HIGH GRADE DECONTAMINATION OF Ni TARGETS FOR SUB-BARRIER TRANSFER REACTIONS

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Sub-barrier neutron transfer reactions with ^{18}O or ^{13}C beams have a high spectroscopic potential. We investigate the 2 neutron transfer reaction of an ^{18}O beam on ^{64}Ni targets at sub-barrier energies. Therefore, we prepared high purity and uniform thickness ^{64}Ni targets. Target preparation considers Ni chemical activity in air, as Oxygen layers are incorporated and formed on target surface. This is a major drawback, since gamma rays from ^{16}O target reactions bring a significant contribution to the recorded spectrum. To overcome this problem, Hydrogen oven thermal treatment was applied. Target characteristics after thermal treatment showed an important reduction of Oxygen contamination. Details of the treatment procedure and its effect on the measured gamma ray spectra are presented in this paper.

Keywords: thermal treatment, sub-barrier transfer nuclear reactions

1. Introduction

The aim of this work is to describe the process and measure the effects for a thermal treatment of ^{64}Ni targets used in 2 neutrons transfer reactions at sub-barrier energies carried out at the 9MV Tandem accelerator in IFIN-HH.

Those experiments can reach a high degree of complexity [1] by using the RoSPHERE spectrometer [2] in its mixed configuration. It consists of two components: a plunger part, which requires a thin target (of ~ 1mg/cm^2) and a fast timing part where thick targets are usually used (of ~few mg/cm^2).

The nucleus of interest in this experiment was ^{66}Ni, which is generally challenging to be produced. Prior to our experiment, it has been produced by using a few mechanisms: β decay of ^{66}Co, nucleon transfer reactions using stable targets like $^{64}Ni(t, p)$, $^{64}Ni(\alpha, 2p)$, $^{68}Zn(^{14}C, ^{16}O)$ and heavy ions induced reactions (quasi elastic and deep inelastic) [3,4].

Recently the high spectroscopic potential of the sub-barrier 2-neutron transfer reaction induced by ^{18}O and ^{13}C beams on Ni targets has been shown [1].

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^{66}Ni is only 2n away from the line of stability, therefore the reaction used in this recently performed experiment [1] is a 2n transfer reaction using a ^{18}O beam delivered by the 9MV Tandem accelerator at an incident energy of 39 MeV on a ^{64}Ni target. The strong point that these reactions bring is the cleanliness of the γ spectra. This is due to the fact that the energy of the incident ^{18}O beam is restricted to be below the Coulomb barrier on Ni, thus minimizing the fusion-evaporation cross-section and consequently the fusion products and their γ decays.

However, special care must be taken in this type of experiments in order to avoid the contamination of the γ spectra: if chemical contaminants such as Oxygen are present in the target or on the target surface, the reaction cross-section on these contaminants can be much higher or similar than in the case of the reaction of interest, as the Coulomb barrier for (Oxygen target, Oxygen beam) is an order of magnitude lower.

The main goal of the present work is to obtain ^{64}Ni targets with a surface free of Oxygen or other contaminants. Section 2 presents the target preparation; Section 3 shows the preliminary results from the nuclear physics experiment, Section 4 describes the thermal treatment of Ni targets for oxygen reduction. Finally conclusions are given in Section 5.

2. Target preparation

The material chosen for target preparation - ^{64}Ni was strongly enriched (99.5 %). This isotope is the most neutron rich from all Ni isotopes and it has a natural abundance of 0.9255(19)% [5].

As afore mentioned, the target must be isotopically pure. Therefore, we prepared thin (~1mg/cm^2) and thick (~5mg/cm^2) metallic layers of ^{64}Ni with high-purity, of good thickness uniformity on the defined surface.

The preparation process started from the metallic powder and followed a series of steps (pressing, heating with an electron-gun and finally rolled), until the required thickness and uniformity were achieved.

