

# COMMISSIONING OF THE SOUTH AFRICAN ISOTOPE FACILITY

H. Barnard<sup>†</sup>, J. Mira, I. L. Strydom, J. Abraham, H. Anderson, S. Baard  
P. Beukes, J. Broodryk, G. Steyn

iThemba Laboratory for Accelerator Based Sciences, Cape Town, South Africa

## Abstract

The South African Isotope Facility (SAIF) is a medical radioisotope production facility based around a 70 MeV H<sup>-</sup> cyclotron from IBA Radio Pharma Solutions (IBA). The commissioning of SAIF started at the end of 2023 and it commenced isotope production at the end of 2024. The facility is located in three vaults at iThemba Laboratory for Accelerator Based Sciences (iThemba LABS) in Cape Town. The facility design is presented here, including the vaults, radiation modelling, cyclotron and beam line layout, wobbler magnets, dedicated target stations, target transporter, control systems and radiation protection. The commissioning tests of the cyclotron are described along with radiation safety measurements, targetry commissioning and first isotope production.

## INTRODUCTION

iThemba LABS hosts a number of accelerators, the largest of which is the K200 Separated Sector Cyclotron (SSC) currently used for isotope production with a 66 MeV proton beam, and for nuclear research with a large variety of particles and energies [1].

Sales of radioisotopes constitute a significant portion of iThemba LABS's funding, but the isotope production is using a large fraction of the SSC's beam time, limiting the time available for nuclear research. Furthermore, the aging SSC started operating in 1986 and is a complex machine requiring increasing maintenance.

The SAIF project was proposed to solve these issues by acquiring a much simpler and reliable 70 MeV H<sup>-</sup> machine from a commercial vendor, so that the SSC could be dedicated to nuclear physics research and undergo proper refurbishment [2, 3].

SAIF, shown in Fig. 1, consists of a central cyclotron vault housing a C70 cyclotron from IBA, and two production vaults [4]. Each production vault will eventually contain two target stations for the bombardment of targets, but currently only a single station is operational per vault, with the other line occupied by a high intensity beam stop. By using dual beam extraction, targets in both production vaults can be bombarded simultaneously.

The SAIF project officially launched in 2018 with a budget of around 40M USD. Factory acceptance tests of the cyclotron were completed in July 2021, completion of the vaults and first beam followed in Oct 2023, with the first targets bombarded in March 2024, and the first test isotopes shipped to a client in September 2024.

<sup>†</sup> ah.barnard@ilabs.nrf.ac.za

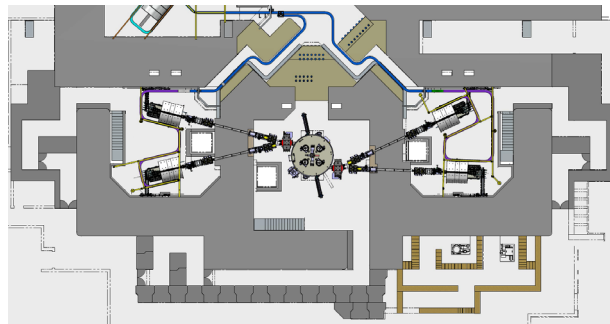


Figure 1: Layout of SAIF.

## DESCRIPTION OF SAIF

### Vaults

In order to reduce costs and make use of existing facilities it was decided to repurpose three vaults previously used for a discontinued particle therapy programme. Each vault is roughly cubical with 10 m side length, a 3 m deep basement and wall thickness of 3 m in most places. Major alterations included removal of existing equipment, demolition of a large concrete mounting plinths, cutting sections out of the walls to provide space for beam lines, drilling holes for the beam lines and other pipes, casting access labyrinths, casting a trolley labyrinth with built-in curved cable routes, casting new ground level floors in all three vaults, and casting additional basement floors to prevent future water ingress.

Numerous modifications were made to the vaults as a result of radiation modelling [5]. These simulations were performed with FLUKA, and verified by comparing FLUKA predictions with actual measurements taken in existing vaults at iThemba LABS.

Access to the vaults is either through 1.5 m wide labyrinths, or through the roof which consists of stackable concrete beams. Installing the cyclotron required use of a temporary gantry crane capable of lifting the two 60 t cyclotron yoke sections.

### Cyclotron

A commercial 70 MeV cyclotron was procured from IBA. The selection of 70 MeV proton energy was due to the energy required for bombarding Rb and Mg targets, and corresponded to the existing 66 MeV proton energy from the SSC. Another requirement was simplicity and reliability: this C70 H<sup>-</sup> is a single frequency machine, accelerates H<sup>-</sup> ions only, and isochronicity of the main field was obtained by shimming of the poles, so that it does not require trim coils. Dual beam extraction is made possible by stripping of the H<sup>-</sup> ions, enabling two targets to be bombarded

simultaneously at the same energy. The intensity of  $375\ \mu\text{A}$  extracted per port exceeds the  $200\ \mu\text{A}$  commonly delivered by the SSC and provides room for planned future improvements of the targetry.

