

Article

Development of New Target Stations for the South African Isotope Facility

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Abstract: The development of new target stations for radioisotope production based on a dedicated 70 MeV commercial cyclotron (for protons) is described. Currently known as the South African Isotope Facility (SAIF), this initiative will free the existing separated-sector cyclotron (SSC) at iThemba LABS (near Cape Town) to mainly pursue research activities in nuclear physics and radiobiology. It is foreseen that the completed SAIF facility will realize a three-fold increase in radioisotope production capacity compared to the current programme based on the SSC.

Keywords: radionuclide production; target stations; targetry; 70 MeV cyclotron

1. Introduction

iThemba LABS is a multi-disciplinary research facility under the management of the National Research Foundation (NRF) of South Africa. The facility currently operates six accelerators at two campuses, located at Faure (near Cape Town) and Johannesburg. The main activities comprise research and training in the physical, biomedical and material sciences, provision of accelerator mass spectrometry (AMS) services, and the production of radioisotopes and radiopharmaceuticals for use in nuclear medicine. This paper discusses an initiative to achieve a three-fold increase in radioisotope production capacity.

The largest of the accelerators at iThemba LABS is a $K = 200$ separated sector cyclotron (SSC) [1] that has been in operation for more than 30 years. This machine is operated in conjunction with two solid-pole injector cyclotrons, one for high-intensity proton beams and one for heavy ions and polarized protons. The SSC is a shared facility. It provides accelerated ion beams for radioisotope production, nuclear physics research and, until recently, neutron and proton therapy. Nuclear physics experiments have mostly been conducted over weekends, the rest of the week scheduled for therapy (during the day) and production of both short-lived and long-lived radioisotopes (mostly at night).

A decision was recently taken that iThemba LABS would not continue with hadron therapy but would rather assist the medical community to pursue a dedicated proton therapy centre for South Africa. The significant progress in recent years on dedicated proton therapy centres as well as the reduction in cost of these facilities (single treatment-room facilities) will benefit the country much more if established at one of the large public hospitals. In contrast, while the therapy facilities at iThemba LABS are still fully functional, they are becoming aged and can only provide limited services due to the restricted beam time available for therapy.

The sharing of beam time on the SSC is also limiting the other programmes. To increase the beam time for radioisotope production and nuclear physics research, the establishment of a new facility, currently known as the South African Isotope Facility (SAIF), has been proposed. The new facility will consist of two parts:

1. The Accelerator Centre for Exotic Isotopes (ACE Isotopes) will be a dedicated facility for radioisotope production. A commercial high-current 70 MeV H^- cyclotron for this purpose will free the SSC and allow an increase in beam time for nuclear physics and related research. Recently, the South African Government approved the ACE Isotopes project and made available the first funding to finance the cyclotron.
2. The Accelerator Centre for Exotic Beams (ACE Beams) will be a radioactive ion beam (RIB) facility for nuclear physics research. The SSC will be used as a driver for an isotope separation on-line (ISOL) facility. A 66 MeV proton beam of up to 50 μA will be delivered by the SSC for producing radioactive beams from a target ion source. Phase 1 of this project will be a low-energy radioactive ion beam (LERIB) project without post acceleration. Phase 2 will be the post acceleration of the radioactive beams with a linear accelerator to energies between 4 and 5 MeV per nucleon. Some of the funding has already been secured for the development of LERIB and work on that project is in progress.

With the above “roadmap” for the future of iThemba LABS in place, a design study on new target stations for radionuclide production with a dedicated 70 MeV cyclotron commenced. This work is now in an advanced stage.

The main aspects of the new stations for batch targets (encapsulated materials and solids) are discussed below. The experience gained on the existing bombardment infrastructure largely influenced the new target station design. A brief historical overview is therefore given, followed by discussing the new station design and the changes necessary to the current facilities at iThemba LABS to accommodate them.

2. Materials and Methods

2.1. Existing Facilities

The routine production of radioisotopes with the SSC started in 1988 with the commissioning of the horizontal beam target station (HBTS, also called Elephant), mainly for short-lived isotopes such as ^{52}Fe , ^{67}Ga , ^{109}Cd , ^{111}In and ^{123}I . Towards the late 1990s, production methods for the long-lived radioisotope ^{22}Na were developed and commercialized. This was followed by targetry development for ^{68}Ge and ^{82}Sr . In 1996, a second target station was introduced for the bombardment of semi-permanent targets, including an enriched ^{18}O -water target for ^{18}F production, which was later transferred to a dedicated 11 MeV Siemens cyclotron. In 2006, the vertical beam target station (VBTS) was commissioned to exploit high-intensity proton beams delivered by the upgraded SSC. Target development for the VBTS focused on the relatively long-lived, high-value radioisotopes ^{22}Na , ^{68}Ge and ^{82}Sr . Various tandem targets, e.g., Rb/Ga for $^{82}Sr/^{68}Ge$ production and Mg/Ga for $^{22}Na/^{68}Ge$ production, are routinely bombarded in the VBTS with 66 MeV proton beams with intensities up to 250 μA .

