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Subatomic Physics

1. Abstract

The iThemba LABS K=200 separated sector cyclotron (SSC) has been used for nuclear physics research, particle (neutron and proton) therapy, and radioisotope production since its commissioning in 1986. In the past 30 years of the SSC's operation, the beam time has been equally divided between the three programs, which severely limited the competitiveness of the nuclear physics research program. The beam time for nuclear physics research will be increased significantly, and will not only be limited to weekends, when the laboratory acquires the 70 MeV accelerator for radioisotope production.

Subatomic Physics research will continue to serve as the backbone of research at iThemba LABS and the research programs in the next 5 to 10 years will be focused on niche areas where the laboratory's research program will complement the research carried out at cognate laboratories around the world. The research infrastructure will be improved and the human resources will be supplemented to enable the laboratory to deliver on the research and training mandate. The number of researchers in the department is subcritical and together with the number of users should gradually increase to double by 2030.

2. Introduction

The vision of the Department of Subatomic Physics (DSP) is to maintain and expand the role of nuclear related physics research in South Africa by being a centre of expertise and innovation in the field and by improving the public perception of the value of basic and applied research in nuclear physics.

The mission of the department is to perform and facilitate world class nuclear related physics research through in-house and collaborative (national and international) projects and to fully exploit all training opportunities that arise from this research effort.

The broad objectives of the Department are:

1. to promote and produce world-class research in the field of basic nuclear science (nuclear reactions, nuclear astrophysics, nuclear structure) and applied nuclear science, and to disseminate the knowledge generated among the scientific community via peer-reviewed journals, international and national conferences, colloquia and public outreach.
2. to actively contribute to the production of the next generation of nuclear scientists by effectively and safely training, and nurturing, graduates and post-graduates.
3. to provide high quality (internationally benchmarked) metrology service in neutron and radiometric measurements to clients.

These objectives define the activities relevant to the Subatomic Physics Group:

2.1 Internationally competitive research

The DSP research program is mainly driven by the use of stable beams from the separated sector cyclotron (SSC). Figure 1 shows the layout of the iThemba LABS research facilities, showing the SSC with the two injector cyclotrons (SPC1 and SPC2), nuclear physics experimental vaults and the planned SAIF project with the ACE Isotopes and the ACE Beams facilities (see the AED section 4.3). Nuclear structure and reaction studies are performed primarily using the AFRODITE gamma-ray array (figure 2) and the K600 magnetic spectrometer. AFRODITE can be coupled to charged-particle detectors, while the K600 spectrometer can be coupled to gamma detectors to form BaGeL (see figure 3), as well as charged-particle detectors.

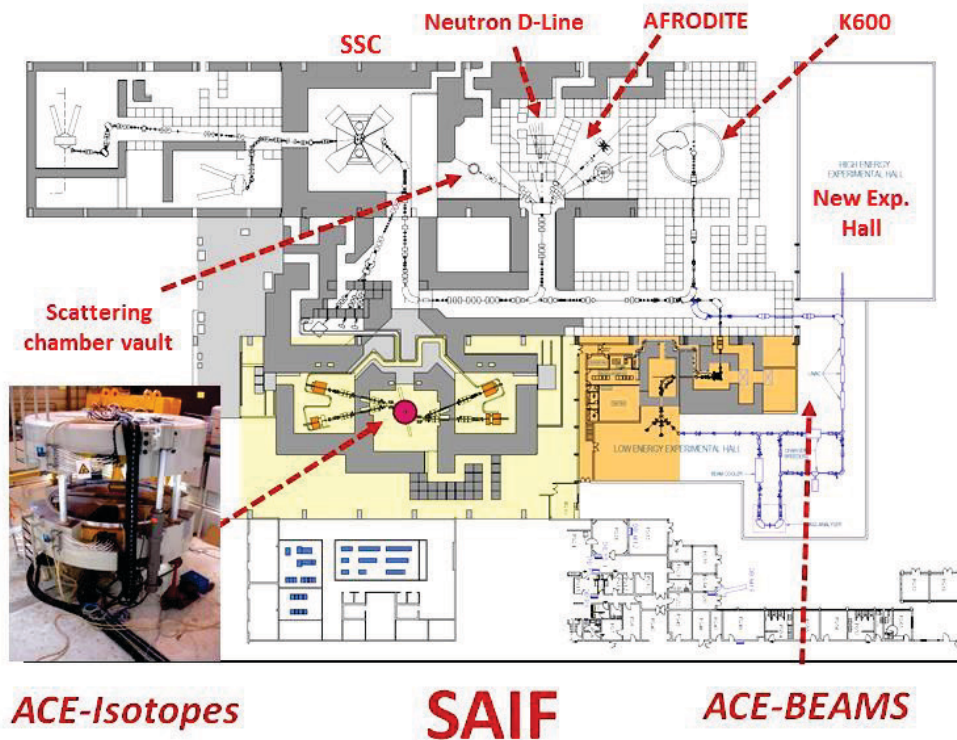


Figure 1: Layout of iThemba LABS research facilities showing the separated sector cyclotron (SSC) and the nuclear physics experimental vaults. The shaded areas show the planned ACE Isotopes and ACE Beams facilities.

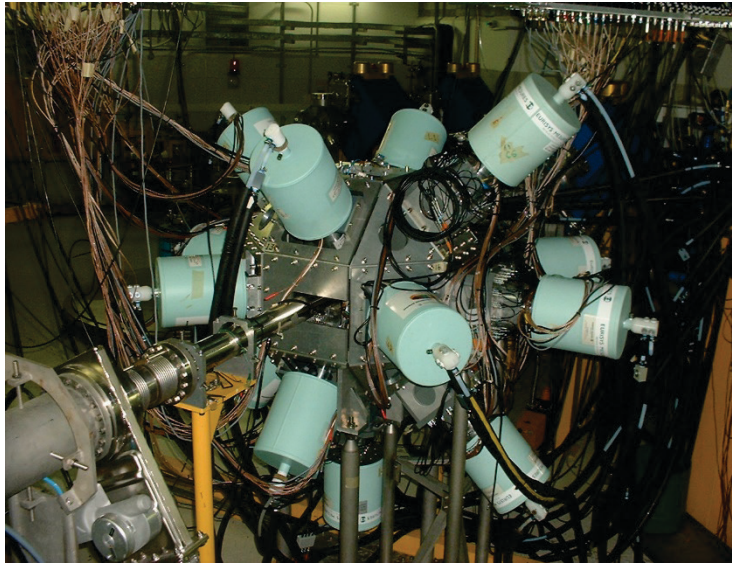


Figure 2: The AFRODITE gamma-ray array



Figure 3: The K600 magnetic spectrometer with the Clover detectors from AFRODITE and large-volume LaBr₃:Ce detectors.

The promotion of internationally competitive scientific research in South Africa is an invaluable part of establishing a knowledge-based economy. Basic research is the cornerstone of economic development and for the establishment of innovation driven industries. The attractiveness of South Africa to foreign investments lies in the availability of a technological knowledgeable workforce of a location and these are increasingly dependent on research which generates innovative thinkers. This is achieved through the driving force of science where human curiosity and competition for knowledge is nurtured. International competitiveness is one of the primary drivers of progress in research. South Africa is a developing country that has recognized that international excellence in research

lays the foundation for technological leadership which is built on cutting-edge knowledge. The departmental objectives can only be achieved through subatomic physics research of international quality, a core competency of iThemba LABS.

The nuclear physics program at iThemba LABS has very good prospects of making an impact internationally due to the unique facilities available and the expertise of the nuclear and accelerator physicists who have developed these facilities over the years and have continued with their upgrading and maintenance. However, the limited amount of beam time for research, and the low number of researchers severely limits the laboratory to reach its potential and being competitive at an international level. The development of the Accelerator Centre for Exotic Isotopes (ACE-Isotopes see AED section 4.3) facility, with a 70 MeV cyclotron dedicated to isotope production will allow the SSC beams to be used only for research. This will increase the amount of beam time available for research by more than a factor of two. Nuclear physics experiments will be done every day of the week as compared to the current situation of beam time only on weekends. This will also be beneficial to the collaborators who have to fly to iThemba LABS as the period of the experiments will be reduced and this will save accommodation and subsistence costs of the collaborators. The South African Isotope Facility (SAIF) with its two components, the Accelerator Centre for Exotic Isotopes (ACE-Isotopes) and the Accelerator Centre for Exotic Beams (ACE-Beams) is essential for the future of nuclear physics in South Africa.

2.2 Education and training

The DSP offers training opportunities to students through lectures for university students such as the MANuS program; supervision of research projects for honours, MSc, and PhD students; internships, in-service training and short term training through workshops, summer/winter schools and vacation programs. DSP staff also mentor local and international postdoctoral fellows and junior researchers.

Many South African historically disadvantaged universities offer science courses but do not have laboratory training equipment for research in nuclear physics and materials science, as the equipment is usually very expensive and not affordable for these universities. This presents a challenge in the training of nuclear physics as the students must first be trained in basic instrumentation before they can fully participate in the research projects offered at iThemba LABS and the international partner institutions. The DSP will address the training needs of students from disadvantaged institutions by means of hosting winter and/or summer schools for the third and fourth year undergraduate university students through the South African Institute of Nuclear Technology and Sciences (SAINTS - see Education and Training section 5). The schools will focus on nuclear physics instrumentation and experimental skills, and data analysis techniques. The school will target undergraduate students from universities that do not have sufficient resources to provide undergraduate nuclear physics lectures and laboratories.

In addition to the summer and winter schools, the department will continue in the organisation of training workshops, such as the Monte Carlo, GEANT4 and other topical workshops. The department will also be more involved in the organization of international schools in collaboration with other institutions, such as the African School of Physics (organised by SA-CERN), and the SA-JINR Student Practice. The DSP will also be involved in the tri-lateral agreement between SA (University and Stellenbosch and iThemba LABS), Norway (University of Oslo) and the USA (University of California in Berkeley) to offer university accredited short courses in nuclear physics and nuclear astrophysics.

The training for MSc and PhD students will be revamped to meet international standards to enable SA students to benefit from iThemba LABS' international collaborations. iThemba LABS will work with the South African Institute of Physics and the South African universities to develop a training program for MSc and PhD students that will prepare the students for research in subatomic physics. The training program will be under the auspices of SAINTS (see Education and Training section 5). The department will continue to work with the community interaction group to engage in outreach activities targeting the general public and high school students. For instance, the DSP hosts the annual ALICE International Masterclass where South African high school students work on data collected at CERN with the ALICE detector and participate in a videoconference with their counterparts from other countries to share and discuss their results.

2.3 International collaborations

International collaborations enable the researchers to work with their counterparts from universities and laboratories from other countries. This enhances the quality of the research program through cross pollination of ideas and keeps South African researchers abreast with the developments in their research areas.

The DSP researchers have several collaborations with their counterparts in the USA, Europe and Asia, and a few collaborations with African (outside SA), and Australian institutes. The department will continue to pursue collaborations with cognate laboratories and research institutions to complement the current research capabilities and expertise in South Africa. There will be a deliberate effort to include student training and human capacity development in the collaborations. The department will pursue collaborations that are of mutual benefit for iThemba LABS and the collaborating partners such as: i) The collaboration with PTB and IRSN to develop the neutron D-Line to meet the international neutron metrology requirement; ii) the SA-JINR collaboration to develop low-pressure gaseous detection system of PPAC type for the K600 spectrometer; iii) the long-term loan of Clover detectors from HH-IFIN in Romania. These are some of the examples of the strategic collaborations of mutual benefit for iThemba LABS and the partner institutions.

The international collaborations such as the SA-CERN and SA-JINR collaborations also enables South African researchers to access facilities that are not available in South Africa,

such as the LHC. South African researchers are playing an important role in these facilities where they not only participate in experiments, but propose and lead their experiments at the HIE-ISOLDE facility at CERN, and also take on leadership roles such as the run coordinator roles in the ALICE detector at CERN.

Collaborations with African countries will primarily hinge on the activities of the environmental radioactivity laboratory (ERL). The monitoring of environmental radioactivity is needed in places where there has been any mining activity. Most African countries are rich in mineral resources and there have been extensive mining activities in these countries. Most of these African countries do not have sufficient expertise to operate and maintain an environmental radioactivity laboratory equipped to measure low-level radiation. iThemba LABS can play a vital role in assisting the African countries in setting up environmental radioactivity laboratories as the equipment is not too expensive and many countries can also access IAEA funding to acquire the equipment. iThemba LABS' ERL staff can increase the collaborations on ERL measurements with the universities on the African continent where the laboratory can provide training in the operation of HPGe and CsI gamma-ray detectors, and advice on data collection methods. Training can also be provided to postgraduate students and researchers on the analysis of the data and ongoing training can be done through research collaborations. The collaboration can lead to a point where the samples will be collected, prepared and measured in the researchers or student's home country. Once the laboratory is established in a country, iThemba LABS researchers will be involved mainly in advising on the collection of samples and the analysis of the data. The African researchers will eventually gain sufficient experience to be able to operate their ERL-type systems with minimum support from iThemba LABS. iThemba LABS will continue to provide support for the maintenance of the equipment and with the annual calibrations and tests of the equipment where required.

2.4 Developing, maintaining and supporting the user base

The department aims to increase the number of researchers from universities in South Africa and from neighbouring countries participating in nuclear physics experiments at iThemba LABS. The international user base will be increased through strategic collaborations with international laboratories and scientific institutions. The department will enter into agreements that will be beneficial to iThemba LABS and South Africa, such as acquisition of equipment that will be utilised at iThemba LABS.

The upgrading of the current research facilities, such as coupling of the K600 to particle and gamma-ray detectors (BaGeL); developing the African LaBr₃ Array (ALBA) to provide high gamma-ray efficiencies, adding more Clover detectors to the AFRODITE gamma-ray array to increase solid angle coverage; and the development of new facilities, such as the setup to measure lifetimes using the Doppler shift method, will attract more users to iThemba LABS as these may be the best facilities in the world to do such experiments.

BaGeL is currently one of two facilities in the world where the magnetic spectrometer is used in conjunction with particle and gamma ray detectors for high-resolution coincidence measurements with the spectrometer at zero degree. The other such facility is in Japan where they use the CAGRA array (Clover Array Gamma-ray spectrometer at RCNP/RIBF for Advanced research) with the Grand Raiden Spectrometer.

The development/upgrading of the neutron D-Line (see the AED section 4.5.1) to meet the metrology requirements will not only increase the research activity in this area but will also bring more users to iThemba LABS who require neutron metrology related services such as the calibration of detectors. After the closure of the neutron laboratory at The Svedberg Laboratory at Uppsala University in Sweden only 3 laboratories remain in the world that can offer quasi mono-energetic neutrons in the 40 – 200 MeV energy range. There is a growing need for the calibration of neutron monitors used in hadron therapy centres and the testing of detectors used at high-energy laboratories for neutron damage.

The build-up of the expertise in environmental radioactivity measurements in African countries will enable these countries to also support their nuclear energy industries. Collaborations with universities on environmental radioactivity measurements will over time be extended to other areas of nuclear physics research, where postgraduate students from African countries can study for MSc and PhD degrees supervised by iThemba LABS staff and participate in experiments at iThemba LABS and any other laboratories that have research collaborations with iThemba LABS. The students will continue with the iThemba LABS collaborations from their home institutions after their PhD studies. This will over time result in a large Subatomic Physics research community on the African continent that will use the research resources at iThemba LABS.

iThemba LABS will be a hub of nuclear physics research on the African continent. The Instrumentation and Information Technology (IIT) department will be involved in the development of portable radiation detectors and monitors for use in the ERL of the African countries. iThemba LABS will play a leading role in the acquisition, development and manufacturing or assembly of the portable environmental radiation monitors.

2.5 Nuclear Physics and Human Resources Development in South Africa

The DSP has users and students from 9 of the 22 South African Institutes of higher learning that participates in the research programmes utilizing iThemba LABS nuclear physics facilities. Many of the students that were trained or did their projects using iThemba LABS nuclear physics facilities are now pursuing careers in the nuclear industry, universities and research facilities. iThemba LABS will continue to play a supporting role in developing capacity for research at the historically disadvantaged institutions. The department intends to increase the number of researchers participating in DSP led research programmes through joint appointments of lecturers, postdoctoral fellows and research chairs with SA universities. The increase in the collaboration with universities will also be extended through the activities

of the IIT department. These collaborations will be mainly on the development of electronics for physics data acquisition and data analysis.

There will also be a concerted effort to encourage female undergraduate students to participate in activities that are aimed at encouraging female students to pursue careers in the nuclear industry.

The department is aiming to appoint a research chair and a research scientist to start a research program in rare ion beams physics to ensure that we make use of beams from the Low Energy Radioactive Ion Beam facility (LERIB) as soon as the beams are available. The group will get involved in experiments at HIE-ISOLDE during the development of LERIB. Research scientists will be required to work on the K600 magnetic spectrometer and on the AFRODITE array. Postdoctoral fellows will also be required to increase the capability of currently understaffed research programs which were highlighted to be strategically important for the DSP. Table 1 shows the human resources requirements for the DSP.

Table 1: Human resources requirements for the DSP.

Position	Experimental Facility/Program	When
Research Scientist	K600	2018
Research Scientist	LERIB	2018
Research Scientist	AFRODITE	2018
Research Chair	LERIB	2018
Postdoctoral Fellow	Electron spectrometer	2018
Postdoctoral Fellow	AFRODITE	2018

3. The next five years

Over the last few years the “traditionally” divisive separation of research groups has begun to disappear as researchers realize the benefits and possibilities of combining research equipment to perform cutting-edge research. The merging of the K600 spectrometer with the AFRODITE Clover detectors is a prime example of a powerful setup that provides iThemba LABS with a significant competitive advantage over other facilities. New silicon particle arrays have also been developed over the last few years and can be coupled to AFRODITE and the K600 spectrometer to perform new science at iThemba LABS. Several major experimental capabilities are in the process of being implemented and are expected to be completed by the end of 2018. These include the electron spectrometer, fast timing and large volume $\text{LaBr}_3\text{:Ce}$ detectors, a tape station and a Doppler Shift Attenuation Method setup. These latest developments, together with the existing infrastructure will lay the foundation for research efforts during the next 5 years and will lead to exciting nuclear physics measurements that are unique and outstanding.

The direction of nuclear physics research at iThemba LABS for the next five years is broadly classified into four topics: Nuclear Reaction, Nuclear Structure, Nuclear Astrophysics and Applications of Nuclear Physics. All research in need of beam time will continue to be reviewed by the Program Advisory Committee which makes recommendation to the director on beam time allocation. However, the department will focus on specific projects and measurements that are unique to our facility capabilities and provide iThemba LABS with high-impact niche results. To this effect, a panel of international experts reviewed proposed projects which were presented by scientists from iThemba LABS and SA universities in 2016. The panel identified those projects which will provide iThemba LABS with internationally competitive and acclaimed research opportunities and have the potential to establish iThemba LABS as a world-class leader to shape the future directions of research fields. The panel’s recommendations will provide guidance to on where to focus departmental resources. Some of the highlights over the next five years are:

1) The coupling of the K600 spectrometer with ancillary equipment will undoubtedly attract international collaborations to participate in research at iThemba LABS and enrich the local programs with expertise and ideas. In particular, the measurements of the E0 response in nuclei with an electron-positron spectrometer are unique and very promising. The measurements in coincidence with gamma-ray and particle decay offer very exciting opportunities to study the nuclear structure in detail.

2) The nuclear astrophysics research program strongly benefits from the coupling of the K600 spectrometer, silicon charged particle and gamma-ray detectors to perform spectroscopic studies of relevant nuclei. The main focus will be on nuclei that are waiting points in the rp-process, and nuclei that are relevant for the CNO cycle. Moreover, the Doppler Shift Attenuation Method provides a unique setup which will be utilized to determine half-lives of excited states of astrophysical important nuclei.

3) iThemba LABS will play a prominent role in the international nuclear physics community by developing a new radioactive ion beam facility. The proposal for an Accelerator Centre for Exotic Beams (ACE see AED section 4.1) at iThemba LABS is based on an ISOL facility using a 66 MeV proton beams on a Uranium-Carbide target, and will initially be restricted to the development of the low-energy beam lines and end stations.

4) iThemba LABS is one of few facilities in the world that can provide quasi mono-energetic neutron beams in the energy range 40 MeV to 200 MeV. iThemba LABS was nominated by the National Metrology Institute of South Africa and Bureau International des Poids et Mesures to be a “designated metrology institute for medium and high-energy neutron measurements” in South Africa. The major activity will be the upgrade (see AED section 4.5.1) and development of the neutron beam line to meet the requirements for a high-energy neutron metrology facility. In the following years it will be used for metrology activities such as inter-comparison studies and calibrations. The facility will continue to be used for measurements of neutron cross sections needed to test nuclear models use in radiation transport codes.

5) The nuclear structure programme has effectively exploited the AFRODITE detector array and is now developing innovative techniques for characterising the quasi-continuum through the measurement of the photon strength function. This provides new opportunities for nuclear structure and astrophysics, in particular with the expansion of the experimental infrastructure by increasing the number of Clover detectors, while also adding fast-timing capabilities with LaBr₃:Ce detectors, high-efficiency large volume LaBr₃:Ce detectors (ALBA), the segmented TIGRESS-type detector, neutron wall, and the electron spectrometer.

6) There is a variety of interesting open questions in nuclear structure on exotic shapes and decay modes. These will be investigated and studied using stable and actinide targets at the experimental facilities of iThemba LABS, as well as theoretically through collaborations with theorists.

7) The scope of activities of the iThemba LABS Environmental Radioactivity Laboratory (ERL) includes measurements of activity levels in samples deemed to have low levels of radioactivity, measurements of radon levels in water and soil samples.

8) iThemba LABS participation in the ALICE Upgrade will be in the Muon Spectrometer: including the Muon Forward Tracker (MFT) Muon Tracking Chambers (MCH) and the Muon Trigger Chambers (MTRG), of which the MCH and MTRG will receive new front-end and readout electronics to allow the detector to be readout at or near the expected interaction rate of 50000 Pb-Pb collisions per second in the RUN 3 phase of the Large Hadron Collider, foreseen in 2020 onwards. At the centre of the MCH upgrade is the SAMPA readout chip, which will require adjustments to the services, particularly the low-voltage power supplies (LVPS), and the readout electronics. iThemba LABS task will be in the MCH LVPS system, which will differ significantly from the current design. iThemba LABS will also contribute to the Muon Identifier (MID) Common Readout Unit (CRU). The MID is a proposed designated

MTRG in RUN 3 and the CRU is a new high-speed readout approach being developed for detector data readout, concentration and multiplexing onto the Online/Offline Computing farm (O2) for event reconstruction and storage, as well as distributing trigger and timing information to the on-detector electronics. The task entails testing and developing a code for the MID CRU firmware and to decode events in the ALICE online/offline computing farm.

4. Experimental facilities

The major equipment needs with a development time of 2018 and beyond are:

The Accelerator Centre for Exotic Beams (ACE Beams see AED section 4.3.1) at iThemba LABS is planned in a phased manner, the immediate goal (within 4 years) being to use the research and development made on the SPES target to produce and extract short-lived fission-fragment beams initially using a less selective surface ion source and using the on-going development for a low-energy beam line. The un-accelerated beams (LERIB) will be used for decay studies and/or trap-assisted studies of fundamental symmetries. The group is already part of a working group with Legnaro National Labs (Italy) for building the Target-Ion Source. The implementation of the separation techniques for the ion beams also requires setting up further international collaborations. This would further increase the visibility of the lab and, as a result, the size of the user community for iThemba LABS. The ACE project, even planned in a staged manner, requires a significant increase in both the research and technical staff, as discussed in the AED section.

The long-term plan for the Accelerator Centre for Exotic Beams (ACE Beams) (~10 years) will include post acceleration by a LINAC taking the energy of the fragments to an energy of around ~ 6 MeV/u.

At the K600 spectrometer, accurate scattering angle information is essential to allow for necessary corrections of the first and second order dependence of the focal plane position on the horizontal scattering angle. This capability is critical and essential if one is to exploit the high-resolution capabilities of the K600 magnetic spectrometer. The K600 experimental program is increasingly dependent on the horizontal and vertical drift chambers and it is important to manufacture one additional such drift chamber which will provide the much needed redundancy for the focal plane detector setup.

ALBA (African LaBr₃ Array) with high efficiency LaBr₃:Ce detectors will cover approximately ½ of a sphere and consist of 23 large volume (89x203mm) LaBr₃:Ce detectors arranged around the target (see figure 4). Coupling particle detection devices to AFRODITE and ALBA will provide a unique combination with each detector type capable of probing a different aspect of the nuclear response. ALBA's efficiencies of 8.7%, 3.7% and 2.3% at 1.3, 6 and 10 MeV, respectively, will provide a huge increase in efficiencies with which cutting edge research, which is not feasible with Clover detectors alone, can be performed.

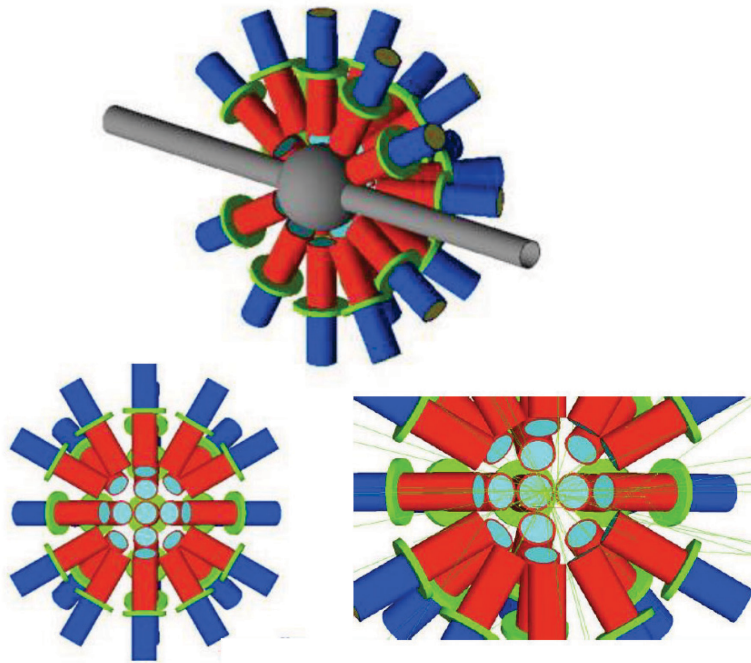


Figure 4: A schematic diagram of the African LaBr₃ Array (ALBA)

The upgrade of AFRODITE, by doubling the number of detectors, will provide the capability to improve on high-resolution measurements with double the efficiency, and factor of 4 increase in the doubles coincidence rate and a factor of 10 for triples coincidences. New gamma-ray detector frames will be designed and manufactured and will provide the best possible utilization and flexibility for the different experimental configuration needs for the ALBA and AFRODITE detectors. The new frames will provide maximum efficiencies as well as additional angles to improve angular distribution measurements.

The iThemba LABS neutron facility can provide quasi-monoenergetic neutron beams of energies 25 – 200 MeV, using the (p,n) reaction on thin Li and Be targets. The neutron D-Line is currently one of the few facilities in the world that can provide quasi mono-energetic neutron beams in the energy range 40 MeV to 200 MeV. The other facilities are in Japan: RCNP (40 MeV – 390 MeV), CYRIC (20 MeV – 90 MeV), and TIARA (40 MeV – 90 MeV). The laboratory signed a Memorandum of Agreement with the Physikalisch-Technische Bundesanstalt Braunschweig (PTB) and The Institut de Radioprotection et de

Sûreté Nucléaire (IRSN) to upgrade the neutron D-Line to meet the requirements for a neutron metrology facility (see AED section 4.5.1). The PTB and the IRSN have expertise in neutron metrology and the collaboration will be for the development and joint usage of a high-energy neutron metrology beam line at iThemba LABS. The development is expected to be completed in a period of three years and thereafter the facility will be used for metrology activities such as inter-comparison studies and calibration activities.

ALICE (A Large Ion Collider Experiment) is a heavy-ion detector at the CERN Large Hadron Collider (LHC) dedicated to study ultra-relativistic heavy-ion collisions in which a hot and dense strongly-interacting medium is formed. ALICE is also studying proton-proton (pp) physics to test perturbative Quantum Chromodynamics (pQCD) theories and to use it as a reference for heavy ion collisions, e.g. lead-lead (Pb-Pb) and proton-lead (p-Pb). At forward rapidity ALICE is equipped with a Muon Spectrometer that allows measurements of dimuon decays of quarkonia, low mass vector mesons and Z boson as well as single muons from the decays of heavy flavours (charm and beauty hadrons) and W^\pm bosons in pp, pPb and Pb-Pb collisions at LHC energies. At ALICE, iThemba LABS is contributing to the operations and maintenance of the Muon Spectrometer and is involved in physics analyses pertaining to the measurement of the production of single muons from the decays of open heavy flavour and W^\pm bosons. In addition, iThemba LABS is contributing to the ALICE Upgrade, in particular the upgrade of the Muon Spectrometer: including the Muon Forward Tracker (MFT), Muon Tracking Chambers (MCH) and the Muon Trigger Chambers (MTRG), for which the MCH and MTRG will receive new front-end and readout electronics to allow the detector to be read out.



Materials and Multidisciplinary Research

This section is dedicated to the Long Range plan of Materials and Multidisciplinary research activities at the newly installed Tandetron facility (Material Research Department - MRD) and the newly refurbished and installed Tandem accelerator with its new Accelerator Mass Spectrometer (Tandem and Accelerator Mass spectrometry Department – TAMS Department).

Tandetron Facility

1. Abstract

The Materials Research Department (MRD), headquarters of the AFRICA-NANOAFNET Network, the AFRICA-International Desk for MATERIALS Research and the Accelerator for Sustainable Development in Africa (ASDA) Network, was constructed in the sixties to house the first 6.0 MV Van de Graff (VDG) accelerator in South Africa. That VDG was the beginning of the first Nuclear Facility in the Cape Town Area to be used for Low Energy Nuclear Physics Research and applications. The VDG successfully operated until the 24 December 2015, for more than 50 years. This accelerator delivered excellence in accelerator-based science through leading-edge low energy nuclear physics research, Ion-Solid Interaction research and provision of high sensitivity analytical technologies for the benefit of internal, South African, African and International users. The main areas of research currently engaged at the MRD are: nano-sciences & nanotechnology and thin film physics using materials characterization and modification with radiation and scanning probe microscopy; biotechnology – trace element distribution and mobilization in biological systems; environmental and geological studies using ion beams; ferrous, non-ferrous alloys, noble metals and materials composites for high technology applications; cultural history materials characterization. These research activities have impacted in the socio-economic development in Southern Africa through innovation in analytical techniques, methods of research, instrumentation and electronics. The MRD has been through all these decades at the forefront of Ion Beam Analysis (IBA) research and applications including the development of state-of-the-art techniques such as *in situ* Real-Time RBS, Cryo Nuclear Microprobe (Cryo-NMP) and Heavy Ion (ToF) ERDA, to mention a few. The MRD would like to continue to produce and keep the standard of competitive research with National and International Collaborations that had created the laboratory that the MRD is today. The awarding of funding by the South African Government to commission a new state-of-the-art, highly stable, 3.0 MV Tandetron Accelerator, that was commissioned in April 2017, will create the necessary conditions to succeed in the realization of a Long-Range-Plan (LRP) that will enrich the Ion-Beam Interaction, Physics and Materials Sciences research in a complementary way for materials surface characterization with light and heavy ions. We are confident that this new accelerator

will continue to support and increase in a substantial way the development of human capacity with particular attention to the service of the previously disadvantaged communities in South Africa. In this regard our first priority will be to fulfill the strategic aim of producing internationally capable PhD graduates that will contribute to the mandate of the South African Government. The MRD - LRP stipulated in this document as a strategic plan based on objectives and actions to succeed is presented here.

2. Introduction

The MRD as part of iThemba LABS is responsible for delivering specialized ion beam analytical expertise, materials characterization services and products to government, industry, academia and other research organizations.

Existing facilities are used annually by over 100 external researchers and users including in-house post-graduates. These users include researchers from a variety of scientific disciplines at South African universities and other research organizations, and a number of international scientific collaborators.

These facilities support work in key areas of nano-sciences, biology and medicine, environmental science, and air pollution. Other important areas of application include surface analysis of thin film systems for solid state physics and materials engineering.

The existing ion beam analytical facilities, including its core instrument the accelerator, was renewed with the commissioning of a state-of-the-art 3.0 MV Tandatron Accelerator. This will ensure that the MRD can continue to be at the forefront of accelerator science applied to materials research. The new Tandem accelerator is highly stable and is thus suitable to handle ultra-sensitive analytical methods, and will complement other research facilities at iThemba LABS. The new accelerator will add additional capability to MRD's existing complementary research capabilities and will ensure that they are truly world-leading facilities.

The need to replace the old accelerator was highlighted in previous MRD Users meetings (2008, 2010, 2013). At a Meeting in October 2016 MRD Users identified the fundamental priorities for the utilization of this new infrastructure for the next 5 years term 2017-2021 (see Table 1).

The MRD works closely with other local and international organizations particularly with many centers, universities and colleges in African countries associated to the NANOAFNET and the ASDA Networks which have encouraged bilateral cooperation and technology transfer from South Africa to other African countries such as Algeria, Ghana, Nigeria, Mozambique, Senegal, Zambia and many others.

The Materials Research Department's core functional objectives are to synthesize materials and probe their surfaces by appropriate radiation probes in a wide variety of fields.

The broad strategic aims of the department are:

1. Maintain and develop a national center of excellence in materials sciences and research, using accelerator based facilities, radiation and associated techniques, for the service of academic users and industry.
2. Human resource capacity development of scientists and technologists in materials sciences through synthesis and characterization of materials using ion beams and complementary techniques. (Producing quality PhD's.)
3. Conduct internationally competitive research in the selected areas of expertise. (Research Themes)
4. Development of scientific and technical literacy of the broader community. (Outreach)

The strategic aims are achieved by doing internationally competitive research in the following thematic areas: Theme 1: Ion-Solid Interaction; Theme 2: Nano-Lithography; Theme 3: Nano Sciences and Nano-technology; Theme 4: Biology and cryo-fixation; Theme 5: Materials Engineering; Theme 6: X-ray spectrometry; Theme 7: Environmental and Cultural Heritage. These main themes and other related sub-themes are supported by all the laboratories for materials synthesis and characterization available at the MRD.

2.1 Capacity development and training

The MRD offers high quality training to South African and African post-graduates thus ensuring that skilled capacity is created to fill the job market in Materials Sciences in South Africa and abroad. This will be achieved in two ways; by lectures at local and international Educational Institutions, and by giving the most efficient supervision in materials research to MSc and PhD students registered at local and international Universities. The training of graduate and post-graduate students at the MANUS / MATSCi program and other departments at other Universities will continue. This will include training on the use of experimental techniques and data processing for materials sciences, in particular those related to surface characterization at the depth of up to 50 μm . Another aspect will be the training of interns and undergraduate students that have to complete a short experimental project as part of their degree. Post-graduates will attend national and international meetings related to their own discipline as stipulated in the themes selection for materials science research. Funding for this mobility will mostly be sourced externally, as has been done in the past. In many instances governments and institutions sponsor post-graduates to achieve this goal. We will encourage the students doing research for their degrees at the MRD to attend meetings such as the School of Physics organized by the SA-JINR bi-lateral; Conferences in Nano-structured Materials, Biology (Bio-PIXE), Materials Engineering research; and international meetings related to Ion-Solid Interaction such as the Ion Beam Analysis Conference, the Nuclear Microprobe Conference (MRD organized and chaired the 1998 edition at Spier State) and the PIXE Conference (the MRD organized and chaired the 2015 edition at the Lord Charles

Hotel). Depending on the potential recruiting of a SARChI Chair for IBA & Materials Sciences the MRD may host the 1st African-International Workshop on Ion Beam Analysis in Cape Town in 2018 or 2019. If possible the MRD will submit a proposal to host the next Nuclear Microprobe Conference.

3. Internationally Competitive research

The MRD will concentrate its effort in the proposed Long Range Plan to perform highly competitive research in all aspects of materials sciences that will be achievable by the infrastructure available. This vision can be translated into new knowledge by encouraging post-graduate students to submit manuscripts for publications at international reputable journals beginning from MSc with at least two manuscripts.

With high stability and high ion sources brightness the Tandetron will play a major role in the characterization of synthesized nano-structures, such as nanowires, nano-alloys, nano-composites, ceramics or composite materials where the internal nanostructured dimension such as layer thickness, grain size or particle size may be well determined down to the nanometer level. We will strive to understand, for example, the effects of particle size, particle shape, and particle surface structure and functionalization on nanocrystal properties, and subsequently to optimize their physical properties.

Semiconductor-metal oxide systems and alloys produced through molecular beam epitaxy or dual e-beam evaporation require the precise determination of thin film thickness and depth profiles at nanometer level. State-of-the-art techniques such as High Resolution RBS and Time-of-flight ERDA will be the techniques of choice including *in-situ* Real-Time RBS for which the MRD is a world leader. The addition of proton beam writing at the nuclear microprobe will contribute to the development of important areas such as low dimension semiconductor systems, quantum transport and dots and electronic devices based on intra sub-band transitions and waveguides.

At the same time these nanometer fabrication capabilities by proton beam writing in combination with AFM will provide researchers with a distinctive platform for the fabrication of MEMS and NEMS surface micromachining, including proton-beam lithographic patterning and investigation of standard or hybrid materials. The projected dual e-beam deposition and sputtering systems envisaged for the near future can accommodate a wide range of substrates, films, and chemicals.

Applications related to bio-chemistry include: membranes and self-assembled films; mesoporous materials; bio-compatible materials; bio molecular mapping recognition and proteomics of biological tissues. The micro-SIMS (Secondary Ion Mass Spectrometry) technique in combination with the NMP will be powerful for three-dimensional mapping of elemental and metabolite components in grains such as sorghum, a potential nutritional crop for human consumption.

