A SECONDARY RADIOACTIVE BEAM LINE FOR THE SPIRAL 2 PROJECT: FIRST STEP, THE DESIGN STUDY

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Abstract

This second generation radioactive ion beam facility will be constructed at GANIL and be operational in 2012 with stable beams and 2013 with radioactive ion beams. The aim of the installation is to produce high-intensity, high- quality radioactive ion beams of isotopes from large regions of the chart of nuclei in the range of 3 to 240u. Following description corresponds to the conceptual design study of a low energy RIB transport line for the SPIRAL 2 project.

INTRODUCTION

The RIB production cave of the SPIRAL 2 project is based on the ISOL technique and will be composed of a thick target, an ion source (TIS), a beam extraction and an adaptation section followed by a mass separator, see Fig. 1. In order to transport secondary beams special attention has to be taken concerning beam transport, containment of radioactive materials and protection against ionizing radiations. In fact, material activation should be kept as low as possible. Equipment activation during beam processing and matching is difficult to estimate and control. Access to the equipments is usually forbidden or restricted. Therefore discrete modules are designed with quick coupling, reduced and standard operations, and remote handling in order to mitigate the doses during maintenance.

The design has to be specially adapted in this project in regard to radioprotection, mechanics, maintenance and alignment. The key issues are the beam characterization at the source, multi particle and multi component beam optics with space charge, nuclear engineering, mechanical integration and optimization. With conventional beam lines, half the working time is spent for the beam optics design. With RIB lines, only 10-20 % of the time is spent for beam optics design, the remaining investigations are devoted to nuclear engineering, maintenance and infrastructure.

MAIN OBJECTIVES OF THE LEBT

The main objectives are to

- Extract the secondary beams from the TIS and realize a preliminary ion selection;
- Perform a mass separation with a resolution power in the range of 240 to 350;
- Transport the single charged ion beam to exit the production building with elements in the range of 3 to 240u, 1 µA current, 80 π.mm.mrad emittance, 60 keV electric rigidity, and 0,39 T.m magnetic rigidity.

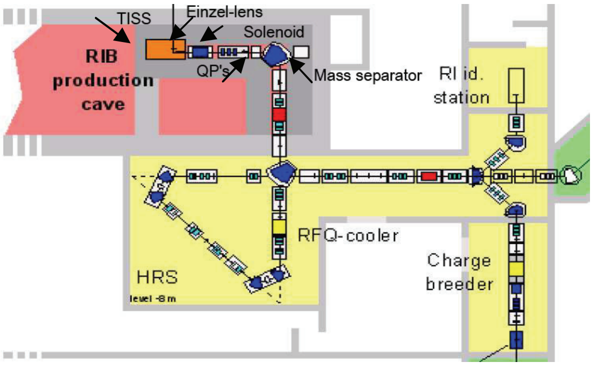

Figure 1: RIB production cave and beam transport line layout with extraction, focusing, and mass separation.

The facility should also:

- Maintain the vacuum level at 10^{-7} mbar;
- Provide the interfaces with all the technical services (vacuum, cooling, magnets, diagnostics, controls, connections, feed throughs, etc.);
- Guaranty the radioprotection and the safety: forbidden access in red class area and controlled access in yellow class area;
- Integer the waste management and the remote operation capacities.

The beam extraction from the TIS is achieved with an extraction potential of 60 keV located in an ECR-ion source, an Einzel-lens and a solenoid focus the beam and contribute to the elimination of the supporting gas. The current of the supporting gas may achieve 1 mA and should be eliminated before the analysing magnet in order to control the transverse dimensions of the extracted beam and the performances of the mass analysis.

BEAM OPTICS DESIGN

At SPIRAL 2, the LEBT system will handle the radioactive beam from the ECR-ion source of the TIS to the idendification station (IBE), the low energy area (DESIR) and to the post-acceleration complex (CIME). The RIB production cave and beam transport line are designed with an extraction, focusing, mass separation (low resolution), high resolution separation (HRS), beam transport and switching to charge breeder, beam identification station and experimental area (DESIR).

