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PRESENT AND FUTURE RADIOACTIVE NUCLEAR BEAM DEVELOPMENTS AT ARGONNE

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A scheme for building an ISOL-based radioactive nuclear beam facility at the Argonne Physics Division, is currently evaluated. The feasibility and efficiency of the different steps in the proposed production- and acceleration cycles are being tested. At the Dynamitron Facility of the ANL Physics Division, stripping yields of Kr, Xe and Pb beams in a windowless gas cell have been measured and the study of fission of ^{238}U induced by fast neutrons from the ^{9}Be(d,n) reaction is in progress. Different aspects of the post-acceleration procedure are currently being investigated. In parallel with this work, energetic radioactive beams such as ^{17}F, ^{18}F and ^{56}Ni have recently been developed at Argonne using the present ATLAS facility.

INTRODUCTION

Within the last decade a growing interest in the production and use of energetic radioactive nuclear beams (RNB) has come forth (1,2). Experiments at first generation RNB facilities have demonstrated the capability of studying new research frontiers in the fields of nuclear physics and nuclear astrophysics. In order to meet the challenging goals of future experimental programs, a concept for a second generation facility, providing high intensity RNB and covering a broad range of nuclei, is highly desired. A novel scheme for producing intense, high-quality RNB based on the two accelerator method has been proposed by a group in the Physics Division at Argonne. Details of this plan, including research possibilities, can be found in a working paper entitled "Concept for an advanced Exotic Beam Facility Based on Atlas" (3). A brief overview of the basic concept is presented in the first section of this paper. At present, R&D related to different aspects of the proposed production- and acceleration methods are in progress. The present status of these RNB developments at Argonne are discussed in the following section of this paper.

THE FACILITY CONCEPT

The proposed method for producing energetic RNB at Argonne, is based on the ISOL (Isotope Separator On-Line) approach, i.e. post-acceleration of low-energy ISOL beams. The different elements involved in the production process are shown schematically in Fig.1. The proposed driver accelerator is a 215-MV drift tube linac which can deliver several light ions (^{1}H,^{2}H,^{3}He,^{4}He,...) with high beam intensities. The addition of a 30-MV RFQ/Linac injector for q/m=1/6 would also permit the acceleration of heavier beams such as ^{18}O and ^{36}Ar up to 100 MeV per nucleon. With this variety of primary beams, several different nuclear reaction mechanisms can be exploited (4). One interesting mechanism is fission of ^{238}U using 0.1 pmA of 100 MeV neutrons from the breakup of 200 MeV deuterons (5). The separation between the breakup target and the thick uranium production target can solve problems related to the high beam power. After release from the target, the produced nuclei will be ionized and mass separated using standard ISOL techniques and an isobar separator, delivering 100 kV 1^{+} beams to an RFQ

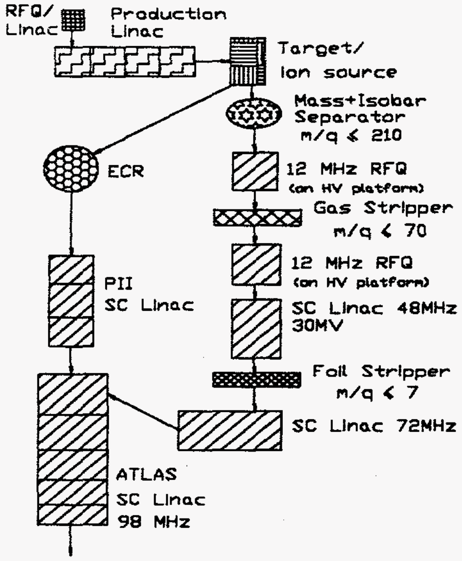

FIGURE 1. Block diagram of the Argonne RNB-Facility concept.

The post-acceleration of the low energy ISOL beams is based on the existing superconducting ATLAS linacs. However, four new acceleration subsystems are required to pre-accelerate the initial low q/m beams to energies of 0.5-1.0 MeV per nucleon, before injection into the existing ATLAS linacs and the further acceleration from 1 to 15 MeV per nucleon, can be achieved. These four new systems consist of a low-frequency 12 MHz RFQ, positioned on a 300 kV high voltage platform, followed by a second 12 MHz RFQ and two new sections of superconducting linacs optimized for low q/m

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optimized for low q/m beams. In this acceleration scenario, the RNB's have to be stripped twice: a first time, gas stripping from 1^+ to 2^+ will occur just off the RFQ high voltage platform and a second time foil stripping to q/m=0.15, just in front of the third matching pre-accelerator linac section, is necessary. The energy range of this acceleration method is quite flexible, i.e. RNB's can be selected at different stages in the acceleration process (i.e. for research in atom or ion traps without acceleration, selection after the pre-acceleration at 0.5-1.0 MeV/nucleon for nuclear astrophysics experiments and at 1-10 MeV per nucleon after acceleration by ATLAS).