Minerals beneficiation through the investigation of noble metals including platinum is of high priority in the South African industry. MBE or co-deposition of metal alloys on metal to develop hard alloys and surfaces and/or special material combination with the possibility of end-product manufacturing in South Africa is a possible goal.

A recent collaboration with the South African National Space Agency (SANSA) and other organizations in South Africa working on materials research for space application and satellite construction has motivated the development of a dedicated beam line and end-station for testing of radiation hardness of CMOS memory chips and CPUs to be used for satellites.

The main highlights in the long range plan for the MRD are as follows:

1. Development of beamlines

- Re-building of beam lines: Micro-probe and RBS/ERDA/Channeling at room temperature,
- Development of a facility dedicated to *in situ* RBS/ERDA/channeling at high temperature (1200⁰),
- Development of real time thin film deposition thermodynamic reaction studies by IBA
- Development of Heavy Ion Time-of-Flight ERDA Spectrometry technique,
- Development of the Heavy Ion PIXE and High Energy PIXE techniques,
- Development of a beam-line for nucleo-synthesis with low energy nuclear reactions in astrophysics,
- Development of an atmospheric (in-air) beam line for cultural heritage and metallurgy studies,
- Development of Secondary Ion Mass Spectrometry (SIMS) technique in tandem with nuclear micro-PIXE,
- Innovation in methods, instrumentation and electronics. Development of DAQ for IBA techniques based on MIDAS-Linux platform.
- Development of a Nano-Micro Prototyping facility at the MRD. In tandem with nano-lithography and MEMS.

2. Research

- International competitive research on Ion-solid interaction: Measurement of stopping force in strategic ion-target couples, Ion Beam Analysis, Ion implantation, Ion beam materials modification, Proton beam writing, Manufacturing of nano-structured materials and devices with nanometer proton beam lateral resolution,

- Research and development of ion implantation and Emission Channeling with Exotic Ions at the low energy RIB facility at iThemba LABS (~60 keV),
- Nanotechnology and thin film physics using material characterization and modification with radiation and scanning probe microscopy. Photonics; smart windows, catalytic membranes,
- Biotechnology –trace elemental distribution and mobilization in biological systems: 1) Bio-medical sciences: psycho-biology, cancer therapy, HIV, Artisanal mining; 2) Microbiology and plant sciences: Micro-PIXE analysis of single cell layer biological tissues in frozen-hydrated state, Quantitative mapping of trace and transition metal elemental distribution in roots of metallophytes;
- Materials engineering studies using ion beams and complementary techniques for full characterization, including synchrotron radiation: Nuclear microscopy of carbides; memory alloys; Si wires for electronic devices,
- Environmental and geological studies: mineral inclusion for mining prospecting, nuclear microprobe of geological ores, meteorites, air pollution studies and accelerator-based studies for cultural heritage in Southern Africa.
- Application for the declaration of the IBA Laboratory at the MRD as a NRF-CoE.

3.1 Materials Research and Human Resource Development in South Africa

By generating new opportunities for multidisciplinary technological development

The implementation of a new Tandem accelerator is a relatively large project for the MRD with numerous technological challenges. This will be a great opportunity to build up capacity by training students in the design and construction of additional beam lines that in the future may be required for ion implantation, strategic nano-materials, bio-technology and materials engineering research. It is envisaged that students and trainees from South African Universities at various levels and across a number of disciplines will be involved in the use of the new facility and will contribute to the development of techniques that are not currently implemented on site.

3.1.1 By effecting transformation

Because iThemba LABS functions as multi-disciplinary, user-driven facility, the potential for outreach and increase in the involvement of Historically Disadvantaged Universities, which may not have formerly been involved in the materials sciences, is far greater and is not merely restricted to the field of materials research.

iThemba LABS has been vigorous in its attempts to address the skills shortage with training programmes that include its jointly run graduate schools, MARST (Masters in Applied Radiation Science and Technology) at the North West University, MANuS (Masters in

Accelerator and Nuclear Science) and MATSCI (Masters in Materials Science), a joint graduate school run together with the University of the Western Cape and the University of Zululand.

iThemba LABS considers it a priority to promote the participation of Historically Disadvantaged Universities in all stages of the research projects. Post-graduate student support in the form of bursaries, appointments, travel funds and local infrastructure will need to be an integral part of the project.

3.1.2 By substantially increasing the available beam time.

It is obvious that the availability of a modern stable Tandem accelerator will contribute to stepping up research intensity due to the substantial increase of available beam time. An important point is that a commensurate increase in the number of MSc and PhD degrees awarded should be expected.

By opening up new research fields accessible only with modern state-of-the-art accelerators.

Post-graduate students need to be exposed and trained in research fields that are at the forefront of science. A great number of graduates from different fields (biology, archaeology, geology, medicine, thin films, semi-conductors, etc.) could make use of the facility to explore other methodologies of ion beam analysis research by the availability of a new accelerator.

3.1.3 By stimulating interest in science.

Projects that are at the forefront of international science and technological development play a significant role in stimulating interest in science and technology. They are important to attract top students into careers in these fields.

4. The next 5 – 10 years

4.1 Accelerator-based sciences

With the availability of a new 3.0 MV Tandatron accelerator (Figures 1 & 2) the MRD will be in an advantageous position to successfully continue the research projects that are currently running in all the different research themes, but most importantly to develop new beam lines and end-stations to support the potential new research projects that users have requested. Following our previous research output and history we will continue to fulfill the strategic aims highlighted earlier on materials synthesis and characterization by radiation sources and ion beams.

After commissioning of the Tandetron and re-commissioning of the two previously available beam lines for nuclear microscopy and thin films characterization we expect that the lateral resolution on the ion probe at the nuclear microprobe (NMP) will be improved to a theoretical estimated of ~300-400 nanometers. This is one order of magnitude better than with the past VDG. Of most significance will be the ability to scan smaller areas with better current intensities. The stability of the new tandetron combined with the improved resolution will allow the IBA Scientists to adjust the quadrupole lenses for optimal 2-dimensional elemental mapping and characterization research by all Users. All themes will benefit from this improvement in experimental conditions.

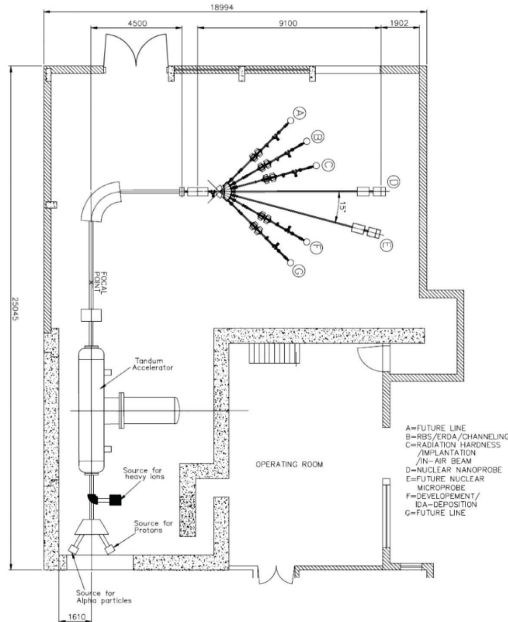


Figure 1: Schematic drawing of new Tandetron accelerator's beam lines.



Figure 2: The 3.0 MV Tandetron Accelerator at MRD.

Going to the nanometer size is a fundamental priority for the development of niche areas of research particularly in nano-structured materials and its applications. Secondly, a stable accelerator will ensure that *in-situ* RBS / ERDA experimental data is collected with a precise and constant ion beam current. This also applies to the NMP since the event-by-event files containing the mapping information will be executed at constant current. In general, all experiments for ion-beam interaction including nuclear physics will benefit.

The Tandetron was purchased with two multicusp sources for H^- and He^- negative ions with current thresholds of $\sim 1\text{mA}$ before the low energy magnet, and $\sim 200\ \mu\text{A}$ post-acceleration. In practice maximum currents on target will be of $\sim 100\ \mu\text{A}$, particularly if the projected beam line for studies of low energy nuclear reactions in nucleosynthesis processes (In collaboration with the Physics Department at UWC and other international partnerships) is commissioned in the near future. At the same time the availability of high current H^- for the NMP will contribute to the further reduction in lateral resolution for the benefit of all users in all themes. Here it is important to emphasize that for the first time the new Data Acquisition Systems (based on the MIDAS platform) build during the last two years for micro-PIXE/BS,

RBS/ERDA (at RT and *in-situ*) and Channeling will be integrated with the tandetron ion sources and re-commissioned. With low frequency ripple, high intensity and stable beam current and a fast DAQ we expect to gather information more conveniently and faster. There will be the re-establishment of the quantitative Real-Time Elemental Mapping algorithm (tested at the NMP with the VDG on the last year of operation), that reconstruct elemental maps for display while experiment is running (in Real-Time).

A Heavy Ion (HI) Sputtering Source was also included in the accelerator infrastructure. The availability of a HI - Sputter Source will create many possibilities for research on Ion-Solid Interactions. In the basic ion-solid interaction research domain, measurements of fundamental parameters (Stopping force S(E), straggling, effective ranges for analysis) which are involved in the physics of slowing down processes of HI in heavy metals will be carried out. On the other hand for analytical applications, by giving the appropriate infrastructure to users, to perform surface characterization elemental depth profiling with highly charged heavy ions particularly in the fields of nano-sciences, materials engineering, condensed matter and characterization of samples used and/or manufactured for nuclear physics experiment at the SSC.

The creation of new information in the domain of ion-solid interaction particularly those which have been mentioned above will guarantee the future development and enthusiasm for the implementation of what we call the “NMP – Secondary Ion Mass Spectrometry (SIMS)” in tandem nuclear microscopy.

Other potential research infrastructure that would be implemented in one of the beam lines, is a facility specialized in low energy nuclear research for the understanding of the processes of how light nuclei nucleosynthesis occurs in the universe (astrophysics). If possible stardust micro particles will also be analyzed with the nuclear microprobe to quantify elemental content and distribution.

A new beam line would be implemented to carry out IBA measurement in-air for cultural heritage studies in relevant Southern African archaeological materials to decipher the non-written history of indigenous communities that were living in the area more than 500 years ago. The same in-air facility could be used for the *in-situ* study of high temperature metal/alloy phases with applications in materials engineering and nano-technology.

4.1.1 Synthesis of nano-structured materials

In Nano-lithography and nanoscience synthesis of nano-structured materials can be achieved using the current laboratories at the MRD (Nano-Sciences Lab, Thin Films Deposition Lab, Nano Spinning Lab) and external laboratories in the Cape Town area and abroad (eg. Laser Ablation). Two new instruments will be available in the Thin Films Deposition Lab: 1) a Dual Electron Beam Evaporator for the simultaneous dual deposition of phases with a high stoichiometric accuracy (achieved by PLC control). The new instrument will allow the study of the thermodynamics of specific stoichiometric alloys deposited over silicon or metals for application in nano-technology, micro-electronics, materials engineering and nano-structured

materials. 2) a new RF sputtering system with three targets. Sequential sputtering of metals on selected substrate will be available to the MRD users. Both systems are PLC controlled, user friendly, improve the turnover of thin film deposition by a big margin resulting in an increase in the number of depositions per day.

The partnership between iThemba LABS and UNISA, via the UNESCO-AFRICA Chair in Nano-Sciences & Nano-Technology is a main contributor to materials science through the development of new avenues for nano-sciences and nano-technology research. The direction of research in nano-sciences will be focused on: Functional nano-Materials for photonics applications; Advanced nano-Materials for solar energy; Mineral Beneficiation & nano-Materials by green chemistry; Bio-inspired nano-Materials & “Biomimicry”;

4.1.2 Nano-Lithography and Proton beam writing

For micro-devices to be used in micro-electronics, nano-technology and bio-medicine it will be necessary to develop a proton beam probe capable of manufacturing specific nano-devices. Technology such as bio-sensors attached to the skin and/or bellow skin surface will require the development and construction of nano-devices to facilitate implant and efficiency. Proton beam writing methodology can be used to manufacture nano-electronics that will be compatible in size with such devices. These fields of application highlight the need for a facility adapted to this kind of work such a nanoprobe based at the Tandetron accelerator.

Proton beam writing will be used to produce three-dimensional (3-D) micro-structures in materials used for electronics and/or nano-technology with appropriate energies of the proton micro-beam. After chemical etching, the quality of the manufactured devices will be analyzed using Scanning Transmission Ion Microscopy (STIM), Scanning Probe Microscope (SPM) and the Ion Beam Analysis (IBA) techniques. The Proton beam writing facility with low-current using protons, alpha particles and heavy ions (few pA or single ions) could be used for single ion machining which has relevance in quantum computing. At the same time single-event-upsets could be investigated as well as the irradiation of cells by single ions or packets of ions. For this to succeed the implementation of. In order to implement a proton beam writer at the MRD, a dedicated scanning system with computer controlled object and scattering slits for the micro-probe is required to guide the proton beam during the writing.

4.1.3 Elemental, microstructural, and nano-mechanical properties of metal materials manufactured by laser 3D printing

Our aim is to understand how materials behave when they are 3-D printed as this can guide designs utilizing conventional alloys with Titanium and Nickle-based metal 3-D printing. This baseline knowledge will also help identify opportunities for improved alloys and processing regimes. Our study will evaluate mechanical properties of specimens in both compression and tension and also with respect to different print orientations. Microstructural analysis, such as dendrite arm spacing analysis and nano-mechanical analysis through nano-indentation will also be performed on the printed specimens and the fracture surfaces will be evaluated. Additional testing, including, elemental and structural analysis by Ion Beam

Analysis (IBA) and X-ray diffraction (XRD), morphology by Atomic Force Microscopy (AFM) and High Resolution Scanning Electron Microscope (HR-SEM), print resolution, porosity, and ultrasonic modulus will be included in our study to develop more baseline data for 3D printed Titanium and Nickel-based alloy properties.

4.1.4 Pulsed Laser-Ablation Deposition

The MRD at iThemba LABS has pioneered nationally the pulsed laser deposition technology as well as the laser induced interfacial growth and interfacial diffusion studies. The three main units are located at the CSIR, University of Stellenbosch and the University of Witwatersrand. The first pulsed laser deposition has been implemented jointly with the Laser Research Institute (LRI) of the Physics Department of the University of Stellenbosch. It consists of a target holder and a substrate holder housed in a vacuum chamber supplied by iThemba LABS and a high-power laser (supplied by the LRI) that is used to vaporize materials and to deposit nano-structured and nano-composites systems. The advantages of pulsed laser ablation are the chemical stoichiometry transfer, flexibility, fast response, energetic evaporates, and congruent evaporation under different type of atmospheres. The iThemba LABS-LRI laser ablation unit has and is being used extensively by MRD students as well as a growing group of African visiting scientists.

4.1.5 Deterministic Single-Ion Implantation Technology for Fabrication of Qubit Arrays for Quantum Computing and Cryptography

The possibility to carry out ion implantation at the 3.0 MV tandetron, allows for research utilizing deterministic single-ion implantation techniques at the nanometer-scale. This will enable us to fabricate single photon sources and single qubit arrays of quantum systems that have particular relevance for quantum cryptography and quantum information. Special emphasis will be given to quantum information systems of particular importance within the South African technology context, such as nitrogen-vacancy (N-V) and nickel-nitrogen (Ni-N) complexes in diamond. We aim to implement and demonstrate the use of basic hardware based in diamond technology for quantum computing and related quantum information and cryptography.

The nano-fabrication process we intend to implement for the production of structures for a quantum computer is based on controlled single ion implantation methods for creating the N-V and Ni-N color centers in diamond by incorporating an online and *in situ* AFM facility and online single-ion hit detection techniques. The AFM will provide the guide for the single ion implantation topology, and the detection of every single hit with 100% efficiency will be based on detection of resulting byproducts from the interaction of the implanted ion and the substrate. The Heavy Ions Source at the new tandetron will provide slow highly charged ions that can be easily detected during single ion implantation by the large secondary electron emission they induce. The source will also be used for fabrication of quantum dots due to the high potential energy deposition from impacting highly charged ions. We plan to investigate the cross sections of formation of N-V and Ni-N complexes in diamond under specific

implantation conditions. A new end-station need to be constructed to incorporate the AFM and the necessary detectors.

4.2 Bio-Medical Research

4.2.1 Biomedicine: The application of ion beam analysis techniques in biomedical research

The aim of this project will be to compare the trace and transition metal content in scalp hair of inpatients with neurodegenerative diseases and infected with neurotropic agents colonizing the gut to that of healthy controls. Ion beam and complementary techniques will be employed to assess endogenous hair elemental content reflecting body trace element status. In addition, exogenous hair elemental content will be assessed to rule out contamination by external sources. Results of this research may advance the application of orthomolecular medicine whereby such patients receive nutritional supplements to correct elemental deficiencies indirectly responsible for disease symptomatology.

4.2.2 Bionanotechnology: Biological Materials for Green Synthesis of Nanomaterials

Nanoparticles and nanomaterials are an important source of innovation in several fields of scientific research. Recently, the focus has shifted from conventional chemical synthesis techniques to more environmentally friendly methods. This technology has been referred to as the green synthesis of nanoparticles. A number of plant extracts (*Sorghum bicolor*, *Aloe barbadensis*, *Helianthus annuus*) are currently being investigated to assess the potential role that they could play in the development of green processes to support the large scale synthesis of certain nanoparticles. We aim to investigate the potential of using other biological materials such as hair and microorganisms in applications intended to promote a greener approach to the synthesis of nanomaterials.

4.2.3 Biomaterial Physics: Heavy Ion Stopping Power in Biological Materials

Particle-induced X-ray emission (PIXE) and Rutherford Backscattering Spectroscopy (RBS) are non-destructive ion beam analysis techniques that can use the same accelerated ion beams and can run simultaneously when analyzing “thin” specimens. More specifically, PIXE used in low energy proton microscopy has distinct advantages as an elemental mapping technique which could in future be expanded to high energy image-guided treatment applications for the therapeutic proton beam. The aim of this research will be to assess the utility of PIXE and RBS when using a range of heavy ions versus 3-MeV protons, with specific emphasis on assessing the time in obtaining data and the quality of spectra and images for different biological materials of varying thickness. The drawbacks of using various heavy ion sources versus 3-MeV protons will also be investigated. Furthermore, fundamental parameters describing heavy ion stopping power in biological material will be assessed.

4.2.4 Materials engineering and metallurgy

Research in materials engineering and metallurgy include i) Characterization of metallic nanoparticles and their electrical properties; ii) Synthesis and nano-device fabrication of crystalline core-amorphous shell silicon nanowires; iii) Studies of transport properties in semiconductor nanostructures; iv) Hydrogen storage by oxygen implanted Pd-coatings and plasma-assisted oxidation of Ti alloy.

4.2.5 Environmental in-situ characterization of metal alloys at high temperatures

An in-air ion beam facility could be used for the *in-situ* study of high temperature metal/alloy phases with applications in materials engineering and nano-technology.

4.2.6 Investigating the diffusion of high level nuclear waste elements in glassy carbon:

To store high level nuclear waste until its radioactivity has decayed to acceptable levels means that the container material(s) must have special properties, e.g. radiation hardness, non-reactivity with the waste, a diffusion barrier to the elements in the waste, etc. This project will investigate the diffusion of mainly nuclear waste elements in glassy carbon. Diffusion is traditionally one of the fundamental topics dealt with in materials science because of technological importance (e.g. doping of semiconductor materials). This project becomes even more important for materials science since it fundamentally investigates the influence of the microstructure of glassy carbon on the diffusion of the different radioactive waste elements with different chemical and physical affinities for glassy carbon, particularly ^{90}Sr and ^{129}I .

4.2.7 Environmental and geology

Emphasis will be directed to the academic and contract collaborations interested in nuclear microscopy of grain and mineral inclusions for mining exploration and/or assets creation. Topics of interest include the 2-D elemental mapping of pyrites, the study of hydrocarbons formations, fluid inclusion analysis using micro-PIXE and micro-PIGE, and investigations aimed at understanding geological accumulation of metals in ores like for example the presence of uranium in coal at concentrations of ca. 50 ppm including elemental maps of other elements such as C, S, Fe, P, Ca and Mn.

4.2.8 Cultural Heritage

Characterization of archaeological artifacts and materials is a well-developed field of research world-wide where low energy accelerators play a major role. iThemba LABS has during the last decades carried out research in many aspects of cultural heritage using IBA techniques to decipher the non-written history of indigenous communities that were living in the area more than 500 years ago, particularly in relation to rock art (painting and engraving). Our intention of continuing with cultural heritage studies at the MRD will be realized with the commissioning of an “in-air” beam line. We will focus our attention particularly on the study of the numerous specimens available in the Western Cape region of South Africa. One of the questions that have yet to be resolved is the accurate estimation of the art age. This will be

possible with techniques available at the MRD, in combination with AMS. Another interesting research objective is the investigation of the type of materials used by long time inhabitants of the area for the manufacturing of the inks to draw the art on the rock surface.

Table 1: Strategic plan activities based in objectives and themes.

1. Accelerator commissioning and beam line development	Next Five years	Next Five-Ten years
1.1 Installation of beam lines	<ul style="list-style-type: none"> • Re-installation of beam lines at zero degrees for the Nuclear Microprobe • Re-installation of beam line at -15 degrees for RBS/ERDA/Channeling • Design and construction of a beam line devoted exclusively to in-situ RBS/ERD and Channeling • Design and construction of beam line for ion implantation with light and heavy ions at +15 degrees (at low energy per nucleon) • Design of beam line at +30 degrees for real time e-beam deposition and IBA analysis 	<ul style="list-style-type: none"> • Design and construction of ToF SIMS in Tandem with the NMP at the 0 degrees line. • Design and construction of an end-station for ion beam implantation of radioactive isotopes and on-line characterization at the new LERIB (60 keV) facility. • Implementation of Maia x-ray microprobe detector and imaging system for real time fast 2-dimensional elemental mapping array at the NMP at the 0 degree-line, for applications in materials sciences, geology, biology, medicine and cultural heritage. • Development of High Energy PIXE at the NMP 0 degree line ($E_p > 5$ MeV). • Design and construction of beam line for a new nano probe for proton beam writing with lateral resolution of less than 100 nanometers

		<ul style="list-style-type: none"> • Design and construction of beam line at +45 degrees for astrophysics (nucleosynthesis of light nuclides) • Design of beam line for Heavy-ion ERDA ToF spectrometer • Development of and in-air beam line for cultural heritage studies and high temperature studies of metal-alloys for materials engineering at -45 degrees line. • Development of a facility for Deterministic Single-Ion Implantation Technology for Fabrication of Qubit Arrays for Quantum Computing and Cryptography. • Astrophysics: Studies of nucleosynthesis of light nuclides by nuclear reactions with high intensity ions (max available $\sim 100 \mu\text{A}$).
1.2 Implementation of data acquisition system	<ul style="list-style-type: none"> • Re-implementation of MIDAS DAQ platform on both lines at 0 and -15 degrees. Synchronization of DAQ functionality for data collection from new Data Room 	<ul style="list-style-type: none"> • Perform experiments
1.3 Beam optics optimization	<ul style="list-style-type: none"> • Optimization of beam optics in the 3 MV Tandatron accelerator for microbeam improvement of lateral resolution for applications in nanosciences 	<ul style="list-style-type: none"> • Perform experiments

<p>1.4 Development of a Centre of excellence in Ion Beam Analysis Research in partnership with national and international institutions</p>	<ul style="list-style-type: none"> • Evaluation of proposals for first experiments with NMP and RBS/ERDA • Discussion on the establishment of a Cost Recovery Exercise for all work done at the Tandetron • Confirmation of SARCHi Chair for Materials Science and Ion-beam interaction • Organization of International Workshop on IBA Techniques for Materials Characterization 	<ul style="list-style-type: none"> • Application to NRF for CoE Status
<p>2. Ion-Matter Interaction</p>		
<p>2.1 Experimental determination of physical fundamental parameters governing the physics of ion-matter interaction. Comparison with theoretical models</p>	<ul style="list-style-type: none"> • Measurement of x-ray production cross sections by heavy ions on transition metals and comparison with theoretical models. Energies <300 keV/A. • Experimental determination of stopping force and energy loss of highly-charged heavy ions on transition metals by standard RBS/ERDA. Comparison with theoretical models and good data will be included in peer-reviewed databases • Thermal spike model interpretation of sputtering yield data for heavy metal thin films irradiated by highly-charged heavy ions • Ion implantation on demand for light and heavy ions for development of semiconductor, superconductor, and ion beam mixing in binary and ternary systems 	<ul style="list-style-type: none"> • Stopping force measurements of heavy ions in transition metals by Time of Flight–Energy spectrometry for applications in materials sciences and Nano-sciences. • Real time e-beam deposition and <i>in-situ</i> IBA analysis on selected binary systems for the understanding of possible phases created during deposition. • Heavy ion energy loss straggling of heavy ions in transition metals by Time of Flight stopping force measurements.

3. Nano-Lithography and thin film technology		
3.1 Atomic Force Microscope Laboratory: Research and Development and support to users	<ul style="list-style-type: none"> • Finalization of repair of the old AFM that was affected by MRD fire in 2013 • Surface modification of silicides and nano-structured materials with a view to the manufacturing of nano-devices for application in semiconductors and the energy economy • Elemental, microstructural, and nano-mechanical properties of metal materials manufactured by laser 3D printing 	<ul style="list-style-type: none"> • Ion beam nanolithography • Manufacturing of nano devices by Proton Beam Writing • Deterministic Single-Ion Implantation Technology for Fabrication of Qubit Arrays for Quantum Computing and Cryptography
3.2 Deposition and annealing of thin films: Solid State Laboratory Development and management	<ul style="list-style-type: none"> • Procurement of new dual electron beam evaporator system • Deposition of thin films of metals as binary or ternary systems over metal substrates for applications in semiconductors, materials engineering, condensed matter, environmental detectors and more areas related to the energy economy • Annealing of binary or ternary films deposited by e-beam over silicon or metal substrates for the purpose of studying the thermodynamics of intermixing and diffusion at different temperatures from RT to 1500 C • Design and adaptation of facilities required for the commissioning of RF magnetron sputtering system (replacement for destroyed one). Commissioning of RF 	

	<p>magnetron sputtering system.</p> <ul style="list-style-type: none"> • Expansion of the Solid State Laboratory to accommodate more furnaces. 	
4. Biological Science		
4.1 Biofortification, biomedicine, bionanotechnology, biotechnology, biomaterial physics	<ul style="list-style-type: none"> • Research on the African cereals and other important food grains to combat malnutrition and food insecurity • Heavy ion stopping power in biological materials • Evaluation of stress tolerance mechanisms in plants • Biological materials for green synthesis of nanomaterials • Application of ion beam analysis techniques in biomedical research • The use of biological materials for green synthesis of important nanomaterials. • Evaluation and development of nutritionally superior African cereals and other seed grains for food security. • Evaluation of heavy ion stopping power in biological materials. 	

Table 2: Human resources requirements for the MRD.

Position	Division/Experimental Facility	When
Research Chair	Ion Beam Analysis	2018
Research Scientist	Thin Film and Nano-lithography	2018
Research Scientist	Biological Sciences	2018
Research Scientist	Biological Sciences	2018
Research Scientist	Low Temperature Lab	2018
Research Scientist	Nanosciences Lab	2018
Research Scientist	Nanosciences Lab	2018
Mechanical Technician	Mechanical Workshop	2018

Tandem and Accelerator Mass Spectrometry

1. Abstract

The Tandem and Accelerator Mass Spectrometry Department, located in Johannesburg on WITS University Campus, hosts Africa's first and only accelerator mass spectrometry (AMS) system, an ion beam analysis (IBA) setup, based on a 6MV EN Tandem accelerator. The department also hosts necessary and thematic accompanying facilities with important synergies for both AMS and IBA. These include a Delta V Mass Spectrometer, a laser water isotope analyser, a Varian Extron 200-20A2F and a 350D/300XP ion implanter, decay counting facilities, and chemical sample preparation laboratories.

The AMS system has been implemented in 2014, commissioned, and verified in actual measurements and inter-comparison over the past 3 years. In this section we lay out the plan to turn our AMS setup from a functional facility into a well-known, internationally recognised AMS laboratory, which is well-integrated into the South African science and higher education community, providing both training and scientific outcomes to South Africans. Our focus will be on heritage studies, environmental research, and geosciences, where we can make the biggest impact for South Africa, and can rely on collaboration with a thriving research community that has significant demand for isotopic measurements.

Our IBA setup comprises a microprobe beam-line, which has both a proton-induced X-ray emission (PIXE) and a Rutherford backscattering (RBS) setup, and a scattering chamber which can be used for elastic recoil detection analysis (ERDA). For materials analysis we envision the development of a "Total-IBA" setup, which will allow performing enhanced elemental analysis with 3 different complementary techniques simultaneously, and the development of heavy-ion ERDA and PIXE on this setup. These increased capabilities will open new materials research opportunities, allowing us to expand the existing IBA research projects, user-base, and training provided to students.

2. Introduction

In 2005 the former Schonland Research Institute (SRI) was signed over from the University of the Witwatersrand (WITS) to the National Research Foundation (NRF) to become part of iThemba LABS. The primary aim of this endeavour was to establish the first Accelerator Mass Spectrometry (AMS) facility on the continent of Africa which is now fully commissioned and operational. The AMS facility is the flagship project at this department of iThemba LABS, but it is complemented by other significant analytical facilities.

It is the vision of the department that the AMS facility of iThemba LABS, currently the only one on the continent of Africa, will be recognized to be among the top five percent of AMS laboratories worldwide. This can only be achieved by demonstrating the capability of the AMS facility through inter-laboratory comparisons with world-leading AMS laboratories. The first steps in this bench-marking have already commenced.

The AMS facility was built up in stages, commencing with the complete refurbishment of the EN Tandem accelerator and its support systems (see figure 1). This was followed by the construction of a custom built Low Energy Injection System (LEIS), and thereafter the procurement and installation of a complete High Energy Analysis System (HEAS) obtained from National Electrostatics Corporation (NEC), as well as setting up of sample preparation facilities. The entire AMS system has been commissioned and optimized for transmission in order to enable the best possible performance. Components of the AMS system are shown in Figure 2.

The bed-rock of any AMS facility is the ability to perform radio-carbon analyses. The fundamental idea of the method is to use the content of the radioactive isotope Carbon-14 in dead plants and animals to determine their age. Radiocarbon, or ^{14}C , has a half-life of 5730 years and, in the atmosphere, is produced continuously by nuclear reaction induced by



Figure 1 : The fully refurbished EN tandem accelerator.

cosmic radiation. The discovery of the radiocarbon method for dating of bones and wood has revolutionized archaeology, and the technique has since also found application in geology, biology, environmental studies, and many other areas. The AMS radiocarbon method is useful up to 50 000 years.

Detecting ^{14}C at environmental levels with mass spectrometry suffers from interference of atomic and molecular ions of equal mass, specifically the isobaric molecules $^{12}\text{CH}_2$, and ^{13}CH as well as the stable isotope of Nitrogen, ^{14}N . Since nitrogen does not form negative ions, the nitrogen interference is eliminated by using a negative ion formation process for extraction. The molecular interference is destroyed in the terminal of the tandem accelerator, where the negative ions are recharged to positive charge states. AMS at iThemba LABS overcomes the molecular interference by selecting high charge states under which these molecules are no longer stable. That way, ^{14}C can be detected against an isobaric background in the environment that is at least 12 orders of magnitude more abundant. AMS is about 1×10^4 to 1×10^5 times more efficient than radioactive decay counting, and as a result required carbon sample size is in the 10-1000 microgram range, whereas several grams are required for decay counting.

An important part of the radiocarbon methods is the so-called $\delta\text{-}^{13}\text{C}$ fractionation correction which is a required correction for radiocarbon dates. $\delta\text{-}^{13}\text{C}$ is the deviation of the sample $^{13}\text{C}/^{12}\text{C}$ -ratio from a reference ratio given in per mille of deviation (δ -notation). The effect of

this correction can be as high as 2% in the case of carbonates. In terms of age this is the equivalent of an error of 162 years for modern samples, but it increases to about 7 000 years for samples that are 30 000 years old. Therefore a precise determination of the $^{13}\text{C}/^{12}\text{C}$ -ratio is required together with the $^{14}\text{C}/^{12}\text{C}$ -ratio of a sample.

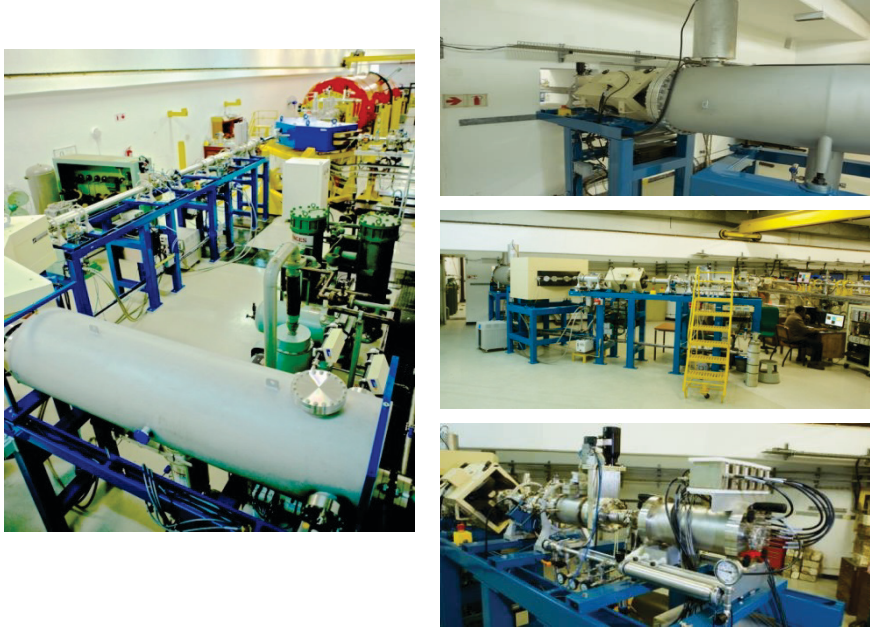


Figure 2 (left) High-energy analysing magnet and off-set Faraday cups of the AMS facility; (Right top to bottom) High energy AMS electro-static analyser; the AMS detector beam-line after the post-ESA switching magnet; and the Multi-anode DE-E gas-ionization detector.

AMS-methods are also the method of choice for some other long-lived radioisotopes, most notably ^{10}Be , ^{26}Al , and ^{36}Cl . These radio-isotopes are produced in both rocks and the high atmosphere by cosmic radiation. There are several ways to employ these isotopes for geological studies; the most widely applied are exposure dating, burial dating, and erosion rate determination of rocks, clasts, sand, and paleosols. TAMS capability for measuring ^{10}Be and ^{26}Al have been implemented and thoroughly tested, and the required sample processing laboratory is in the final stage of implementation.

3. Internationally competitive research

In the past years an overview of the AMS facility has been presented to the main radiocarbon and cosmogenic isotope user-base at many meetings. Furthermore, Africa, and Southern Africa in general, is a country and a region which hold the unique Cradle of Humankind. The origins and evolution of the human species are topics to which everyone can relate, so the proximity of an AMS facility “on the door step” means that analyses can now be carried out within South Africa, rather than having to send them abroad, where the waiting times can be up to 12 months and significant charges are made for the analyses

In addition to the big question of “where do we come from” is the looming question of “where are we going” in terms of climate change. AMS offers the possibility of investigating this through ^{10}Be analyses from samples taken from ice-cores in Antarctica. South Africa has

a permanent station at Antarctica and support for the AMS facility has already been given from the South African Antarctic Expedition.

In between “where do we come from” and “where we are going” is the question of “why are we like we are” in terms of understanding the human condition in terms of social and cultural development. These aspects were highlighted in a number of presentations made by experts based at local universities at the Long Range Plan meeting that was held in the department on 7/3/17.

Possible applications of AMS isotopes relevant to national, regional and international interests include the following:

- Anthropology, History and National Heritage (^{14}C , $^{26}\text{Al}/^{10}\text{Be}$)
- Research in Global and Regional Climate Change by studying the Carbon cycle (CO_2 dynamics with ^{14}C) and ^{10}Be from Antarctic ice cores
- Geosciences and Isotope Geology (^{14}C , ^{10}Be , ^{26}Al , ^{36}Cl , and many others)
- Characterisation of atmospheric pollution in terms of different anthropogenic activities (CO_2 isotopic analysis via ^{14}C)
- Characterization of Regional Groundwater Systems (with ^{36}Cl , ^{14}C , and ^3H)
- Biomedical Sciences
- Qualifying Therapeutic Drugs
- Radioactive Waste Management
- Nuclear Astrophysics, Meteoritics, and Astronomy
- Dosimetry
- Materials Science

As well as AMS analyses of rare isotopes, the department has a well-founded capability for analyses of stable isotopes (SI) via Mass Spectrometry (MS) located in the Environmental Isotope Laboratory (EIL). From the outset, the intention was to incorporate the EIL into a wider isotope analytical operation along with the AMS facility. The EIL also carries out radio-carbon and tritium analyses in water with Liquid Scintillation Counters (LSC). Plans are underway to implement radio-carbon (Carbon-14 or C-14) water capability with AMS, as is undertaken at the NOSAMS facility at Woods Hole in the USA. The stable isotope capabilities for water analyses have received a considerable boost from procurement of a Laser Water Isotope Analyser (Figure 3). For a water-stressed country such as South Africa, this expansion in analytical capability is clearly desirable.

