NEW DEVELOPMENTS AND A REVIEW OF THE ACCELERATOR FACILITIES AT ITHEMBA LABS

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Abstract

iThemba LABS is a multi-disciplinary research facility that provides accelerator-based facilities for physical, biomedical and material sciences, treatment of cancer patients with neutrons and protons and the production of radioisotopes and radiopharmaceuticals. The successful utilization of beam diagnostic equipment is critical and essential for the effective running of such a facility and will be discussed in more detail. The current status of the facility and future projects, which entail a radioactive-ion beam project as well as a dedicated facility for proton therapy, will also be discussed.

INTRODUCTION

At iThemba LABS proton beams are accelerated with a K=8 injector cyclotron (SPC1) for injection into a K=200 separated sector cyclotron (SSC) [1]. Production of radioisotopes and neutron therapy is done at 66 MeV and a 200-MeV beam is used for proton therapy. For radioisotope production a beam current varying from 80 to 300 µA is used depending on the target material. Low intensity beams of light and heavy ions and polarized protons, pre-accelerated in a second injector cyclotron (SPC2) with K=11, are available for nuclear physics research.

During the past several years extensive development work has been done on the accelerators to increase the beam intensity for radioisotope production. Flat-top acceleration systems were installed in both the injector SPC1 and the SSC which led to a threefold increase in beam intensity for radioisotope production [2]. The increase in beam intensity also necessitated the development of beam diagnostics that can handle the high beam intensity.

OPERATING STATISTICS

The performance of the iThemba LABS facility was outstanding during the 2011 calendar year. The unscheduled interruptions to operations amounted to a meagre 4.8% of the scheduled beam time, down from 7.3% the year before.

Fig. 1 shows the beam outages per failure category for the calendar year 2011. The bulk of the beam outages in 2011 were caused by RF interruptions, amounting to 25%. Despite this, the beam time loss to the user communities as a result of RF interruptions shows a very encouraging decline. In 2010, the beam outages as a result of the RF systems amounted to 224 hours and in 2011 this figure decreased to only 98 hours. This significant drop in interruptions can largely be ascribed to a pro-active approach to maintenance. As part of this approach, a number of water-cooled components in both the 150-kW amplifiers were replaced and ICs on various PCB boards in the amplifiers were resoldered to remove dry joints after 28 years of operation. These steps greatly contributed to the reduced beam time loss as a result of RF interruptions.

Another major interruption that plagued the operations at the facility in 2011 was power failures. In 2011, power failures resulted in a beam time loss of 40 hours, which was significantly lower than the 60 hours of beam time loss it caused the previous year. This beam time loss is mostly caused by power dips, which are brief interruptions of power to the facility. To lessen the impact of such power dips, iThemba LABS has invested in a 4-MW Uninterrupted Power Supply (UPS). The UPS sustains power when the externally supplied power falls away. However for certain beam energies, power cannot be delivered to all equipment by the UPS. Developments are underway to improve this situation.

Other contributions to operational interruptions were caused by water leaks interrupting the vacuum, servicing and tuning of the ion sources, and problems with cooling water and power supplies.

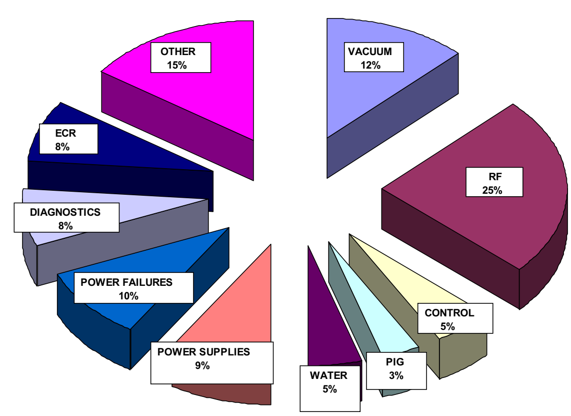

Figure 1: Beam outages per failure category in 2011.

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SSC NON-DESTRUCTIVE BEAM PHASE PROBE MEASUREMENT SYSTEM

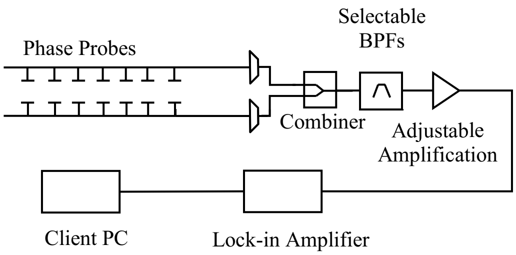

Figure 2: A block diagram of the SSC non-destructive beam phase probe measurement system.

