This report covers the period
1 April 2012 to 31 March 2013

Some of the results presented in this report
are in part preliminary and should not be
quoted without the approval of the authors.

Editor: Kobus Lawrie

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Telephone:
International  +27-21-843-1000
National: 021-843-1000

Fax:
International +27-21-843-3525
National: 021-843-3525

web: http://www.tlabs.ac.za
e-mail: director@tlabs.ac.za
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* Until May 2012
# From November 2012
FOREWORD:

The mission of iThemba LABS lies in its uniqueness and reputation within the National System of Innovation for the efficient delivery of reliable beams to a variety of users straddling a vast and disparate array of research interests. At the heart of this vast accelerator complex is the Separated Sector Cyclotron (SSC) which delivers beams to various target vaults. The three main user groups are nuclear physics, therapy and the nuclear medicine community.

The activities within three user groups are constantly challenging the Accelerator and Engineering Department to enhance the capabilities of the SSC. Specific needs linked to Materials Research have furthermore prompted the need to enhance the capabilities of the Van de Graaff accelerators, both in the Johannesburg and Faure facilities.

I would highlight the following as key achievements for the year – noting though that this is by no means (owing to space constraints) an exhaustive overview:

- iThemba LABS hosted the International Workshop on Nuclear Spectroscopy at Magnetic Spectrometers. This workshop marked the celebration of the German-South African Year of Science. The opening address was delivered by the Minister of Science and Technology, Mr Derek Hanekom, who was accompanied by the German Consul General to South Africa, Mr Roland Herrmann.

- During a test run on 5 July 2012 beam intensity delivered to the Vertical Beam Target Station for the first time ever reached 300 $\mu$A. This was maintained for approximately one hour. This test provided valuable information on the strength of the targets. If this current could be maintained for an entire production run the radionuclide production yields will increase substantially. More tests will be done in future.

- Members of the CERN-ALICE group were involved in organizing the International Muon Workshop which was successfully hosted at iThemba LABS from 30 April to 4 May 2012. South African researchers form part of the lead teams within this project underway at the Large Hadron Collider – CERN, Switzerland. Sixteen international delegates attended this workshop and a further 20 were able to be part of the workshop via EVO, using the newly installed video conferencing facilities at iThemba LABS.

- During October iThemba LABS realized the major milestone of inaugurating the 11 MeV cyclotron. This achievement is the culmination of many years of collaborative efforts between iThemba LABS and NTP (Pty) Ltd, a wholly owned subsidiary of Necsa. Since 2005, the two institutions have had a cooperation agreement in place for the supply of the radiopharmaceutical $^{18}$F-FDG to the SA nuclear medicine
community with iThemba LABS responsible for the Western and Eastern Cape market while NTP covered the Northern regions of the country. Following the opening of the PET-CT scanner in April 2012 at Tygerberg hospital it became very urgent for iThemba LABS to provide a reliable and regular supply to this unit. Indeed, the first routine production of this radio-pharmaceutical took place on 25th September 2012. This remarkable feat is – once again – testimony to the wealth of talent and commitment by all those (within iThemba LABS and outside) who helped in the process.

Great progress can be reported on the Johannesburg facilities with the achievement of injection of Carbon-13 and Carbon-12 beams into and accelerated by the EN Tandem accelerator. These beams were transported up to the Faraday cup on the high-energy side of the accelerator. The exercise was undertaken as part of full commissioning of the low-energy injection system of the AMS facility.

Very robust growth in sales of isotopes and radio-pharmaceuticals indicates that there could be scope for new markets for our isotope business – provided there is excess capacity on the cyclotron, which is not the case at present. In that regard, we are therefore factoring this demand into the business plan for the acquisition of a dedicated 70 MeV cyclotron that will also address the long-term research plan to establish a Rare Isotope Beam facility that will certainly keep iThemba LABS and the South African research community at the forefront of developments in the field of nuclear physics.

After two years (2011/12 and 2012/13) of relatively low $^{82}\text{Sr}$ sales orders, Bracco, Nordion’s major client, placed orders for the month of March and April 2013, an indication that the FDA will soon make a pronouncement in regard Nordion’s validation runs. This is, indeed, positive news considering the heavy reliance iThemba LABS places on Radionuclide sales to fund the shortfall resulting from lower than expected (inflation) Parliamentary Grant increases. In an attempt to diversify the client base we have had discussions with (possible) new clients for $^{82}\text{Sr}$. Discussions are at an advanced stage and are expected to be concluded around June 2013.

This is my final report as director of iThemba LABS as I am about to assume office as Deputy Vice-Chancellor (Research and Postgraduate affairs) with the University of the Witwatersrand, Johannesburg.

I would like to thank all staff of iThemba LABS, colleagues at the NRF and my senior management team for the support I have received during the past 7 years. I also wish to thank our partners within the South African Higher Education Landscape, members of several advisory councils and committees, and overseas collaborators. It has been a great honour to have served the National Science System in my capacity – both as head of iThemba and head of research at Necsa (the South African Nuclear Energy Corporation).

Best wishes.

Zeblon Z Vilakazi.
DIRECTOR

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iThemba LABS Annual Report 2012/13
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1. Overview and Highlights
1.1 Accelerator and Engineering Department

1.1.1 Overview

The department is responsible for the development, operation and maintenance of all the accelerators and associated infrastructure, as well as for the provision of accelerated charged particle beams of the type, quality and quantity, that meet the requirements of the users. The department continually strives to improve the quality of the research platforms and service provided to users and stakeholders through the research, design and implementation of innovative accelerator and beam transport technologies. Major projects in progress are digital Radio Frequency (RF) control and monitoring systems, beam development with the Electron Cyclotron Resonance Ion Sources (ECRIS), the migration of all accelerator motion control elements to the Experimental Physics and Industrial Control System (EPICS) platform, as well as the continuation of the Accelerator Mass Spectrometry (AMS) upgrades planned for the tandem accelerator at the iThemba LABS (Gauteng) facility. Other major projects that are receiving support from the Accelerator and Engineering Department as part of ongoing feasibility studies include the replacement of the Van de Graaff accelerator with a 3 MV Tandetron and the development of a new ion source for the production of Rare Ion Beams (RIB) as part of the RIB Demonstrator project.

The beam from the Separated Sector Cyclotron (SSC) was supplied for a total of nearly 82% of scheduled beam time with interruptions totalling 8% of scheduled beam time. The majority of interruptions were due to faults with the RF systems. Due to the higher intensity beams required for radionuclide production, extra care is needed to minimize beam losses and therefore the time spent on energy changes also increased slightly. The excellent overall performance can be attributed to the rigorous preventative maintenance schedules, motivated and dedicated staff, as well as the ongoing upgrading and replacement programme of obsolete equipment.

1.1.2 Electron Cyclotron Resonance Ion Sources (ECRIS)

1.1.2.1 Grenoble Test Source 2 (GTS2)

In the framework of the collaboration agreement with the CERN ion source group, experiments for the production of intense Argon beams were performed. The source was optimized for Ar$^{11+}$ as required for direct injection into the CERN linear accelerator and booster ring. Figure 1 below shows the measured charge state spectrum for the Argon beam. A current of 65 eμA was obtained for charge state 11$^+$ in the continuous wave mode of operation. For injection into the RF linear accelerator at CERN pulses with a pulse length of 200 μs at a maximum repetition frequency of 5 Hz are required, which can be produced from the source in the so-called afterglow regime. For the afterglow operation the plasma was generated with 50% duty cycle to maintain thermal stability in the source. In this mode of operation, with O$_2$ as the supporting gas, an intensity of 200 eμA was achieved. The pulse is stable...
over more than 500 µs. Additional experiments at iThemba LABS are scheduled to further optimize beam performance.

![Argon charge state spectrum, optimized for Ar^{11+}](image)

**Figure 1:** The Argon charge state distribution for continuous wave (CW) and afterglow operation with O₂ supporting gas.

### 1.1.2.2 Hahn Meitner Institute (HMI) ECR Ion Source

During the current reporting period H, D, He, C, N, Ne and Kr ion beams were produced with the HMI ECRIS, which were then accelerated with the second injector Solid Pole Cyclotron (SPC2) and the SSC to energies ranging from 14 to 620 MeV. The source operated very reliably throughout the year. For all ion species sufficient beam intensity could be obtained.

### 1.1.3 Digital Radio Frequency Control System

The new digital low level RF control system is in the final stage of development. The modular digital control system as illustrated in Figure 2 utilizes a 32 bit ARM CPU, a FPGA, high speed 500 MHz 16-bit DACs and fast high resolution ADCs.

This system is generically designed to replace the 16 RF control systems that operate at frequencies between 8 and 81 MHz. All user configurable parameters and diagnostic information is available to the user through an EPICS interface.

![Modularized digital RF control system](image)

**Figure 2:** Modularized digital RF control system
1.1.4 Upgrading of the accelerator electronics and migration of the control systems to EPICS

The control electronics of all the motor drive systems of the SPC1 diagnostics probes, extraction components and the internal ion source have been replaced. The CAMAC control and interface hardware was replaced with SABUS hardware and the computer control of the new SABUS system was migrated to the Linux based EPICS platform, which is more user-friendly and versatile than the outdated OS/2 software. The integration of these new electronic modules with the existing wiring and safety interlocks was successfully completed and all channels were fully calibrated and tested.

iThemba LABS also embarked on an extended project to migrate all vacuum control software from the traditional OS/2 platform to EPICS. Since the vacuum software exists as modular units controlling specific predetermined sections of the overall vacuum system, the new software could be developed on a modular basis as well. Some sections have already been migrated to EPICS and as the software development progresses, more and more sections will be migrated. This approach allows thorough testing of the new software without completely removing the old software. Systems already running on the Linux based EPICS platform are the ECR ion sources and the entire vacuum system of the Gauteng tandem accelerator facility. Other systems in the development and testing phases include the SPC2, Q-line, K-line, and SSC systems.

1.1.5 Numerical Field Analysis

1.1.5.1 Sweeper Magnet

The existing laminated, air-cooled, window frame type AC electromagnets that are used to sweep the beam at a frequency of 450 Hz on the isotope production targets were recalculated with increased magneto motive force (mmf = ampere-turns). The yoke dimensions remained the same, but the number of turns per coil was increased from 648 to 888 in order to increase the bending power. With the increase in the number of turns and of the current, the bending power was increased from 1.2 mrad to 3.3 mrad for a 66 MeV proton beam. The calculated maximum flux density inside the laminated yoke is still less than 1 T and it was decided to apply the magneto motive force at 100 Hz instead of the existing 450 Hz to reduce the eddy current losses in the yoke.

1.1.5.2 Experimental capacitive pick-up for accurate bunch length measurements

A new capacitive phase probe was designed and manufactured at iThemba LABS and installed directly after slit 7J in the low energy transfer beam line. The geometry of the probe and its shielding was optimized to have the recorded signal directly representative of the true length of the beam pulse. First test measurements proved promising, though further modifications are required to reduce unwanted noise.

Figure 3: Detail of new probe
1.1.6 Accelerator Mass Spectrometry (AMS) at iThemba LABS (Gauteng)

The AMS injection beam line was integrated with the existing injection beam line to allow beam production from the 860C-, as well as the multi-cathode AMS Cesium sputter ion sources. The AMS beam is transported and injected into the injection system of the tandem accelerator by means of a 90° electrostatic energy analyser and a 90° magnetic mass analyser. The magnetic analyser was designed as a so-called bouncer magnet, in which the vacuum chamber is insulated from the beam lines to allow a high voltage to be applied to the vacuum chamber. With this capability the manipulation of the electrostatic forces created across the insulating gaps can be used for fast selection (≈100 μs) of different isotopes while maintaining a constant magnetic field. This ability is absolutely necessary for AMS work where ratios of isotope abundances must be measured to determine the isotopic signature of a specific sample. The system was successfully commissioned with Carbon beams from the multi-cathode AMS ion source injected into- and transport through the tandem accelerator. The functionality of the AMS injection system was tested and only minor adjustments may be required once the complete AMS system becomes operational.

Subsequent to the commissioning a mechanical flaw was discovered in the vacuum chamber of the bouncer magnet. The best practical solution was to remanufacture the entire vacuum chamber. This opportunity was seized to redesign the vacuum chamber, not only to correct the defect, but to also simplify the layout by relocating all diagnostic components away from the high voltage region. To achieve this, the insulating gaps had to be moved away from the natural focal points of the magnet. It was clear that this decision would lead to a minor degradation of the focusing properties of the magnet/bouncer system, but that the effect could be minimized by means of detail computer simulations. After a few simulation iterations a final solution was reached and the changes in the horizontal- and vertical focusing properties at the image point of the system were calculated and compared to the focal properties of the theoretically optimum solution, which is where the insulating gaps are located at the natural focal points of the magnet.

The new proposal has the horizontal focal point of $^{14}$C the same as for the reference value, but the focus point of $^{13}$C is now about 25 mm further downstream. This shift is insignificant when viewed against the small divergence angles at the focus point and this small shift will be masked by the true horizontal width of the beam at the focal point. The vertical focus region shifted 20 mm downstream, which is also insignificant. The separation between the horizontal and vertical foci is now about 190 mm. This separation between the foci may be reduced by changing the variable exit edge angle of the magnet pole, if required.

As part of the AMS development the high energy extraction beam line also required upgrade since it is good practice not to use any magnetic elements to transport AMS beams between the accelerator and the AMS mass analyser magnet. The design of the new high energy beam line (Figure 4) was completed during the third quarter of 2012 and manufacturing of components commenced during the last quarter of 2012. Manufacturing, planning
and upgrade of control software continued until the end of the first quarter of 2013, at which time all items were shipped to Gauteng for installation. Installation and commissioning will be completed by the end of the second quarter of 2013. A complete high energy AMS Transport and Analysis system was ordered from National Electrostatic Corporation during 2011 and delivery is expected during September 2013.

1.1.7 Cyclotron Beam Statistics

The beam statistics over the past five years is shown in the table below.

<table>
<thead>
<tr>
<th>Year</th>
<th>Beam Supplied as:</th>
<th>% of Scheduled beam time lost due to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% of Total time</td>
<td>% of Scheduled* time</td>
</tr>
<tr>
<td>2008</td>
<td>62.0</td>
<td>75.17</td>
</tr>
<tr>
<td>2009</td>
<td>70.5</td>
<td>82.45</td>
</tr>
<tr>
<td>2010</td>
<td>67.6</td>
<td>82.18</td>
</tr>
<tr>
<td>2011</td>
<td>68.9</td>
<td>85.91</td>
</tr>
<tr>
<td>2012</td>
<td>69.9</td>
<td>82.04</td>
</tr>
</tbody>
</table>

* Scheduled time is total calendar time minus scheduled maintenance time and minus the time that the laboratory is officially closed during December

Table 1: Cyclotron beam delivery statistics for the period 2008 to 2012.

From this table it is apparent that there has been a slight increase in interruptions during 2012 when compared to 2011. The pie-chart below summarizes total interruptions in terms of the contribution of the various categories of interruptions. From this chart it can be concluded that unscheduled interruptions due to the various RF systems is a major area of concern. This concern is being addressed by means of a large capital investment to
Overview and Highlights  Accelerator and Engineering Department

recondition the RF amplifiers of the SSC, as well as the development of a new generic low-level RF control system, which will eventually replace the control electronics of all the 16 different RF systems at iThemba LABS. The time lost due to energy changes has also increased slightly. This could largely be attributed to the increased beam intensity delivered to the radionuclide target stations as this requires more set-up time to minimize the beam losses.

Figure 5: Breakdown of interruptions in terms of the various categories of interruptions.

1.1.8 Van de Graaff Accelerator

1.1.8.1 Remote control of the accelerator terminal

During the major service period of 4 weeks in March 2013 the computer control of the terminal in the Van de Graaff accelerator was installed. This has been found to be working well and it now enables the accelerator, vacuum system, beam diagnostics, beam line selection and setup to be controlled remotely.

1.1.8.2 Beam Statistics

<table>
<thead>
<tr>
<th>Year</th>
<th>Beam Supplied (Hours)</th>
<th>Maintenance/Conditioning (Hours)</th>
<th>Development (Hours)</th>
<th>Interruptions (Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>4975</td>
<td>1072</td>
<td>352</td>
<td>514</td>
</tr>
<tr>
<td>2009</td>
<td>6587</td>
<td>1235</td>
<td>149</td>
<td>272</td>
</tr>
<tr>
<td>2010</td>
<td>3682</td>
<td>1525</td>
<td>1009</td>
<td>688</td>
</tr>
<tr>
<td>2011</td>
<td>5712</td>
<td>1425</td>
<td>995</td>
<td>86</td>
</tr>
<tr>
<td>2012</td>
<td>5712</td>
<td>1055</td>
<td>231</td>
<td>1025</td>
</tr>
</tbody>
</table>

Table 2: Van de Graaff beam delivery statistics for the period 2008 to 2012.
1.1.9 Green initiatives and alternative energy

1.1.9.1 Proposal for a Thermal Storage System for iThemba LABS

The rising electricity demand at the facility and the recently announced tariff increases prompted iThemba LABS to consider a fresh approach in handling these realities. The first line of defence was to improve the power factor of the incoming power from 0.86 to 0.99. This has already resulted in sustainable energy savings and therefore reduced electricity costs.

The central cooling plant is the item with the single highest electrical demand (1.5 MW at maximum demand). The Eskom electricity tariffs structure applicable to iThemba LABS falls under the Time-of-Use scheme whereby different energy rates are applicable at different time periods during the day. This fact could be exploited with the introduction of a thermal storage system to produce ice at night when the ambient temperature is lower and the cost of electricity is much cheaper (off-peak rates). The ice can then be melted to assist the cooling process during hotter daytime periods when electricity costs are significantly higher (peak- and standard rates). The more even demand over a 24 hour period along with the lower power usage will contribute substantially to a lower carbon footprint.

1.1.9.2 Photovoltaic System - integration with the Uninterruptible Power Supply (UPS)

At iThemba LABS the electrical supply from the UPS is isolated from the Eskom supply and therefore provides an ideal interface for feeding solar energy into the local grid. The implementation of solar support can be made very modular, as strings of 34 or 35 x 80 W photovoltaic panels can be connected in series to deliver the required voltage at maximum power transfer. Additional strings can be added in parallel to increase capacity.

A 5 kW pilot plant (comprising two photovoltaic strings) will be installed soon at a cost of about R100 000 to demonstrate the principle. The reduction in the carbon footprint makes this project attractive.

A 1 MW photovoltaic installation will deliver 20% of maximum demand during sunny periods. The payback period was calculated to be less than 6 years. With an expected lifespan of 20 years (maintaining 50% of original performance) and relative low maintenance, this option should be seriously considered. The fact that our sole supplier of electricity is implementing a scheduled 8% per annum increase in the cost of electricity over the next 5 years makes this proposal even more viable.
1.2 Radionuclide Production Department

1.2.1 Overview

The mission of the Radionuclide Production Department (RPD) of iThemba LABS is to develop methods to produce high-grade radionuclides with the 66 MeV proton beam and to apply these methods to produce regularly, on a weekly basis, radionuclides and radiopharmaceuticals for nuclear medicine in South Africa, and also to produce longer-lived radionuclides for the export market. It includes the objective to sustain and upgrade the production facilities, and to increase the production yield while simultaneously reducing radiation exposure to staff. In compliance with the mission of iThemba LABS the group strives to pursue active and internationally competitive in-house research, development and training programmes.

The RPD performs routine production and contributes to research and development with a staff complement of 24, compromising of chemists, physicists, pharmacists, chemical technologists, mechanical/electronic technologists and administrators. More than 90% of the personnel are involved in both routine production and research and development activities.

Relative to the previous financial year the income generated from the sales of radiopharmaceuticals and radionuclides had shown an increase of 49% (see Table 1). The accumulated revenue peaked at a record R28,8m for the review period. This was mainly attributed to the increase in sales for the products $^{82}$Sr, $^{68}$Ge, $^{68}$Ge/$^{68}$Ga generators, $^{123}$I and $^{18}$F-FDG. The sales of $^{22}$Na, $^{68}$Ge/$^{68}$Ga generators and $^{82}$Sr for the export market now accounts for more than 75% of the sales revenue.

The increase in $^{82}$Sr sales comes on the back of the Food and Drug Administration (FDA) of the United States allowing nuclear medicine departments to use $^{82}$Sr/$^{82}$Rb generators again following a revalidation process that took almost 12 months to complete. The revalidation process was as a direct consequence of the reported radiation overexposure of two patients linked to the use of $^{82}$Sr/$^{82}$Rb generators in 2011.

The sales of $^{68}$Ge/$^{68}$Ga generators have continued to grow at greater than 20% year-on-year and had peaked at a record R6,1m. $^{123}$I and $^{18}$F-FDG products had also shown a sales increase of 16% and 20%, respectively. The increase in $^{18}$F-FDG sales was attributed to the installation and commissioning of the new Siemens 11 MeV cyclotron in October 2012. This had given iThemba LABS the added flexibility of producing $^{18}$F-FDG on a Monday and during the maintenance period of the SSC.

The sales revenue of the other products such as $^{22}$Na, $^{67}$Ga and $^{81}$Rb/$^{81m}$Kr generators were stable and had shown no significant growth. This could be partially attributed to the extended maintenance periods (12 weeks in total) in this review period.
In January 2013, after extensive consultation with the only user in the market, Tygerberg Hospital, the production of $^{81}\text{Rb}/^{81m}\text{Kr}$ generators was stopped. When the production of $^{81}\text{Rb}/^{81m}\text{Kr}$ generators started in the late 1980's, 5 hospitals were using this product twice a week. In recent times, the demand of this product had declined due to the availability, 5 days a week, of an alternative reactor-based product called Technogas. In the last two years,
Tygerberg Hospital was the only user of the $^{81}\text{Rb}^{81m}\text{Kr}$ generator and it is for this, mainly economic, reason that iThemba LABS had decided to discontinue the production of this product.

iThemba LABS still remains the only supplier in the world of $^{22}\text{Na}$ positron sources and this market is expected to level out in the coming years due to the economic downturn in Europe and USA. This was particularly evident in the past year when the Physics Departments at Universities (the main users of these positron sources for positron annihilation studies) indicated that restrictions had been placed on their research grants.

For the review period, more than 1300 consignments were dispatched to over 80 clients worldwide and the delivery of consignments correctly and punctually was maintained at 96% (Figure 1). This contributed to the patient management of over 100 000 nuclear medicine patients. Non-delivery or delayed delivery was mainly attributable to i) unscheduled power outages, ii) cyclotron downtime, iii) breakdown of ageing equipment and infrastructure.

![Local GMP Products](image)

**Figure 1:** Service delivery of local GMP products.

Distributor agreements for $^{68}\text{Ge}^{68}\text{Ga}$ generators were maintained with IDB-Holland B.V. (exclusivity in Europe, Australia and Brazil) and isoSolutions (exclusivity in USA, Canada and Mexico). A principle distributor agreement is in place with QT Instruments for exclusivity in Singapore, Malaysia and Thailand. iThemba LABS together with its distributors have started the process to aggressively pursue other prospective markets such as the Middle East, India, Russia and China and we expect to have distributor agreements in place for these markets by the next review period. In November 2012, both iThemba LABS and IDB-Holland B.V. started the process to obtain market authorisation of the iThemba LABS $^{68}\text{Ge}^{68}\text{Ga}$ generator in the European market. It is anticipated that once registration of the product is obtained in Europe, this will enhance the market profile of the generator and lead to increased sales.
The Nordion (Canada) supply agreement contract, i.e. supply of $^{82}\text{Sr}$ (irradiated Rb metal targets), has been in place for the past 8 years. Even with the reduced sales in 2011 due to the USA Food and Drug Administration directive, this contract continues to form a large part of the iThemba LABS sales revenue. In January 2013, Positron (USA) approached iThemba LABS for the purchase of $^{82}\text{Sr}$ (targets and/or processed material). In order to have diversification around the $^{82}\text{Sr}$ business, iThemba LABS entered into discussions with Positron and we will report on progress in the next review period.

The iThemba LABS-NTP Cooperation Agreement on $^{18}\text{F}$-FDG was further enhanced when both parties agreed in December 2011 to the joint acquisition of a dedicated 11 MeV cyclotron. In October 2012 a Siemens 11 MeV cyclotron (Figure 2) was fully installed and commissioned on the iThemba LABS Radionuclide Production site. This was completed in 10 months, testament to the tremendous technical effort on the part of iThemba LABS staff together with the Siemens technical officials. In October 2012 an official launch celebration of the 11 MeV cyclotron was hosted by iThemba LABS and NTP with various local nuclear medicine department heads and staff together with officials from the Department of Science and Technology in attendance (Figures 3 and 4).