In addition to rare and stable isotope analyses, the department has considerable infrastructure with which the properties of materials can be modified and characterized. These include two Varian-Extrion ion implanters, namely the 200-20A2F model, and the newer 350D/300XP model (Figure 4)., The design energy of the 200-20AF model is 205 keV, with a Freeman ion-source for gaseous elements or their compounds, modified for carbon-tetrachloride assisted production of most metallic ions (except noble metals). Additional modifications

allow for ultra-low energy implantations and the implantation of powders/granules. The 350D/300XP model has a similar design energy and basic gaseous ion-source but modified with a sputter-system to produce noble metal ions. Although it can also ionize base-metals, a CCl_4 modification is currently being added in order to get bigger beams. There are two end-stations for a faster turnaround on this machine.



Figure 3: Laser Water Isotope Analyser



Figure 4: The Varion-Extrion 200-20A2F (left) and 350D/300XP (right) ion implanters .

Implanted samples as well as a variety of others can be characterized with a suite of Ion Beam Analysis (IBA) techniques. These include elemental analysis with Particle Induced X-ray Emission (PIXE) with the micro-probe which has recently been upgraded with the implementation of the latest OMDAQ3 software as well as a new detector that does not require any LN2 cooling. In addition to micro-PIXE, Rutherford Back-Scattering at the sub-micron level (micro-RBS) is also implemented such that samples can be characterized simultaneously with both techniques.

In addition the department has a facility for Heavy Ion Elastic Recoil Detection Analysis (HI ERDA) that had resulted in a considerable number of publications (on average six per annum) over the last few years.

4. Education and training

As the department resides on the campus of the University of the Witwatersrand (“WITS”) many users and postgraduates are from WITS. However, as a department of a National Facility of the National Research Foundation (NRF) we are mandated to provide support for

research and training to all universities. The nature of the user-base is taking a dramatic shift since unlike the bulk of IBA users, AMS users, in common with those of the EIL, are generally from non-physics backgrounds who require the measurements and analysis to be carried out for them, including sample preparation.

All four of the in-house PhD-level scientists are (co-)supervising MSc and PhD students, as well as providing in-service training. Most of the co-supervised students are enrolled at the nearby universities, namely WITS, University of Johannesburg, University of Pretoria and the Tshwane University of Technology, though some are enrolled at Universities of Cape Town and KwaZulu-Natal. An increasing number of Honours, Master's and Doctoral students are using the services of the EIL for the dissertations including many registered at the University of Stellenbosch.

Student supervision and training is seen as an entrenched activity, and not a peripheral activity facilitated by sample analysis. In other words the analysis of samples on behalf of graduate students only marginally meets the criteria for training. The model for the AMS scientists is to formalise co-supervision agreements. The co-supervisory role will require a high level of engagement in the design and execution of research, as well as overseeing learning related to analytical techniques. It involves a deep level of engagement in student projects from proposal through execution and writeup to publication phases.

In order to merit this level of engagement the AMS scientists at iThemba LABS are expected to conduct research programs that directly engage students, and they will also participate in supervision in which their knowledge is key to the student success.

Engagement with students has proven to be problematic as top students are typically recruited in to research programs by established academics purely because of their exposure to students in their final undergraduate years. The AMS team at iThemba LABS already participates in teaching at some institutions. This is typically in the form of guest lectures on an ad hoc basis. The AMS scientists also participated, and have for many years, in the “isotope ecology” course offered by the University of Cape Town, which is the premier training in the field of isotope applications in southern Africa. This course attracts international students from across Africa and beyond. This level of teaching is fundamental to attracting postgraduate students to programs involving iThemba LABS' AMS facility. For this reason a dedicated curriculum will be developed that can be deployed at any, but preferably all, tertiary education facilities as a third year module in AMS applications. This would normally be offered in the third year of courses such as geology and archaeology.

In addition to the formalised training curriculum, the AMS team, and all graduate students involved in the facility, and all users that choose to, will present an annual research workshop. This workshop will cultivate academic debate around all the applications that are undertaken at the laboratory. The forum will be fundamental to ensuring that the value chain from project design through to publications has suitable emphasis.

5. International Collaborations

The AMS facility has received considerable support from overseas which proved vital in securing the grant funding to complete the AMS system. Letters of support were received from leading AMS facilities worldwide like VERA (Austria), SUERC (United Kingdom), CAMS (USA), ANU (Australia), ANSTO (Australia), ETH (Switzerland) and Cologne

(Germany). These were reinforced by considerable support shown for the facility at the AMS-13 conference that took place in Aix-en-Provence (France) where a poster was presented to herald in the completion of Africa's first AMS laboratory. This has led into further collaborations with GNS (New Zealand) and NOSAMS (USA). It is further expected that the AMS facility will be included in round-robin inter-laboratory comparisons whereby samples prepared in one batch at a world-leading laboratory are sent to a significant number of participating AMS facilities for analysis.

A clear objective of the AMS facility at iThemba LABS is to maintain a strong international and local footprint. The facility has to be the market leader for local African scientists to participate in high profile research so that they can overcome legacy issues and take their rightful place in the global science community using state-of-the-art AMS facilities. The AMS scientific team needs to comprise world leaders in both the technique and the applications of AMS. Scientific excellence at an international level is maintained through networks, and these are mostly nurtured through conference attendance.

On-going and starting collaborations with other AMS laboratories include laboratories at University of Vermont (USA), NOSAMS (USA), Helmholtz-Zentrum Dresden Rossendorf (Germany), and University of Vienna (Austria), and SUERC (United Kingdom). Furthermore, close collaboration is envisioned with the AMS and sample preparation groups at Atomki (Hungary) and UJF (Czech Republic).

The international profile of the AMS facility is witnessed by the ongoing support of the International Atomic Energy Agency (IAEA) which has funded the 64-sample ion source, a multi-anode DE-E detector plus electronics, a static induction heater for ^{14}C preparation, a suite of cosmogenic standards (^{10}Be , ^{26}Al , ^{36}Cl), a Laser Water Isotope Analyzer as well as the current procurement of vacuum equipment for the EN Tandem accelerator.

6. The next five years

6.1 Accelerator Mass Spectrometry

The AMS system has been implemented and tested for ^{14}C and ^{26}Al , and the ^{10}Be is in the final stages of verification. For the next five years our focus will be on improving and expanding on sample preparation in scale and to new types of samples, implementing $\delta\text{-}^{13}\text{C}$ measurements at our laboratory, running an applied research program for the AMS isotopes – including training of students and postgraduates, and possibly the addition of ^{36}Cl as a new isotope, which could be implemented without expansion on the existing equipment on the accelerator.

For the main isotope, radiocarbon, we are busy producing samples for a number of ecological, environmental, and climate change research projects, and user-driven heritage study projects. There is no lack of applications and demand for these in South Africa. We have a manual graphitisation system, which has been tested in combination with our AMS system. It is acknowledged that the future bottleneck in analytical production will be in the preparation laboratories for ^{14}C and indeed for the cosmogenic isotopes. How to expand the preparation capabilities remains an open question, though the most direct method for increasing ^{14}C sample preparation throughout would be to obtain an automated graphitization system, or systems, such as the AGE3 system offered by Ionplus.

The δ - ^{13}C fractionation correction will be undertaken offline and this correction will be implemented with a commercially available laser-based Carbon Dioxide Isotope Analyzer which will work directly on the CO_2 gas that is produced in the graphitization process. On-line measurements are standard for new off-the-shelf systems ranging from 0.1 to 3MV terminal voltage, but attempts to bring it to old larger tandems have generally not yielded satisfactory results. Generally speaking, the capacity to measure ^{13}C independently from ^{14}C would be a thematic and very useful addition to our laboratory, so it does make sense to invest in a dedicated laser spectrometer as stated above.

Another focus for ^{14}C sample preparation will be the implementation of the pre-treatment for water samples, as there is already standing demand for such analyses. The great attraction of using AMS for C-14 hydrology rather than the LSC method is the dramatically smaller water samples (1l for AMS as opposed to 50l for LSC) needed which obviously allows for many more samples to be gathered at any one site or sites.

A crucial study would be the radiocarbon production rates in the atmosphere taken from rain samples. Production rates in past times can be measured in ice cores, tree rings, varves and sediment cores. This would be vital for the study of processes of climate and sea level change, a topic currently of great interest. It has been suggested that these processes are linked to climate changes, so a greater understanding is of great practical importance.

We are working on implementing the sample preparation for ^{14}C from carbonates, as this will open a number of interesting research opportunities for climatology and research into ^{14}C calibration. Samples ready for analysis include

- A speleothem from the Cango caves, stretching back from today to the limit of the ^{14}C technique
- Several coral cores covering the southern African side of the Pacific ocean.

We will combine the development of ^{14}C for carbonates with the implementation of $\delta^{13}\text{C}$ directly from our graphitisation line (using the anticipated laser analyser). The implementation of ^{14}C from carbonates also goes in hand with the developments for ^{14}C water analysis. These come on top of an existing research program of southern African climate records from trees.

On the back of first measurements of ^{14}C and ^{26}Al the next major step is the implementation of ^{10}Be measurements which is required for already committed projects, and the most important AMS isotope for geological applications, and together with ^{26}Al is also used in burial dating of fossil sites. The situation for ^{10}Be at the iThemba LABS AMS facility is promising, since the high output of the ion source for BeO lays the ground for us to be not just internationally competitive, but excellent in measurements of this isotope. Moreover, South Africa has a great wealth of geological settings where ^{10}Be can be employed to resolve research.

The AMS isotopes ^{10}Be , ^{26}Al , ^{36}Cl are for the most part used in heritage studies and the geosciences. We expect these isotopes to be an important part of the AMS capability, and we are also building capacity for the chemical sample preparation from rock samples, funded predominantly from the SRIG allocations. Other possible applications (oceanography, biosciences) as listed before will of course not be excluded if not detrimental to other applications, but priorities exist regarding the focus of sample preparation facilities and time

allocated. For some of these applications important parts of the sample preparation will have to be provided by the collaborator in their specialized clean laboratory.

For cosmogenic isotopes – while our first collaborative project using ^{26}Al in an erosion/burial dating study on a heritage site (Rising Star) is currently in write-up – we have several in-house projects with two research grants as funding source, and a number of collaborative projects for the next years:

- Dating of the Tswaing impact crater, both a heritage site and an important paleo-biological archive (the crater lake provides drill cores giving pollen records going back to the very uncertain date (100k-400k) of formation of the crater.
- Burial Dating at the Duinefontein fossil site.
- Erosion study of the Vaal river valley.
- The study of the formation of pot-holes in the Orange River.
- Erosion of Mooi river dolorites.

Implementation of ^{10}Be could be followed by implementation of ^{36}Cl -measurements, depending on demand and the success in suppressing the interfering isobar (^{36}S) at our AMS system. This requires improvement in the resolution of the detection system, the development of measurement procedures, and will require the accelerator system being maintained at best level to reach highest possible terminal voltage. Moreover, improvements in the overall vacuum of the EN tandem need to be achieved for optimum background suppression. In addition the beam-optics of the electrostatic analyser/switching magnet combination needs reassessment to check for a better solution to optimize the impact of the electrostatic analyser.

Besides its geological applications ^{36}Cl is the principal AMS isotope used in hydrology, and has been used in determining the ages of groundwater, in measuring recharge rates, and in studying past climates. When radiocarbon results for water samples fall below 1 per cent modern carbon, ^{36}Cl is required, which has a half-life of 301 ka. This is another motivation for a push to implement this isotope at our facility.

6.2 Environmental Isotope Laboratory

I. Stable Isotope Analyses (SIA) with Mass Spectrometry

Current SIA fields of research are:

- Isotope hydrology - water resources assessment
- Pollution studies
- Urban hydrology
- Isotope geology
- Environmental studies
- Ecology and forensics

The analytical capabilities for SIA are:

$\delta^2\text{H}$ for water and organics

$\delta^{18}\text{O}$ for water, organics, carbonates

$\delta^{13}\text{C}$ for carbonates and organics

$\delta^{15}\text{N}$ for nitrates and organics

$\delta^{34}\text{S}$ for sulphates and organics

where, for example, $\delta^2\text{H}$ is the deviation of the sample $^2\text{H}/^1\text{H}$ -ratio from a reference ratio.

Throughout 2016 and at the start of 2017, the Environmental Isotope Laboratory (EIL) ran at full capacity, particularly on the Delta V mass spectrometer (see figure 6), but to a large extent also on the Liquid Scintillation Counters. The new laser water analyser has relieved a considerable amount of pressure placed on the mass spectrometer. Currently, a batch of 38 water samples (run in duplicate) on the Delta mass spectrometer takes four days to measure the stable isotope ratios of hydrogen and oxygen. These analyses occupy a substantial amount of machine-time which could instead be used for determining the carbon isotope ratios in carbonates, the sulphur isotope ratios in sulphides, or the isotope ratios of carbon and nitrogen, as well as sulphur and hydrogen, in organic samples.



Figure 6 : Delta V Stable Isotope Mass Spectrometer in the Environmental Isotope Laboratory.

With more time available on the mass spectrometer, the development of further isotope analyses is possible. One possibility is to use this opportunity to implement and verify capacity to measure nitrogen and oxygen isotope ratios of dissolved nitrates and nitrites – an essential part of pollution studies in the hydrology. A second area that requires development and testing is the measurement of oxygen isotope ratios in organic samples. These would be done in conjunction with the hydrogen isotope analyses, carried out using a pyrolysis system.

Freeing up machine-time is not the only benefit of the laser water analyser. The new spectrometer allows the rapid analysis of both hydrogen and oxygen isotopes for 150 unknown samples per day. The rapid turnover of results would be beneficial to both the

commercial and academic fields as first results could be delivered during the sampling process in the field. In addition to this, the cost of analyses would drop considerably, attracting additional commercial clients.

A further benefit of the laser spectrometer is its ease of use. This would allow students who bring their samples to the isotope laboratory to run their own samples. Students will be able to run their samples over the weekend, freeing up machine time for other analyses during the week.

With the added laboratory capacity, there will be greater opportunities for user-led research and collaborations with the EIL. Currently, collaborations exist with the University of the Witwatersrand, the University of Stellenbosch and the University of Johannesburg. This is expected to expand to the other universities with hydrology departments.

The analysis of samples from three rainfall stations in southern Africa (Cape Town, Marion Island and Gough Island) as part of the Global Network for Isotopes in Precipitation (GNIP), will continue for the foreseeable future. The GNIP programme is a worldwide survey of oxygen and hydrogen isotope content in precipitation. These include the stable isotope ratios of oxygen and hydrogen, as well as the analysis of tritium. The isotope content of precipitation on a global scale is analysed to determine temporal and spatial variations of environmental isotopes in precipitation and, consequently, to provide basic isotope data for the use of environmental isotopes in hydrological investigations.

II. Radioactive isotope analyses with Liquid Scintillation Counting (LSC)

Tritium for water

The analysis of tritium is expected to continue, even with the post-bomb levels at the current low concentrations. Tritium concentrations are an important component in rural water supply studies, as well as pollution studies. They are also used as indicators of pollution from landfills.

Radiocarbon for water

Radiocarbon sample preparation and analysis using LSC will continue to some degree as the precision obtained from AMS analysis is generally not required for hydrological studies. The commercial cost per analysis is also substantially lower than for AMS, however this is offset against the high sample size requirement, which often cannot be met by the user.

Analytical potential

Analysis	analyses/annum
Tritium	750
Radiocarbon	400
Oxygen-18 + Deuterium	1500 (mass spectrometer) >25000 (laser spectrometer)
^{15}N , ^{13}C , ^{34}S	~5000

Looking forward, there will also be development of procedures for the analysis of δN in water, and possible development towards both δN and $\delta^{18}\text{O}$. To remain one of the top isotope laboratories in the country, we would require additional equipment. The liquid scintillation counters are both beyond their serviceable lives, and one would need replacing in the near future. We are one of the few laboratories in the world with only one mass spectrometer. A second would be required for us to be able to service this rapidly growing field.

6.3 Ion Implantation and Ion Beam Analysis

The Tandem and AMS (TAMS) Department and Materials Research Department (MRD) have beam-lines for Ion Beam Analysis (IBA). Both departments possess a scanning microprobe for PIXE analyses and also carry out Rutherford Back-Scattering (RBS) measurements. TAMS also offers Heavy Ion Elastic Recoil Detection Analysis (HI ERDA) and it is anticipated that this will also be available at the MRD. Thus, both departments provide a combination of IBA capabilities and an expert advisory committee will be set-up in order to recommend which approved measurement should be undertaken at which department. This will ensure optimization of IBA research and training undertaken at iThemba LABS.

6.3.1 Ion Implantation

Ion implantation enables any species of ionized atoms to be accelerated and injected into any solid, free of thermodynamic constraints. The subsequent modification depends primarily on the ion-solid combination, and so there is a very broad range of possible effects. Some of the effects being explored with the ion implantation facilities are:

- Corrosion inhibition of titanium nitride using ruthenium implantation: Tungsten carbide cutting tools, with and without titanium nitride coatings, have been implanted with Ru^+ ions followed by practical cutting tests. Rutherford Back-Scattering (RBS) analysis will be used to monitor the ruthenium.
- Related work on dust corrosion inhibition of stainless steels by implantation with nitrogen ions has been started. Here the technique would not replace bulk alloying but could be used for rapid testing of new atom-substrate combinations, using a bench-top chemical reactor. Similar work to the above is expected to continue for the next few years.
- Allotrope modification to produce very hard layers: Conversion of soft hexagonal BN into a hard cubic BN nano-particle layer by light ($M < 15$) ion implantation has the possible spinoff of being able to surface-harden otherwise softer (and therefore machineable) industrial materials, and will be continued.
- Ion implantation damage in annealed diamond: The nature of the damage profiles in ion implanted diamonds, as a function of ion fluence, substrate temperature, and other parameters.
- Colloidal nano-particles in substrates by ion implantation: Electron microscopy of colloidal nano-particles induced by (mostly) Ag and Au implantation into Al_2O_3

and MgO gave good results. The optical activity which was shown to occur in some of these samples could be very useful for modern photonic applications.

- Surface Brillouin scattering of laser light on polished diamond: the metallization of diamond surfaces and their examination by surface Brillouin scattering was the first such work to be reported on this transparent and therefore difficult substrate. Good results were obtained and the emphasis developed into deducing the damage profiles introduced by carbon ion irradiation of the diamond samples, complementing our microscopy results.

6.3.2 Heavy Ion ERDA

The Heavy Ion – Elastic Recoil Detection Analysis (HI-ERDA) instrument at the AMS department at iThemba LABS site in Gauteng is an important integral part of the Ion Beam Analysis (IBA) facilities available at the laboratory, which also includes the microprobe (figure 7). Not yet available commercially, the technique was developed in-house and has been used in research work that has produced roughly three journal articles per year over the past six years.



Figure 7 : Scanning microprobe facility with new detector and OMDAQ3.

An outline of Heavy Ion ERDA related projects envisaged over the next 5 years from users in categories two and three is given below.

- **Depth profiling of ion implanted polymer-metal nano-composites for radiation sensing and photovoltaic applications**

The advent of polymer based electronics, or organic electronics as it is alternatively known, is characterised by research into application areas previously regarded as the preserve of silicon based electronics. In this project a systematic study of the relationship between the structural and electrical properties of metal-ion implanted semiconducting polymer films will be carried out, with a view to developing sensor elements for applications in nuclear radiation detectors and organic solar cells. The Heavy Ion ERDA set up will be used for quantification and depth profiling of implanted ion species. The technique's main advantage over other non-nuclear

spectrometries is standard-free measurement and quantification of all major and minor elements in a given film in a single run.

- **Diffusion behaviour of fission fragments in Silicon Carbide**

The safety of modern nuclear reactors depends on the retainment of all the radioactive fission products that may leak during its operation. This is normally achieved by coating the fuel kernel with chemical vapour deposited layers of pyrolytic carbon and silicon carbide (SiC). These layers act as diffusion barriers for the fission products produced in the UO₂ kernels during reactor operation. The most important diffusion barrier layer is polycrystalline SiC. Hence, the diffusion of the important fission products in SiC has been investigated extensively over the past two decades. This research work will focus on the thermally induced migration behaviour of different fission fragment species co-implanted into SiC under varying conditions. The Heavy Ion ERDA technique will be used to obtain depth profiles of the implanted species before and after thermal treatment so as to better understand the effect of elevated temperatures in fuel kernels on fission fragment diffusion.

- **Heavy ion stopping force in polymeric films**

The quantitative analysis of thin layers using Heavy Ion ERDA can be reliably performed if, among other parameters, the stopping force of the probing ions and recoils in a given target matrix are known accurately. While the prime source of stopping force data, the semi empirical code SRIM has (as of 2010) a global average of 4.3% accuracy for all ions in all matter, its predictive accuracy can worsen by up to 20% for heavy ions in compound targets, especially in the region of the stopping force maximum, the Bragg peak. The main goal in this project is to measure the stopping force of heavy ions commonly used for Heavy Ion ERDA in polymeric films. Of specific interest will be to measure the stopping force of ions such as Ag, Cu and Si in conjugated conducting polymer films such as Polyanniline and Polypyrrole. These polymers are found in high potential emerging technologies such as organic nano-electronics.

6.3.3 Towards *total IBA*

In tandem with normal research experiments, there will be beam time slots dedicated to instrument development. Of particular interest here will be the possibility of mounting more than one detector in the ex-Necsa scattering chamber on the zero degree line (see figure 8), to perform simultaneous Heavy Ion ERDA, RBS and PIXE analyses of the same sample. This is the current trend in IBA labs the world over towards what is regarded as '*total IBA*', i.e. detecting all photons emitted and particle beams scattered/recoiled from a target sample to get optimum description of the target from a single measurement.

6. Beyond the next ten years

The demands on beam-time on the EN tandem accelerator are expected to increase as the requests from users for AMS analyses for their samples will burgeon. When a persistent state of oversubscription of beam-time for AMS is achieved it will become necessary for iThemba LABS to enter into a broad discussion with the NRF, the universities, and other South African stake holders for the next Long-Range plan. This discussion would aim to anticipate future demand and best possible actions to meet that demand, funding for such actions, but also look at the possibility of shaping the future of AMS and mass spectrometry based radioactive isotope analysis, including new methods and new isotopes.

6.1 Staff Requirements

Position	Focus area(s)	By When
Mechanical Technician	Machining, vacuum	ASAP
Junior technician	C14 preparation	1/6/17
Scientist/Post-doc'	Ion implantation/IBA	ASAP
Scientist/Post-doc'	HI ERDA	ASAP

Table 1 : Staffing requirements.

All facets of AMS operations need to look towards joint appointments as a means of alleviating staffing constraints. This also extends to the use of students to develop methods, etc.



Nuclear Medicine Department



Introduction

Nuclear medicine related endeavours at iThemba LABS is a major pillar of the facility and is supported by two main activities: i) the Radioisotope Production Programme and ii) Particle Therapy Research activities with protons and neutrons. Proton and neutron therapy is no longer sustainable at a research facility like iThemba LABS, thus activities in particle therapy research have been replaced along this LRP resolution, by radiation biology and radiation physics research activities. The following sections describe the road map and plans for both radioisotope production and radiation biophysics research activities. In order to optimize synergy and efficiency at iThemba for the Nuclear Medicine related activities, both activities described in this section will be conducted in one single Nuclear Medicine Department. This will comprise of a Commercial Programme for the manufacture of radioisotopes for medicine and a Research and Development Programme that will focus on the development of new radiopharmaceuticals, in particular alpha emitting radiopharmaceuticals. Research and development will also include related radiobiology studies as well as radiation biophysical research using particle beams of protons and neutrons.

The long range plan of the Commercial Programme is entirely based on the Accelerator Centre for Exotic Isotopes (ACE Isotopes) pillar of the South African Isotope Facility (SAIF) strategy of iThemba LABS. Thus the ACE Isotopes plan is presented below and this will be followed by the LRP for Medical Radiation Biophysics

Accelerator Centre of Exotic Isotopes (ACE Isotopes)

Executive Summary

iThemba Laboratory for Accelerator Based Sciences (LABS), as a pioneering nuclear research activity in South Africa, presents the South African Isotope Facility (SAIF) strategy.

The foundation of the SAIF strategy is based on two Pillars of Excellence; the Accelerator Centre of Exotic Isotopes (ACE Isotopes) and, Accelerator Centre of Exotic Beams (ACE BEAMS).

The SAIF strategy is based on the acquisition of a dedicated 70 MeV cyclotron for the ACE Isotopes project which will realise the upscaling of radioisotope research and innovation for society (nuclear medicine diagnostic and therapeutic applications), the generation of knowledge as well as supporting and strengthening South Africa's radioisotope exports.

iThemba LABS is a multi-disciplinary laboratory specializing in accelerator based sciences and its applications with its main objective being the provision of technologically modern platforms for research, human capacity development and knowledge generation (innovation) in the fields of basic nuclear physics research, material and environmental research, radiation therapy and radioisotope production and research. The iThemba LABS Separated Sector Cyclotron (SSC) beam time is allocated to the Nuclear Physics, Medical Radiation Therapy and Radionuclide Production programme on an equal basis.

The Radionuclide Department (RD) of iThemba LABS is currently mandated to develop methods to produce high-grade radioisotopes using the 66 MeV proton beam from the SSC and to apply these methods to produce regularly, on a weekly basis, radioisotopes and radiopharmaceuticals for the nuclear medicine sector in South Africa, and also to produce longer-lived radioisotopes for the export market. Part of the objectives includes the continuous sustainability and upgrade of the production facilities, to increase the production yield while simultaneously reducing radiation exposure to staff. As such, and in compliance with the mission of iThemba LABS, the RD strives to pursue an active and internationally competitive in-house research, development and training programme.

The available beam time of the SSC is essentially fixed by the present beam schedule. To increase radioisotope production, iThemba LABS has introduced a number of innovations to increase the beam current to produce a greater quantity within the allocated beam time. These include the introduction of "flat-topping" in the SSC, a new vertical beam target station, and beam-splitting. The possibilities for further increases in beam current with the SSC are now exhausted. Any further growth in production can only be met by an increase in beam time which would come at the expense of one or more of the other programmes or procuring a dedicated cyclotron for the production of radioisotopes.

For ACE Isotopes to materialise, the planned 70 MeV Cyclotron is a major strategic intervention that will change the landscape of accelerator based sciences research in South Africa as well as substantially increasing South Africa's footprint in the global radioisotopes market, supplying both medical and industrial radioisotopes.

The 70 MeV cyclotron dedicated to the ACE Isotopes programme (radioisotope production and research) is proposed to be releasing the SSC for pure nuclear physics research, in particular, the Low Energy Rare Isotope Beam (LERIB) project.

1. Introduction

1.1 Radioisotopes for Nuclear Medicine

Diagnostic techniques in nuclear medicine use radioactive tracers which emit gamma rays from within the body. These tracers are generally short-lived radioisotopes linked to chemical compounds which permit specific physiological processes to be scrutinised. They can be given by injection, inhalation or orally. The first type is where single photons are detected by a gamma camera which can view organs from many different angles. The image is enhanced by a computer and viewed by a physician on a monitor for indications of abnormal conditions. This technique is generally referred to as Single Photon Emission Computed Tomography (SPECT) imaging. Commonly produced SPECT radioisotopes include ^{99m}Tc -labelled products, ^{131}I -labelled products and ^{177}Lu which is produced by the reactor and ^{67}Ga , ^{81m}Kr , ^{111}In and ^{201}Tl which are produced by a cyclotron.

A more recent development is Positron Emission Tomography (PET) which is a more precise and sophisticated technique using radioisotopes produced in a cyclotron. A positron-emitting radioisotope is introduced, usually by injection, and accumulates in the target tissue. As it decays it emits a positron, which promptly combines with a nearby electron resulting in the simultaneous emission of two identifiable gamma-rays in opposite directions. These are detected by a PET camera and give very precise indication of their origin. PET's most important clinical role is in oncology, with fluorine-18 (^{18}F) as the radioisotope, since it has proven to be the most accurate non-invasive method of detecting and evaluating most cancers. It is also often used in cardiac and brain imaging. Other prominent cyclotron produced PET radioisotopes include gallium-68 (^{68}Ga), rubidium-82 (^{82}Rb), oxygen-15 (^{15}O), nitrogen-13 (^{13}N) and carbon-11 (^{11}C).

New procedures combine PET with computed X-ray tomography (CT) scans to give co-registration of the two images (PET-CT), enabling 30% better diagnosis than with a traditional gamma-camera alone. It is a very powerful and significant tool which provides unique information on a wide variety of diseases from dementia to cardiovascular disease and cancer (oncology).

Positioning of the radiation source within the body makes the fundamental difference between nuclear medicine imaging and other imaging techniques such as X-rays. Gamma-ray imaging by either method described provides a view of the position and concentration of the radioisotope within the body. Organ malfunction can be indicated if the radioisotope is either partially taken up in the organ (cold spot), or taken up in excess (hot spot). If a series of images is taken over a period of time, an unusual pattern or rate of isotope movement could indicate malfunction in the organ.

A distinct advantage of nuclear imaging over X-ray techniques is that both bone and soft tissue can be imaged very successfully. This has led to its common use in developed countries where the probability of anyone having such a test is about one in two and rising.

More than 10,000 hospitals worldwide use radioisotopes in medicine, and more than 90 percent of all such interventions are diagnostic: for early detection and more accurate localisation of cancer, or for functional examination of organs. The radioisotope most frequently used for these purposes is the reactor-produced technetium-99m (^{99m}Tc) produced from a $^{99}\text{Mo}/^{99m}\text{Tc}$ generator, which emits gamma rays when it decays. Roughly 35 million scans are performed on an annual basis worldwide and this accounts for about 80% of the nuclear medicine scans worldwide.

A similar generator system is used to produce rubidium-82 (^{82}Rb) for PET imaging from a $^{82}\text{Sr}/^{82}\text{Rb}$ generator and gallium-68 (^{68}Ga) for PET imaging from a $^{68}\text{Ge}/^{68}\text{Ga}$ generator. Both these radioisotopes are produced with a cyclotron. The $^{68}\text{Ge}/^{68}\text{Ga}$ generator system is used as a source for ^{68}Ga which is used to label peptides and monoclonal antibodies for the diagnosis of neuroendocrine tumours.

In diagnostic medicine, there is a strong trend to using more cyclotron-produced radioisotopes such as fluorine-18 (^{18}F) as PET and PET-CT become more widely available. For PET imaging, the main radiopharmaceutical is fluoro-deoxy glucose (FDG) incorporating ^{18}F which has a half-life of just under two hours as a radioisotope. The ^{18}F -FDG is readily incorporated into the cell without being broken down, and is a good indicator of cell metabolism. However, the procedure needs to be undertaken within two hours reach of a cyclotron, which can be a limitation.

Alpha-particle-emitting radioisotopes have been the subject of considerable investigation as cancer therapeutics, and a number of reviews on this topic have been published. In the context of targeted therapy, alpha particle emitters have the advantages of high potency and specificity. This technique is also referred to as Targeted Alpha Therapy (TAT). There is a strong probability that TAT will play an important role in the treatment of disseminated, chemoresistant and radioresistant metastatic disease, against which there are no efficacious treatment options. Recently a pharmaceutical grade radium-223 chloride solution (reactor-produced radioisotope) was the first Alpha-particle-emitting radiopharmaceutical to be approved for clinical use in the treatment of metastatic bone disease. Other Alpha-particle-emitting radioisotopes that are medically relevant and currently available for the potential therapeutic application are astatine-211 (^{211}At), bismuth-213 (^{213}Bi), actinium-225 (^{225}Ac), lead-212 (^{212}Pb), thorium-227 (^{227}Th) and terbium-149 (^{149}Tb). The production of these radioisotopes range from reactors, cyclotrons and generator systems. The cyclotron produced Alpha-emitting radioisotopes are limited to ^{225}Ac , ^{213}Bi and ^{211}At .

Theranostic (therapeutic-diagnostic) radioisotopes have in recent times also been receiving attention. Theranostic radioisotopes i.e. matched pairs of radioisotopes that behave in the same way in vivo as an imaging radioisotope and a therapeutic radioisotope. For example the matched pair of scandium radioisotopes has been cited in literature as a typical example. The ^{43}Sc (half-life = 3.9 h) radioisotope can be used for the diagnostic nuclear medicine application and the match pair of ^{47}Sc (half-life = 3.4 d) can be used for the therapeutic

nuclear medicine application. Others include the matched pair of ^{123}I (diagnostic) and ^{131}I (therapeutic); ^{64}Cu (diagnostic) and ^{67}Cu (therapeutic); ^{152}Tb (diagnostic) and ^{149}Tb (therapeutic).

1.2 Existing Operations and Markets

The iThemba LABS Separated Sector Cyclotron beam time is allocated equally to the three major programmes: nuclear physics, medical radiation therapy and radioisotope production. The iThemba LABS Radioisotope Department (RD) uses the 66-MeV proton beam with high currents (up to 250 μA) to produce high-grade radionuclides. Primarily it uses these radioisotopes to produce regularly, on a weekly basis, radiopharmaceuticals under Good Manufacturing Practices for the health benefit of the South African community and secondarily to produce longer-lived radionuclides for the export market to assist cost recovery.

The following diagnostic radiopharmaceuticals are produced routinely by iThemba LABS and delivered to over 25 Nuclear Medicine departments at private and public healthcare facilities, throughout South Africa and Namibia,

- ^{123}I capsules, ^{123}I oral solution/injection and ^{123}I -mIBG injection for tumour localisation and for observing heart, kidney, thyroid and brain function
- ^{67}Ga - citrate injection for inflammatory lesions and tumour localisation
- ^{67}Ga oral resin used as a radioactive solid food tracer
- ^{18}F -FDG for oncology, cardiac and neurological applications and
- $^{68}\text{Ge}/^{68}\text{Ga}$ generators for neuroendocrine tumours (for the export market as well).

The short-lived radiopharmaceuticals such as ^{67}Ga , ^{123}I and ^{18}F -FDG that are produced by iThemba LABS on a weekly basis for the local South African market (>25 clients) cannot be imported into the country because of its relatively short half-life (shelf-life). Only ^{18}F -FDG is produced by two other facilities (Necsa/NTP and PETLABS) within South Africa, but iThemba LABS is the only facility in the Western Cape that is able to produce this 2 hour half-life radiopharmaceutical. iThemba LABS thus performs a very important function in the service chain of nuclear medicine studies and applications in South Africa.

The long-lived radionuclides that are produced and despatched to over 100 clients worldwide include ^{82}Sr targets (used for the preparation of $^{82}\text{Sr}/^{82}\text{Rb}$ generators for myocardial perfusion studies), $^{68}\text{Ge}/^{68}\text{Ga}$ generators (used for neuroendocrine tumours) and UHV ^{22}Na positron sources (used in positron annihilation studies). iThemba LABS still remains the only supplier of UHV ^{22}Na positron sources in the world and is presently servicing a market base of over 35 active clients worldwide. It is also one of the three major suppliers of the $^{68}\text{Ge}/^{68}\text{Ga}$ generator worldwide with a market footprint of 40%. It produces 20% of the world demand of ^{82}Sr (in the form of irradiated Rb metal targets).

The existing supply agreement with Nordion (Canada) – i.e. the supply of ^{82}Sr (irradiated Rb metal targets) has been in place since 2005 and remains the largest contract for iThemba LABS that contributes close to 50% of the annual sales revenue. Distributor agreements for $^{68}\text{Ge}/^{68}\text{Ga}$ generators are also in place with DSD Pharma (Europe and Middle East), isoSolutions (North America, South American and China) and QT Instruments (Singapore, Malaysia, Thailand, Vietnam and Myanmar markets). The iThemba LABS–NTP Cooperation Agreement on ^{18}F -FDG has been in existence since 2005. The latest development around this agreement was the joint acquisition of an 11-MeV cyclotron dedicated for ^{18}F -FDG production, installed and commissioned at iThemba LABS in 2012.

A quality assurance system in line with current Good Manufacturing Practice (cGMP) requirements encompassing all customer-related activities, legal requirements and production processes is constantly maintained by a staff complement of 25 personnel comprising of chemists, physicists, pharmacists, chemical technologists, mechanical / electronic technologists and administrators. These processes are planned and monitored, using well documented and recorded systems. The RD facilities include two vaults consisting of a high current bombardment station (up to 250 μA) in vault 1 and a medium current bombardment station (up to 80 μA) in vault 2, a 11 MeV cyclotron, two rows of hot cells (each row containing 7 hot cell chambers), three class 100 cleanrooms, quality control and microLAB laboratories and research and development laboratories together with two technical workshops (mechanical and electronic). This system ensures consistent efficiency, reliability and quality of both the radiopharmaceuticals and services rendered to clients. The RD continuously maintains its regulatory licences with the Department of Health (Medicines Control Council and Radiation Control) and South African Pharmacy Council for the production and delivery of radiopharmaceuticals in South Africa and worldwide.

iThemba LABS produces more than 1300 consignments per annum to over 80 clients worldwide and the delivery of consignments correctly and punctually is maintained at a service delivery of above 98%. This has contributed to the patient management of over 100 000 nuclear medicine patients of which 10 000 are local patients.

The RD maintains an active research and development program that encompasses the self-development of personnel involving further studies, supervision of external students from universities and the upgrading of existing processes / products and the development of new products. The RD participated in various Science and Technology bilateral agreements (Germany, Hungary, Italy, Reunion, Algeria, Russia, Switzerland and Reunion) over the years and other research initiatives include projects with the International Atomic Energy Agency (IAEA), Nuclear Technologies in Medicine and the Biosciences Initiative (NTEMBI) and nuclear medicine departments of local hospitals and universities. The research themes are based on the development and the transfer of technology that involve i) targetry development and modelling ii) chemical processing iii) radiolabelling and iv) production, dispensing, quality control processes together with cGMP principles. In recent years, the research and development programme has been continuously compromised because of the demands of the routine production of radioisotopes. Table 1 indicates the publications and conference proceedings since 2009.