For noble gases (e.g. Kr and Xe isotopes) or volatile compounds, an alternative and efficient scheme for producing RNB's at ATLAS can be conceived, as is also shown in Fig 1. In this case, transport of the radioactivity from the shielded target to an ECR ion source, positioned on a 350 kV platform, can be accomplished by using a cold transfer line, which also enables a certain isobaric selectivity. The now highly charged ion beams from the ECR ion source can then directly be injected in the existing SC positive ion injector of ATLAS (PII) (6).

PRESENT RNB DEVELOPMENTS AT ARGONNE

Stripping in a gas target

As described in the previous section, gas stripping of the low energy 1^+ ISOL beams will be performed at about 8 keV per nucleon, just before injection into the second RFQ. Stripping from 1^+ to 2^+ and from 1^+ to 3^+ for masses larger than 70 and 140, respectively, is necessary in order to match the velocity requirements of the pre-accelerator. Since, at these low energies, few experimental data are available, a systematic study of the stripping efficiency and the multiple scattering of N^{1+}, Kr^{1+}, Xe^{1+} and Pb^{1+} beams in He and N_2 gas targets, has been performed. The beams were delivered by the 5.0 MV Dynamitron accelerator at the ANL Physics Division. An overview of the results is given below and the details of these experiments will be presented elsewhere (7).

The 1^+ beams from the Dynamitron were first analyzed by two bending magnets and then further collimated using different circular apertures along the beam line, yielding a beam with an angular divergence < 0.1 mrad. This beam was then focused on a 10 cm long gas cell having an entrance aperture of 2 mm in diameter and a vertical aperture of 2 mm wide and 6 mm high as exit. The different charge states were analyzed using a parallel plate deflector and the charge state fractions were measured by using a movable silicon particle detector, positioned 5.4 m downstream with respect to the gas target. The best results were obtained with He as a stripper gas, high 1^+ to 2^+ stripping efficiencies of 40%, 49% and 50% were obtained for 0.8 MeV Kr, 1.0 MeV Xe and 1.0 MeV Pb beams, respectively. An efficiency of 33% for stripping a 1.0 MeV Pb beam from 1^+ to 3^+ in a He target, has been measured. Figure 2 shows the results of the charge state fractions, obtained with a 1.0 MeV Xe and Pb beam, versus the He target thickness.

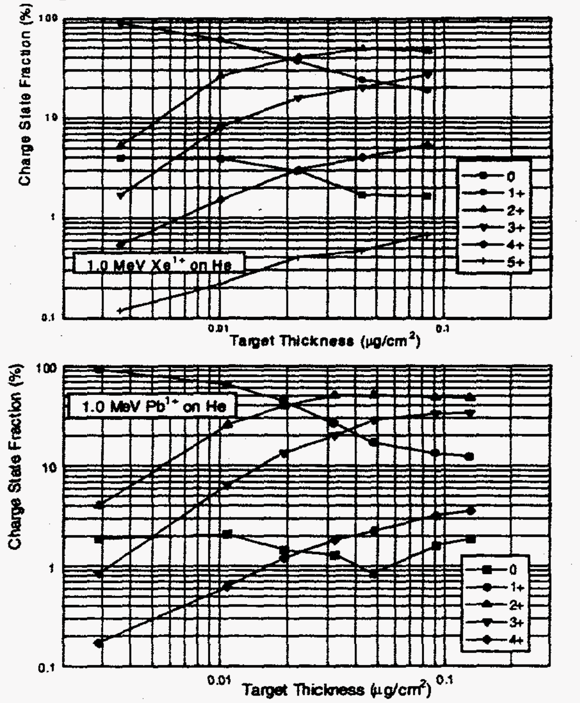

FIGURE 2. Measured charge state fractions for Xe^{1+} and Pb^{1+} (1.0 MeV) beams after passing a He gas target.