The extracted beam is fed with a combination of Einzel, solenoid and triplet of magnetic quadrupoles lenses. The former has to purify the beam from contaminants (charge state, space charge, and residual gas) and to focus on the object point for the subsequent part of the design. For this set-up, first order ion optics matrix calculations using TRANSPORT [1] and GALOPR [2] codes were primarily

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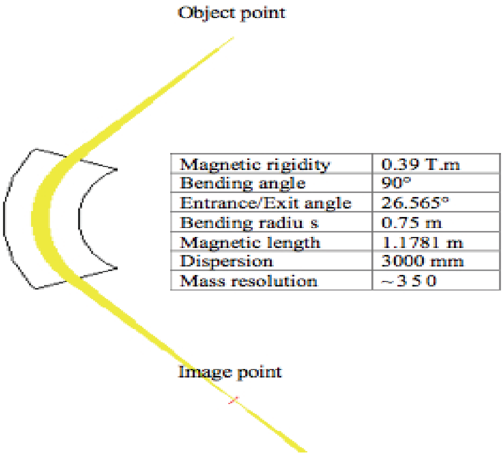


Magnetic rigidity	0.39 T.m
Bending angle	90°
Entrance/Exit angle	26.565°
Bending radiu s	0.75 m
Magnetic length	1.1781 m
Dispersion	3000 mm
Mass resolution	~350

Figure 2: Main parameters of the mass separator. The trajectories correspond to a mass of 122u and magnetic field of 5.213 kG (GEANT4 model).

performed assuming a mass of 122u with kinetic energy of 60 keV for different object sizes at the exit ion source.

The pre-selected species are transported according to their mass/charge ratio and analyzed with an achromatic system of two 90° sector-bending magnets, aperture slits, and two electrostatic quadrupole doublets. The last doublet is used to inject the beam in a cryotrap in order to confine the residual contaminants not stopped by the first separator and then refocus the beam on the object point of the second analysing magnet.

Despite of a large acceptance of the beam line, a transverse space charge due to the supporting gas could lead to a halo formation increasing the emittance of the beam in interest and then its losses. A model is currently under development with GEANT4, see Fig. 2.

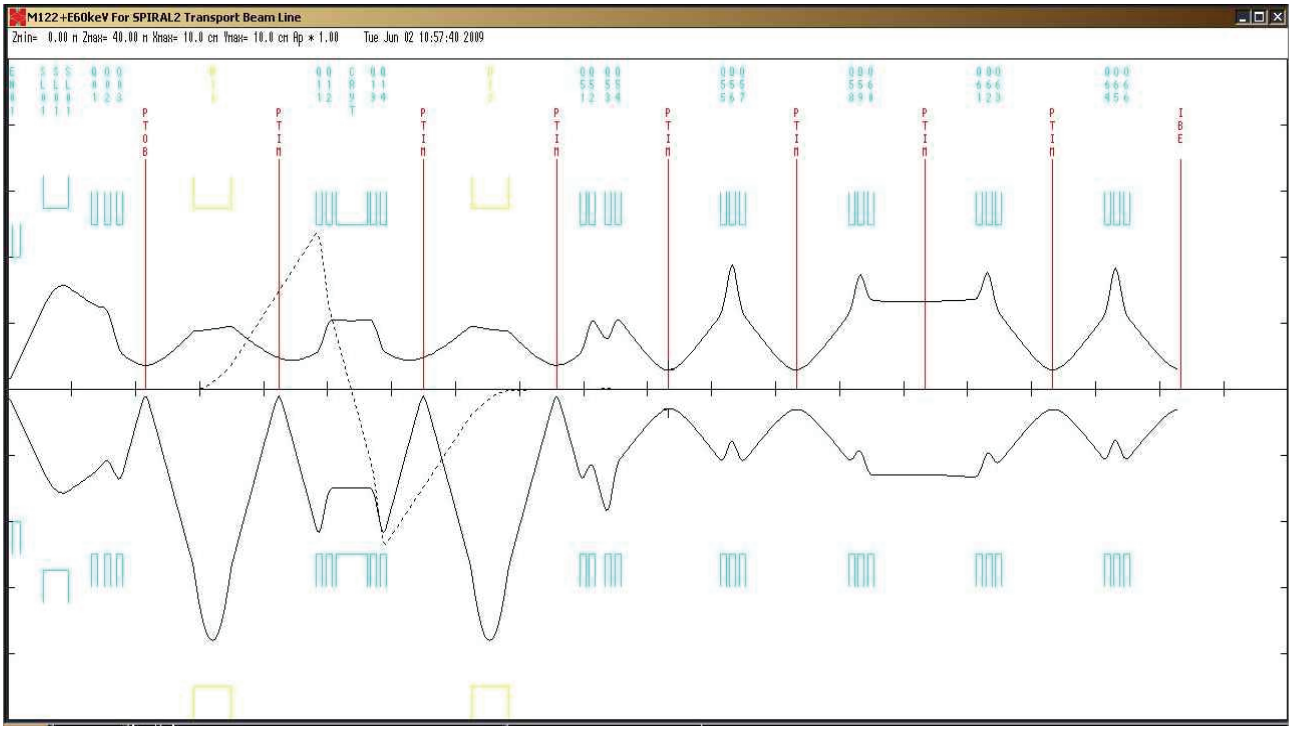
Due to the low rigidity of the beam, the final part of the transport line is designed with electrostatic lenses. The beam envelope along the line is shown in Fig. 3 for an object point of 2.25mm horizontal half-width and 4.35mm vertical half-width leading to a mass resolving power of 333 for the mass 122u. The tuning of the system is evaluated and scaled from the magnetic rigidity and diagnostics along the transport beam line.