A non-destructive beam phase probe consisting of 21 probes, which spans from the injection radius to the extraction radius, has been installed into the SSC. Each probe consists of two double-shielded electrodes, symmetrically arranged with respect to the median plane. The hardware and software control of the system has been completed. A high level block diagram is shown in Fig. 2.

Each of the upper and lower plates of the phase probes can be selectively multiplexed to a single output port. The signals are then combined. This reduces the unwanted RF pickup in the system. The second harmonic of the beam packet was chosen (for spectral purity reasons) to extract amplitude and phase measurements. The second harmonic is filtered using selectable band-pass filters. The bank of 7^{th}-order band-pass filters comprises thirteen 4-MHz band-pass filters, each with a 1-MHz overlap. The centre frequencies of the filters are evenly spaced from 16 MHz to 52 MHz. Each of the filters is designed to reject the fundamental and higher order harmonics by 60 dB. The signal is then passed through an adjustable amplification unit, with 0–60dB amplification in steps of 20 dB.

Amplitude and phase information of the signal is extracted using a Stanford Research Systems SR844 lock-in amplifier. A LabVIEW interface to the lock-in amplifier, as well as the control hardware for the system has been developed. The LabVIEW client scans through the 21 probes and plots the amplitude and phase of the second harmonic.

The phase information of the beam from the 21 probes is used to isochronize the magnetic field of the SSC.

DIAGNOSTICS

High Intensity Beamstop (Faraday Cup)

A pneumatically operated remote-controlled beamstop, Fig. 3, is used to accurately measure beam current of the extracted beam when optimising the beam transmission through the SSC at high beam intensities. The beamstop has a length of 660 mm and a 120 mm square aperture. It was designed for a 50-kW beam of 66 MeV protons, provided that the beam diameter is not less than 35 mm. For a beam diameter of 10 mm the maximum allowable beam power is 32 kW. The main parts of the beamstop are two 600 mm long water-cooled copper blocks mounted at an angle with respect to each other. Insulated electrodes around the entrance of the beamstop provide current measurements that are used for interlocking in case of beam mis-alignment. The metre-long vacuum chamber of the beamstop is surrounded with a 50 mm thick lead shield to reduce radiation exposure to staff.

Beam Position and Beam Intensity Monitoring

Significant efforts have been made to develop non-destructive beam diagnostic equipment. A beam position monitoring (BPM) system, making use of four-segment capacitive pickup probes, was developed and put into operation to provide beam position data along the injection and the high-energy beam lines and has become an indispensable diagnostic tool for medium- and high-intensity operation [3]. Ionisation chambers mounted around the beam pipes are used as stray-beam detectors.

It is essential that the beam current is monitored continuously during target bombardment at high intensities. Capacitive probes and digital signal processing provide the cheapest and most accurate solution to non-destructive current measurement [4].

High Intensity Beam Scanner

The first element used for splitting the high intensity 66-MeV proton beam for isotope production on two

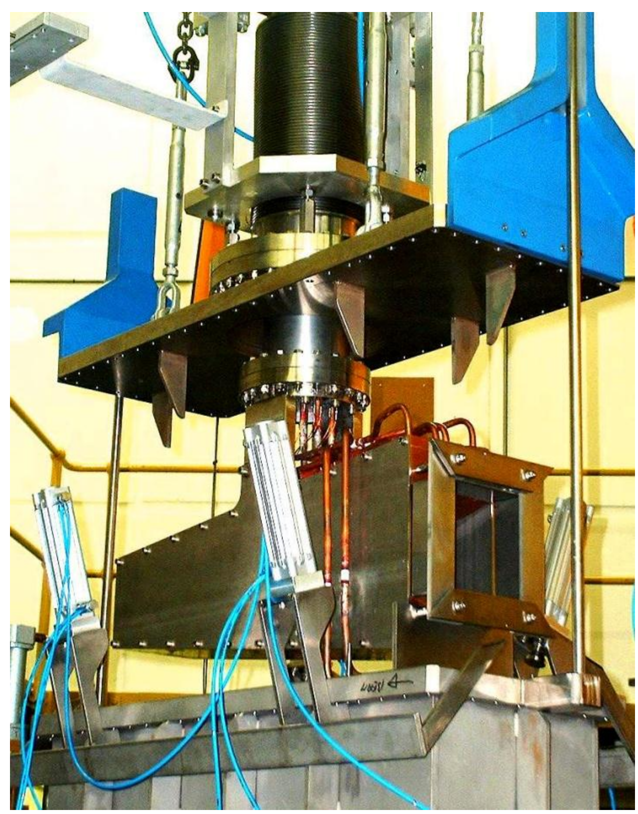

Figure 3: The 50-kW beamstop lifted out of its vacuum chamber; the positioning cylinder is mounted on the lid of the vacuum chamber.

