SIRIUS - A RADIOACTIVE NUCLEAR BEAM FACILITY FOR ISIS

T. A. Broome, CLRC, Rutherford Appleton Laboratory, Chilton, Didcot, Oxon., OX11 0QX, UK
For the SIRIUS Collaboration

Abstract

The design of a Radioactive Nuclear Beam Facility, which could be based on the ISIS accelerator, is described. The facility will use a new 100 μA proton beam, energy 800 MeV directed into a tantalum target. A surface ionisation source followed by mass separation will give beams of radioactive ions at an energy of 200 keV covering a mass range up to 240 amu. Post acceleration to an energy of 10 MeV/nucleon would be achieved using an RFQ and a superconducting linac. Details of the design are described

1 INTRODUCTION

The use of radioactive nuclear beams is an established research tool in a wide range of disciplines including nuclear physics, astrophysics and condensed matter. The success of the existing facilities has resulted in a clear scientific requirement for much higher beam intensities.

A project team from UK Universities and CLRC have carried out a design study for a Radioactive Nuclear Beam Facility, SIRIUS, based on the ISIS 800 MeV, 200 μA proton synchrotron.

The specification was for a facility which could operate at up to 100 μA proton current and deliver high quality radioactive ion beams in the mass range 10 to 240 amu with post acceleration giving up to 10 MeV/nucleon.

At this stage the decision has been taken to base the design on proven technology. Thus a 1^+ ion source has been adopted with the consequence of a more complex post acceleration system than would be required by a multiply charged ion source.

The layout of the proposed facility is shown in figure 1. This was constrained by the topology of the site and the requirement that the SIRIUS facility did not compromise the provision of a second neutron scattering target station at ISIS. There are two experimental areas. One Hall, S4, for the post accelerated beams and the other which will be at a mezzanine level above the linac for three independent beams at 200 keV directly from the ion source. There is space on the site for a further experimental area should this be necessary.

2 EXTRACTED PROTON BEAM LINE

The SIRIUS beam transport line carries a 100 μA, 800 MeV beam from the existing ISIS extracted proton beam line to the new SIRIUS target station. The target station houses two vertically separated targets. The beam line will operate at 16.7 or 25 Hz, depending on whether the ISIS intensity is 300 or 200 μA, and have the capability of switching from one target to the other at 8.3 or 12.5 Hz.

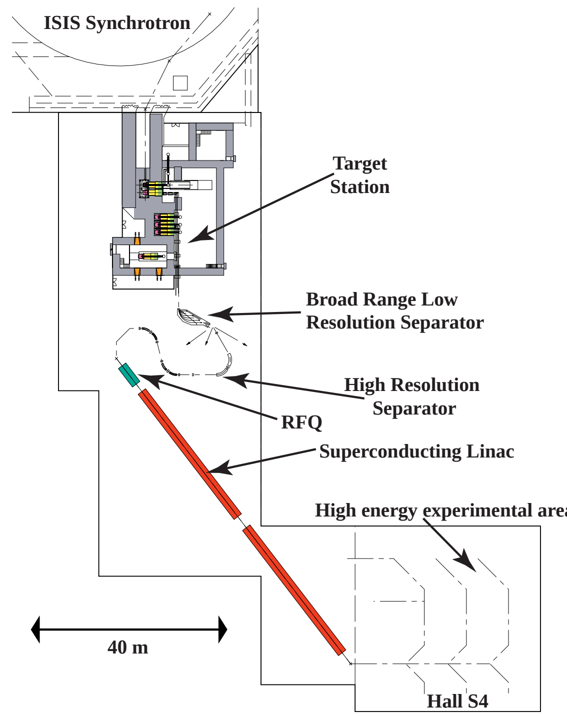

Figure 1 Overall layout of the SIRIUS facility.

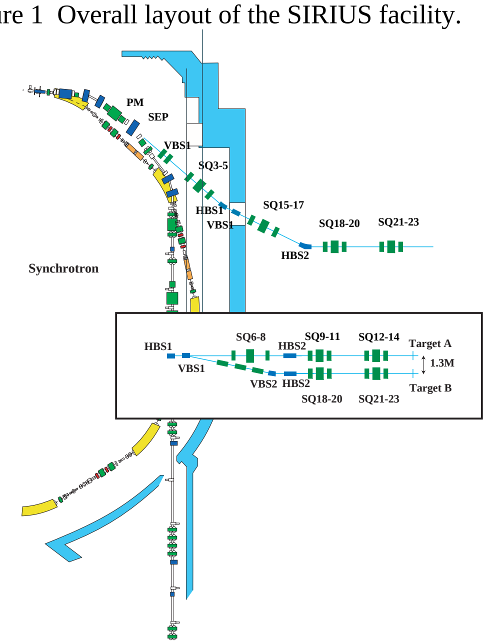

Figure 2 The SIRIUS extracted proton beam.