Table 1. Publications and Conferencing Proceedings since 2009

	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16
Publications	5	6	5	2	3	3	1
Conference Proceedings	3	1	3	2	1	3	1

Table 2 shows a list of some of the radioisotopes that iThemba LABS had produced over the past >25 years for commercial and research purposes.

The available beam time of the SSC is essentially fixed by the present beam schedule. To increase radioisotope production, iThemba LABS has introduced a number of innovations to increase the beam current to produce a greater quantity within the allocated beam time. These include the introduction of “flat-topping” in the SSC, a new vertical target station, and beam-splitting. The possibilities for further increases in beam current with the SSC are now exhausted. Any further growth in production can only be met by an increase in beam time which would come at the expense of one or more of the other programmes or procuring a dedicated cyclotron for production of radioisotopes.

Table 2: A list of some of the radioisotopes produced by iThemba LABS over the past 25 years for commercial and research purposes

Isotope	Half-life	Use
Gallium-67	78 h	Tumour imaging, localisation of inflammatory lesions (infections).
Iodine-123	13 h	Thyroid, heart, brain, kidney studies
Fluorine-18	109.8 m	F-18 in FDG (fluoro-deoxy glucose) is important in detection of cancers and monitoring of treatment, using PET.
Gallium-68	68 m	Positron emitter used in PET and PET-CT units. From Ge-68. Neuroendocrine tumour localisation
Germanium-68	271 d	Generator to produce Ga-68. Calibration sources.
Rubidium-81	4.6 h	Generator for Kr-81m.
Krypton-81m	13 s	Kr-81m gas can yield functional images of pulmonary ventilation, e.g. in asthmatic patients, and for the early diagnosis of lung diseases and function.
Strontium-82	25 d	Generator for producing Rb-82.
Rubidium-82	1.26 m	Convenient PET agent in myocardial perfusion imaging.

Sodium-22	2.2 y	Positron-annihilation studies
Indium-111	2.8 d	Specialist diagnostic studies, e.g. brain studies, infection and colon transit studies.
Thallium-201	73 h	Diagnosis of coronary artery disease and other heart conditions such as heart muscle death and for location of low-grade lymphomas.
Palladium-103		Used as seeds for prostate cancer therapy
Copper-67	2.6 d	Beta emitter, used in therapy.
Copper-64	13 h	Study of genetic diseases affecting copper metabolism, e.g. Wilson's and Menke's diseases, and for PET imaging of tumours, and therapy.
Cadmium-109	463 d	Calibration sources.
Cobalt-57	272 d	A marker to estimate organ size and for in-vitro diagnostic kits.
Iron-52	8.3 h	Generator for manganese-52, a positron emitter used for PET diagnostics. Fe-52 itself is a positron emitter used as an iron tracer for the study of red blood cell formation and brain uptake.
Magnesium-28	21 h	A tracer in bone studies.
Barium-128	2.43 d	Generator for positron-emitting cesium-128, a potassium analogue, used for heart and blood-flow imaging.
Yttrium-88	106.7 d	Calibration sources.
Zirconium-88	83.4 d	Used as a $^{88}\text{Zr}/^{88}\text{Y}$ generator for biodistribution studies

2 ACE Isotope Programme

2.1 Introduction

The ACE Isotope programme is expected to respond to (i) additional beam time for research and human capacity development, (ii) maintain and develop South African radioisotope research to remain at the international forefront, and (iii) increase radioisotope production to exploit market potential/opportunities consolidating and strengthening South Africa's market footprint in the global market. It is also anticipated that the increase in revenue from radioisotope sales will be used to fund Phase II of the LERIB project which requires post acceleration of radio-active beams for high energy research applications. There are very few high-energy cyclotrons (>45 MeV energy) in the world that produces radioisotopes on a commercial basis. These cyclotrons shown in Table 3 are limited to the facilities such as iThemba LABS (South Africa), INR (Russia), Cyclotron Co.(Russia), ARRONAX (France), TRIUMF (Canada), LANL (United States), BNL (United States), and soon to be

commissioned facilities such as ZEVACOR (United States) and LEGNARO (Italy). Many of these facilities are heavily subsidised by their own government funding and have been in existence for many decades. Many of these facilities also have a radioisotope production programme that competes with other programmes such as the nuclear physics research and/or medical therapy for the available beam time of the cyclotron. The new facilities coming on-line include ZEVACOR (USA) and Legnaro National Laboratory (Italy). ZEVACOR is the first private company based in the United States of America that will commercialise the production of radioisotopes using a 70 MeV cyclotron.

Independent survey reports suggest that the market growth for high energy cyclotron produced radioisotopes is expected to grow between 15-20% on an annual basis. The two high energy cyclotron-produced radioisotopes where demand outstrips supply include ^{82}Sr and ^{68}Ge . This was the basis of the ZEVACOR business plan. It is therefore imperative to understand that South Africa only have a finite window of opportunity for the full installation and commissioning of the 70 MeV cyclotron so as to avoid the possible loss of existing market footprint and/or possible expansion of the market footprint.

The ACE Isotope programme with its dedicated 70 MeV Cyclotron is expected to fully exploit the radioisotope commercial opportunities thereby making South Africa a leading global facility for the supply of high energy accelerator-based radioisotopes. In parallel to the commercial programme, the current research and development programme is expected to be expanded from the existing SPECT and PET radiopharmaceuticals to the investigation of the new wave of radioisotopes which includes Alpha-particle-emitting radioisotopes used for cancer therapy and Theranostic (therapeutic-diagnostic) radioisotopes. Developing and commercialising the aforementioned radioisotopes would greatly enhance the diagnostic and therapeutic nuclear medicine application capabilities of nuclear medicine departments across South Africa.

Table 3: *Worldwide high-energy cyclotron facilities producing radioisotopes.*

Facility	Proton energy	Current (μA)
iThemba LABS, South Africa	Up to 200 MeV	250
INR, Russia	Up to 600 MeV	120
Cyclotron Co., Russia	Up to 22 MeV	1000
ARRONAX, France	Up to 70 MeV	700
TRIUMF, Canada	Up to 500 MeV	100
LANL, United States	Up to 100 MeV	200
BNL, United States	Up to 100 MeV	100
ZEVACOR, United States	Up to 70 MeV	350
LEGNARO, Italy	Up to 70 MeV	350

2.2 ACE Isotope – Commercial Programme

The 70 MeV cyclotron dedicated for radioisotope production and research is proposed to have two separate vaults each containing two bombardment stations. Vault 1 will consist of a medium current (80 μA) bombardment station and high current (250 μA) bombardment station and Vault 2 will consist of a high current (250 μA) bombardment station and a research bombardment station (targetry development). The cyclotron is proposed to have two extraction ports operating simultaneously at the desired currents for each station 24/7 for 48 weeks of the year (4 weeks maintenance period). Figure 1 shows the proposed layout of the 70 MeV cyclotron with its two vaults each containing two bombardment stations which is proposed to be positioned in the existing proton and neutron vaults of the Medical Radiation Therapy programme. The blue part of the Figure 1 indicates the Low Energy Radioactive Beam (LERIB) project which is discussed in the DSP and AED sections. The full installation and commissioning of phase 1 - ACE Isotopes over a 4 year period is estimated to be R550m.

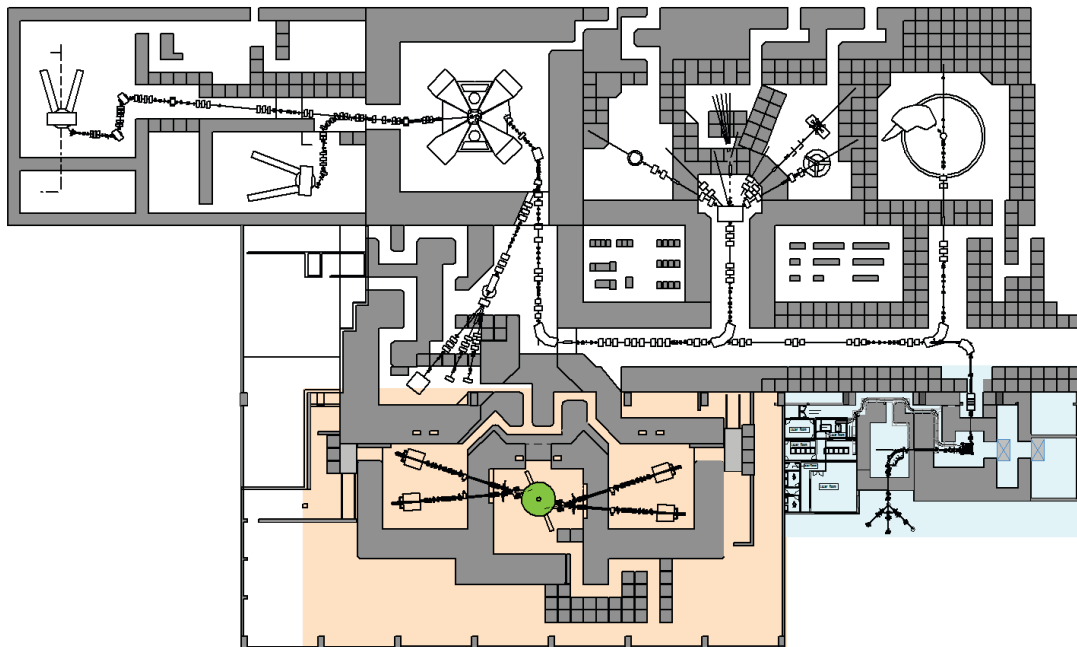


Figure 1: Proposed layout of the 70 MeV cyclotron with its two vaults each containing two bombardment stations

An independent market survey compiled by an external company, Chrysalium Consulting in March 2015, revealed that a strong market demand exists for products produced by a 70-MeV cyclotron. Various other products could also be developed and added to the product mix.

Table 4 below shows the costing breakdown of the Radionuclide Department Facilities that needs to be upgraded. The large part of the upgrade requires the establishment of four new bombardment stations and its related infrastructure such as the cooling systems, transport system and control systems together with the upgrades of hot cells, production laboratories, quality control laboratories and technical workshops for mechanical and electronic manufacture.

Table 4: Costing Breakdown of Radionuclide Department Facilities

Cost Item	Cost R'000
Bombardment Target Stations (x4)	50 000
Water Cooling System	10 000
Helium Cooling System	10 000
Transport System	5 000
Target Storage Area	5 000
Control Electronics / Infrastructure	5 000
Upgrade of reception hot cells and chemical processing hot cells	5 000
Upgrade Targetry workshop: electron beam welder, milling and turning machines, etc.	10 000
Upgrade hot workshop: milling and turning machines, etc	5 000
Chemical Processing, Dispensing and QC equipment	15 000
Total	120 000

2.3 ACE Isotope – Research and Development Programme

The ACE Isotope research and development programme is expected to expand on the current programme which focused mainly on the development of SPECT and PET radioisotopes as indicated in Table 2. The radiolabelling focussed mainly on SPECT ^{123}I -labelled products (^{123}I -mIBG, and fatty acids), PET ^{68}Ga -labelled products (^{68}Ga -DOTATATE, ^{68}Ga -DOTATOC and ^{68}Ga -DOTANOC) and ^{18}F -labelled products (^{18}F -FDG and ^{18}F -fallypride). Several other PET ^{68}Ga and ^{18}F based radiopharmaceuticals would be developed and these include ^{68}Ga -Bombesin and ^{68}Ga -PSMA for prostate cancer diagnosis, ^{68}Ga -RGD as a biomarker for angiogenesis, ^{68}Ga -bisphosphonates for bone scanning, ^{68}Ga -UBI (29-41) for imaging infection, ^{18}F -DOPA for brain tumour localisation and ^{18}F -FLT for cell metabolism studies.

The new wave of radioisotopes which includes Alpha-particle-emitting radioisotopes used for cancer therapy and Theranostic (therapeutic-diagnostic) radioisotopes are receiving considerable attention in recent years. Developing and commercialising the aforementioned radioisotopes would greatly enhance the diagnostic and therapeutic nuclear medicine application capabilities of nuclear medicine departments across South Africa. In the context of targeted therapy, alpha particle emitters have the advantages of high potency and specificity. These advantages arise from the densely ionizing track and short path length of the emitted positively charged helium nucleus in tissue. The practical implication of these features is that it is possible to sterilize individual cancer cells solely from self-irradiation with alpha-particle emitters, a result that is not possible to obtain with beta-particle emitters

given dose-deposition characteristics, achievable radiopharmaceutical specific activity, tumour-cell antigen expression levels and the need to avoid prohibitive toxicity. This is a clear distinction between the potential of alpha-therapy and that of the more widely used radionuclide therapy based on beta-particle emission (generally radioisotopes produced by a reactor).

These attributes combine to provide the fundamental strength and rationale for using Alpha-particle-emitting radioisotopes for cancer therapy. Current approaches to cancer treatment are largely ineffective once the cancer has metastasized and cancer cells are disseminated throughout the body. Thus the task is to eliminate isolated cancer cells in transit, cancer cell clusters and vascular tumours. There is also increasing evidence that not all tumour cells are relevant targets for effective tumour eradication and that sterilization of a putative sub-population of tumour stem cells may be critical to treatment efficacy. The eradication of such stem cells requires a targeted therapy that is potent enough to sterilize individual cancer cells and microscopic cancer cell clusters (even at low dose-rate and low oxygen tension), and that exhibits an acceptable toxicity profile. Alpha-particle emitting radioisotopes address this critical need. This technique is also referred to as Targeted Alpha Therapy (TAT). There is a strong probability that TAT will play an important role in the treatment of disseminated, chemoresistant and radioresistant metastatic disease, against which there are no efficacious treatment options. Combined with other therapies, including chemotherapy, signalling pathway inhibitors and even targeted beta emitting radioisotopes, TAT is likely to improve survival. In specific cases (e.g., brain tumours) TAT may also play a role in first line treatment of cancer, prior to surgery, for instance. Radium-223 chloride solution (reactor-produced radioisotope) was the first Alpha-particle-emitting radiopharmaceutical to be approved for clinical use in the treatment of metastatic bone disease. Other Alpha-particle-emitting radioisotopes that are medically relevant and currently available for the potential therapeutic application are astatine-211 (^{211}At), bismuth-213 (^{213}Bi), actinium-225 (^{225}Ac), lead-212 (^{212}Pb), thorium-227 (^{227}Th) and terbium-149 (^{149}Tb). There is a continuous effort to develop simpler and more efficient production methods of Alpha-particle-emitting radionuclides to make them widely available for investigational and clinical purposes. The production of these radioisotopes range from reactors, cyclotrons and generator systems. ACE Isotope will focus on the development and commercialisation of the cyclotron produced Alpha-emitting radioisotopes that is limited to ^{225}Ac , ^{213}Bi , $^{225}\text{Ac}/^{213}\text{Bi}$ generator and ^{211}At (requires an alpha beam).

The radioisotope ^{225}Ac is a pure alpha emitter with a half-life of 10 days. The predominant decay path of ^{225}Ac yields net four alpha particles with a large cumulative energy of 28 MeV and two beta disintegrations having maximum energy of 1.6 and 0.6 MeV. Its relatively long half-life of 10 days and the multiple alpha particles generated in the rapid decay chain render ^{225}Ac a highly cytotoxic radioisotope. The radioisotope ^{213}Bi is a mixed alpha/beta emitter with a half-life of 46 min. The majority of the total particle energy emitted in each disintegration of ^{213}Bi originates from alpha decay (92.7%), while only 7.3 % of decay energy is contributed by beta particle emission. The alpha particle energy emitted per disintegration of ^{213}Bi is considered in the main to be responsible for its cytotoxic effects. Based on the levels of ^{213}Bi activity administered in clinical studies to date, it can be

estimated that combining all sources of $^{225}\text{Ac}/^{213}\text{Bi}$ currently available up to 100–200 patients could be treated annually worldwide. However, for a widespread clinical application of ^{213}Bi the availability of $^{225}\text{Ac}/^{213}\text{Bi}$ has to be increased significantly and an automated cheaper production scheme is needed. The production of ^{225}Ac is limited due the high energy cyclotron (100 MeV) required for optimal production. The 7.2h half-life radioisotope ^{211}At offers many potential advantages for TAT. However, its use for this purpose is constrained by its limited availability. ^{211}At can be produced in reasonable yield from irradiation of natural bismuth targets via the $^{209}\text{Bi}(\alpha,2n)^{211}\text{At}$ nuclear reaction utilizing straightforward methods. The intrinsic cost for producing ^{211}At via this nuclear reaction is reasonably modest and comparable to that of commercially available reactor-produced Iodine-131. Moreover, its production cost is lower than that of most other alpha-particle emitters under consideration for therapeutic application.

Theranostic (therapeutic-diagnostic) radioisotopes have in recent times also been receiving attention. This is where radioisotopes of matched pairs behave in the same way in vivo as an imaging radioisotope and a therapeutic radioisotope. For example the matched pair of scandium radioisotopes has been cited in literature as a typical example. The ^{43}Sc (half-life = 3.9 h) radioisotope can be used for the diagnostic nuclear medicine application and the matched pair of ^{47}Sc (half-life = 3.4 d) can be used for the therapeutic nuclear medicine application. Others include the matched pair of ^{123}I (diagnostic) and ^{131}I (therapeutic); ^{64}Cu (diagnostic) and ^{67}Cu (therapeutic); ^{152}Tb (diagnostic) and ^{149}Tb (therapeutic). ACE Isotopes would have the capacity to research and develop the aforementioned radioisotopes and make them commercially available in order to greatly enhance the diagnostic and therapeutic nuclear medicine application capabilities of nuclear medicine departments across South Africa. ACE Isotopes will collaborate with universities and radioisotope institutions to develop a cohort of researchers in the field.

The research and development of the above radioisotopes and radiopharmaceuticals will cover all research aspects as described below:

- Targetry Development (Nuclear Physics)
- Measurement of excitation functions and target yields for radioisotope production.
- Computational flow dynamics (CFD) modelling of target irradiations.
- Radiation modelling of the bombardment stations and target transport (using MCNPX).
- Radiochemical separations for the development of radioisotopes
- Radiolabelling for the development of radiopharmaceuticals
- Optimisation and development of dispensing processes
- Optimisation and development of quality control processes

2.4 ACE Isotope – Proposed Structure

It is envisaged that the ACE Isotope structure will consist of two arms. One arm focussing on the commercialisation programme and the other arm on the research and development of radioisotopes / radiopharmaceuticals. It is expected that there will be three bombardment stations allocated for the commercial programme and one bombardment station for the research and development programme and therefore resources will be allocated accordingly to meet the demands for both programmes. It is expected that the current complement of 25 personnel would under the ACE Isotope commercial programme increase to 40 personnel. The additional 15 personnel will include the following:

- Targetry and Bombardment Technologist X4
- Chemical Technologist (Chemical Separations/Dispensing/Quality Control) X10
- Administrative Clerk X1

The Research Arm to consist of 2 x chemists, 2 x physicists, 1 x organic chemist and 2 post docs (on contract) to focus on targetry, radiochemistry and radiolabelling aspects of radioisotope / radiopharmaceutical development.

3 Conclusion

The current radioisotope production and research programme of iThemba LABS has over 25 years' experience in the development and commercialisation of SPECT and PET radioisotopes and radiopharmaceuticals. It has an established market network of over 100 clients worldwide. It produces these radioisotopes and radiopharmaceuticals under stringent national and international regulatory requirements and is able to ship these products from the tip of Southern Africa to all parts of the world. It has a proven track record on the research and training of resources in the radioisotopes. The newly formed Nuclear Medicine Department of iThemba LABS is well equipped and positioned to take on the new mandate of ACE Isotopes.

Medical Radiation Biophysics

1. Abstract

Future research and development in medical radiation biophysics will be driven by the unique strength of the Department: the convergence of expertise in the fields of radiation biology, medical physics, and applied mathematics. The repurposed Department will exploit this optimally to investigate the relationship between radiation quality and biological effect.

The tools needed for this must include accurately-specified radiation beams of different modalities (protons, neutrons, and photons) with a range of energies. This must be supported by a research infrastructure which comprises the necessary laboratory, dosimetry, and computer equipment; as well as the staff to use it all. The radiation qualities will need to be precisely quantified by physics measurements, supported by Monte-Carlo simulation where measurements are not practical.

The results of exposing different biological systems to different radiation qualities will ultimately contribute to the unfolding of biological response functions from these various radiation qualities. This will be of fundamental importance to a range of applications in particle therapy and radiation protection. These include the biological effective dose in treatment planning, evaluation of the dose-volume effect in small-field treatments, calculation of effects of secondary radiation during therapy, and prediction of health effects of accidental exposures.

Other activities of the department will still be included, such as participation in national initiatives to develop novel radiopharmaceuticals by studying the in-vitro cell-receptor mediated uptake of radiolabelled compounds in specific cancer cell types. Extension of the current biodosimetry research to include modern molecular methods to answer critical questions in radiation protection and medical surveillance of radiation workers is also envisaged. This will allow participation in the research programmes of large international consortia of biodosimetry laboratories.

The envisaged research activities, and their supporting infrastructure, will foster a broader interaction with local and international universities as well as national research platforms in South Africa established to improve research output in radiation medicine. This will attract undergraduate and post graduate students in physics, life sciences, radio-chemistry, and nanomedicine.

2. Introduction

2.1 *Vision*

The vision of the department is to use its unique expertise and the variety of radiation modalities and energies available at iThemba, to explore the interactions of different radiation qualities with different biological systems.

2.2 Goal

The goals of the Department are to:

- Conduct world-class research leading to a better understanding of the biological effects of different particle radiation types and energies and radiopharmaceutical compounds.
- Contribute to future research by inspiring and training a new generation of researchers
- Continue to serve the broader community by offering bio-dosimetric follow-ups to radiation incidents nationally and internationally

2.3 History

The Medical Radiation Biophysics Department at iThemba LABS has long-standing expertise in medical physics and radiobiology research for particle therapy, and a history of upgrading existing facilities and developing new ones. Until recently, the main object of the Department was patient therapy with beams of protons or neutrons.

The medical physics involvement focused on the quality assurance, maintenance, and upgrading of existing facilities, as well as the development of new facilities. The proton-therapy treatment nozzle and the entire patient positioning and beam control system are examples of such in-house developments. Despite this, research was undertaken, with a total of 90 publications over the 30-year history of the department. Topics covered include beam spectroscopy, dosimetry, microdosimetry, radiation safety, and studies of radiation effects on solid-state devices. Some of these projects took place in-house, and others in collaboration with national or international institutions; most recently with the international “Proton Radiotherapy Verification and Dosimetry Applications” (PRaVDA) consortium, of which iThemba is a member.

Biological research activities in the Department are aligned with national health priorities as defined by the Nuclear Technologies in Medicine and Biosciences Initiative (NTEMBI) survey made 6 years ago. These include nanomedicine, stem cell research, infectious disease, neurology and priority cancers. These priorities are addressed in the Department’s research, which includes: in vitro cancer cell uptake studies of radiolabelled compounds for early detection and treatment of cancer; tissue response to small field irradiations; radiosensitivity of breast and cervix cancer patients; as well as the influence of HIV status on patient radiosensitivity. This resulted in 29 publications in the past five years.

The Department has offered a bio-dosimetry service to radiation workers in South Africa and neighbouring States for the last 25 years under the auspices of the Department of Health. This activity is recognized by Radiation Emergency Medical Preparedness and Assistance Network (REMPAN) of the World Health Organization. In recent years, the laboratory also participated in emergency response exercises organised by the EU initiative ‘Realizing the European Network of Biodosimetry’ (RENEB). This resulted in 4 publications in 2016/17.

The excellent facilities and availability of neutron and proton beams which are accurately characterised have attracted visiting scientists for years, and many students have been trained in radiobiology, radiation oncology, and medical physics in the department. This has been aided by 2 international grants from the Flemish Inter University Council (VLIR), which

made it possible to acquire new equipment, and by financial support from the NTeMBI network.

2.4 Current status

The Department has not had a clinician since December 2015, which marked the end of the routine therapy programme. This has been followed by the departure of several key medical staff members. Proton therapy is not supported anymore by the medical community as they request fractionated treatments that cannot be provided by iThemba LABS. Neutron therapy is poorly supported by the radiation oncology centres in South Africa as both academic hospitals and private radiotherapy practises lack radiation oncologists trained in using high-LET radiation for cancer therapy. The proposed use of the neutron and proton therapy vaults by the South African Isotope Facility (SAIF) project for the installation of a new 70 MeV cyclotron and isotope bombardment stations clearly indicates that the resumption of the therapy programme is extremely unlikely. This necessitates a long range plan that is completely different to what has been before.

In order to realise the goals of the Department the following decisions have already been taken and implemented:

In the absence of a therapy programme the future of the Department lies in research and training.

The various sections in the Department must come together with mutually complementary research.

These decisions have already been put into effect. A series of measurements in March and April by the Department in collaboration with institutions in Belgium and Australia have exploited the synergy between radio-biology, dosimetry, and microdosimetry. Thanks to our collaborators a number of detectors which were not available at iThemba can now be used. Monte-Carlo (MC) modelling will be added to complement the measurements.



Figure 1: Cell survival of samples irradiated to the same dose at 6 different positions in the distal edge of the proton therapy beam. A large variation of radiation quality is evident.

2.5 *The future*

The proposals for future research in the Department have already begun, and can be continued as long as the current beamlines are available. If the SAIF project does move into the current therapy vaults it will necessitate the development of new beamlines elsewhere. This will result in a possible delay in the research programme, and is dealt with in a subsequent section.

A list of proposed research projects for the future has been drawn up, several of which align with the broad objectives of the Nuclear Medicine Research Infrastructure (NuMeRI). Most of the research projects will use a combination of physics and biological techniques to investigate the topic and reach their conclusion. In addition to these projects, the Department will remain open to approaches by other groups who need accurately characterised beams and want to use our facilities for their own projects.

Proposed fields of research are:

- A series of radiobiology and microdosimetry measurements will be conducted using a wide range of neutron beam energies to obtain the data needed for the unfolding of the radiobiological response functions.
- The existing bio-dosimetry service will be continued, and new techniques will be investigated. MC modelling will be implemented to investigate the doses delivered to victims of radiation incidents.
- The Department will extend its current capabilities for studies with radiolabelled compounds in order to support the development of novel radiopharmaceuticals within the framework of the SAIF project and existing national initiatives, such as NTeMBI and Nuclear Medicine Research Infrastructure (NuMeRI). These include:
 - Identification of compounds suitable for early detection and treatment of cancers by in-vitro uptake studies of radiolabelled compounds.
 - Development of more sophisticated methods to verify cell membrane receptor-mediated uptake of radiolabelled compounds. These include molecular methods to up/down regulate cell receptor expressions as it is vital to identify promising compounds suitable for micro-PET/SPECT pre-clinical imaging.
 - In vivo bio-distribution studies in collaboration with NuMeRI stakeholders using our well-detector and liquid-scintillation-detection methods for different tissue types.
 - Studies of cancer and normal cell response to alpha- and Auger electron-emitting radionuclides.
- Investigation of the variations in the biological effectiveness of proton beams at different positions in the Bragg curve. This project has already begun (in March/April 2017), with the ultimate aim of developing radiobiological-based treatment planning:

where the treatment will be prescribed in terms of the final biological result, rather than in terms of the physical dose delivered.

- Out-of-field radiation risk estimates for paediatric proton therapy applications. This project also began in March/April 2017, and uses radiobiological measurements, ionization chambers, proportional counters, bubble detectors, track detectors, and thermo-luminescent dosimetry to evaluate the different components of the mixed-radiation field adjacent to the treatment volume.
- If the SAIF project does take over the therapy vaults, and new beam lines are developed, then the energy spectra of the new beams (proton and neutron) must be measured. MC techniques will be used to design new neutron sources. The gamma components of the new neutron beams must also be characterised.
- Investigation of radiosensitivity of haematopoietic stem cells to protons and neutrons of different energies.
- Investigation of radiosensitization effects on cancer cell responses to particle therapy using gold nanoparticles.
- In vivo neuro-radiobiology studies including neuro-chemical studies in brain tissue following exposure to protons and neutrons. This to assess both early and late central nervous system effects in normal brain tissue. DNA double strand induction and repair in small tissue sections. As a prerequisite there will be an investigation into the dosimetry of small fields.
- The development of methods to evaluate complex functional endpoints is essential for future particle therapy research. These will aim to follow clustered DNA damage and repair pathways, anti-angiogenic and metastatic effects of protons on cancer cells.
- Gene expression and apoptosis for neutron irradiation to predict late normal tissue toxicity for high- and low-LET particle therapy.
- Ex-vivo early tissue damage studies from protons and neutrons to follow dose volume effects using small fields.
- Developing single cell sorting methodologies to investigate low dose hypersensitivity and radiation induced resistance to particle radiation types.
- Investigating the use of new molecular markers for stable chromosomal aberrations to assess residual radiation damage for radiation exposure incidents
- Studying HIV influence on the radiosensitivity of individuals exposed to alpha-particles, as it is relevant to large populations of miners working in South Africa. Cell exposures to radiation beams with ionization densities greater than 100 keV/micron will be conducted using the dose build-up region of a fast neutron beam.
- Validation of neutron-measurement data. The quasi-mono-energetic neutron beams with energies 40 – 200 MeV available at the proposed iThemba LABS neutron metrology facility will be used to validate the response of proportional counters, bubble detectors, and track detectors to neutrons of different energies.

- Investigation of the angular dependence of silicon-based microdosimeters.
- Investigation of the response of bubble detectors to charged-particle fields.
- Investigation of weighting factors for different energy fast neutrons to predict biological effectiveness using physical hypersensitivity of cellular radiation response at very low doses of neutrons and protons. This to elucidate underlying mechanisms on the linear no-threshold model used in radiation protection.
- Extensive simulations to validate physical models used in MC codes against measured data.
- Investigation of the use of Monte Carlo codes for treatment planning including radiobiological dose, tumour control probability and normal tissue complication probabilities.

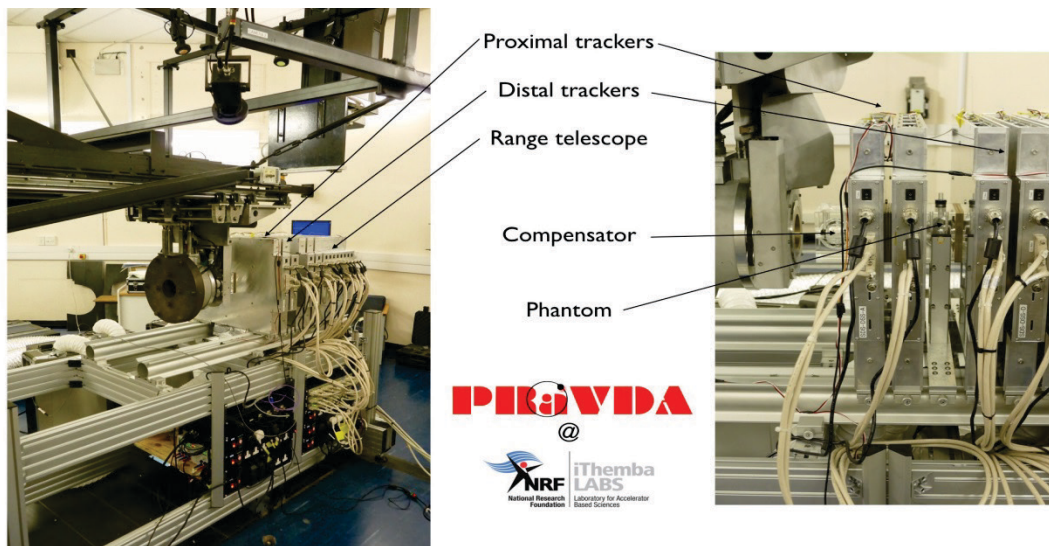


Figure 2: Experimental set up for Proton Computerized Tomography (pCT)

2.6 Development of new research facilities

2.6.1 Background

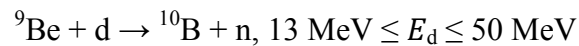
The research plan requires modern beam delivery systems capable of providing proton and neutron fields of clinical interest, with a precise control over the beam properties and dose delivery. The current beam delivery systems in the proton and neutron radiotherapy vaults are ideally suited for the research to be conducted in the next year or two, but will have to be modernized and adapted to support the long-term research goals. However, such developments and long-term use of the existing infrastructure is improbable, given that the SAIF project proposes to utilize the therapy vaults for the installation of a new 70 MeV cyclotron and additional isotope bombardment stations. The Department therefore requires the development a new radiation research facility at iThemba LABS to carry out its long-term research objectives.

2.6.2 Requirements

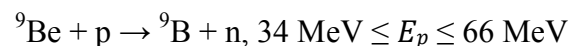
The new facility will be composed of a radiation vault equipped with two horizontal beam lines, together with ancillary facilities, such as a power supply room, physics laboratory, radiobiology preparation room, and a storage room. One beam line will be equipped with a proton beam delivery system (treatment nozzle) and the other with a neutron beam delivery system. The beams for these two delivery systems will be supplied by the separated sector cyclotron (SSC), with a switching magnet used to direct the beam to the required system.

The physics laboratory will house the control systems for the beam delivery systems and the electronic instrumentation needed for dosimetry, and will also serve as the control room from which to operate the beam delivery. The preparation room is essential for the preparation and temporary storage of biological samples and animals to be irradiated during experiments, whereas the storage room will be used to keep the instrumentation and equipment that is not actively used. These rooms should all be in close proximity to the radiation vault so as to facilitate experiments in which numerous radiobiological samples have to be irradiated, one at a time. Ideally, the new radiation research facility should be located close to the existing radiobiology facilities at iThemba LABS.

The treatment head and various other components from the existing neutron therapy unit will be used to construct the neutron beamline for the new facility. This treatment head provides a convenient platform for the production of collimated neutron beams with different energy spectra, or beam qualities. This follows since the target system in the head is readily replaceable when the latter is mounted in a horizontal beam arrangement. The particle type and energy of the beam from the SSC can readily be chosen to match a specific target. It is therefore possible to cater for different neutron sources based on both the d-Be reaction:



and the p-Be reaction:



thus yielding neutron beams with a wide range of beam qualities as required by the research plan. The flattening filters and hydrogenous filter in the treatment head will ensure that the neutron beams are modulated to produce large rectangular fields of clinical interest. The size of these fields can readily be adjusted by means of the main book-end collimator of the treatment head. A tapered insert for the main collimator will also be developed to produce small circular neutron fields that are less than 1 cm in diameter.

A new control system will have to be developed for the neutron beam line to cater for the adjustment of collimator jaws, to remove or insert the flattening filters, to keep the beam aligned on the target, to read the target current and quadrant signals as part of the beam quality control, and to monitor the dose delivered. In addition, a new safety interlock system will be required for both the proton and neutron beam lines.

A modern proton beam delivery system is essential to do competitive research in particle therapy and to encourage international research collaborations. The pencil-beam scanning technique is rapidly becoming the standard method of beam delivery in modern proton therapy. It offers the advantage of providing complex treatment fields, as well as a single

static pencil beam with a well-focused and narrow dose distribution (especially at shallow depths). However, the traditional passive-scattering technique simplifies many experimental setups and therefore remains extremely useful for a wide range of applications. The proton beam line for the new facility should therefore be equipped with a universal treatment nozzle capable of supporting both the passive and active beam delivery techniques.

The development of a universal proton treatment nozzle is a complex task, but some simplifications can be made since it will only be used for experimental work, and not for the treatment of patients. For example, it is not necessary to cater for very large field sizes, or to have passive-scattered beams with widely spread-out Bragg peaks, or to cater for a large number of energy layers in the case of pencil-beam scanning. Furthermore, only a limited number of discrete beam ranges are required. A particular range can be achieved by tuning the SSC to supply the beam with the required energy. This eliminates the need for a continuously-adjustable energy degrader and simplifies the design of the flattening filters needed for the passive-scattering technique. However, these simplifications do not reduce the complexities involved in the detectors and control systems needed for the active pencil-beam scanning technique. It will therefore be more cost-effective to procure a commercial solution instead of developing the nozzle and the associated control systems in-house.

2.6.3 Possible scenarios

The layout of iThemba LABS allows for three possible scenarios to realize the implementation of the required radiation research facility. One option is to continue using the existing beam lines and infrastructure currently available in the proton and neutron therapy vaults. The proton beam delivery system will have to be modernized as outlined above, whereas the treatment head of the neutron gantry can readily be adapted to cater for the different neutron sources. This scenario is the least expensive option since it requires no new buildings, and will also be the most convenient one for the Department since all the support structures are in place. However, as mentioned earlier, this scenario is improbable in view of the proposed plans for the SAIF project.

