3 Targets, electrostatic accelerators and target area issues related to proton beam intensity upgrade of the ISOLDE facility

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3.1 Introduction

Following the naturally evolving requirements of the ISOLDE Collaboration, the ISOLDE facility develops new radioactive ion beams to extend the assortment of the 800 Radioisotope Beams (RIBs) available today. The R&D work on ion sources, new target materials, or new beam purification methods is closely related to the constant effort to improve the lifetime and reliability of the equipment.

The lifetime of ISOLDE targets at the PS booster is of the order of a million proton pulses which corresponds to a few 10^{19} protons. The proton beam pulsed structure is at the origin of the thermal-shock-induced material sintering and is today's limitation to the target lifetime characterized by a drop of the radioactive ion beam yield. Independently, for high-Z target materials (U, Th, Pb, and Ta), the integrated radiation dose generated by 10^{20} GeV protons corresponds to the radiation hardness limit of the weakest component, namely, the vacuum vessel sealing. The average proton-beam intensity upgrade from 2 μA to 10 μA would therefore proportionally increase the frequency of changes of today's standard targets. The setting up time (3–6 days) of a target unit would then be longer than the RIB production period and would become the limiting factor.

While the target handling is done via industrial robots, the maintenance of the equipment of the facility requires human intervention. Therefore, the radiation doses on staff must be minimized by developing maintenance-free equipment or dedicated remote-controlled handling systems.

The EURISOL-DS European project [1] is currently developing targets and target stations for orders of magnitude higher proton beam power. Evident synergies on modelling, materials development and design of remote handling equipment will be exploited.

In Section 3.2, the implications of a proton-beam intensity increase on the electrostatic accelerators are discussed; Section 3.3 deals with the necessary upgrade of the vacuum system while Section 3.4 covers the aspects of targets and ion sources. The adaptation of the facility to the radioprotection and waste disposal issues outlined in Chapter 6 of this report is considered in Section 3.6. The civil engineering is considered in Section 3.5 and target handling in Section 3.7.

3.2 Electrostatic accelerators

The so-called 'front-end' is composed of two vacuum sections: the electrostatic acceleration section consisting of a moveable electrode, two pairs of electrostatic deflectors and the platform supporting the remote-controlled vacuum coupling of the target unit; and the beam optics section containing an electrostatic quadrupole triplet and a Faraday cup used to monitor the total ion-beam current. Two 1000 l s^{-1} turbo pumps and two all-metal valves are suspended below the vacuum vessel. The front-end is supported by a vehicular chassis to ease its hands-on maintenance. It is connected to the separator beam line, inside an aluminium Faraday cage and perpendicular to the proton beam trajectory. Cables and fluids are connected to the front-end either on ground potential or from a high-voltage platform via a HT transfer tube (Boris tube).

3.2.1 Optics

With a view to minimizing the number of moving parts, and consequently the number of human interventions, the ion-beam optics will be studied with the objective of removing the extraction electrode mechanism. While this solution will minimize occasional interventions throughout the year, the exchange of extraction electrode tips that are the most contaminated parts (contact dose rate of the order of 1 Sv/h) must also be addressed. The new front-ends should be designed so that interventions are reduced to an absolute minimum while the performance of the front-end, at a higher dose rate, remains constant.

3.2.2 Cabling and fluids

The insulation of all cables within the vicinity of the front-end is subject to radiation damage. All cables must be insulated with the most radiation-resistant material possible; provisions should be made for the quick exchange of cables in the event of a breakdown. The same quick exchange practice should also apply to all compressed-air and water-cooling components and distribution. In the event of a complete front-end exchange, all connections should be rapidly accessible. Ideal on paper, remote-controlled connections should be designed such that their own maintenance does not add to the dose.

3.2.3 Alignment

To limit the time spent in situ while aligning a new front-end, a new and faster protocol should be devised. The front-end should be pre-aligned on a reference jig prior to installation. External alignment points should then be used for verification while the final beam axis adjustment is obtained by electrostatic deflectors.