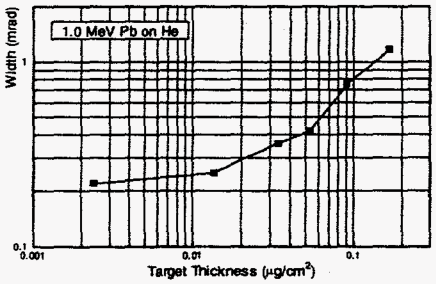

FIGURE 3. Measured full width at half maximum (in mrad) of a 1.0 MeV Pb^{1+} beam after passing a He gas target.

By installing a small rectangular slit (width = 1.6 mm) in front of the silicon detector a scan of the beam profile with an angular resolution of 0.2 mrad could be performed and information about multiple scattering in the gas target could be obtained. In Fig. 3 the full width at half maximum of a Pb beam in function of the He target thickness, is plotted, showing that the effects of multiple scattering in a thin gas cell are less than 1 mrad, with helium gas thickness adequate for $^{208}Pb^{3+}$.

Target concept for the production of fission fragments

At the 5.0 MV Dynamitron Facility of the Argonne Physics Division, a test area for production- and ion source studies has been constructed. A shielded cave has been build, as build, as shown in Fig 4, which enables the use of high intensity deuteron beams for production studies. As explained above, the fission of ^{238}U by secondary neutrons is a promising reaction mechanism for the production of a variety of neutron rich isotopes. This reaction mechanism can be studied at the Dynamitron facility. A 4.8 MeV deuteron beam will be used to generate neutrons from the ^{9}Be(d,n)^{10}B reaction which will then be used for the irradiation of an ^{238}U target. Absolute fission yields and release studies from the target material will be performed.

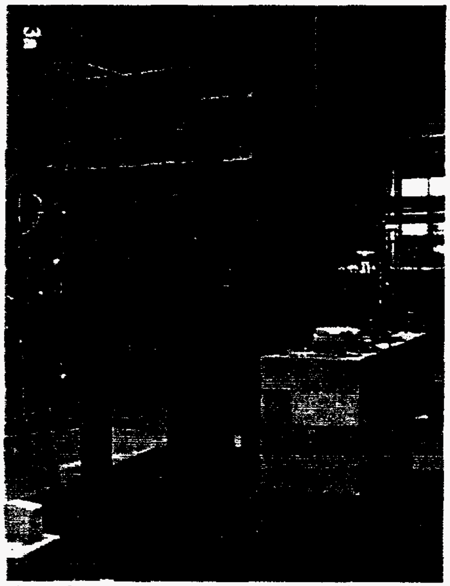

FIGURE 4. View of the shielded cave (during construction) at the Argonne Dynamitron Facililty, which will be used for fission studies of ^{238}U, target release measurements and on-line ion source developments.

A calculation of the production yields of neutron rich Kr, Xe and Sn isotopes, obtainable with this specific production method, has been made. The results of this production calculation and the geometry of the target system are shown in Fig 5. , These calculations include the experimentally determined neutron energy distribution (at 0°) from the ^{9}Be(d,n)^{10}B reaction (8) and the fission cross sections and the fractional yields are taken from Ref. (9) and (10), respectively. These results show that with a 100 pμA deuteron beam, high yields for these isotopes can be obtained and that systematic studies of the production and the release properties of fission products from a ^{238}U target matrix are possible. Irradiations will start in the fall of 1996.

Ion Source Developments

Concerning the production of the 1^{+} ISOL beams, inspiration will come from the experience of existing ISOL facilities such as CERN-ISOLDE or GSI Darmstadt which have proven to be successful (11,12). Unfortunately, no universal ion source exists, specific ion sources have to be optimized for specific elements or groups of elements (13).