The pressing process consists in compacting the metallic powder in a pellet using an automatic hydraulic press produced by Specac [6]. The pellet dies produce circular pellets sized 5 to 40 mm diameter. All the parts of the die are manufactured from hardened stainless steel for optimum quality and durability, and highly polished surfaces for contact with the sample. The applied pressure and release are well controlled. The LCD display show press status and load conditions giving a digital display of the load applied. In this case we used a pellet die of 5 mm in diameter and the applied force was about 20kN.

Fig. 1: Automatic hydraulic press for pellet production

The second step of the target preparation was heating the obtained pellet in order to compact the powder; follows a rolling process. The heating was achieved using the electron-gun method [7]. The electron-beam evaporation source used provides a self-accelerated bent beam generated with the beam former together with the cathode assembly and the deflection plate. The electron beam is accelerated by a 5kV difference with respect to the anode and injected in a permanent magnetic field in order to be deflected through a permanent 270-degree arc towards the evaporant/heated material.

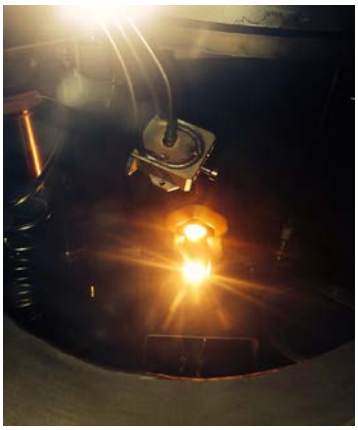


Fig. 2: Electron-gun in process for pellet heating

The rolling technique [8-10] is an extremely efficient one for self-supported foil production using a small amount of material. It allows preparation of metallic foils with thicknesses ranging from several hundreds of $\mu g/cm^2$ to

several hundreds of mg/cm^2. By using this technique we obtained metallic foils used as targets for the "in beam" experiments without any material loss.

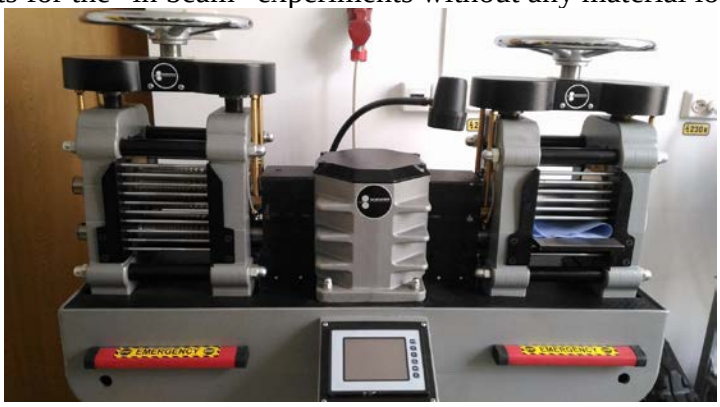
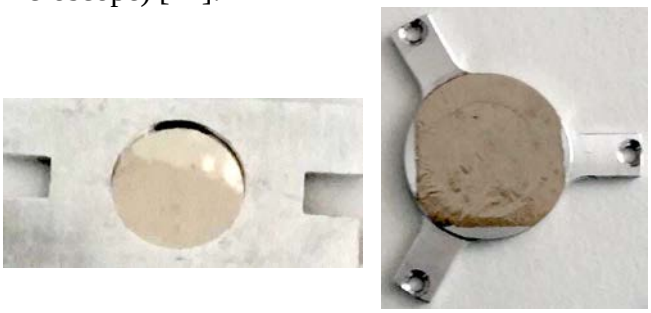


Fig. 3: Rolling equipment for foils production

By using these techniques we prepared 4 thin targets (~1mg/ cm^2) and 2 thick targets (~5mg/ cm^2) of ^{64}Ni. The thicknesses of these metallic layers were determined by weighing the foils using a dual range analytical balance (Mettler Toledo XS205) [11] and by measuring the surface with an optical microscope (Dino-Lite Digital Microscope) [12].



