AN OVERVIEW OF THE SOUTH AFRICAN ISOTOPE FACILITY (SAIF) PROJECT

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Abstract

The South African Isotope Facility (SAIF) is a project to establish a new facility based on the production and usage of unstable isotopes for nuclear science and nuclear medicine. Phase-1 of SAIF is a new radioisotope production facility currently under construction at iThemba LABS in Cape Town and scheduled for completion in 2022. A commercial 70 MeV proton cyclotron from IBA with a number of beam lines equipped with isotope production stations, are being installed in retrofitted concrete vaults. The facility will be supported by new infrastructure and services which are being constructed. The completion of SAIF will greatly increase the radioisotope production capability of iThemba LABS, and enable the existing Separated Sector Cyclotron to be dedicated to produce stable ion beams and to post-accelerate unstable isotopes from phase-2 of SAIF for nuclear physics and nuclear astrophysics research activities. An overview of the SAIF project (Phase 1) from the inception phase through to the construction phase is provided here, discussing all related workstreams and progress made to date. A more detailed discussion of some specific systems is given, including the design of the isotope production stations, target handling system, and a new radioactive waste management facility.

1. INTRODUCTION

iThemba LABS is a national facility of the National Research Foundation (NRF) in South Africa, an entity of the Department of Science and Innovation. The mandate of iThemba LABS is to operate a number of cyclotrons for purposes of conducting research in subatomic physics, producing medical radioisotopes and performing patient treatment using proton and neutron beam therapeutic protocols.

The available beam time of the facility was historically divided more-or-less equally between the above-mentioned operational mandates since its commissioning in the early 1980's. However, in recent years the ageing facility for patient treatment was no longer compatible with modern neutron/proton treatment protocols and the patient treatment service was subsequently discontinued a few years ago. Since then, the allocation of available beam time gradually became more weighted towards medical radioisotope production due to growing demand for radioisotope products from the public and private health sectors. Today, iThemba LABS is a key producer and supplier of medical radioisotopes which are distributed throughout South Africa and globally into ~60 countries. As a result of this demand growth for radioisotopes, more than 50% of beam time is currently utilised for radioisotope production.

The demand for increased beam time for subatomic physics research at iThemba LABS as well as the necessity to continue to serve the health sector both locally and globally are the main driving factors for phase 1 of the South African Isotope Facility (SAIF) project which was conceived several years ago and which started officially in 2019 when the first budget for the SAIF project was approved. The SAIF project involves the installation of a new 70 MeV cyclotron into the decommissioned patient therapy vaults at iThemba LABS and which will be dedicated to radioisotope production. This will in turn release the existing Separated Sector Cyclotron complex to be fully dedicated to the subatomic and nuclear physics research programmes of the international scientific user base of iThemba LABS.

2. EXISTING ACCELERATOR FACILITIES AT ITHEMBA LABS

A number of existing accelerator facilities are currently in operation at iThemba LABS. The main facility is located at Faure near Cape Town, South Africa where the following accelerators are installed:

— 200 MeV Separated Sector Cyclotron (SSC)
— 8 MeV Solid Pole injector Cyclotron (SPC1) with internal PIG ion source for proton beams
— 8 MeV Solid Pole injector Cyclotron (SPC2) with a number of external ion sources for both light and heavy ion production
— A number of experimental beam lines dedicated to neutron production, gamma ray arrays (ALBA and Aphrodite facilities) and radiation biophysics
— K600 magnetic spectrometer for light ions
— 11 MeV self-shielded cyclotron for F-18 production
— Hotlab and cleanroom complex for chemical extraction and production of radiochemical and radiopharmaceutical products under cGMP conditions
— 3MV Tandetron accelerator and beam lines for materials research using Ion Beam Analysis (IBA) and microprobe analysis.