**Figure 2:** The Siemens 11 MeV cyclotron installed at the iThemba LABS Radionuclide Production Department.

**Figure 3:** iThemba LABS Project Team at the 11 MeV Cyclotron Launch Celebrations

**Figure 4:** Drs T auf der Heyde (DST), Z Vilakazi, and R Scheef (NRF) at the 11 MeV Cyclotron Launch Celebrations
1.2.1.1 Radiopharmaceutical Manufacturing

For the review period the following diagnostic radiopharmaceuticals were produced routinely by the RPD and delivered to over 40 Nuclear Medicine departments at private and public healthcare facilities throughout South Africa and Namibia, i) $^{123}$I capsules, $^{123}$I oral solution/injections and $^{123}$I-mIBG injections for tumour localisation and for observing heart, kidney, thyroid and brain function ii) $^{67}$Ga-citrate injections for localization of inflammatory lesions and tumours iii) $^{67}$Ga oral resin used as a radioactive solid food tracer iv) $^{81}$Rb/$^{81m}$Kr generators for lung studies v) $^{18}$F-FDG for oncology, cardiac and neurological applications and vi) $^{68}$Ge/$^{68}$Ga generators for neuroendocrine tumours (export market as well). Short-lived accelerator-based radiopharmaceuticals such as $^{123}$I, $^{67}$Ga, $^{81}$Rb and $^{18}$F-FDG are only produced in South Africa by iThemba LABS, with the exception of $^{18}$F-FDG that is also produced by Necsa-NTP and PET Labs Pharmaceuticals. Generally short-lived accelerator-based radiopharmaceuticals cannot be imported into South Africa cost effectively because of their relatively short half-life ranging from 2 hours to 3 days, thus making iThemba LABS an important link in the service chain of nuclear medicine studies / applications in South Africa.

A quality assurance system in line with current Good Manufacturing Practice (cGMP) requirements encompassing all customer-related activities, legal requirements and production processes was maintained in the review period. These processes are planned and monitored, using well documented and recorded systems. This system ensures consistent efficiency, reliability and quality of both the radiopharmaceuticals and services rendered to clients. In December 2012 the Medicines Control Council (National Department of Health) approved the renewal of the GMP licence of iThemba LABS for a further 5 years.

1.2.1.2 Bombardments and Targetry

The long-lived radionuclides that were produced and despatched to over 40 clients worldwide included $^{82}$Sr targets (used for the preparation of $^{82}$Sr/$^{82}$Rb generators for myocardial perfusion studies), and non-medical radionuclides such as $^{22}$Na solution and $^{22}$Na positron sources used in positron annihilation studies. iThemba LABS still remains the only supplier of $^{22}$Na positron sources in the world and is presently servicing a market base of over 35 active clients worldwide.

The physics and targetry division of the RPD started to use advanced manufacturing techniques in the development of our production targets. The first project to benefit from this was the development of liquid targets for the production of $^{18}$F at high beam currents as well as for future research into dissolved, enriched target materials ($^{44}$Ca) as part of the Swiss/South Africa bilateral collaboration. The target cavities were designed using the Solid Edge 3D design program and rapidly prototyped using 3D printing in plastic. After prototyping, the design was transferred to a computer

Figure 5: Finished target of Nb in brass (left) and 3-D printed target (right).
numeric controlled milling machine for final manufacture. The complex shape of the cavities made this the quickest route to a final prototype (Figure 5).

During the review period we also started collaborating extensively with the National Laser Centre of the CSIR for the welding of our target capsules and infrastructure. This collaboration has been progressed under the recently signed Memorandum of Understanding between iThemba LABS and the CSIR. The advanced laser welding technology will augment our current use of electron beam welding for the manufacture of some of our target capsules.

The new water cooling system (phase 2) advanced to 75% of completion and is targeted for final implementation at the end of 2013. This brings the conversion of our control systems to LabVIEW to 90%. The next system to be totally re-engineered will be the target transport system.

We also implemented a new interlock system during this review period. A new system was built around a standardised safety interlock SABUS card (manufactured at iThemba LABS) via a PCI card in a dedicated PC. A “Heartbeat” signal from this PC is also monitored by the main cyclotron interlock system. A graphic user interface running in the isotope production control room shows line statuses and faults. The system can now log both previous alarm histories as well as override histories. In addition to direct monitoring of the field devices for flow of both helium and cooling water, the system also receives interlock signals from the LabVIEW-based beam monitoring PCs for the horizontal- and vertical-beam vaults and associated stations.

The RPD operates three bombardment stations routinely for the production of radiopharmaceuticals and radionuclides. Figures 6, 7 and 8 show the beam time allocation to the various target stations and targets.

![Figure 6: Production parameters of the horizontal bombardment station.](image-url)
1.2.1.3 Training and Development

The RPD maintains an active research and development program that encompasses the self-development of personnel involving further studies, supervision of external students from universities, the upgrading of existing processes / products, and the development of new products. The RPD participates in various Science and
Technology bilateral agreements with countries such as Switzerland and Reunion. Other research initiatives include projects with the International Atomic Energy Agency (IAEA) and nuclear medicine departments of local hospitals and universities. The research themes are based on the development and the transfer of technology that involves i) targetry development and modelling, ii) chemical processing, iii) radionabelling, and iv) production, dispensing and quality control processes together with cGMP principles.

For the review period 2 peer-reviewed publications and 2 conference contributions were produced. Over 35 national and international users / collaborators have interacted with RPD personnel and/or used the RPD facility in one way or the other.

RPD personnel that are enrolled for external studies at universities during the review period are as follows: BTech (2), MTech (3), MSc (2) and PhD (2). The external students that use RPD facilities and are co-supervised by RPD personnel are MTech (2), MSc (1) and PhD (1).

One external MTech student graduated in December 2012, whilst four MTech students and one BTech student completed all their requirements for their respective degrees and are expected to graduate in April 2013.

1.2.1.4 Major Projects

Participation in NTeMBI

iThemba LABS RPD is directly involved in two research projects initiated by the Nuclear Technologies in Medicine and the Biosciences Initiative (NTeMBI): Imaging Brain Receptors Using Radiolabelled Compounds and The Use of Radiolabelled Receptor Site Targeting Compounds for Early Detection and Therapy of Cancer. The first project involves the use of a 18F-labelled brain-imaging compound in a study on primates, using the newly acquired PET-CT scanner at Tygerberg Hospital. The tracer will be synthesized at iThemba LABS, followed by quality control tests and subsequently transported to Tygerberg Hospital. For this purpose, a custom-made semi-automated synthesizer, built by staff members of the South African Nuclear Energy Corporation (Necsa), was delivered to iThemba LABS in May 2012. After its commissioning iThemba LABS staff members were trained to operate the system, followed by a number of trial runs to test its operational reliability. Due to certain inherent technical shortcomings of the system, results have not been entirely satisfactory thus far and more experiments need to be carried out. The logistics for the animal experiments have also not been finalized as yet. The second project involves 123I-labelled receptor site targeting compounds. Cell uptake work showed that the originally targeted compound only exhibited non-specific binding to the receptor. This result was attributed to its low specific activity. Its chemical structure did not lend itself to the synthesis of a high specific activity radiotracer, hence a structural variant was proposed. Studies on the latter are still on-going. We are also indirectly involved in another NTeMBI project: Development and Assessment of Metal Containing Drugs for Cancer Treatment using Radiolabelling. The research work of a University of Cape Town PhD student at iThemba LABS is linked to this project. It involves the synthesis of 67Ga (and eventually also 68Ga)-labelled hypoxia radiotracers. Preliminary assessments involving studies of its uptake into hypoxia-induced cells look promising and will be progressed further.
IAEA Consolidated Research Project on $^{68}$Ga-based PET-Radiopharmaceuticals

The objectives of this project were outlined in the iThemba LABS 2011/2012 Annual Report. Several of our in-house manufactured $^{68}$Ge/$^{68}$Ga generators have already been comprehensively evaluated. The development of robust formulations of $^{68}$Ga-labelled DOTA-conjugated somatostatin peptide derivatives such as -TOC, -NOC and -TATE, as well as the development of quality control and quality assurance procedures for their formulations are nearing completion. Data on this work was presented at the South African Nuclear Medicine Society Congress in September 2012, as well as at the IAEA feedback meeting in Vienna, Austria in December 2012. The venue for the pre-clinical micro-PET/CT evaluations of the labelled peptides has in the meantime been changed from the Erasmus Hospital in Rotterdam to GIP CYROI (Cyclotron Réunion Océan Indien) on the island of Reunion. This work will hopefully commence during October 2013.

South Africa – Reunion Science and Technology Bilateral Agreement between iThemba LABS and GIP CYROI (Radiochemistry and Pre-Clinical Imaging Department)

This project was approved in March 2013 and is expected to be completed in March 2015. The project will focus on the usage of a $^{68}$Ge/$^{68}$Ga generator for the development and evaluation of various $^{68}$Ga-labelled DOTA-conjugated somatostatin derivatives such as -TOC, -NOC and -TATE used for the management of neuroendocrine tumours. The peptides will be labelled with a PET radioisotope, $^{68}$Ga, and be subjected to pre-clinical trials on small laboratory animals for initial biodistribution work. iThemba LABS with its extensive experience in the usage of $^{68}$Ge/$^{68}$Ga generators and $^{68}$Ga-DOTA radiolabeling, and CYROI with its experience in micro-PET imaging will exchange knowledge and information in the form of reciprocal visits of scientists between the two participating institutions in order to develop useful biodistribution data around $^{68}$Ga-labelled DOTA-conjugated somatostatin derivatives. Ethical and regulatory requirements will be strictly adhered to at all times.

University of Cape Town-Positron Emission Particle Tracking (UCT-PEPT) – iThemba LABS

The UCT-PEPT research programme that commenced in 2009 at iThemba LABS continued to grow in collaboration with the RPD at iThemba LABS. While the focus continued to be on minerals applications, particularly commination and flotation, new research activities started in granular and fluid flow. A second instrument for the laboratory, an ADAC gamma camera, was donated by the University of Birmingham and allows particle tracking over a larger field of view. The RPD provides the tracers $^{68}$Ga (from the $^{68}$Ge/$^{68}$Ga generator) and $^{18}$F required for radiolabeling. One research highlight was the labelling and tracking of a 50 micron tracer, the smallest ever used in positron emission particle tracking.

South Africa – Swiss Science and Technology Bilateral Agreement between iThemba LABS, Cape Peninsula University of Technology and Paul Scherrer Institute

The South Africa-Swiss Science and Technology Bilateral Agreement that involves the Cape Peninsula University of Technology, Paul Scherrer Institute and iThemba LABS has been active from 2009 to 2012. The objectives of the project that were outlined in previous annual reports were completed in December 2012. In
February 2013, this consortium, together with the University of Pretoria and Steve Biko Academic Hospital, Necsa, the University of Stellenbosch, and the Tygerberg Academic Hospital submitted a new project to the principle funders in an attempt to continue this very fruitful collaboration. It is expected that a response to the submission will be received in June/July 2013. The title of the project is: “Improving the management of patients suffering from neuroendocrine tumours in South Africa and Switzerland”.

1.2.2 Highlights 2012/2013

- The Siemens 11 MeV Cyclotron was fully installed and commissioned in October 2012 to produce $^{18}\text{F}$, five days a week, 48 weeks of the year.

- The RPD produced over 1300 consignments of radionuclides and radiopharmaceuticals that impacted on over 100 000 patients locally and internationally.

- The service delivery of the radiopharmaceuticals and radionuclides was maintained at the gold standard of >95% efficiency.

- iThemba LABS has progressed to have a world market share for the $^{68}\text{Ge}/^{68}\text{Ga}$ generator at >30% and that of $^{82}\text{Sr}$ supply at >25%.

- iThemba LABS still remains the world’s only supplier of Ultra High Vacuum $^{22}\text{Na}$ positron sources which is mainly used at universities for positron annihilation studies.

- In December 2012, the Medicines Control Council, Department of Health, renewed the iThemba LABS RPD GMP licence for a further 5 years (valid until 2017).

- RPD produced 2 publications in peer refereed journals, 2 conference contributions, and the co-supervision of one MTech graduate.
1.3 Department of Nuclear Physics

1.3.1 Overview

The Department of Nuclear Physics at iThemba LABS has as its main activities research and training (mainly at postgraduate level) in basic and applied nuclear physics. The basic research can be broadly divided into nuclear reaction mechanism and nuclear structure studies. The K600 magnetic spectrometer and the AFRODITE gamma-ray detector array are the two major facilities that are used in these research projects. The department has a dedicated target maker, who mostly produces targets for in house and iThemba LABS (Gauteng) experiments. Presently some theoretical support is also available from two research associates working on shell model calculations and clustering phenomena in nuclei.

Our department is formally linked to CERN and participates in the ALICE research programme. Three departmental scientists work together with UCT on the muon spectrometer which is an integral part of the tracking detector system of ALICE. These three scientists together with a post doc and three students participated in the data taking runs at the LHC during the past year.

The applied research is largely centred around the Environmental Radioactivity Laboratory but also through the use of neutron (secondary) beams from 40 – 200 MeV. Research in the Environmental Radioactivity Laboratory is conducted into natural and anthropogenic radioactivity in soils, sediment and water. Here in-situ and ex-situ gamma-ray spectrometry techniques are used. Routine measurements of environmental samples for the Radiation Safety Division at iThemba LABS are also performed.

Neutron beams in the energy range available in the D-line at iThemba LABS are becoming increasingly scarce world-wide. Applied studies undertaken have largely been into the biological effects of ionizing radiation as well as international intercomparisons of neutron dosimetry systems for personnel at proton therapy facilities, airline personnel, as well as astronauts. Complementary to this Monte Carlo simulation are performed to model the interaction of radiation with materials, shielding requirements and ambient backgrounds to experiments.

Part of the responsibilities of our department is lecturing and organizing practicals for students in the Masters in Accelerator and Nuclear Science (MANuS) programme which is part of the MatSci/MANuS programme jointly organized by iThemba LABS, and the Universities of the Western Cape and Zululand.

There were few staff movements during the reporting this period. The department secured funding and appointed an additional 5 PhD students and one post-doctoral researcher within the Department of Science and Technology Professional Development Programme. In August 2012 Dr Francesco Bossú from Italy joined the department as a post-doctoral researcher to work in the ALICE collaboration.

Dr Ricky Smit was acting head of the Nuclear Physics Department for a large portion of the time until the post was filled in July 2012. iThemba LABS was fortunate to obtain the services of Dr Rudolph Nchodu who till then was a lecturer in the Department of Physics at the University of Cape Town. Rudolph did his postgraduate
studies in measurements of high energy neutron and proton fields under the supervision of Prof Frank Brooks at the University of Cape Town. He lectured at the University of the Western Cape before joining UCT in 2004.

### 1.3.2 Highlights

- For a number of years the AFRODITE working group has been doing research on the topic of chirality. During the course of this year they have published an article in Physics Letters B. In new data on the high spin states of $^{194}$Tl gathered with AFRODITE. Exceptionally close near-degeneracy in the excitation energies was found between two 4-quasiparticle rotational bands. Their alignments and $B(M1)/B(E2)$ reduced transition probability ratios were also found to be very similar. These indicators point to $^{194}$Tl having a chiral geometry in angular momentum space under these circumstances.

- iThemba LABS hosted the annual International Muon Workshop in Cape Town, South Africa from 30 April to 4 May 2012. This Workshop was held under the auspices of the Muon Group of ALICE and the SA-CERN Program. The scientific program was mainly related to research performed on the Muon Spectrometer of ALICE and covered on-going research projects in the field of the muonic decays of heavy flavour systems and quarkonia produced both in pp and Pb-Pb collisions. Also topics concerning the status and performance of both the Muon Tracking as well as the Muon Trigger chambers were discussed. The workshop was concluded with presentations regarding the upgrade of the detector hardware, the readout electronics as well as the motivation for the Muon Forward Tracker, a new detector in ALICE.

- A successful workshop focusing on the physics vision for high energy-resolution nuclear spectroscopy with magnetic spectrometers and the associated requirements to achieve these measurements was held at STIAS Stellenbosch from 19 to 22 November 2012. The focus of this very specialized workshop was on $0^\circ$ and small angle scattering and reactions investigated with magnetic spectrometers, as well as on recent developments and future plans at rare isotope beam facilities. It formed part of the German / South African “Year of Science 2012”, and recognized the iThemba LABS / University of the Witwatersrand / Technical University Darmstadt collaboration, with a track record of nearly two decades. The workshop was opened by the Minister of Science and Technology, Mr Derek Hanekom and was attended by the German Consul General in South Africa, Mr Herrmann (Figure 1). There were 45 attendees of which 10 were students.

- During a test experiment we demonstrated the feasibility of performing high resolution light ion experiments in which the iThemba LABS K600 particle spectrometer, operated in zero degree mode, can be used in conjunction with High purity Germanium gamma detectors. This unique combination that opens exciting new research opportunities has been made possible by extensive developments on the spectrometer as well as by the excellent beam quality for the iThemba LABS SSC.
A digital data acquisition system using Pixie16 modules (from XIA LLC, USA) was commissioned for AFRODITE experiments during 2012. The acceptance rate of gamma-gamma coincidence events with the digital system is 5 times faster than with the analogue system, with similar detector performance. The implementation of the digital DAQ is a major step forward, which also allows for a large number of additional channels e.g. from Si strip detectors.

Figure 1: The dignitaries at opening of the International Workshop on Nuclear Spectroscopy Frontiers at Magnetic Spectrometers held as part of the German-South African Year of Science were (from left to right) Professor Peter von Neumann-Cosel (workshop chairman), Dr Zeblon Vilakazi, Director of iThemba LABS, Mr Derek Hanekom, Minister of Science and Technology, and Mr Roland Herrmann, the German Consul General to South Africa.
1.4 Electronics and Information Technology 2012/2013

The Faure laboratory's new 10 Gbps fibre optic access circuit to the South African Research and Education Network (SANReN), which was installed during the previous year, has operated reliably since installation, and, despite experiencing breaks in the fibres at regular intervals, the redundant nature of this fibre optic ring has resulted in only a single outage of Internet connectivity due to simultaneous problems in both legs of the ring.

Progress on the upgrading of the IT network and services infrastructure has continued as finances have allowed. The efficiency and reliability of the air cooling in the main server room has been improved with the purchase of two in-row direct expansion cooling units that are fed from two independent power sources. A major upgrade of the laboratory's WiFi infrastructure was begun during the year with the purchase of new WiFi controllers and access points for the Faure and Gauteng sites. The main Faure building and some of the accelerator plant areas are now covered by this new infrastructure, while the whole Gauteng site is covered. It is planned to extend coverage to the remaining areas of the Faure site as funding becomes available. Videoconferencing infrastructure was installed at both sites (part-funded by a NRF drive to provision all of its facilities with such infrastructure), and this has proved very effective in enabling meetings and workshops to be held where participants are distributed across the country (or the world) with significant concomitant savings in both costs and time.

A centralised Kerberos/ldap authentication and authorization system has been developed as a single-sign-on service for e-mail, file access, web logins, etc. This is currently being deployed. A new dual-node cluster using redundant storage has been developed for the upgraded mail stores, together with an extended webmail client which will become an integrated collaboration tool, and this will come into operation with the deployment of the centralised authentication and authorization system. A 125 TB NetApp high-availability failover file storage system has been installed, and is being used to store experimental data, physics users' home directories and to provide virtual computer hard disk space. All users now have the potential for centralized disk space in AFS with strong passwords, allowing it to be opened for remote access.

Development of the K600 spectrometer data acquisition system (DAQ) has continued, and some code has been re-written to increase data capture speeds. A general FPGA-based triggering system for DAQ systems has been developed and integrated into existing systems. A Parallel Root Facility cluster has been installed, and is used to perform high-speed analysis of data from nuclear physics experiments.

Development of DAQ systems for experiments based on the Van de Graaff accelerator has continued. These include the Rutherford Backscattering facilities and the nuclear microprobe.

The development of new, and the porting of the old, accelerator control subsystems on the EPICS platform has continued.

- The deployment of Ubuntu 1204(LTS) has been completed for the IOC control nodes currently operational in the accelerator control systems. Some work had to be done on getting MEDM (Motif
Editor and Display Manager) to compile on the latest releases for Ubuntu 1204 due to its multi-architecture nature, with help being sought from the open source EPICS community.

- Additional EPICS control code and protocols have been written for commercial devices from ioLogic, Genesys, Micronor and Group3, as well as new code for the control of the lab’s custom instrumentation including all the SPC1 internal devices, AMS and beam line components.

- New vacuum control systems have been developed and installed for the HMI and GTS ion sources. In addition code has been written for the Q-line, K-line, SPC2 and SSC vacuum systems and will soon be installed.

- Beam-current measurement systems, developed for use in the lab, have been supplied to Forschungszentrum, Jülich, and the European Spallation Source, Sweden.

- Code has been written to enable rapid automatic switching of the cyclotron beam between the radiotherapy and radionuclide production beam lines.

- EPICS ELOG (Electronic Logbook) software has been configured to allow for the easy capture of cyclotron performance data and the production of useful reports.

- Software that captures and displays profile data of the beams in SPC1 and SPC2 has been rewritten.

- A new graphical user interface has been developed for control of the Van de Graaff accelerator. It displays live values of all measured parameters, and allows accelerator operators to control devices.

- Upgrades from the OS/2 system to EPICS over this period include:
  
  - New higher current Geckodrive-based stepper motor cards were installed to speed up the movements of three J beam line slits. This was needed to improve the beam line switching program used in the sharing of the beam during therapy treatment sessions.
  
  - The commissioning of three SPC1 slits, namely Radial and Axial Slit1, Radial Slit 2 and Axial Slit 2, was completed and deployed.
  
  - The two extraction elements, namely the Electrostatic Extraction Channel (EEC) and the Magnetic Extraction Channel (MEC), were added together with the spare EEC. The mathematical equations describing the movement of these devices were implemented using an aSub EPICS record. Most problems that were encountered were associated with the differences in drive electronics and interlocking, especially on the MEC, and care had to be exercised during the testing of these radioactive components.
  
  - The movement of the last of the control variables over to EPICS on the Materials Research Department’s Van de Graaff accelerator’s control system was completed with the deployment of the eighteen string control variables.
• The magnetic field measurement system was upgraded to include an EPICS IOC and QT application software. The IOC controls the field mapping table, Hall probe head selection and meter multiplexing.

• In preparation for the mid-year shutdown of the Gauteng tandem accelerator numerous developments were undertaken, most concerned with the control of the AMS ion source and the low and high energy beam line components. These developments included:
  
  • The configuration of an IPSec VPN tunnel between Faure and Gauteng sites to allow for direct access to the Gauteng control network for Faure-based developers and operators.
  
  • The provision of three IOCs, the one being an in-house developed SABUS CPU/differential driver module based on an ETX plug-in card.
  
  • For the AMS ion source a Glassman high-voltage power supply, two DC power supplies and two temperature measurements on a high-voltage platform were catered for using MODBUS protocol over an optically isolated serial bus connected to an ioLogic analogue input and output device.
  
  • On the AMS injection beam line, controls were provided for six slits, two harps, an attenuator, thirteen Faraday cups, and another four Glassman high-voltage power supplies.
  
  • Test code has also been written for the high-energy beam line components along with feedback control of the low-energy analysing magnet.
  
  • Code for the control of the high-energy beam line high-voltage power supplies and thirteen-port USB hub interface has been fully tested.
  
  • The modification of the safety interlock and vacuum control systems to cater for the addition of components for the AMS system.
  
• SABUS card frame developments included:
  
  o An ETX PC-compatible controller module which can replace a computer connected to the crate. It has been tested with the latest Ubuntu 1204 Linux operating system, and completed a full IOC install.
  
  o The backplane has been upgraded to include a 30 V power track suitable for stepper motor and brake-release currents.
  
  o A number of card enhancements have been introduced, including an optimization of the card locking system on the SABUS crates.
• Maintenance of the control system.
  o For the older mechanical components, most problems centre around limit switch failures, leaks on vacuum feed-through components, and lack of lubrication which can necessitate recalibration of the software.
  o The N02PS1 computer node in the power supply room was replaced as the old machine was starting to show signs of disk failure and was proving difficult to reboot.
  o Slit 13Y on the J-line was removed to check a faulty collision switch. This was re-tensioned and it was found that the mid-point calibration of the slit was slightly off, giving rise to software issues in moving off a collision limit. The software calibration point was adjusted.
  o During the period under review about 1050 fans were checked and 39 replaced. These fans are located in the control PCs, and SABUS, CAMAC, stepper motor power supply and UPS crates.
  o 128 batteries were installed in the 40 kVA UPS in the data room using good quality easily-available batteries.

