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Release of Kr, Ag, Sn, I and Xe from UC_x targets

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Abstract

The release properties of a UC_x thick target associated with a hot plasma ion source have been studied. Measurements have been performed for various elements: Kr, Ag, Sn, I and Xe. The analysis is made assuming pure diffusion or pure effusion as the release processes. The results obtained are compared to the data available in the literature.

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1. Introduction

For about fifty years, constant efforts have been made by the nuclear physics community to produce more and more exotic radioactive nuclei. At first nuclear and atomic spectroscopy studies performed on the radioactive nuclei allowed to determine the properties of these exotic nuclei, contributing to a better understanding of nuclear structure, nuclear astrophysical processes and fundamental interactions. More recently, the first experiments using accelerated radioactive ion beams have been carried out, but the possible research field remains limited by the low intensity of the available radioactive ion beams. The present challenge is to achieve second generation facilities accelerating radioactive ion beams of high intensity [1–3].

In order to produce radioactive nuclei, two methods exist: the in-flight separation method and the isotope separation on-line (ISOL) one. Each method has its own advantages and drawbacks. In the first case, radioactive isotopes are produced through the fragmentation of high-energy heavy-ion projectiles on thin targets. Isotopes with very short half-lives can be reached. The fragment products leave the target with a velocity determined by the energy of the primary beam thus further acceleration is not required but the secondary-beam quality and consequently its purity are poor. However the energy loss, specific for the various fragments, can be used for their reliable identification and separation. In the second case, the unstable nuclei

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are produced in reactions such as spallation, fusion–evaporation, fission, etc. induced in a thick target by neutrons, protons, heavy-ions, electrons or γ-rays. The radioactive atoms released from the target move into a suitable ion source where they are transformed into 1^+ ions. The ions are extracted under a high voltage and mass-separated. The quality of the secondary-beam obtained is good, but the use of thick targets limits the beam intensity of the short-lived atoms. The number of radioactive atoms created in the target is proportional to the number of target nuclei, thus a high beam intensity can be expected but the time required (i) for diffusion of the radioactive nuclei inside the target, (ii) for desorption from the material surface and (iii) for effusion to the ion source, reduces the number of radioactive ions available, especially for isotopes with short half-lives. The relative importance of these processes (diffusion, desorption and effusion) depends on the nature of the targets and on the chemical and physical properties of the elements to be released with regard to the surrounding materials. It is the reason why numerous works have been undertaken to obtain the data necessary for the design of targets and ion-sources with good release properties and high efficiency, respectively [4,5].

To contribute to this general effort of research and development, the PARRNe (Production d'Atomes Radioactifs Riches en Neutrons) program, initially devoted to the study of the production of neutron-rich nuclei obtained by the fission of uranium induced by fast neutrons, has been developed at the Institut de Physique Nucléaire in Orsay. In a previous paper [6], we presented a direct method for the measurement of the release time for molten U targets. In the present paper, this method is extended to the UC_x solid targets. First, we describe how the release time measurements were performed. Then we present the analytical expressions used to extract the value of the release time when the dominant release process is effusion/desorption or diffusion. Finally the results obtained for krypton, silver, tin, iodine and xenon are presented and compared to the release time values available in the literature for various solid targets containing uranium.

2. Description of the release time measurements

The 26 MeV deuteron beam delivered by the 15 MV tandem accelerator in Orsay [7] hits a 4 mm-thick graphite converter that is in contact with the UC_x target. The fast neutrons, produced in the break up of the deuterons [8], induce fission of the target ^{nat}U and give rise to neutron-rich radioactive atoms. The target, composed of 149 UC_x disks 14 mm in diameter and 1 mm thick, contains ~75 g of ^{238}U, which corresponds to a mass concentration of U in the target of 3.2 g/cm^3, a UC_x density of 3.8 g/cm^3 and a U thickness of 48 g/cm^2. The UC_x disks are manufactured according to the technique developed at ISOLDE [9,10]. The UC_x target was associated with an ISOLDE-type hot plasma ion source [11]; a 79 mm long transfer line links the target container from the middle of its length to the entrance of the ion source (see Fig. 1). During the experiment, the temperatures of the target and of the transfer line were 2080 °C and 2150 °C, respectively. The ions are extracted under 30 kV then mass-separated by a uniform-field H-shaped magnet with a 65° deflecting angle and a mass resolving power of 1300. The radioactive ions of the chosen mass are finally collected on a mylar/aluminium tape and the release time measurements are performed at the collection point using a Ge(HP) detector. A reliable identification of the isotope for which we want to measure the release time is achieved through its γ-lines.

The ion beam deflector located in the ion beam line upstream from the magnet is held in the "on" position during the measurement, that means the ion beam of the selected mass can reach the collection point. In order to verify that the target does not contain any radioactive atom of the isotope that we want to study, a γ-spectrum is recorded with the ion beam deflector "on" but with the deuteron beam stopped before reaching the converter. From the time $t = 0$ to the end of the measurement, the data acquisition is valid. The deuteron beam hits the converter from $t = 0$ to $t = t_{irrad}$ and is stopped during the remaining time of the cycle. In other words, from $t = t_{irrad}$ up to the end of the measurement cycle, neutrons no longer irradiate the target and the direct generation of radioactive isotopes inside the target is stopped. The atoms present in the target continue to be released and since the deflector is still "on", radioactive ions continue to be collected on the tape. The whole measurement cycle can be repeated in order to increase the statistics.

Each γ-energy is recorded on a DLT tape with the time information given by the COMET-6X (COdage et Marquage En Temps) module [12,13] developed by the Institut de Physique Nucléaire in Orsay. Off-line, we can build energy-versus-time matrices, a tridimensional plot of which is shown in Fig. 2 as an example. In such a matrix, we select gates on the energy of the γ-rays corresponding to the decay of the nuclei collected on the tape. The time spectra obtained show the variation of the intensity of a given γ-ray versus time: each channel represents a time interval with a content related to the number of nuclei that decay during this time interval. Such time spectra are also presented in Fig. 2. The spectrum labelled "total projection" was obtained without any energy selection. The spectra labelled "^{136m}I" and "^{136g}I" were obtained by putting gates on the 197.3 and 1321.1 keV γ-lines identifying unambiguously the ^{136m}I and ^{136g}I decays. One can note that these time spectra have very different shapes due to the different half-lives, $T_{1/2} = 46.9$ s for ^{136m}I and 83.4 s for ^{136g}I, leading to different disintegration numbers during a given time interval. Moreover the contribution of the parent nuclei in the variation of the γ-intensity as a function of time is different for the 197.3 and 1321.1 keV transitions. Indeed, the ^{136}Te nuclei, also produced by the uranium fission induced by fast neutrons, released from the target, ionized by the hot plasma ion source and collected on the tape,