NEW DEVELOPMENTS AT iTHEMBA LABS

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Abstract

iThemba LABS has been in operation for more than 30 years and is now at a stage at which refurbishment and – in some cases – replacement of the infrastructure and critical components is required. The replacement and refurbishment of the cooling system, which include the cooling towers and chillers, the 4.4-MVA uninterruptable power supply batteries and other critical components, are discussed. Progress with a facility for low-energy radioactive ion beams will be reported on. A proposal to remove radioisotope production from the separated sector cyclotron (SSC) and the production of the future radioisotopes with a commercial 70-MeV cyclotron to make more beam time available for nuclear physics research with the SSC will also be discussed. Developments on our electron cyclotron resonance ion sources, the PIG ion source and low-level digital RF control system have also been carried out. Good progress with integration of the existing control system to an EPICS control system has been made. The adoption of EtherCAT as our new industrial communication standard has enabled integration with much off-the-shelf motion, actuator and general interface hardware.

BEAM STATISTICS

The SSC's performance over the past six years is shown in Table 1. The increase in the number of interruptions can be expected as the facility has now been in operation for 30 years. The time lost due to interruptions has increased to more than 10% for some years. This is at the upper limit of what can be tolerated for medical applications. There was an increase in the beam time lost due to power failures. The facility has run without the Uninterruptable Power Supply (UPS) for more than two years, i.e. since early 2013. The average number of power interruptions without the UPS was about 3 per month. This meant that the various subsystems of the accelerators were prone to power failures, which resulted in increased downtime. Another factor which accounts for the increased downtime is interruptions relating to various radio-frequency (RF) systems of the accelerators. Many of these interruptions were due to power amplifiers. A project was initiated to build spare RF amplifiers for the injector cyclotrons and bunchers and refurbish the power amplifiers of the SSC. All the low-level RF control systems will be replaced during the next 2 years. To reduce the unscheduled interruptions to about 5% of scheduled beam time, the rate of refurbishment and replacement of the infrastructure has been increased.

Table 1: Operational Statistics of the SSC for the past 6 Years

Year	Beam supplied as		% of scheduled beam time for	
	% of total time	% of sched-uled time	Energy changes	Inter-ruptions
2010	67.6	82.18	5.2	7.3
2011	68.9	85.91	5.4	4.8
2012	69.9	82.04	6.1	7.9
2013	63.0	81.17	6.2	10.7
2014	67.3	80.81	5.4	8.1
2015	64.1	77.69	5.6	10.8

INFRASTRUCTURE REFURBISHMENT

A number of infrastructure refurbishment projects have been initiated recently. Two of the larger projects are the replacement of the batteries of the 4-MVA uninterruptable power supply and the chillers of the central cooling plant. Both these projects will make a valuable contribution to sustainable stable operation of the facility.

Cooling Towers and Chiller Upgrade

The accelerator complex utilizes a central cooling plant for all the cooling requirements. The heart of the system comprises four water-cooled chillers, seven cooling towers and associated pumps supplying chilled water at 6°C with a capacity of 4.4 MW. The chillers are operated in parallel and switched in on demand as the heat load increases. Since installation in 1982 the system has performed well, but has become inefficient and troublesome to maintain. During 2011 the cooling towers have been replaced and subsequently funds have been approved to replace the chillers and pumps during 2016. An extended mid-year maintenance period of 2 months has been scheduled to allow the work to be completed. As part of the upgrade a new programmable logic controller (PLC) and building management system (BMS) will also be installed. The new equipment will not only be more reliable, but will also offer a sustainable energy saving due to the high Coefficient of Performance (COP) of the modern technology chiller units.

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Replacement of 4.4-MVA UPS Batteries

The batteries that supply backup power to the 4.4-MVA UPS have recently been replaced. The previous gel-technology batteries lasted only 3 years. The new installation of low-antimony alloy, vented lead-acid batteries from BAE has a lifetime of 20 years. A total of 4 banks of 264 *BAE 25 OGI 2000* [1] batteries were installed. The installation is dimensioned to keep the facilities operational for 20 minutes at full load. A photograph of the new installation is shown in Fig. 1.

