed and all residual nuclei stopped inside the sample. Intrinsic activity of uranium samples before irradiation was 1.5 kBq, activity of plutonium was 1.0 MBq.

3 Irradiation conditions and beam monitoring

Every double-experiment consisted of one short irradiation and one longer irradiation. Shorter ones were used to observe isotopes with half-lives in the range of minutes and hours while the longer ones were used to observe long-lived isotopes. Uranium samples were irradiated with proton beam integral intensity of $1.15 \cdot 10^{15}$ (short irr. – 5 min.) and $8.09 \cdot 10^{15}$ (longer irr. – 27 min.). Average proton current was during both irradiations about 0.8 μA. These are data from aluminum beam monitors placed just in front of targets (proton current on the target), data from ionization chambers (control desk of Phasotron) gave almost 3 times higher proton currents (average proton current in the whole beam). Duralumin container of plutonium samples has parameters, which limited the maximal proton intensity of 10^{15} protons to maximum six hours of irradiation, and also labor protection restriction did not allow to irradiate plutonium at the same proton current level as uranium. So short plutonium irradiation (5.25 min.) was performed with integral intensity of $4.93 \cdot 10^{13}$ (proton current on the target was 25 nA) and longer irradiation (90 min.) with integral intensity of $5.61 \cdot 10^{14}$ (17 nA on the target). Stability of beam current during irradiation was not ideal, changes were within 30%. Beam profile was monitored by ionization chambers, stability of profile was very good. Average beam profile FWHM(x) was 1.92 cm for uranium experiment and 1.50 for plutonium one; FWHM(y) was 1.68 cm for uranium and 2.31 cm for plutonium. As a beam monitors thin aluminum foils were used. Three foils were put in front of the target to suppress impacted nuclei phenomena, one behind the target as a control foil. Three well known reactions were used to determine average beam current on target – ^{27}Al(p,3np)^{24}Na, ^{27}Al(p,5np)^{22}Na, and ^{27}Al(p,10n10p)^{7}Be. Results are in relatively good agreement with maximal differences within 10%.

4 Data acquisition

Samples were immediately transported from irradiation room No. IX to γ-spectroscopy laboratory. Two HPGe detectors were used, one ORTEC GMX-20190 28.3% and one CANBERRA GR-1819 18.9%. Measurement of irradiated samples were started about 5 minutes after the end of irradiation. Measuring times were increasing, distance of samples from HPGe descreasing. Intensive measurement lasted for 14 days, then were samples measured from time to time for more than two years. Also planar ORTEC detector GeLP-36360/13 were used for some uranium measurements. Total number of 105 uranium spectra and 156 plutonium spectra were acquired. About 500 other spectra (calibration, monitors, background) were measured.

5 Data processing

Measured data were processed using standard γ-spectrometry methods – γ-peak area determination, background suppression, target isotopes own background suppression, calibration, identification ($T_{1/2}$, E_γ, I_γ), corrections, etc. Standard software packages from ORTEC, CANBERRA, NPI as well as own-made programs (e.g., [7]) were used to cross sections determination.

6 Results

Until now, data from uranium experiments are almost processed; results were partially published [5],[6], and are preparing to be published completely. Due to some problems in processing of plutonium data, there are only cross sections for long lived isotopes determined; short-lived isotopes data are joined with large uncertainties which should be further analyzed and improved. Data will not be published partially, authors would like to wait for complete publication.

7 Conclusions and future plans

Authors plan to publish final results in reviewed journal as soon as it will be ready. They hope they will be able to manage cooperation with computational groups and together publish comparisons of experimental and calculated values. Similar experiments are planned in the future, but are postponed and endangered.

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