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Abstract

We have started the R&D program PARRNE. Its aim is the investigation of the optimum conditions for the production of neutron-rich fission fragment beams extracted from thick targets irradiated by fast neutrons. First results are given.

On several recent occasions, it has been established that neutron-rich beams with energies around the Coulomb barrier will provide a wealth of new opportunties in nuclear structure physics [1,2]. Fission is a very powerful mechanism to produce such beams e.g. the ISOLDE facility uses since long high-energy proton induced fission [3]. Inverse kinematic fission of relativistic projectiles has allowed the first synthesis of ^{78}Ni [4] at the GSI fragment separator, thermal neutron induced fission is used to study the region around ^{132}Sn at Studsvik [5] and is on the basis of projects for radioactive beam facilities at ILL and Munich [6]. Proton induced fission allows particularly high luminosities (L $\sim 10^{13}$ barn$^{-1}s^{-1}$), fragments separators excel in the efficient selection of very short-lived species (L $\sim 10^3 - 10^6$ barn$^{-1}s^{-1}$), whereas the highest cross-sections in the top of the isotopic distribution are found for thermal neutrons (L $\sim 10^{11}$ barn$^{-1}s^{-1}$).

A novel concept has been proposed by J. Nolen: fast neutrons may be used for achieving the highest possible luminosities without dissipating too much power in the fissioning target, the traditional Achilles heel of fast particle induced reactions. Indeed, by breaking up an intense deuteron beam (E=100-300 MeV) in a dedicated (and well-cooled) converter, and irradiating a thick fission target by the secondary neutrons flux, the luminosities may, at least in principle, exceed L = 10^{15} barn$^{-1}s^{-1}$ [7]. Of course, the challenge consists in the R&D for a device in which the produced activities are transfererred to an ion-source with high efficiency. This will be crucial for the viability of projects like the one proposed by the Argonne laboratory [8]. It will also be of high interest for radioactive beam facilities under construction [1,2], which like SPIRAL at GANIL, may benefit from an intense deuteron beam.

We have decided to build a test bench (PARRNE = Production d'Atomes Radioactifs Riches en NEutrons) for the R&D with thick fission targets at the 15 MV tandem of IPN Orsay where 1 μA deuteron beam is available. Literature on cross sections [9] show that the threshold for fast neutron induced fission on ^{238}U is at 2 MeV. It rises from 0.5 barn by a factor of 3 for a ten-fold energy increase.

In a first test, PARRNE-0, a 1mm thick Uranium disk was irradiated by neutrons produced from a 20MeV, 100nA deuteron beam stopped in a carbon covered Faraday cup for 2 min. Off-line γ-ray spectroscopy, showed that it is easy to identify numerous radioactive species with a neutron excess of up to ten, see table 1. This validates the method in accordance with a somewhat similar recent test at MSU (see in [8]).

We now have constructed a first version of an UC$_x$ target, containing 20 g of uranium, which is heatable up to 2000^{0}C for fast effusion of the produced activity. A graphite container housing 50 disks of

UC_x with a diameter of 14 mm, sourrounded by a heated Ta tube, was kept in a vacuum vessel with 1mm thin Al windows. This vessel was installed at the end of a beamline from the tandem, consecutive (8 cm distant) to a 3 mm thick Be disk used for the deuteron to neutron conversion. The effective deuteron energy after a window in the beam pipe was about 15 MeV. The target container had a 10 mm opening in the middle to which a 7.2 m long transferline, through a 1 m concrete shielding, was connected. Thus the activity could be collected under good background conditions for γ-spectroscopy measurements. We have started the study of the produced noble gases Kr and Xe by collecting on a cold Cu finger. The latter was kept below 20K by means of a cryo-generator with a pressure of 10^{-7} hPa. Table 2 shows the collected yields for ^{90,91,92}Kr and ^{138,140}Xe.

Isotope	$T_{1/2}$	$N_0(10^6)$	Rate (10^{-7} g^{-1})
^{84}Se	3.1 min	0.99	3.06
^{86}Br	54 s	0.84	1.19
^{89}Kr	3.07 min	4.14	12.7
^{90}Kr	32.32 s	1.6	1.92
^{94}Sr	1.24 min	5.7	9.42
^{103}Tc	54.2 s	6.33	8.97
^{132}Sn	40 s	0.46	0.58
^{132m}Sb	2.8 min	3.44	9.79
^{133}Sb	2.3 min	3	7.37
^{136a}I	1.38 min	2.28	4
^{136b}I	46 s	0.76	1.01
^{140}Cs	1.07 min	3.8	5.81
^{137}Xe	3.83 min	6.58	24.1
^{139}Xe	39.5 s	1.45	1.832
^{144}La	40.7 s	2.08	2.66
^{145}Ce	3 min	3.66	11

Table 1 : Production of neutron-rich species in a 1mm thick U metalic disk during 120 s of irradiation by neutrons from a C target exposed to a 20 MeV, 100 nA deuteron beam. N_0 indicates the total number of Atoms produced and R the Yield per incident deuteron per second and grams of Uranium.