3 TARGET STATION

The target station has two installed target positions with 1.3 metres vertical separation. These are removed horizontally for servicing or replacement. Figure 3 shows the overall layout. The two target assemblies are at 2.564 metres and 1.264 metres above ground level and each is backed by a separate beam stop. This allows the option of operating each target independently or the operation of both targets simultaneously, if required.

All of the targets and beam stops are contained within a common void vessel that has no inlet proton beam window, therefore the vacuum system in the vessel is the same as that in the extracted beam line. A vacuum valve is installed between the beam line and the void vessel to allow separate pumping of each volume when needed. The two target and two beam stop shielding plugs have circular inflatable all metal seals on their front faces to maintain the beam line vacuum in the void vessel. The void vessel has a removable stepped shielding plug in the top to permit access to the vessel during installation.

The design allows for straightforward replacement of the target/ion source assembly. Servicing takes place in the remote handling cell and complete replacement of the target and ion source in envisaged as a routine operation. This will allow new developments in the technology to be exploited rapidly. Spare assemblies can be condition in the cell or in the storage positions. A change from the operating unit to a conditioned spare will take about 8 hours.

Access into the cooling plant room, target transfer area and remote handling cell is by sliding steel shielding doors and removable roof lintels.

The beam stop behind each target is a cylinder of copper 20 cm. In diameter and 40 cm. long which is edge cooled by a stainless tube wrapped around its length.

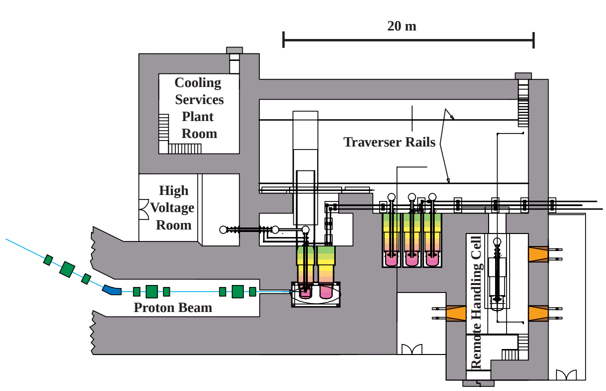

Figure 3 The SIRIUS target station

High voltages are required for both the extraction of the ions from the target and the focus electrode. These are fed through the 3 metre thick shielding plug by a series of concentric aluminium tubes which transmit the voltages, interspaced with tubes of insulating aluminium oxide ceramic.

4 TARGET AND ION SOURCE

The initial high intensity targets will be of the RIST design [1], consisting of thin, 25 µm, tantalum foil discs diffusion bonded together to form a rigid assembly and capable of dissipating proton beam powers of ~20-45 kW, at temperatures of 2000-2700 K, by thermal radiation from the finned surface. These targets are 4 cm in diameter and 20 cm long and are suitable for proton beams of 4-7 cm diameter.

5 MASS SEPARATORS

5.1 Broad range low resolution mass separator

The separator is designed to deliver four independent beams of different masses simultaneously. The device has a long focal plane simultaneously providing separated beams of mass 5-240. Ray-tracing indicates a minimum dispersion of ~ 6 mm per amu at A=200. This is adequate provided that slits are incorporated in the device in the focal plane where the transmitted beam is to be defined, and that unwanted masses are prevented from painting the contents and walls of the vacuum chamber and its devices.

5.2 High resolution mass separator

A high resolution separator is required to operate at resolutions of $\Delta M/M$>10,000, and as near to 30,000 as possible. to provide mass separation of isobars for the reduction of contamination and for injection into the linac.

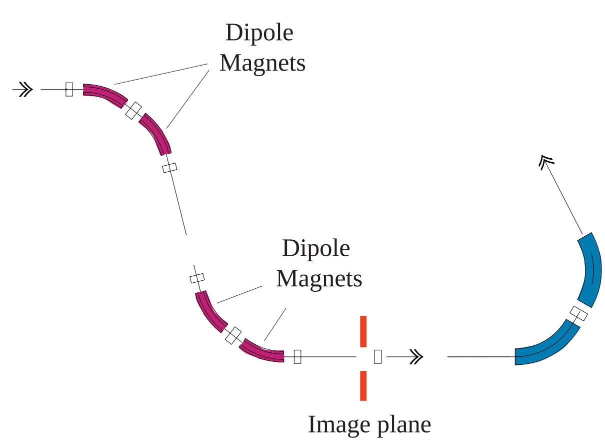

Figure 4 Schematic of the high resolution mass separator based on the ANL [2] design.