Thick target ***Thin target***

Fig. 4: ^{64}Ni targets used in the proposed experiment

3. Preliminary results from the nuclear physics experiments

The nuclear reactions are induced by ^{18}O projectile incident on ^{64}Ni target nuclei. The incident energy of the ^{18}O beam was chosen such that it was lower than the Coulomb barrier, such that it will transfer 2 neutrons to the target nuclei, thus creating ^{66}Ni, which will gain recoil energy and will move forward. ^{66}Ni nuclei are created in a nuclear excited state, which subsequently decay by emitting gamma radiation, which is detected by Germanium detectors from the RoSPHERE array [2] in IFIN-HH (DFN). A schematic picture of the process is shown in Figure 5.

For this experiment, the incident energy was chosen in order to maximize the transfer probability and lower as much as possible the fusion-evaporation reaction mechanism on ^{64}Ni [1].

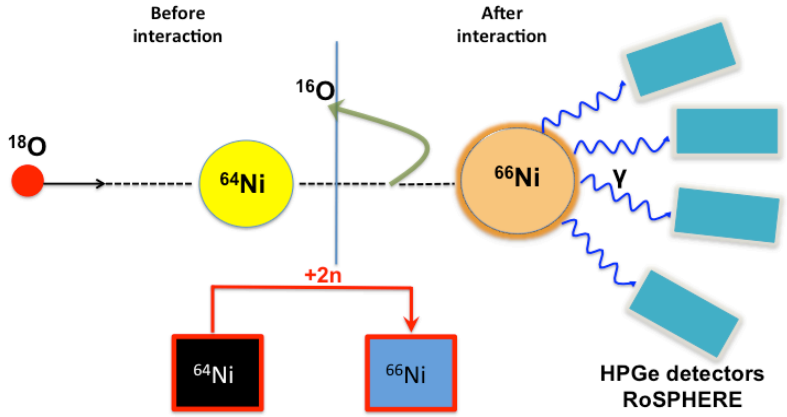


Fig. 5: The schematic representation of the 2-neutron transfer reaction experiment performed at Tandem accelerator

Fig. 6 presents the HPGe spectrum of the gamma lines emitted by the target after a week of continuous beam irradiation. Besides the lines of ^{66}Ni (reaction of interest), several contaminant lines produced by the reactions of the beam (^{18}O) with the Oxygen (^{16}O) build up on the target surface can be observed.

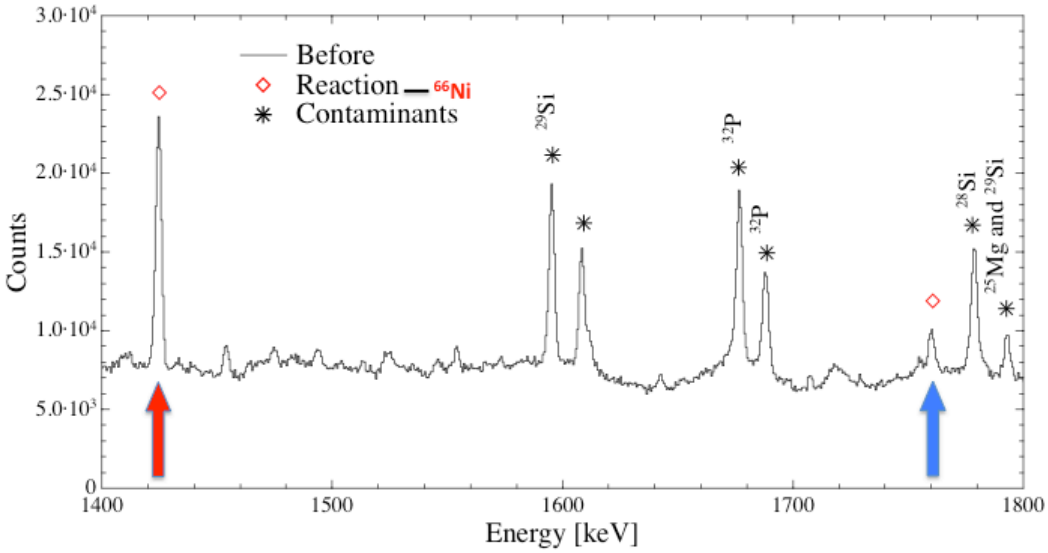


Fig. 6: Gamma spectrum for the reaction of interest (^{18}O beam on ^{64}Ni target) and contaminants from the reaction of ^{18}O beam on Oxygen contamination