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targets simultaneously is an electrostatic channel [5]. In order to position this element in such a way that the beam is split in the right proportions and to minimise beam loss on the septum, two scanners were installed in front of and behind the channel, respectively. On command, a single sweep of the beam is executed, and the profiles of the beam at these positions are displayed. The single sweep prevents the tantalum scanner finger from being exposed to the beam for an extended time, which would result in destruction by melting.

Non-destructive Beam Profile Monitors

Beam diagnostic devices that measure the beam profile and position by registering electrons or ions produced by the interaction between the beam particles and the residual-gas atoms are already in practical use. Non-destructive, two-dimensional beam profile measurements are achieved by measuring these secondary particles, which are accelerated in an electrostatic field towards micro-channel plates (MCP) for signal amplification and processing. One-dimensional residual-gas beam profile monitors are already used successfully but space limitations and the need to measure both dimensions of the beam at the same location, initiated an investigation of two-dimensional systems. Prototypes of these diagnostic devices have been produced and successfully tested; they still need to be developed further before being implemented [6].

Other devices use the light emitted by beam excited residual-gas atoms for these measurements. The light can be focused with a lens onto a photomultiplier (PMT) array. From the signals the beam position and profile can be reconstructed. A prototype device has been installed in the beam lines of iThemba LABS to illustrate the principle and feasibility [7]. The system is in use and we plan to produce a few more of these monitors.

PROGRESS IN THE CONVERSION OF THE IN-HOUSE DEVELOPED CONTROL SYSTEM TO EPICS AND RELATED TECHNOLOGIES

The current iThemba LABS control system is based on a LAN of PCs running OS/2, using C-code and hardware interfacing developed in-house consisting of elderly CAMAC and locally manufactured SABUS modules.

It was decided not to re-invent another in-house system and rather to adopt the now widely used EPICS tool-kit for the many reasons that others have considered previously.

The control system consists of about 4000 devices resulting in approximately 40000 process variables. To date we have moved about 40% of these variables onto EPICS IOCs running the UBUNTU Linux distribution (1004 and 1204 LTS) on low-cost PCs. We are keeping the existing SABUS crates of the previous system and are busy replacing the CAMAC crates with new SABUS cards and crates designed in-house. The in-house card design is challenging at times but does buy us independence from manufacturer changes and their lack of longevity. We have found that the EPICS platform and Channel Access network protocol has proven to be stable and programming at the record layer very useful. By joining with the EPICS community we have saved considerable time in not having to develop everything ourselves. We are also extending Linux and EPICS into the embedded on-circuit-board environment.

ION SOURCE DEVELOPMENT

iThemba LABS operates two Electron Cyclotron Resonance Ion Sources (ECRISs). ECRIS4, which was originally built by GANIL for the Hahn Meitner Institute [8, 9], delivers beams from gases and fluids. Typical intensities and charge states for argon are: 25, 6 and 3 eμA for Ar^{11+}, Ar^{13+} and Ar^{14+}, respectively. Since 2011 a second ECRIS, the GTS2, which is based on the design of the Grenoble Test Source [10] has been installed. The source is connected to the injection beam line via a 104° bending-magnet. This set-up of the beam lines in the ECRIS vault with the new diagnostic beam line for the GTS2 source allows simultaneous operation of both sources, i.e. the required beam for cyclotron acceleration will be delivered from one source, while the second source can be used for beam development. Recently, in the framework of our collaboration with the ion source group at CERN, experiments with the GTS2 source have been performed for the production and optimization of Ar^{11+}. In CW operation a stable current of 90 eμA of Ar^{11+} ions was measured which was increased, for pulsed operation of the source with a duty cycle of 50%, to 110 eμA. In the afterglow mode, Ar^{11+} ion currents of 240 eμA with a pulse width of approximately 2.5 ms were obtained. The layout of the two sources and the beam lines is shown in Fig. 4.

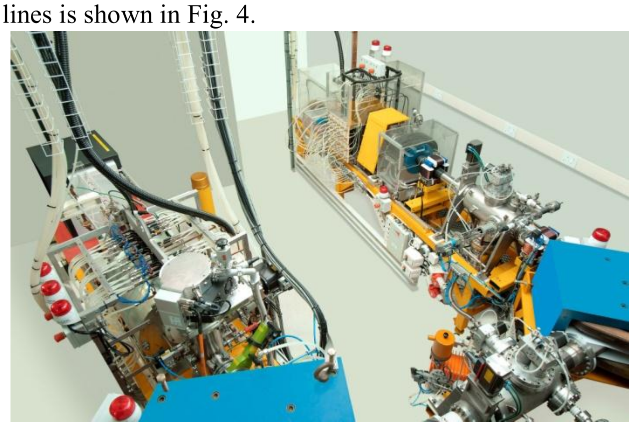

Figure 4: The GTS2 (left) and the ECRIS4 (right) ion sources and sections of the beam line.