The electronics support division currently provides a service to the whole of iThemba LABS and several external users of the facility. Approximately half of the division’s time is spent on the development of new systems, while the remainder is spent on maintenance, fault-finding and repair of electronic instrumentation, and involvement in training and teaching. Some of the major projects undertaken by the division for the accelerator and engineering, nuclear physics, materials research, radionuclide production and medical radiation departments included:

• New or upgraded instrumentation modules and interfaces were designed and manufactured, such as stepping motor controllers, power supply controllers, ADCs and PCI SABUS interface cards.

• The design and implementation of a Beagle board interface to the 48-channel current measurement system.

• The development of a phase probe measurement system using a SRS844 lock-in amplifier and multiplexor unit with external filtering, which is now in regular use.

• The development of a real-time solution for beam collimator current measurement, together with parallel testing of the new ISOCUR current monitoring system on the radionuclide production beam line. The beam parameter logging system was extended to add logging of SPC1 ion source variables, and RF systems to monitor the beam stability and uptime of the VBTS and ISOCUR target stations.

• Members of the EIT Department contributed to the design and implementation of several electronic subsystems required for the upgrade of the current proton therapy programme for the Medical Radiation Department. Two of the milestones were the new floor control PLC and the use of an ETX computer in the Dose Monitor Controller.
Time was spent on the general support of the lab’s physics user community to have high availability of electronics during experimental runs. NIM, CAMAC and VME equipment used on a regular basis was repaired. In addition, repair and maintenance was carried out on numerous specialised systems and subsystems such as the nuclear microprobe control system, the AFRODITE filling system, electromagnetic interference detection and clean-up in the AFRODITE vault, and the installation of a new UPS for the AFRODITE vault.

Document delivery remains a core function of the Library and Information Service Division of the lab. Information is sourced from libraries across South Africa as well as from the British Library and directly from researchers across the world. A total of 520 document delivery requests were processed during the year.

The Library and Information Service staff captured the 2012/13 research output for iThemba LABS on the Research Information Management System (RIMS) database maintained at NRF Pretoria. All submissions were verified and supporting documentation collected.

The library’s InMagic Genie software was once again upgraded to the latest version. A pilot project to implement an institutional repository, based on the use of the open source dSpace software, was instituted. Capturing of procedures and drawings, and uploading these to the document server, for the Accelerator and Engineering Department has commenced.

Usage of the iThemba LABS (Gauteng) library continues to increase steadily. A total of 352 books were circulated during this period. The basic records for the WITS and Sellschop Collection were prepared for import into the InMagic Genie database. Cataloguing and classification of the WITS collection is in progress.

The Library and Information Service Division organized and managed the following conferences and workshops during the year:

- Nuclear Spectroscopy Frontiers Workshop 19-22 November 2012 – 45 delegates
- International Workshop on Discovery Physics at the LHC 3-7 December 2012 – 98 delegates
1.5 iThemba LABS (Gauteng)

1.5.1 Overview

The major project at the Gauteng site of iThemba LABS remains the establishment of the first Accelerator Mass Spectrometry (AMS) facility on the continent of Africa. Significant progress was achieved in this endeavour, as discussed below. The High Energy Analysis System is under construction by National Electrostatics Corporation (NEC) in the USA and delivery is expected in the latter half of 2013. With the complete AMS facility installed and commissioned the future of iThemba LABS (Gauteng) looks bright.

Other significant steps forward centred around two key appointments, one technical, one scientific, as highlighted below. The challenge remains to make further key appointments as the AMS facility, as well as the other operations, moves into a sustained delivery phase, since a 24-hour, 7-day-a-week operation of the EN tandem accelerator is on the horizon.

Relationships with users, both present and potential, remain vital, and the invitation of the Head of Department to two strategic meetings at Wits, one hosted by the Materials Physics Research Institute, the other by the School of Physics, bodes well in this regard. In addition, the approach from the University of Johannesburg to be considered for a Visiting Professorship in the Department of Physics promises a future whereby iThemba LABS (Gauteng) will act as a research hub in analytical science and postgraduate training, not only for local institutions and users, but as a true national facility that will also attract users from overseas.

1.5.2 Operational Highlights

- On 1/8/12 Tony Miller joined the staff at iThemba LABS (Gauteng) as a Senior Technician. He thereupon installed the Varian 350D (300XP) ion implanter which had been jointly procured with the Wits School of Physics, who also jointly funded Tony’s position for the first year of his appointment to cover the installation and commissioning period. The installation included the addition of a sputter ion source in November 2012 procured by Wits and the fitting of scientific end-stations to replace those used for commercial purposes at SAMES (the company that formerly owned the implanter). This enabled the delivery of gold, carbon, copper, platinum and silver beams to the end-stations.

- The AMS system took a major step forward with the commissioning of the Low Energy Injection System. This was done in two stages, the first during December 2012 with the assistance of Albert Zondervan of GNS, New Zealand, and the second in late February 2013, when on 25/2/13 a carbon-12 beam from the IAEA-funded 64-sample ion source was injected into the EN tandem via the Low Energy Injection System. It was then accelerated and read on the high energy Faraday cup after the post-accelerator analysing magnet. A carbon-13 beam was also accelerated, after “manual bouncing” of the Low Energy Injection System magnet to achieve the correct field. The performance of the system in terms of injection and transmission efficiencies compared favourably with top-performing AMS facilities as
confirmed by Peter Steier of the VERA facility in Vienna. There was also a visit earlier in the year by Alain Jorge Cardoso Cabezon and Vuvu Msutwana-Qupe from the IAEA to iThemba LABS (Gauteng) since the IAEA provided funds to procure an additional E-ΔE detector, as well as other AMS-related equipment. Significant progress was also made in the setting up of the sample preparation laboratory, located in the office building.

- The general refurbishment of the office building at iThemba LABS (Gauteng) commenced, with the fitting of new flooring, ablutions and kitchen facilities. Further refurbishment will continue into the new financial year.

- Improvements to general site infrastructure included the installation of a new chiller plant and new separate electricity meters by the Wits Property Infrastructure Management Department. This allowed the power consumption of the office building, the accelerator building and the Wits Radiation and Health Physics Unit, as well as the sump-pump meters to be read separately and remotely, since the latter remain the responsibility of Wits.

- In order to comply with Occupational Health and Safety requirements, cabinets for the gas cylinders to be coupled with the Delta V mass spectrometer were delivered. These allowed the cylinders to be placed in the laboratory next to the Delta V and hence at the same nominal ambient temperature, as required by the suppliers of the spectrometer, Thermofisher.

- A broad energy-range High Purity Germanium detector was procured from and delivered by Bio-teknik. The detector was installed in the low-background counting facility and thence used for analysing a variety of samples, including those supplied by the Wits School of Geosciences.

- On 15/2/13 Dr Stephan Woodborne, formerly of the CSIR, was interviewed for the post of Senior AMS Scientist. He was offered the position and will commence on 1/4/13.
1.6 Medical Radiation Department

The hadron therapy facility continues to treat patients with neutrons, as referrals are still being done through the two local academic hospitals and nationwide. Twenty patients were treated with neutrons during the year, well below capacity but representative of staff resources available. For proton treatments the issue of not having a permanent radiation oncologist on the iThemba LABS site is more critical and it explains why no treatments were done during the year. One patient from Germany was treated with neutrons.

Although the facility has been operating reasonably smoothly, there were some major equipment failures that resulted in delays in neutron dosimetry measurements. This caused the re-scheduling of about 10% of patient treatments. A major delay occurred when the 66 MeV proton beam burnt a hole in the vacuum chamber immediately upstream of the 160 degree bending magnet in the neutron gantry. Other problems were associated with source instability in the 8 MeV SPC1 cyclotron that feeds the 200 MeV SSC.

The Medical Radiation Department hosted important national and international visitors. In March, Professor Frank Verhaegen from Maastricht Radiation Oncology gave a series of lectures to staff and medical physicists from the Western Cape. In July, the South African Health Minister, Dr Aaron Motsoaledi, visited the particle therapy facility and expressed his support for the continuation of this important National asset. Professor Branislav Jeremić, the new head of Medical Imaging and Radiation Oncology at Tygerberg Hospital in Cape Town visited the Department to familiarize himself with the Proton and Neutron Therapy operations to assess future patient referral.

Important discussions were held with officials from the Health Provincial Department on the best way to manage the 22-bed Faure Hospital and with the Heads of the academic hospitals in Cape Town to help resolve the radiation oncology staff crisis that iThemba LABS has been facing for the last two years.

Two important international collaborations were implemented; one with the National Institute of Radiological Sciences in South Korea, whereby iThemba LABS and the Korea Institute of Radiological and Medical Sciences (KIRAMS) joined efforts to develop a Real Time Range Monitor for the proton therapy beam delivery system. This collaboration was completed with the delivery of a Multichannel Current meter device designed and built by the Koreans, and by the simulation and test of a Multi-Layer Faraday Cup detector manufactured at iThemba LABS.

A second International collaboration was established between iThemba LABS and the PRaVDA Consortium formed by a number of hospitals and universities in the United Kingdom, to jointly explore the development and testing of dedicated imaging detectors for a conceptual Proton Computed Tomography System. The above projects are currently work in progress.

At the National level, the Medical Radiation Department has engaged with the University of Cape Town to undertake research in prompt gamma detection in the 200 MeV beam with the aim of reducing uncertainties in proton therapy treatments.
A number of important instrumentation and equipment acquisitions were done during the year. A dedicated water phantom for the fixed horizontal proton beam line was manufactured and delivered by IBA in Belgium. The Department replaced all old electrometers used for Quality Assurance and patient dosimetry with the latest Kethley units, and a programmable current source of the same make was acquired. A total of four Tissue Equivalent Ionization chambers were purchased, two of them with gas flow inserts for neutron radiation dosimetry. Two low level current digitizers were also brought in to replace faulty units; one of them was designed in-house and the other was bought from an international supplier.

A portable dehumidifier unit was assembled in-house to cater for large variations in humidity levels affecting the dosimetry detectors in the neutron gantry during the summer months. A reference chamber used with the proton beam dosimetry phantom was re-designed and installed in the beam line.

The Department reached an important milestone in its efforts to upgrade and improve the therapy facilities by having completed the development of the new portal radiographic system for proton therapy. This system is expected to make proton therapy more attractive to the clinicians since it will considerably simplify the verification of the treatment setups and improve the accuracy of the treatments. The system is currently being thoroughly tested to evaluate its performance and to commission it for clinical use. The preliminary test results are very promising.

The Department continued to be engaged in the training of Medical Physicists in collaboration with the University of Free State in Bloemfontein, and the supervision and training of Therapy Radiographers from the Cape Peninsula University of Technology in the areas of medical physics, quality assurance and treatment planning in particle radiotherapy.

Members of the Department attended the International Proton Therapy Congress (PTCOG) in South Korea and a number of local conferences such as the South African Association of Medical Physics and Biology (SAAMPB), the Society of Radiographers of South Africa (SORSA), and the South African Society for Clinical and Radiation Oncologists (SASCRO) conferences.

1.6.1 Radiotherapy and Research in Biomedical Science

A total of 20 patients were treated on the p(66)/Be isocentric neutron unit during the year. A total of 5.9% (15 out of 222) of treatments had to be rescheduled. Problems which caused rescheduling are listed in Table 2. Neutron therapy statistics are given in Table 1 and Figures 1-3.

No patients were treated on the 200 MeV horizontal beam proton therapy facility during the year.
Table 1: Hadron therapy statistics

<table>
<thead>
<tr>
<th></th>
<th>Neutron therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012/13</td>
<td>TO DATE</td>
</tr>
<tr>
<td>Treatments per day</td>
<td>2.0</td>
</tr>
<tr>
<td>Fields per day</td>
<td>7.7</td>
</tr>
<tr>
<td>Fields per treatment</td>
<td>3.8</td>
</tr>
<tr>
<td>Time per field (min)</td>
<td>8.0</td>
</tr>
<tr>
<td>Time per day (min)</td>
<td>62</td>
</tr>
</tbody>
</table>

Table 2: Neutron therapy rescheduled treatments – Causes

<table>
<thead>
<tr>
<th>Cause</th>
<th>Number of treatments rescheduled</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPC1 problems</td>
<td>11</td>
</tr>
<tr>
<td>High-pressure air supply failed</td>
<td>2</td>
</tr>
<tr>
<td>SPM water leak</td>
<td>1</td>
</tr>
<tr>
<td>Flattening filter drive</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 2: Treatment statistics of patients receiving neutron therapy.
Figure 3: History of completed neutron therapy treatments expressed as a percentage of those scheduled each year.

Figure 4: Frequency distribution of number of neutron therapy fields treated per day.
1.6.2 Radiation Biophysics

Various developments in life science methodologies have been implemented to further research in radiation biology. This includes the establishment of cell preparation methods and immune-histochemical staining to follow the induction of double strand breaks and repair using γH2AX foci. Semi-automated analysis methods can now be used to help understand repair kinetics of neutrons and X-rays in fractionated radiotherapy treatments as well as to investigate this early endpoint for use in bio-dosimetry.

The role of different repair proteins after exposure of breast epithelial cells to different radiation qualities can now be examined. This follows previous studies on the Ku heterodimer on non-homologous end-joining after exposure of human MCF10A breast epithelial cells to low-LET (Linear Energy Transfer) γ-rays and high-LET neutrons. Currently the role of one of the major breast cancer susceptibility proteins, BRCA1 is investigated as the protein plays a major role in the homologous recombination pathway.

Funding provided by the Flemish Interuniversity Council allow postgraduates from different Universities to conduct experiments at iThemba LABS and the University of Ghent. This includes the study of prostaglandin A2 as a sensitizer in mammary MCF-7 breast cancer cells. Also, immune-histochemistry for characterisation of cervical cancer biopsy has been established for smear cultures and is used to follow the radiosensitivity of these to radiotherapy.

By optimizing the cell image classifiers of the Metafer auto-image analysis system, the detection of variations in radiosensitivities of T-lymphocytes for different individuals is now possible. The high precision of micronuclei counting allowed by the Metafer system identified unique radiosensitivities to 60Co γ-rays for almost all persons in a cohort of 10 individuals.

The radiobiology laboratory continues to support studies promoted under the Nuclear Technologies in Medicine and Biology Initiative (NTeMBI). One of these projects quantifies the uptake of radiolabelled receptor targeting compounds in oesophageal cancer cells.

Apart from supporting many training initiatives in radiation protection, personnel also help numerous companies with practical radiation regulatory issues. During the year great advances in dealing with liquid radioactive waste on site has been made. This includes the installation of a reverse osmosis plant for treatment of our radioactive liquid effluent. As a result since October 2012, there has been zero radioactivity released to our on-site dams. Historical liquid waste in the form of acidic radioactive liquids have been re-organised, labelled and stored in a safe, retrievable manner. This has long-term benefits for the future as the waste can be segregated according to half-life and released as non-radioactive waste.
1.7 Radiation Protection Division

1.7.1 Operational Highlights

Repackaging Of Toxic Radioactive Liquid Effluent

The manufacture of nuclear medicine requires target material to be dissolved in a highly acidic medium. This process creates radioactive liquid effluent that is highly acidic. For the first twenty years of operation, this liquid effluent was stored somewhat haphazardly in the basement. This was not only a radiological problem but also represented a hazardous chemical environment.

In 2013 the Radiation Protection Division decided to tackle this historical problem. All the liquid waste had been stored in 25 litre plastic drums, some of which had begun to leak. After consulting the Safety Health and Environment Department for the proper working methods, we removed the drums, sorted them according to age and content and re-packaged them into larger square containers. This is to contain leaks and to create easy identification and removal for treatment.

Figure 1: Mixed waste – acid and metals (left) and leaking drums placed in plastic bins.

Figure 2: New Storage System With Clear, Chronological Labeling
Storage of Highly Radioactive Metal Waste

For many years the basement was used as a dumping ground for materials that were too radioactive to be kept anywhere else. While this was a suitable solution at the time, the situation has become untenable since the radiation doses rates were too high for staff to spend time in the basement. In June 2012 a decision was taken to procure two thick-walled concrete drums for storing this waste. The first drum was filled in August 2012 and has been placed in a low-occupancy area for long-term storage.

Activity Released To On Site Dams

The commissioning of the Reverse Osmosis water treatment system took place during 2011. As this is a relatively new technology in this type of application we have had to make several modifications to the system. These include bigger pumps, better filters, a UV system to kill algae and a change in membrane supplier. Total cost is still less than our annual budget for ion-exchange resins, which was the old method of treating the liquid effluent. We are delighted to report that during the last four months of this reporting period, no radioactivity was pumped to our dams. This is a major achievement and bodes well for our long-term environmental footprint. Radiological releases are measured in ALI’s (Annual Limit of Intake) and our Department of Health (DoH) license allows us to release 10 ALI’s per month.
Nuclear Security in Southern Africa

The U.S. State Department has recognized the need to improve the security culture at facilities that hold or manufacture radioactive material. There have been many incidents in recent years where radioactive material has been released or stolen, resulting in uncontrolled radiation exposure of the public and staff at a facility. Extra gates and fences are effective for a while but real improvement takes place when there is an improvement in security culture of the staff in general.

To further this idea, the U.S. State Department, through the Partnership for Nuclear Security, has arranged a series of workshops and lectures in South Africa. The first of these took place at the University of the Witwatersrand in Johannesburg in December 2012. As iThemba LABS has always been at the forefront of source safety and retrieval we were naturally selected to take part in these workshops. The initial workshop was to identify the educational needs and types of courses that should be offered at Universities in order to fulfil the demands of industry. The next workshop, planned for June 2013, is to address the needs of industry.

To this end, iThemba LABS is becoming a centre of excellence for radiation safety and nuclear security. Not only do we provide Nuclear Safety Training to anybody who requires it, we will also be expanding our courses to include Nuclear Security Culture changes.

Training Radiation Protection Officers (RPO’s)

To date there is no DoH-accredited RPO training in South Africa. This is a long-term problem that will eventually be addressed by the DoH. In the interim, iThemba LABS has been providing RPO training to anybody who requires it. Although it is not accredited by the DoH, several companies have informed us that they may not apply to own radioactive material until they have attended our course.

We have therefore modified our RPO training program to include certain aspects of the regulatory requirements on how to complete the necessary application forms and the types of instrumentation they should procure, and generally make ourselves available for any queries, complaints or crises. At present, this training is free but once accreditation is acquired we should be able to generate some income from this service.
1.8 Safety, Health and Environmental Management

1.8.1 Highlights 2012/2013

The Safety, Health and Environment (SHE) Department assisted with safety legislative and best practice requirements while the new 11MeV Accelerator was installed at D-Block (Radionuclide Production). Installation of the accelerator was conducted by Siemens and regular communication was held with their Safety Division. The project was successfully completed without incident.

1.8.2 Occupational safety management

Safety, Health and Environmental Committee

The meetings are scheduled to take place every two months. The Sub-Committee at iThemba LABS Gauteng has been incorporated ensuring that only one meeting is held. Elections of the SHE Representatives were held in accordance with Occupational Health and Safety (OHS) Act requirements. Newly elected SHE Representatives were trained before being appointed to the SHE Committee.

Hazardous Substance Control

Disposal of hazardous substances and medical waste takes place in accordance with the Hazardous Substance Control Act. The SHE Department collects and sorts hazardous waste before removal off-site by a contracted Service Provider. The SHE Department also administers the collection and disposal of medical waste.

Emergency Response Management

Annual servicing of hand-held Fire Fighting equipment took place in the last quarter of 2012. Emergency evacuation drills were held randomly every 2 months, and first aid triage exercises were integrated. Emergency lighting was inspected and serviced by the SHE Department and the GMR2 appointee as per legislative requirements. A fire detection system survey was initiated to investigate the need for upgrading the current system.

First Aid Management

Monthly first aid update training is offered by the Occupational Health Clinic to enhance first aider knowledge. Recertification was brought up-to-date as required by the OHS Act no. 85 of 1993. First aid boxes were replenished and additional boxes were acquired for vehicles. Diphtherine eye-wash equipment was installed in laboratories where chemicals are used.
Health & Safety Management

Non-scheduled safety walkthroughs were conducted throughout the facility with the aim of identifying safety non-conformances.

The SHE Department provides technical support and acts as a resource for the Safety function at iThemba LABS Gauteng. The SHE Department Manager visited iThemba LABS (Gauteng) to assist with the implementation of the SHE management program and to ensure all safety organization members received the required training. The election of 3 safety representatives was also conducted and an intensive walkthrough was conducted throughout the site, highlighting numerous non-conformances. An action plan was implemented to address the identified issues.

An inspection of all bulk gas installations was conducted in order to ascertain the legal compliance. The local Fire Department assisted with the inspection. It was agreed that all gas installations will be upgraded to comply with SANS 10400 – T: 2011 requirements.

Incident Reporting

A computer in an IT Office malfunctioned and caught fire. Staff members responded and the fire was put out quickly resulting in minimal damage. The smoke, however, caused damage to surrounding equipment.

Four disabling incidents were reported and investigated during 2012/2013 resulting in a total loss of 104 man-hours. All incidents were reported to the Compensation Commissioner as per the Compensation for Occupational Injuries and Diseases Act, no. 19 of 1993. Two of these incidences were reported to the Department of Labour as per the OHS Act requirements.

Non-disabling incidents were reported and investigated to during 2012/2013. These cases were also reported to the Compensation Commissioner. Eleven first aid incidents were investigated and attended to during 2012/2013.

Incident/Accident statistics reported for 2012/2013 are as follows:

<table>
<thead>
<tr>
<th>Incident Type</th>
<th>Number of Incidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near miss</td>
<td>2</td>
</tr>
<tr>
<td>Minor/First aid incident</td>
<td>11</td>
</tr>
<tr>
<td>Non-disabling incident</td>
<td>2</td>
</tr>
<tr>
<td>Disabling incident</td>
<td>4</td>
</tr>
<tr>
<td>Motor vehicle accidents</td>
<td>4</td>
</tr>
<tr>
<td>Fire incident</td>
<td>1</td>
</tr>
<tr>
<td>Theft / Property loss</td>
<td>2</td>
</tr>
<tr>
<td>Attempted theft</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total Reported Incidents</strong></td>
<td><strong>27</strong></td>
</tr>
</tbody>
</table>
Occupational Health and Hygiene

The Occupational Health Clinic conducted annual lung function tests during November 2012. Tests on 60 staff members were conducted based on their exposure risks to airborne contaminants as identified through a hazard identification process.

The occupational hygiene monitoring survey is scheduled to take place in the second half of 2013. An occupational hygiene survey is also scheduled for iThemba LABS (Gauteng) in the final quarter of 2013.

Environmental Management

Water Management

Water samples are collected from selected inflow, process and outflow points throughout the wastewater sewage treatment plant. The samples are sent to an approved laboratory for microbial analysis. The purpose of the sampling and analysis is to ensure the efficacy of the Biofilter Plant in reducing harmful bacteria being released into the dams.

Waste Management

The collection and removal of general waste is administered by the SHE Department. Such waste is removed by a third party service provider under contract. Waste paper and cardboard is collected in separate boxes and sold for recycling. The collection and removal of used oil is administered by the SHE Department. The oil is removed by a third party service provider for recycling.

The administration of redundant batteries, printer cartridges and scrap metal disposal and recycling is overseen by the main stores and administered by the SHE Department

1.8.3 Training

Training Statistics for 2012/2013 are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Safety Induction Training</th>
<th>Fire Team Training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contractor/s</td>
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<td>-</td>
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<tr>
<td>SHE Department</td>
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<td>3</td>
</tr>
<tr>
<td>Material Research Division</td>
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<td>-</td>
</tr>
<tr>
<td>Nuclear Physics</td>
<td>10</td>
<td>-</td>
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<tr>
<td>Administration</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Radio-Frequency Division</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Human Resources</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Radionuclide Production</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td>Accelerator</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Site Services</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Radiation Protection Division</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hospital</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Finance Department</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>
Recertification for first aiders and emergency response personnel (fire-fighters, evacuation wardens, etc...) is scheduled to take place in 2013 as the current certification is valid for 2 years.

**Security Management**

The installation of an electrified perimeter fence took place during 2012. The fence is monitored at the main security gate. The system, however, has been marred by technical difficulties since installation. The GMR2 has been tasked to rectify all technical matters regarding the fence.

Additional security measures were taken when required by contracting additional security staff via a service provider.