To determine the performance of such a separator, illustrated in figure 4, beams with a $M/\Delta M$ of 20,000 have been traced through the magnetic system. A real object of ±0.1 mm and ±20 mr is defocused in the dispersive plane to generate a virtual image of ±0.02

mm and a divergence of 100 mr formed by a quadrupole element prior to the magnet. The entrance and exit faces of the magnets (R=2m) have a small curvature to correct aberations. The virtual image is 2m in front of the first magnet and 1m separtates the two magnets. This drift space can be used for re-focusing or multipole correcting elements. The beam from the first magnet is almost parallel entering the second which focuses 0.427 m down stream, although this can clearly be controlled with quadrupole elements.

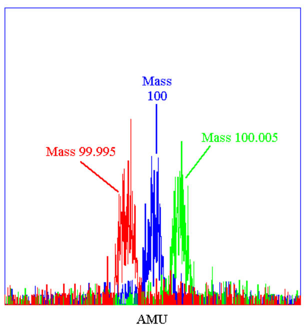

Figure 5 The image at the focal plane of the second magnet for 9999 particles of mass 100, 100.005, and 99.995 amu. The object size is ±0.1 mm and has a divergence of ±20 mr

The resolution of the system is much better than 1:20,000 as shown in figure 5, and can accommodate an acceptable energy spread in the beam. In the case of a ±5 eV spread in the energy from the ion source, 44% of the central beam is transmitted through an 0.1 mm wide slit at the focal plane, along with approximately 8% of each side mass. This can be decreased by minimising the aberrations in the system.

6 RFQ AND LINAC

The SIRIUS post-accelerator is designed to accelerate radioactive ions initially in a 1^+ charge-state to an energy of 10 MeV per nucleon for a mass range of 10-240 amu. A schematic of the system is shown in figure 6. The ions emerge from the ion-source at an energy of 200 keV. They are matched into the RFQ by setting the RFQ on a high voltage platform to give an injection energy into the RFQ of 1 keV/amu for the entire mass range. The RFQ accelerates the ions to 25 keV/amu from where they are injected into the linac. The linac is combined with foil stripping to give a beam of energy 10 MeV/amu.

Both the RFQ and the cavities are based on designs in use or planned at Argonne National Laboratory [2]. The cavities themselves have been described and costed in reference 3 (a design study for a machine at GANIL). The scheme adopted for SIRIUS is outlined below in figure 6.

The beam from the ion-source is mass separated in the high-resolution spectrometer [see 5.2] before injection into the RFQ section. The RFQ is preceded by a gridded buncher operating at the RFQ frequency (12.125 MHz) which compresses the beam and saves a considerable length of the RFQ normally needed to fulfil this function. The RFQ is just short of 5m in length and accelerates the full range of particles by varying the voltage on the vanes. The device is of the split-coaxial type because of the low frequency. Following the RFQ there is a second gridded buncher and a gas stripper to raise the charge state.

The beam is then injected into a number of super-conducting accelerating cavities. The devices are based on the Argonne frequency of 12.125 MHz and its multiples. The IQWR are described as Inter-digital quarter wave resonators in reference 3. They are essentially combinations of pairs of the two gap quarter wave resonators (QWR) driven by a common RF source.

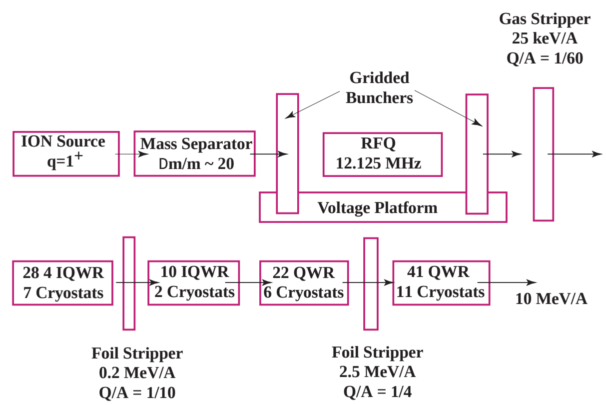

Figure 6 Schematic of post accelerator.

Foil stripping is used at optimal points along the linac to raise the charge state and to improve the accelerating efficiency. As the beta of the beam increases, a switch is made to the individual QWR since the structure is becoming larger and more use can be made of the accelerating field by independent phasing.

REFERENCES

[1] J.R.J. Bennett, C.V. Densham, P.V. Drumm, W.R. Evans, M. Holding, G.R. Murdoch and V. Panteleev, Nucl. Instr.and Meth. B, **126**, 117 (1997).

[2] "Concept for an advanced Exotic beams facility Based on Atlas", 1995.

[3] "Proposition d'un ensemble de production et d'acceleration d'ions secondaires a GANIL", GANIL R 92 04.