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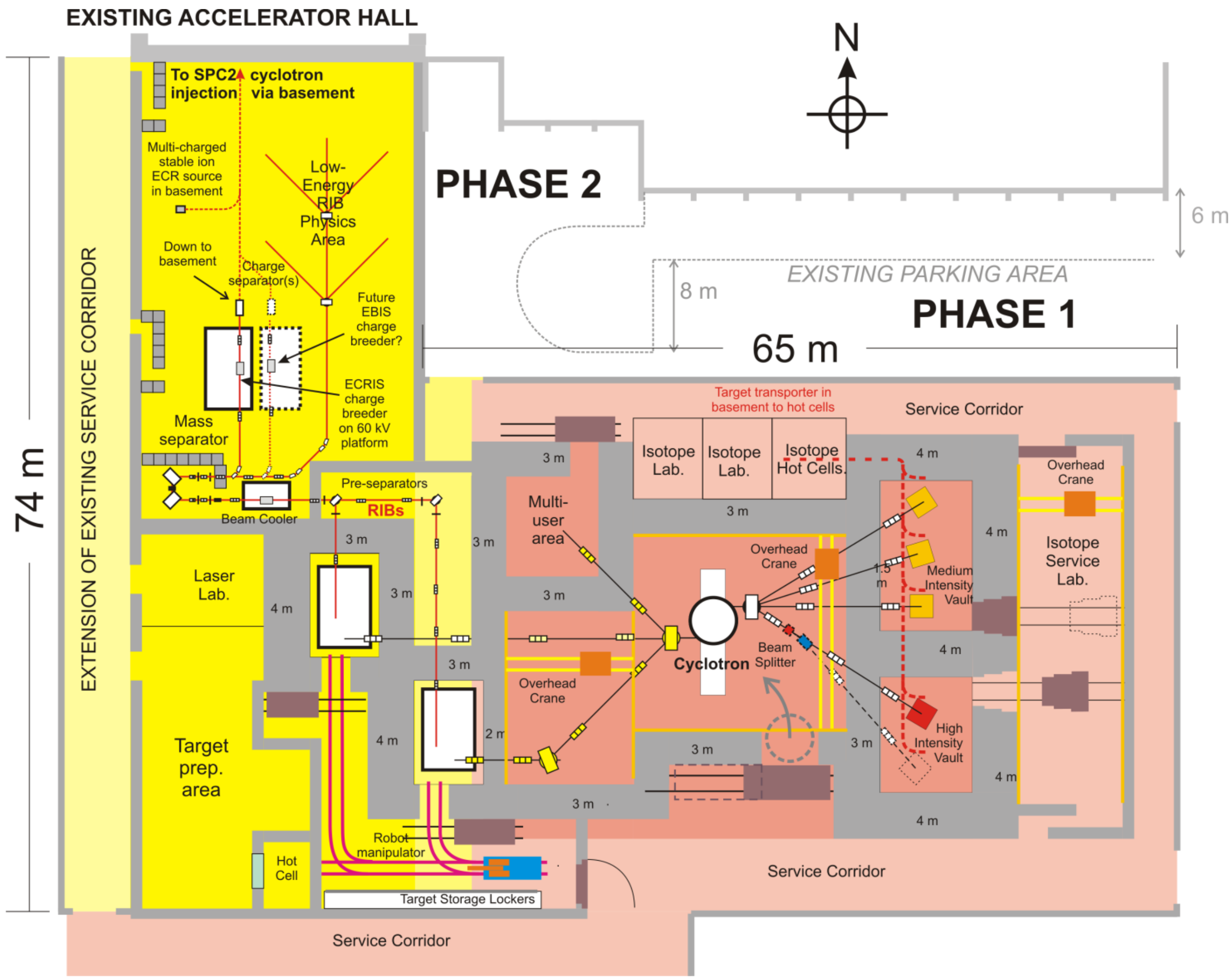

Figure 5: Schematic diagram of the proposed new RIB facility, showing Phase 1 (pink) and Phase 2 (yellow). Darker shades indicate basement areas. Radioactive-ion beams will also be post-accelerated via the SPC2 injector and the SSC (not shown) in the existing Accelerator Hall, indicated at the top left of the diagram.