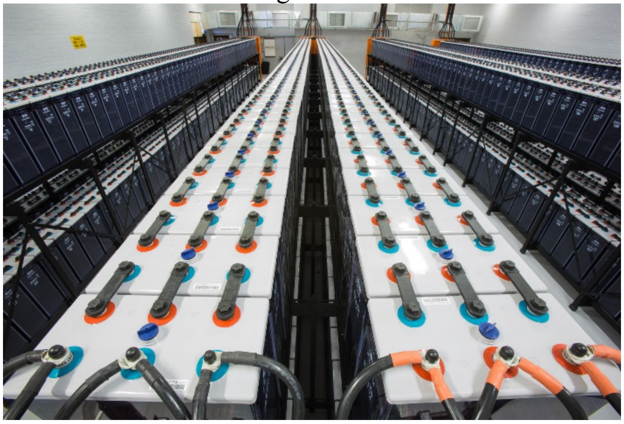

Figure 1: The new 4.4-MVA battery installation.

LOW-ENERGY RARE-ISOTOPE BEAM FACILITY

To stay abreast and explore new frontiers in the field of nuclear physics, iThemba LABS has embarked on a flagship project to establish a Rare-Isotope Beam (RIB) facility, to augment the existing research facilities. Of special interest is the study of neutron-rich nuclei, which is only possible with the production and analysis of RIBs.

As a precursor, iThemba LABS has received a Strategic Infrastructure Grant from the National Research Foundation (NRF) for a pilot project to construct a Low-Energy RIB (LERIB) test facility to develop the techniques for RIB production. Knowledge, experience and equipment gained with this endeavour will be carried over into a full-fledged RIB facility that will include charge breeding, beam cooling and post-acceleration.

A Memorandum of Agreement (MOA) was drawn up and signed during February 2015 to formalize collaboration between the NRF and the Istituto Nazionale di Fisica Nucleare (INFN) in Legnaro, Italy. The MOA involves the procurement of a replica of the Target/Ion Source (TIS), shown in Fig. 2 that has been developed by Laboratori Nazionali di Legnaro (LNL) in Legnaro, Italy for their SPES project. The TIS produces radioactive ions via the Isotope Separation On-line (ISOL) method and will form the basis of the proposed LERIB test facility at iThemba LABS. Neutron-rich atoms can be produced by proton-induced fission of uranium. The SSC will be used as the driver for the LERIB facility.

As part of the collaboration an online test of the power dissipation of the multi-slice target assembly has been performed at iThemba LABS [2]. A 60-µA, 66-MeV proton beam from the SSC was stopped on the target assembly, comprised of 13 thin silicon carbide discs housed in a graphite container. The test results validated the thermal finite-element simulations and confirmed that the multi-foil target system is suitable for ISOL-RIB production.

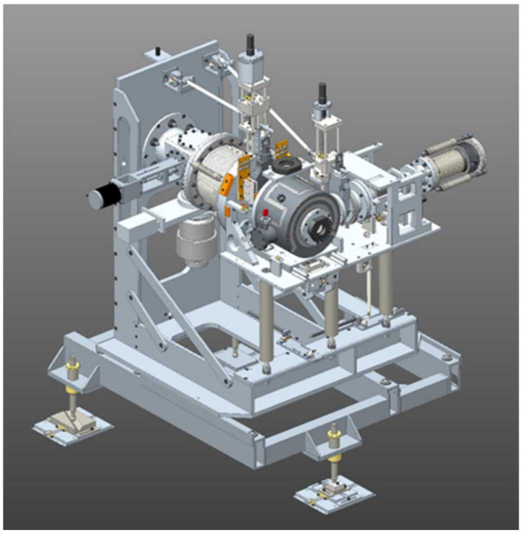

Figure 2: 3D illustration of the complete LNL front-end housing of the Target/Ion Source (TIS).

A new building will be constructed to house the vaults, the LERIB test facility and infrastructure, as illustrated in Fig. 3. The atomic species of interest will be selectively ionized, using either surface or resonant laser ionization, and the isotope will be selected with a high resolution mass separator. Thereafter the ions will be transported to a number of end stations for low-energy (<60 keV) experiments.

RADIOISOTOPE PRODUCTION FACILITY

Previously iThemba LABS reported on a proposal for the acquisition of a 70-MeV H$^-$ cyclotron with two extraction ports for simultaneous production of radio-active ion beams (RIBs) and medical and industrial radioisotopes [3]. The existing cyclotron complex would be available for post acceleration of the radioactive ion beams.

Since then a comprehensive feasibility study to investigate all aspects of the proposal has been completed. Part of the feasibility study included a detailed preliminary design of the new facility, including the buildings and infrastructure. The outcome of the feasibility study revealed a number of reasons to reconsider the viability of the proposal:

a) Due to beam intensity instabilities resulting from dual beam extraction, simultaneous production of RIBs and isotopes will be problematic and is not recommended.
b) The injector cyclotron, which is intended for use as part of the post-acceleration scheme for RIBs uses axial injection and has poor transmission of 5 to

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15% for heavy ions. It is therefore not ideally suited for the intended application.

c) The post-acceleration chain from source to the end-station is very long (>150m). It will be challenging to achieve stable beam transport over long periods.

d) The complete beam acceleration and transport system will need a vacuum system upgrade of at least one order of magnitude to limit beam losses.

e) The new buildings and infrastructure that are required will be expensive.