**Insurance Management**

Six incidents have been reported for claims from the Insurance service provider for 2012/2013, consisting of five motor vehicle accident claims and one property damage incident claim. All claims were successfully settled.

**Housekeeping Management**

Housekeeping staff’s areas of responsibility were reviewed and reassigned. One staff member was transferred to the Receptionists position which reports to the CIT Department and the vacancy was filled, and staff member was seconded to the Technical Support Services Division. This post was filled by a contractor to ensure service continuity.

A staff member is currently on long term sick leave and has been declared temporarily unfit for duty. This matter is currently under review by the Insurer. She has been replaced by a temporary worker on a one year contract.

The Housekeeping Department assisted with various conferences and meetings by providing required services. Housekeeping provided deep cleaning services as requested by various Departments. These services were conducted over weekends due to the intrusive nature of the work to be done.
1.9 Community Interaction and Training.

The National Research Foundation’s vision is to ensure research excellence within a transformed research workforce, and a sustainable environment, not only for the benefit of the present generation but also for future generations of South Africans. At the heart of this statement is the need to grow human capacity; not only developing, strengthening and supporting the current cohort of researchers, but increasing the pool of graduates interested in pursuing research careers.

The National Research Foundation is committed to increase the number of South Africans with PhDs on a yearly basis. One of the major challenges in achieving this ideal is the existence of the “leaky pipeline”; the fact that we are constantly losing talented youngsters as they progress from primary education into secondary education and finally into tertiary education and postgraduate studies.

The division for Community Interaction and Training at iThemba LABS has three main foci, namely Science Advancement, Science Communication and Student Training and Development. The extended portfolio aims to impact prospective students, current students and the general public.

1.9.1 Science Advancement

The science advancement activities focus on promoting an awareness and appreciation of general science, with specific reference to nuclear physics where possible, amongst learners, teachers and undergraduate students.

The division makes use of interactive workshops and science shows to engage the target audience. The division was able to support the science advancement activities through an internship offered to a student, Mr Akhona Mali, who completed a National Diploma at Cape Peninsula University of Technology.

The activities of the division is supported through additional funding that is secured from DST through proposal writing, such as the participation in the National Science Week and the purchasing of a dedicated vehicle for outreach.

The division interacted with more than 13 000 learners and 1 300 teachers through its interventions. The division makes use of partnerships to extend its offering to areas further afield such as the road trips to the West Coast Education district (Vredendal, Lutzville, Klawer, Ebenhaeser) and the Northern Cape (Carnarvon, Vanwyksvlei, Williston).

Partnerships with IMSTUS (Institute for Mathematics and Science Teaching at SU), PSP (Primary Science Programme), KDA (Kids Development Academy) and SLCA (Science Learning Centre for Africa at UWC) afforded the division opportunities to engage teachers on curriculum-specific content. The division has also partnered with the Western Cape Education District to offer training to Mathematics lecturers in the Further Education and Training sector. The training comprised sessions on teaching methodology and classroom visits.

One of the key projects within the division is Sophumelela; a targeted intervention which interacts with grade-7 learners at 8 primary schools in close proximity to the facility. The project not only attempts to impact the
teaching and learning of natural science, but also develops leadership skills through a 3-day environmental camp. The “scientific highlight” of the project is the competition for future scientists where the learners showcase their knowledge and communication skills.

The division has been able to impact the teaching and learning of science and mathematics through the award of grants to various schools (more than 10) ranging from R 2 000 – R 10 000. This activity is supported through funding generated through the renting of facilities to film companies.

1.9.2 Science Communication

The need to effectively engage various stakeholders remains a strategic priority within the organization. Not only do we need to communicate our activities to external stakeholders, but we also need to ensure that there is a common understanding of our strategic direction amongst staff members. The division is responsible for the production of a monthly newsletter that facilitates this process. The division is furthermore responsible for the production of advertorials and editorials that are placed in various magazines on a regular basis.

The division coordinated the media coverage of the visit of the Minister of Health, Dr Aaron Motsoaledi, which was screened on SABC2 News. The division Furthermore coordinated the launch of the 11 MeV cyclotron for the production of $^{18}$F. A press release was issued to local newspapers.

The division hosted Profs Roy Maartens and Valerie Corfield for public lectures. The possibility of hosting public lectures on a regular basis in 2013/14 will be investigated.

The division hosted the 1st Open Day entitled “A day in the life of a proton”. The Open Day provides members of the general public an opportunity to experience the facility during the yearly shutdown period. The Open Day was marketed in local newspapers and interviews were conducted on a local radio station (Radio Helderberg) in both English and isiXhosa. More than 250 visitors participated in guided tours on the day. The division also coordinates all requests to visit the facility; more than 30 visits were organized throughout the year.

The division has also participated in a number of career and motivational sessions conducted at schools. The division is developing a discussion document: “Towards a communication strategy” that will be submitted to management for consideration. It is hoped that this strategy will pave the way for future engagements, especially around the use of social media as a vehicle for communication.

1.9.3 Student training and development

The division was responsible for the financial administration of the MANuS/MatSci programme as well as the coordination of the “top-up scheme” that provides financial assistance to students pursuing postgraduate studies in Nuclear Physics and Material Science. The division awarded scholarships to 8 BSc(Hons) students in experimental physics at Stellenbosch. This was a feasibility study to assess the possible impact of financial assistance at an earlier stage. The division also coordinated the placement of a number of in-service trainees (students who need to complete work-place learning as part of their formalized qualification).
The division supports the activities of the postgraduate forum which, amongst others, create a platform where postgraduate students can develop their presentation skills in preparation for participation in upcoming conferences. The division coordinated a matriculant tutor programme called Abafundi that provides an opportunity for postgraduate students to develop their teaching and facilitation skills. The intervention interacted with learners from 3 high schools in the vicinity of the laboratory. The schools were selected by the Curriculum Adviser of the Metropole South Education district who also provided the tutors with guidelines.

The division furthermore created opportunities for 6 students from Further Education and Training colleges through the Work-Integrated Learning programme.

iThemba LABS is committed to find innovative ways to advance knowledge and to transform society. The basic premise is that education is the gateway to development and growth, i.e. make education attractive, and the rest will follow.
1.10 Human Resources

The following report provides a snapshot of the Human Resources (HR) activities for the 2012/13 financial year. In line with the NRF’s HR Strategy, the IThemba LABS HR Division focusses on:

- development and promotion of good HR practices in line with NRF HR policies and procedures, and
- recruiting, developing, rewarding and retaining high quality talent in order to sustain the future of IThemba LABS.

1.10.1 Key Achievements

Staff career development either through job enlargement or enrichment which resulted in five internal movements. These included promotions, ranging from a Receptionist position to that of a senior appointment of the Head of Physical Sciences.

The DST Professional Development Programme (PDP) intervention, resulted in an additional twelve Junior Scientists and Postdoctoral Fellows in our employ as at March 2013.

Some other key appointments made during the year in critical research and engineering departments included:

- The appointment of a senior technician responsible for the ion implanter at IThemba LABS (Gauteng) was successfully made. Also, a Senior Scientist for the AMS was identified for appointment in 2013.
- The appointment of the head of the Nuclear Physics Department.
- The appointment of a Mechanical Engineer as well as Accelerator Physicists to the Accelerator and Engineering Department.

1.10.2 Challenges

A few critical positions remained vacant such as the Senior Mechanical Technician; Radiation Oncologist and Medical Physicist. This has hampered the effectiveness of operations in the respective areas. With regards to the Oncologist position, discussions are underway with a local teaching hospital to consider alternatives and joint working arrangements.

There is a need for on-going and more effective succession planning tactics within IThemba LABS. The Education, Training and Development Committee headed by a Senior Manager (Head of Physical Sciences) has committed to ensuring that all priority be given to the alignment of skills development to address succession planning of critical positions.

1.10.3 Recruitment & Staffing

The table below summarises all appointments and terminations during the year. Recruitment activity and appointments were reduced by some 40% compared to the 2011/2012 financial year where thirty appointments were made. The number of resignations (eight) remains unchanged from the previous year. There has also been
a 4% increase in the number of staff under the age of 39. The total researcher/scientist representation has also grown by 1%. This could mainly be attributed to the appointment of individuals through the DST Professional Development Programme.

Recruitment & Turnover for the period April 2012 to March 2013

<table>
<thead>
<tr>
<th>Designated</th>
<th>Non-designated</th>
<th>GRAND TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>Female</td>
<td>Foreign Nationals</td>
</tr>
<tr>
<td>Male</td>
<td>Female</td>
<td>Foreign Nationals</td>
</tr>
<tr>
<td>Afr</td>
<td>Cld</td>
<td>Ind</td>
</tr>
<tr>
<td>Recruits</td>
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<td>2</td>
</tr>
<tr>
<td>Resignations</td>
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</tr>
<tr>
<td>Retirements</td>
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<tr>
<td>Medical Disability</td>
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<tr>
<td>Contract Expired</td>
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</tr>
<tr>
<td>Dismissals</td>
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<td>0</td>
</tr>
<tr>
<td>Death/Other</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Grand TOTAL</td>
<td>8</td>
<td>3</td>
</tr>
</tbody>
</table>

Total Staff representation as at 31 March 2013

<table>
<thead>
<tr>
<th>Occupational Level</th>
<th>Designated</th>
<th>Non Designated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Female</td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>Foreign Nationals</td>
</tr>
<tr>
<td></td>
<td>Grand Total</td>
<td></td>
</tr>
<tr>
<td>Senior management (P3-P4)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Professionally qualified and experienced specialists and mid-management (P5-P6)</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Skilled technical and academically qualified workers, junior management, supervisors, foremen and superintendents (P7-P12)</td>
<td>34</td>
<td>59</td>
</tr>
<tr>
<td>Semi-skilled and discretionary decision-making (P13-P14)</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Unskilled and defined decision-making (P15)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Total Permanent</td>
<td>43</td>
<td>70</td>
</tr>
<tr>
<td>Non-permanent employees</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>50</td>
<td>72</td>
</tr>
</tbody>
</table>
Overview and Highlights

Human Resources Department

iThemba LABS RACE REPORT: 31 MARCH 2013

- 69% Black
- 24% White
- 2% Non-SA: Africa
- 5% Non-SA: Other

iThemba LABS COMPLEMENT: 31 MARCH 2013

- 118 Indian
- 7 Coloured
- 67 African
- 5 Non-African: Africa
- 3 White
- 1 Non-African: Other

iThemba LABS GENDER REPORT: 31 MARCH 2013

- 198 Male
- 85 Female
Average Age profile

<table>
<thead>
<tr>
<th>Age Categories</th>
<th>20-29</th>
<th>30-39</th>
<th>40-49</th>
<th>50-59</th>
<th>60-65</th>
<th>66-71</th>
<th>72+</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Staff</td>
<td>39</td>
<td>90</td>
<td>82</td>
<td>63</td>
<td>8</td>
<td>1</td>
<td>0</td>
<td>283</td>
</tr>
<tr>
<td>Total %</td>
<td>14%</td>
<td>32%</td>
<td>29%</td>
<td>22%</td>
<td>3%</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Proportion of Researchers to total staff

<table>
<thead>
<tr>
<th>Total Researcher/Scientist</th>
<th>Total Staff</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>283</td>
<td>18%</td>
</tr>
</tbody>
</table>

1.10.4 Industrial Relations & Wellness

There were four formal disciplinary actions taken during the year of which one resulted in a dismissal. There have been quite a number of cases where staff members were referred for medical investigation either due to performance or extended absences from work. This has resulted in substantial intervention to improve the wellness of staff. As a proactive measure, Management has agreed to formalise staff wellness activities coordinated by the HR Division together with INCON. Some of the existing services include a social worker; limited primary health care for staff including chronic disease management and assistance and health tasks.

A summary of IR incidents are provided below.

<table>
<thead>
<tr>
<th>Designated</th>
<th>Non-designated</th>
<th>Foreign Nationals</th>
<th>GRAND TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>Female</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Afr</td>
<td>Clrd</td>
<td>Ind</td>
<td>TOTAL</td>
</tr>
<tr>
<td>Formal lodged Grievances</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Formal Disciplinary Action taken</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CCMA reported cases</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

1.10.5 Training & Development

Twenty seven (27) members of staff were engaged in part-time studies during 2012 with an additional seven (7) registrations for 2013. A combination of NRF Corporate Training Courses as well as iThemba LABS specific training courses were offered during the year with over 100 staff members in attendance. Four members of staff (Managers and high potential staff) were also elected to attend the NRF’s Customised Management Development Programme.
1.11 Annual Financial Report

1.11.1 Financial Overview

*High Level Analysis (Year on Year Comparatives and Current Year Actuals vs Budget)*

Current year funding remains tight, with iThemba LABS reporting an underlying deficit of R1,4m for the 2012/13 financial year. Farsighted and prudent management ensured that iThemba LABS expenses remained within levels of the available funding considering the Core Grant increased a paltry 1,5%.

Radionuclide sales were 51% higher year on year, largely attributed to the securing of $^{82}$Sr orders from Nordion, following the lifting a moratorium by the FDA of the USA on the sale of CardioGen-82 generators.

With order book commitments included 95% of running expense budget and 93% of capital budget was spent.

In year savings from funded vacancies realised R7m (including freezing 4 vacancies) and the lower electricity increase R1,5m. Further saving were realised through global Supply Chain Agreements. These savings were re-allocated to fund the capital maintenance programme, in the main.
### 1.11.2 Abridged Income Statement for the Period Ending 31 March 2013

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>ACTUAL 31–March-12</th>
<th>ORIGINAL 2011/12</th>
<th>2nd PROJECTION 2012/13</th>
<th>ACTUAL 31–March-13 AUDITED</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL INCOME</strong></td>
<td>185 964</td>
<td>192 808</td>
<td>197 586</td>
<td>188 713</td>
</tr>
<tr>
<td><strong>STATE FUNDING</strong></td>
<td>132 615</td>
<td>134 605</td>
<td>134 605</td>
<td>134 605</td>
</tr>
<tr>
<td><strong>EXTERNAL FUNDING</strong></td>
<td>40 067</td>
<td>40 593</td>
<td>43 334</td>
<td>42 131</td>
</tr>
<tr>
<td>Isotope Production Revenue</td>
<td>19 103</td>
<td>31 740</td>
<td>27 513</td>
<td>28 788</td>
</tr>
<tr>
<td>Contracts – DST and State</td>
<td>14 339</td>
<td>4 000</td>
<td>10 242</td>
<td>7 571</td>
</tr>
<tr>
<td>Other</td>
<td>6 625</td>
<td>4 853</td>
<td>5 579</td>
<td>5 772</td>
</tr>
<tr>
<td><strong>INTERNAL GRANTS</strong></td>
<td>13 282</td>
<td>17 610</td>
<td>19 647</td>
<td>11 977</td>
</tr>
<tr>
<td><strong>TOTAL EXPENSES</strong></td>
<td>(183 152)</td>
<td>(192 681)</td>
<td>(210 668)</td>
<td>(194 405)</td>
</tr>
<tr>
<td>OPERATING EXPENSES (Net)</td>
<td>(61 642)</td>
<td>(66 768)</td>
<td>(69 136)</td>
<td>(63 723)</td>
</tr>
<tr>
<td>Electricity</td>
<td>(15 227)</td>
<td>(20 645)</td>
<td>(18 773)</td>
<td>(17 382)</td>
</tr>
<tr>
<td>Travel and Accommodation</td>
<td>(8 358)</td>
<td>(6 823)</td>
<td>(10 804)</td>
<td>(8 260)</td>
</tr>
<tr>
<td>Repairs &amp; Maintenance</td>
<td>(7 519)</td>
<td>(6 334)</td>
<td>(6 591)</td>
<td>(6 931)</td>
</tr>
<tr>
<td>Other</td>
<td>(30 538)</td>
<td>(32 966)</td>
<td>(32 968)</td>
<td>(31 150)</td>
</tr>
<tr>
<td><strong>SALARIES</strong></td>
<td>(98 105)</td>
<td>(110 413)</td>
<td>(108 605)</td>
<td>(107 639)</td>
</tr>
<tr>
<td><strong>CAPITAL EXPENSES</strong></td>
<td>(23 405)</td>
<td>(15 500)</td>
<td>(32 927)</td>
<td>(23 043)</td>
</tr>
<tr>
<td><strong>NET SURPLUS/(DEFICIT) 2009/10</strong></td>
<td>2 812</td>
<td>127</td>
<td>(13 082)</td>
<td>(5 690)</td>
</tr>
<tr>
<td><strong>PRIOR SURPLUS/(DEFICIT) 2008/09</strong></td>
<td>10 271</td>
<td>117</td>
<td>13 083</td>
<td>13 083</td>
</tr>
<tr>
<td><strong>CUM. SURPLUS/(DEFICIT) 2009/10</strong></td>
<td>13 083</td>
<td>245</td>
<td>1</td>
<td>7 391</td>
</tr>
</tbody>
</table>
1.11.3 Variance Analysis 2012/13 Actual vs Budget Projection 2

- The R10m variance on Income is attributed to carry forward funds for the AMS of R6m and various travel grants of R3m. The carry forward funds on travel were as a result of lower travel expenses R2.7m.

- The R1.3m variance on electricity is a result of savings attributed to infrastructure upgrades, together with savings realised at iThemba LABS (Gauteng) from invoice credits processed by Wits University.

- The R1.7m variance on Other Expenses is largely attributed to CERN fees R1m, that will be paid during the second quarter of 2013 and sundry funding re-allocated to Capital post Projection 2 budget.

- The R10m variance on Capital is largely attributed to the R10m order for the AMS which will be installed during the latter part of 2013 and commissioned in 2014.
2. Scientific and Technical Reports
2.1 Department of Nuclear Physics

2.1.1 Characterization of the 2+ excitation of Hoyle state in $^{12}$C

F Nemulodi$^{1,6}$, J Carter$^2$, E A Cherepanov$^8$, V Chudoda$^8$, R F Fearick$^2$, M Freer$^4$, H Fujita$^5$, M Jingo$^2$, N Keeley$^7$, C O Kureba$^2$, J P Mira$^{1,6}$, R Neveling$^1$, E Yu Nikolski$^8$, P Papka$^{1,6}$, F D Smit$^1$, J A Swartz$^{1,6}$, I Usman$^2$, J J van Zyl$^6$

$^1$ iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa
$^2$ School of Physics, University of the Witwatersrand, Johannesburg 2050, South Africa
$^3$ Physics Department, University of Cape Town, Rondebosch 7700, South Africa
$^4$School of Physics and Astronomy, University of Birmingham, Edgbaston Birmingham, B15 2TT, United Kingdom
$^5$ Research Centre for Nuclear Physics (RCNP), Osaka University, Ibaraki, Osaka 567-0047, Japan
$^6$ Physics Department, University of Stellenbosch, Private Bag X1, Matieland 7602, South Africa
$^7$ Nuclear Physics Division, National Centre for Nuclear Research, Warsaw, Poland
$^8$ Flerov Laboratory of Nuclear Reactions, JINR, RU-141980 Dubna, Russia

Even though numerous investigations have been performed in the past to study the $^{12}$C nucleus, questions still remain regarding some of its unbound states. One of the mysteries of this nucleus involves the $0^+$, $E_x = 7.654$ MeV state also known as the Hoyle state. This state was first predicted by Fred Hoyle in 1954 [1] and discovered experimentally three years later [2]. It had been reported in several theoretical and experimental studies that it possesses an $\alpha$-cluster structure. One of the long-standing problems of the Hoyle state is proving the existence of a $2^+$ excited state built on the Hoyle state. Recently the search for this state attracted much interest both theoretically and experimentally, leading to several candidates being reported [3 - 6].

With interest in the $2^+$ excitation of the Hoyle state growing rapidly, it was considered important to perform an experiment to further characterize this state. An experiment was performed at iThemba LABS with the high resolution K600 magnetic spectrometer in coincidence with an array of silicon detectors. We used the $^{14}$C($p$, $t$)$^{12}$C reaction with a 66 MeV proton beam. The silicon detectors were placed inside the scattering chamber, upstream of the target ladder. The measurements were performed at a spectrometer angle of $\theta_{lab} = 21^\circ$ where the angular distribution is a maximum for $2^+$ states and the lowest for $0^+$ excitations. In this way the contribution from the broad dominant states in the excitation energy region around 10.3 MeV was kept as low as possible. The tritons were detected in the spectrometer focal-plane, in coincidence with alpha particles from the decay of the excited $^{12}$C, as measured in the silicon detectors. The measurements were successfully completed after four consecutive weekends of beam time.

The $^{12}$C excitation energy spectrum is uniquely determined by the momentum of the outgoing tritons detected in the spectrometer focal plane. The left panel of Figure 1 shows the two dimensional spectrum of the energy deposited in the focal plane scintillator detector versus the relative time-of-flight (TOF) of particles through the spectrometer, measured relative to the SSC radio-frequency signal. The triton events are clearly distinguished from the background events. The excitation energy spectrum shown in the right panel of Figure 1 is generated by gating on the tritons. In our measurement we covered the excitation energy range from 6 to 17 MeV. With the $3\alpha$-threshold situated at 7.27 MeV, the states populated in this spectrum are open to $\alpha$ decay and $\gamma$ emission,
with the exception of the 16.105 MeV state which is also open to proton emission since the proton separation energy is at 15.96 MeV. In the $\alpha$-decay process a state can decay via one of three different decay paths, namely through direct decay ($^{12}$C* $\rightarrow$ $\alpha\alpha\alpha$), sequential decay via $^8$Be$_{gs}$ ($^{12}$C* $\rightarrow$ $\alpha + ^8$Be$_{gs}$ $\rightarrow$ $\alpha\alpha\alpha$), and sequential decay via $^8$Be$_2^+$ ($^{12}$C* $\rightarrow$ $\alpha + ^8$Be$_2^+$ $\rightarrow$ $\alpha\alpha\alpha$).

The decay properties of the populated states are studied during offline analysis by requiring the coincidence of tritons with one, two, or three alpha particles detected in the silicon detectors. For the analysis presented here we considered events where tritons are detected in coincidence with two alpha particles. Using the missing momentum technique, we could reconstruct the missing alpha particle.

To validate the analysis technique we reproduced the known behaviour of some of the states shown in Figure 1. In Ref. [7] it was reported that the Hoyle state ($E_x = 7.654$ MeV) decays predominately through the $^8$Be$_{gs}$ decay path. In Ref. [8] it was mentioned that the conservation of angular momentum forbids the unnatural parity states, 12.71 MeV $^1$ and 15.110 MeV $^1$, to decay through the $^8$Be$_{gs}$ decay path i.e. they can only decay through democratic decay or sequentially via the $^8$Be$_2^+$ path. Plotted in Figure 2 are the two dimensional plots of individual $\alpha$-particle energy versus $^{12}$C excitation energy. The rectangles around the loci indicate, from left to right, the Hoyle-, 12.71 MeV, and 15.110 MeV states, respectively. In Figure 2(a) all decay paths are included in the analysis; in Figure 2(b) only the $^8$Be$_{gs}$ events are considered. The fact that the 12.71 MeV and 15.110 MeV states disappear indicates some agreement between previously reported results and our results. The Hoyle state vanishes in Figure 2(c) where only the $^8$Be$_2^+$ and democratic decay events were considered. This is in agreement with the conclusion drawn in Ref. [7].

The next step in the data analysis is to try to characterize the states that are populated in the 10 MeV excitation energy region. We are also performing Monte Carlo simulations of events in this excitation energy region for comparison with the obtained experimental results.