Isotope	T−1/2[s]	Yield 1/μ C
^{90}Kr	32.3	1.9 10^5
^{91}Kr	8.6	4.1 10^4
^{92}Kr	1.8	1.5 10^4
^{139}Xe	39.7	2.2 10^5

Table 2 : Yields for noble gas atoms collected on a cold finger.

The release and transport time distributions could be studied by pulsing the deuteron beam. Fig. 1,2 show such distributions. The solid line corresponds to a fit with one set of four parameters according to a method described in reference [10].

It is interesting to note that the observed yields of PARRNE-1 (neutron luminosity L $\sim 10^7$ barn$^{-1}s^{-1}$) are only about a factor of 10^4 below those from 1GeV protons (luminosity L $\sim 6\times 10^{12}$ barn$^{-1}s^{-1}$) impinging at ISOLDE on ThC targets. By modifications of the test-experiments at the Orsay tandem (effective deuteron energy, neutron angular distribution seen by the UC_x target) an order of magnitude can be gained in the luminosity. The main goal of the future experiments will be to see a further improvement by one order of magnitude, by an increase of the target thickness can be obtained without a deterioration of the release properties. This is the aim of the set-up PARRNE-2, presently under construction where we will connect 1^+ charge-state ion-sources followed by a small ISOL separator to UC_x-targets.

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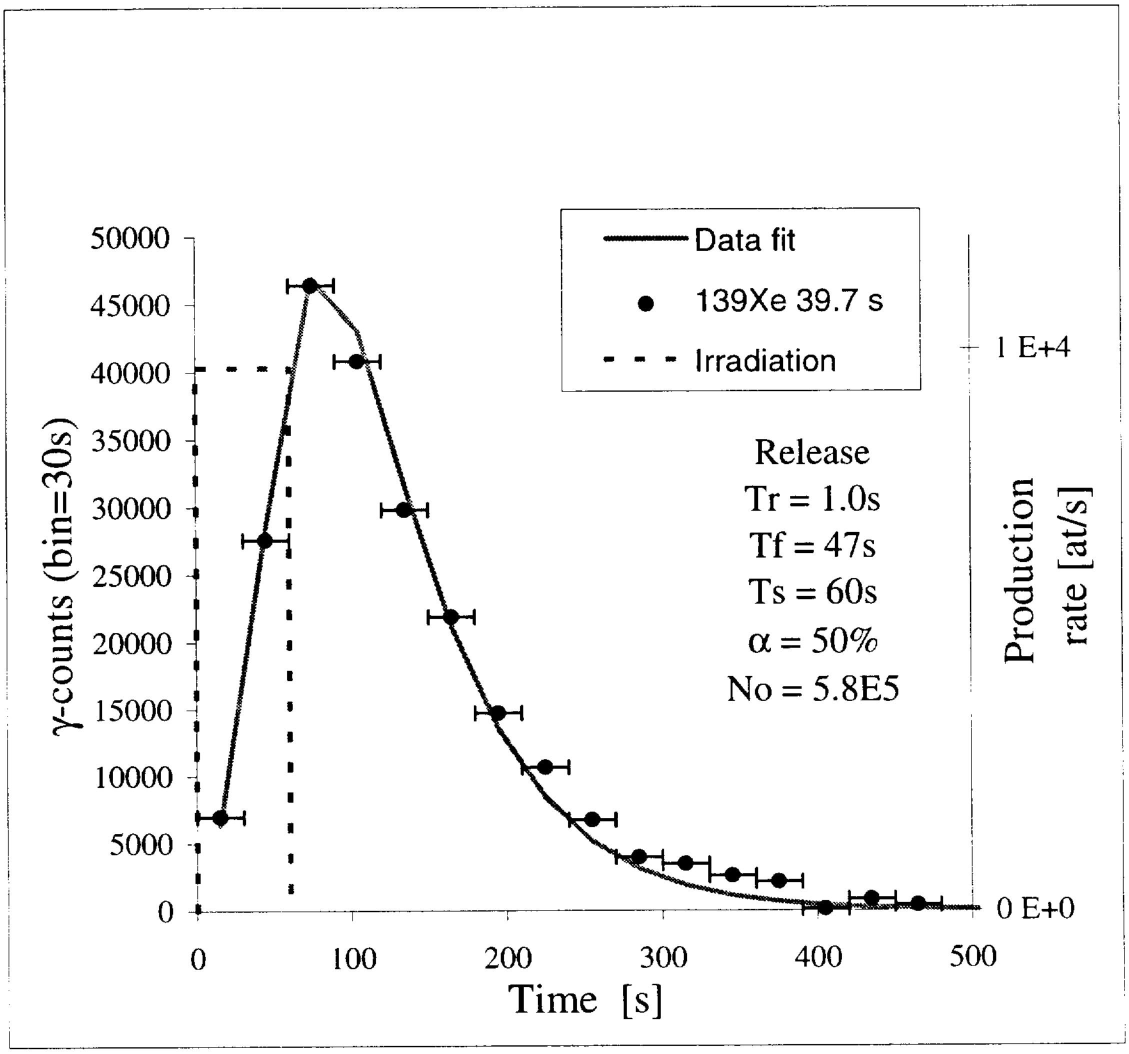