SAFETY MANAGEMENT

The production cave is the heart of the process; it delivers 10^{14} Fission/s and generates a neutron dose rate of 10^5 Sv/h. That neutron flux induces an integrated dose of 10^5 Gy/FY at the mass separator. The access to the production cave will be forbidden and the equipments will need remote handling.

The activation of the equipments is generated by beam loss, on-line volatile propagation and contamination (mostly neutral particles), and secondary radiations due the neutron flux and gamma-ray irradiation under service conditions. Containment of volatile radioactivity is obtained by carrying out the principle of double barrier: the first one is a static one and is provided by the vacuum chamber, the second is a dynamic one and is provided by the pumping system.

Safety is provided by correct sizing of the radiological shielding for all ionising radiations: neutrons, β, and γ,



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M122+E60keV For SPIRAL2 Transport Beam Line
Zmin=  0.00 m Zmax= 40.00 m Xmax= 10.0 cm Ymax= 10.0 cm Ap * 1.00     Tue Jun 02 10:57:40 2009
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Figure 3: Beam-line optic from the extraction point to the IBE station: Einzel-lens (EN01), solenoid (SL01), magnetic quadrupole triplets (Q01, Q02, Q03), bending magnets (D11, D12), cryotrap (CRYT), electrostatic lenses (Q11-14, Q51-64). The horizontal (negative, 2 cm/unit) and vertical (positive, 2 cm/unit) beam profiles are drawn for an emittance of 80 π.mm.mrad along the longitudinal axis (2 m/unit).

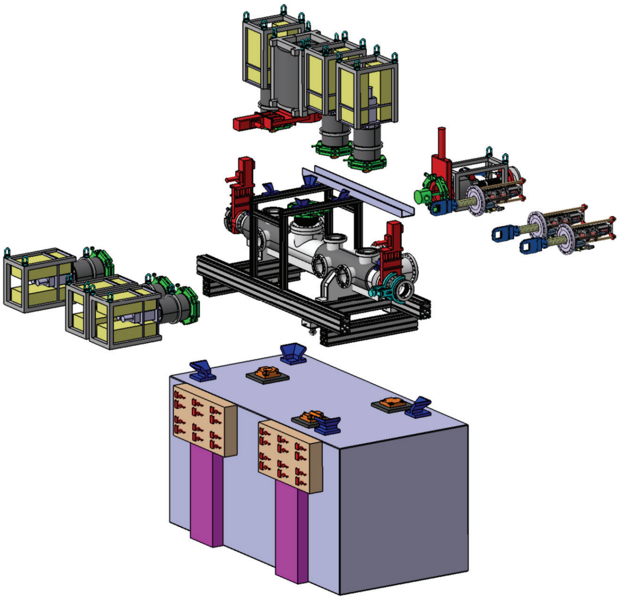

Figure 4: CATIA V5® mock-up of a modular beam line, here different beam diagnostics, vacuum pumping, shielding, connections and mechanical structure.