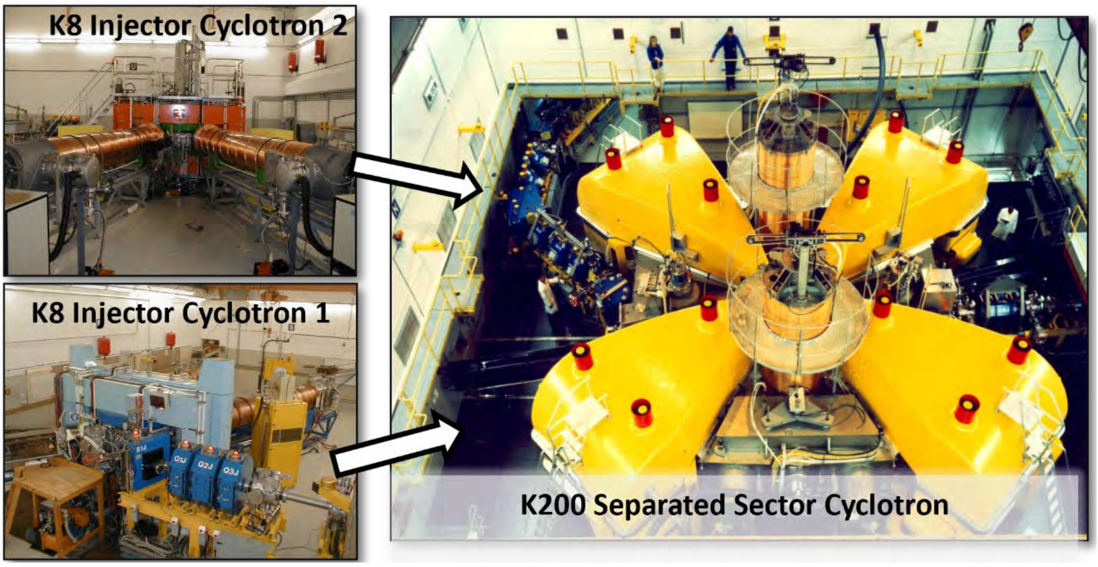

FIG. 1: Photograph of the 200 MeV Separated Sector Cyclotron (SSC) and SPC1/SPC2 injector cyclotrons in Cape Town.

Additionally, a 6MV tandem accelerator is in operation in Johannesburg, South Africa. This facility is dedicated to materials research using IBA, microprobe analysis as well as Accelerator Mass Spectrometry (AMS).

FIG. 2: Photograph of the Tandem AMS facility in Johannesburg.

3. MOTIVATION FOR SOUTH AFRICAN ISOTOPE FACILITY (SAIF) PROJECT

The oversubscription of beam time on the existing SSC complex and the increasing interest for research with unstable isotopes led to the concept of establishing the South African Isotope Facility (SAIF) which involves in its first phase the procurement and installation of a new 70 MeV cyclotron, four beam transport lines and target stations to be dedicated to radioisotope production. Once fully commissioned, this will release approximately 50% of SSC beam time currently allocated for radioisotope production to be used for subatomic and nuclear physics research programmes of the international scientific user base of iThemba LABS.

The SAIF facility was conceptualised to be housed in the three vaults of the decommissioned patient treatment facility, where the cyclotron would be installed in the centre vault with beam transport lines leading into two adjoining target vaults on either side which will house the four target stations.

The re-purposing of the existing vaults previously used for the patient therapy programme would realise significant cost savings for the SAIF project, but also introduced some spatial constraints for the installation of equipment and radiation shielding requirements which had to be met. The general layout of the SAIF facility is shown in *FIG. 3* below.

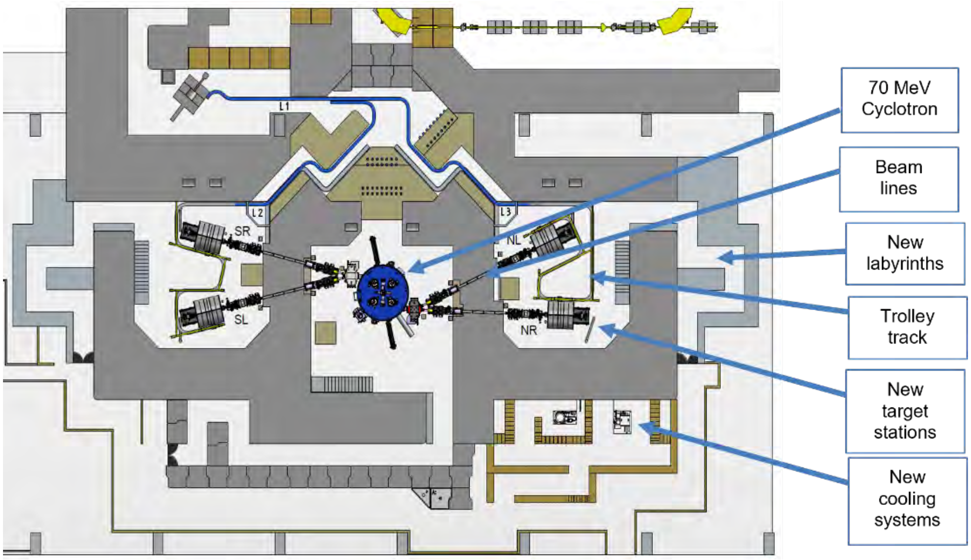

FIG. 3. General layout of the SAIF facility in the three existing vaults.