A beam splitter commissioned in 2007 allowed the simultaneous bombardment of four targets, i.e., beams on tandem targets in the HBTS and VBTS at the same time.

Thus, over the years several upgrades were undertaken to increase the production yield, especially for the long-lived radioisotopes, to meet an ever increasing market demand. The options for further growth on the SSC, however, have now been exhausted. Further growth can only be met by introducing a significant increase in allocated beam time for radioisotope production, which would come at a large expense to the other programmes, or by procuring a dedicated cyclotron for this purpose. This last option was chosen and will be achieved with the ACE Isotopes facility.

2.2. ACE Isotopes

The new radioisotope production facility will make use of three thick-walled concrete vaults previously occupied by the radiotherapy programme, as shown in Figure 1.

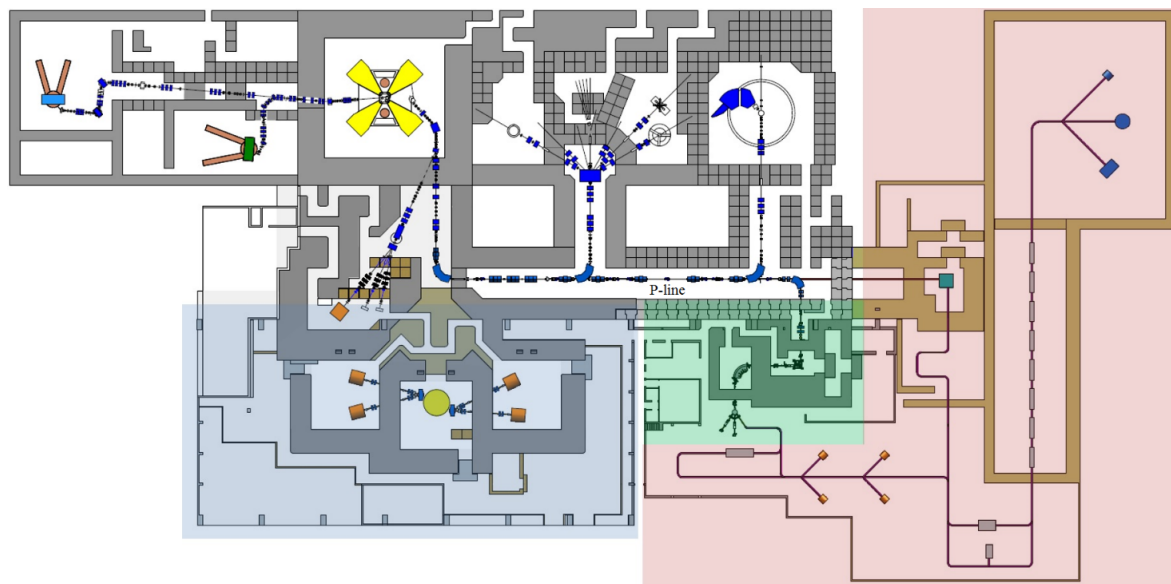


Figure 1. Layout of the cyclotron facility at iThemba LABS, showing ACE Isotopes (shaded blue), Phase 1 of ACE Beams, LERIB (green) and Phase 2 of ACE Beams (pink).

The layout of the ACE Isotopes facility is shown in Figure 2. The cyclotron will be located in the centre vault, with the bombardment of targets taking place in the two adjacent vaults. This will ensure flexibility since the production vaults are independent of each other, thus production can continue in one vault while maintenance is being performed in the other.

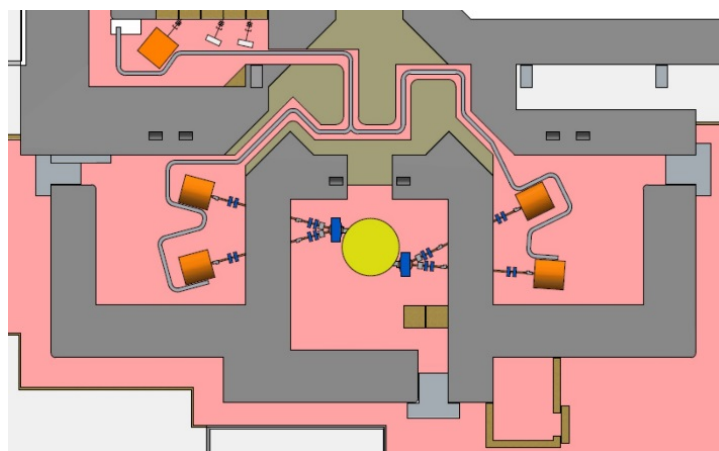


Figure 2. Layout of the ACE Isotopes facility, showing the cyclotron vault (middle), production vaults (left and right) and the expanded Telelift target transport system.