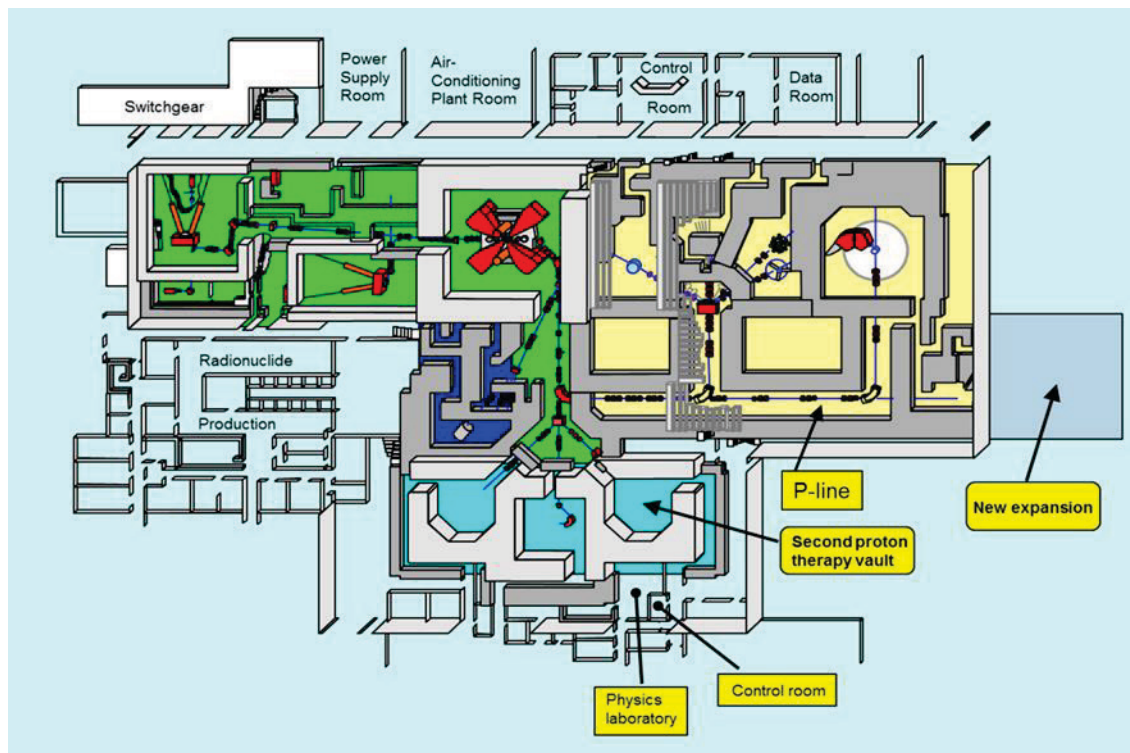


Figure 3: Layout of the iThemba LABS facility showing the second proton therapy vault and a possible new expansion (grey block) at the end of the P-line to accommodate the new radiation research facility.

Another very attractive option is to utilize the second proton therapy vault for the establishment of the new radiation research facility (figure 3). This vault is large enough to accommodate all the equipment needed for the two beam lines, while leaving enough space to cater for water tanks, dosimetry phantoms, optical benches, trolleys and tables needed for different experimental setups. This vault is also relatively close to the existing radiobiology facilities at iThemba LABS. Furthermore, the building costs will be low as a physics laboratory and a control room already exist near the vault. The Department’s mechanical workshop, which is also close to the vault, can readily be converted into a preparation room needed for the radiobiological experiments. This proposal allows for the development work on the new research beam lines to commence as soon as it is approved and funded.

A third option is to construct a new facility at the end of the P-line, including a new vault large enough to accommodate the required neutron and proton beam lines (figure 3). This option will most certainly be the most expensive one, given the large cost for constructing a radiation vault with adequately thick concrete walls needed for proper shielding. The required construction work will also lead to much a longer implementation schedule, which will be highly problematic if the infrastructure in the existing therapy vaults will be dismantled in near future to prepare for the installation of the new 70 MeV cyclotron and additional isotope bombardment stations.

2.6 4 Feasibility study

A feasibility study will be conducted to finalize the location of the new radiation research facility, to determine the final specifications for the new beam lines, and to obtain cost estimates for the major equipment. The feasibility of developing the new research facility and the research objectives needs to be submitted to the DST for approval for possible funding through NuMeRI.

3. International collaborations

Although the particle therapy facility at iThemba LABS already existed for more than 25 years, it has been frequently updated and well maintained, which continues to make it attractive for international users. Furthermore, iThemba LABS does not only offer access to unique particle radiation facilities for both proton and neutron experiments, it also provides the opportunity for on-site radiobiology experiments in a fully equipped lab within walking distance from the irradiation facility. This is one of the key assets to guarantee reliable, reproducible results and at present, only a minority of particle therapy centres in the world can offer this. The experienced personnel and the unique infrastructure have resulted in a strong international network and user base. Over the past 5 years, international collaborations with the following institutes and research projects took place:

- Belgian Nuclear Research Centre (SCK-CEN) - Institute for Environment, Health and Safety
- Ghent University (Belgium) – Department of Basic Medical Sciences
- Université Catholique de Louvain (Belgium) – Department Molecular Imaging and Experimental Radiotherapy
- Joint Institute of Nuclear Research (Russia) – Laboratory of Radiation Biology
- University of Wollongong (Australia) – Centre for Medical Radiation Physics
- University of Insubria (Italy) Dept. of Life Sciences
- European Network of Bio-dosimetry (RENEB)
- University of Lincoln. PRaVDA Program currently engaged with The Engineering and Physical Sciences Research Council (EPSRC) in the UK for further funding.
- German Cancer Research Centre (DKFZ)
- Universidad Nacional de Colombia, South-South co-operation initiative.

The proposed research beam lines will increase the interest and participation of international users in the long term and should result in an increase of scientific exchange of students, extension of the existing international collaborations and more international project funding for the department.

4. Local Education, Training and User Base

Lectures at local universities are vital to identify postgraduates and suitable new research projects. This is very important for future succession planning in the department and to improve our local user base.

In the past 5 years, 150 undergraduates received practicals on simulation teaching for radiation therapy, 14 Registrars and Fellows were trained in Particle therapy, and 56 courses in radiation biology were given by iThemba LABS personnel throughout the country in the following institutes and training centres:

- University of Witswatersrand (WITS)
- University of Cape Town (UCT)
- University of the Western Cape (UWC)
- Stellenbosch University (SU)
- Cape Peninsula University of Technology (CPUT)
- North West University - part of the MARST programme
- University of the Free State (UFS)
- Charlotte Maxeke Academic Hospital – Johannesburg
- Steve Biko Hospital – Pretoria
- Groote Schuur Hospital – Cape Town
- Chris Hani Baragwanath Hospital – Johannesburg
- Inkosi Albert Luthuli Central Hospital – Durban
- Greys Hospital – Pietermaritzburg
- Eskom training centre – Johannesburg/Koeberg Nuclear Power Plant
- NECSA – Pretoria
- iThemba LABS - using laboratory infrastructure

With these training initiatives, postgraduates suitable for radiation medicine research projects at iThemba LABS and in collaboration with their host institutions have been identified.

Specifically in the last 5 years a user base for various universities has been established. The following National Collaborators are enunciated in the framework of postgraduate research projects:

- University of Pretoria – Dept. Radiotherapy
- University of Stellenbosch – Dept. of Physics
- Free State University – Dept. Radiation Oncology & Medical Physics Department
- WITS University – Dept. Radiation Oncology

- University of Cape Town – Dept. of Radiation Oncology & Medical Physics Department.
- University of Western Cape – Dept. of Medical Sciences
- Cape University of Technology – Dept. Bio-Medical Sciences
- North West University – Centre for Applied Radiation Sciences and Technology
- Postgraduates and local users stem from the Depts. Above

Research and training of postgraduates can be extended by participating in lecture courses at local Universities. New opportunities include the training of staff members at the Centre of Nuclear Safety and Security – the NNR centre of excellence at the University of Pretoria. New recommendations by the IAEA have resulted in new demands for suitably qualified radiation regulators in South Africa. These individuals will need to do research projects and training in radiation biology for radiation protection.

5. Staff requirements

The current structure of the department caters for particle therapy and therefore has a substantial number of medical posts which cannot be accommodated in the proposed new research-oriented long-term plan. These comprise the research radiation oncologist (1 vacant), radiation therapists (2 vacant), and nurses (4 vacant). The decision as to the future of these medical posts falls outside the scope of this plan, and is therefore deferred to Management for resolution.

There are currently additional vacant posts: medical physicist (1), software engineer (1), and data co-ordinator (half-day post). The funding for all vacant posts can be redirected to the proposed new posts.

The following posts can be re-aligned to meet the objectives of the long-term plan: division head (planning and development); division head (operations and treatment); computer vision scientist; supervisor (operations and treatment); medical electronics engineer; software engineer; and mechanical technician.

The following posts will be required to implement the long-term plan:

Permanent research posts:

Current posts

Department Head - retires within 1 year - Replace by Snr Radiation Biophysicist / Radiation Biologists

Administrative Officer - Vacant

Radiation Biologist

Biomedical Technician

Post-Doctoral Fellow – Organic Chemistry – April 2017 to March 2019 (NTeMBI funded)

Medical physicist (x 3)

Radiation Therapists (x 2) – move lateral as Research Assistants in Radiation Biology

New posts

Radiation Biologist - Post-Doctoral Fellow

HPCSA registered Biomedical Technician (B Tech)

Molecular Biologist (MSc)

Micro-dosimetry Specialist

The following new and existing posts that will be relocated to the Instrumentation Department are critical to enable set-up of new proton and neutron irradiation infrastructure for Radiation Biology and Bio-Physical Research.

Software Engineer

Mechanical Technician

Medical electronics Engineer

Numerical Computation Specialist

Monte Carlo Modelling Specialist (new) – to be shared with Radiation Protection and Sub-Atomic Physics



Instrumentation and Information Technology

This section describes the Department of Instrumentation and Information Technology that is proposed to be created as part of iThemba LABS Long Range Plan.

1. Introduction

An Instrumentation group was formed in 2016 as part of the Nuclear Physics Department (now known as the Department of Subatomic Physics DSP). This group was instated in order to address the technical developments needs for nuclear physics experiments. In the past, such developments were often using resources from other departments or undertaken by senior scientists using both internal and external resources.

The Instrumentation group, within the Department of Subatomic Physics (DSP), was initially formed from the EIT (Electronics and Information Technology Department) at the end of 2016. The EIT department was divided into functions that supported the accelerator, IT and research instrumentation departments of iThemba LABS. This group serviced primarily the researchers' needs within the DSP but is also involved in development work in other departments. IT on the other hand was established as a stand-alone-entity to service the entire laboratory in 2016.

Even though the establishment of an instrumentation group has improved the situation within the DSP, it is still subcritical due to skill gaps of the relatively small group. In the context of the long range plan, this group will be converted into a department not only serving physics research but it will more generally address all instrumentation related needs of iThemba LABS for all research departments. The vision of the Instrumentation division of the new Instrumentation and Information Technology Department (IIT Department) is to centralise expertise in the fields of electronics, slow control, IT, high performance computing, detectors technology, target manufacturing and mechanical engineering specifically for designing and developing the needed resources for research. The IIT Department will provide the research groups of iThemba LABS with an efficient channel for instrumentation development to meet international standards promoting research in the physical- and biomedical sciences.

The vision of the Instrumentation part of the department is to be a trusted instrumentation partner to provide the necessary tools for researchers to enable iThemba LABS to be a Centre of Excellence that provides internationally renowned research facilities offering competitive research infrastructure in accelerator based sciences to local and international researchers.

The mission of the Instrumentation Division of IIT Department is to design, manufacture, maintain and support the instrumentation and IT infrastructure of iThemba LABS. It covers a large number of skills and technical fields and it will strive to rationalise instrumentation developments across the various departments to provide users and stakeholders through the research, design and implementation of innovative technologies.

Fragmented technical resources

Currently, the resources at iThemba LABS are very fragmented across the five existing research departments. This has certain advantages in terms of day-to-day operations but on the other hand this proves very inefficient regarding optimal use of resources for large or long term projects and reasonable turn over time for smaller projects. Within the last decade, the procurement process has evolved in South Africa, and indeed in many places worldwide, making it nowadays a very important component in project management. Long procurement process times impact very negatively on delivery times and makes planning increasingly difficult. This becomes a source of inefficiency for smaller groups that are very dependable on delivery times of external suppliers.

Centralised Instrumentation Department

In order to adjust iThemba LABS to this new situation, resources must be re-organised. iThemba LABS needs now to align to similar or larger scale international laboratories using a centralised system for optimal use of resources. Centralisation of resources must be accompanied with rational planning and prioritisation of instrumentation related projects. This will enable the department to reduce the time between start and completion time of projects and increase the overall efficiency by:

- Reducing overhead times, with technical staff working on a lesser amount of projects at a time.
- Faster implementation with less down time during upgrade or changeover of equipment with more staff available for short periods of time
- Better usage of purchased equipment during their warranty period.

The IIT Department will also ensure a better homogeneity of the technology employed within the laboratory with more opportunities of using similar equipment or computer codes across the departments making portability and maintenance more efficient.

The IIT Department, locally and internationally

The centralisation of resources allows for embarking on occasional projects of larger magnitude than currently achievable. This capacity is highly desirable in the context of the Rare Ion Beam projects or other high impact developments which are not achievable within the current organisation. Even though local developments are the priority, international collaboration is also a very important item in a world class laboratory portfolio. iThemba LABS is already exporting a number of such high tech items but iThemba LABS can be even more visible internationally. This needs strategic concerted decisions and access to well-structured technical resources.

A very important goal of the IIT Department is to keep up to date with technology worldwide in other laboratories and in industry. The managing body of the IIT Department will be responsible for exposing and keeping qualified staff up-to-date with modern technologies and industrial standards. Consequently, this ensures efficient deployment of skills and knowledge within the department and increased training opportunities to students and younger staff.

The establishment of the South African Isotope Facility (SAIF) project encompasses the Accelerator Centre for Exotic Isotopes (ACE-Isotopes) and the Accelerator Centre for Exotic Beams (ACE-Beams). The SAIF project is the natural route for iThemba LABS to stay competitive in accelerator based research internationally for decades to come. New technologies and techniques have emerged in the field of rare ion beams. The IIT will be very prominent in the instrumentation development related to these new research platforms. Subsequently, research with accelerated beams will be ever more demanding in terms of highly integrated electronics and complexity of detectors and experimental setups involved. Adequate technical support needs to be gradually implemented, accordingly.

2. The Instrumentation Division of the IIT Department

2.1 Objective

The Instrumentation division of the IIT Department always endeavours to deliver a high quality service to all the stakeholders of the laboratory, either internal or external.

The internal clients are the Materials Research Department, AMS Department, Radionuclide Production Department, Biophysics Department and the Department of Subatomic Physics as seen in figure 1.

External clients are for instance the SA-CERN consortium and researchers from South African universities.

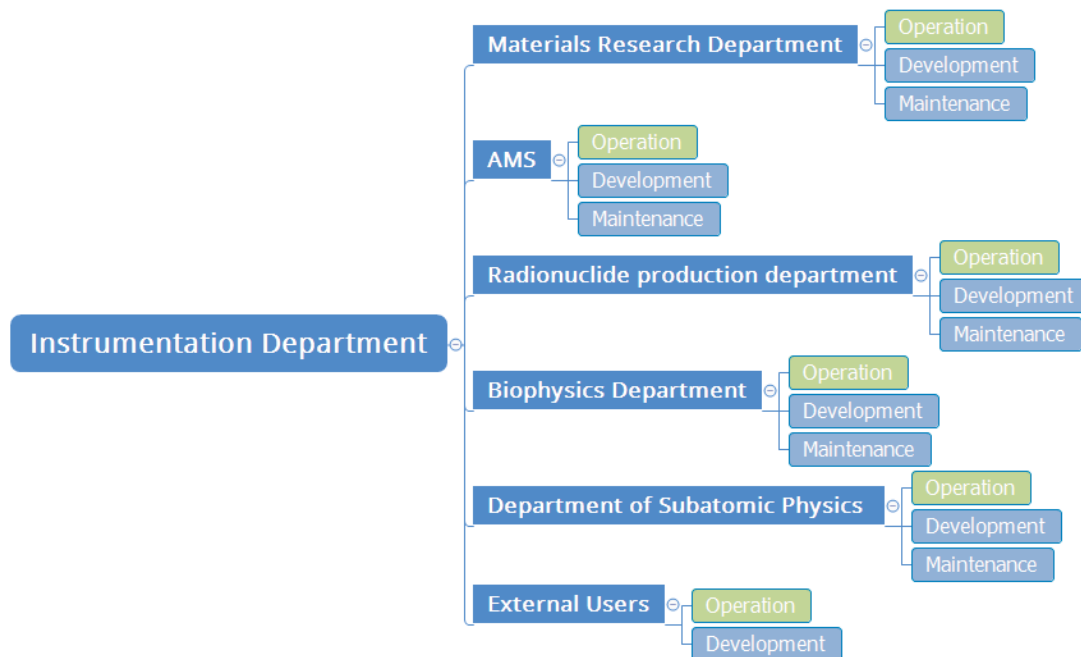


Figure 1: Clients of the instrumentation division.

In broad terms, the objectives of the Instrumentation Division comprise the following (see below and figure 2):

Provision of full support to the following aspects of an experimental project for research

- Data Acquisition and control Function (DAQ and Control),
- Target handling and manufacture
- Detector Development and supporting infrastructure
- Electronics developments and maintenance
- Mechanical developments and maintenance
- IT function for handling large data sets which includes the computing cluster, data handling and high speed networking.

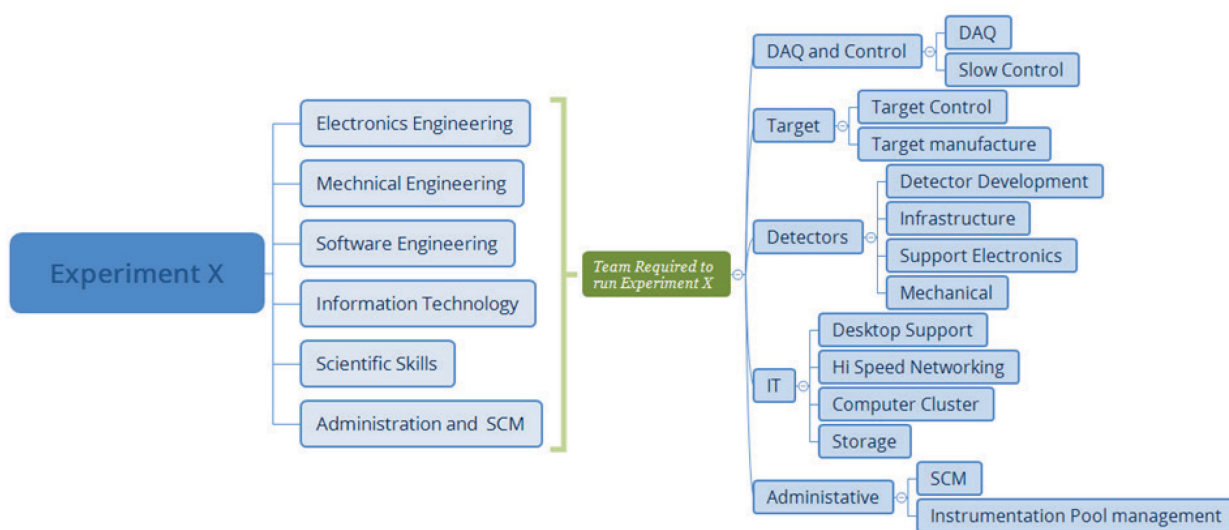


Figure 2 Integral parts of a typical experiment for research at iThemba LABS.

By utilising skills in the fields of software, electronics and mechanical engineering to support projects through (see figure 3):

- Design new research equipment for the research community at iThemba LABS
- Maintain, calibrate and repair equipment and instrumentation
- Operation of current equipment
- Manage equipment life cycles
- Design and manufacture of detectors and targets for research.

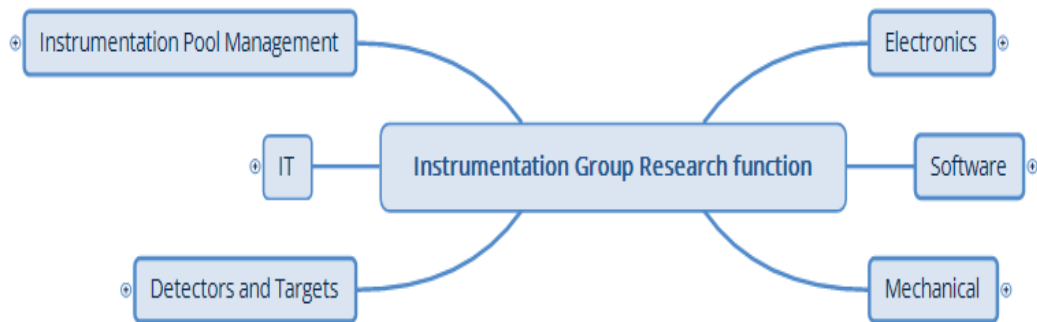


Figure 3 Functions within the Instrumentation Department.

To expand the skills and capabilities within the department to address the future projects that requires more human resources, such as the SAIF project.

2. Current and future prioritized projects within the DSP

To highlight the diversity of projects the current list of prioritized projects within the DSP are listed. It should be noted that each research department at iThemba LABS has a similar list of priorities and the below is to be seen as representative of all research departments.

- Integration of Low /High Voltage systems to EPICS. The AFRODITE group has recently upgraded its high-voltage system for both germanium and LaBr3 detectors. For the GAMKA project, more detectors will be utilised and it is of utmost importance to ensure they are supported with high voltage, and can be easily controlled. Low voltage supplies also need to be monitored. These systems are over different systems such as native EPICS, CAN-bus, and also old hardware should be considered to be added to a system.
- Upgrade of the iThemba LABS DDAS Front End Systems. The aim of this project is to update the front end (acquisition PC that connects to PXI crate, allocated firmware and uploads settings to each one of the modules). This also offer the opportunity for iThemba LABS to take ownership of the code, documentation, and also offer to other laboratories.
- Development of the iThemba LABS DDAS Trigger System.
- ALICE Muon Tracking Chambers (MCH) Low Voltage System.
- Test bench for the ALICE Muon Identifier (MID) Common Readout Unit (CRU)
- Upgrade of Isotope software for target monitoring on the vertical and horizontal stations

- Replacement of Non-destructive current measurement probe software with PICO-Scope and Labview.
- Mechanical and electronics infrastructure of the 23 large-volume LaBr₃:Ce detectors for ALBA and expanded AFRODITE (See DSP section)
- Infrastructure development for the GAMKA consortium (liquid nitrogen, electronics, mechanical infrastructure design and development.
- Design and manufacturing of new K600 spectrometer focal plane detector to enable detection of heavy and low-energy particles. The current multi wire technology employed in the vertical drift chambers developed at iThemba LABS is limiting the energy range and particle species detected at the focal plane. Modern gaseous detectors such as GEM or micromegas need to be implemented. These are accompanied with large number of electronics signals to be handled with a more complex DAQ.

3. Education and training

The IIT department will offer training opportunities to students in the form of internships, apprenticeships, in-service training and vacation programs. Numbers vary as training interventions are completed and new students are recruited but in general, a total of between 4-6 training opportunities will be accommodated at any given time. These programs will continue into the future and could also be expanded where opportunity arises.

The IIT Department is also committed to ongoing Education, Training and Development Plans (ETDs) for its staff members. Staff members are afforded the opportunity to receive assistance to further their studies by means of the Education, Training and Development programme offered by iThemba LABS. This type of intervention is in the interest of the IIT department and can be utilized to assist with the succession management plans of the department. All applications are considered on merit and approved by a central committee based on motivations from divisional managers. This form of assistance is in line with the education, training and development mandate of iThemba LABS.

4. Succession Management

The human resource capacity of the Instrumentation Division is crucial to the overall performance of the department. In many cases the skills set required of staff members is specialised and honed over many years of service. Skills retention is important to ensure continuity in operations. In the present composition of the Instrumentation Division one Senior Electronics Technician will retire in the next 5 years.

5. Vacant Positions

Vacant positions need to be filled as soon as practically possible. Where possible some of the positions can be filled by structural changes within the iThemba LABS by moving from a decentralised to a centralised service model for research. These positions are shown as (Internal ITL structure) in Table 2.

Where vacant positions are not filled the work pressure is increased on the remaining staff members. Due to the large number of projects in progress a shortage of manpower can lead to

inefficiencies in the workflow of the department. Where vacant positions are deemed crucial for operations, the positions must be filled immediately.

Table 2 Vacant Positions in the Instrumentation department.

	Post Description	Source
Department Head	Department Head IIT	Internal ITL Structure
Manager	Software Engineer DAQ	External
	Software Engineer Control	Internal ITL Structure
Software	Senior Software Engineer DAQ	External
	Software Engineer Control	Internal ITL Structure
	Software Programmer Control	Internal ITL Structure
	Software Programmer Control	Internal ITL Structure
	Software Programmer Control	Internal ITL Structure
Electronic Engineering	Electronics Engineer	Internal ITL Structure
	Electronics Engineer	Internal ITL Structure
	Electronics Technician	Internal ITL Structure
	Production Technician	Internal ITL Structure
Mechanical Engineering	Mechanical Engineer	External
	Mechanical Technician	Internal ITL Structure
	Draftsman	Internal ITL Structure
	Artisan	Internal ITL Structure
Instrumentation Asset Management	Storeman	External
	Technical Procurement	Internal ITL Structure
	Secretary	External

6. Personnel

The current personnel of the Instrumentation division consists of three electronics engineers, three software engineers, a mechanical technician, detector scientist and target maker and are managed from within the DSP.

A software and electronics engineer is assigned to the SA-CERN (ALICE) projects to meet expectation for these international projects. One of the software engineers are currently reporting to the materials research department and is focusing his tasks on DAQ projects for this department. (See fig 4)

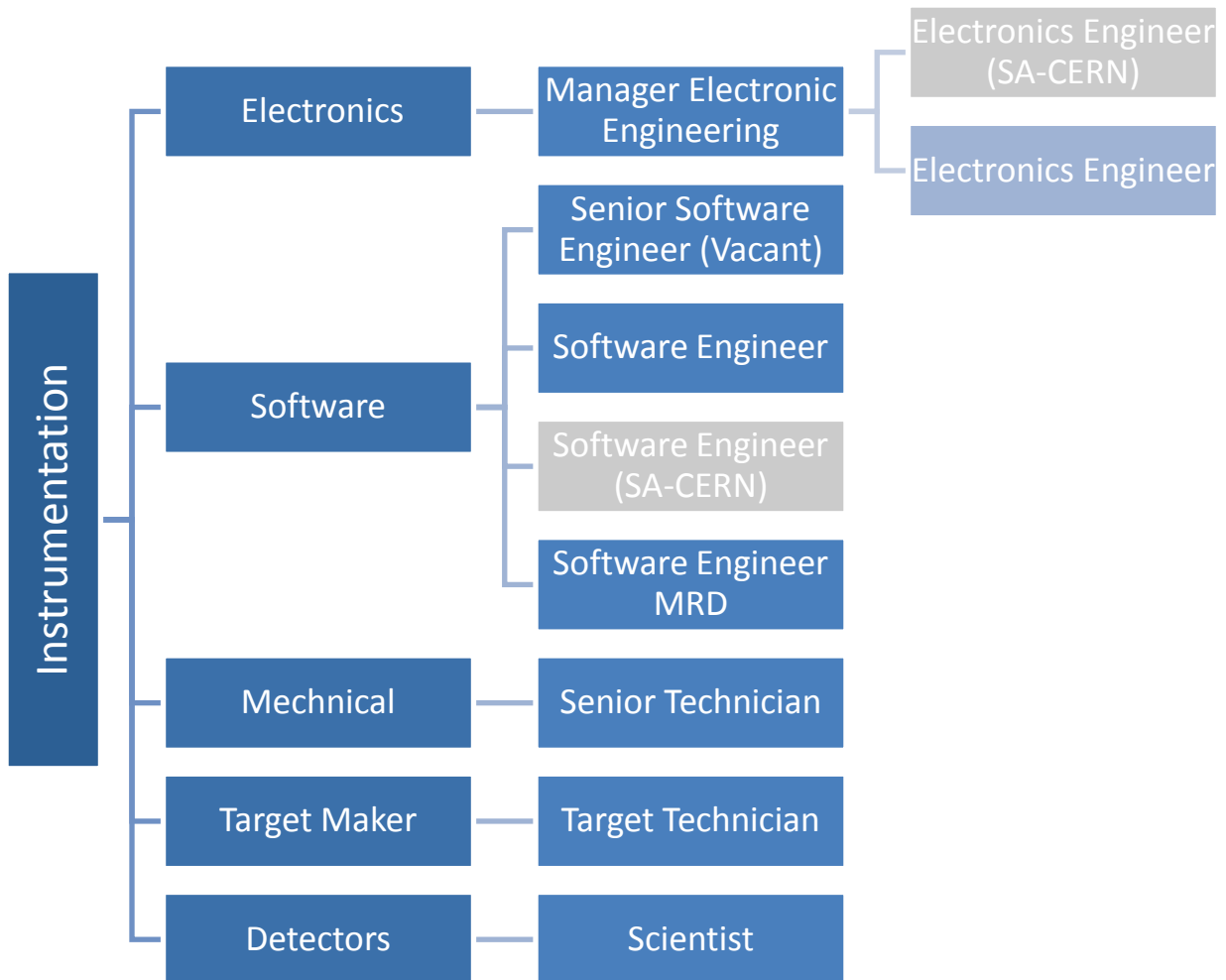


Figure 4: Current Instrumentation organogram.

To improve service to the internal and external research users of iThemba LABS for all research departments a centralised high performance team consisting of specialists in Electronics, Software development, IT, Mechanical, detector, target making and instrumentation asset management will be implemented and staffed drawing from the individual departments across iThemba LABS.

A possible structure of such a team is shown figure 5.

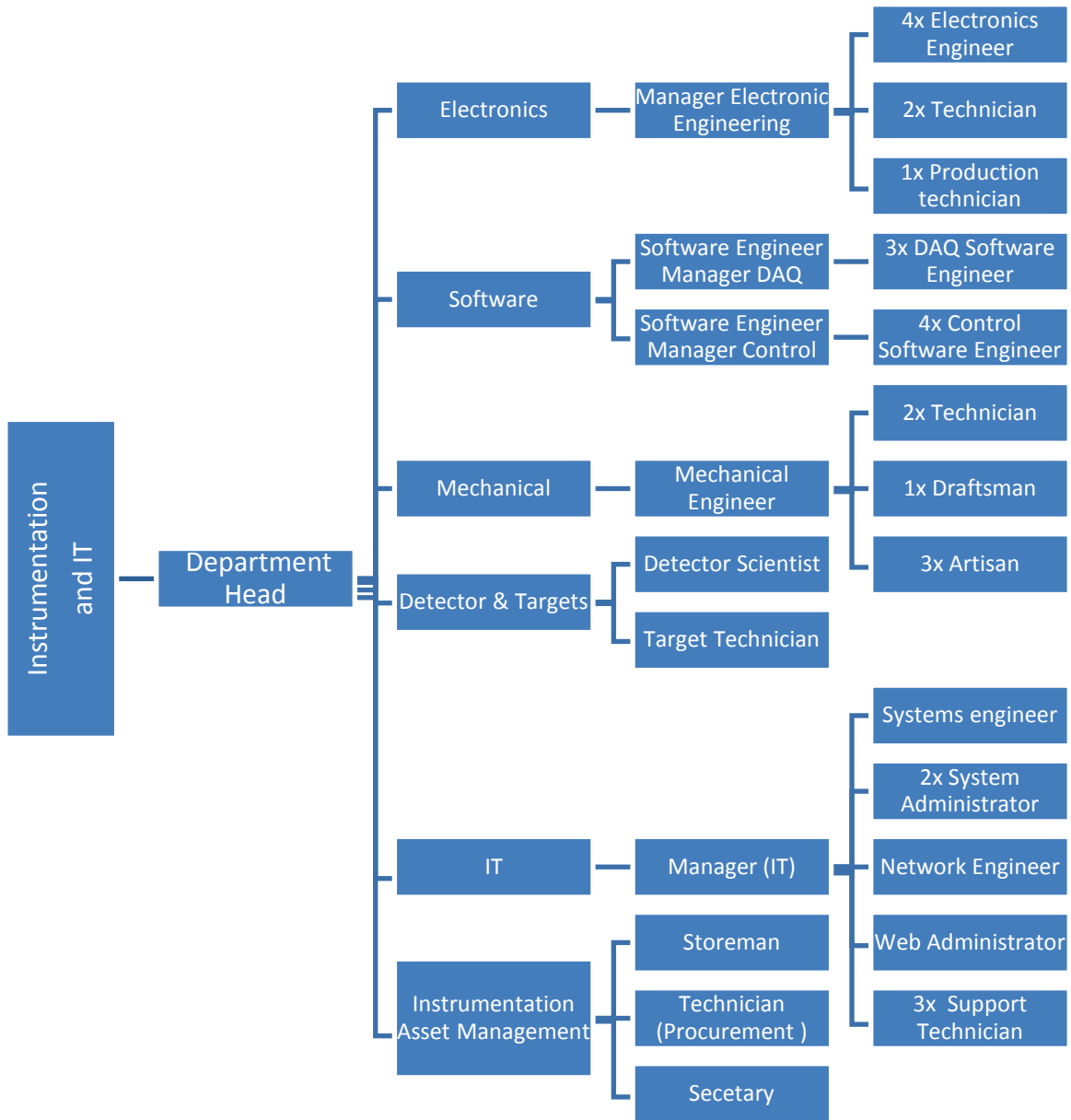


Figure 5: New structures for the Instrumentation and IT Department.

7. The Instrumentation Technology Division of the IIT Department

7.1 Introduction

Technology evolves rapidly in the IT domain and for IT to stay relevant to the business unit it has to be equipped to state up-to-date with various technologies. A modern, operationally efficient IT network and services infrastructure is a critical requirement in providing adequate IT resources for its internal and external users as well as being compliant with business rules and NRF ICT Corporate Governance.

The role of the IT department at iThemba LABS is to plan, operate and support the organisations IT infrastructure, enabling users to carry out their roles efficiently, productively and securely. The plan addresses a number of dynamics that will impact our IT environment as we strive to provide effective technology support in the future.

This long range plan attempts to establish key technology strategies that will allow the lab to continue to meet current technology needs effectively and be able to meet the challenges it will be facing in the coming years. Considering the nature of our environment we will work with our stakeholders to ensure this document is designed to meet our objectives aligned with organisational objectives while maintaining a level of flexibility and adaptability to reflect the changes in priorities and technology needs.

Mission: *Deliver a technology environment that supports iThemba LABS to meet its mission and objectives. Our mission is to empower our users to achieve their goals through providing up-to-date technology infrastructure and services.*

Vision: *Enhance collaboration and service delivery through the application of strategic technologies and secure universal access. To create great customer experience and become the first point of contact for IT Services within iThemba LABS.*

Goal: *Our goal is to build and maintain a secure and robust technology infrastructure; provide technology support for all users through ensuring strong customer support; explore innovative technological opportunities to improve services and to promote collaborative initiatives involving technology.*

7.2 Background

IT System Support was a division reporting to the Electronics and Information Technology group head. The division shared a budget with the electronics division which in effect reduced available funding for IT use. The Information Technology (IT) department was temporarily established as an independent unit outside of the Electronics department in December 2016. The reason being that most of the electronics department was dedicated to activities related to accelerators whereas an IT division is ideally organized within an instrumentation department that is planned to be formed within the LRP vision. The IT Team, depicted in figure 6, is comprised of an IT System Support Manager, supported by two Desktop Technicians, one Network Engineer, one Web Administrator / Technician and one

Procurement Administrator / Technician. The overall responsibility of the IT department is to provide the entire IT services required to support iThemba LABS. There is no resource for System Administration. iThemba LABS has a department in Gauteng which the division provides email and network infrastructure support.

The Division Currently

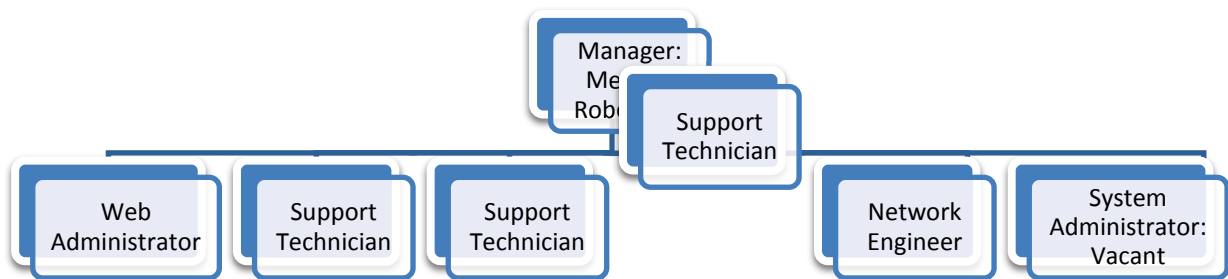


Figure 6. Structure of the IT team

The division provides the services listed in figure 7 to 286 staff members and currently 86 students with 320 workstations, 140 notebooks and 70 servers.

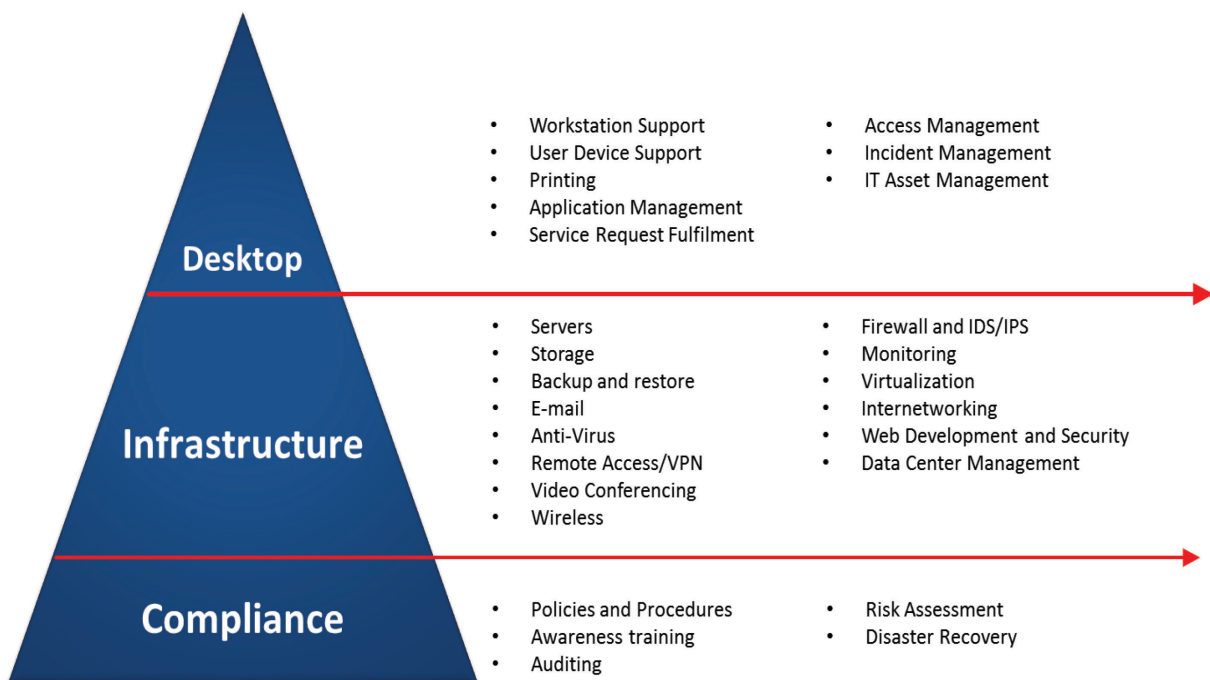


Figure 7. IT Services

7.3 Current State

The division has been operating without a Systems Administrator since 2015. This has been followed by the departure of another staff member with whom the System Administrator worked closely. They were responsible for handling the electronic mail system, managing the TLABS Cloud hosting 25 Virtual Machines, managing the 125TB NetAPP storage, backup of experimental data including giving software assistance to physics user. In the absence of a System Administrator the duties have been segregated and these services are managed by various individuals residing in different departments. Development on these systems are curtailed due to the absence of human resource.