### Beam Lines

The four beam lines have similar designs and are about 12 m long each. After extraction from the cyclotron a switching magnet is used to select the active beam line. Focussing is provided by two sets of quadrupole doublets, one set in the cyclotron vault, and one in the production vault. The optics were designed to produce a minimum beam spot size of less than 5mm FWHM on the target, with a view to full raster scanning over the target in the future. Two Faraday Cups are used during beam tuning, one just downstream of the switching magnet, and another just in front of the target station. Water cooled graphite collimators are placed along the beam line and provide diagnostics for beam tuning. A neutron shutter placed next to the wall prevents high energy neutrons from travelling down the beam pipe when the beam is not in used, and forms part of the interlocking safety system. These beam line components, including the vacuum system, were provided by IBA.

### Sweeper Magnet

iThemba LABS supplied a wobbler system for sweeping the beam over the target [6]. This is to protect the vacuum window and the target from excessive localised heating. It consists of X and Y alternating current steerer magnets, operating at 1600 Hz, and producing 40 mT fields, capable of displacing the beam by 20 mm at the target. To limit the induced eddy current losses, the yoke is made of ferrite, a ceramic beam pipe is used and air-cooled coils are wound from Litz wire. Each coil is placed in series with a capacitor bank to produce a resonant LC system, and driven by an audio amplifier. The phase difference between the X and Y magnets is adjusted to be 90 degrees to obtain a circular beam on the target. A hard-wired interlock measures the magnetic field and trips the cyclotron RF when required.

### Target Stations

iThemba LABS has 30 years' experience of working with local shields around the target [7]. These target stations, shown in Fig. 2, reduce the dose rate in the vault by a factor of 1000 during bombardment, limiting activation of the vault, and provide shielding of the highly activated components like the target collimator, when personnel have to enter the vault post bombardment.

During operation the beam enters the target station through an axial opening in the shielding. At the centre of the station beam passes through a 4-sector graphite collimator used for beam alignment, then a vacuum window made from two  $50\ \mu\text{m}$  foils of Havar cooled by room temperature helium gas, then the target holder and finally the target. The target stations can open up to allow targets to be installed and removed by a pneumatic robotic arm.

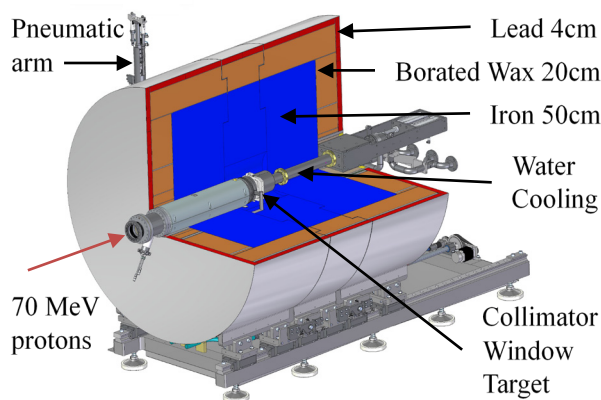


Figure 2: Target bombardment station.

### Trolley Transporter

The target discs are contained in a target holder and the target holder is transported using a modified trolley based on a system provided by Telelift. The trolley is suspended from an overhead track with a length of about 200 m from the production vaults to the hot cells. Sliding air locks are used to cover the track openings to prevent air flow due to the radiation protection pressure cascades.

### Target Holder

The aluminium target holders [8] have three main functions: they hold the target discs in place during bombardment, they direct the water-cooling flow to the targets, and they fit on and engage with the target transport system. The SAIF target holders were redesigned based on CFD simulations to obtain higher water flow rates than before, resulting in 240 litres per minute at an overall 10 bar pressure drop over the water-cooling system.

### Targets

iThemba LABS uses a tandem target system with an upper energy window (a Rb target for  $^{82}\text{Sr}$ , or a Mg target for  $^{22}\text{Na}$ ) and a lower energy window (a Ga target for  $^{68}\text{Ge}$ ). These materials are encapsulated in stainless steel or niobium containers, and separated by 1-2 mm thick water layers for cooling. The beam is calculated to have its Bragg peak in the middle of the low energy target. The SAIF targets are 50 mm in diameter, which is substantially bigger than the previous 38 mm used at the existing vertical beam target stations (VBTS) on one of the SSC beam lines, although one SAIF target station has been configured to bombard VBTS targets.