Fig. 1 : Time distribution for release and transport of ^{139}Xe.
The solid line corresponds to a fit (see text)

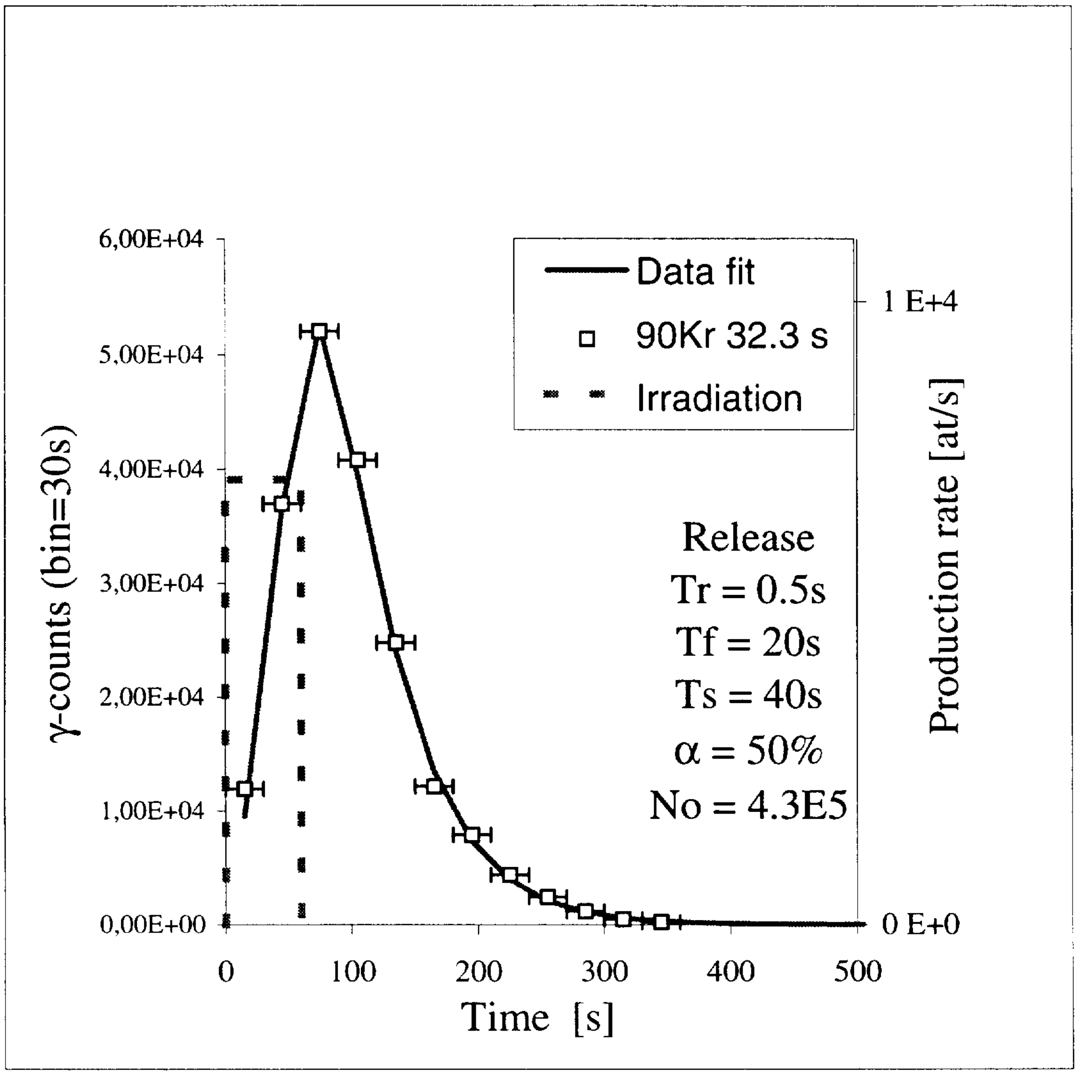

Fig. 2 : Time distribution for release and transport of ^{90}Kr.
The solid line corresponds to a fit (see text)