The first budget allocation for the SAIF project was approved in 2018 when the project formally launched. The execution of the project was planned within five major workstreams:

- 70 MeV cyclotron and beamline procurement
- Additional beamline equipment development and manufacturing
- New target stations manufacturing
- New building construction for utility services and radioactive waste disposal
- Regulatory licensing

4. CURRENT STATUS OF THE SOUTH AFRICAN ISOTOPE FACILITY (SAIF) PROJECT

The SAIF project is currently in the construction phase with equipment procurement taking place in parallel. The status of the various workstreams is further described in detail below.

4.1. Procurement of 70 MeV cyclotron

Following a competitive bidding process, IBA Radiopharma Solutions in Belgium was appointed to manufacture and supply a commercially available Cyclone 70P cyclotron with four beam transport lines for the SAIF facility. The C70 cyclotron can supply variable energy proton beams with energy from 30 – 70 MeV and up to 750 uA beam intensity. It has the capability to extract two beams simultaneously from two extraction ports with up to 375 uA intensity each.

A multicusp ion source can provide 10 mA of H- current for injection into the cyclotron. The cyclotron is equipped with a 1.6 T four-sector magnet, a directly coupled RF system with 2 dees operating in the 4th harmonic mode. The four beam transport lines are fully equipped with beam diagnostics, Faraday cups and neutron shutters to isolate the cyclotron vault from the two target vaults.

The C70 cyclotron successfully passed factory acceptance testing in Belgium in July 2021 and was delivered to South Africa in December 2021. It was finally installed in the centre vault in April 2022. Due to space constraints imposed by the use of existing concrete vaults for the new facility, special logistical arrangements had to be made to install the heavy cyclotron parts inside the vaults. The vault walls extend 10m above ground level inside an existing building. In addition, the capacity of the overhead crane inside the building was insufficient to lift the heavy cyclotron parts, being the two magnet yokes weighing ~ 60 ton each.

A special temporary gantry therefore had to be constructed on the vault walls to lift the two magnet yokes over the 7 m high wall and to install them in the designated position inside the vault, as shown in *FIG. 4* below.

FIG. 4: Rigging of the magnet yokes into the centre vault.

FIG. 5: The C70 cyclotron installed in its final position

4.2. Additional beam line equipment development and manufacturing

In addition to the beam transport line equipment supplied by IBA Radiopharma Solutions, iThemba LABS is also implementing a beam sweeper/steerer facility designed to sweep the proton beam in a circular pattern over the target surface. This is required to assist with dissipation of up to 26 kW of heat from the target capsule with diameter of 54 mm.

The beam sweeping is achieved by constructing a sweeper magnet with two H-type dipole magnets operating with 90 degrees phase difference which is placed directly in front of the target system at the end of the beam transport lines.

The sweeper magnet makes use of a ceramic beam pipe inside the magnet in order to minimise the generation of Eddy currents and subsequent power losses and heat generation.

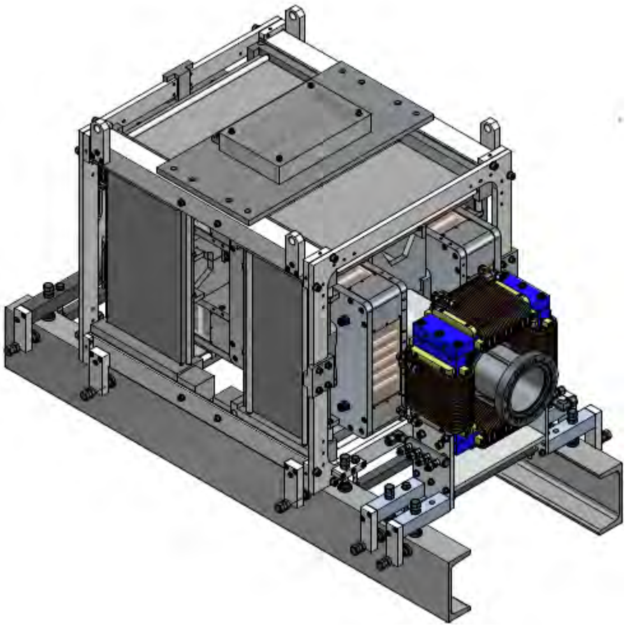

FIG. 6: The beam sweeper magnet.

4.3. New target station manufacturing

The target system is based on an in-house development[1] of a target station design that has been in use in the existing radioisotope facility for some 25 years. The target station provides for placement of the target capsule in front of the beam using a pneumatically controlled robot arm, retrieval of the target holder at the completion of bombardment and placement of the target holder on a trolley system to transfer the target from the target station to the radiochemical process facility some 120m distant from the target vaults.

The target station furthermore provides local radiation shielding inside the target vault by using a combination of shielding elements manufactured from steel, lead and borated wax. The target station is designed with a motorised mechanism to open and close the shielding elements to allow for placement and retrieval of the target holder with the robotic arm.