controlled access to the areas, definition of tolerable levels of accumulated and residual doses at different time delays, use of remote-handling system for the irradiated materials (blinded cell, crane, containment chamber). For correct sizing the design takes into account normal and accidental service conditions. The safety of the process requires hazard and accident analyses to ensure workers, the public, and the environment is protected against hazards such as radioactivity, fire, electric discharge, etc. The process is analyzed in order to determine the vulnerabilities and their treatment, it includes:

- Comprehensive hazard analysis to identify surges and off-normal conditions that require technical or administrative controls;
- Accident analysis to demonstrate effective mitigation of worst-case hazard;
- Additionally, risk analysis to define optional maintenance devices and procedures. In all cases, components with high or adapted radiation durability are selected.

MECHANICAL DESIGN

In addition to their complexity, the beam line equipments have to be accurately positioned and sustain severe operation conditions and requirements: radiation, neutron flux, mechanical rigidity due to the replacement and alignment (0.1 mm tolerance), and must satisfy our safety administration. The transport of radioactive matter is a regulated field of activity in the nuclear industry.

The system should be constructed ab-initio using components with high reliability, long life time and minimizing maintenance duration. Material properties specification requires low out gassing rate, high radiation tolerance, low activation under irradiation, mechanical reliability, and in some cases non-magnetic. The main cost drivers are maintenance equipments, more expensive than process equipments. Standard components (commercially available) should be used whenever it is possible in order to lower the costs. Due to the nature and characteristics of the beam transport equipments in the RIB production cave the remote handling system should be highly reliable. Virtual mock-ups are built with CATIA V5®, see Fig. 4, and most numerical analysis is performed with COMSOL Multiphysics®. Different modelling and simulation technologies are employed to reduce development cycles and to lower costs instead of with time-consuming, costly and some times less precise physical testing which remain nevertheless indispensable.

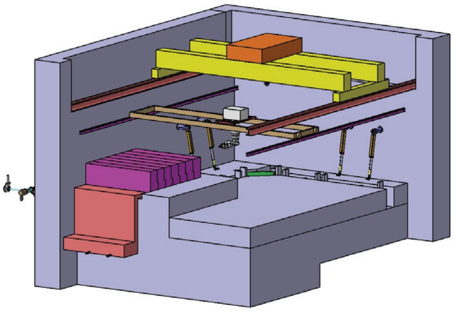

Figure 5: RIB production cave with infrastructure and maintenance tools. Process is installed inside a channel in the concrete and covered by blocks.

MAINTENANCE AND MISCELLANEOUS

Concerning the process: in-situ remote handling is required for the modular equipments of the beam production area, the high vacuum pumping units, and some specific devices of the yellow class area placed in a hot cell. Equipments in yellow class area have partial remote handling abilities and allow hands-on maintenance under controlled conditions. Complex operations resulting in significant maintenance downtimes and high operational risk are avoided. In the case a failed component cannot be repaired in-situ, complete module is therefore replaced. Redundancy may be applied whenever possible taking into account global risk and cost effectiveness.

Concerning the infrastructure: maintenance and monitoring of remote tooling is a significant cost, frequently greater than the operational costs associated with the process due to the use of dexterous and mobile manipulators, see Fig. 5. The preliminary design of the production building and the infrastructure is currently externalized. On some places, conventional components can be used if integrated radiation tolerance is less than 10^5 grays and so must be replaced more frequently.

ACKNOWLEDGEMENT

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