Even though the division has been hampered by the shortage in human resources during this period the division has continued to improve on their service delivery. The division received R3.2m to assist in the IT infrastructure backlog in 2016. Two new Fortinet Next Generation Firewall, active and passive units with 3 year maintenance were procured for iThemba LABS in Cape Town and two new firewalls were installed at iThemba LABS in Gauteng. The new firewalls will enhance the security of the network and the users. Expansion of extra 10GBps fibre optic ports on the Cape Town firewall will increase data access speeds within the data centre.

The Data Centre has been fitted with a new APC Hot Aisle Containment Solution (HACS). In addition, four new APC cabinets have been installed with two APC In-Row cooling units, all with redundant power distribution units. The 40kVA UPS in the data centre has been replaced with a 60kVA UPS.

The migration of users to Active directory is ongoing. Active Directory provides a centralised repository of information and secured access to data through security policies thereby improving management of data. New VPN services now managed by the firewall integrated with Active Directory for secure access to the internal network using the firewall Forticlient. Single Sign-On is implemented with the new firewall and Active Directory.

The IT Division is faced with aging and obsolete infrastructure and upgrading the infrastructure has continued as finances allowed. We procured two new fileservers with a combination of 32TB of storage for user data and staging of data for back up to tape. An automated tape library system has been procured to replace the old TLS-5000 tape library. The Oracle Storagetek SL150 automated tape Library with backup server using Veeam Backup and Replication Software.

The video conferencing infrastructure was expanded. The use of Vidyo, which we receive as Platform-as-a-Service (PaaS) from Tertiary Education Network (TENET), has enabled us to enrich our user experience. Through this service we are able to live stream and record our video conferences. We provided this service for the following international conferences; Open Access Symposium 2016, 2017 ALICE International Masterclasses, ATLAS Tile Calorimeter Upgrade Week. In addition we were able to procure two new Vidyo SE units, a new Polycom Real Presence including Eagle Eye Director.

7.3.1 Strategies going forward

7.3.1.1 Global Strategies

Comprehensive Disaster Recovery Plan:

Develop a plan to address all facets of iThemba LABS key services and establish specific actions and accountabilities for reinstating those services in the event of disaster or major interruption.

- Disaster Recovery site (Gauteng site and TENET cloud services).
- TENET is considering Cloud implementation it would be wise to use this service for disaster recovery.

Integrated Information Security:

Information fraud and privacy concerns are now a top priority of most IT organizations. IT must play a leadership role in remaining aware of information security and privacy issues, and take all steps necessary to minimize risk to iThemba LABS.

- At the NRF IT Forum 2016 a Cyber Security IT Security Community of Practice was established, each facility will be represented at this committee. In conjunction to this, the South-African National Research Network (SANReN) established a Computer Security Incident Response Team (CSIRT) responsible for receiving, reviewing, and responding to computer security incident reports and activity.
- Once the IT hardware and software infrastructures are sufficiently up to date to mitigate the risks of obsolete hardware and software, an external vulnerability assessment will be considered to assess our resilience against Cybercrime.

7.3.2 Functional Strategies

Currently	Envisaged Plan
<p>IT Infrastructure Obsolescence Cisco Catalyst switches (Core)</p> <ul style="list-style-type: none"> • Purchased early 2010 • Critical, provide access to the Internet as well as connecting the various internal network switches together. • Failure will result in complete communication loss both internally (within the lab) and externally (to the Internet). 	<ul style="list-style-type: none"> • Envisaged installation 2019/2020 as this will have to go to tender. • Interim measure is to secure a maintenance contract from one of our suppliers. • Future need to provide for a high end replacement with additional modules that will support 40Gbps and 100Gbps.
<p>NetApp Storage</p> <ul style="list-style-type: none"> • Fragmented. • Procured early 2012. • No maintenance on it for the last 3-4 years. • Storage of experimental data, email and cloud - Risk loss of data 	<ul style="list-style-type: none"> • This should be done in a phased approach. • 2018/2019 implementation in Cape Town and Gauteng. • Electronic data storage plan for storage of research, enterprise and personal data, this should include capacity planning or projection over a three year horizon including backup of data.

Decentralised Systems NACMS, Email, Gate System, AD	<ul style="list-style-type: none"> Centralised System Using Active Directory
Email <ul style="list-style-type: none"> No centralised email archiving system Individual email backups VPN access is required when sending remotely from work 	<ul style="list-style-type: none"> Hosted or on Premise Exchange with Mimecast for email Archiving, Security and Continuity. Envisioned for 2018 /2019 should funding be available
Incident Management Process <ul style="list-style-type: none"> Not formally practised therefore no metrics Slow response times 	<ul style="list-style-type: none"> Formalise and Improve IT User Support Processes Logging of support tasks on the ticketing system should be the mandatory process to enlist IT support. Establishment of SLA's envisioned 2018.
Student and Research IT Support <ul style="list-style-type: none"> No formalised Agreement IT staff expected to assist with specialised software Support for Private desktops and laptops 	<ul style="list-style-type: none"> Define and Implement a Formal IT Support Model for Students. This will clarify the type of IT services and support, to manage expectations. General software support for new software is done by IT or a training plan for students should be established when they enter the organisation..
Tandem and AMS department at Gauteng Support provided for Network and Email only.	Ensure that a degree of accountability towards central IT is established.

7.3.3 Staff Requirements

The division is responsible for IT Services and Operations of iThemba LABS. The absence of human resources and non-existent skills impedes on the department's ability to timeously refresh technology, provide redundancy and availability of key services as well as drive innovation.

There is currently one vacant post, which is the System Administrator. It is crucial that the current team skill set be expanded through training of required skills and the recruitment of non-existing skills. To align the department with the objectives of the long range plan the following is proposed.

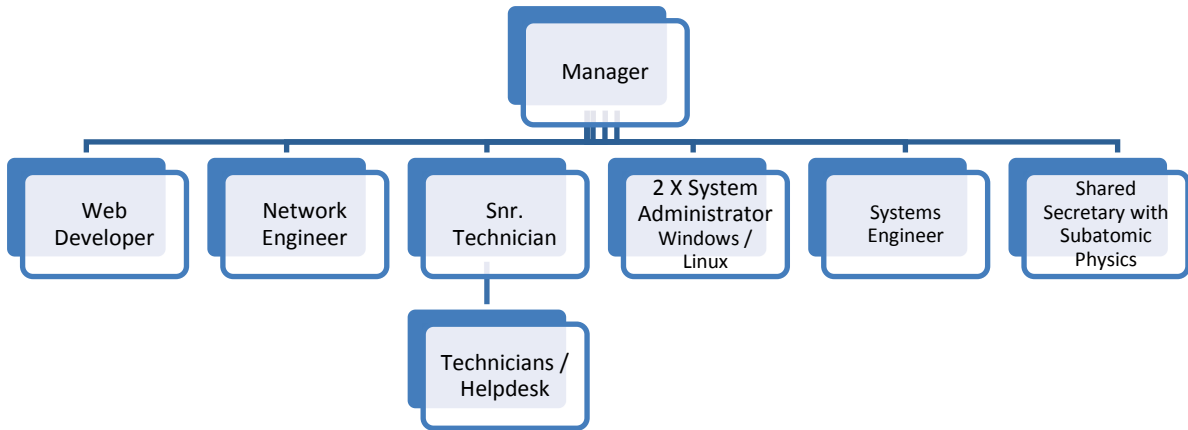
The following staff plan is envisioned.

Skills Gaps and Capacity Constraints - Review IT Staffing Needs and Required IT Skills

Training – currently all IT staff have training plans. Expand skills in the following areas:

- Microsoft and Linux System Administration
- Workstation support
- Management and administration of data storage
- Video Conferencing support

- ITIL (IT Infrastructure Library) is an international best practice framework on IT service management.



Envisioned Staff Plan

Figure 8 Envisaged staff organogram

Current Positions	New Additional Positions
Manager	Senior Technician
Web Developer – cum Technician (30%)	System Administrator
IT procurement -cum Technician (30%)	
IT Technician	
IT Technician	
System Administrator	
Systems Engineer	

Table 3. Current and envisaged positions



Accelerators

1. Introduction

The Accelerator & Engineering Department (AED) provides the research platforms for iThemba LABS to offer state-of-the-art facilities for high quality research, training and services in nuclear sciences and applications.

The vision of the AED is to sustain and expand the research platforms to enable iThemba LABS to be a Centre of Excellence that provides internationally renowned research facilities offering competitive research opportunities in accelerator based sciences to researchers from South Africa, Africa and beyond.

The mission of the AED is to develop, operate and maintain the various accelerators and associated infrastructure, as well as the provision of accelerated charged particle beams of the type, quality and quantity that meet international standards to promote research in the physical- and biomedical sciences.

2. Principal activities

The AED continually strives to improve the quality of the service provided to users and stakeholders through the research, design and implementation of innovative accelerator and beam transport technologies. Well-organized and trained maintenance teams ensure top performance of research platforms and infrastructure by implementation of routine planned- and preventative maintenance programs.

The above obligations form the basis of the long range planning of the AED. Recording and analysis of statistical operational data provides a measure of performance of the department in meeting its obligations to iThemba LABS and also drives the need for the renewal or upgrade of research equipment and infrastructure.

Some new projects are initialised based on specific research requirements which sprout from discussions and interaction with users and stakeholders at various forums. High on the agenda is the establishment of the South African Isotope Facility (SAIF) project that encompasses two components, i.e. the Accelerator Centre for Exotic Isotopes (ACE-Isotopes) and the Accelerator Centre for Exotic Beams (ACE-Beams). The SAIF project is considered vital to propel iThemba LABS into the future to stay competitive and keep abreast of international notions in accelerator based research. The AED will be very prominent in the realisation and establishment of these new strategic research platforms.

3. Operational Objectives

The AED always endeavours to deliver a high quality service to all the stakeholders of the department, albeit internal- or external clients. Operational statistics are generated and used as a benchmark to gauge the level of performance. Objectives are set based on recorded statistical data.

In broad terms the objectives of the AED comprise the following:

1. Optimize the operation and maintenance of the Faure cyclotrons and associated beam transport systems for the provision of consistent, high quality beams to all users for at least 80% of scheduled beam time (72% of calendar time). Reduce unscheduled interruptions to less than 8% of scheduled beam time.
2. Optimize the operation and maintenance of the 11 MeV cyclotron to deliver productive beams to the isotope production facility for 96% of the scheduled time.
3. Optimize the operation and maintenance of the 6 MV tandem accelerator of the AMS Department located at the WITS campus in Johannesburg to ensure quality beams to all the users. The main focus will be aimed at Accelerator Mass Spectrometry (AMS) and its applications. Reduce unscheduled interruptions to less than 6%.
4. Optimize the operation and maintenance of the 3 MV Tandetron accelerator and associated beam transport systems. Specific targets will be set on completion of the Tandetron commissioning and beam line construction periods. The ultimate aim will be to deliver high quality beams to users for 95% of scheduled beam time.
5. Increase the ability to deliver heavy ion beams of many different species at higher intensities and higher energies by means of the two ECR ion sources.
6. Operate and maintain the electrical and mechanical infrastructure effectively and efficiently in order to meet operational expectations.
7. Provide effective building- and grounds maintenance to ensure a safe and functional working environment free of hazards and risks.
8. Set up collaboration agreements with international peer facilities to share ideas and keep abreast of state-of-the-art technological developments in the field of accelerator physics.
9. Investigate and implement innovative and effective methods, including green initiatives, of curbing electrical power consumption.

4. Current and Future Projects

In order to fulfil the operational objectives of the AED, various projects are underway to improve the level of service delivery and reliability of research platforms throughout the facility.

New projects are initiated based on the research needs/requests/wishes as identified during interaction with the user communities and other stakeholders of iThemba LABS. Some of these projects are specifically aimed at providing brand new research platforms.

4.1 New 3 MV Tandatron accelerator for the Materials Research Department (MRD)

During 2017 the AED provided engineering support with the replacement of the 5.5 MV Van de Graaff accelerator with a new 3 MV Tandatron accelerator. During the first quarter of 2018 the last infrastructure upgrades will be completed, which include the cooling water plant, air conditioning and the completion of two experimental beam lines. Going into the future, the AED will continue to provide support to MRD as far as operations, maintenance and future enhancements of the Tandatron facility and associated infrastructure are concerned.

The following tasks will form the basis of the ongoing support:

1. Assist with the final installation and commissioning tasks associated with the new 3 MV Tandatron accelerator.
2. Provide the necessary infrastructure upgrades, including building enhancements, to fulfil the requirements of the new Tandatron accelerator and associated research equipment.
3. Complete the installation and commissioning of the experimental beam lines and data acquisition systems, including micro-probe. Beam line upgrades can continue until 2020 as users define requirements and funds are made available.
4. Optimize the operation and maintenance of the Tandatron, ion sources and associated beam transport systems for the provision of consistent, high quality beams to all users of the facility.
5. Upgrade and refurbish the existing Tandatron accelerator building complex and roads.



Figure 1: New 3 MV Tandatron Accelerator for the Materials Research Department (MRD).

4.2 Radio Frequency (RF) systems upgrades

(Refer to Addendum 1 – Timeline 2)

1. Continue with the development and construction of a spare 150 kW RF amplifier for the SSC.
2. Upgrade the electronic control and pre-amplifier sections of the main RF amplifiers of the SSC.
3. Develop and install upgrades for the RF amplifiers of SPC1, SPC2 and bunchers.
4. Replace the low-level RF analogue control systems of all RF amplifier systems with new digital control systems.
5. Replace all obsolete motion control components of the various RF systems with new Beckhoff industrial electronics.
6. Upgrade and install new flat-top resonators for SPC1.

4.3 SAIF Projects

SAIF is a major strategic intervention that will forever alter the landscape of accelerator based physics research in South Africa and on the African continent. Through SAIF the increased production of innovative radioisotopes will secure South Africa's position in the global market.

SAIF will be developed on the existing infrastructure and capacity, which include niche technical skills and strong links to global networks. The SAIF strategy will be approached in two phases:

Phase 1 – *ACE-Isotopes* is the migration of the radioisotope production programme from the SSC to a new cyclotron. While freeing up the SSC for research, this migration will increase production capacity of exotic radioisotopes at a significantly reduced cost. Parallel to Phase 1 the Low-energy Rare Isotope Beam (LERIB) project will be implemented by existing staff.

Phase 2 – *ACE-Beams* will produce artificial isotopes at high energies to allow iThemba LABS to expand its research agenda into understanding the structure of matter and the origin of the universe.

SAIF PROJECT	2018	2019	2020	2021	2023--
LERIB	UNDER CONSTRUCTION				
ACE-Isotopes	PHASE 1				
ACE-Beams					PHASE 2

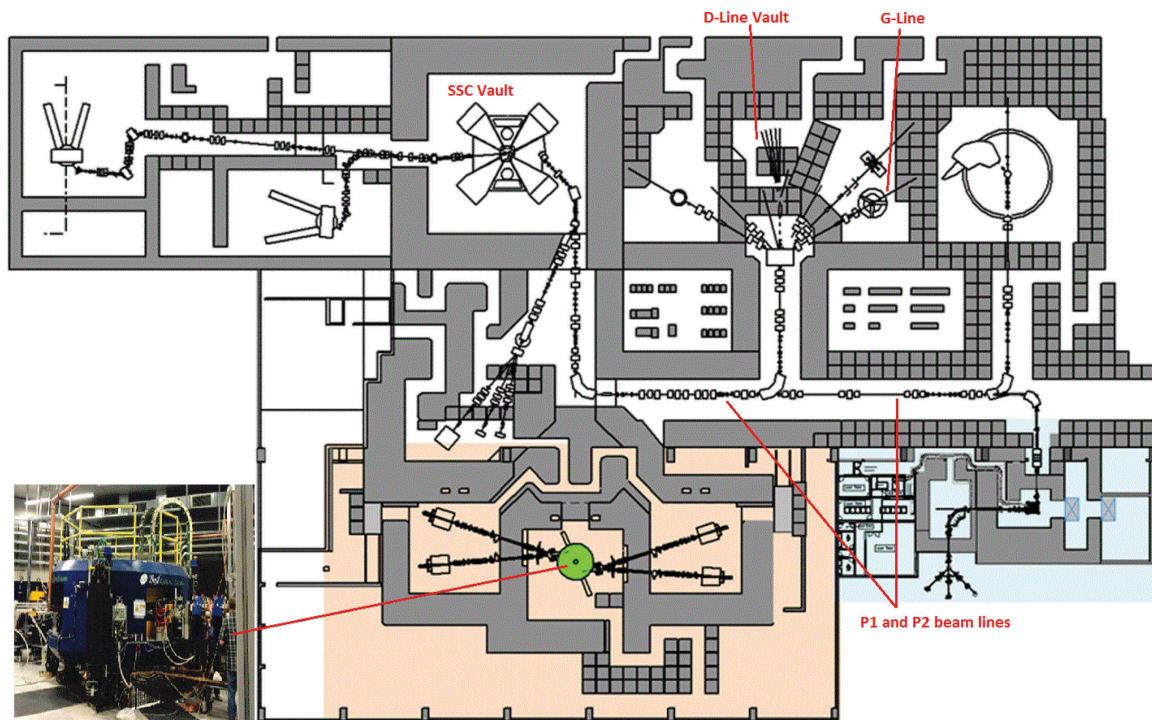


Figure 3: iThemba LABS floorplan highlighting the location of the proposed ACE-Isotopes in the existing buildings (shaded brown) and LERIB project in a proposed new building (shaded blue). A commercial 70 MeV accelerator as indicated will be used for ACE-Isotopes and the driver for the LERIB project will be the SSC.

ACE-Beams projects (Refer to Addendum 1 – Timeline 1)

1. Complete the Rare Isotope Beam (RIB) off-line test facility in S-block.

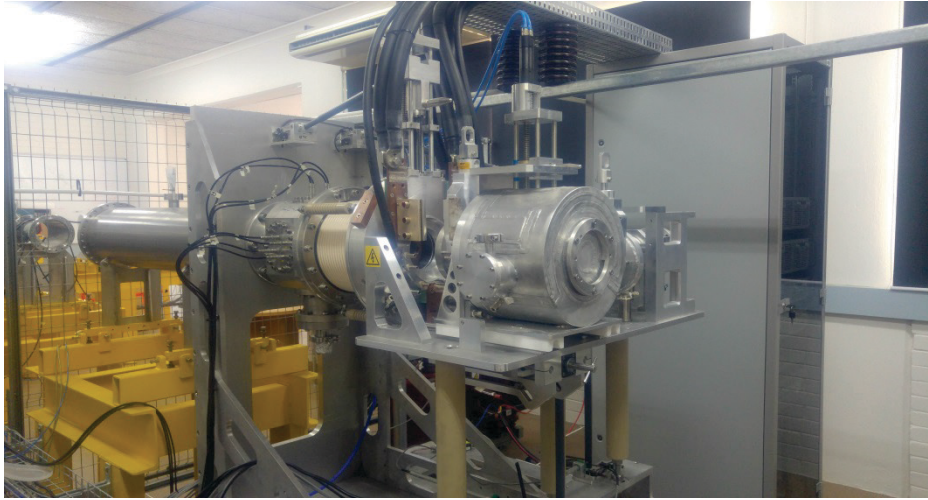


Figure 4: Front End assembly as installed in the RIB off-line test facility at iThemba LABS.

2. Design, develop, construct and commission the Low Energy RIB (LERIB) Facility and associated beam lines and infrastructure to produce low-energy rare isotope beams for research.
3. Participate in a Feasibility Study to determine the viability of an extended RIB facility to deliver post-accelerated rare isotope beams by means of new infrastructure, including new post-accelerator.

ACE-Isotopes project (Refer to Addendum1 – Timeline 3)

The ACE-Isotopes project involves the acquisition of a commercial 70 MeV cyclotron, dedicated to a new radioisotope production programme with an increased output. This will release the existing SSC from the radioisotope production schedule and permit its dedicated application to research only.

The AED has been actively involved in the preparation of a Technical Design and Feasibility Study and will also provide engineering support for the establishment and implementation of an isotope production facility utilising a new 70 MeV cyclotron.

The ACE-Isotopes facilities encompass, apart from the accelerator and beam lines, facilities for an operations control room, mains power reticulation, power supply room, electronic control, cooling plant, air conditioning and waste management. The AED will be actively involved in the planning and implementation of all these aspects of the project. The project will span a period of 4 years and the project team will work closely with external service providers and contractors to ensure the project stays within the allotted time frames and budget.

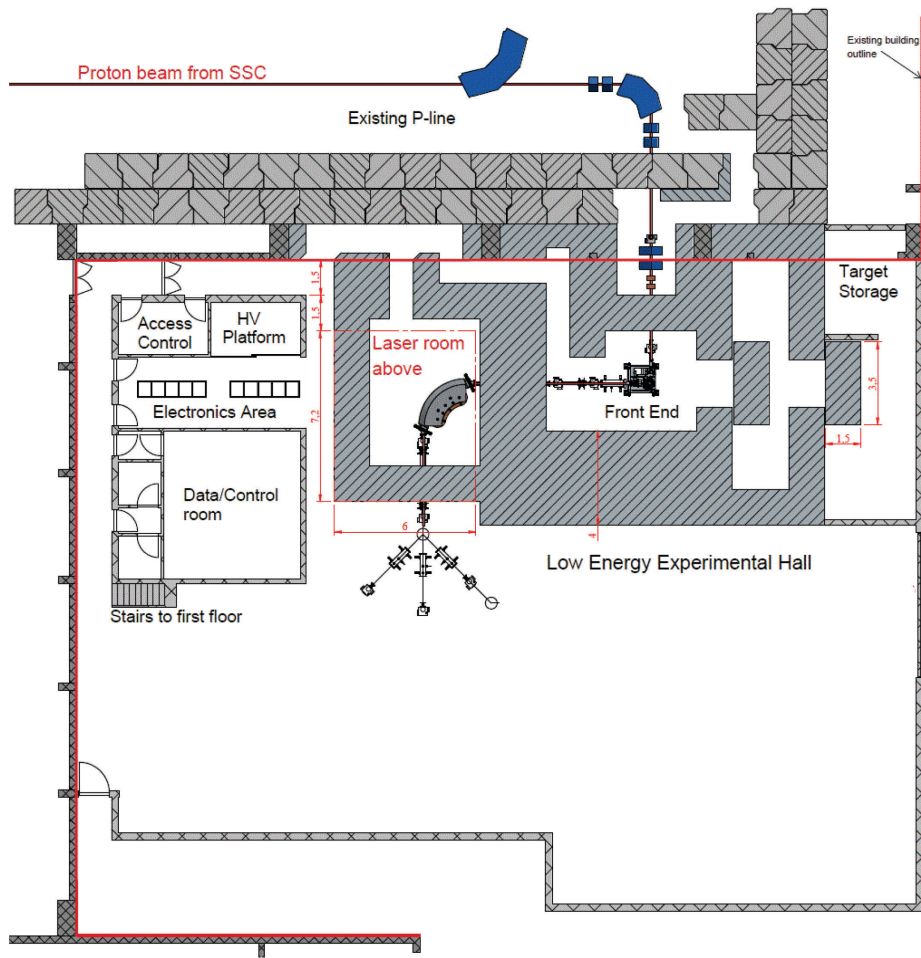


Figure 5: Layout of the proposed LERIB facility.

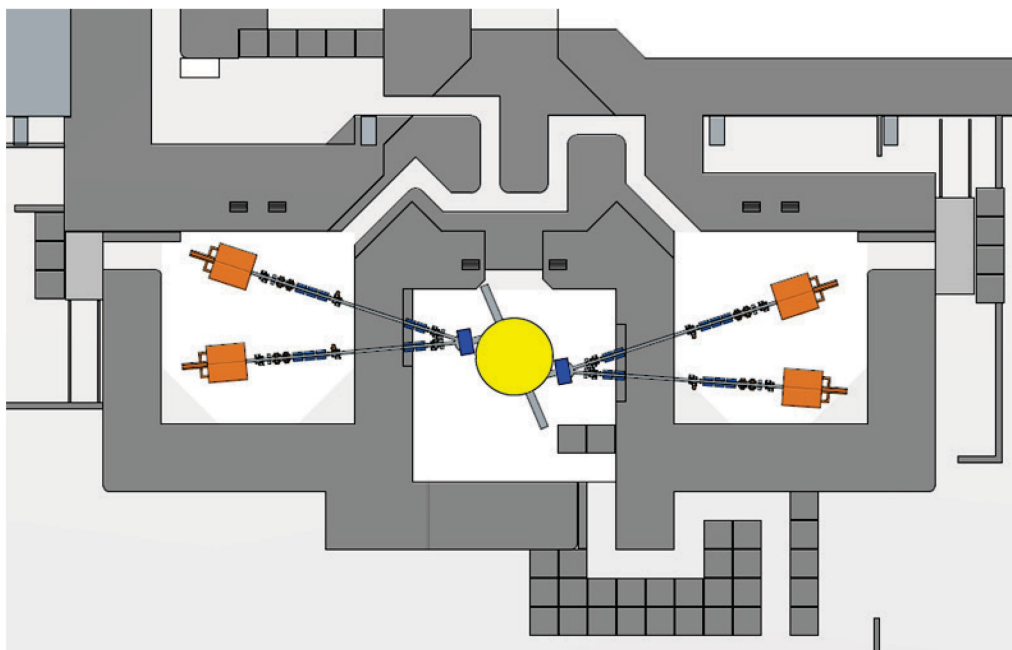


Figure 6: ACE-Isotopes layout of the cyclotron and beam lines in the existing therapy vaults.

4.5 Cyclotron upgrades

1. Replace all the critical water cooling channels and pipes of the injector cyclotrons and the SSC.
2. Continue with the upgrade and development of the diagnostic- and electronic control systems of the injector- and main accelerators to improve beam delivery and stay abreast of new technological developments.
3. Investigate and develop a variable frequency flat-top system for SPC2.
4. Investigate and implement ideas to improve the transport efficiency of SPC2.

4.6 Beam line upgrades

1. Work with the Subatomic Physics Department to upgrade and improve the Fast Neutron Beam Facility vault layout (D-line vault, fig. 3) over the next three years as part of a collaboration between French Institut de Radioprotection et de Sûreté Nucléaire (IRSN), German PTB and iThemba LABS, with UCT Physics and the National Metrology Institute of South Africa (NMISA) as additional partners.
2. Install new end station, beam transport- and beam diagnostic components on the G-line (fig 3) in the third experimental vault to be ready by the first quarter of 2018.
3. Upgrade the P1 and P2 beam lines (fig 3) to allow the transportation of high intensity (up to 50 μ A) 66 MeV proton beams from the SSC to the LERIB facility.
4. Investigate the possibility of establishing new neutron- and proton beam lines dedicated to research in radiation therapy.

4.7 Deployment and upgrades of Control Systems

(Refer to Addendum 1 – Timeline 4)

1. Develop EPICS controls for all devices still on the old control system.
2. Replace older interfacing electronics with new technology or improved designs as components become obsolete.
3. Develop new ways of setting up the accelerators and beam lines replacing the existing energy tables.
4. Improve the detection of equipment failures by implementing alarm handling.
5. Improve the recording of events, correlations and trends by implementing process variable data archiving.
6. Improve the operator experience by introducing larger display screens, touch sensitive controls and adding uniformity to the display content.
7. Deploy a control system for the beamlines, vacuum system and diagnostics of the Tandatron.
8. Modernize the Safety Interlock, Radiation Monitoring and Vault Clearance systems.

9. Deploy a control system and operator GUI screens for the SAIF ACE–Beams projects starting with the RIB off-line test facility in S-block, followed by the LERIB Test Facility and associated beam lines.
10. Compile specifications for the SAIF ACE–Isotope project of the communications between the chosen supplier’s control system and on-site requirements for integration.

4.8 Infrastructure maintenance and upgrades

1. Replace ageing and obsolete medium voltage electrical switchgear to ensure sustainability of the power supply to the facility.
2. Upgrade the mechanical workshop with at least one modern CNC machine to assist with manufacturing and to empower workshop personnel with CNC manufacturing skills.
3. Various building repair and maintenance projects are also planned, not only to improve the aesthetics, but to prolong the life of the building infrastructure to ensure a safe and functional working environment for all.

These projects include:

- a. Cleaning, painting and waterproofing of various buildings
- b. Replacement of underground diesel storage tanks
- c. Re-surfacing of roads
- d. Replacement of dilapidated parking bay coverings
- e. Waterproofing of various concrete roof areas

5. Education and Training

Various staff members of the AED form part of a joint venture between iThemba LABS and the University of the Western Cape (UWC) to offer a masters’ course in accelerator physics for post-graduate students. The Masters in Accelerator and Nuclear Sciences (MANuS) course involves practical and theoretical training/lecturing in accelerator physics and vacuum systems. This collaboration has been in existence many years and is envisaged to continue indefinitely. Post-graduate students are recruited to enter the MANuS course from most universities in South Africa.

The AED also offers training opportunities to students in the form of internships, apprenticeships, in-service training and vacation programs. Numbers vary as training interventions are completed and new students are recruited, but in general a total of between 5 – 8 students are accommodated at any given time. These programs will continue into the future and could also be expanded where opportunity arises.

Although the AED is an operational department and not a specialist training department, post graduate students are accommodated from time-to-time to undergo studies in the field of mostly accelerator physics and the like. Students are mentored by dedicated AED staff

suitably qualified to provide the required mentoring and training. This commitment will continue into the future, especially where students can assist the AED to investigate and/or develop application specific solutions to scientific challenges or new developments.

The AED is also committed to ongoing Personal Development Plans (PDPs) for its staff members. Staff members are afforded the opportunity to receive assistance to further their studies by means of the Education, Training and Development program offered by iThemba LABS. This type of intervention is in the interest of the AED and can be utilized to assist with the succession management plans of the department. All applications are considered on merit and approved by a central committee based on motivations from divisional managers. This form of assistance is in line with the education, training and development mandate of iThemba LABS, will always be encouraged by the AED and will be continued into the future.

6. Collaborations

The AED believes in strong collaboration with international peer facilities to share ideas and keep abreast of state-of-the-art technological developments in the field of accelerator based sciences. These collaborations are mutually beneficial to participating partners and offer valuable training opportunities to staff members and students. Collaborations stimulate innovation and growth and contribute to keeping science alive and interesting. The AED managed to cultivate a culture of association and partnership with many international peer facilities and will continue to do so in years to come.

List of accelerator technology and development collaborations:

1. *Joint Institute for Nuclear Research (FLNR), Dubna, Russia - Collaboration Agreement 2017*
2. The GIP ARRONAX, Nantes/St-Herblain, France - Memorandum of Understanding 2017
3. ISTITUTO NAZIONALE DI FISICA NUCLEARE (INFN), di Legnaro, Italy - Memorandum of Understanding 2016
4. The Helmholtz Zentrum Berlin (HZB) - Memorandum of Understanding 2016

7. Succession Management

The human resource capacity of the AED is crucial to the overall performance of the department. In many cases the skill set required of staff members are specialised and honed over many years of service. Skills retention is important to ensure continuity in operations. Some of the specialised skills are not freely available on the open market and can be difficult to recruit. As a first tactic to succession management the AED endeavours to diversify the workforce through cross training to develop multi-skilled individuals. This approach alleviates many of the difficulties experienced where staff members performing specialised duties fall ill or are away on leave.

Where retirements are concerned the process is more complicated to manage and mostly depends on availability of funds and suitably qualified successors. In cases where loss of special skills are at risk due to compulsory retirements, the practice will be to appoint a successor well ahead of the retirement date to allow a reasonable time overlap to transfer

skills. The successor can either be recruited internally or externally depending on circumstances.

A number of critical retirements are looming in the next 5 years and need to be addressed as soon as possible to ensure continuity in operations. Refer to Table 1.

8. Vacant Positions

Vacant positions need to be filled as soon as practically possible. Where vacant positions are not filled the work pressure is increased on the remaining staff members. Due to the large number of projects in progress a shortage of manpower can lead to inefficiencies in the workflow of the department. Where vacant positions are deemed crucial for operations, the positions must be filled immediately. Refer to Table 2.

Table 1: List of compulsory retirements within the next 5 years (up to 2022)

Post Description	Years to retirement
Deputy Department Head: Control Systems and Administration	1
Accelerator Physicist: ECR Ion Sources and SPC2	1
Tool & Die Maker: Magnet Coil Manufacturing	1
Department Head: Accelerator and Engineering	2
Senior Electronics Technician: RF Systems	2
Senior Electronics Technician	2
Accelerator Physicist: Numerical Field Analysis and Simulations	3
Deputy Department Head: Cyclotron and Beam Transport	4
Deputy Department Head: Projects, Training and Administration	4
Electrical Engineer (GMR2)	4
Electronics Engineer: Electronics, Installation and Maintenance	4
Senior Software Engineer	5
Electronics Engineer: RF Systems	5
Electronics Engineer: Control Systems	5
Mechanical Design Draughtsman	5

Table 2: Current vacant positions in the AED

Post Description
Manager: Mechanical Engineering
Division Head: Beam Diagnostics and Vacuum
Electronics Engineer: Electronics, Installation and Maintenance
Electronics Technician: ECR Ion Sources and SPC2
Mechanical Technician: Cooling Water
Mechanical Design Draughtsman
3 X General Assistant/Handyman: Site Services

9. Personnel

The current workforce profile of the AED is adequate to operate and maintain the research platforms and associated infrastructure, as well as attend to a number of small to medium sized projects. At times during project planning and implementation stages, where it is deemed necessary to increase the workforce temporarily, use is made of contract positions to supplement the workforce. This strategy works well where new projects do not culminate in additional workload for permanent staff members.

Larger projects like the proposed SAIF projects will add significantly to the infrastructure of the accelerator complex and will require the appointment of additional permanent staff members once in full operation. From the time the project is approved the additional staff will need to be employed in stages to keep up with the demand for human resources. At the end of the project the number of additional staff members should be adequate to operate and maintain the additional infrastructure and equipment. Refer to the tables below for a forecast of additional permanent staff requirements for the ACE-Isotopes project.

Table 3: Timeline and additional permanent staff requirements for ACE-Isotopes

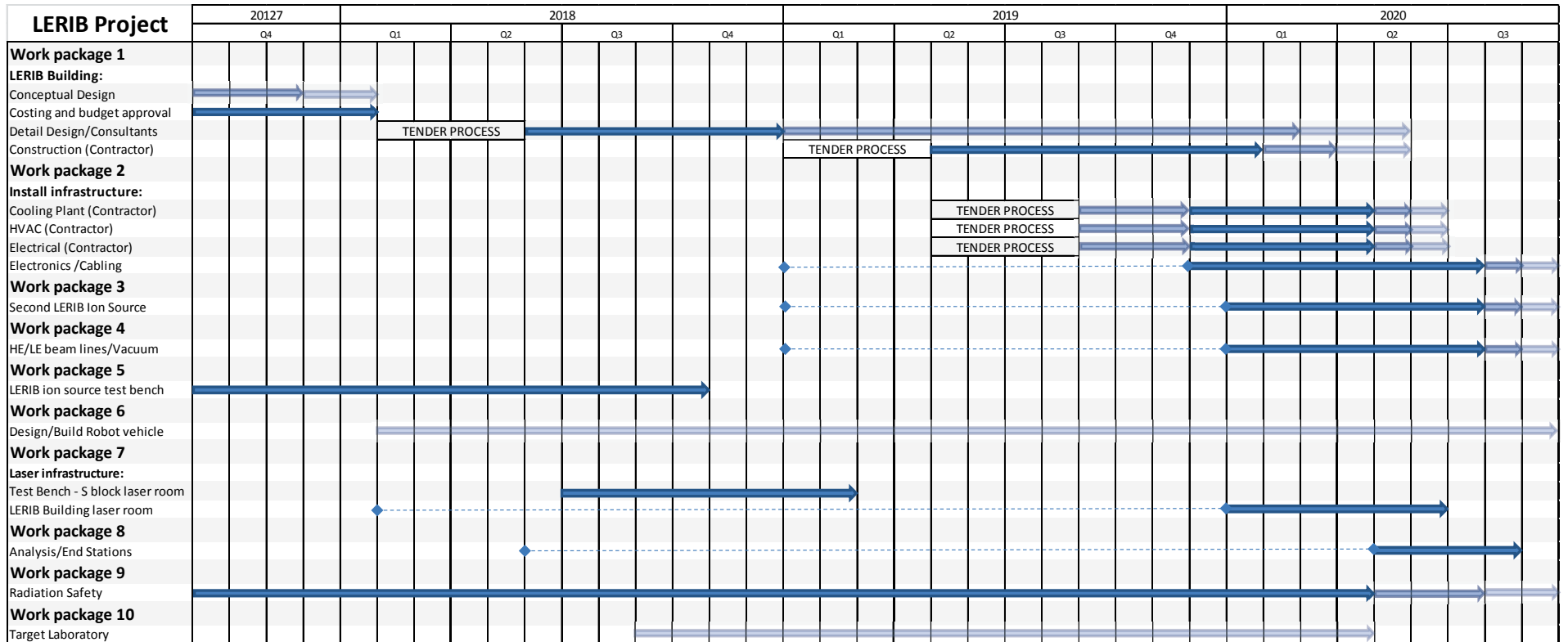
Project component	Year 1	Year 2	Year 3	Year 4
Cyclotron				
Buildings				
Isotope production				
Infrastructure				
Beamlines, controls				
Additional staff complement	5	7	8	10

Table 4: Staff requirements for the ACE-Isotopes facility

Staff	Profile
1 Physicist	To oversee the entire 70 MeV H ⁻ cyclotron facility. The physicist will, amongst others, solve issues with beam optimization, reliable operation and performance improvements.
1 Radio-Frequency(RF) Engineer	To oversee and maintain the fixed frequency RF system of the cyclotron.
1 Power Supply Technician	The facility has a number of beam line power supplies for the beam line components, as well as the power supply of the cyclotron. The technician will be responsible for all these power supplies.
1 Vacuum Technician	This person will be responsible for the various vacuum systems of the 70 MeV H ⁻ cyclotron facility.
1 Mechanical Technician	This person will be responsible for the maintenance of the mechanical components e.g. ion source, beam diagnostic elements, stripper systems, etc. of the cyclotron
5 cyclotron operators	One operator per twelve hour shift. Five operators are required to comply with HR policies and LRA.