Therefore, the experiment requires eliminating ^{16}O located on the target surface. We have achieved this via thermal treatment as described in the following section.

4. Thermal treatment of ^{64}Ni metallic foil for Oxygen reduction

During the target preparation process, due to the known chemical activity of the Ni powder in air, atomic layers of Oxygen are formed on the target surface, as Oxygen is incorporated.

In order to remove the Oxygen, a thermal treatment with a hydrogen oven was applied. This process is schematically shown in Fig. 7.

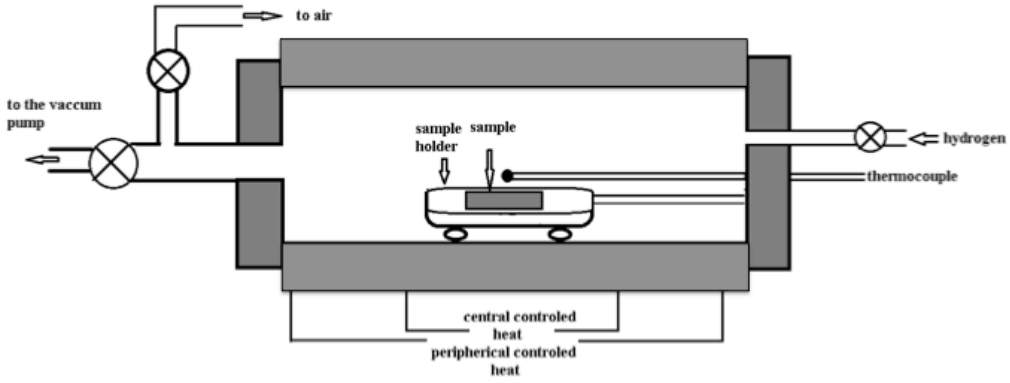


Fig. 7: H_2 oven used for the thermal treatment of targets

A ^{64}Ni metallic foil was heated in H_2 gas at high temperature. This treatment is meant to reduce the atomic layers of Oxygen, which are formed on the target surface. The optimum temperature range for the H_2 treatment was found to be of 600-700°C [13].

In order to carry out a thermal treatment in hydrogen environment it is very important to keep the (maximum) temperature constant, having a minimum thermal gradient; to achieve this, separate heating processes for the central and peripheral zone of the oven are needed. There are 3 intermediate heating stages; for two of them the temperature at the heater level is maintained constant. Following this process, the temperature around the sample spot (~ 10 cm^3) is maintained at 650 ±1 °C. The treatment is carried out in reduced pressure mode (hydrogen at room pressure). Before heating, the oven tube in which we inserted the sample was vacuumed (10^{-2} mbar), then the tube was filled with hydrogen (1 bar). During the entire heating and cooling processes a hydrogen flow of 100 sccm (Standard Cubic Centimeters per Minute) went throughout the oven tube. The sample is extracted from the oven at room temperature and immediately inserted into a storage device vacuumed down to 10^{-3} mbar.