![Figure 1](image)

**Figure 1:** Left, Scintillator 1 vs time-of-flight (TOF) spectrum showing the triton locus (circled) for the $^{14}$C($p$,t)$^{12}$C reaction at 66 MeV. Right: An excitation energy spectrum for the $^{14}$C($p$,t)$^{12}$C reaction at a laboratory scattering angle of 21°, as determined using the momentum of the outgoing tritons detected in the K600 spectrometer focal plane.
2.1.2 Search for low spin states at high excitation energy in $^{20}$Ne with the ($p$,t) reaction

J A Swartz$^{1,2}$, P Papka$^{1,2}$, F D Smit$^3$, R Neveling$^3$, B A Brown$^3$, E Z Buthelezi$^4$, M Freer$^4$, S V Förrsch$^4$, Tz Kokalova$^4$, F Nemulodi$^{1,3}$, J N Orce$^5$, W A Richter$^{1,5}$, G F Steyn$^5$

$^1$ iThemba LABS, National Research Foundation, PO Box 722, Somerset West 7129, South Africa
$^2$ Department of Physics, University of Stellenbosch, Matieland 7602, South Africa
$^3$ Department of Physics and Astronomy, and National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321, USA
$^4$ School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham, United Kingdom
$^5$ Department of Physics, University of the Western Cape, Private Bag X17, Bellville 7530, South Africa

This research project has two main objectives, namely to measure and characterize low spin states at high excitation energy (15 to 25 MeV) in the $^{20}$Ne nucleus, and to search for an indication of the $0^+$ five alpha cluster state which is expected near to the five alpha decay threshold at $E_x = 19.17$ MeV. The $^{22}$Ne($p$,t)$^{20}$Ne reaction at a spectrometer angle $\theta_{\text{LAB}} = 0^\circ$ was deemed to be optimal for this investigation since it provides low particle background, sufficient resolution and good selectivity of the low spin states of interest.
The experiment was performed using the K600 magnetic spectrometer with a 60 MeV proton beam from the SSC. A gas cell, filled with $^{22}$Ne to a pressure of 1.5 bar, was used as the target. Unfilled, the target has 1 cm separation between the two window foils of 6 $\mu$m thick Aramid. Data were obtained at 19 different combinations of K600 angles (0°, 7°, 16°, 27°) and magnetic field settings (31, 33.5, 37, 42, 46, 52 MeV) for tritons. Shown in Figure 1 are the data from the five different field settings taken at $\theta_{LAB} \sim 0°$.

Candidate new states are indicated by a * in Figures 1 and 2, and were observed at the excitation energies of $E_x = 17.67, 18.841, 20.6, 21.17$ and 21.8 MeV. The states at 21.17 MeV and 21.8 MeV are unexpectedly strong and narrow for such high excitation energies in $^{20}$Ne. These properties, along with isobaric mass multiplet equation- and shell-model calculations [1, 2], indicate that these states may be isobaric analogue states of two known states in $^{20}$O. Further investigations of this hypothesis are underway.

![Figure 1: Excitation energy spectrum collected at magnetic field settings for 52, 46, 41, 36, and 33.5 MeV tritons, from left to right respectively. The black spectrum represents background data from the Aramid foils, while the lines with various colours show data from the $^{22}$Ne gas-filled target. States from $^{22}$Ne are indicated by blue labels, and states from Aramid by black labels. Possible new states are indicated by a * symbol.

![Figure 2: High excitation energy region of the spectrum shown in Figure 1. Gas-filled target data at 36 MeV and 33.5 MeV field sets are in red and blue respectively, while the Aramid background data are in black.]
There are no definite indications of a state with the expected characteristics of the five-alpha cluster state, although a tentative candidate is seen at 22.5 MeV, very close to the predicted value of 22.18 MeV [3]. In the spectrum it unfortunately coincides with the 10.89 MeV state from $^{16}$O($p,t^{14}$O, but it does retain some strength after subtraction of the normalized background data.

References

1. W A Richter, Private communication.

2.1.3 Non-resonant Triple-$\alpha$ Reaction Rate at Low Temperature

T Itoh$^1$, A Tamii$^1$, N Aoi$^1$, J Carter$^2$, L Donaldson$^2$, H Fujita$^3$, T Furuno$^3$, T Hashimoto$^1$, T Kawabata$^3$, M Kamimura$^4$, K Miki$^1$, F Nemulodi$^5$, R Neveling$^5$, K Ogata$^1$, E Sideras-Haddad$^2$, F D Smit$^5$ and J A Swartz$^5$

$^1$Research Center for Nuclear Physics, Osaka University, Ibaraki, Osaka 567-0047, Japan
$^2$School of Physics, University of the Witwatersrand, Johannesburg 2050, South Africa
$^3$Department of Physics, Kyoto University, Sakyo, Kyoto 606-8502, Japan
$^4$RIKEN Nishina Center, Wako, Saitama 351-0198, Japan
$^5$iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa

The goal of this project is to determine the $^{12}$C non-resonant triple-$\alpha$ reaction rate at low temperature (T < $10^8$ K). $^{12}$C is one of the most fundamental elements as it provides the path for the production of all heavier elements. In stars, $^{12}$C is mainly produced by a three $\alpha$-particle fusion process. This reaction is called “triple-$\alpha$ reaction” which is classified as two reactions: the resonant triple-$\alpha$ reaction and the non-resonant triple-$\alpha$ reaction. Usually the reaction rate is calculated by using the NACRE compilation [1] and is very small at low temperatures. On the other hand, Ogata et al. calculated the rate by applying the continuum-discretized coupled channels (CDCC) method [2]. The prediction from the CDCC calculation is 20 orders of magnitude larger than that of NACRE at low temperatures (T ≈ $10^7$ K). Recently two further predictions were published, each using their own method [3, 4]. No experimental investigation of the non-resonant part of the reaction rate existed prior to this project being undertaken.

The main difference between the prediction of the CDCC calculation and the NACRE compilation lies in the prediction of the three-$\alpha$ scattering state at low excitation energies (see Figure 1). As the transition strength from the $^{12}$C ground state to the $\alpha$-unbound continuum state is closely related to the non-resonant triple-$\alpha$ reaction rate, the focus of the investigation was on observing the $\alpha$-unbound continuum state which is located between the $\alpha$-threshold and the Hoyle resonance. To observe the excitation of the $\alpha$-unbound continuum state, use was made of the $^{12}$C($p,p\prime$) and $^{13}$C($p,d$) reactions and the K600 magnetic spectrometer at an incident proton energy of $E_p = 66$ MeV.

Prior to the experiment a proton induced X-ray emission (PIXE) investigation at the Materials Research Department was done to identify contaminants in the targets. The low cross section of the excitation cross section to be measured increased the sensitivity to all forms of background. Therefore ($p,d$) reaction data on
$^{nat}$N, $^{nat}$Si, $^{nat}$Ca and $^{nat}$Ta targets were also collected for identifying the contributions from the impurities to the background in the $^{12}$C spectra.

Good statistics were accumulated, especially during the second and the third weekend, when the beam current was stable. High energy-resolution of 23 keV was achieved by using the spectrometer in dispersion matching mode. Figure 1 is a histogram from the on-line analysis. To tell whether the NACRE or CDCC predictions are favoured will however require a very careful offline analysis, which is underway.

![Figure 1: An excitation energy spectrum of the $^{12}$C(p, d) reaction at 66 MeV. The solid lines are CDCC (green) and NACRE (red) predictions respectively. Blue dots are the experimental results. The vertical axis is normalized to the Hoyle state at 7.65 MeV.](image)

References


2.1.4 Investigation of the ($\alpha$, $\alpha\gamma$) reaction at zero degree

R Neveling$^1$, F D Smit$^1$, P Papka$^2$, R W Fearick$^2$, P Jones$^1$, F Nemulodi$^{1,2}$, E Sideras-Haddad$^4$, J A Swartz$^{1,2}$, J J van Zyl$^2$, M Wiedeking$^1$

$^1$ iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa
$^2$ Department of Physics, University of Stellenbosch, Matieland 7602, South Africa
$^3$ Department of Physics, University of Cape Town, Rondebosch 7700, South Africa
$^4$ School of Physics, University of the Witwatersrand, Johannesburg 2050, South Africa

The successful development of the capability to perform high energy resolution particle-$\gamma$ coincidence measurements at zero degrees can open up a host of new opportunities to be explored with the K600 magnetic spectrometer. For example, the combination of $\gamma$-spectroscopy with inelastic $\alpha$-particle scattering at zero degrees is known to be a powerful tool for the spectroscopy of isoscalar $E1$ transitions [1].
The first \((\alpha, \alpha\gamma)\) development run at iThemba LABS was performed with an incident \(\alpha\)-beam of 160 MeV. The K600 was positioned at zero degrees and was instrumented with a focal plane detector system in the high dispersion focal plane that consisted of two X-U vertical drift chambers as well as 1/4" and 1/2" trigger scintillators. The \(\alpha\)-particles were stopped in the first scintillator, with only high energy protons reaching the second scintillator.

In order to detect the \(\gamma\)-rays two HPGe Clover detectors from the AFRODITE array, as well as the big NaI crystal (a cylinder with radius 11.9 cm, length 35.6 cm), were utilized. One of the Clovers and the NaI detector were placed at \(\theta_{\text{lab}} = 90^\circ\) on either side of the beam. The other Clover was placed at a backward angle of \(\theta_{\text{lab}} = 147^\circ\). The distance between the target and the front of the Clovers was approximately 270 mm while 460 mm separated the target from the entrance window of the NaI detector.

The K600 VME-based DAQ was triggered by the first (1/4") scintillator. The XIA digital DAQ accumulated data in singles mode, but was supplied with a copy of the K600 trigger signal to tag \(\alpha\)-related events. Dead time was below 2% for the VME DAQ and negligible in the XIA DAQ.

The K600 energy resolution was 57 keV (FWHM), improved from the resolution reported in a previous zero degree \(\alpha\) scattering experiment (~80 keV at 200 MeV [2]) but slightly worse than the 48 keV achieved in a finite angle measurement at 196 MeV [3]. One should however keep in mind that target thickness effects are more pronounced for \(\alpha\)-particles at this lower beam energy. The focal plane position spectrum of the \(^{24}\text{Mg}(\alpha,\alpha')\) reaction is shown in Figure 1. The quality of the data in terms of background and resolution compares very favourably with zero degree \(^{24}\text{Mg}(p,p')\) data obtained previously at 200 MeV. The accessible excitation energy range is ~ 6 - 21 MeV, although full angular acceptance is only reached from ~7.5 MeV.

![Figure 1](image.png)

**Figure 1:** A comparison between inelastic proton and alpha particle scattering from \(^{24}\text{Mg}\) at zero degrees. The energy resolution of the \((p,p')\) data is 36 keV. The two datasets were normalized in the 14 -16 MeV excitation energy region to allow for easy comparison.
A two-dimensional $\alpha$-$\gamma$ coincidence matrix of $^{24}$Mg for gammas observed at $\theta_{\text{lab}} = 147^\circ$ is shown in Figure 2. The diagonal red lines indicate decays to the ground state and first excited state (1.368 MeV) of $^{24}$Mg. This illustrates that it is indeed possible to do high energy resolution $\alpha$-$\gamma$ coincidence measurements at 0° at iThemba LABS.

![Figure 2: Two-dimensional coincidence matrix for the $^{24}$Mg($\alpha$,\alpha'\gamma$) reaction with excitation energy on the horizontal axis and Clover $\gamma$-energy on the vertical axis.](image)

This successful test run with an $\alpha$-particle beam show that particle-$\gamma$ coincidence measurements at zero degrees are worth pursuing with a combination of an array of gamma ray detectors in coincidence with the K600 magnetic spectrometer. The infrastructure required to have an array of gamma-ray detectors in the K600 magnetic spectrometer vault must be built up as funds become available.

References

2.1.5 Investigation of the photon strength function in $^{74}\text{Ge}$

D Negi$^1$, B V Kheswa$^{1,2}$, M Wiedeking$^1$, R A Bark$^1$, L A Bernstein$^3$, D L Bleuel$^3$, S Bvumbi$^4$, J T Burke$^3$, L Crabtree$^5$, T S Dinoko$^{1,6}$, N Erasmus$^6$, J L Easton$^{1,6}$, R B Firestone$^7$, B L Goldblum$^8$, A Görgen$^9$, M Guttormsen$^9$, R Hatarik$^7$, A Hurst$^7$, P Jones$^1$, J D Koglin$^3$, N Khumalo$^{1,10}$, A C Larsen$^9$, E A Lawrie$^1$, J J Lawrie$^1$, S N T Majola$^{1,11}$, L P Masteng$^4$, M R Nchodu$^4$, J Ndayishimye$^{1,2}$, R T Newman$^3$, S P Noncolela$^{1,6}$, J N Orce$^6$, P Papka$^2$, S Paschalis$^7$, M Petri$^7$, T Reed$^5$, T Renstrøm$^7$, J Ressler$^3$, D G Roux$^{12}$, D H G Schneider$^3$, N Scielzo$^3$, O Shirinda$^1$, S Siem$^9$, T D Singo-Bucher$^4$, P S Sithole$^6$, M A Stankiewicz$^{1,11}$, P C Uwitonze$^{12}$

$^1$ iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa
$^2$ Department of Physics, University of Stellenbosch, Matieland 7602, South Africa
$^3$ Lawrence Livermore National Laboratory, Livermore, California, USA
$^4$ University of Johannesburg, Johannesburg, South Africa
$^5$ University of Tennessee, Knoxville, TN 37996, USA
$^6$ University of the Western Cape, Bellville, South Africa
$^7$ Lawrence Berkeley National Laboratory, Berkeley, California, USA
$^8$ University of California, Berkeley, California, USA
$^9$ University of Oslo, Oslo, Norway
$^{10}$ University of Zululand, KwaDlangezwa, South Africa
$^{11}$ University of Cape Town, Cape Town, South Africa
$^{12}$ Rhodes University, Grahamstown, South Africa

The photon Strength Function (pSF) represents the ability of nuclear matter to absorb and emit photons. It is one of the input parameters, along with the nuclear level density and the optical-model potential, for calculations of neutron capture cross sections and reaction rates relevant to astrophysical processes which are invoked to explain the origin of elements heavier than iron. It has been shown that modifications in the low-energy region of the pSF can have a significant effect on nuclear reaction rates for r-process nuclei [1]. In this work we investigate the dependence of the pSF on the spin and parity of the final state and on different reactions to excite quasi-continuum states, which are found in the region of high-level density below the particle threshold. This provides not only information about the validity of the Brink hypothesis [2] but will also support a better understanding of reactions in astrophysical environments. To this effect, an international collaborative effort was made to study the pSF of the quasi-continuum states in $^{74}\text{Ge}$ using different reactions at different experimental facilities in the USA, Europe and South Africa.

In this report we present preliminary results from experiments using $^{74}\text{Ge}(\alpha,\alpha')^{74}\text{Ge}$ and $^{74}\text{Ge}(p,p')^{74}\text{Ge}$ reactions. The method [3] of extracting the pSF consists of detecting correlated particle-$\gamma$-$\gamma$ events. By selecting the specific energy of the scattered particles the entrance excitation energy into the system is determined. A gate on $\gamma$-transitions from the discrete states of the excited nucleus selects the coincident primary transitions feeding this state. The additional condition that the sum of the primary and the discrete $\gamma$-ray energies be equal to the excitation energy provides unambiguous primary $\gamma$-ray spectra from which the pSF is determined. The ratio of the pSF to two different discrete states $E_{1\perp}$ and $E_{2\perp}$ of the same spin and parity provides information which is independent of level density and cross-sections.
The experiment using the $^{74}$Ge($\alpha,\alpha'$)$^{74}$Ge reaction was performed at iThemba LABS, with the AFRODITE gamma detector array in conjunction with two particle-telescopes consisting of two silicon detectors each with dimensions 5 cm X 5 cm. The telescopes were placed at angles of $\pm 45^\circ$ with respect to the beam axis. The beam energy for the reaction was 47.6 MeV. The energy and efficiency calibrations of the gamma detectors in the high-energy region were measured from the $^{12}$C($d,p$)$^{13}$C and $^{13}$C($d,p$)$^{14}$C reactions with a beam energy of 13.9 MeV. The decay of excited states in $^{14}$C provides transitions with energies 6.1 and 6.7 MeV while in $^{13}$C the energies are 3.1 and 3.7 MeV. The data were sorted using the SIMSORT code. Corrections due to energy losses in the aluminium absorber foil, the target and the recoil energy of $^{74}$Ge were carried out. A particle identification (PID) plot is shown in Figure 1. In Figure 2 $\gamma$-ray spectra with a gate on the quasi-continuum states are shown. The next step in the data analysis will be to extract the pSF of statistical $\gamma$-rays from the $\alpha$-$\gamma$-$\gamma$ events.

The experiment using the $^{74}$Ge($p,p'$)$^{74}$Ge reaction at a beam energy of 18 MeV was performed at, Berkeley, USA with a set up consisting of 6 HPGe and 4 silicon annular particle detectors. The analysis parallels the above description. Preliminary results of this experiment are shown in Figure 3, where the ratios of the pSF’s ($R = f_{EL1}/f_{EL2}$) to various discrete states of $^{74}$Ge as a function of excitation energy are plotted. Here $f_{EL}$ is the pSF from the quasi-continuum to a discrete state $E_{Ln}$. These ratios indicate a relative change in strength functions. In this work a large change in ratio at excitation energies below 5 MeV is observed, which is indicative of an...
enhancement in the low energy part of the pSF. This upbend in the pSF has been observed in other light and medium mass nuclei [1] and has recently been confirmed [3] but the current measurement is the first report of this phenomenon in $^{74}$Ge. A comparison of the results from the $^{74}$Ge($\alpha,\alpha$)$^{74}$Ge and $^{74}$Ge(p,p$'$)$^{74}$Ge reactions will provide information about the reaction dependence of the pSF and will be performed following the completion of the individual analyses.

![Figure 3: Ratio of the pSF to various discrete states as a function of excitation energy obtained in the $^{74}$Ge(p,p$'$)$^{74}$Ge reaction.](image)

**References**


### 2.1.6 Measurement of the Photon Strength Function and Level Density in $^{138}$La

B V Kheswa$^{1,2}$, M Wiedeking$^1$, F Giacoppo$^3$, F Bello$^2$, T K Eriksen$^2$, A Görgen$^3$, M Guttormsen$^3$, T W Hagen$^3$, P E Koehler$^3$, M Klintefjord$^3$, A C Larsen$^2$, H T Nyhus$^3$, P Papka$^{1,2}$, T Renstrøm$^3$, S Rose$^3$, E Sahin$^3$, S Siem$^3$, T Torny$^3$

$^1$IThemba LABS, National Research Foundation, P O Box 722, 7129 Somerset West, South Africa

$^2$Department of Physics, Stellenbosch University, Matieland, South Africa

$^3$Department of Physics, University of Oslo, Oslo, Norway

Most nuclei that are heavier than iron are produced in the interior of stars, during neutron star mergers or in supernovae by means of the s- and r-processes. The existence of a few stable and low abundant proton-rich nuclei, referred to as p-nuclei, cannot be explained by invoking these processes. Most of the p-nuclei with A<110 are most likely produced by proton capture reactions while A>110 p-nuclei are probably produced by photodisintegration of nuclei created in the s- and r-process [1]. However, for a couple of nuclear systems these processes are not sufficient to explain their observed abundance. One of them is $^{138}$La, which is one of the least abundant (0.09%) proton-rich isotopes found in the solar system. In order to reproduce the measured abundances, exotic processes, such as neutrino capture, have to be invoked in the form of neutrino induced neutron evaporation [2]. Although the neutrino induced reactions can to some extent explain the abundance data
for \(^{138}\text{La}\), other processes such as \((\gamma,n)\), responsible for the creation of many heavier p-nuclei cannot be ruled out at present. This is due to the relatively little experimental data available for \(^{138}\text{La}\), which yield critical model input parameters to calculate reaction rates. It has been pointed out that the errors in the rate predictions can amount to factors of 2 or more for the synthesis of \(^{138}\text{La}\) and that the main sources of uncertainties lie in the nuclear level densities, \(\gamma\)-ray strength function and neutron optical potentials [3]. Clearly, additional experimental nuclear physics information is needed to improve our understanding of \(^{138}\text{La}\) production.

The level density and \(\gamma\)-ray strength function in \(^{138}\text{La}\) was studied using the equipment and experimental techniques developed at the Oslo Cyclotron Lab of the University of Oslo. States in \(^{138}\text{La}\) were populated through the \(^{139}\text{La}(^3\text{He},\alpha)\) reaction at a beam energy of \(E_{\text{lab}} = 38\) MeV. The 2.5 mg/cm\(^2\) thick \(^{139}\text{La}\) target was manufactured at the target lab facility of iThemba LABS. The grazing angle of the reaction is estimated at \(\theta_{\text{lab}} = 30^\circ\) and allowed for the 64-channel silicon particle telescopes SIRI to be mounted in the forward position. Gamma radiation, in coincidence with \(\alpha\) particles, was detected with the CACTUS array consisting of 28 collimated 5x5 inch NaI detectors. Experimental rates were comparable to previous Oslo experiments in this mass region using a similar experimental setup [4]. The average beam current during the 6 day experiment was 0.4 – 0.7 nA.

The data are being analysed using the Oslo Method, which allows for a simultaneous extraction of the level density and photon strength function using particle-gamma coincidence data [5]. The method is based on an iterative subtraction technique to isolate the primary \(\gamma\)-ray transitions. This provides the first-generation matrix and is proportional to the level density (invoking Fermi’s golden rule) and the gamma-transmission coefficient (invoking the Brink hypothesis). A least \(\chi^2\) fit can be applied simultaneously to the two functions (level density and transmission coefficient). Preliminary results for the level density in \(^{138}\text{La}\) are shown in the left panel of Figure 1.

![Figure 1: Preliminary results of level densities (left panel) and photon strength function (right panel) in \(^{138}\text{La}\).](image)
The extracted level density has been normalized to the known level density at low-excitation energy (level counting). At the neutron separation energy the level density, $\rho(S_n)$, is usually obtained using experimental neutron resonance data. Unfortunately, such data are not available for $^{138}\text{La}$ and $\rho(S_n)$ was calculated using the Back-Shifted Fermi Gas Model and spin cut-off parameter formula from [6]. The interpolation between $\rho(S_n)$ and the experimental level density was done using the constant temperature level density model, to which the experimental level density was normalized.

In the right-hand panel of Figure 1 the preliminary photon strength function for $^{138}\text{La}$ over the measured energy range of $E_x = 1$ to 7 MeV is shown. At low energies (up to $E_x \sim 1.6$ MeV) the photon strength function is observed to be a decreasing function with $\gamma$-ray energy before levelling off at intermediate energies. The up-bend observed at low energies has been reported previously by the Oslo group for light and medium-mass nuclei [5] and has recently been confirmed independently [7]. Many heavier systems ($A=111$ [8] up to $A=233$ [9]) have been investigated over the past 10 years and none of these systems exhibits this enhancement. As such, this preliminary work being indicative of a low-energy enhancement is surprising and interesting. The data analysis will proceed and results from $^{138}\text{La}$ will be compared to $^{139}\text{La}$ and $^{140}\text{La}$, which were both measured during the same experimental campaign and populated in the $^{139}\text{La}(\alpha,\alpha')$ and $^{139}\text{La}(d,p)$ reactions, respectively.

References

2.1.7 ¹⁹⁴⁰Tl as the best example revealing chiral symmetry breaking in a pair of four-quasiparticle bands.

P L Masiteng¹,², a, E A Lawrie⁴, T M Ramashidzha¹,², R A Bark¹, B G Carlsson³, J J Lawrie¹, R Lindsay², F Komati¹,², J Kau¹, P Mainel,², S M Maliage¹,², I Matamba², S M Mullins¹, S H T Murray¹, K P Mutshena¹,⁵, A A Pasternak⁶, I Ragnarsson³, D G Roux², J F Sharpey-Schafer¹,², O Shirinda¹,², P A Vymers¹,²

¹ iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa
² University of the Western Cape, Private Bag x17, 7535 Bellville, South Africa
³ Division of Mathematical Physics, LTH, Lund University, 221 00 Lund, Sweden
⁴ University of North West, Private Bag X2046, 2735 Mmabatho, South Africa
⁵ University of Venda for Science and Technology, Thohoyandou, South Africa
⁶ A.F. Ioffe Physical-Technical Institute, 194021 St.-Petersburg, Russia
a Present address, University of Johannesburg, P.O. Box 524, 2006 Auckland Park, South Africa

Nuclear chirality is a novel appearance of spontaneous symmetry breaking resulting from a perpendicular coupling of angular momentum vectors in triaxial nuclei [1]. Three orthogonal angular momenta can form two systems of opposite handedness. A consequence of this in the laboratory frame is the observation of a pair of bands with degenerate energy levels with the same spin and parity. Extensive experimental investigations in different mass regions have been carried out in order to search for such bands. As a result more than 21 nuclei in A~80, 100, 130, 190 mass regions have been reported as exhibiting possible candidate chiral bands.

It can be noted though that the reported possible chiral partner bands show similar properties rather than degeneracy, with a varying degree of similarity. We are reporting here on a pair of four-quasiparticle bands in ¹⁹⁴⁰Tl showing exceptionally close near-degeneracy [2], which is perhaps the best near-degeneracy in partner bands observed to date. The partial level scheme showing the two partner bands in ¹⁹⁴⁰Tl is shown in Figure 1.

