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REX-ISOLDE - POST-ACCELERATED RADIOACTIVE BEAMS AT CERN-ISOLDE

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Abstract.

The ISOLDE RIB-facility at CERN has today been producing a vast range of radioactive beams since more than 30 years. The low-energy beams of ISOLDE will be complemented by a post-accelerator, REX-ISOLDE, currently being assembled. In order to convert the pseudo-DC, singly-charged beam from the ISOLDE mass separators into a cooled and bunched beam at higher charge states, a novel scheme of trapping, cooling and charge-state breeding has been devised, using a linear Penning trap and an Electron Beam Ion Source (EBIS). This allows for subsequent acceleration by a short, cost-effective LINAC consisting of an RFQ, an IH-structure and three seven-gap resonators, reaching 0.8 - 2.2 MeV/u. The installation of REX-ISOLDE is well underway and the first post-accelerated radioactive beams are expected to be obtained during late 2000.

Introduction

Radioactive Ion Beam (RIB) Facilities is presently a topic attracting interest from a large part of the nuclear physics community. A number of new or upgraded facilities are currently being planned, built or commissioned world-wide, and in a longer perspective, NUPECC (Europe) and DOE (USA) independently have recommended the construction of a "second-generation" RIB facility where radioactive beam intensities 100 times higher than at the current facilities can be produced.

The production of RIB is done according to two different methods; one is to let an energetic heavy-ion beam impinge on a thin production target and by subsequent in-flight ($B\rho - \Delta E - B\rho$) separation of the fragments select the wanted isotopes (1). The other method, which is the one used at ISOLDE (2), is to let a driver beam (protons, neutrons or heavy ions) impinge on a thick production target where a huge amount of unstable nuclides are created, and from this target volume extract, ionise and separate the wanted isotopes.

The driver beam of the ISOLDE facility is a pulsed

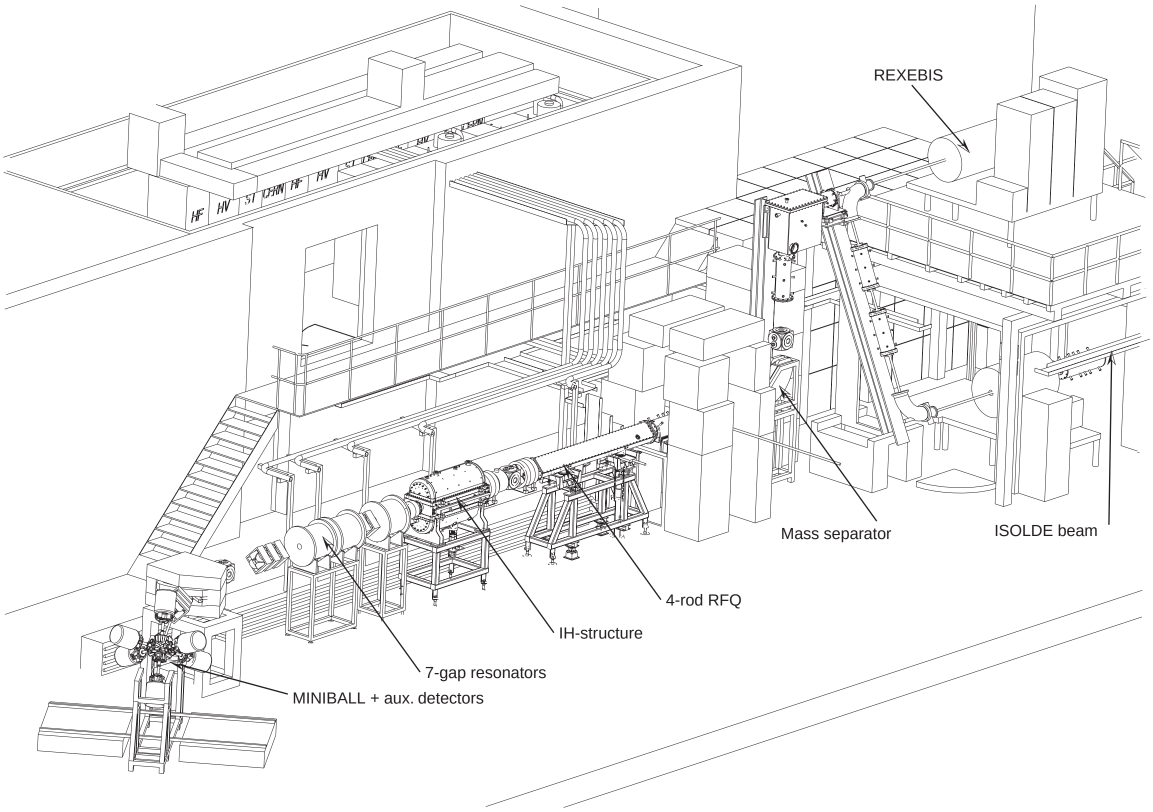

FIGURE 1. Schematic view of the REX-ISOLDE installation in the ISOLDE experimental hall.