Addendum 1: Timelines of the various projects

1. LERIB Project Plan



2. Radio Frequency (RF) Upgrades

RF Upgrade Projects	2017				2018				2019				2020			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Spare 150kW Amplifier																
Complete New Amplifier	→															
Upgrade of existing amplifier control									→				→			
Low Level RF Control Systems																
SPC1																
SPC2	→															
SSC			→													
Motion Control	→															
Upgrade of RF Amplifiers																
Prototype			→													
SPC1							→									
SPC2								→								
Bunchers												→				

3. Proposed timeline and cash flow budget for the implementation of the ACE-Isotopes facility

Table1: Projection of required funding (in R1,000,000's) and cash flow per annum

Phase 1: Isotope Production	Year 1				Year 2				Year 3				Year 4				Total Cost
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
Cyclotron	57.6			57.6							57.6			19.2		54.1	246.1
Buildings		0.5	8.8	7.7	8.0	8.8	4.9	1.7									40.4
Isotope Production				4.6	8.6	9.3	9.5	9.9	20.9	20.9	19.7	12.7	4.6	4.6	4.6		130.0
Infrastructure					11.1	11.1	11.1	11.1	6.8	1.9	2.9	2.9	1.1	1.1	1.1		62.2
Beam lines, Controls		3.8	3.8	3.8	3.8	3.8	3.8	3.8	4.4	4.4	4.4	4.4					44.4
Salaries	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	7.5
Contingency				6.9				6.9				6.9				6.9	27.7
Totals per quarter:	58.1	4.8	13.1	81.2	32.0	33.5	29.8	33.9	32.6	27.7	85.0	27.4	6.2	25.4	6.2	61.5	558.3
Totals per annum:	157.2				129.2				172.7				99.3				558.3

4. Control System Upgrades

Control System Deployment and Upgrades	2017		2018				2019				2020				2021			
	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
MRD Tandatron																		
Experimental beam lines	→																	
SAIF ACE - Beams																		
RIB off-line test facility (S-block)	→																	
Low Energy Test Facility (LERIB)			→															
SAIF ACE - Isotope Project																		
Integration with supplier Control System																	→	
HMI & GTS Ion Sources																		
USB serial to eherCAT modules and software development	→																	
Upgrade Power supply controllers		→																
SPC1 Electronics and control																		
Replace current measurement electronics		→																
Redesign Ion source Interlock hardware			→															
SPC2 Electronics and control																		
Convert Slits and power supplies to EPICS				→														
SSC Electronics and control																		
Covert existing mezzanine equipment to EPICS					→													
Beam Diagnostics																		
Covert Beam Positioning/Profile Monitoring to Linux/EPICS							→											
CAN bus to EPICS stream device code							→											
Hall probe Monitoring to EPICS							→											
Phase Measurement (FASE) Applications to be upgraded										→								
Upgrade Wire Scanner systems														→				
Physics																		
Covert Target currents and feedback loops to Linux/EPICS								→										
Other Control Systems Upgrade to EPICS																		
Entire power supply room F5				→														
Improve Harp reliability			→															
Remote access to Control parameters											→							
Control Desk upgrade (larger screens, touch control)												→						
Alarm Handler	→																	
All vacuum systems to EPICS	→																	
Site Alarms system upgrade			→															
Upgrade backend control system servers (dbase, bridges, dhcp)							→											



Risk Management:

Radiation Safety Health Environment and Quality (RSHEQ)

1. Background

Amalgamation of the Radiation Protection (RP)- and the Safety Health Environment (SHE) division will be effected to stimulate synergistic interaction and coordination of activities of the former independent divisions. The rationale to merge these units to incorporate all facility occupational risks under a single department, RSHEQ, and integrate Safety and Security is wholly in line with the International Atomic Energy Agency (IAEA) guiding principles.

The merger of these divisions under a quality management umbrella, the norm at nuclear/radiation facilities, will promote a shift from ad hoc safety and security practises to a proceduralized system of Radiation Protection and Occupational Health and Safety in line with the regulations and international best practice. This to warrant regulatory compliance encompassing all spheres of the business unit.

2. Future Challenges

The primary objective is the successful incorporation of the RP and SHE divisions into the RSHEQ; restructuring, redeployment and integration of staff, establishing reporting lines and streamlining of operations in line with organisational goals. Continuation of operations and maintenance of full compliance to the legislation, regulations and policies amid the restructuring and adaptation period will be a priority.

Secondly, the operational capacity of the department will be challenged by key developments in the near future; prospective legislative changes that will bring about an increased demand for procedural documents and specialist input by the future radiation regulatory authority. Infrastructure expansion and new projects associated with the acquisition of a 70 MeV cyclotron and the generation of highly radioactive targets with long half-lives in the LERIB program, will place additional demands on radiation protection operations.

A review of the security infrastructure and operational protocols has to be undertaken, including the integration of security and safety. The access and egress policy and enforcement thereof as well as perimeter and on site security has to be assessed and updated to ultimately be in line with the IAEA guidelines. Lastly contract management must be implemented and service level agreements (SLA) established with vetted providers to ensure quality service without compromising safety and security.

3. Organisational and Staff Establishment

3.1 Legislative and Policy Environment

The RSHEQ will be tasked to maintain regulatory compliance in terms of the Hazardous substances act no. 15 of 1973, relating to Group III (electronic products producing ionizing radiation) and Group IV (radioactive material) hazardous substances. In terms of these regulations, internal rules and policies drafted to promote radiological safety are binding and compliance has to be demonstrated. Likewise, assurance on the state of operational safety, health and environment in the facility in terms of the Occupational Health and Safety Act (act no. 85 of 1993), related regulations and policies have to be delivered. In addition, security elements pertaining to the respective mandates and authorities of the former RP and SHE are to be compliant and in future integrated with safety in line with IAEA guidelines.

3.2 Current Systems, Internal Control and Organisational context

The scope of the RSHEQ is not limited to radiation related and operational health and safety in the facility. Onsite security and housekeeping/hygiene services form an integral part of the group. Resourcing in this department over the next two years will require review, considering upcoming retirements, restructuring and changes in the scope of activities.

To meet the targets set out in the long range plan of the RSHEQ department and address the forthcoming challenges, key staff will have to be attracted and assigned to identified functions. Additionally, redeployment of staff to leverage synergy opportunities has to be effected as depicted in the organogram (Fig 1).

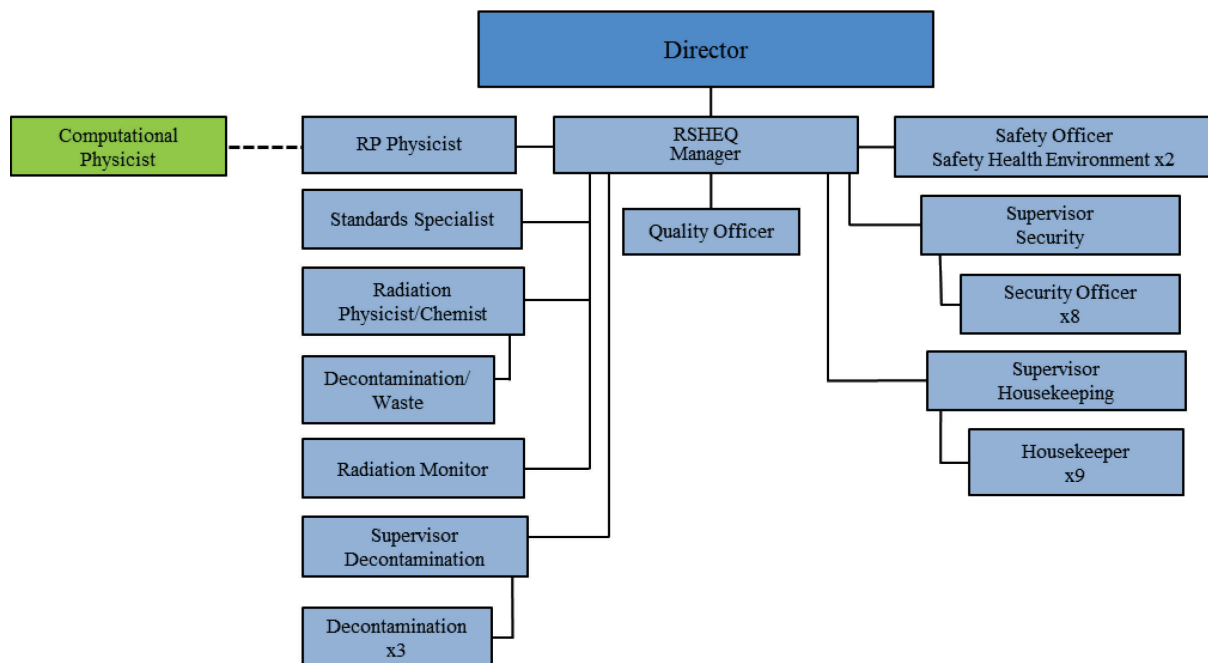


Figure 1: Organogram depicting the RSHEQ departmental structure and organisational reporting lines.

The department with its extended mandate will be established in phases as detailed below:

- Phase 1: Recognized essential human resource vacancies will be filled and skills transfer programme to commence
 - Skills Transfer SHE manager to SHE Officer
 - Fill Radiation Protection Physicist (rad-waste) vacancy
 - Fill Radiation Monitor vacancy
 - Fill Standard Specialist position
 - Fill Supervisor Security and Security officer positions
 - SLA - outsource housekeeping services partially
- Phase 2: Redeployment of staff to fulfil existing and new roles within the RSHEQ department
 - SHE Officer job progression – Safety, Health and Environment increased scope (job description (JD) change & job evaluation (JE) review)
 - Housekeeper to move to Decontamination duties
 - Housekeeper move to rad-waste management following Physicist (rad-waste) appointment
 - Fill Computational Physicist position – joint appointment
- Phase 3: RSHEQ department fully established as per organogram
 - Formal changes in reporting lines (JD change & JE review)
 - Fill Quality Officer position

4. Planned Deliverables

The mandate of the RSHEQ encompasses occupational risk management and certification of end-user's compliance with legislation, regulations and policies governing their respective applications in a regulated environment. Intrinsicly, identification and controlling risks or mitigating their impact is in the best interest of the organisation.

At present, looming regulatory changes governing the production, trade and application of radioisotopes places the business unit potentially at risk. As such the short term strategic area of development will focus on aligning functions and operations with international practices and guidelines as the full extent of the change will only be clear once the requirements for both the current and possible new regulator are known. A substantial increase in the demand for specialist input and procedural documentation can with relative certainty be expected.

Key areas of need/development:

1. Pre-emptive realignment of operational and administrative aspects to conform to IAEA guiding principles
2. Drafting and technical revision of policies, standards, rules and plans in line with IAEA guidelines

3. Operational capacity expansion to accommodate the isotope production expansion, SAIF (ACE-LERIB), new regulatory framework
4. Radioactive waste and effluent management and monitoring developed
5. Contract management and SLA's undertaken
6. Computational Physics capability trained/enlisted
7. Professional development and training at various levels – demand driven
8. Quality management systems implementation

4.1 Deliverables Implementation - Next Five Years

4.1.1 Short term (0-1 years)

Initially the operational capacity challenges posed by unfilled vacancies, increased operational demands and imminent regulatory changes need to be addressed. By appointing key personnel and leveraging divisional synergies during the course of the merger, the short term goals can be achieved.

Outcomes:

- Smooth transitional phase with clearly defined roles for RP and SHE to progress to RSHEQ
- Supplement critical needs and resource deficiencies through cost-competitive service level agreements
- Review all insourcing and outsourcing services
- Address operational deficiencies by employing a physicist/chemist to manage all radioactive waste and effluents and maintain a compliant waste management programme
- Likewise, a radiation protection standards specialist to compile regulatory required documentation; in the interim update all documents, rules and policies in line with IAEA guidelines
- Formalise channels (digital and physical) to engage with users and visitors – training, personnel dosimetry, safety, security, indemnity, and interaction with their respective institutions
- Enlist the services of a suitably qualified Monte Carlo expert to perform shielding and activation calculations for the proposed new cyclotron and associated activities

Supplementary staff will allow the currently employed physicists to focus on regulatory compliance and operational matters which are vital to align the division to deal with prospective changes in the regulatory authority and increased user demand. Compilation and

review of technical documents and hazard assessments in line with legal requirements is critical. The DoH/SAHPRA has escalated regulatory document requirements, a direct result of the regulatory review conducted by the IAEA.

4.1.2 Medium term (1-2 years)

Expected changes in the demands of regulatory functions needs to be clarified with respect to the use and possession of radioactive materials and ionizing radiation producing electronic products as defined by the IAEA. The demand on staff to deal with regulatory compliance issues will be determined by the level of the regulatory requirements and administrative burden imposed by the prospective new regulatory authorities. Additionally, security services to be fully integrated and operations aligned to international trends.

Objectives:

- Introduction of a quality management system to assess and improve the various functions of the department to ensure that user and regulatory requirements are met and continually improved
- Skills development for staff – quality management systems, legislative refresher as well as operational demands driven professional development
- Overhaul security operations, access control (policies and procedures) perimeter and onsite security (infrastructure and protocols)
- Emergency preparedness response in support of the biodosimetry programme – radiation protection related research opportunity and incident exposure monitoring
- Accommodating students and interns in learnership programmes
- Training of postgraduate students

4.1.3 Long term (2-5) years)

The quality management system should be used to identify shortfalls and to ensure that adequate measures are in place to address technical issues relating to safety, protection of health, protection of the environment and security. Growth within the areas of competence will be driven by regulatory and user demand.

Outcomes:

- Implemented quality management programme covering all RSHEQ activities
- Established capacity to perform radiation transport simulations as this capability will be necessitated by the activity expansions, regulatory and licensing conditions
- Competency in the field of proton and neutron induced activation calculations and assessments developed – regulatory and operational use
- Comprehensive waste management programme – fully implemented

- Environmental monitoring programme to assess all effluents/activation products and its dispersal into the environment (groundwater, soil, air and waste streams)
- Established user and visitor interface for all occupational health related risk – training, reporting and action
- Emergency preparedness response in support of the biodosimetry programme – research activities, personnel monitoring, emergency personnel dosimetry and training
- Enlist students and interns in learnership programmes
- Training of postgraduate students – Health Physics, computational physics and effluent management

5 Planned Five-year Performance Targets

- Regulatory compliant operations
- No Major Incidents
- No Major Customer Complaints
- Internal Audit pass
- External Audit pass



Communication and Training

This section is dedicated to the Long Range Plans of the Information services, Training activities and Community interaction.

1. Information Services (CIS)

1.1 Overview

1.1.1 Library and Information Services

The Communication and Information Services (CIS) of iThemba LABS provides a total information and research support service to the staff and users of iThemba LABS. Current collections and information services support globally competitive research and knowledge generation.

The IS, in addition, provides full project management of all local and international conferences, symposia, workshops and events and have developed systems and skills over a period of more than 20 years. The successful quality hosting of events contribute to the promotion of iThemba LABS to local and international stakeholders and the growth of the influence, impact and reputation of the institution. More than 22 international conferences have been hosted since 1999.

The library collections, based in Cape Town and Gauteng, comprise of a core journal collection, monographs, reports, internal documents, theses and more. The journal collections are available in both print and online, accessible across the iThemba LABS' network to researchers, collaborators and students. Monographs are purchased in response to research and operational needs.

Document delivery and information retrieval represents one of the core functions of the LIS. This service supplements the collections and provides access to essential research material to all staff and students. Approximately 600 document delivery requests are processed annually.

The CIS manages the following databases/software:

InMagic Genie, an integrated and customised library management system, which provides access to the collections, circulation and loans control, cataloguing and classification and overall collection management;

DSpace, an open source digital institutional repository, providing centralised access to internal documentation such as technical drawings, procedures and policies.

Indico, an open source tool developed by CERN, offering complete management of conferences and events, including registration, full abstract and timetable management.

The IS is responsible for the identification and capturing of all research output for iThemba LABS on the Research Information Management (RIMS) system and provides management

with research data for quarterly KPI reporting and for the Research and Innovation Reward Programme (RIRP) application.

Training opportunities are provided for students of library and information science and office management and technology. On average 4-5 students are trained per annum.

1.2 Key Objectives

- Information services, including library in response to research, strategic and operational needs
- Research support services
- To facilitate knowledge generation, sharing and Open Access
- Orientation & information literacy training services
- Offering training opportunities for students of library and information science and office management and technology
- Conference and event management services
- Communication

1.3 Current Staffing

The permanent library staff currently comprise of four (4) professionally qualified librarians, namely the Head of the Division, two (2) Librarians (one in Cape Town and one in Gauteng), and one (1) Assistant Librarian (currently vacant).

In addition, there are currently two Office Management and Technology (OMT) students and one Library Intern working in the CIS.

1.4 Challenges and Risks

- Head: CIS retirement
- Loss of skills and expertise (both library and conferencing)
- Vacant position
- Added pressure on current staff
- Failure to progress essential projects
- NRF Open Access IR
- Annual Stocktake
- MRD journal collection relocation
- Retrospective cataloguing and classification
- Communication portfolio

The filling of the current vacant post in the library services would relieve the overall workload and ensure that all projects are progressed, including communication projects. The appointment of a communication/journalist intern or contract person would provide the opportunity to transfer skills and knowledge and to supplement the current conferencing team.

The library space has reached its full capacity due to the annual growth of the print and hard-copy collections. Additional shelving is necessary to accommodate the still growing paper collections. The current journal subscription agreement (print and online) is in place for the period 2016-2020, which means shelving space has to be provided for another 5 year's growth of print journals. E-only access should be investigated for the future iThemba LABS library. The Springer journals and sub-set of books are available in full-text online only from 2016-2020.

Procurement processes requires substantial staff time to progress ordering and payment of suppliers. This is valid for both library procurement as well as conference and event procurement. This has to be factored in when calculating staff time spent on projects.

1.5 Future Projects and Plans (2017-2021)

1.5.1 Refurbishment and branding of library space

The library space and furniture is in urgent need for refurbishment as it has not been updated in almost 20 years. The library is not only used by staff, but is frequented regularly by local and international visitors, using the library services, board room for meetings and during conferences. It is therefore critical to refresh and update the space. In view of the current communication strategy it is particularly important to present the NRF iThemba LABS branding and provide a modern and inviting space for visitors. The library main information centre and archives are very well used by staff and postgraduate students for research and study.

The following has to be done:

- Main Information Centre: new carpeting/flooring, painting, furniture, equipment, LED screens for communication;
- Soundproofing of meeting room;
- Addition of study cubicles in library and archive;
- Expansion and refurbishment of archive (dry wall to be removed between archives and work area, new flooring, window blinds, additional compact shelving, study/work cubicles, air-conditioning);
- Investigation and costing of a possible relocation of the LIS to form part of a future Visitor Centre. This would be a longer term project and has major cost implications. Various factors have to be considered, including convenient access to all target clients, proximity to conference facilities in main building and cost of construction and fitting of a modern, client-friendly multi-purpose facility.

1.5.2 Dspace IR customisation

The DSpace Institutional Repository needs to be customised and branded. This project has not been progressed due to lack of manpower and expertise. The SU Library Services has

some expertise and could recommend training options that are available. It is important to have these skills in-house and for the IR to be correctly branded before we make it widely available.

1.5.3 Contribute to the NRF IR by capturing all iThemba LABS research output

This project is behind schedule due to lack of staff resources. It has to be commenced to comply with the NRF Open Access Mandate. The filling of the vacant post and a contract post can progress this in the next year.

1.5.4 Ensure adequate virtual machines and storage for e-collections and IR

The increase of e-resources and growth of databases content on an ongoing basis requires that adequate electronic storage and back-up is in place.

1.5.5 Digitisation

The NRF is currently preparing the Sellschop Collection (Gauteng) for digitisation as part of their digitisation project. An initial audit of iThemba LABS digitisation needs was conducted in 2016 by the NRF. There is a variety of technical documentation, including drawings that should be digitised to improve site-wide centralised access. To date 5700 technical drawings have been digitised and uploaded to the DSpace IR by LIS staff. A digitisation strategy with priorities should be developed for iThemba LABS.

1.5.6 DSpace Institutional Repository

Departments should identify and prioritise documentation for upload to the DSpace IR. Currently the collection comprises of technical drawings, annual reports, procedures, news clippings. NAC reports have been digitised in readiness for upload.

1.5.6 RD and MEDRAD departmental collections

The Materials Research Department print collection has to be relocated to the Main Library. The MRD library space has been repurposed for meeting/office space. The collection is currently in boxes and can only be moved once additional shelving has been installed.

The MEDRAD collections (books and journals) are currently housed in the MEDRAD department meeting room. The available physical space is limited.

The centralisation of all collections emphasises the need for review of the content and the expansion of the current physical space of the library and information services.

1.5.6 Weeding of collections

The library collections have to be reviewed and obsolete materials identified for withdrawal. This would ensure that available space is optimally utilised.

1.5.7 Virtual vs physical access

Investigation of migration to electronic access only vs print of journal and book collection. Currently most titles are provided in both print and online.

2. Future Staffing

The permanent library staff currently comprise of four (4) professionally qualified librarians, namely the Head of the Division, two (2) Librarians (one in Cape Town and one in Gauteng), and one (1) Assistant Librarian (currently vacant).

In addition, there are currently two Office Management and Technology (OMT) students and one Library Intern working in the LIS.

It is proposed to fill the vacant position of Assistant Librarian as soon as possible and to appoint a communication intern in the current year. A senior librarian has to be appointed upon retirement of the current Head of Division. Training of interns and OMT students should continue. The appointment of a library intern to assist with the Open Access Project and Cataloguing would relieve some of the workload. In 3-4 years a Conference and Events position would have to be created and filled unless such services would be outsourced once the current incumbent exits.

To ensure that all planned projects can be progressed it will be important to review the future staffing composition for the Library and Information Services as well as Communication (including conference and event project management). The proposed merging of the Library, Information and Communication Division with the CIT Division requires further review and investigation as to the skills and expertise required, but also how to best ensure a smooth transition and especially the transfer of skills and knowledge. These discussions still have to take place between the divisions.

The Library and Information Services would require the appointment of a qualified and experienced senior librarian to take over the overall management of all library services once the current incumbent retires. The vacant Assistant Librarian position has to be filled with urgency to relieve the workload which is currently shared between the two librarians in addition to their normal responsibilities. The addition of a library intern to the staff has been welcome and made it possible to provide an excellent training opportunity for the incumbent, while ensuring that normal operations and services are able to continue. It is recommended to continue with the addition of library interns to the staff. It is also recommended to appoint a communication/journalist intern or contract person to assist with the communication portfolio.

iThemba LABS has committed to host a number of international conferences between 2017 and 2019. These projects have commenced and is expected to be concluded at the end of 2019/beginning of 2020. Expertise and skills have been developed over a period of 20 years

and a plan for transfer of skills has to be implemented. This is not only valid for the Head: LIS, but also the Librarian who has gained considerable skills and expertise in areas of conference management. Training of future staff and the development of a “Conference Management Handbook/Guidelines has to be prioritised over the next three to four years.

To ensure a smooth transition an interim organogram is proposed. The second organogram is a first attempt at a future structure for a merged library, information, communications and community outreach department.

3. Communication Strategy

3.1 Objectives

To promote the NRF Brand according to the NRF Strategic Objective 5: ***Grow NRF influence, impact and reputation;***

To promote the NRF position as “*The lead agency driving the transformation of South Africa into a knowledge intensive economy*” (Draft NRF Brand and Communication Strategy p3);

To increase visibility of iThemba LABS;

Positioning iThemba LABS as the hub for the accelerator based research community in South Africa;

To leverage support from stakeholders for proposed new projects.

3.2 Brand Values and Message

The brand values of the NRF are:

- Passion for Excellence
- World-class Service
- People-centred
- Respect
- Integrity and Ethics
- Accountability

3.3 Overview

There is a need for iThemba LABS to be much more visible to all communities and to all its stakeholders than it is at the moment. Due to the the specialized nature of research and technical operations all departments need to acknowledge an aspect of communication from within their operations. However it is imperative that communication is well coordinated and that it is effective in reaching the specific target audience for which it is intended.

Therefor a Communications Team was put in place during November 2016 to plan a strategy and implement improved communications and visibility for iThemba LABS.

3.4 Target Audiences

The communications strategy has to be focused on specific target audiences, customising the key messages and communication channels accordingly. Priority audiences and key messages should be clearly defined.

Primary stakeholders

NRF and DST

The major stakeholder for the NRF and iThemba LABS is the DST as the primary funder for the organisation. It is therefore critical to demonstrate return on investment.

Internal Community

The success of the organisation is largely dependent on the staff and efficient internal communication will determine whether organisational objectives can be met.

Academic and Scientific Community

Communication with HEIs on all levels including leadership, research departments and students is essential to build relationships and collaborations.

General Public and local community

Science engagement and community outreach are important tools to create positive perceptions of the societal benefits and value that iThemba LABS offers to the Southern African communities.

Visitors

Effective communication with external visitors to iThemba LABS will enhance key messages and extend reach and visibility. Levels and content of communication should be adapted to suit a variety of visitors, whether learners, researchers, international visitors, conference delegations or other professionals.

International Community

The international communities are key to demonstrate a reputation of excellence and peer confidence, while building awareness and providing critical support.

Media

The media can be an influential partner to increase awareness and improve visibility for iThemba LABS. This is an area that should receive more attention over the next 5 years and can be utilised to demonstrate societal impact and value, while focusing attention on new projects.

3.5 Future Projects and Plans

3.5.1 Conferences and Events

The Communication and Information Services (CIS) Division provides full project management of all local and international conferences, symposia, workshops and events and have developed systems and skills over a period of more than 20 years.

The hosting of conferences and events forms an important element of the communication strategy for iThemba LABS.

The successful quality hosting of events contribute to the promotion of iThemba LABS to local and international stakeholders and the growth of the influence, impact and reputation of the institution. More than 22 international conferences have been hosted since 1999.

As an example, the following events and conferences were amongst those organised and/or hosted in 2017:

- ATLAS TileCal Upgrade Workshop 15-17 March 2017
- NRF DA Workshop
- SAASTA/NPEP Science Writing Workshop 29-30 May 2017
- 4th China – South Africa Joint Symposium on Nuclear Physics 5-7 August 2017
- 30 Year Celebrations November 2017

And as another example, the following international conferences were successfully bid for and will be hosted during 2018-2020.

- ATLAS Muon Workshop February 2018
- Advanced Nuclear Science and Technology Techniques Workshop (ANSTT) March 2018
- 6th Collective Motion in Nuclei under Extreme Conditions Conference (COMEX6) 29 Oct-2 November 2018
- International Workshop on Discovery Physics at the LHC (Kruger2018) 3-7 December 2018
- International Conference on Cyclotrons and their Applications 23-27 September 2019
- Conference on Neutrino and Nuclear Physics (CNNP) February 2020

A bid has been submitted to host the 15th International Accelerator Mass Spectrometry Conference in Cape Town from 7-11 September 2020. The outcome should be known by the end of December 2017.

3.5.2 Communication Projects 2017+

Publications

Print and digital publications are useful tools to increase visibility and awareness. Appropriate publications targeting a variety of audiences has to be identified and the

necessary budget allocated. Examples are Quest Magazine, Career-oriented publications and thought leadership publications.

3.5.3 Online

Significant progress has been made with the redesign of the website, but the content has to be updated and refreshed in the next year to ensure that the right messages are presented. The Intranet has to be updated and essential information added for improved internal communications. The lack of access to documents leads to misinformation and an inability of staff to be able to promote the NRF iThemba LABS brand and future vision. The use of social media, such as Facebook is an essential tool as this has become a standard means of communications in the modern society. The iThemba LABS Facebook Page has proven to be a useful tool to disseminate information and a more structured communication plan should be put in place.

3.5.4 Media

Increased efforts should be made to raise visibility via media coverage through press releases, articles, interviews, radio and television. Relationships should be built with journalists and other media partners. Invitations should be extended to the media to inform them about the activities of iThemba LABS. Collaboration with the NRF Communications Team will be essential in this regard and should be actively pursued.

3.5.5 Audio-Visual

A variety of audio-visual tools can be applied, such as photographs, sound bites, official video clips (you tube), LCD Screens and Electronic Billboards.

3.5.6 Events (other than conferences)

Events such as exhibitions, public lectures, other lectures and Science Week are effective communication channels and should be maximised. Visibility at local scientific conferences, such as SAIP and DST will increase impact and influence. The most valuable events should be identified. Annual advance planning and scheduling is important as well as the preparation of appropriate marketing materials. The past year has seen increased visibility and strengthening of the brand with improved marketing materials, such as brochures and posters and location of exhibition stands.

3.5.7 Corporate Materials

The design of new corporate marketing materials has to be fast-tracked as these are necessary tools for promotion. Successful marketing at events, exhibitions and to visitors is dependent on the availability of ready-made materials. Some progress have been made with materials prepared for the 30 Year Celebration Stakeholder event, but new corporate brochures, banners and branded gifts have to be developed and produced in 2018. Special events, such as the 30 Year Celebrations, offer excellent opportunities for promotion and should be identified and utilised.

The branding of all vehicles and the iThemba LABS bus should be discussed as this is a very visible way of promoting the organisation.

4. Communication Staffing

Current communication activities are coordinated by the Director and the Communications Team (see paragraph 2). The conferences and events management is managed by the Library and Information Services Division. Science Engagement and community outreach resides within the Community Interaction Division.

Project management of conferences and events are led by Naomi Haasbroek, with support by Audrey Sauls, students and a variety of internal departments, namely Housekeeping, Canteen, IT Support, Transport, Site Services, SCM and Finance

Future staffing needs (2019/2020 +)

- Communication and Conference Manager or Conference Organisers contracted out
- Journalist/communication interns/copywriter/staff
- Conference logistics and admin staff
- Photographer – to be contracted out
- Visitor Centre staff (guides and information officers)
- Community Outreach staff

6. Risks And Priorities

Within the next one to three years the greatest risk will be the loss of expertise and resource when the Head of the CIS division retires. A major priority item for the long-range planning will be the transfer of skills and knowledge (also of systems), and training. The appointment of additional staff for conferencing and communication is essential for a successful communication strategy.

A structured communication plan with a dedicated budget and adequate staffing will need to be put in place to reach the envisaged objectives.

Discussions to determine the possible merging of Community Interaction and Communications Activities has to take place and a suitable structure and skills requirements have to be developed.

Immediate priorities are the further improvement of internal communication, in particular the flow and sharing of information from top management to middle management to staff. Sharing of information from iThemba LABS to the NRF with regards to communication has to receive further attention.

7. Education and Training Opportunities

1. Introduction

iThemba LABS (Laboratory for Accelerator Based Sciences) is an NRF-administered, multi-disciplinary national research facility which is based at Faure near Cape Town, with a satellite laboratory located in Gauteng. In partnership with Higher Education Institutions

(HEIs) and Industrial Councils, the research platforms offered by iThemba LABS contribute significantly to the building and growing of South Africa's technically-skilled Human Resource capacity.

2. Education, Training and Development (ETD) for iThemba LABS Staff

iThemba LABS has a dedicated Education, Training and Development (ETD) Committee one of whose main remit is to assist iThemba LABS employees to enhance their formal qualification profiles through part-time studies. Through the ETD scheme, regular annual calls are released to invite applications from iThemba LABS employees who wish to further their studies, and upon review of applications by the ETD committee, successful employees subsequently get their study costs subsidised at levels determined by the NRF policy.

The ETD employee part-time study subsidy scheme has proven a successful mechanism to enable continuous staff development. Departmental managers are encouraged to provide continuous guidance for employees to assist them choose courses or modules most relevant to the departmental operational needs.

3. Post Graduate Students Training

iThemba LABS also offers a number of Education and Training programmes for post-graduate research students in selected fields of Science, Engineering and Technology, with a specific focus on research projects that utilize accelerated ion beams as primary research tools.

Post-graduate research projects are available for post-graduate students to pursue either applied or basic research in the fundamental studies of nuclear structure and phenomena, application of ion beams with associated analytical techniques in materials science and nanotechnology, radiation biology and particle therapy, and the production of accelerator-based radionuclides for medical applications.

Post-graduate research students pursuing their degrees in association with iThemba LABS are academically registered at a tertiary institutions of Higher Learning, and are assigned co-supervisory assistance from iThemba LABS staff, together with financial support offered on established need basis.

4. Post-Graduate Teaching Programmes

In partnership with the University of the Western Cape and the University of Zululand, iThemba LABS has participated in the MANuS/MatSci post-graduate programme for Masters in Accelerator and Nuclear Science, and Masters in Materials Science. This two year course currently offers an intense schedule of taught modules in the first year equivalent of honours, and a fairly comprehensive research project in the second year equivalent of Masters. The MANuS/MatSci programme was launched in 2004, and since then, a relatively higher number of Physics post-graduates from mainly historically disadvantaged backgrounds and institutions have benefited from the course. Latent deficiencies of the programme, both structural, academic and logistic, were highlighted in the 2011 review together with recommended remedies to enhance the impact of the programme.

Recent discussions on the need to move towards the establishment of a broader student training platform under the overall umbrella of the South African Institute of Nuclear Technologies and Sciences (SAINTS) were also to a large extent stimulated by the need to enhance the efficiency of programmes such as the MANuS/MatSci.

5. SAINTS

iThemba LABS will consolidate all the training initiatives in the laboratory under the umbrella of the South African Institute of Nuclear Technology and Science (SAINTS). Staff learning and development initiatives, courses for MSc and PhD programmes, short courses for professional development and international schools and workshops will be coordinated through this institute. The French National Institute of Nuclear Sciences and Technology (INSTN) which operates under the aegis of the French AEA (Atomic Energy Commission), and iThemba LABS has entered into a co-operative agreement to establish SAINTS. iThemba LABS will also collaborate with South African and international institutions of higher learning to offer training courses through SAINTS. To date, a total of seven Higher Education Institutions have indicated their support for both the establishment of SAINTS and their willingness to partake in it as it is intended (amongst other things) to enhance the current quality of post-graduate teaching, especially with its intended focus on a taught Master degree.

Over the years, the expertise at iThemba LABS in areas such as accelerator technology, radiochemistry and electronics have diminished due to retirements and attrition. iThemba LABS is busy with the modernisation and upgrading of the accelerator and research facilities. This process involves changing the operating systems to new technologies such as digital electronics in the place of obsolete analogue electronics that are now too expensive to maintain due to the shortage of spare parts and the dwindling expertise to carry out the maintenance in of this old technology. The detection system and data acquisition system must also be updated to meet the requirements of the researchers. For instance, the accelerator control system is now being replaced with the modern EPICS system that is widely used in other research laboratories. The skills required to achieve these goals is currently not adequately available at iThemba LABS, and in South Africa in general, hence there is a need to train and upskill the technicians and engineers in the lab to empower them to carry out these functions.

The lab is also planning to expand the research program to develop new radioisotopes such as alpha emitters for targeted therapy. This will require expertise in radiochemistry that is no longer available at iThemba LABS, and is scarcely available in the country as a whole. It is thus imperative to implement training programs for the iThemba LABS staff and students in the areas of accelerator technology and radiochemistry to implement the goals of the SAIF project.

Training programs will also be developed to address the growing human capacity development needs in the nuclear sciences, radiation protection and awareness, radiochemistry, radiation biophysics, material science, and nuclear medicine, needed in South

Africa and the African continent. These tailor-made training programmes will provide training for the skills required within the broader scope of the nuclear industry. Currently iThemba LABS staff offer training courses and short courses for health professionals. Additional courses that are relevant for the nuclear industry will be developed in collaboration with the stakeholders where needed. The lab will collaborate with international organisations such as the IAEA to develop training programs for the nuclear industry that will address the skills needs for the African continent.

