HIE-ISOLDE

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Abstract

The HIE-ISOLDE project proposal is a major staged upgrade to the existing REX accelerator facility at ISOLDE with the objective to provide radioactive beams up to 6 MeV/u with a future option of going to 10 MeV/u. The ambition is to make all isotopes produced at ISOLDE (>800) available as post accelerated beams. The beam quality will be much improved for ISOLDE users with the installation of a RFQ cooler, a new resonant laser ionization system and a renovated high resolution mass separator. New isotopes will be made available through target and ion source development. The driver intensity will be increased (5×), with a first increase coming from a faster cycling of the PS Booster and a later increase coming from the new Linac-4. We will in this contribution review the project and report on the present status of the staged proposal.

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1. Introduction

ISOLDE is one of the premier ISOL facilities world-wide for the production of radioactive beams. The existing facility for accelerated RIB at ISOLDE, REX-ISOLDE, exploits innovative techniques using ion traps and new methods for charge breeding of atoms that are unique world-wide. REX (Radioactive beam EXperiment) was originally constructed for specific experiments and was funded by several CERN member states. It now utilises nearly 50% of the ISOLDE running time. REX has the potential to transport and accelerate most of the 700+ radioisotopes from 65 elements of ISOLDE's repertoire. These radionuclides are produced following the bombardment of various primary targets with 1.4 GeV protons from the CERN PS Booster. Since it became operational in 2001, REX has accelerated 50 different radioactive isotopes [1], which surpasses by far any other European ISOL RIB facility. The HIE-ISOLDE proposal represents a major upgrade of the facility [2] and the physics case for the upgrade is documented in [3].

2. The REX-ISOLDE energy and intensity upgrade

The REX-ISOLDE system [4] was initiated in 1993, construction started in 1995 and operation in 2002 and has since then, on average, delivered some 120 eight hour shifts of physics per year for nuclear physics. The facility has demonstrated that a compact linac combined with a cooler, buncher and charge breeder is a cost efficient and reliable option for the production of radioactive ion beams. The upgrade proposed within HIE-ISOLDE concerns the top energy and the capacity to handle the full intensity and mass range of available ISOLDE isotopes.

During two months in spring 2006 the AB RF group made a study of two possible technologies for the REX energy upgrade; a super conducting (SC) option and a normal conducting (NC) option. The two options were presented for an international advisory panel which gave a unanimous recommendation for a superconducting linac. Quoting from the IAP report [5] conclusions: *Indeed, the inherent flexibility of an SC-linac based on independently phased superconducting cavities, further allowing at term (conditioned by a new injector) 100% duty factor operation, guarantees a much wider experimental programme. On the longer term, the experimental programme will quest for more*

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precision experiments, intimately linked to high beam quality for which the SC solution has more asset. The panel also stressed the importance of synergies with other projects at CERN, such as LINAC4 and SPL and other European projects like SPIRAL-2, SPES and EURISOL.

2.1. The REX linac upgrade

In order to meet the energy specifications maintaining at the same time the transverse and the longitudinal beam quality, we propose here a superconducting linac based on quarter wave resonators which can be installed downstream the present linac and eventually replace some of the existing accelerating structure. The energy upgrade will happen in three stages; in a first stage the maximum energy will be limited to 6 MeV/u with energy variability between 2 MeV/u and 5 MeV/u. In a second stage the final energy will be incremented up to 10 MeV/u, and in a final stage the present low energy section from 1.2 MeV/u will be changed with superconducting cavities. This latter stage will allow to decelerate and to transport the beam to energies lower than 1.2 MeV/u hence increasing the possible use of this machine.

We have chosen two gap quarter wave resonators as building elements of the linac. The reduced numbers of gaps assure a very high flexibility in terms of velocity acceptance and at the same time they assure a small number of different geometries necessary to cover the whole energy range. The energy range between 1.2 MeV/u and 10 MeV/u corresponds to a reduced velocity between 5.1% and 14.5%. Energy of 6 MeV/u corresponds to a reduced velocity of 10.8%.

The RF cavities should give 6 MV/m as effective accelerating gradient with a power dissipation less than 7 W. The active lengths are 180 mm for the low beta cavity and 300 mm for the high beta one. This means a total of 1.08 MV and 1.8 MV of voltage gain respectively at the optimum velocity. From the transit time factor curve it is possible to calculate the energy for different masses. Fig. 1 shows the final energy of beams with different A/q as a function of the cavities number. For the quarter wave cavity there are two different types of technologies that can be used for the production of the cavity itself, bulk niobium technology and sputtered niobium technology. From the RF point of view the performance of the cavities built with the two technologies are very similar [6], high gradients are achievable in both cases with the only important difference that the mechanical stability and hence the RF stability is much higher in the sputtered cavities. On the other hand, the technologies for building bulk niobium cavities are already available in the industry while the sputtering technology for this kind of geometry only is available in a few research laboratories such as INFN-LNL and CERN. The superconducting cavities require a Helium liquefier locally at ISOLDE as the total cooling power needed for the full linac is almost 450 W.