3.2.4 Target coupling

The existing remote target coupling system is very sensitive to mechanical tolerances. At present, the electrical, fluid, and vacuum connections are simultaneously provided and coupled remotely by one compressed-air piston. In the event of a slight misalignment, the system is jeopardized during the coupling phase. The fact that the front-end is sealed with a mechanical shutter sets stringent safety requirements on those who need to intervene in case of potential hazardous contamination. Once this mechanical shutter is open, experience has shown that volatile contamination is prone to migrate from the unsealed on-line front-end. The vacuum coupling could be dissociated from the mechanical coupling of electrical and fluid connectors. This would also address the risk of pumping on a large vacuum leak that rapidly fills the exhaust-gas storage tanks.

3.2.5 Vacuum equipment

Access to the vacuum equipment on the front-end (turbo-molecular pumps, valves, vacuum gauges, etc.) is already strictly limited on account of the ambient dose rate in the front-end Faraday cage. One proposal is to extend the vacuum pumping ducts of the front-end so as to house the vacuum equipment farther away and shielded from the main radioactive source. Owing to the confinement of the existing facility, this would imply the construction of a service gallery above the existing Faraday cage. The consequences of such a gallery are discussed in Section 3.6.1.

3.2.6 High-voltage power supply

The present pulsed 60 kV high-voltage power supplies are designed to recover to 60 kV (± 1 V) within a time interval of 6 ms [2]. Recent tests have shown that the use of a high-*Z* converter coupled to actinide targets producing n-rich fission isotopes [3] has already imposed limitations on the voltage recovery time due to the heavier dynamic load generated by an increased temporal ionization profile from secondary particles. Increasing the proton pulse intensity would require a full re-evaluation of the power supply design.

3.2.7 High-voltage transport tube

The two existing 7 metre long high-voltage transport tubes consist of an inner aluminium tube kept under high voltage, centred and separated from the external grounding tube by two Araldite insulators at either end. In 2006, after 14 years of exposure to high radiation levels, the insulators in the Faraday cages are showing signs of degradation leading to high-voltage breakdowns. Although a temporary repair is planned for the 2006/2007 shutdown period, a more reliable solution needs to be developed for the HIE-ISOLDE upgrade. In parallel, and as mentioned in Chapter 6, the HT transport tubes provide a direct pathway between the highly radioactive Faraday cage and the high-voltage power supply room. Consequently, the design of the new high-voltage transport tubes should also include dedicated shielding or chicanes and be compatible with the eventual construction of a service gallery.

3.3 Vacuum

There are many aspects to the vacuum issues in the event of an upgrade to 10 μA proton beam. These include the integrated vacuum system of the front-end, the target units, the primary pumping system, and the collection, storage, and exhaust of radioactive gases [4].

3.3.1 Front-end vacuum system

The proposal to extend the vacuum pumping ducts requires an engineering study. Pumping speed, vacuum pressures, system design and controls are only part of the extensive study.

3.3.2 Target units

The installation of metallic sealing on all feed-throughs implies an increase in the sealing pressure and non-reusability of the sealing. A major modification of the standard geometrical arrangement with repercussions on the front-end coupling is unavoidable. The engineering study should clarify within two years the constraints of a metallic and ceramics based vacuum vessel on the front-end.

3.3.3 Primary pumping system

At present, an array of four roughing pumps assures the primary pumping of both front-ends. Although reliable, it is currently located in a highly radioactive zone and is itself a strong radiation source due to the capturing of long-lived radioactive isotopes in the pump oil. These concerns must be addressed; to provide easier access, the pumping array could be situated in the same aforementioned service gallery. However, as the contamination of the pump oil requires that the oil be changed with the utmost precaution in a Class A type radioactive laboratory [5], the possibility of containing the contamination before capture by the pump oil should also be investigated.

3.3.4 Exhaust-gas storage

Currently, the exhaust gases of the primary pumps after repeated target changes are stored up to an over-pressure of 2 bar in two separate tanks approximately 3 m^3 each. During the shutdown period and after a minimum of three months radioactive decay, the gases are released into the atmosphere under the supervision and monitoring of the radiation protection service. As mentioned in Chapter 6 of this report, the radiation protection service recommends that the exhaust gases should be stored at an under-pressure to minimize the consequences of accidental leakage. This would imply an increase in the number of storage tanks required to store the present quantity of exhaust gases. An increased front-end volume, more frequent target changes, and a five-fold increase in proton-beam intensity are all factors that need to be considered when dimensioning the new storage tanks.