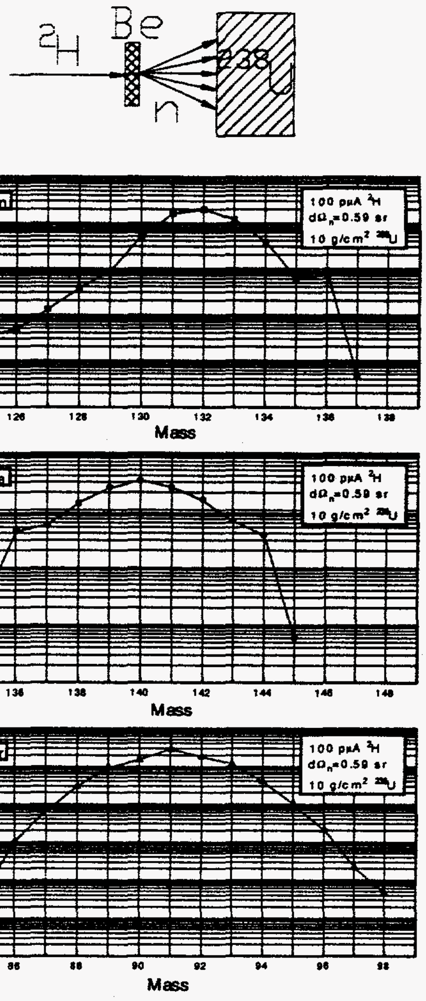

FIGURE 5. Calculated ^{238}U fission yields for the Sn, Xe and Kr isotopes. Fission is induced by fast neutrons from the ^{9}Be(d,n) reaction. Yields are calculated for a 4.8 MeV deuteron beam (intensity=100 pμA) and only the neutrons emitted within a solid angle of 0.59 sr are taken into account. Isotopes with half-lives in the seconds to minutes range can be studied.

A test bench for ion sources is now available at ATLAS and, as a first step, a Gill-Piotrowski-type high temperature plasma ion source has been installed (14). In the future other types of plasma sources might be developed and installed at the test stand in order to gain experience in this particular ion-source technology and to elaborate more the specifications, such as ionization efficiency, emittance and energy spread, of these sources.

As mentioned above, an alternative way of producing RNB's at ATLAS, is by coupling the production target with the present positive ion injector by means of an efficient high-charge-state ECR ion source. On-line ECR ion sources for low charge states have been used successfully since several years at the Louvain Facility (15,16) and the TISOL facility (17). Efforts to develop on-line ECR ion sources for efficient production of high charge states at Ganil (18) look very promising. Possible losses due to the transport time between target and the ion source, can be compensated by the gain in overall acceleration efficiency, mainly due the fact

fact that with this method at least the first gas stripping is not required. Of course, the target-ion source distance should be kept as short as possible. This method of ionizing the radioactive atoms in an ECR ion source, followed by post acceleration with a SC linac, will be tested using ^{18}F ($T_{1/2}$=109 m) atoms. A proposal has been submitted at ATLAS to produce ^{18}F at the Dynamitron facility and post accelerate the ^{18}F atoms with the positive ion injector of ATLAS (19). Fluorine and neon efficiency measurements and the fluorine release time out of the ATLAS ECR ion source have been performed. The production of ^{18}F at the Dynamitron will start in the fall of 1996. The beam will be used for nuclear astrophysical measurements (19). This ^{18}F beam development is a continuation of a former program at ATLAS with radioactive ^{18}F beams (see below).

An interesting progress could be the combination of using 1^+ ISOL beams and an ECR ion source playing the role of a charge-state amplifier. First results with a high-charge-state breeder, developed for the PIAFE project, show that 1^+ ISOL beams can be transformed into higher charge states with relatively high efficiencies (20). Optimization and generalization of such a device could be a helpful solution for coupling ISOL beams with the ATLAS positive ion injector.

Acceleration Developments

Different aspects of the post-acceleration method are currently being examined (21,22). A low-charge-state CW RFQ prototype is under construction (23).

Present Radioactive Beams at ATLAS

Besides this specific R&D for a future RNB facility, first generation radioactive beams are presently being developed at ATLAS. Large amounts of ^{18}F were produced by the $^{18}O(p,n)^{18}F$ reaction, using the medical radioisotope production cyclotron from the University of Wisconsin (24). With these samples, a radioactive ^{18}F beam has been generated at Argonne using the ATLAS Tandem accelerator and nuclear physics experiments have been performed (24,25). The development of a ^{56}Ni beam at ATLAS is currently in progress (26). In addition, a ^{17}F beam has been developed using an in-flight technique; by bombarding a hydrogen gas target with a 83 MeV ^{17}O beam, a ^{17}F beam was produced (p,n reaction) and further transported to the experimental area (27).

SUMMARY

An ISOL-based facility for the production of energetic RNB at Argonne has been proposed. The post acceleration of the beams is based on Superconducting Linacs, a technology which has been developed successfully during the last decade at Argonne. At present, R&D related to important parts of the production process, such as primary production targets, ion sources, gas targets for beam stripping, and different other issues related to the development of a RNB facility, is in progress at the Argonne Physics Division. In parallel with these developments first generation radioactive beams are being developed and used for research at ATLAS.

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