Fig. 1. Beam energy as a function of the cavity number for different masses (i.e. A/q).

The new extension hall provides an additional space of around $23 \times 17 \text{ m}^2$. The magnetic rigidity for a beam of 10 MeV/u with $A/q = 4.5$ is about $B = 2 \text{ Tm}$, and in order to optimize the space availability, large bending angles are necessary. Fig. 2 shows a layout of the full superconducting linac leaving most of the space in the new extension available for the experiments.

3. The REX low energy stage upgrade

The REX low energy stage [7] consists of a Penning trap used for cooling and bunching and an electron beam ion source (EBIS) for charge state multiplication. This approach to charge state multiplication was pioneered at REX-ISOLDE and has proven highly successful. The EBIS source operates with UHV vacuum and, as a result the extracted ion beam is close to background free with the only source of contaminating ions being the inherent isobaric contamination of the injected radioactive ion beam itself. An upgrade of the REX low energy stage is necessary to enable charge breeding of heavier elements with maintained breeding time (half life limitation) and to handle higher intensities.

To maintain breeding times for heavier ions a higher electron density is required in the EBIS source. The possible upgrades of the present source are limited and in order to meet the requirements we propose to install a new EBIS similar to the BNL Test EBIS [8]. This system has higher electron beam current density and total current so both the breeding time (reachable charge state) and the total space charge capacity can be improved with this system. The BNL EBIS has a total electron beam of 10 A (present EBIS $< 0.3 \text{ A}$) from a new type of cathode with longer life time and better reliability. The electron density is close to 575 A/cm^2 with electron beam energy of 10–20 keV. The resulting charge capacity is 1×10^{12} charges and if operated in accumulation mode together with the new RFQ

Fig. 2. Layout of the new linac with a possible beam line arrangement in the experimental hall.

cooler (see Section 5.2) the space charge limit of the existing REX Penning trap can be overcome. For lower beam intensities the existing Penning trap will continue to be used.

There is also a study in progress within the EURONS and EURISOL DS studies at ISOLDE of an electron cyclotron resonance (ECR) phoenix charge breeder. This system is of key importance if physics would require continuous (CW) beams from REX-ISOLDE. Such a development would mean that a phoenix ECR charge breeder is installed in parallel to the present REX low energy stage and it would also need a new low energy acceleration stage. The ECR source can also deliver a pulsed beam in after-glow mode but at a higher A/q compared to the EBIS system. Ions at this higher A/q can only be accelerated at the REX linac after important modifications to the RFQ and the first IH booster structure. The plan is to review the progress on the ECR towards the end of 2007 to take a final decision on a possible parallel installation of an ECR phoenix charge breeder.

4. ISOLDE driver and radioactive beam intensity upgrade

4.1. Faster cycling of the PS booster

The approved proton beam based physics programme at PS, SPS and LHC will from 2008 and onwards need a large fraction of the protons delivered by the PS Booster. A continued operation of ISOLDE with the average proton beam intensity ($2 \mu\text{A}$) maintained will require an increase of the number of protons delivered by the PS booster. The PS booster itself can be run (with substantial system upgrades)

with a 600 ms cycling with maintained beam quality and intensity but neither the injection lines nor the transfer lines from the booster can cope with this higher rate. During the 2005 run a PS booster cycle of 900 ms was tested with ISOLDE as a single user. Shared operation would require the replacement of some transfer line power supplies. However, more machine studies, especially to understand the impact on PS operation are needed before implementation.

4.2. Linac 4

The proposed new injector for the PS Booster, LINAC 4, would result in a doubling of number of protons per pulse from the PS Booster. This will together with the faster cycling of the PS Booster permit an important intensity upgrade at ISOLDE. In average ISOLDE could hope to receive up to $6 \mu\text{A}$ and for limited periods even higher intensities. To enable ISOLDE to receive the higher proton beam intensities from LINAC 4 a number of safety related modifications of the targets and front-ends have to be done.