proton beam from the PS-Booster synchrotron of 1.0 or 1.4 GeV energy with a repetition rate of typical 1/2.4 s^{-1}. The average current exceeds 2 μA. The high-energetic protons induce spallation, fragmentation and fission, giving rise to a large number of radioactive species. ISOLDE regularly uses a large variety of target materials (metal foils, oxides and carbides) and 1^{+}-ion sources (surface, plasma and laser ionisation) to produce more than 600 isotopes of $>$60 elements. A constant development of targets with respect to new materials with release of the often short-lived species of interest (down to a few ms) is intensely pursued. The Resonant Ionisation Laser Ion Source (RILIS) (3, 4) has been intensely and successfully used at ISOLDE in recent years to improve the ionisation efficiency, enhance selectivity and to ionise elements not otherwise achievable with the traditional ISOLDE ion sources.

With this as a starting point, it is clear that the prerequisites for building a post-accelerator at ISOLDE are optimal, apart from the proliferation and intensities of the available radioactive beams, it also benefits from the large know-how in targetry and RIB handling and the existence of CERN infrastructures.

The REX-ISOLDE post-accelerator

Until now, ISOLDE has been limited to study radioactive nuclei at very low energies only, 60keV. The REX-ISOLDE (5, 6) experiment will change this situation dramatically; almost any nuclide currently produced at ISOLDE will be possible to accelerate to an energy in the range 0.8 - 2.2 MeV/u. This opens up a completely new field of experiments with RIB with A$<$50, with an energy range tailored for Coulomb excitation and few-nucleon transfer reactions, being well-proven spectroscopic tools for stable beams. An overview picture of REX-ISOLDE in its final state is shown in 1.

REXTRAP - REXEBIS Cooling, bunching and charge breeding

The RIB from the ISOLDE separator is a continuous beam, with the intensity varying in time after the proton impact as a function of the release characteristics and the half-life of the nuclide in question. To transform this singly-charged, "pseudo-DC" beam from the ISOLDE separator to a multiple-charged (q/A $>$ 1/4.5) pulsed

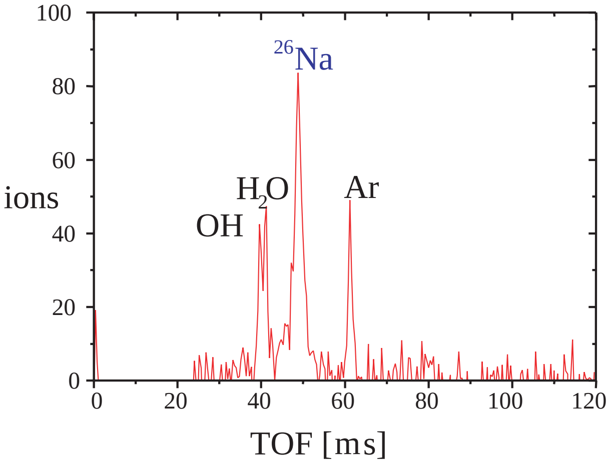

FIGURE 2. TOF distribution of captured, cooled and bunched ^{26}Na ($T_{1/2}$ = 1.07 s) ejected from REXTRAP.

beam suitable for acceleration with acceptable losses requires novel techniques. Bunching of the radioactive beam is required in the chosen acceleration scheme because the charge-state breeding in the REXEBIS requires a typical time of about 20 ms and the LINAC operates with a duty factor of 10%. The basic technique applied to accumulate and bunch the beam is to continuously inject the radioactive ions into a large Penning trap, REXTRAP, where they are stopped by collisions with the atoms of a buffer gas, accumulated and finally extracted as pulses. REXTRAP consists of a 1 m long cylindrical trap structure filled with buffer gas in a 3 T magnetic field. It is mounted on a high voltage platform close to 60 kV in order to retard the ions from 60 keV to some eV suitable for injection into the trap. After the ions have passed the potential barrier at the entrance of the trap, final deceleration is done by friction in the Ar buffer gas. The ions can be fully captured if their energy loss during a single oscillation in the trap is larger than the energy spread of the ISOLDE beam after deceleration, after which they can not escape the entrance barrier. Typical cooling times down to room temperature are a few ms. By this cooling the emittance of the extracted beam is considerably improved. The trapping and cooling are expected to reach almost 100% efficiency. Recent tests with stable and radioactive beams have shown capture efficiencies up to 27% for ion beams from ISOLDE and 45% from an auxiliary ion source. In fig 2 a TOF distribution of captured, cooled and bunched ^{26}Na ($T_{1/2}$ = 1.07 s) ejected from REXTRAP is shown.