3.4 Targets and ion sources

Target and ion source development will be a key issue for the HIE-ISOLDE project. Connectivity and geometry with respect to a new front-end have already been mentioned, however, emphasis should be put on improving the reliability and lifetime of target and ion-source systems and their performance.

3.4.1 Targets

The PS booster provides proton pulses of up to 3×10^{13} protons within 2 μs. The quasi instantaneous heating generates thermal shocks that in the past led to the destruction of the target Ta oven and today contribute to the rapid sintering of the target material [6]. By keeping the same irradiation parameters, the typical target lifetime of seven days would shorten with increased intensity. A proportional increase of the target diameter and proton-beam size leading to quadratic reduction of the temperature jump but increased target volume (and increased effusion time) may be unavoidable.

3.4.2 Transfer line, oven, and effusion

Once the target material arrangement is optimized, the desorption enthalpies define the residence time of chemicals on substrates and, therefore, the effusion time. For some of the slowly released elements, the choice of rhenium or carbon, for example, instead of tantalum as construction material for the transfer line and oven would speed up the effusion process considerably. Systematic studies of desorption enthalpies have been published and were investigated for RIB production by the TARGISOL EU-project [7].

3.4.3 Beam purification

Beam purity is an important key to the success of experiments, therefore, the suppression of easily ionized alkali isobaric contamination must be pursued. Internal drift fields for Ta targets and micro bunching increased the signal-to-noise ratio up to a factor of 5. Despite a reduction of the RILIS efficiency by at least a factor of 100, orders of magnitude improved signal-to-noise ratio are expected from electrostatic suppression of surface ionized ions. On-line tests are pending. Chemical separation of alkali elements in a quartz transfer line is a promising purification method [8]. On-line tests have demonstrated that the quartz surface keeps its properties while coupled to an out-gassing high-temperature container.

3.4.4 Ion sources

ECR ion sources for gaseous elements and RILIS dedicated ionization schemes for new elements such as mercury and gold will be developed. Systematic modelling of the plasma and beam-optics properties of existing ion sources will be undertaken. The planned measurements of emittances and efficiencies of existing and new ion source designs are the observables that will validate their simulation.

3.5 Radiation protection

3.5.1 FLUKA simulations

To fulfil the criteria highlighted in Chapter 6 of this report, a detailed FLUKA [9] simulation of the existing ISOLDE target area will define the critical issues and provide the parameters for the major changes to the existing facility.

3.5.2 Radioactive waste characterization

The estimation of the produced radioactive waste resulting from high-energy accelerators and facilities is an obligation stated in CERN's radioprotection manual. A program is being written to follow up the irradiation of ISOLDE targets and the decay of the produced radionuclei over decades. The release parameters, the ionization efficiency, and the chemical form of the released elements will be integrated to identify the final destination (target, vacuum system, separator or experiments) of specific radio-elements. The description of the full process is complex and rather than ultimate precision, the model aims at characterizing the various transport mechanisms and opening the path for specific optimizations. The final radio-isotope cartography is a vital element for the radioactive waste inventory.

3.5.3 Radioactive waste transport intermediate storage and conditioning

Irradiated targets are stored at for least four, and up to eleven months in a dedicated area located between the irradiation zone and the Class A laboratory. The irradiated targets are then transported to a remote intermediate storage for a period of 10 years and then brought back to the Class A laboratory for conditioning prior to disposal. The target handling system should be reviewed to accommodate higher activities, a remote handling procedure must be designed to operate within the Class A laboratory and a similar system must be installed at the intermediate storage location for the reception of used targets. The transport of irradiated targets between the Class A laboratory and the intermediate storage requires dedicated shielding and confinement matching today’s standards in matters of radioactive transport. The transport procedure should be executed with a minimum of human intervention.

The intermediate storage requires a dedicated aerosol monitoring system and an upgrade of the access control.