4.3. Safety

The CERN safety commission has already made a first study of the safety aspects of a driver beam intensity upgrade. The most costly of the required modifications is the construction of a gallery above the existing ISOLDE target area in order to provide shielded access to the equipment and minimize the radiation dose received during routine operation and maintenance of the facility. A number of other important changes are also necessary e.g. the

present target handling system has to be replaced, the front-ends which connect the targets to the separators have to be re-designed and replaced and the shielding must be improved and the targets has to be modified for the very high instantaneous proton beam intensity. The development of new targets and target materials are profiting from the on-going EURISOL [9] design study in which CERN plays a key role for target development.

5. ISOLDE beam quality improvements

5.1. A new high resolution separator and highly charged ions

The high resolution separator (HRS) at ISOLDE has never been running with a better mass resolution ($m/\delta m$) than approximately 3500 in standard operation. The reason for this is the limited higher order multipole correction power available from the surface mounted correction coils inside the analyzing magnets. To resolve this problem the correction coils and the existing flat pole face magnets should be replaced with new magnets with shaped pole faces for passive correction. In addition, an improvement of the instrumentation at the HRS with compact emittance meters to enable simpler setting-up and tuning of the separator is highly desirable. In a longer time perspective, the HRS should be reconfigured with the first magnet being used as pre-separator feeding an RFQ cooler for transverse and longitudinal cooling so that isobars can be resolved with a second magnet after the cooler. Finally, the installation of an electron beam ion trap (EBIT) down stream in the experimental hall would provide highly charged ions for implantation at the existing high voltage platform and for mass measurements.

5.2. The RFQ cooler

The requirements of the users on the beam quality delivered by the facility are more and more stringent. Experiments ask for better beams, with higher intensity, smaller transverse emittances or bunched beams with small longitudinal emittance (energy spread and bunch length). The device best suited to tailor low energy beams transversally and longitudinally is an RFQ cooler which delivers a small transverse emittance beam with the freedom to adapt the time structure and energy spread of the beam to meet specific user requirements. A general purpose RFQ cooler (ISCOOL) [10,11] with many new features compared to similar systems operating at e.g. the ISOLDE mass experiments, ISOLTRAP and at the cyclotron lab in Jyväskylä has recently been developed at ISOLDE and it will be installed in 2007.

5.3. The RILIS and LARIS laboratories

The resonant ionization laser ion source (RILIS) at ISOLDE is the first ion source of its type to be in standard operation at a RIB facility [12]. It is the most requested

ion source system and the stable performance of the RILIS setup is of great importance for the ISOLDE facility.

The RILIS system is based on copper vapor lasers (CVL) pumping dye lasers with non-linear crystals for frequency doubling and tripling. The dye lasers can be pumped by solid state lasers (SSL) instead of CVL. Since the wavelength of the second harmonic generation of a Nd:YAG laser (532 nm) is close to the wavelength of CVL (511 nm), most of the currently used ionization schemes can be used after such a replacement. In addition, a broader choice of ionization schemes will be possible through the SSL fundamental frequency, third and fourth harmonics beams. Regarding operation and maintenance, SSLs are better: they do not require long-time preheating, the power supply control is relatively simple, and the level of electromagnetic noise is much lower compared to CVLs. In the long term the dye lasers can probably be replaced by emerging state-of-the-art wavelength-tunable solid state lasers improving further the reliability of operation [13].

The development of new ionization schemes and the R&D to improve existing schemes is very time consuming. It can today only be done at the on-line facility, so a very limited number of hours are available each year for this work. Thanks to a grant from the Knut and Alice Wallenberg foundation in Sweden, the construction of an off-line LASER Resonance Ionization Spectroscopy laboratory (LARIS) for R&D work [13] has already started and we expect to have first results in 2008.

6. Resources and planning

The resources required for the HIE-ISOLDE project has been studied by the AB department in 2007. The total material cost is estimated at 35 MCHF with a staff need of 125 person-years. The ambition is to complete the first stage of the energy upgrade to 6 MeV/u in 2010 and to complete the project in 2012 to benefit from the higher intensities available with the start of linac 4 operation in that year.

6.1. Already financed activities

A grant was given in the UK to finance the construction and installation of an RFQ cooler for general use at the high resolution separator at ISOLDE. The off-line testing and installation has been possible thanks to additional support from the AB department, the ISOLDE collaboration, the Ludwig-Maximilian University in Munich, the University of Mainz, the university of Jyväskylä, LPC in Caen and CSNSM in Orsay.

The new RILIS system and the LARIS laboratory have been fully funded by a generous grant from the Wallenberg foundation in Sweden. The lasers for the LARIS laboratory have been inherited from the SILVA project at CEA Saclay. The work to upgrade the RILIS system and to construct the LARIS laboratory is done in collaboration with the Royal Institute of Technology in Stockholm and CEA Saclay participates in the work with the LARIS laboratory.

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