![Figure 1: Partner band structures in ¹⁹⁴⁰Tl, from present work [2]](image-url)
The properties of these two bands are compared with those of the best chiral candidates known to date, such as the bands in $^{126,128}$Cs (note that the near-degeneracy in $^{124}$Cs is very similar to that in $^{128}$Cs), $^{104}$Rh and $^{135}$Nd. Figure 2 shows the excitation energies as a function of spin for the partner bands in these four nuclei ($^{194}$Tl, $^{128}$Cs, $^{104}$Rh and $^{135}$Nd).

The plots shown in Figure 2 illustrate the fact that the partner bands in $^{194}$Tl exhibit exceptionally good near-degeneracy and for the longest observed spin range. They maintain energy separation of not more than 110 keV between the partner bands, with the states at spin 21$^-$ observed at an energy difference of about 37 keV. The relative excitation energies of the levels in the $^{126,128}$Cs partner bands remain approximately constant at $\Delta E \sim 200$ keV within the observed spin ranges of $I = 11 - 22$ and $I = 11 - 17$, respectively.

The energy difference in the $^{135}$Nd near-degenerate partner bands is not constant but decreases from 497 keV at $I = 27/2$ to a value of 94 keV at $I = 39/2$ and a subsequent increasing trend is then observed. In the case of $^{104}$Rh these partner bands also show a decreasing trend of the energy differences from 413 keV at $I = 11$ to an almost vanishing value of -1 keV at $I = 17$.

Further illustration of the exceptional near-degeneracy of the pair of bands in $^{194}$Tl is shown in Figure 3. In these plots the differences in the excitation energies $\Delta E = E_{\text{side}} - E_{\text{yrast}}$, alignments $\Delta i = i_{\text{side}} - i_{\text{yrast}}$, and ratios of reduced transition probabilities $\Delta B(M1)/B(E2)_{\text{yrast}}$ for the four-quasiparticle bands in $^{194}$Tl and the partner bands in $^{104}$Rh, $^{135}$Nd, and $^{128}$Cs are shown. The spin $\Delta l = I - I_0$ is with respect to the band head spin of 9, 10, 25/2, and 18 adopted for $^{104}$Rh, $^{128}$Cs, $^{135}$Nd and $^{194}$Tl, respectively. The alignments are calculated with reference parameters of $J_0=8 \hbar^2/\text{MeV}$ and $J_1=40 \hbar^2/\text{MeV}^3$ for $^{135}$Nd and $J_0=16 \hbar^2/\text{MeV}$ and $J_1 = 33 \hbar^2/\text{MeV}^3$ for $^{128}$Cs. The near-degeneracy in the 4-quasiparticle bands in $^{194}$Tl is obviously better than any of the other cases.
In summary, a new chiral candidate is found in $^{194}$Tl. Furthermore the relative excitation energy of this pair of negative-parity bands is compared to the relative excitation energies of the four best chiral candidates known to date. This comparison shows that the near-degeneracy in the 4-quasiparticle bands in $^{194}$Tl is possibly the best found to date.

References


2.1.8 Status of the production of $W^\pm$ bosons at ultra-relativistic energies


1Department of Physics, University of Pretoria, Private Bag X 20, Hatfield 0028, South Africa.
2Department of Physics, University of Cape Town, Rondebosch 7700, South Africa.
3iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa.

Electroweak $W^\pm$ boson production was studied [1, 2] via the single muon decay channels at forward rapidity in proton-proton (pp) collisions at LHC energies with ALICE. These studies are part of on-going investigations, motivated by previous predictions [3] for the production of $W^\pm$ bosons in the forward rapidity range (-4.0 < $y$ < -2.5) of ALICE in pp, Pb-Pb and pPb / Pbp collisions at centre of mass energies available at the LHC.

In ALICE the forward rapidity is covered by the Muon Spectrometer which is composed of absorbers, a dipole magnet, five tracking stations each consisting of two planes of Cathode Pad Chambers, and two stations of trigger chambers equipped with two planes of Resistive Plate Chambers [4]. The alignment of the tracking chambers is a crucial aspect for single muon analysis because it can affect the performance of the detector [5]. Thus it is necessary to investigate inefficiencies which may be caused by the misalignment of the tracking chambers or individual detector elements.

At LHC energies $W^\pm$ bosons are produced at high transverse momentum, $p_T \sim M_W/2$, where $M_W$ is the mass of $W^\pm$, and are measured via the single muon channel, $W^\pm \to \mu^\pm$, with a branching ratio of 10.6% [6]. Due to the weak interactions of the $W^\pm$ decay via the $\mu^\pm$ channel these processes are not affected by the quark gluon plasma. Since these cross sections are well known, with a precision that is dependent on uncertainties of the Parton Distribution Functions (PDFs - describe the behaviour of a patron inside a nucleon and they are dependent on the energy scaling variable Q and Bjorken-x), they can be used as “standard candles” for luminosity measurements. Furthermore this characteristic can be used to evaluate the performance of the detector [7].
In this report we present results obtained in studies by K J Senosi [1] and P W J Du Toit [2] where the pure W± signal was extracted from PYTHIA simulations of pp collisions at 8 TeV in the forward rapidity range of ALICE, followed by realistic simulations involving the reconstruction of various misalignment scenarios in order to evaluate the performance of the detector. For the ideal detector configuration an efficiency of 100% was assumed, while for the realistic configuration an efficiency of 80%, based on the conditions of the tracking chambers during the 2011 Pb-Pb data taking period, was adopted in the simulations. Different misalignment cases, each based on a random residual misalignment [8], were considered by making use of a special package explained in detail elsewhere [9]. Muon tracks were selected by requiring reconstruction in the geometrical acceptance of the muon spectrometer (i.e. pseudo-rapidity \(-4 < \eta < -2.5\), with the track polar angle at the end of the absorber given by \(171° < \theta_{\text{abs}} < 178°\)). To remove tracks not originating from the interaction vertex [5] the correlation between the momentum \(p\) and distance of closest approach (DCA), so-called “\(p \times DCA\)”, was considered to be \(5\sigma\) where \(\sigma\) was extracted from the Gaussian fit to the \(p \times DCA\) distribution measured in two regions of \(\theta_{\text{abs}}\). The trigger matching cut (\(p_T > 4\) GeV/c) was applied to make sure that the track in the tracking chambers matched the corresponding track in the trigger chambers. Results from these simulations are summarized in Figures 1 and 2 below. Figure 1 shows \(p_T\) distributions of \(\mu^+ \rightarrow W^+\) and \(\mu^- \rightarrow W^-\), respectively, for the ideal and realistic cases. The difference in the trend (shape) between the \(p_T\) distributions of \(\mu^+ \rightarrow W^+\) and \(\mu^- \rightarrow W^-\) can be attributed to the total net isospin available in pp collisions and the parity-violation effects [3]. Also, when comparing the ideal case to the realistic case there is a notable change in the distributions where we observe broader \(p_T\) distributions for the latter case and also more \(\mu^- \rightarrow W^-\) in the high \(p_T = 40 – 80\) GeV/c region.

Results from the misalignment analysis are presented in Figure 2 where \(p_T\) distributions of \(\mu^+ \rightarrow W^+\) are shown in the figure on the right-hand side while \(\mu^- \rightarrow W^-\) is plotted on the left-hand side. The data in red markers are from the ideal case while other colours denote various misalignment scenarios. As expected, the production of \(\mu^+ \rightarrow W^+\) is favoured in pp collisions compared to \(\mu^- \rightarrow W^-\). In the case of \(\mu^+ \rightarrow W^+\) the distribution of the ideal case (red points) is narrower and has a prominent peak around \(p_T \sim 40\) GeV/c with respect to those obtained from the other misalignment cases, whose distributions are shifted at various \(p_T\) values with respect to the former case.

![Figure 1](image1.png)

**Figure 1**: \(p_T\) distributions of \(\mu^\pm \rightarrow W^\pm\) obtained from PYTHIA simulations at forward rapidity in pp collisions at 8 TeV. The figure on the left represents data obtained from the ideal case while the figure on the right represents data obtained from the realistic case.
The spread (variation) in the trends is indicative of a systematic uncertainty (see Figure 3) and might be the result of “misaligned” tracking chambers or detector elements, which has to be taken into account when conducting a single muon analysis, especially in high $p_T$ studies ($p_T > 20$ GeV/c).

**Figure 2:** $p_T$ distributions of $\mu^+ \rightarrow W^+$ on the right and $\mu^- \rightarrow W^-$ on the left simulated in pp collisions at forward rapidity at 8 TeV using PYTHIA. The red markers denote the ideal case while other coloured markers denote the various misalignment cases.

**Figure 3:** The ratio obtained from $\mu^+ \rightarrow W^+ / \mu^- \rightarrow W^-$ is plotted as a function of $p_T$ simulated at forward rapidity in pp collisions at 8 TeV using PYTHIA. In this case we show only the range 0 < $p_T$ < 80 GeV/c to emphasize the charge asymmetry in this region.

These results demonstrate the crucial role played by the analysis of $\mu^\pm \rightarrow W^\mp$ production as it also forms an important test of the performance of the detector. Further studies are being carried out to understand the “unexpected” dominance of $\mu^- \rightarrow W^-$ over $\mu^+ \rightarrow W^+$ in the region $p_T = 10 - 30$ GeV/c as can be seen in Figure 1. Also, these studies have been extended to include the analysis of Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV as well as pPb/Ppb at 5.03 TeV centre of mass energies.

References

2.1.9 Simulating the position sensitivity of the iThemba LABS segmented clover detector

T D Bucher¹, S P Noncolela¹, ², E A Lawrie¹, O Shirinda¹, J L Easton¹, ², P Medina³, N J Orce²

¹iThemba LABS, National Research Foundation, P O Box 722, 7129 Somerset West, South Africa
²University of the Western Cape, Private Bag X17, 7535 Bellville, South Africa
³Laboratoire Aerologie, Universite Paul Sabatier, INSU, Toulouse, France

Germanium detectors are used to measure gamma-rays and extract information about different properties of nuclear states, such as energies, spins, parities, magnetic moments, etc. iThemba LABS has recently purchased a highly segmented gamma-ray detector and aims to fully utilize its position sensitivity capabilities. A detector able to perform gamma-ray tracking will be very valuable as it has the potential for high efficiency and high resolving power due to its larger size and ability to reduce Compton background. For fast moving nuclides, such a detector has the ability to greatly reduce Doppler broadening in the gamma-ray peaks because of the substantially reduced opening angle. In order to evaluate the tracking capabilities of this detector, we have to perform simulations to determine the position sensitivity based on an analysis of the shape of the core and segment pulses.

The iThemba LABS segmented clover detector comprises of four HPGe crystals (with approximately 39% relative efficiency) arranged in a clover-leaf geometry for optimal efficiency purposes. Each crystal is electrically segmented into 8 regions on the outer contacts. This adds up to 32 segments for one detector plus four full-volume signals from the inner core contacts. The inner contacts provide high resolution measurements of gamma-ray energy deposition for each crystal whilst the outer contacts give information about the location of the gamma-ray interaction inside the detector. The total efficiency of the detector in add-back mode is 220%. Each crystal is 60 mm in diameter and 90 mm in length before tapering. The depth segmentation is at 35 mm.

When an incoming γ-ray interacts within a germanium crystal, it generates electron-hole pairs which can be considered as the charge clouds. The Coulomb field that results from these charge clouds extend throughout the entire crystal volume. As charge clouds drift toward their collecting electrodes, according to the strength of the electric field, their Coulomb field changes. For a detector with multiple electrodes, a current is induced on all conducting electrodes.

This phenomenon can be simulated using a Multi Geometry Simulation (MGS) code [3]. For a given interaction point inside the detector MGS performs the following routines in order to simulate a pulse shape response:

![Diagram of the iThemba LABS segmented clover detector with four front segments labelled as 1, 2, 3, and 4 and the back four segments labelled as 5, 6, 7, and 8.](image-url)
To investigate the position sensitivity of the iThemba LABS segmented clover detector, the gamma-ray interaction simulations were performed at different location within the crystal. The three parameters that were varied in this investigation were the azimuthal angle, the radius and the depth in crystal A.

When the radius is varied from $r = 5$ to $29$ mm, it was found that the core pulses have a very distinct shapes, which makes it easy to distinguish different positions. The different shapes of the pulses carry information about the distances that the electrons and the holes travel to their collecting electrode. At positions closer to the inner electrode the movements of the holes determines the general shape of the charge collection signal as they travel a longer way to be collected at the cathode. As the position is moved towards the outer electrode the total charge collection signal changes its shape, as now the electrons travel a larger distance and that determines the general shape of the pulse as seen in Figure 3.

A second set of simulations were performed for the gamma-ray interactions at different angles, from $1^\circ$ to $90^\circ$ while keeping the radius and depth the same. No significant difference was observed in the shape of the pulses at the core electrode, but a noticeable difference is found in the induced pulses from the neighbouring segments. As the interaction position is moved from $35^\circ$ (closer to segment 2) to $80^\circ$ (closer to segment 4) the amplitude of the induced pulse on segment 2 decreases and the one on segment 4 increases, Figure 4. Thus the amplitude of the induced signals changes substantially, and makes it possible to distinguish interaction points for which the inner-core signals remain unresolved.
Pulse shape simulations were also performed for interaction positions at different depths. The induced pulses were found to differ as the interaction position was varied from a depth of 5 mm (along the z-axis) up to 85 mm. The transverse segmentation at 35 mm is used to differentiate between the pulses induced at the front or back segment as seen in Figure 5. The back segment however, is large (55mm) and hence makes the detector less position sensitive at depths around 60 mm to 80 mm.

The position sensitivity of the segmented iThemba LABS clover detector was studied with the MGS code. Pulse shapes have been simulated at different positions (for different radii, azimuthal angle and depth) within the detector volume. For interaction points at different radii, the shape of the pulses at the inner contact can be used to resolve the positions. For different azimuthal angles, the induced signals at the neighbouring segments are important for determining the position. Different depths can also be resolved, but the detector seems to be less sensitive for interactions at the back of the detector.

**Figure 4:** The pulse shapes from the hit and induced segments for gamma-ray interaction at the same radial positions and depths, but different azimuthal angles.

**Figure 5:** Induced segment signals for gamma-ray interactions occurred at different depths, while the radius and azimuthal angle were kept constant.

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2.1.10 Depletion voltage measurements with the new iThemba LABS segmented clover detector

J L Easton\textsuperscript{1,2}, O Shirinda\textsuperscript{1}, E A Lawrie\textsuperscript{1}, T D Bucher\textsuperscript{1}, S P Noncolela\textsuperscript{1,2}, N Orce\textsuperscript{2}

\textsuperscript{1}iThemba LABS, National Research Foundation, PO Box 722, 7129 Somerset West, South Africa
\textsuperscript{2}University of the Western Cape, Private Bag X17, 7535 Bellville, South Africa

The depletion voltage of a germanium crystal is an important property of any germanium detector. The depletion voltage gives us an insight into the current state of each crystal in terms of its efficiency and minimum operating voltage that is needed for optimal use. It is also a measure of the impurity concentration of a crystal. The impurity concentration is an important value for simulating gamma-ray interactions inside each crystal. The depletion voltage measurement forms part of the testing of the detector, thus a detailed analysis was done to evaluate the depletion voltage of each crystal.

Three gamma-ray sources, \textsuperscript{241}Am, \textsuperscript{60}Co and \textsuperscript{137}Cs, with gamma-ray energies of 59, 662 and 1332 keV respectively were used. The depth at which gamma-rays interact is probabilistic in nature with low energy gamma-rays having a high probability of photo absorption in the front part of the detector. The middle and high energy gamma-rays Compton scatter until sufficient energy is lost and then they get absorbed towards the centre and back of the detector. Each of the three sources was placed at 22.5 cm from the face of the detector. Data were collected until at least 100 000 counts were registered in the photo peaks of the sources. This required 15 minutes of data collection for \textsuperscript{60}Co and \textsuperscript{137}Cs and 7 minutes for \textsuperscript{241}Am. A shorter time was needed because \textsuperscript{241}Am had a ~2 μCi higher activity and furthermore the low energy gamma-ray of 59 keV has a small probability for Compton scattering out of the detector. The centroids and peak areas were then measured for each run. After each run the bias voltage was decreased in steps of 50 - 100 V starting from the operating voltage. To infer when the detector is no longer depleted the centroid and peak area as a function of the bias voltage was investigated.

Generally the shifting of the centroids towards lower energy indicates that charge is lost when the charge carriers pass through dead regions of the detector. Since there is no effective electric field in the dead region to transport the charge to the cathode the energy of the photo peak decreases. The amount of centroid shift is related to the size of the dead region in the crystal. Another indication that the detector is no longer depleted is a loss of efficiency. Efficiency and thus peak counts are lost when no charge is collected. This happens when an incident gamma-ray deposits its full energy in a dead region.

Data plots of the centroids and peak areas as a function of the bias voltage for crystal A are shown in Figures 1 and 2. The centroids of the \textsuperscript{241}Am and \textsuperscript{137}Cs peaks have had appropriate constants added to them so that they could be easily compared on one figure.

Figure 1 shows that the middle and high energy gamma-ray centroids start shifting away from the average horizontal line at around 2300 V. The lower energy gamma-ray (blue curve) has an approximately zero slope for
much lower bias voltage and we see a prominent loss of charge collection at around 2000 V, i.e. when the slope of the curve deviates beyond the natural variation of data points.

Figure 2 shows a rapid loss of efficiency of the detector for the low energy gamma-ray very close to its operating voltage of 3000 V. On the other hand the detector stays efficient up to 1000 V below operating voltage for middle and high energy gamma-rays.

Crystal A is unique in the rapid loss of efficiency for low energy gamma-rays. This is not the case for the other crystals see for example crystal B (Figure 3).

All the data were analysed in a similar way as described above and the results are summarized in Table 1. As mentioned earlier crystal A has poor efficiency for low energy gamma-rays not far below its operating voltage. Crystal B sees a loss of charge carriers at ~300 V below the operating voltage but this does not affect its efficiency. For all gamma-rays efficiency losses are only seen at ~800 V below the operating voltage of crystal B. Crystals C and D behave in an excellent way when decreasing the bias voltage.
The depletion voltages as measured by the manufacturer tend to be lower than what was found during our analysis. The manufacturer used the Van der Pauw method to measure depletion voltages. This method uses the capacitance versus applied voltage to infer the depletion voltage of a crystal sample.

### Table 1

<table>
<thead>
<tr>
<th>Crystal</th>
<th>Operating Voltage (V)</th>
<th>Depletion Voltage (V)</th>
<th>Centroid</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3000</td>
<td>2000</td>
<td>2300±200</td>
<td>2900±200</td>
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<td>B</td>
<td>4000</td>
<td>3500</td>
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<td>C</td>
<td>4000</td>
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<td>2300±200</td>
<td>2500±200</td>
</tr>
<tr>
<td>D</td>
<td>3500</td>
<td>2250</td>
<td>2500±200</td>
<td>2600±200</td>
</tr>
</tbody>
</table>

2.1.11 Preamplifier response and energy resolution measurements for the iThemba LABS segmented clover detector

Large volume high-purity germanium (HPGe) detectors are commonly used in applications (such as gamma-ray spectroscopy) that require good energy resolution and high detection efficiency. iThemba LABS recently bought a new state of the art segmented clover detector. The new detector contains four cylindrical HPGe crystals housed in a common vacuum cryostat. This detector has 32 outer contacts in addition to the four inner-core contacts. The principal reason for this segmentation is to provide information about the three-dimensional
localization of the gamma-ray interactions within the detector. Charge sensitive preamplifiers allow all thirty-six electrical signals to be read out, providing precise energy information from the core contact and pulse shapes for position localization from all contacts. Due to its segmentation, the detector can also be used in a gamma-ray tracking mode. Therefore measurement for the performance of this detector is very important prior to developing γ-ray tracking. In this work results obtained from tests which include measuring the energy resolutions (FWHM) for each crystal and for all electrodes at different rates, and measuring signal rise- and decay times are presented. Measurements were carried out mainly by means of Pixie-4 digital electronics.

Detector energy resolutions were measured for the 121 keV and 1332 keV γ-rays from $^{152}$Eu and $^{60}$Co standard sources with activities of approximately 10 μCi. Sources were placed at a distance of 22.5 cm in front of the Ge crystals. The data were collected for 15 minutes per measurement and recorded with Pixie-4 digital electronics with digital shaping parameters optimized for best resolution (pulse rise time = 11.84 μs, pulse flat top = 1.6 μs, pulse shaping time = 6 μs, pulse delay time = 1 μs, pulse delay time constant = 50 μs). The detector count rates per crystal for $^{60}$Co and $^{152}$Eu sources were less than 1400 and 2500 respectively. The energy resolutions (FWHM) of the iThemba LABS segmented clover detector in direct mode are shown in Figure 1. The specification is FWHM ≤ 1.35 keV and FWHM ≤ 2.35 keV at 121 keV and 1332 keV respectively for the cores; and FWHM ≤ 3.00 keV and FWHM ≤ 3.50 keV at 121 keV and 1332 keV respectively for the segments. We found that in add-back mode the width of the peaks is slightly larger than in direct mode. Furthermore in direct mode some of the measured FWHM for the core and segment electrodes at 121 keV and 1332 keV are larger than the guaranteed values given by the manufacturer, see Figure 1. We also found that changing the position between the detector and the source has little impact on the FWHM of the detector.

![Figure 1: Measured energy resolutions (FWHM) of iThemba LABS segmented clover detector for a 121 keV (squares) and 1332 keV (circles) photo-peaks from $^{152}$Eu and $^{60}$Co respectively. Solid and dashed lines correspond to the manufacturer guaranteed values of FWHM for 1332 keV and 121 keV respectively.](image-url)
The preamplifier represents an interface between the detector and the signal processing electronics. Its basic function is to amplify and shape the small signal from the detector and to transfer it to the electronic chain with the least degradation. The preamplifier response of the iThemba LABS segmented clover detector was measured by injecting a 5 ns rise time square wave into the test input of each crystal, and measuring the rise time and fall time of the subsequent core signal. The rise and fall times were measured using a Tektronix DPO3054 digital oscilloscope (500 MHz, 2.5 GS/s). The shapes of the injected and preamplifier output signals from crystals A, B, C and D are shown in Figures 2 and 3. All core contacts exhibit good rise times and decay constants, falling well below 44 ns and 52.5 μs respectively (see Table 1). It can then be concluded that the detector preamplifiers are fast enough to enable time variations larger than 40 ns to be distinguished. This time resolution is sufficient for measuring variations in the signal rise time, which for the iThemba LABS segmented clover detector is of the order of 200 ns. Note that the shape of the signal observed from crystal C shows some oscillations (see Figure 2(c)). When the signal oscillates, the settling time is an issue in addition to the amounts of over/under shoots. Thus the performance of the preamplifier of crystal C raises a concern.

![Figure 2(a)-(d): Rise times of each full volume signal from iThemba LABS segmented clover detector, resulting from an injected 5 ns rise time square pulse.](image-url)
2.1.12 Development of the iThemba LABS Digital Data Acquisition System

P Jones¹, R Bark¹, S P Bvumbi¹, T D Bucher¹, T S Dinoko², J L Easton¹-³, M S Herbert³, B V Kheswa¹,², N Khumalo³, E A Lawrie¹, J J Lawrie¹, S N T Majola¹,², S H T Murray³, J Ndayishimye¹,², D Negi¹, S P Noncolela¹,³, J N Orce³, P Papka¹,², O Shirinda¹, J F Sharpey-Schafer³, M A Stankiewicz¹,² and M Wiedeking¹

¹iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa
²Stellenbosch University, Department of Physics, P/B X1, Matieland 7602, South Africa
³University of Western Cape, Department of Physics, P/B X17, Bellville 7535, South Africa
⁴University of Johannesburg, Department of Physics, P O Box 524, Auckland Park 2006, South Africa
⁵University of Cape Town, Department of Physics, P/B X3, Rondebosch 7701, South Africa

The existing CAMAC based with FERA readout system for AFRODITE experiments has suffered from dead-time limitations due to being trigger based for data throughput, and the limited number of extra channels available for the ever increasing complexity of experiments. Moreover the operational reliability of the system, including detector gain-drifts has added to the complications of running experiments.

The Pixie-16 based system, supplied by XIA LLC, comprises of three Compact PCI/PXI crates, each connected to a front-end control PC (Intel 2 Quad CPU) for control and readout of each crate via a PCI/PXI bridge. Each crate can furnish up to seven 16-channel Pixie-16 100 MHz Digital Gamma Finder cards, thus providing many more channels for more demanding experiments. The readout of active crates uses a simple polled method per card, providing a data stream on a per card basis. These data consist of time-stamped data (48 bit) together with extracted energies, baseline information, etc. and the data acquisition system has been designed to manage these data in order to supply a single time-ordered stream of data similar to the Total Data Readout method [2].