The target station provides pressurised water cooling to the target capsule through a pusher arm mechanism as well as helium cooling to a vacuum window which separates the beam line vacuum from atmosphere in front of the target capsule.

A prototype target station without the heavy shielding elements was manufactured and installed to assist with development of the electronic control systems of the mechanical systems and target transport system, as well as to qualify the designs of the cooling systems and target transporter.

4.4. New building construction for utility services and waste disposal

Construction works are currently underway on various infrastructure modifications and additions required for the SAIF project. These include the following:

— Construction of new plant rooms for a main water-cooling system and electrical distribution (including rotary UPS systems);
— Structural modifications to the existing vaults to accommodate the new C70 cyclotron and beam transport lines, as well as to provide new entry labyrinths for radiation shielding;
— Construction of new facilities to house the various electronics, power supplies, cooling systems and control room for the C70 cyclotron;
— Construction of a new building to house the radioactive waste processing and storage facility;
— Manufacturing of the new target cooling systems;
— Installation of new ventilation systems required to maintain the specified air changes and air pressure cascades of the cyclotron and target vaults;
— Installation of the supervisory control systems for vault clearance and safety interlocking.

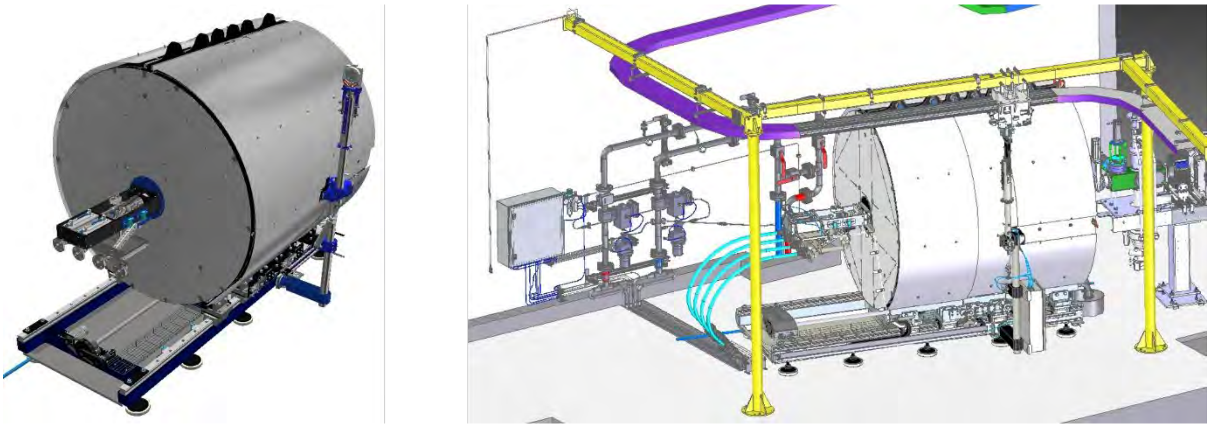

FIG. 7: 3D models of the SAIF target station showing the pneumatically controlled pusher arm and robot arm mechanisms.

FIG. 8: The prototype target station being commissioned.

The structural modifications to the cyclotron and target vaults were informed by the radiation shielding requirements as dictated by the facility licencing conditions. The radiation levels inside and outside the vault areas were simulated by using the FLUKA simulation software under worst-case conditions for dose conversion factors (FLUKA option EWT74) based on data sets from ICRP74.

FIG. 9: *Bird's eye view of the new mechanical and electrical plant rooms under construction*

4.5. Regulatory licensing

An important aspect of the SAIF project is to obtain the necessary regulatory licenses for the new facility. In this respect, a license to import the cyclotron and beam transport line equipment was granted by the regulatory authority (Department of Health) on 8 Oct 2019. This follow a process of basic design with safety assessment, submission of plans and designs as well as decommissioning strategies and construction reports.

Subsequently, a license to install the cyclotron and beam transport line equipment was granted on 18 Nov 2020.

Application for a license to operate the C70 cyclotron will be launched when the facility is ready for cold commissioning, when further safety case documentation will be submitted for approval.

5. SUMMARY

Construction and equipment installation on the South African Isotope Facility (SAIF) project are in progress. An overview of the status of the SAIF facility is provided, where progress with the installation of a new 70 MeV cyclotron and beam transport lines, manufacturing of the target stations and additional beam line equipment, and construction of buildings for utility services is reported.

Completion of the project is scheduled for the end of 2022 when first beam will be extracted from the cyclotron. Final site acceptance testing of the C70 cyclotron is planned for February 2023 after which production of radioisotopes can commence.

ACKNOWLEDGEMENTS

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[1] STEYN, G.F. et al, Development of New Target Stations for the South African Isotope Facility, Instruments **2** 29 (2018).