Each production vault will contain two target stations, classified as either “high intensity” (up to 350 μA) for production of long-lived radioisotopes or “medium intensity” (up to 100 μA) for production of short-lived radioisotopes. To maintain uninterrupted bombardment of batch targets, two high-intensity stations (one per production vault) and one medium-intensity station will be required. The fourth station will be dedicated to experimental development work and semi-permanent targets. The four beamlines all have the same design. An extracted beam will pass through a switching magnet and then continues through a straight section of beam pipe to a target station. Two sets of quadrupole doublets per beamline will be used for focussing. A “wobbler” system for sweeping the beam over the target surface will be located after the last quadrupole. Diagnostic systems will include profile grids for low-intensity beams and non-destructive capacitive beam position monitors for high-intensity beams.

2.3. New Target Stations

The transfer of the radioisotope production programme from the SSC to ACE Isotopes will take several years to complete. The existing target stations will continue to receive beam from the SSC while the new target stations are being built and commissioned.

Currently, the transfer of batch targets between the two existing target stations (HBTS and VBTS) and the processing hot-cell complex is by means of a Teletlift rail system [2,3]. This system will be expanded to the two new production vaults. The existing PC-based transporter control system will also be modernized. Details on the targetry can be found in Ref. [2] and references therein.

The design of the new batch-target stations, shown in Figure 3, is now in an advanced stage. The four planned stations will be identical in all respects except for the entrance collimator aperture, which will be larger in the high-intensity stations. The local radiation shield will consist of complementary shielding materials, namely an inner iron shield, followed by borated paraffin wax as a middle layer, followed by an outer lead γ -ray shield. Monte Carlo radiation transport simulations provided the optimal layer thicknesses to achieve a dose attenuation of three orders of magnitude.

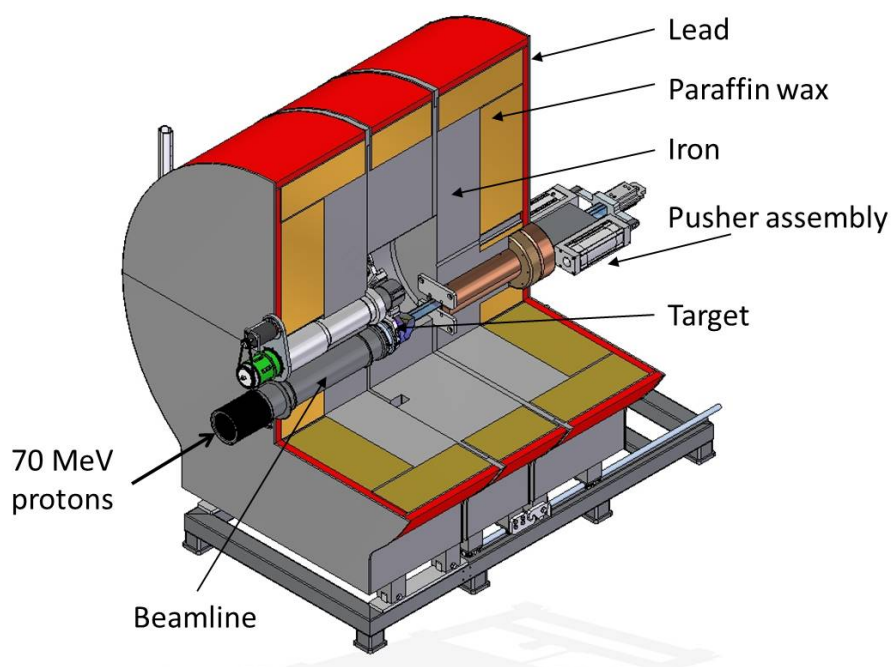


Figure 3. Cutaway view of the production station. The pusher assembly locates the target in the irradiation position and also connects the cooling-water lines. The beamline is 1.5 m above the floor.

The new target stations will all be fitted with a rotatable magazine that can hold three target holders. This will be a significant simplification compared to the current HBTS magazine, the latter of which can hold nine target holders. Figure 4 shows a cross-sectional view of a target station as

seen in the opposite direction to the beam direction. The magazine is shown with one target in the bombardment position (the lowest position) with all three target positions filled. The structure mounted on the right is a pneumatically controlled robot arm for transferring target holders between a Telelift transporter and the station. A close-up view of a target magazine is shown in Figure 5. It can be rotated to put any of the target holders in the bombardment position or in the “transfer” position when loading or unloading a target holder from the station with the robot arm.