Mass separator and LINAC

The bunched beam is then transported to REXEBIS (Electron Beam Ion Source). An EBIS makes use of a dense electron beam that is focused to a high current density by a strong magnetic field of a solenoid. The electron beam forms a radial potential well for the ions while the longitudinal confinement is performed by electric potentials applied to cylindrical electrodes surrounding the electron beam. Trapped low-charged ions undergo stepwise ionisation via electron impact collisions until the ions are extracted by changing the longitudinal potential distribution. The centroid of the charge distribution is determined by the product of the confinement time and the electron beam current density. In the REXEBIS a superconducting solenoid creates a magnetic field of 2 T, with a homogeneity of about 0.25% along the confinement length of 0.8 m which compresses the 0.5 A, 5 keV electron beam into a current density larger than 200 A/cm^2. The isotopes used at REX-ISOLDE will require breeding times between 5 and 20 ms to reach a charge-to-mass ratio larger than 1/4.5. In order to decrease the injection energy into the RFQ to 5 keV/u the platform voltage has to be switched from 60 kV (injection potential) down to 20 kV, and rapidly back again to accept the next bunch of ions.

The yield of the radioactive isotopes from ISOLDE can be several orders of magnitude lower than the amount of residual gas ions from C, N, O and Ar coming out of the EBIS. Therefore, a mass separator similar to a Nier-spectrometer will be employed with a q/A-resolution of about 1/150 which is sufficient to select the highly charged rare radioactive ions from rest-gas contaminants.

In the first stage of REX-ISOLDE LINAC the ions are accelerated from 5 keV/u to 300 keV/u by a 4-rod RFQ. In order to match the beam from the RFQ into the acceptances of the IH-structure a section consisting of two magnetic quadrupole triplet lenses and a rebuncher is required.

The Interdigital-H-type (IH)-structure is an efficient drift-tube structure, similar to structures like the GSI HLI-IH-structure or ’tank 1’ of the lead LINAC at CERN. A new feature of the REX-ISOLDE-IH resonator is the possibility to vary the final energy between 1.1 and 1.2 MeV/u by adjusting the gap voltage distribution via two capacitive plungers and by adjusting the rf-power fed into the resonator. The lower final energy of the IH-structure is important for deceleration of the ions down to 0.8 MeV/u, since the deceleration from 1.2 MeV/u down to 0.8 MeV/u through the 7-gap resonators would perform a non-acceptable phase spread at the target.

The high-energy section (0.8 - 2.2 MeV/u) of the REX-ISOLDE LINAC consists of three 7-gap resonators similar to those built for the high-current injector at MPI

Heidelberg. These spiral resonators are designed and optimised for synchronous velocities of β=5.4%, 6.0% and 6.6%. Each resonator has a single resonance structure, which consists of a copper half shell and three arms attached to both sides of the shell. Each arm consists of two hollow profiles, surrounding the drift tubes and carrying the cooling water. All LINAC structures are operated at 101.28 MHz.

Planned experiments at REX-ISOLDE

The REX-ISOLDE pilot experiments (7, 8)aims to probe whether the magic numbers N=20 and N=28 are conserved when going to very neutron-rich nuclei by using Coulomb excitation and transfer reaction experiments. Other experiments have hinted a weakening of the nuclear shell structure in the region of ^{32}Mg (9) and below ^{48}Ca (10, 11), with deduced sizable deformations. The main detector system to be used here is the state-of-the-art gamma-detector array MINIBALL (12) currently being assembled by a large European collaboration. To facilitate Doppler corrections, charged particles will be detected in a high-granularity, segmented silicon detector with "compact-disc" geometry, the CD. The residual nuclei will be detected in a PPAC (Parallel Plate Avalanche Counter) downstreams from the reaction target.

A large number of other experiments will also be using REX-ISOLDE. Two further experiments (13, 14) are already approved; both concerned with investigating the unbound sub-systems of halo nuclei by one-neutron pick-up reactions and elastic resonance scattering. E.g. the unbound sub-system ^{10}Li of the halo nucleus ^{11}Li will be studied by the ^{9}Li(d,p)^{10}Li reaction and through the IAS in ^{10}Be by the ^{9}Li(p,p')^{9}Li reaction. Other experiments are foreseen in the short-term future concerning the structure of nuclei along the N=Z line, proton radioactivity and nuclear astrophysics.

The bunched and cooled beams from REXTRAP are also well suited for other experiments without subsequent acceleration. In one approved experiment (15), the cooled beam will be extracted and stored in an electromagnetic trap, combined with a retardation spectrometer. The latter is used to measure the recoil momentum of the daughter nuclei after beta decay, allowing studies of β-ν correlations. This could give information on possible scalar current components in the nuclear beta decay, meaning "new physics" beyond the Standard Model. Furthermore, the higher available implantation energy gives rise to new possibilities to use radioactive methods to probe the bulk properties of condensed matters.

Outlook

The REX-ISOLDE post-accelerator will keep ISOLDE in a unique position in the world, with a unprecedented choice of radioactive beams for low-energy reactions. Together with the continuous beam development, this assures many years to come with ISOLDE research at the forefront of physics. The techniques used in REX-ISOLDE are also highly interesting for future, second-generation ISOL-facilities, such studied in the recently started EURISOL (16) project. It is foreseen that after the commissioning phase and the first generation of pilot experiments, REX-ISOLDE will be integrated into the CERN accelerator structure.

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