The success/completion rate of the students registered for MSc and PhD programmes and co-supervised by iThemba LABS researchers is disappointingly low. The MANuS/MatSci program has been successful in training students at the MSc level but the performance of these students at the PhD level indicates that there are gaps in the training of the students. An informal review of the postgraduate training indicates that the students do not have adequate instrumentation skills. A formal review of the training program will be carried out in the first half of 2018, and the outcomes of the review will inform the content of the mooted training program. iThemba LABS intends to offer taught MSc courses to complement the current MSc programmes at the South African Universities. The taught Master Program in Subatomic Physics and Material Science aimed at improving the quality of the postgraduate program offered by iThemba LAB and the collaborating university is envisaged to be offered from 2019.

Discussions are underway with the INSTN and the local collaborators on how the SAINTS should be structured and how the course content and curriculum should be designed. The collaboration will start with the training of radioisotope department's staff in areas of radiochemistry by the INSTN experts, and the INSTN will assist iThemba LABS in establishing training programs in radiochemistry that will cover the following areas: Production of radiopharmaceuticals; Quality control of radiopharmaceuticals; Development of radiopharmaceuticals; and Molecular and Cellular Markings. This will provide the radioisotope department staff with the necessary expertise to develop the expertise required to produce the radiopharmaceuticals that will be used in the proposed targeted alpha therapy program.

The training of more MSc and PhDs in the nuclear sciences, radiation protection and nuclear medicine will have a positive impact on South Africa in that it will fill the technically scarce skill gap with competent, professionally qualified and accredited personnel who can render expert services in a number of strategic economic sectors, including engineering, energy and health. SAINTS will thus be used as a vehicle for human capacity development in South Africa and the African continent as a whole to train the next generation of accelerator physicists, researchers and technicians that will support the building, maintenance and utilisation of the South African Isotope Facility (SAIF).

The January 2018 Summer School to be hosted at iThemba LABS shall serve as a dry run for some of the course modules that will be incorporated into the broader SAINTS curriculum.

6. Internships

Other education and training interventions on offer at iThemba LABS include internship opportunities for both post and under-graduates, which are offered for a period ranging from six months to two years, together with vocational training available for a period of 1 – 2 months.

7. Undergraduate Bursaries

A limited number of undergraduate bursaries is offered by iThemba LABS, covering only tuition fees in the selected fields of Mechanical Engineering, Electrical and Electronic Engineering, Mechatronics Engineering, Computer Science and Radiation Biology. Prospective recipients of such bursaries must already have completed their first year of study with an average pass-grade of no less than 60%.

8. Post-graduate research Students

With post-graduate research training output featuring as one of the main key performance indicators, iThemba LABS has (recently) conducted a review of challenges faced by post-graduate students when undertaking their research projects. In consultation with the students themselves, a range of challenges were identified with a variety of mitigating strategies suggested for implementation on a short to long term basis.

iThemba LABS endeavours to improve the over-all quality of post-graduate student training as a means to progressing towards the long term objective of transformation. *iThemba LABS may for example have to consider setting up mechanisms to screen the feasibility of postgraduate research projects before they are assigned to the research students as one of the means to minimize the in-ordinate average length of time the students are taking to complete their programmes.*

The role of both supervisor and research students should be formalized in a simplified partnership memorandum which spells out clearly what the student and supervisor's individual and joint responsibilities are for the duration of the research projects. Such agreements should however remain broad enough to leave room for project specific peculiarities which could be dealt with on exceptional basis. However, as one of the mitigating interventions to lessen the length of time it is taking students to complete their degrees, the mooted agreement is considered necessary to spell out guidelines for both students and supervisor's responsibilities

Beyond the need to train students (and staff) simply as a form of compliance, a strong and innovative culture of training should be cultivated within iThemba LABS to safeguard institutional sustainability through adequately capacitated human resource.

Presented below is a summary of the highlights resulting from the post-graduate student training review.

- a. Post-graduate student funding:** The funding scheme for the students has disparities. For example, PDP bursaries are higher than SANHARP and Scarce Skills Bursaries administered by the NRF, and when iThemba LABS tops up, it tops PhDs (for example) by only a limited amount (R60kR); with no top up provided beyond R110 000.

For the long term planning, iThemba should on a regular basis adjust top-up threshold levels, with the threshold for the next cycle targeted at R150 000 for PhD. In light of recently released NRF bursary figures a top up amount of R65 000 for PhD and R45 000 for MSc should be feasible, above which figure the numbers of students topped up will have to be controlled.

A drastic increase in the top up values is only sustainable if there is a concomitant increase in the baseline allocation for NPGS (Post- Graduate Student Support) cost center. Periodic benchmarking exercises are necessary to undertake against similar institutions (within the South African National System of Innovation) that also host both post-graduate research students and interns. For iThemba LABS interns in particular (currently JE23 cost center), the funding levels may as a guiding principle simply have to be aligned with those of the DST internship programme.

- b. Monitoring Efficiency in Student Supervision Interaction:** To mitigate against the lethargic rate at which post-graduate research students complete their projects and degrees, iThemba LABS should institute a mechanism to assess the practicality of certain research projects that are formulated for students by the supervisors to determine if they (the projects) are likely to be completed within stipulated time-frames. A clearly formulated project description should be drawn and formalized, possibly accompanied by an MoU or some framework document spelling out what is expected from the supervisor and from the student.
- c. Soft Skills Training:** Whereas postgraduate students receive training at iThemba LABS within the focussed specialized areas in hard core sciences, it is imperative upon iThemba LABS to also equip the students with soft skills since not all of them will/or aspire to end up working within the R&D environment, either at iThemba LABS or elsewhere. *Skills such as computer programming, presentation methodologies and general project management are important to incorporate into the overall post-graduate training schedule.* In this respect, iThemba LABS should on a regular, ongoing basis, organize on site presentations on communication skills together with both basic and advanced computer programming modules. To this end, a post-graduate student workshop on science writing and communication was held at iThemba LABS on 29 – 30 May 2017, followed in November 2017 by basic training on Microsoft Office applications such as Advanced Excel.
- d. Access to Scientific Journals:** Lack of open access to certain journals is one of the main obstacles retarding the post-graduate's learning progress. Applications such as Eduroam should serve as a means towards a possible solution since it would allow students to gain electronic journal access through the university. iThemba LABS should work towards implementing Eduroam to facilitate and broaden student access to electronic scientific journals.

- e. **Interaction with other institutions similar to iThemba LABS:** iThemba LABS should do more to encourage student linkages with other institutions with a similar research and training agenda, eg SKA, SAAO, CSIR, Koeberg, NECSA, MINTEK, SASOL, etc. *The need for iThemba LABS to broaden its interaction with industry should also be viewed as one way of impacting on and influencing positively the future employment prospects for the graduates trained by the institution.*
 - f. **Student Office Space and Access to Desktops:** Limited physical office space is currently a challenge for both staff and post-graduate students at iThemba LABS. Relatively more post-graduate research students than before are coming to iThemba LABS to complete their research projects, and as a host institution, iThemba LABS institution has to provide more desktops and work-stations. iThemba LABS is in the process of re-organizing current space allocations to maximize current holding capacity, with certain office blocks having been identified to undergo major physical revamping and upgrading.
 - g. **Late working hours schedules for post-graduate students:** Students who tend to work after hours often feel that the LAB should consider paramount their safety as some of them work until very late at night; and that an arrangement of transporting them to their respective places of abode would be most welcome. Although it is currently considered impractical for iThemba LABS to guarantee transport for students at any given time, all available forms of assistance should continue to be rendered to students without either depleting organizational resources and manpower, or indeed compromising on student safety. In the event where late transport is seen as a non-viable option, students are encouraged to consider scaling down on late working hours, for safety reasons, or utilize through prior approved arrangement the available resting flats on site.
 - h. **Visa Challenges for Foreign Students:** Both application and renewal of Visa (for study purposes) feature most prominently amongst a myriad of challenges experienced by foreign post-graduate students. iThemba LABS shall continue to assist, through HR, to facilitate application and renewal of post-graduate student visas (for study purposes). The LABS can however assist in this respect only to a certain point, beyond which the *visa* application process becomes the exclusive domain of the relevant department; in this case the South African Home Affairs Department.
- 9. Adopt a school/learner training campaign:** As part of a broader long-term training strategy to reach out to the community, iThemba LABS is working on a project to identify a school within its proximity from which a limited number of potential learners will be identified for long term mentorship and support which shall be provided on a continuous basis from high school until post-graduate level.
- 10. International Collaborative Networks:** iThemba LABS commands a wider network of international partner institutions of similar research agenda and focus. These include international laboratories such as RIKEN in Japan, JINR in Russia, LEGNARO in Italy, FAIR-GSI in Germany, CERN in Switzerland, BNL in the USA, Helmholtz Center in Germany, Berlin, SOLEIL and CNRS in France and many more. Such wide network of collaborating institutions allows iThemba LABS to serve as Africa's gateway to access large scale international research centres for competitive training in a variety of fields that utilize accelerated ion beams as the basis of their research and analytical techniques. On a regular basis, both students and staff of iThemba LABS are sent to spend a period of time at these

international research centres for specific collaborative and training program. The long term training strategy on this front should involve a clear budgetary provision for continuous training development of staff at international collaborating institutions.



Human Resources

Introduction

Human Resources (HR) plays a vital role in the achievement of an organization's overall strategic objectives, and it is required for the human resources function to fully understand and support the direction in which the organization is moving. The Human Resources department aims to capture the "people element" of what the organization is hoping to achieve in the medium to long term strategy by ensuring that:

- We have the right people occupying key positions
- We have the right mix of skills organizationally
- Employees display the right attitudes and behaviors
- Employee work experience and skills profiles are continuously improved and
- Employees are developed/empowered in the right way (through appropriate training interventions)

There are exciting and challenging times ahead and this plan recognizes that our employees are fundamental to the organization achieving its ambitious objectives and therefore employee engagement, motivation, leadership and development are critical.

The HR is in the process of transforming the HR services we provide to ensure it is aligned to business needs. We continue to embed and develop our service delivery model in supporting iThemba LABS in achieving its strategic priorities by providing a business-oriented and client-facing service through our HR Partnering, Employment Services and Learning and Development engagements.

1. Translating Strategy into Practice

Our Plan sets out an HR strategy that will be underpinned by a detailed implementation plan, the HR Operational Plan, which sets our clear actions, timescales, responsibility and measures of success. The successful implementation of both the Strategic and Operational Plan will be monitored by the HR Manager and the Managing Director.

2. Purpose, Vision and Mission

The HR Strategic Plan is aligned to the challenges faced by the organization. It is informed by many challenges facing the Lab and the caliber of employees it employs in the unique service that we provide.

2.1 HR Vision

To be recognized by our stakeholders, both internal and external, as an HR Function which adds value, provides quality driven service and enables the business to achieve its strategic objectives.

2.2 Aims and Goals

Our overall aim is to advance iThemba LABS significance through our approaches to attracting, retaining, developing focusing on the well-being and resilience of the employees. This is reflected in the 6 key strategic people aims and supporting goals as outlined below:

Aim 1 : Attraction and retention of key talent	
Goal	Description
Establish modern and tailored recruitment and retention strategies that promote iThemba LABS as a great place to work.	<ul style="list-style-type: none"> - Provide an HR service that acts as an enabler in creating recruitment processes that are tailored to circumstances and are effective and efficient - Work with business to develop iThemba LABS Employee Value Proposition (EVP)
Attract and retain employees that are best or have a potential to be the best	<ul style="list-style-type: none"> - Enable the appointment of the best talent and aim to achieve greater diversity across our staff workforce - Develop a Talent Management Framework for the business
Aim 2 : Encourage a high performance culture	
Goal	Description
Increase leadership capability at all levels	<ul style="list-style-type: none"> - Support managers in employee engagement interventions - Translate excellence into procedures to support the delivery of a performance management culture
Embed the principles of performance management in line with deliverables	<ul style="list-style-type: none"> - Embed a performance management culture which encourages, enables, recognizes high performance
Create an environment that gives staff the opportunity to thrive	<ul style="list-style-type: none"> - Establish career pathways, encourage and enable staff to achieve their full potential in whatever way they wish their career to develop

Aim 3 : Outstanding, inclusive and supporting work environment	
Goal	Description
Forster an inclusive and supportive work environment	<ul style="list-style-type: none"> - Cultivate a work environment where the wellbeing of staff is of paramount importance
Ensure that Diversity and Transformation forms part of the iThemba LABS anatomy	<ul style="list-style-type: none"> - Drive the commitment to equality and diversity through the EE Plan and pay parity principles - Support senior management with interventions that will improve diversity and transformation of the staff complement at iThemba LABS
Social Responsibility and Sustainability	<ul style="list-style-type: none"> - Engage in activities that promote the iThemba LABS brand

Aim 4 : Development, Management and Leadership	
Goal	Description
Forster a culture of developing leaders	<ul style="list-style-type: none"> - Support managers in identifying and nurturing talent to support effective succession planning. - Invest strategically in staff to inspire and equip them to shape, influence and lead
Forster an environment of high aspirations and performance.	<ul style="list-style-type: none"> - Work with management in leadership development opportunities, linked by clear career pathways and succession planning routes, to build the next generation of researchers and professional leaders - Develop a talent pipeline and retention plan for scarce and critical skills
Invest in interventions that will ensure that managers are equipped to take decisive action and take responsibility for their decisions	<ul style="list-style-type: none"> - Support managers in increasing their awareness and taking responsibility for their people management activities - Equip managers in dealing with matters of diversity

Aim 5 : People, processes and systems focus	
Goal	Description
Building a high performance culture through Organisational Change Management (OCM).	<ul style="list-style-type: none"> - Reassess skills levels in order to develop and implement training programmes to address skills gaps - Implement a performance and development plan for all staff - Work with the business in developing an Employee Value Proposition - Develop iThemba LABS leadership competency framework and learning programmes

3. Activities that will lead to the attainment of the Aims include

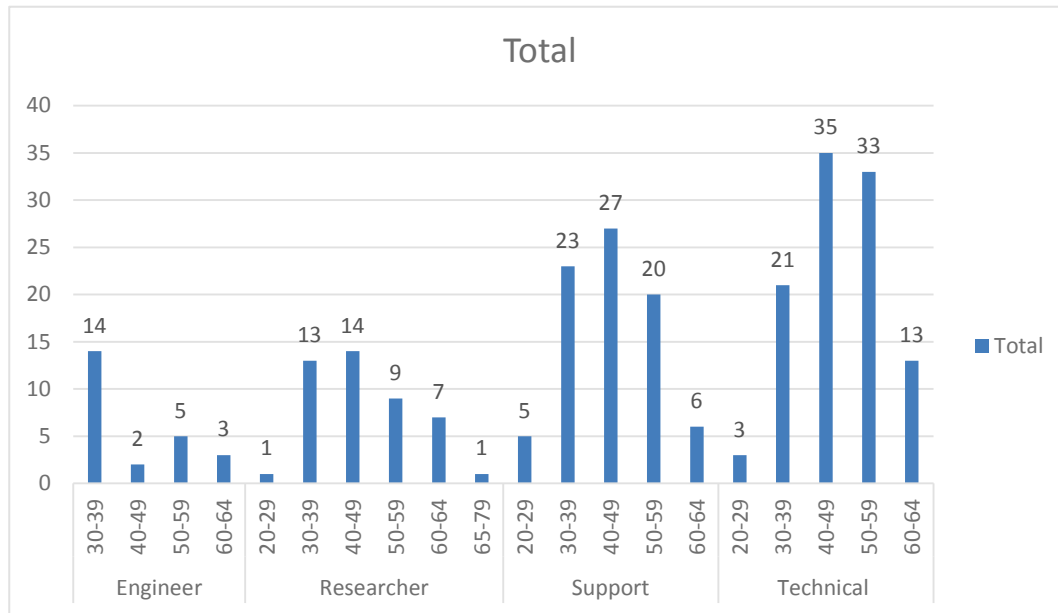
Activity	Task
Attractions	<ul style="list-style-type: none"> - Define a compelling Employee Value Proposition for iThemba LABS - Take a girl child to work programmes - Define engagement enablers - Collaborations - Leadership Competency Matrix - Unlock Social Media Potential
On Boarding & Integration	<ul style="list-style-type: none"> - Induction Programme for iThemba LABS - Research Associates/Affiliates - Cultural Acclimitisation - Engagement interviews - Skills gap analysis
Employee Engagement	<ul style="list-style-type: none"> - Strategic Human Capital optimization - Reward and Recognition - Team Effectiveness - Leadership Coaching - Health and Wellness Days
Succession Planning and Career Management	<ul style="list-style-type: none"> - Identify critical and scarce skills for iThemba LABS - Leadership pipeline <ul style="list-style-type: none"> Secondment appointments - Building Talent Pools - Skills Transfer initiatives - Monitor and evaluate - Align appointment to our Employment Equity targets
Separation	<ul style="list-style-type: none"> - Voluntary and involuntary attrition - iThemba LABS Alumni
Funding	<ul style="list-style-type: none"> - Business to come up/engage in activities with innovative funding model/s

4. Challenges

The above aims and activities are influenced by our current experiences. We acknowledge that as a mature organization the biggest challenge that we are faced with is ageing talent.

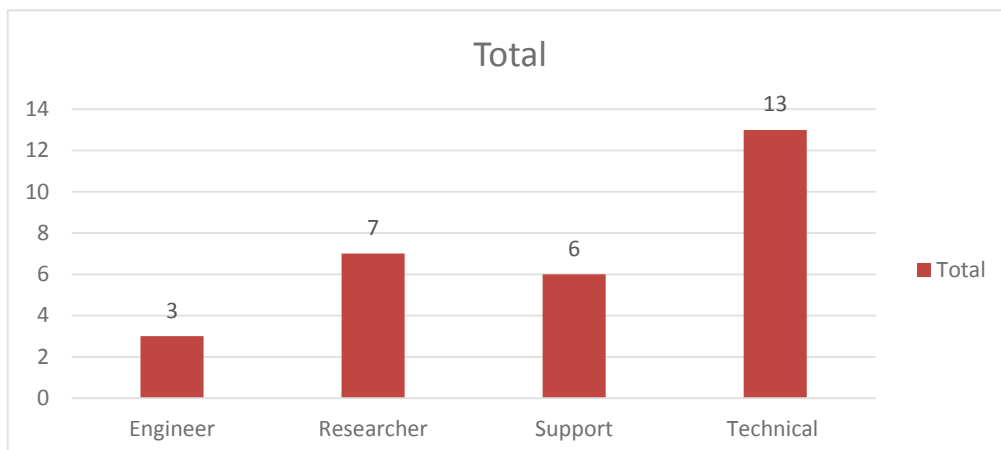
The above activities acknowledge the challenges that we are faced with and our commitment to address these effectively.

Our current staff distribution



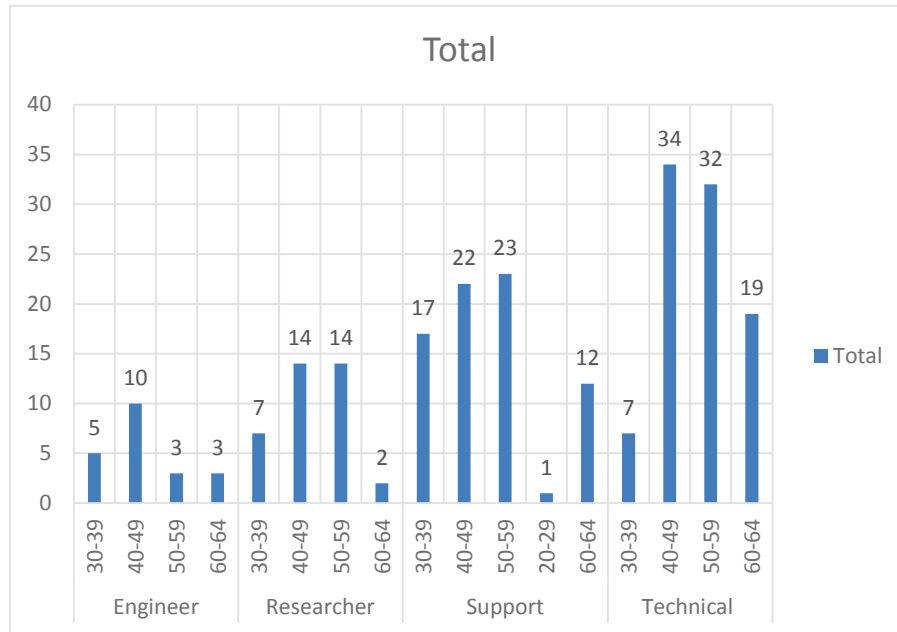
As a matured organization the biggest challenge that we are faced with is the natural attrition of experienced staff. It is evident from the graph above that much as we are a research institution, the number of researchers and engineers is low and it is highly overpowered by Support and Technical staff. This dynamic poses a challenge for development in the core business. It is acknowledged that some of the support staff are a core existent but the numbers of researchers poses a risk in terms of development and delivery. This means that our researchers are highly stretched in terms of , but not limited to, supervision of students, publications and running of experiments or innovation.

Distribution of staff retiring in the next 5 years (2023)



In the next five (5) years a total of twenty nine (29) staff members will be exiting the system. In line with our core business we will be losing seven researchers and that is highly detrimental for our progress. However, we are noting and planning for their exit and also ensuring that there is proper transfer of skills, training and transformation.

Staff distribution in the next 5 years without the retirees in 2023



5. Promoting Efficiencies

iThemba LABS has a limited supply of manpower and capital. The LAB aims to evaluate our organizational strengths in order to determine the allocation of limited resource at our disposal in a manner that will result in the highest possible potential for performance, revenue growth and sustainability thereafter. Furthermore, the effectiveness of the people strategy is depended on the identification of past performance shortfalls and identification of most critical areas that require improvement in order to accelerate the attainment of the people excellence journey.

The Human Resources Long Range Plan is interwoven into three pillars:

5.1 Organisational Culture

The success of the people strategy is depended on understanding the current organizational culture. Through the NRF wide Transformation and diversity intervention conducted in 2016, it became evident that deep considerations and engagement needs to focus in this area if we would like to attain and promote a high performing culture amidst organizational change.

5.2 Leadership Development

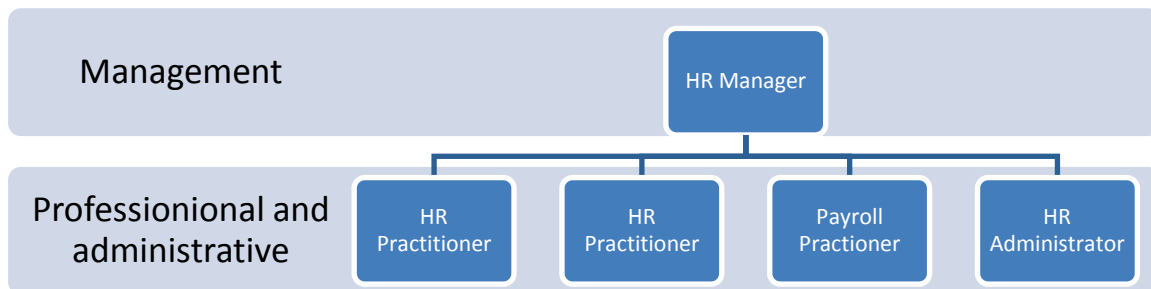
Behavioral research has stated categorically that leadership shapes organizational culture. Any planned change needs to be influenced by the leadership team. The management at iThemba needs to identify competencies/skills required for leaders at iThemba LABS.

5.3 Talent Management

There is demonstrable effect between better developed talent and high performance. Focus will be on a sound talent management plan designed to close the talent gaps and intergrated to organizational Long range plan. The People strategy needs to also acknowledge that the workforce dynamics are changing and the people strategy needs to be progressive and take this into consideration.

6. Resourcing and Support

6.1 Human Resource Department



The team currently consists of a total of five (5) members. Of the Five, one is the HR manager and the rest are professional and administrative staff. The structure consists of fairly new staff members, with the longest serving member being with iThemba in her current position for just over 3 years.

There is a need to review the adequacy of the capacity of the team to effectively support the needs to the business unit moving forward. Areas that need additional professional and administrative capacity includes Learning and Organisational Development.



Finance and Administration

1. Introduction

The purpose of the Department is to provide leadership to iThemba LABS and its various departments to ensure the successful implementation of the mandate through sustainable and integrated resource allocation and services that are end-user driven. In doing so, the Department provide end-user centric service portals and integrated resource solutions through Financial Management, Supply Chain Management (SCM), Risk Management (SHE), Logistics, General Services and Administration. These shared services portals are provided to aid the fulfilment of the goals and objectives of iThemba LABS and the various departments.

Core Values

The Department fully subscribe and live the NRF values: Accountability, Ethics & Integrity, World-class Service, People Centred, Passion for Excellence and Respect. The daily espousing of these values facilitates the Department to be responsive to the NRF core tenets of Service Culture, Excellence, Sustainability and Transformation.

2. Existing Environment and Structures

2.1 Legislative and Policy Environment

iThemba LABS, as a National Facility of the NRF, falls within the scope of all applicable NRF policies and procedures. These policies and procedures are in place to secure transparency, accountability and sound management of revenue and expenditure, assets and liabilities. Through these policies and procedures iThemba LABS derives its powers and functions and these include (for this Department), amongst others, the following:

- Preparing and exercising control over the implementation of the budget;
- Promoting and enforcing transparency and effective management in respect of revenue, expenditure, assets and liabilities of the facility;
- Issuing of procedures that are consistent with NRF policy;
- Enforcing the PFMA, Regulations, NRF policy and any prescribed directives;
- Monitoring and assessing Risk Management
- Monitoring and assessing the implementation of NRF policy and intervening by taking appropriate steps to address serious or persistent non-conformances;

- Timeously provide any information required by the NRF in terms of the PFMA;

2.2 Key and Relevant Legislation and Policies

- Public Finance Management Act, Act 1 of 1999, as amended and the regulations
- National Research Foundation Act, Act 23 of 1996
- Occupational Health and Safety Act, Act 85 of 1993
- Consolidated Financial Policy
- Consolidated Supply Chain Management Policy
- Health and Safety Policy and Risk Management Policy
- General Recognised Accounting Practice

2.3 Planned Policy Initiatives

- Socio- Economic including BB-BEE imperatives
- Transversal contracts implementation – NRF as well as NT gCommerce
- Local content procurement
- Contract Management Policy implementation
- Consolidated Financial Policies

2.4 Current Systems, Internal Control and Organisational context

The State (incl. the NRF) operates in a highly **regulated environment** and this Department is the custodian of the NRF policy for iThemba LABS. This Department ensure end-users comply with legislation, regulations and policies governing their respective sections. The business processes adopted and implemented naturally results in standardisation of systems and procedures which facilitates the managing of people, finance, procurement, governance as well as ensuring monitoring and evaluation. These official procedures are often blamed for blockages and delays in service delivery, whereas often the challenge lies in acceptance of the procedures and law, and finding ways to operate within the law rather than to find reasons why something may not be done. The Department places high value on enhancing governance and integration needs and fostering as well as encouraging responsiveness for acceptance of the policies to ensure achievement of objectives.

Underpinning all of the facility's governance efforts are the NRF transversal financial systems, which in its current state, is both value adding and limiting at the same time. Currently, the Great Plains Accounting System (GP) and various other system on a lesser scale are being utilised by iThemba LABS. These systems are not the most updated and comparable systems, and is very fragmented and not sufficiently integrated thereby creating challenges for iThemba LABS in effectively managing their financial affairs. Much effort has been made to continually upgrade the GP system. This said, the NRF has embarked on investigating an organisation-wide Enterprise Resource Planning (ERP) software system. The expected dates and clear scoping plan is however not understood and the NRF is yet to provide more details. Internally, iThemba LABS makes use of various platforms to record information and data which is used to provide reports to NRF monthly and quarterly. Though, much effort has been made to centralise information and data sharing at iThemba LABS, much more still needs to be done. Various initiatives are afoot to respond to this need.

2.5 The Financial Management in iThemba LABS is sound and provides the requisite leadership, advisories and support to the facility and its departments. The general state of the general ledger and reconciliations are such that it provides sufficient and appropriate information on the health and sustainability of the facility, by way of the management reports which allows and facilitates credible management decision. Planning and budgeting are done annually with the broader management team in line with the budget and planning guidelines issued by the Corporate Office. The existing budget and managing of resources, more so giving effect to new priorities aligned to the Long Range Plans as well as the various governance related requirements brought about by the cost containment measures and governance, requires responsive managerial decisions to give effect to these new priorities and requirements. There is thus a compelling need to present information to the Corporate Executive in a more strategic focussed, priority driven and credible manner to enable effective decision-making.

2.6 Supply Chain Management (SCM) is one of the key mechanisms enabling iThemba LABS to implement and achieve its objectives. With the initial implementation of SCM at iThemba LABS, and probably the wider NRF, much of the negative sentiment can largely be attributed to misunderstanding and undervaluing the benefits of this critical business process. Its strategic importance has not been sufficiently recognised, and it has been under-resourced from day one. This lead to extensive reports issued on the negative effects of an inefficient SCM globally. This said, much has been done to provide a service to the facility amidst the minimal allocated resources and iThemba LABS plays a key role in shaping SCM policy in the NRF. In addition, iThemba LABS has begun a process to review its SCM processes/workflow, and resourcing the SCM unit to be the strategic and user-centric shared portal responsive to the needs of the facility and the departments.

2.6.1 The **Support Services** section, within the SCM division, focusses on centralised office and logistics services. These functions include Fleet, Messenger and Central Copy Room services. This unit functions effectively and operates seamlessly in the organisation. This unit is sufficiently capacitated.

The **Safety, Health and Environment** Division provides the requisite assurance on the state of operational health and safety environment in the facility. Over the years much has been done to ensure full compliance to the legislation, regulations and policies. Over the past five years two audits have been conducted (external and internal) and no material non-conformances reported. The division is also responsible for onsite security and housekeeping services. Positioning and resourcing of this division over the next year will see alignment with the RSHEQ strategy, considering the upcoming retirements and leveraging synergy opportunities with the Radiation Protection division in iThemba LABS. The alignment strategy and implementation plan is detailed in RSHEQ section.

2.7 Skills Development

The requisite skills in the Department are sufficient and responsive to the needs of the facility and the departments. Annually the Department reviews and assesses the skills needs which informs the training needs in the Individual Development Plans of staff. Prior to 2009 internal audit reports made reference to the inadequate resources, skills, expertise and competency levels in accounting and procurement. Over the past 8 years these inadequacies have been mitigated through new appointments and training interventions. With the advent of the modernisation and revised reforms of government's SCM, most entities (including NRF) have been continually adapting and resourcing the SCM function to respond to the NT strategic policy changes. Over the next few years, in order to maintain the excellence and increasing our competitive advantage, focus will be on PFMA training, Contract Management, Accounting Technical training and Safety and Health refresher training.

2.8 Intellectual Property Management

Facilitate Intellectual Property (IP) Management through the IP committee.

2.9 Number of Financial Transactions

- Purchase orders 500 to 700 per month with approximately 16 000 line items per annum.
- Payments approximately 1200 to 1500 per month.
- Deviations on average 65 per month and tenders per annum average at 15 to 20 per annum with more than 30 processed in 2016/17.

2.10 Organisational Design and Establishment

The Department has an expanded mandate ranging from strategic and operational value chain processes, technical accounting and health and safety to governance and administration. The below figure and table depicts organogram and positions of the Department. (SHE moved to RSHEQ)

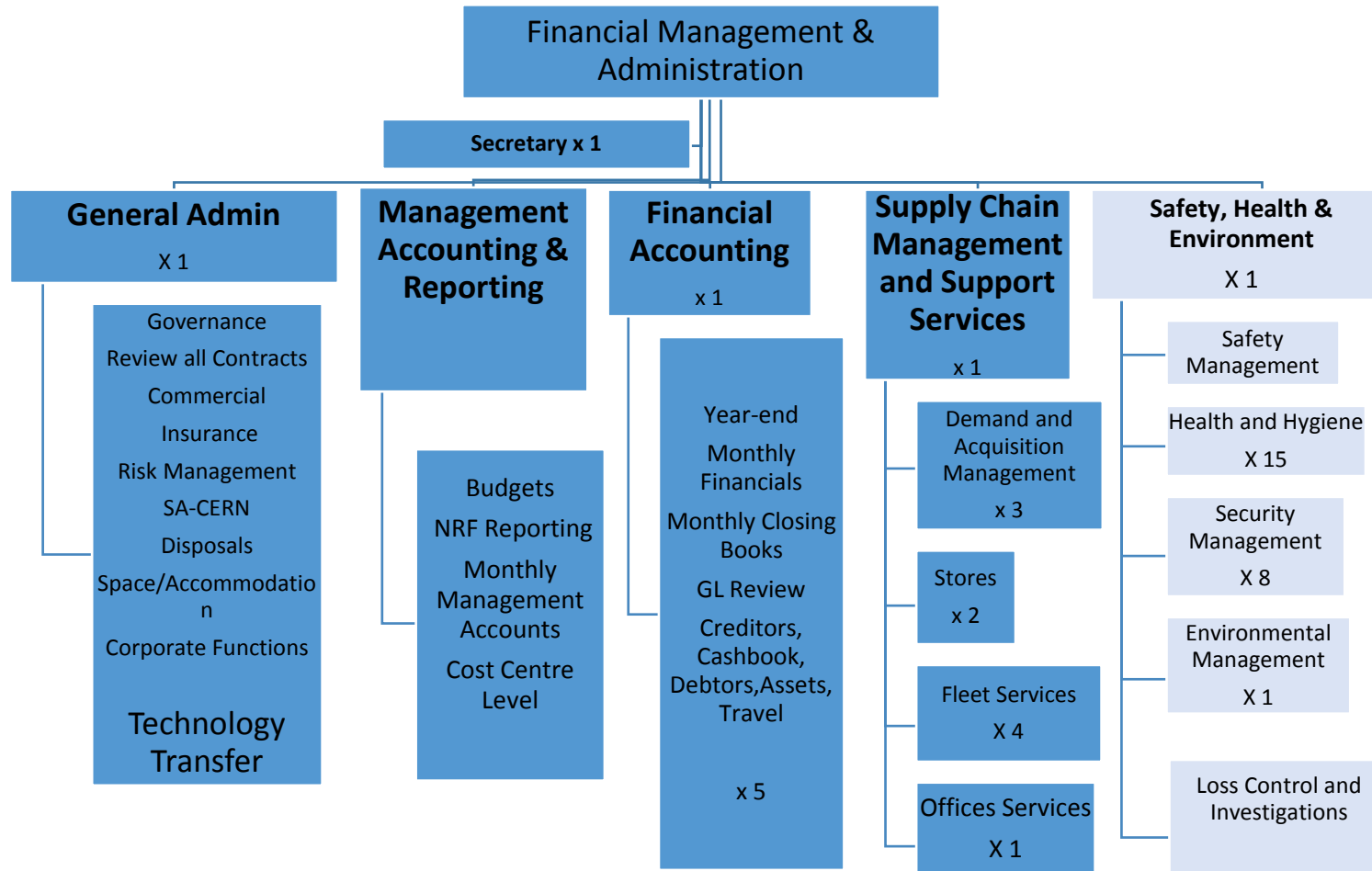


Figure 1: Departmental Organogram per division 31 March 2017

2.11 Staff Establishment, Upcoming Retirements and Vacancies

Table 1: Upcoming retirements 31 December 2017				
Position	Grade	Division	Years to Retirement	Years employed
SHE Manager	7	SHE	1,1	16,3
Supervisor - Housekeeping	12	SHE	2,6	22,5
Driver	12	Support	3,4	38,3
Housekeeper	15	SHE	4,0	18,3

Table 2: Staff Establishment and vacancies by divisions/sections, 31 December 2017			
Divisions	# of posts on approved establishment	# of posts filled	Vacancy rate
Financial Accounting	6	6	0%
Supply Chain Management & Support Services	11	10	9%
Safety, Health & Environment	25 (Move to RSHEQ)	21	12%
Department	2	2	0%
Total	44	41	6,8%

Vacancies – 31 December 2017

- Supply Chain Manager
- Housekeeper x 3
- Junior Accountant

2.12 Long Range Planning

2.12.1 Planned Deliverables - Next Five Years

Table3: Planned deliverables

Division	Deliverables
Financial Management	Budget Alignment to LRP
	Change in reporting in line with LRP
	Cost Containment planning & reporting
	Local iThemba LABS rules and procedures
Supply Chain Management	SCM Governance
	Quality Assurance review and introduction of new approaches (Skills)
	Improving and Intensifying Demand Management Strategies
	Local Content and Emphasise on BB-BEE procurement
	Development and Implementation of a new Internal feedback system (Electronic)
	Contract Management portal
	Supplier Performance measurements
	Centralised Procurement over R30k – Formal RFPs
	Co-ordinating the decentralised buyers into a forum
	SCM Capacitation and training
	Strategic procurement
	SCM technology.
Logistics and Support Services	Handling of fines new process
	Centralised Management of Onsite Accommodation
	Boardrooms Centralised Management
	Transportation to and from site for onsite tenants
Safety Health and Environment Management	Final integration into RSHEQ
General Administration	Contracts Register
	Space & Accommodation Committee
	Intensify Skills transfer of Accounting, SCM and Stores
	Audit outcomes – Value Adding
	AMS Department financial admin staff reporting

2.13 HR Resourcing Requirements

The following positions are required within the department

Accountant – Increased transactions, legislative compliance increase, additional reviews, special programmes and reporting

Supply Chain Practitioners - (3+ persons) staged and phased

2.13 Planned Performance Targets Annual

Financial Management

- No Repeated audit queries
- No Material Financial Adjustments
- No Major Customer Complaints

Supply Chain Management

- No Repeated audit queries
- Increase in Socio-economic and BB-BEE spending (Baseline required)
- Improved Quality Assurance on SCM documentation
- At least two information sessions on SCM per annum
- No Major Customer Complaints