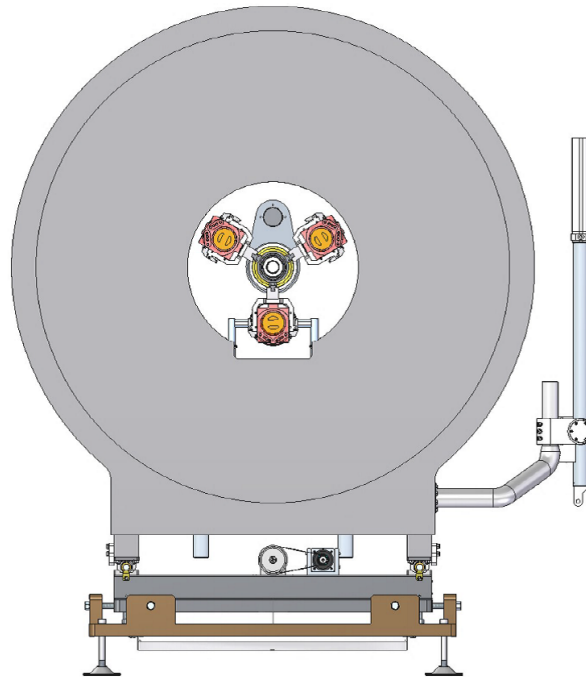


Figure 4. Simplified cross-sectional view of a target station. The robot arm is on the right. The beam axis is perpendicular to the page and points towards the reader.

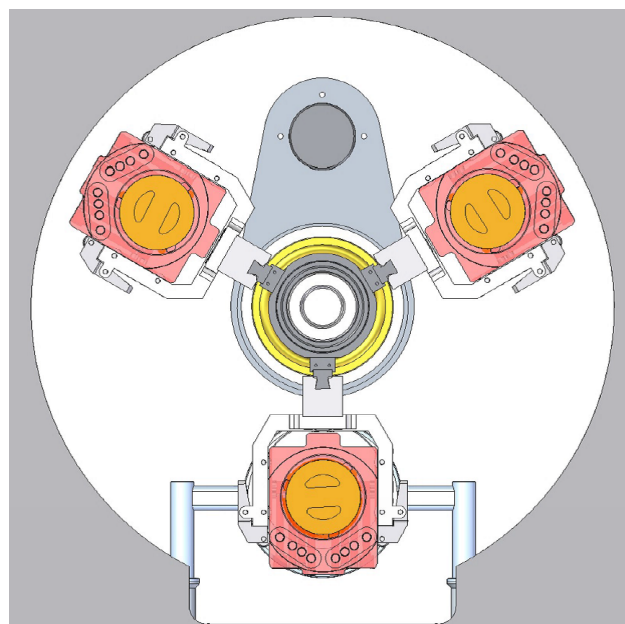


Figure 5. Close-up view of a target magazine with target holders loaded in all three positions. The target at the bottom is located on the beam axis (see also caption to Figure 4).

A new 70 MeV tandem Rb/Ga prototype target (see Figure 6) has recently been assembled and pressure-tested. It will be operated with a 20% higher cooling-water flow rate compared to the existing VBTS targets. The new prototype target capsules have an outer diameter of 40 mm, similar to the present VBTS targets, however provision is made to increase the diameter of future capsules up to 52 mm. This will enable an increase in beam current from present nominal values of 250 μA to more than 300 μA . Figure 6 shows the encapsulated Rb and Ga targets mounted on a bayonet-mount plug, which in turn can be fitted onto a tandem target holder. The Rb metal is contained in a stainless steel capsule (grade 316) while the Ga target capsule is made from niobium [2].



Figure 6. The tandem Rb/Ga targets mounted on a bayonet-mount plug.

Figure 7 shows an open target holder while Figure 8 shows the closed target holder after the targets have been loaded. The eight holes at the bottom of the holder are cooling-water inlet and outlet ports.



Figure 7. An open tandem target holder with the bayonet-mount plug removed.



Figure 8. A closed tandem target holder with the bayonet-mount plug in position.

3. Results and Conclusion

Some development work towards Phase 1 of the ACE Beams project has commenced. The final approval for the ACE Isotopes project has recently been obtained from the South African Government and a funding model is in place. A dedicated 70 MeV cyclotron for radioisotope production will free the SSC to focus exclusively on scientific research, including a new RIB programme. The completed SAIF facility will be positioned to realize a three-fold increase in radioisotope production capacity.

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Conflicts of Interest: The authors declare no conflict of interest.

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