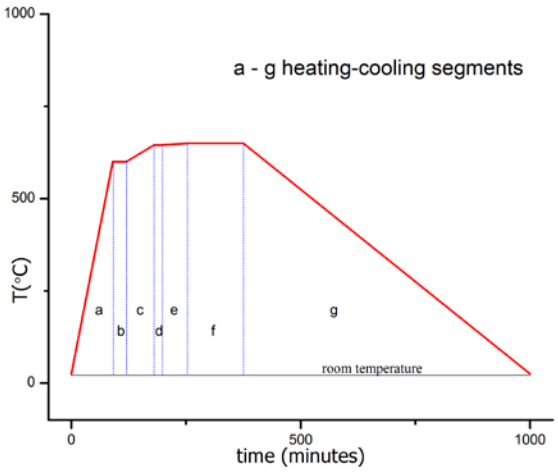


Fig. 8: Heating-cooling segments of thermal treatment

Segment (a) represent a linear temperature increase up to 600 °C (90 minutes). At this stage, the temperature was stationary for 30 minutes (b). Segment (c) reveals a linear increase up to 645 °C, follows a stand-by of 15 minutes (d). One of the most important steps of the thermal treatment was segment (e) corresponding to a temperature increase up to 650 °C, followed by a stationary period of 2 hours (f). The last segment, also very important for the thermal treatment, represents the constant speed cooling process (g).

After the thermal treatment previously described, we obtained a significant reduction of the O contamination by comparing the gamma lines energy spectra as shown in Fig. 9. We could directly compare the intensities of the peaks corresponding to the reaction on Oxygen in the target given the fact that the 1425 keV gamma ray that corresponds to the decay of the first excited state of ^{66}Ni has the same intensity.

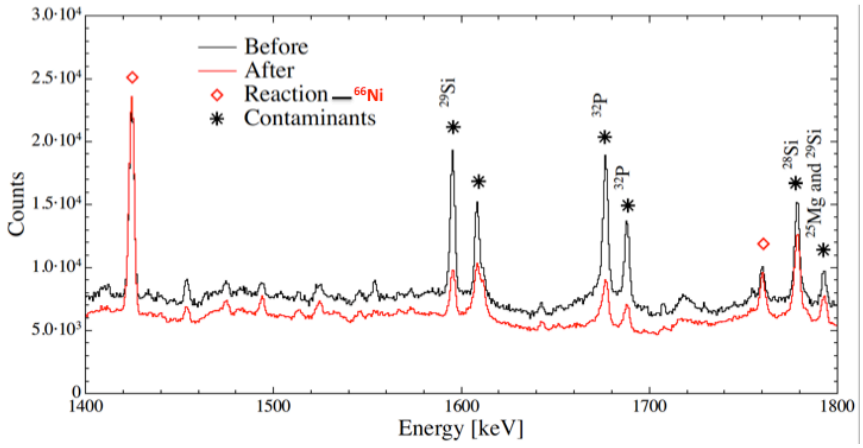


Fig. 9: Gamma spectrum for the reaction of interest before /after thermal treatment of the target

This treatment also reduces the yield of the reaction channels involving fusion on the O, which contribute to the background. Estimating the effect of the thermal treatment undergone by the target showed two of the most intense peaks that are known to belong to the fusion-evaporation reaction of ^{18}O on ^{16}O present in the target were reduced by about 35%.

5. Conclusions

This work aimed to improve the quality of Ni targets employed in nuclear physics experiments, particularly in sub-barrier 2 neutron transfer reactions on ^{64}Ni. Nickel is a transition metal. Pure nickel, powdered to maximize the reactive surface area, shows a significant chemical activity and reacts slowly in air under standard conditions, as an oxide layer covers the surface.

Oxygen is a major contaminant in the target, seriously polluting the prompt gamma ray spectra. In order to avoid this drawback, serious improvements were made by treating the ^{64}Ni foil before using it in the experiment. The rolling method for producing the foil and the thermal treatment are rather classic, still the results are significantly improved in terms of the spectroscopic analysis subsequent to our experiment.

We are currently looking forward to the next step for developing our procedure, which shall consist of applying a similar thermal treatment to the metallic powder before the rolling process, after which we would apply the thermal treatment again, to the metallic foil this time.

Finally, the results obtained following quantitative analysis of the data provided by the nuclear physics experiment validated the target purity [1].

R E F E R E N C E S

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