A preconditioning programme prior to shipment to the Paul Scherrer Institute for further treatment has already started at ISOLDE. Basically, the preconditioning consists of separating and identifying the different materials of a target unit, with emphasis on separating aluminium, before storing them in standard 200 l drums. Whilst after 10 years cooling this is feasible in fume cupboards with slightly radioactive low-*Z* targets, high-*Z* and more radioactive targets will have to be processed in a dedicated hot cell currently under design.

3.6 Civil engineering

An upgrade to 10 μA of proton-beam intensity will inevitably lead to civil engineering modifications of the existing facility. The proposal of an overhead service gallery, improved shielding, and the modification of the target handling system are major contributions to the final design of the future ISOLDE target area. Furthermore, owing to the higher levels of unfixed contamination, the construction of a new facility will have to abide by the Class A regulations defined by the Office Fédéral de la Santé Publique [10]. Each aspect of the infrastructure services should be identified and implemented within the new building. These include ventilation, fluids, cabling, controlled access, target handling, vacuum systems, etc.

3.6.1 Service gallery

Concerning the overhead service gallery, the issue of converting an existing tunnel to a shielded building spanning the Swiss–French border has first to be addressed. The existing earth mound will provide insufficient shielding in the event of a five-fold increase in proton-beam intensity so its replacement by shielding blocks seems unavoidable. The overhead service gallery could be incorporated into the extra shielding and at the same time, by installing a roof, the issue of activated rain water, identified in Chapter 6, could be properly addressed. Already discussed as a solution to distance vacuum equipment from the source of radiation, the option of a service gallery could satisfy similar requirements for both the front-ends and other services already housed in the target zone. This includes the primary pump array, exhaust-gas storage tanks, ventilation equipment to mention but a few.

3.6.2 Closure

Should a major overhaul of the existing building be approved, past experience during the construction phase of the Class A laboratory has shown that running a facility during parallel construction work is not an option. This is even more evident in the case of HIE-ISOLDE and such an overhaul will require the closure of the facility for at least 18 months.

3.7 Target handling

The present target handling system consists of two modified industrial robots controlled remotely from the robot control room in Building 179. Built and installed in 1995, the robot system was upgraded in 2002 to prolong its expected lifetime to 2010. Beyond this date, the unavailability of spare parts along with the continuous irradiation of the robot arms parked in the target area will inevitably have an impact on the maintenance of the system. The actual system is also very limited in terms of flexibility and the adoption of a new target design may be unacceptable both in terms of weight and programming.

3.7.1 A new target handling system

It is proposed to install a new state-of-the-art robot system which will have, besides the specifications of the existing system, more flexibility in terms of programming and a manual backup system in the event of an automatic sequence failure. When not in use, the robot arms will be stored behind adequate shielding.

3.7.2 A new front-end intervention device

With an expected five-fold increase in the radioactive dose rate at the front-end, human intervention for maintenance and repair will be at an utmost minimum. The design and construction of a shielded manipulator/transport device will be essential for both minor interventions and an eventual front-end exchange.

3.7.3 Target zone observation of remote-controlled handling

The exposure of the existing cameras to current radiation levels in the target zone has often contributed to their premature failure and annual exchange. A more adequate and reliable camera system, possibly shielded when not in use, will be required to assure the target manipulations both in automatic and manual mode.

3.7.4 Target storage

The current position of the used-target short-term storage hinders all access to the remaining areas of the target zone. Either the shielding of these targets should be improved or their storage should be moved to another more convenient area of the target zone.

3.8 Conclusion

This chapter describes the targets, electrostatic accelerators, and target area issues and necessary upgrades of the ISOLDE facility related to a proton-beam intensity increase to 10 μA. Many of these represent the much needed upgrade and maintenance of the existing facility after 14 years of operation and in addition cover the necessary modifications required to accommodate the intensity increase of the HIE project.

The relative aspects of these changes regarding the target units, electrostatic accelerators and target area infrastructure have been outlined in this report. Further in-depth studies and a close collaboration with other CERN specialists are required to finalize the project that should be started well in advance of the eighteen months required to transform the facility.

The upgrade of the targets, front-ends, target area, and infrastructure is a project in itself to be managed in close collaboration with the radioprotection service.

A first-approach cost and manpower evaluation is estimated at 8.8 MCHF and 29 FTEs over a period of up to six years.

References

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