### Control System

The SAIF control system is largely built on the EPICS framework and mostly utilises off-the-shelf Beckhoff Ether-CAT I/O terminals and third-party PLC's [9]. The cyclotron and beam lines are controlled by a turnkey proprietary system installed by IBA. Communication from the closed IBA C70 control system was made possible with EPICS Process Variables made available by IBA,

integrated to the broader SAIF control system via an EPICS IOC developed by iThemba LABS.

### Services

The intention of the SAIF design was to keep the services completely separate from the existing iThemba LABS facility, so that its maintenance did not depend on the aging infrastructure. A new electrical building houses a rotary UPS to smooth out spikes in the power supply and provide bridging power in case of a power cut from the utility, allowing time for a diesel generator to start up. A new mechanical building contains pumps and air-cooled chillers, providing cold water to the vaults and air handling units. A power supply room in close proximity to the vaults houses all the cyclotron and beam line electronics and power supplies. A new radiation waste storage building was constructed to temporarily store contaminated material. Various smaller services include: compressed air, nitrogen and hydrogen gas supplies, fire detection and fighting systems, and replaceable video cameras in the vaults.

### Radiation Protection

SAIF is divided into white/blue/red radiation protection zones [10]. A pressure cascade of -40 Pa for blue, and -80 Pa for red is maintained. To limit activation, air is filtered before entering the vaults and extracted air passes through HEPA filters before discharging to the atmosphere through 30 m tall stacks equipped with radiation monitors. A system of double separation via two heat exchangers is used to keep activated water and clean water apart in the cooling system. A hot workshop is provided for work on activated components. Concrete pigeon holes with lead doors provide long term storage of highly radioactive equipment. Wastewater is collected from all the vaults, and treated in a reverse osmosis plant. Several radiation detectors are used, including a full body portal monitor when moving from the blue to white areas.

## COMMISSIONING OF SAIF

### Radiation Protection

Radiation measurements started as soon as the cyclotron produced beam. The measurements corresponded reasonably well with the FLUKA predictions, as shown in Table 1 which provides the dose rates for 375  $\mu\text{A}$  on the target. The calculations were generally correct within a factor of 2-3, although computations for very long labyrinths were slightly less accurate.

Table 1: Computed and Measured Dose Rates

Location	FLUKA [ $\mu\text{Sv/h}$ ]	Measured [ $\mu\text{Sv/h}$ ]
Roof	4	2.2
Labyrinth	0.3	1.4
Outside wall	< 0.1	< 0.1

An initial license to import, and a hot commissioning license were granted to SAIF based on the FLUKA calculations. A final production license was issued following the successful radiation measurements during operating conditions.

### Cyclotron

The bid documentation from iThemba set out a list of commissioning tests. In concert with IBA a testing program was devised, progressing from initial injection tests, to transmission efficiency tests, to full beam line tests. The final test demonstrating the use of the cyclotron under operational conditions was a 120-hour run with simultaneous dual beam extraction of 375  $\mu\text{A}$  from each extraction port. Following this a radiation survey was performed to assess the short-lived dosage around the cyclotron, and found to be within the accepted limits.

### Targetry

The target holders were tested on an offline prototype target station to verify their water flow rate design. Commissioning tests of the target stations were then conducted with dummy copper targets. Runs were completed at 100, 200 and 300  $\mu\text{A}$ . The beam spot size was determined from post bombardment autoradiograms taken of the front of the target holders, as shown in Fig. 3. This verified the optics of the beam line design requiring a beam spot with a FWHM of 5 mm.

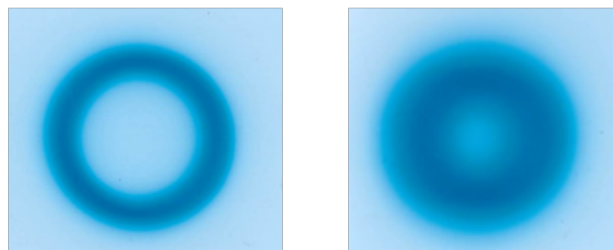


Figure 3: Autoradiogram showing beam shape on target holder, with a swept focussed beam (left) and the ordinary production beam (right).

### Isotope Production

The first Rb test targets were irradiated for a customer in Sept 2024. A number of targets, ranging from 1Ci to 4Ci were produced and shipped, testing the transporter and hot cell infrastructure. Based on the customer's measurement of activity, the make-rate (Ci/ $\mu\text{Ah}$ ) could be determined. This was found to be within 10% of the expected value calculated from integral yield curves. The first tandem targets with Mg-Ga discs were bombarded in Nov 2024, and the first Rb-Ga discs in Feb 2025.

## CONCLUSION

The construction of SAIF is complete. The facility has passed its commissioning tests and is now actively producing isotopes.

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