Since 1992 iThemba LABS has operated an atomic beam source for the production of nuclear spin-polarized protons. We plan to exchange the existing electron ionizer with an ECR ionizer which will result in a reduction of the emittance of the extracted beam and will therefore allow higher beam transmission through the injector cyclotron.

RADIOACTIVE-ION BEAM FACILITY

A new proposal has recently been compiled for a radioactive-ion beam (RIB) facility at iThemba LABS. This project is based on a new, commercially-available, 70-MeV H^- cyclotron, with two beams of protons extracted, one for RIB production and another for the production of medical radioisotopes for local hospitals and for export. The proposal has still to be submitted for consideration by the relevant Government Department. It would involve considerable new construction of buildings, as indicated in Fig. 5. A new experimental area for both nuclear physics (with a large-acceptance spectrometer) and for materials science will be built as an extension to the north end of the existing Accelerator Hall.

Phase 1: Radioisotope Production

The first phase would see the construction of the cyclotron vault and two heavily-shielded concrete vaults with several stations for production of radioisotopes.

Phase 2: RIB Production

The second phase would include construction of the shielded vaults for RIB production, as well as an extension to the existing Accelerator Hall, in which low-energy physics will be possible with un-accelerated RIBs. This hall will also house an RFQ beam cooler, high-resolution mass-spectrometer, with a charge-breeder in the basement close to the existing SPC2 injector cyclotron.

Finally, the high charge-state RIBs will be injected into SPC2, and subsequently into the SSC for acceleration to higher energies. Provision will also be made for

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additional experimental areas at the north end of the existing Accelerator Hall, in which devices such as a large-acceptance spectrometer can be installed. The RIBs will be used for experiments in both nuclear physics and materials science.

This project is estimated to cost almost 1 billion rand (about 118 million US dollars, or 94 million euros) and construction will extend over an 8-year period, depending on the rate of financing.

DEDICATED PROTON THERAPY CENTRE

The current utilization of the iThemba LABS cyclotrons permits proton therapy only on Mondays and Fridays and treating with a fixed horizontal beam. These limiting factors prevent the implementation of fully fractionated treatments to a wide variety of cancers. Consequently, iThemba LABS cannot accommodate all the patients that could potentially benefit from such treatment. The proton therapy facility at iThemba LABS was designed mainly for treatment above the clavicle, including lesions in the brain, inter-cranial and base-of-skull lesions [11].

Some 12 years ago a centre for dedicated proton therapy, with fully fractionated treatments using multiple treatment rooms was proposed, but further progress was extremely slow, mainly due to the cost implications of such a facility. The proton therapy centre will be based on an accelerator with a maximum energy of about 250 MeV. The beam from the accelerator will be delivered to treatment vaults with isocentric gantries and fixed horizontal and near vertical beam lines. In this proposal the therapy centre would have been situated at iThemba LABS at Faure near Cape Town.

During the past year there was renewed interaction regarding this proposal between the Department of Health, Department of Education and the Department of Science and Technology, with iThemba LABS part of the latter. From one such strategic discussion it emanated that the proposed proton therapy centre should rather be an integral part of the Department of Health, with iThemba LABS providing the technical support for the project. Such an allocation to the Department of Health will allow the freedom to have the facility at any hospital that already has an infrastructure for oncology, medical imaging and supporting services for radiotherapy patients.

At present there are high-level discussions between the different Government Departments to ensure rapid progress with this project.

GREEN INITIATIVES AND ALTERNATIVE ENERGY

Proposal for a Thermal Storage System for iThemba LABS

The rising electricity demand at the facility and the recent announced tariff increases, forced iThemba LABS to consider a fresh approach in handling these realities.

The cooling facility is the single item with the highest demand (1.5 MW). The solution is to use a Thermal Storage System (TSS). One hundred thousand kg of ice is to be produced during the cooler night temperatures when the cost of electricity is low. The ice is to be melted in the cooling process during hotter day-time when tariffs are high. The more even demand over 24 hours plus the lower power usage will contribute substantially to a lower carbon footprint.

Solar Voltaic Panels - Integration with the Uninterruptible Power Supply

At iThemba LABS the supply from the UPS is isolated from the national electricity supplier. The UPS is fortunately an ideal interface for feeding solar energy into the local grid. This eliminates the need for a solar grid inverter and makes it 25% more economical. The change to solar support can be made modular, as strings of 34 PV panels (80W each) are connected in series to deliver the appropriate voltage. Additional strings can be added in parallel to increase capacity. A pilot installation will be installed soon at a cost of about R100 000.

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