Production of light nuclides in 1 GeV proton-induced fission of ^{238}U

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A dedicated experimental program, devoted to reaching a full comprehension of the proton-induced spallation reactions, started in 1996 at the GSI. The accurate knowledge of these reactions is relevant both for the development of methods of incineration of radioactive waste [1] and for the production of secondary beams [2]. Within this program, the first ever complete survey on nuclide production cross sections in ^{197}Au + ^{1}H [3, 4] and ^{208}Pb + $^{1, 2}$H [5, 6] at around 1 GeV per nucleon was obtained. Experiments on other systems in the energy range 0.5-1.5 GeV per nucleon are still being analyzed or in preparation (^{238}U + ^{1,2}H [7, 8], ^{56}Fe + ^{1,2}H and ^{136}Xe + ^{1}H [9]). Two methods can be used for the production of residual nuclides in nuclear reactions: the target fragmentation ("direct kinematics") and the projectile fragmentation ("inverse kinematics"). The above quoted experiments were performed in inverse kinematics at relativistic energies. In these experimental conditions the fragment escapes the target and is detected in-flight prior to its β decay.

In this report, we present new results on the formation of light fission fragments produced in the reaction ^{238}U + ^{1}H at 1 *A* GeV. The 1 *A* GeV ^{238}U beam impinged on a liquid hydrogen target of 87.3 mg/cm thickness, which was enclosed in a thin titanium casing [10]. The fully stripped reaction products were identified at the FRS [11] by detecting their nuclear charge, Z, with a ionization chamber and their mass, A, from the A/Z ratio deduced from the magnetic rigidity and from the time-of-flight between the mid plane and the exit of the spectrometer. Once the nuclides were identified, so A and Z were integer numbers, their velocity was precisely evaluated by the magnetic rigidity.

As described in ref. [12] the ratio of transmitted reaction residues can be calculated. By the known beam intensities, target properties and transmission ratios the production cross sections were calculated on the basis of the measured yields. The measured velocity spectra allowed deducing the reaction mechanism in which the residues were formed. In this way, fission events, mostly originating from reactions with hydrogen, could be disentangled from the fragmentation ones, produced in the titanium windows. The results for the fission cross sections in the ^{238}U + ^{1}H reaction are shown on figure 1. The lower part of the complete nuclide distribution of this reaction, measured in our experiment is presented.

This reaction has been the basis for the production, in direct kinematics, of long isotopic chains of a few elements at ISOLDE [13] (see fig. 1). A direct measure of the production cross sections and of the kinematics of the reaction mechanism does not exist in this case, since the production and identification of the residues are separated by the intermediate extraction process. Our experiment provides the normalization factors to determine the extraction efficiency of the ISOL-target-ion-system. Although with the uranium beam intensities used in our survey experiment it was not possible to observe the extremely neutron-rich isotopes which were detected at ISOLDE, our experiment revealed the continuity in the production of all these light elements in the high-energy fission processes. Our experiment reveals that all these nuclides could be made available at ISOL facilities with a high-energy proton driver by developing appropriate extraction methods.

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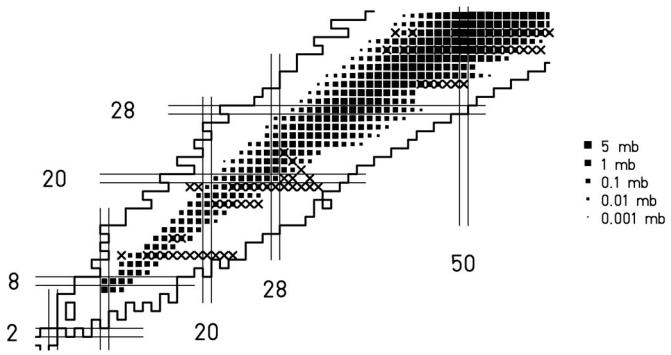

Figure 1: Measured nuclide cross sections from the reaction ^{238}U (1 A GeV) + ^{1}H. The crosses indicate nuclides observed at ISOLDE [13].

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