The outcome of the feasibility study made it clear that simultaneous production of RIBs and radioisotopes will be problematic and very costly. Therefore alternative solutions had to be considered. For these reasons it was decided to separate RIBs and radioisotope production by utilising a commercial 70-MeV H-minus cyclotron as a driver for a dedicated radioisotope production facility. Removing isotope production from the SSC will increase the beam time for nuclear physics research by at least a factor of 2.

This idea prompted the initiation of a Technical Design Study to investigate the feasibility of a dedicated radioisotope facility utilising as much as possible of the existing infrastructure to limit the cost of the project. Existing infrastructure will become available when iThemba LABS stops proton therapy treatment in 2017. A dedicated proton therapy facility for South Africa will be pursued. A number of options for a dedicated radioisotope production facility have been investigated. The most feasible layout is illustrated in Fig. 3. There are two vaults with two bombardment stations in each for the production of radioisotopes. Each bombardment vault [4] will host a high-intensity (350 µA), and a low intensity (100 µA) target station. The target stations will be shielded to reduce activation of the equipment and the vault itself. The 70-MeV H-minus cyclotron will be in a separate vault between the two bombardment vaults. This is an economic configuration since existing vaults will be used.

ION SOURCE DEVELOPMENT

iThemba LABS operates two electron-cyclotron-resonance ion sources. ECRIS4, which was originally built by GANIL for the Hahn Meitner Institute [5, 6], delivers ion beams from gases and fluids. In recent years this source has been equipped with an injection system for the so-called Metal Ions from Volatile Compound (MIVOC) method [7]. The production of nickel and ruthenium beams was studied. A second ECRIS, GTS2, which is based on the design of the Grenoble Test Source [8], is used to supply beams for nuclear physics experiments, which require elements like ^{1,2}H, ^{3,4}He, ^{14}N, ^{16,18}O, ^{20}Ne, ^{36,40}Ar and ^{86}Kr. In addition, under our collaboration with the ion source group at CERN, experiments for the production of intense xenon beams were performed. The source was optimized for different charge states ranging from 18+ to 25+. Beam currents of the order of 50 eµA were obtained with CW operation. For injection into the RF linear accelerator at CERN short pulses are required, which can be produced from the source in the so-called after-glow regime. In this mode, intensities of the order of 100 eµA with oxygen supporting gas were achieved [9].

Since 1994 the atomic beam source has delivered nuclear spin polarized protons for physics experiments. The source consists of a dissociater, a polarizer, and an ionizer. In 2013 the Paul Scherrer Institute donated their ECR ionizer unit, that was used in their polarized ion source, to iThemba LABS. Because the ECR principle is known to be more efficient than an electron bombardment ionizer of the CERN-AMAC design and will deliver a better beam quality with a lower energy spread, the unit was integrated into the source. First beam experiments to determine the polarization degree and beam performance will be carried out in the near future.

During the past few years, a source of concern was the instability of the proton beam extracted from the internal PIG source of solid-pole injector cyclotron SPC1. The influence of the composition and density of the lanthanum hexaboride (LaB_6) pellets, used as cathodes and anti-cathodes, in the source was investigated. This led to a recommendation to decrease the density of the LaB_6 pellets by 5%. This results in quicker degradation of the cathode (lifetime about 1 week) and reduces coating of the cathode surface exposed to the plasma by sputter material from the anode. With the new LaB_6 pellets the source stabilizes much faster and a more stable extracted proton beam is obtained.

IMPLEMENTATION OF AN EPICS CONTROL SYSTEM

In 2008 we made the decision to convert our OS/2-based distributed control system to EPICS. Currently 60% of the control hardware is under EPICS control. In order to aid the migration of the control system to EPICS we adopted EtherCAT as our new industrial communication standard in 2015. We built on the work done by the Diamond Light Source [10] and have successfully integrated stepper motors, dc motors, analog and digital input and output terminals as provided by Beckhoff and Weidmuller. This has given iThemba LABS the advantage that we are now able to easily deploy modern off-the-shelf hardware under EPICS control.