Data are received from the main acquisition cycle, and transferred over gigabit Ethernet to a collection unit, where individual processes called “collectors” check and correct the time-ordering per card, and apply data filtering or marking. These data are output to the data merge unit to be time-ordered into a single stream, and

<table>
<thead>
<tr>
<th>Crystal</th>
<th>Rise time (ns)</th>
<th>Decay constant τ (μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>42.6</td>
<td>49.9</td>
</tr>
<tr>
<td>B</td>
<td>42.2</td>
<td>49.9</td>
</tr>
<tr>
<td>C</td>
<td>33.0*</td>
<td>50.5</td>
</tr>
<tr>
<td>D</td>
<td>43.8</td>
<td>51.7</td>
</tr>
</tbody>
</table>

Table 1. Rise times and decay time constants τ for the iThemba LABS segmented clover detector. The value marked with * is measured when ignoring the oscillation of the signal.

Figure 3: Decay time constant τ of the full volume signal of the crystal A of the iThemba LABS segmented clover detector, resulting from an injected 5 ns rise time square pulse.
then be further filtered, or have events constructed before being written out to storage. The acquisition process, run control and sorting are controlled in the user area from a separate computer. The architecture of the acquisition and processes has been designed to be flexible and expandable. As data are available via network sockets, these can be sent to the same destination or to any other computing hardware such that the data load can be balanced and upgraded easily.

A schematic for the data acquisition is shown in Figure 1, and a photograph in Figure 2.

For the instrumentation of AFRODITE (9 Clover detectors and 4 LEPS detectors), initially each of the Clover detectors, and its associated Bismuth Germinate (BGO) shield could be coupled to the existing analogue DAQ and also to a single crate with two detectors per card. Time was taken to understand the parameter settings for the detectors, and to optimise for resolution. Trapezoidal rise times of ~4 μs, and a flat top of ~1 μs showed similar resolution as per the analogue system, and should be compared to an analogue shaping time of 6 μs giving the possibility of faster throughput per channel. Detailed measurements with radioactive sources showed comparable detector performance (resolution and peak-to-total). Stability of the electronics and detectors were also tested, showing no noticeable gain shifts over a 72 hour period. Compton suppression of the Clover detectors were performed in software using temporal coincidence between the Clover detector timestamps and BGO shield timestamps to veto the data. Coincidence requirements between detectors, together with a fold threshold, were also implemented. This is similar to the analogue acquisition where a hardware veto and trigger threshold are used.

Experimental beam time was allocated for performance tests of the system under experimental conditions and also for differing beam intensities using a $^{197}$Au target with an alpha beam at 52 MeV. The DDAS was running untriggered, thus collecting all singles data and forming events with a software trigger of at least two Clover detectors in a 150 ns overlap time window.
Performance was compared with the analogue system. At low beam intensities (10 nA) both systems performed similarly with trigger rates of 5 kHz. For the analogue system this trigger rate is the limit without incurring more than 10% dead-time due to readout limitations. The beam intensity was further raised incrementally by a factor of four before reaching a CPU bound condition on the merging unit. Data from this intensity are shown in Figure 3, showing the same spectral quality, but with a factor of five in increased statistics.

![Figure 1: Sample spectra from the data. Red data are from the digital system, while black data are from the analogue system. In the upper frame the data has been offset for ease of identification while the lower frame has the data overlayed.](image)

The DDAS has been commissioned and is now used for AFRODITE experiments. Multiple crates have been used together in addition to instrument complementary detectors such as the Si detectors, DIAMANT (CsI), and neutron wall detectors (plastic scintillators) at iThemba LABS. Due to the flexible design the data from other crates can be neatly merged together. Further upgrades, such as replacing the merge unit with a faster multi-core machine, has allowed a factor of five in throughput compared with the analogue system, allowing the possibility for future experiments to take increased beam intensities where applicable.

The Pixie-16 firmware for iThemba LABS incorporates also a Constant Fraction Timing measurement to provide timing information below the 10 ns timestamp. Using fast detectors, such as the neutron wall, resolutions of 1 - 2 ns have been achieved. Further work is progressing in this area.

In addition to calculated energies, traces can be recorded for pulse-shape analysis and a “charge to digital” method has been implemented to provide online integration of waveform data over user defined time periods. These are being investigated for particle discrimination in DIAMANT detectors.

References

1. www.xia.com
2.1.13 Measurement of the cross section for the production of $^{68}\text{Ge}$ by $(n,xn)$ reactions on Ge isotopes

A R Domula$^1$, K Zuber$^1$, A Buffler$^2$, D Geduld$^{2,3}$, D Gehre$^1$, P Maleka$^3$, R T Newman$^{3,4}$, R Nolte$^5$, F D Smit$^3$, C Vermeulen$^3$

$^1$Technische Universität Dresden, Institut für Kern- und Teilchenphysik, Zellescher Weg 19, D-01069 Dresden, Germany
$^2$Department of Physics, University of Cape Town, Private Bag, Rondebosch 7701, South Africa
$^3$iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa
$^4$Department of Physics, University of Stellenbosch, Matieland 7602, South Africa
$^5$Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany

One of the most important background nuclides for the investigation of the neutrinoless double beta decay of $^{76}\text{Ge}$ is $^{68}\text{Ga}$ due to its high $Q$-value of 2921.1 keV. In underground laboratories this short lived ($T_{1/2} = 67.629$ min), radiogenic nuclide occurs as a decay product of the long-lived $^{68}\text{Ge}$ ($T_{1/2} = 270.8$ d) (Figure 1) that is produced by cosmogenic activation in germanium itself. Therefore, the main production processes are $(n,xn)$ reactions induced by high-energy neutrons on the more heavy Ge isotopes. Experimental cross-section data for these reactions are not available. The neutron energy range below 100 MeV is of particular relevance because the cosmogenic neutron spectrum has a fluence maximum around 100 MeV. For a determination of the $^{68}\text{Ge}$ production-rates, the cross-section of the main production path $^{70}\text{Ge}(n,3n)^{68}\text{Ge}$ has been investigated with quasi-monoenergetic neutrons [1] of $E_n = 35.9$ MeV. The foil activation method has been used with quasi-monoenergetic neutrons produced with the $^7\text{Li}(p,n)^7\text{Be}$ reaction over two weekends at $E_p = 66$ and 100 MeV.

Figure 1: $^{68}\text{Ge}$ is produced by $^4\text{Ge}(n,xn)^{68}\text{Ge}$ reactions due to cosmogenic activation of germanium. It decays with $T_{1/2} = 270.8$ d into $^{68}\text{Ga}$ by electron-capture. The decay chain is continued by $^{68}\text{Ga}$ with $T_{1/2} = 67.629$ min. [2]
The neutron yield was characterised using the time-of-flight method with a $^{238}$U fission chamber and a BC501 detector. A thin NE102 transmission detector and a second $^{238}$U fission chamber were employed as monitors to relate the beam characterisation to the activation of the samples. Additional monitor reactions on silver and copper foils have been used. The saturation activity for $^{68}$Ge and the resulting cross-section has been calculated using the $^{68}$Ge/$^{70}$Ge ratio from AMS measurements. The analysis of these measurements and of data at additional energies is still in progress. First preliminary results are plotted in Figure 2 in comparison with evaluated and simulated data. The AMS technique is proven extremely sensitive for $^{68}$Ge-detection [5], working well for those cross-section measurements on germanium isotopes.

![Graph](image)

**Figure 2:** The preliminary cross-section of the present measurement with the given uncertainties represents a range of data from different results in the ongoing analysis process. The data is compared to evaluated data from MENDL-2 [3] and with CEM 3.02 simulated data from [4].

**References**

2.2 Medical Radiation Department

2.2.1 Digital Portal Radiograph Verification for Proton Therapy

N Muller\textsuperscript{1,2}, C Carstens\textsuperscript{2}, L van der Bijl\textsuperscript{2}, C Callaghan\textsuperscript{1}, T Ransome\textsuperscript{3}

\textsuperscript{1}iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa
\textsuperscript{2}Division Applied Mathematics, Department of Mathematical Sciences, Private Bag X1, Stellenbosch University, Matieland 7602, South Africa
\textsuperscript{3}Department of Electrical Engineering, Private Bag 3, University of the Witwatersrand, 2050

In conformal radiotherapy the final position should be confirmed with a portal radiograph showing the relationship of the patient anatomy to the beam line. Historically this radiograph is verified by manual comparison with a reconstructed radiograph of the expected patient position. We have recently completed the development of an automatic system designed for use in the proton therapy facility at iThemba LABS.

iThemba LABS uses a novel vision based patient positioning system for proton therapy. The relationship between the patient and the marker carrier is established during treatment planning, and verified by a portal radiograph taken after the patient has been positioned and before the prescribed dose is delivered. This portal radiograph is compared with a synthetic digitally reconstructed radiograph (DRR) calculated using the expected patient position and CT data used for the treatment plan. The current system relies on manual comparison of the portal radiograph and the DRR and trial and error correction. We recently completed development of a system which acquires a digital portal radiograph and automatically verifies this against the expected patient position [1,2].

We assume that the patient is close to the correct position and that the error is a small rigid transformation $T_{err} = [t_x, t_y, t_z; \theta_x, \theta_y, \theta_z]$ where $t_x$, $t_y$, $t_z$ are the translation errors and $\theta_x$, $\theta_y$, $\theta_z$ are the rotational errors around each axis. By calculating multiple DRR’s using small perturbations of the expected patient position, we can find the transformation error that maximises the similarity between the portal radiograph (PR) and the generated DRR, i.e. we maximise $M(\text{DRR}(T_{err}), PR)$ where $M$ is a suitable similarity measure [3,4]. We used Mutual Information as the similarity measure, since it is well suited to this type of image comparison problem [5]. If this calculated transformation is sufficiently small, the patient is correctly positioned. The process is illustrated in Figure 1.

Van der Bijl [6] showed that, under these assumptions, this registration problem can be solved efficiently and robustly using non-gradient optimisation methods [7], such as Powell’s method, and is stable across a variety of DRR calculation approaches [8], which significantly reduces the complexity of the system. Since the optimisation step requires calculating a large number of DRRs, it is essential that this be accomplished quickly. Carstens [9] investigated a number of DRR calculation methods and concluded that light fields [10], as proposed by Levoy and Hanrahan[11], was the best method for this problem. In addition to the efficiencies gained by using light
fields, the calculations involved are also easily parallelisable [12], allowing for further speed gains on modern multi-core hardware.

We also automatically verify the alignment of the beam collimator, which provides robustness against manufacturing defects or errors with the collimator drive assembly.

A portal radiograph is taken of the patient with the collimator in position, and from this, the outline of the collimator is extracted and compared to the predicted outline. We also calculate the correction required to fully align the observed and predicted collimator outlines.

To ensure accurate results, we use a novel calibration cube [13]. The exterior of the cube has a number of retro reflective markers and its position can be accurately determined by the positioning stereophotogrammetric (SPG) system. The interior of the cube has a number of fiducials than can be easily observed in the portal radiograph (see Figure 2).

Since the position of the cube is observed by the SPG system, we can accurately determine the position of these fiducials relative to the proton beam. Using these fiducials, and modelling the portal radiograph system as a pin-hole camera, we can calculate the approximate parameters for the radiograph system.

We further refine this approximate calibration by minimising the difference between the observed portal radiograph of the cube and the predicted view given the current calibration parameters.
In addition to determining the internal parameters of the portal radiograph acquisition system, this process also establishes the relationship between the portal radiograph system and the proton beam line, which is required to correctly solve the registration problem.

Since the verification system is intended for use during treatment, we have developed a fully functional user interface which provides easy access to all the relevant information and the results of the registration process in a convenient manner. The user interface also provides various tools for visualising the difference between the portal radiograph and the digital reconstructed radiograph and visualising the calculated correction. Examples are illustrated in Figures 3 and 4.

The new portal radiograph system is closely integrated with the existing SPG system. This allows for smooth transitions between the two systems and allows for improved monitoring of the patient position during the process of taking the radiograph.

As an addition benefit, since we calculate the error in the patient position, in addition to verifying that the patient is correctly positioned, this error can be used by the SPG system as a correction term if required.

While final testing is still on-going, the results are most promising. The system is able to verify a portal radiograph in less than 4 minutes, which is a considerable improvement on the manual process, and the accuracy is within the desired limits for treatment. The performance for the collimator verification step is also promising, taking
around 1 minute to calculate the position of the collimator, and the accuracy is within the required limits, being comparable to the mechanical limits of the collimator assembly.

The use of a digital detector for the portal radiograph significantly simplifies the process of acquiring the radiographs, removing much of the manual work involved in using film radiographs. This, combined with the automatic verification process, mean that the new system will significantly reduce the time required to verify the patient setup, which will consequently reduce the time required for treatment. The improved monitoring of the patient around the acquisition of the portal radiograph and the improved accuracy of the system will also reduce the number of exposures required before treating the patient, which will be a significant benefit.

The new detector also allows us to use lower exposures for the portal radiograph, which reduces the X-ray dose to the patient [14]. Furthermore, since we no longer need to double expose a single film radiograph to verify the position of the collimator, and we only need to be able to extract the outline from the collimator radiograph, this radiograph can be taken with a higher tube voltage and significantly lower exposure than the current system, which will further reduce the X-ray dose.

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2.3 Radiation Biophysics

2.3.1 Evaluation of γH2AX foci after exposure of human lymphocytes to γ-rays or high energy neutrons.

V Vandersickel¹, P Beukes¹, J Depuydt², A Vral² and J P Slabbert¹

¹iThemba LABS, National Research Foundation, P O Box 722, Somerset West, 7129, South Africa
²Department of Basic Medical Sciences, Ghent University, Belgium

In the event of a large-scale radiation accident a rapid assessment of radiation doses absorbed by individuals is needed to facilitate triage and to assist decisions with respect to medical treatment of exposed individuals. Since most people involved in large mass-casualty radiation emergencies would not be wearing personal dosimeters, triage need to be based on biological dosimetry. Current methods using dicentric or micronuclei formations need cell culture times of up to 72 hours. For triage, a faster method to identify individuals that have been overexposed is needed. Currently, the use of γH2AX foci is investigated as a tool for biological dosimetry. The assay is based on observing double-strand break formations by ionizing radiation. γH2AX foci show within minutes after radiation exposure and can be visualised within several hours after obtaining a blood sample. This technique is also suitable for automation.

In this work induction of γH2AX foci in lymphocytes of 6 donors to different doses of 60Co γ-rays or p(66)+Be(40) neutrons has been evaluated. Results obtained with an automated image analysis system for foci quantification are compared to those observed manually. Following irradiations, isolated peripheral blood lymphocytes cell cultures were incubated at 37°C for 30 minutes to allow foci formations. Cell samples were spotted onto poly-L-Lysine coated slides using a Cytospin centrifuge, and fixed overnight. Then incubated with anti-γH2AX and RAM-TRITC and counterstained using DAPI. Slides were scanned automatically using the Metacyte software module of the Metafer 4 scanning system as described by Vandersickel et al. In each slide, about 2000 lymphocytes were captured automatically. After coding of the slides, 100 randomly distributed nuclei on each slide were analysed manually for the presence of γH2AX foci by visual inspection of the image gallery.

Figure 1 shows the mean number of foci obtained automatically or manually after exposure of lymphocytes to different doses of either γ-rays or neutrons. For both the manual and automated scores, γH2AX foci formation gradually increases with increasing dose. This is so for foci formed after exposure to either γ-rays (Figure 1A) or neutrons (Figure 1B). For doses up to 0.2 Gy, lower foci numbers are noted after manual scoring compared to the automated scores. For doses higher than 0.2 Gy, higher foci numbers are evident after manual scoring. This could be because at lower doses, the discrimination between artefacts and foci is more accurate by eye. At higher doses a better capacity of the eye to distinguish closely spaced and/or overlapping foci is evident. Using a paired samples t-test, a threshold dose of detection of 0.01 Gy could be determined for γ-rays and 0.025 Gy for...
neutrons when foci were manually scored. A threshold dose of detection of 0.01 Gy for γ-rays and 0.05 Gy for neutrons is evident when foci were automatically determined.

![Image of the number of γH2AX foci/cell in peripheral blood lymphocytes after irradiation of cells with different radiation doses.](image1)

When comparing the number of foci obtained after exposure to either gamma-rays or neutrons, a higher number of foci is seen after exposure of cells to γ-rays compared to neutrons. This is so when scoring the number of foci automatically or manually (Figure 2). A reasonable explanation for this observation is that the probability of clustering of either double-strand breaks or foci is higher after cells exposed to high-LET radiation compared to low-LET treatment modalities.

It is concluded that the γH2AX foci assay has the potential to serve as a biodosimetric tool when analysing foci after a fixed post-irradiation time, and that automated analysis for this seem to be very useful in that it will allow for processing of large numbers of samples for triage.

**Reference**

2.3.2 Prostaglandin A2 as a Radiosensitizer in MCF-7 Breast Cancer Cells

B Alexander1, M De Kock1, J Slabbert2, V Vandersickel2

1Department of Medical Bioscience, University of the Western Cape, Bellville, South Africa
2iThemba LABS, National Research Foundation, P O Box 722, Somerset West, South Africa

Preliminary studies have shown that the endogenous metabolite, prostaglandin A2 (PGA2), inhibits cell growth of some cancer cells by inducing a mitotic block [1,2,3]. It is well known that depending on the phase in the cell cycle that cells reside, their sensitivity to the effects of ionizing radiation can differ [4,5]. Since a mitotic block increases the number of cells in the M-phase of the cell cycle, known to be most sensitive to the effects of radiation, we investigated a possible radiosensitizing effect of PGA2 exposure on breast (MCF-7) cancer cells to ionizing radiation. After incubation with different concentrations of PGA2 for 48 hours, the cells were exposed to various doses of 60Co γ-rays. The crystal violet cell proliferation assay was used to analyse the proliferative capacity of cells after irradiation, measuring the effects of the combined treatment on a cellular level. The micronucleus assay was used to detect chromosomal aberrations induced by the combination of PGA2 and radiation.

Compared to cultures not treated with PGA2 a clear increase in number of cells in mitoses could be noted for cultures exposed to 20 µg/ml PGA2 (Figure 1). Cells exposed to only 10 µg/ml PGA2 do not show any significant accumulation in metaphase.

Both 10 µg/ml and 20 µg/ml PGA2 treatments resulted in reduced cell growth and this appears to be concentration dependent (Figure 2). Treating the MCF-7 cells with graded doses of 60Co gamma rays resulted in an increase in micronuclei formations that is dose dependent (Figure 3). Notwithstanding this, micronuclei formations in cells grown under control conditions and that are cultivated in the presence of 10 µg/ml PGA2 were not any different. By contrast MCF-7 treated for 48 hours with 20 µg/ml PGA2 do show on average higher numbers of micronuclei formations for most doses applied.

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Figure 1: The mitotic indices observed in the MCF-7 cell cultures following 48 hour exposure to 10 µg/ml and 20 µg/ml prostaglandin A2.
Cell survival measurements do not confirm the trend in radiosensitization noted with micronuclei counts. Cell proliferation using crystal violet readings 5 days after exposure to different doses of 60Co gamma rays, was not different for control and treated samples (Figure 4).

**Figure 2.** The percentage of MCF-7 cells proliferating in the presence of 10 µg/ml and 20 µg/ml prostaglandin A2 during a 48 hour incubation period.

**Figure 3.** Micronuclei noted in the binucleated MCF-7 cells following exposure to graded doses of 60Co γ-rays. Results are shown for cell samples treated with different concentrations of prostaglandin A2 for 48 hours prior to irradiation.

**Figure 4.** Proliferation of the MCF-7 cells following exposure to graded doses of 60Co γ-rays. Results are shown for cell samples treated with different concentrations of prostaglandin A2 48 hours prior to irradiation.
It is concluded that PGA₂ may act as a radiosensitizer but that conditions more optimal than that applied in this study needs to be established. A clear mitotic block and different cell cycle kinetics can be obtained with PGA₂ treatments and further investigations are warranted.

References


2.3.3 Immunohistochemistry for characterisation of cervical cancer biopsy and smear cultures

O Herd¹, J P Slabbert¹, A Baeyens¹,², A Vral³

¹iThemba LABS, National Research Foundation, P O Box 722, Somerset West, South Africa
²Radiobiology, Department Radiation Sciences, WITS University Medical School, Johannesburg, South Africa
³Department of Basic Medical Sciences, University of Ghent, Belgium

Cervical cancer is the second most common cancer amongst South African women and the leading cancer amongst black South African women. The vast majority of cervical cancers are caused by infection with carcinogenic HPV viruses. Despite the high incidence of cervical cancer in Africa, and the extensive use of radiotherapy to treat it, there is little data on the radiosensitivity of African cervical cancer patients. The overall aim of this project is to investigate radiosensitivity of South African cervical cancer patients by developing a Micronucleus (MN) assay that can be performed on cultured cervical tumour biopsies, exfoliated cervical cells and blood lymphocytes. Thereafter we aim to determine if there is concordance in micronucleus values measured in the different tissue types, as well as to determine the effect of HIV and HPV types on the micronucleus, values and thus on the radiosensitivity of cervical cancer patients.

When culturing cervical biopsies and smears it is important to ensure that cervical squamous epithelial cells (Keratinocytes), the cells infected and transformed by HPV, are cultured and that micronucleus values are scored in these cells only. This can be achieved with the use of immunohistochemistry using antibodies specific to cytokeratins which are expressed in the cytoskeleton of cervical epithelial cells.

The immunohistochemistry technique was learned at the histology laboratory of Prof Vral, Ghent University, Belgium. With this technique it was determined whether the Anti-pan Cytokeratin Antibody AE1+AE3 from abcam, which recognizes epitopes present in most human epithelial tissues, stains specifically to cervical epithelial cells and if this can be used for characterisation of cervical biopsy and smear cultures.

Immunohistochemistry was performed on 5 μm sections of formalin-fixed, paraffin-embedded tissue specimens from five cervical biopsies (thee normal ectocervix and two tumour biopsies), collected at Charlotte Maxeke Academic hospital. Sections were deparaffinised with Toulene and rehydrated in ethanol. H&E staining was
performed to visualise cell morphology. For immunohistochemistry, antigen retrieval was achieved by incubating tissue sections in boiling 1 mM citrate buffer (pH 6.0) for 2 x 5 minutes in a microwave oven. After removing endogenous peroxidase with Hydrogen Peroxide (3% in Phosphate Buffer Solution) for 10 minutes at room temperature, the sections were incubated with blocking Serum (Phosphate Buffer Solution with 5% Normal Rabbit Serum, 1% Bovine Serum Albumin and 0.2% Tween 20) for 30 minutes at room temperature to avoid non-specific staining. Sections were then incubated for 2 hours at room temperature with prediluted mouse monoclonal Anti-pan Cytokeratin Antibody AE1+AE3, followed by an incubation with biotinylated rabbit anti-mouse secondary antibody (1/200 in dilution buffer of Phosphate Buffer Solution with 10% blocking serum) for 30 minutes at room temperature. The final incubation with horseradish streptavidine peroxidase (1/200 in dilution buffer) was for 30 minutes at room temperature, followed by treatment with enzyme substrate 3’3 Diaminobenzidine to detect peroxidase activity. Negative control sections were treated in the same way except that they were incubated with dilution buffer instead of primary antibody. The cells were counterstained with Haematoxylin and viewed under a light microscope.

Immunostaining of both normal cervical tissue and cervical carcinoma tissue with Anti-pan Cytokeratin Antibody AE1+AE3 (abcam), showed this antibody to be very specific for cervical epithelial cells and adequate for the classification of cells cultured from cervical biopsies and smears (Figure 1 and 2).

Baseline micronucleus values observed in cell cultures of radiation workers were successfully stimulated for analysis.

Figure 1: Normal stratified squamous epithelium from one of the cervical ectocervix samples. Immunostaining allows the visualisation of layers including: the basal layer (next to connective tissue), parabasal layer, intermediate layer, superficial cells and exfoliating cells. As the cells move to the surface they mature. (12.5X magnification).