NEW DIGITAL LOW-LEVEL RF CONTROL SYSTEM

A new digital low-level RF (DLLRF) control system to replace the 30-year-old analog RF control systems has successfully been developed. The system [11] is based on field-programmable gate arrays (FPGAs) and is capable of synthesizing RF signals between 5 MHz and 100 MHz in steps of 1 µHz. It can achieve a closed-loop amplitude stability of better than 1/10000 and a closed-loop phase stability of less than 0.01°. A total of 35 new RF controllers have been manufactured, of which 10 systems have been fully assembled and tested. Three of these systems are in operation. The remaining systems will be installed during the coming months.

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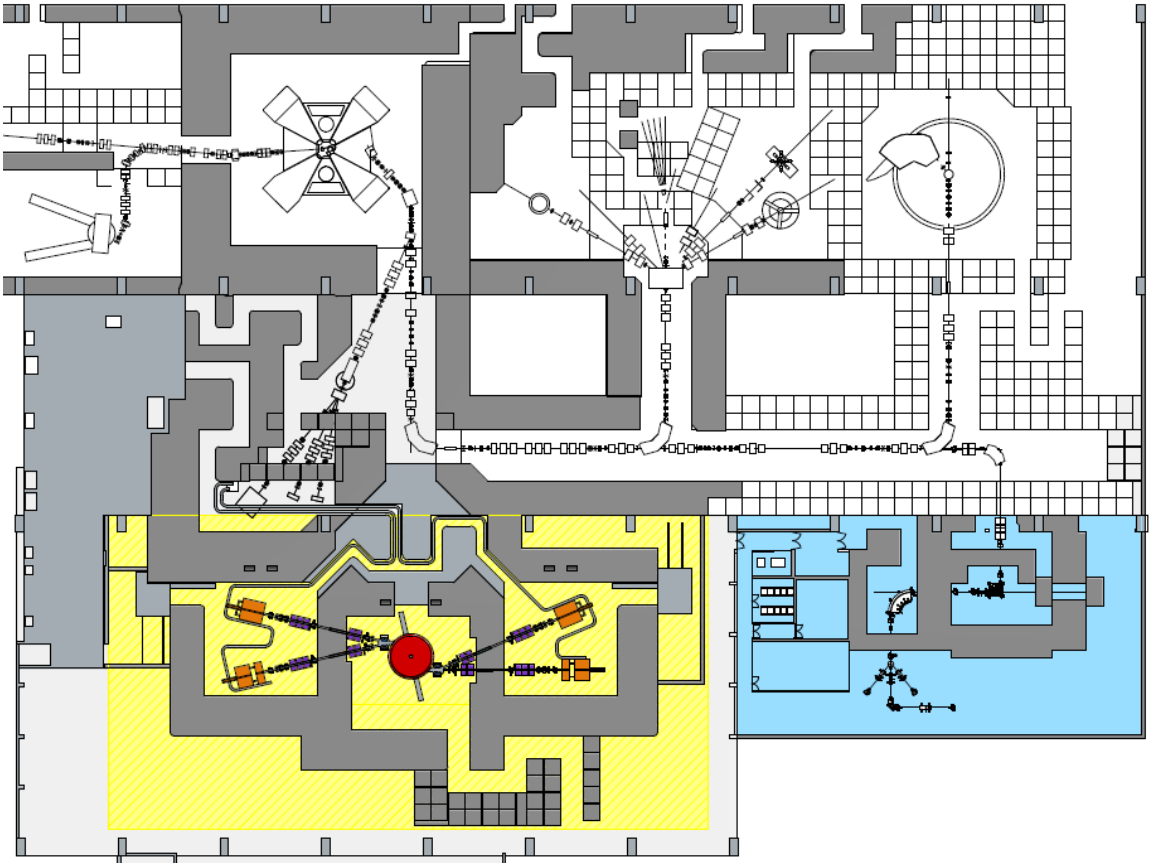

Figure 3: Layout of the proposed 70-MeV H-minus radioisotope production facility (yellow) and the low-energy rare isotope facility (blue).

CONCLUSIONS

A great effort, in manpower and finance, to refurbish and replace old infrastructure components to reduce the unscheduled interruptions back to about 5% of scheduled time has been started.

The LERIB project will be the first isotope separation on line (ISOL) facility at iThemba LABS and will open up a new field of research. The first beam from the LERIB is planned for 2019. The proposed dedicated radioisotope production facility with a commercial 70-MeV cyclotron will also have benefits for nuclear physics research, since it will at least double the beam time available from the existing SSC because radioisotope production with the SSC will be stopped. This proposal is financially attractive because existing buildings and infrastructure will be used.

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