Figure 2: Invasive carcinoma sample. Atypical cells from the basal layers have proliferated and spread into the underlying connective tissue. (Left picture: 25X magnification, right picture: 12.5X magnification).
2.3.4 Variations in Radiosensitivity of Different Individuals Following Exposure to $^{60}\text{Co }\gamma$-rays

P R Beukes$^1$, V Vandersickel$^1$, J P Slabbert$^1$

$^1$ iThemba LABS, National Research Foundation, P O Box 722, Somerset West, South Africa

The calculation of radiation weighting factors ($w_R$), for different radiation qualities, is based on the comparison of specific biological endpoints for cells exposed to test and reference radiation modalities. Variations in the biological response of cells or tissue to the reference radiation modality increase the uncertainty in estimating $w_R$ for high linear energy transfer sources of radiation. Consequently a study was undertaken to quantify the inherent radiosensitivities of lymphocytes obtained from different donors to a reference radiation type, $^{60}\text{Co }\gamma$-rays.

Micronucleus induction in lymphocytes was chosen as the biological endpoint to measure differences in biological response over a wide dose range. This was decided on as the cytogenetic damage in lymphocytes has previously been well documented by several authors for such studies [1 - 4]. Furthermore micronucleus induction has been shown to be a suitable endpoint to quantify lymphocyte radiation damage using a semi-automated image analysis system [5, 6]. It is essential to numerate micronucleus frequencies consistently in order to ascertain subtle differences in the inherent radiosensitivities of lymphocytes from different donors.

Peripheral blood samples were collected from ten consenting adults of varying age (Ethics Reference S12/04/091). Lymphocytes were isolated from whole blood samples through a density gradient centrifugation method and re-suspended in 10 ml RPMI 1640 medium supplemented with 15% fetal calf serum. Test tubes containing cell cultures were irradiated with graded doses of $^{60}\text{Co }\gamma$-rays using a teletherapy unit. Following irradiation, cultures were prepared to show micronuclei in binucleated lymphocytes using standard methods. Slides for microscopy were analysed using the semi-automated MetaSystems Metafer 4 platform.

The biological response to a wide range of doses was investigated for the different donors. Distinct differences in the $^{60}\text{Co }\gamma$-ray dose response curves are observed. To qualify inherent radiosensitivity differences at the 95% confidence level, ellipses were constructed that relate the covariance parameters of $\alpha$ and $\beta$ that describes the dose response curve for lymphocytes from each donor. The mean and variances were used to calculate a set of $\alpha$ and $\beta$ coordinates that demarcates the 95% confidence interval [7].

Variations in the inherent radiosensitivities of lymphocytes of donors to $\gamma$-rays are noted to be statistically significant at the 95% level of confidence. The confidence ellipses around the mean $\alpha$- and $\beta$-value estimated in each instance were separate with the exception of micronucleus formations for donors 5 and 7 and 5 and 8. For these individuals an overlap of the confidence ellipses were noted which represents a common set of $\alpha$- and $\beta$-values that could be used to describe both dose response curves.
It is concluded that results from the automated image analysis yield consistent micronucleus frequency counts. This allows the construction of well fitted dose response curves and is the principal reason why lymphocytes for 8 of the 10 donors proved to have meaningful variations in radiosensitivities to $^{60}$Co γ-rays.

Figure 1: Dose response curves for micronucleus (MN) formations in isolated T-lymphocytes of 10 different donors after exposure to various doses of $^{60}$Co γ-rays.

Figure 2: The 95% confidence ellipses for dose response parameters for lymphocyte samples of different individuals irradiated with $^{60}$Co γ-rays.
2.3.5 Synthesis and cell uptake studies of a radiolabelled receptor-targeting compound for early detection of oesophageal cancer

K Hadley1, D Hendricks1, D D Rossouw2, P Beukes2, J P Slabbert2

1 Division of Medical Biochemistry, Faculty of Health Sciences, University of Cape town, Observatory, 7925, South Africa
2iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa

The aim of this project is to develop a radiolabelled form of a small molecule antagonist (named SB) of a cell surface receptor known to be up-regulated in oesophageal cancer. This will be tested in vitro for binding activity, with a view to using it as marker for radiodetection of oesophageal cancer at early stages of development, at which stage patients have a higher survival rate.

Work to date has included development of an in vitro model system for testing, synthesis of an iodinated analogue (I-SB) and testing the biological activity of the iodinated molecule compared to the brominated parent compound. Results indicated that I-SB retained various in vitro effects on cells compared to the parent molecule. These included inhibition of proliferation, cell cycle arrest and induction of apoptosis. The I-SB molecule was labelled with $^{123}$I by ion exchange. Unfortunately this labelling strategy resulted in low specific activity, and the high non-specific binding prevented discrimination between cells that expressed the receptor, and those in which the receptor was knocked down.

In an effort to circumvent the low specific activity of the labelled iodinated compound, it was decided to reduce the amount of total activity with which the cells were incubated, in the hope that the affinity of the ligand for the receptor would be strong enough to allow detection of this low amount of radioligand, below the saturation threshold of the cell surface receptors. Unfortunately, as shown in Figure 1 below, reducing the amount of labelled ligand by 10- to 100-fold (from 3 μCi to 0.3 μCi or 0.03 μCi) still did not allow specific detection of the presence of the cell surface receptor.

This prompted an alternative strategy for labelling the compound, which necessitated structural modification of the small molecule antagonist. The unlabelled modified molecule (SM for structurally modified) was tested in vitro for its ability to block cell proliferation, and induce cell cycle arrest and apoptosis. The results showed that SM
had a higher IC₅₀ (approximately 18 μM in WHCO1 and WHCO6 cells) compared to the original small molecule antagonist SB (approximately 2 μM in these cell lines). Furthermore, it did not induce significant cell cycle arrest in the cancer cell lines (data not shown). As shown in Figure 2, SM did not induce apoptosis, as measured by Western blotting for the cleaved form of PARP.

Although it is not yet clear whether the SM molecule binds to the receptor in the same way as the parent SB, the reduced cytotoxicity of this compound could present a significant advantage in the in vivo setting. This is also in line with other small molecule antagonists of the same receptor, which have also been found to have low cytotoxicity.

Current work is aimed at developing an in vitro assay to detect antagonism of the cell surface receptor, in order to confirm specific binding by the SM molecule, and any other derivatives that may be developed. Attempts at assaying this by Western blotting for phosphorylation of kinases downstream of the cell surface receptor have revealed that high background may make this approach extremely tricky. An alternative approach using reporter-based assays for transcription factors activated by the cell surface receptor in response to its cognate ligand are underway.
2.3.6 The role of DNA double-strand break repair proteins after low- and high-LET radiation exposure.

J Depuydt 1, V Vandersickel 2, P Beukes 2, J Slabbert 2 and A Vral 1

1 Department of Basic Medical Sciences, University of Ghent, Belgium
2 iThemba LABS, National Research Foundation, P O Box 722, Somerset West, 7129, South Africa

The collaborative project between iThemba LABS and the University of Ghent (Belgium) allows us to investigate the role of different repair proteins after exposure of breast epithelial cells to different radiation qualities.

Previous work focused on the role of the Ku heterodimer after exposure of human MCF10A breast epithelial cells to low-LET γ-rays and high-LET p(66)+Be(40) neutrons. In this work, the role of one of the major breast cancer susceptibility proteins, BRCA1, is also investigated. The major pathways involved in the repair of double-strand breaks (DSB) induced by ionizing radiation are the non-homologous end-joining (NHEJ) and the homologous recombination (HR) pathways. While the Ku heterodimer is considered one of the key players in the NHEJ pathway, the BRCA1 protein plays a role in the HR pathway.

An important difference between the two DSB repair pathways is the need for a homologous DNA template to repair the break. While in the HR pathway, repair can only take place when a homologous strand is available, in the NHEJ pathway end-joining occurs without the use of a homologous template. As a result, functioning of both pathways is believed to be cell cycle phase specific, with the HR pathway operating mainly during late S/G2, and NHEJ working during all phases of the cell cycle.

![Figure 1](image_url)

**Figure 1:** Results of western blotting after loading whole cell lysates of Ku70/80 and BRCA1 MCF10A knockdown and their respective control cell lines. After separation of proteins, antibodies of interest were used to visualize proteins of interest. Actinin was used as a protein loading control. In the Ku70 knockdown cell line, a clear knockdown of Ku70 and Ku80 proteins is visible. In the BRCA1 knockdown cell line, a clear reduction in BRCA1 proteins is observed.
To analyse the role of the Ku and BRCA1 proteins in repair after radiation exposure, human breast epithelial MCF10A cell lines which have a stable knockdown of either the Ku70/80 or BRCA1 proteins were generated (see previous annual reports, Figure 1). To understand the role of these proteins in DSB repair after induction of DSBs by ionizing radiation, Ku70/80 and BRCA1 knockdown cell lines with their respective controls were irradiated with graded doses of $^{60}$Co $\gamma$-rays or p(66)+Be(40) neutrons. The effects of radiation were measured using different biological endpoints. These include (a) detection of micronuclei in binucleated cells to analyse the result of mis- or non-repair of DSB [1] and (b) analysis of the proliferative capacity of the cells using the crystal violet cell proliferation assay [2]. Since BRCA1 is implicated in the HR pathway, detection of micronuclei was limited to cultures stopped 16 hours after radiation exposure instead of the normal 48 hours.

Preliminary results show that knockdown of the BRCA1 and Ku70/80 proteins resulted in an increase in the number of micronuclei compared to their respective controls and this after exposure of cells to both radiation qualities (Figure 2). In addition, a decrease in the proliferative capacity of cells with a BRCA1 and Ku70/80 deficiency was observed (Figure 3). Importantly, we observed that both the extent of the increase in micronucleus number and the decrease in proliferative capacity are influenced by the protein down-regulated and the radiation quality used.

![Figure 2](image2.png)

**Figure 2:** Micronuclei induced after exposure of BRCA1 (upper panel) and Ku70/80 (lower panel) knockdown and control cell lines to $\gamma$-rays and neutrons.

![Figure 3](image3.png)

**Figure 3:** Cell survival analysed with the crystal violet cell proliferation assay after exposure of BRCA1 (left panel) and Ku70/80 (right panel) knockdown and control cell lines to $\gamma$-rays and neutrons.
From these results it is clear that the Ku70/80 heterodimer as well as BRCA1 play an important but different role in DSB repair after exposure to $^{60}$Co $\gamma$-rays as well as high energy neutrons. These results may have important implications for the use of strategies that can improve the outcome of radiotherapy by interfering with the DNA repair capacity of tumour cells.

References

2.4 Radioisotope Production Department

2.4.1 Development of $^{68}$Ga-based PET Radiopharmaceuticals for the Management of Cancer and other Chronic Diseases.

D Rossouw, D Prince, C Davids

iThemba LABS, National Research Foundation, P O Box 722, Somerset West, 7129 South Africa

South Africa has only been introduced in the last six to seven years to the routine supply of positron emitting radionuclides such as $^{18}$F-FDG for Positron Emission Tomography (PET) imaging. To ensure that South African PET grows beyond $^{18}$F-FDG, an IAEA-sponsored research project was proposed to introduce $^{68}$Ga-labelled DOTA-conjugated somatostatin peptide derivatives such as -TOC,- NOC and -TATE for the management of neuroendocrine tumours [1, 2] within the South African context. This study focuses on the usage of the tin dioxide matrix $^{68}$Ge/$^{68}$Ga generator of iThemba LABS over a 12 month period. Its main objectives are based on a comprehensive evaluation of the eluate of the iThemba LABS generator for $^{68}$Ga-radiopharmaceutical formulation, to develop safe and robust formulations of the mentioned $^{68}$Ga-labelled DOTA-conjugated somatostatin derivatives, to develop quality assurance procedures for the formulations of the above radiolabelled peptides, to ensure safe clinical application, and to do the necessary biological evaluations. This report covers the first three objectives of this study.

Elution data of two generators have been compiled over a 12 month period. The generators were eluted with 0.6 M hydrochloric acid which offers a suitable balance between optimal elution efficiency and usability for labelling. Data obtained for a 50 mCi generator that was manufactured in April 2012 is presented in Table 1 and indicate that a good quality sterile eluate is obtained. Elution efficiencies are high, minimal $^{68}$Ge breakthrough is encountered during the first six months, and total metal content is less than 14 ppm after 1 year.

<table>
<thead>
<tr>
<th></th>
<th>Outset</th>
<th>3 months</th>
<th>6 months</th>
<th>9 months</th>
<th>12 months</th>
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</thead>
<tbody>
<tr>
<td>Elution efficiencies (%)</td>
<td>125</td>
<td>124</td>
<td>109</td>
<td>87</td>
<td>85</td>
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<tr>
<td>$^{68}$Ge breakthrough (%)</td>
<td>0.0004</td>
<td>0.0074</td>
<td>0.0101</td>
<td>0.075</td>
<td>0.2672</td>
</tr>
<tr>
<td>Total metal (ppm)</td>
<td>3.5</td>
<td>6.27</td>
<td>6.77</td>
<td>8.55</td>
<td>13.48</td>
</tr>
<tr>
<td>Endotoxin conc. (EU/ml)</td>
<td>0.73</td>
<td>0.73</td>
<td>0.75</td>
<td>0.91</td>
<td>1.13</td>
</tr>
</tbody>
</table>

Table 1: Elution data of a 50 mCi iThemba LABS $^{68}$Ge/$^{68}$Ga generator. Eluates were found to be sterile during the whole period.

The three DOTA-peptide ligands were labelled with $^{68}$Ga eluates under identical conditions. Portions of the eluates in 0.6 M HCl were mixed with a sodium acetate buffer solution to render a buffered mixture at a suitable pH for labelling. In order to assess the influence of peptide ligand content on labelling efficiency and yields, various amounts of the three peptide ligands were introduced in labelling mixtures. The latter were heated for short periods and subsequently purified on reversed phase silica gel cartridges. The labelled peptide was
desorbed with saline/ethanol mixtures. Activities in ethanol/saline fractions were expressed as percentages of decay-corrected starting activities and represent the labelling yields. Radiochemical purities were assessed by means of High Performance Liquid Chromatography (HPLC) and paper chromatography (ITLC). An ITLC method had been tested and validated to ensure its robustness and reliability under various conditions. In addition to the described labelling procedure, the feasibility of using pre-prepared kit formulations of the three peptide ligands was also investigated. Kits containing 35 µg peptide and buffer salt were prepared and stored in solid state at −20°C for periods up to 32 weeks. Labelling was carried out after certain storage periods.

<table>
<thead>
<tr>
<th>Peptide ligand</th>
<th>Amount of peptide (µg)</th>
<th>*Mean decay-corrected labelling yields (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOTA-TATE</td>
<td>15</td>
<td>46 ±20 (n=8)</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>66 ±11 (n=8)</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>70 ±8 (n=8)</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>68 ±4 (n=4)</td>
</tr>
<tr>
<td>DOTA-TOC</td>
<td>15</td>
<td>45 ±22 (n=9)</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>70 ±10 (n=7)</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>75 ±7 (n=6)</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>77 ±3 (n=4)</td>
</tr>
<tr>
<td>DOTA-NOC</td>
<td>15</td>
<td>34 ±27 (n=5)</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>52 ±24 (n=5)</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>74 ±7 (n=6)</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>74 ±3 (n=4)</td>
</tr>
</tbody>
</table>

Table 2: Mean decay-corrected labelling yields of 68Ga-labelled DOTA-peptides as a function of amount of peptide. (*Yield data for DOTA-TATE and TOC were obtained by silica desorption with 50% ethanol/saline; for DOTA-NOC 70% ethanol/saline was used).

Mean labelling yields (displayed in Table 2) were most consistent when using at least 35 µg peptide ligand. Labelling data for the three peptide ligands appear to be similar, but DOTA-NOC required a stronger desorption solvent during purification. Purification post labelling provided a radionuclidically and radiochemically pure product (close to 100%) as shown by both HPLC and ITLC. The ITLC method appeared to be robust and results compared well with HPLC, implying that it can be safely applied in a hospital setup lacking HPLC equipment. The use of saline/ethanol mixtures in the purification step ensures that the purified product can be easily converted into an injectable radiopharmaceutical. The use of labelling kit formulations appeared to be highly feasible (Table 3), with no consistent decline in labelling yields when kits are stored at −20°C over a period of 32 weeks.
In conclusion, radiochemical yield data suggest that the relatively highly acidic eluates from a tin dioxide based generator are suitable for direct use in the radiolabelling of all three peptide ligands, making them all available as $^{68}$Ga-labelled neuroendocrine tumour PET imaging agents.

References

2.5 Materials Research Department

2.5.1 Real-Time RBS investigation of the stability of GeSn strained layers

C M Comrie1,2, C B Mtshali1 and A Vantomme3.

1 iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa
2 Department of Physics, University of Cape Town, Rondebosch 7700
3 Department of Physics and Astronomy, KU Leuven, Leuven, B-3001 Belgium

When Group IV elements, C, Si, Ge and Sn, are alloyed with each other it gives rise to a change in lattice constant. If the alloy film is now grown on a single crystal substrate the difference in lattice constant between the alloy layer and single crystal substrate will result in the film being strained. This strain will in turn alter the band structure and hence the electronic properties of the layer. Alloys of Si with C and Ge have been extensively studies, and the increased electron and hole mobility found in SiGe strained layers has already been used to increase the speed of electronic devices. In the case of Ge there are theoretical predictions which indicate that if Ge is alloyed with Sn (in sufficient quantities) the strain introduced would not only increase mobility in the layer but it could give rise to an indirect-to-direct transition of the band gap, thus opening up the possibility of creating opto-electronic devices – the holy grail of the microelectronic industry.

Unfortunately the diamond structure of α-Sn is unstable above 13°C thus making it difficult to incorporate Sn in the Ge. Furthermore the Ge-Sn phase diagram predicts very little immiscibility, limiting thermodynamically stable Sn incorporation to about 1%. This is far too low to give rise to the desired properties, but despite these constraints careful preparation by molecular beam epitaxy (MBE) and chemical vapour deposition (CVD) has enabled metastable alloy layers with Sn levels of around 10% to be achieved.

Up until now most of the attention has gone into understanding the growth mechanism and properties of the as-grown strained GeSn films. Integration of these strained films into advanced electronic devices will also expose them to thermal treatments and to metallization, which may alter the stability of these metastable films. We have investigated the stability of Sn in GeSn thin films grown on Ge by CVD and MBE techniques using real-time Rutherford Backscattering Spectrometry (RBS) during a ramped thermal anneal to monitor their thermal stability during a thermal treatment. Real-time RBS has also been used to monitor the effect of metallization on the stability of Sn in the GeSn layer.

Figure 1(a) below shows a contour plot obtained during a ramped thermal anneal at 2°C/minute of a 20 nm Ge(6%Sn) layer grown on Ge(100) by CVD. As can be seen in the figure the contours formed by the Sn RBS signal (which falls between channel 405-435) run roughly parallel in a vertical direction, which indicates that the Sn is stable in the GeSn strained layer at temperatures up to 600°C. Similar results were obtained from MBE grown samples. RBS channelling along the <110> axis will be undertaken to establish if any relaxation occurs in the strained metastable films during the thermal anneal.
The situation during Co metallization depicted in Figure 1(b) is significantly different. As soon as the Co begins to react with the GeSn film (around 330°C) the Sn contours moves to higher channels indicating that the Co has begun to diffuse into the GeSn layer and react to form Co2(Ge1-xSnx).

However, instead of forming a single broad uniform layer one soon finds a more intense contour appearing at the higher channels, which continues to grow in intensity as the temperature is raised (and long after the Co/Ge reaction has been completed). This indicates that the Sn is not stable in the germanide and is released, where after it diffuses to the surface of the sample. Metallization using other metals such as Pt, Pd, Ni, and Cu show similar results.

The results obtained so far therefore show that Sn is stable in GeSn layers up to temperatures as high as 600°C but is not stable in ternary germanides, with the Sn that is released segregating at the sample’s surface. Unfortunately in all the samples analysed to date the amount of metal deposited on top of the GeSn strained layer was more than sufficient to consume all the Ge and Sn in the strained layer. What has not yet been established is what happens if the metal were only to consume a portion of the GeSn strained layer during metallization, because if the Sn was still stable in the remaining GeSn layer sandwiched between the germanide contact layer and the underlying Ge(100) substrate, the beneficial effects of the strained layer could still persist. The next stage of the investigation will therefore investigate the reaction between thin metal layers and thick GeSn strained layers, with a focus on the properties of the GeSn layer remaining after metallization.

Real-time RBS has proven to be an invaluable tool to monitor the stability of Sn in the GeSn strained layers. The software has recently been adapted to enable RBS data to be collected simultaneously on two detectors. This enables greater depth resolution to be obtained from a glancing angle detector while at the same time achieving good mass separation from the other detector placed at 165°. We are presently looking at ways to extend the thermal anneal range to at least 800°C, which would make the technique more versatile for diffusion studies.
2.5.2 Compositional analysis and depth profiling of thin film CrO$_2$ by heavy ion ERDA and standard RBS: a comparison

S Khamlich$^1$, M Msimanga$^2$, C A Pineda-Vargas$^3$, Z Y Nuru$^3$, R McCrindle$^1$, M Maaza$^3$

$^1$Department of Chemistry, Tshwane University of Technology, Private Bag X 680, Pretoria, 0001 South Africa
$^2$iThemba LABS Gauteng, National Research Foundation, Private Bag 11, WITS 2050, South Africa
$^3$iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa

Chromium dioxide (CrO$_2$) thin films have generated considerable interest in applied research due to the wide variety of its technological applications. However, its synthesis is usually a difficult task due to its metastable nature, and various synthesis techniques are being investigated. In this work a polycrystalline thin film of CrO$_2$ was prepared by electron beam vaporization of Cr$_2$O$_3$ onto a Si substrate. The stoichiometry and elemental depth distribution of the deposited film were measured by two ion beam nuclear analytical techniques, viz. heavy ion elastic recoil detection analysis (ERDA) (Figures 1(a,b,c) and Rutherford backscattering spectrometry (RBS) (Figure 1d), which both have relative advantage over non-nuclear spectrometry techniques in that they can readily provide quantitative information about the concentration and distribution of different atomic species in a layer. Moreover, the analysis carried out highlights the importance of complementary usage of the two techniques to obtain a more complete description of elemental content and depth distribution in thin films.

Figure 1(a): 2-D ToF–energy scatter plot from the analysis of a CrO$_2$/Si sample using a 27.5 MeV Kr$^{15+}$ incident beam. The dashed line encloses an example of a region used for O elemental analysis.

Figure 1(b): Elemental energy spectra of recoils (and scattered beam) from the CrO$_2$/Si target sample.

Figure 1(c): Atomic depth profiles of recoils from the CrO$_2$/Si target sample.

Figure 1(d): Elemental energy spectra of recoils (and scattered beam) from the CrO$_2$/Si target sample.
2.5.3 Sputtering and surface topography modification of bismuth thin films under swift \(^{84}\text{Kr}^{15+}\) ion irradiation

S Mameri\(^1\), S Ouichaoui\(^2\), H Ammi\(^1\), C A Pineda-Vargas\(^3\), A Dib\(^1\), M Msimanga\(^4\)

\(^1\) Centre de Recherche Nucléaire d’Alger, CRNA, B.P. 399, 02 Bd. Frantz-Fanon, Alger-Gare, Algiers, Algeria
\(^2\) Université des Sciences et de la Technologie H. Boumediene (USTHB), Faculté de Physique, Laboratoire SNIRM, B.P. 32, El-Alia, 16111 Bab Ezzouar, Algiers, Algeria
\(^3\) iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa
\(^4\) iThemba LABS (Gauteng), National Research Foundation, Private Bag 11, WITS 2050, South Africa

The electronic sputtering, induced by swift heavy ion irradiation and expected to be caused by inelastic collisions, has been studied principally for insulators and for some metallic targets \([1]\). In the case of semi-metallic (polycrystalline) targets having specific properties like bismuth (Bi), however, swift heavy ion irradiation-induced effects and underlying mechanisms are still not well understood \([2]\).

The observed modifications suffered by the Bi film surface upon swift heavy ion irradiation are moderate and likely essentially caused by electronic collision interaction mechanisms (ion/atom recoils and displacements). However, although one expects these processes to be the main cause behind the observed high Bi sputtering yield and other irradiation-induced surface effects, elastic nuclear collision mechanisms may also play a non-negligible role in this respect.

The sputtering and surface topography modification of bismuth thin films deposited onto Si substrates and irradiated by 27.5 MeV \(^{84}\text{Kr}^{15+}\) ions over the fluence range \(10^{12} \text{ – } 10^{14} \text{ cm}^{-2}\) have been studied using three complementary techniques: Rutherford backscattering spectrometry (RBS) (see Figure 1), atomic force microscopy (AFM), and X-ray diffraction (XRD). The RBS analysis reveals a linear reduction of the initial thickness of the irradiated bismuth samples by \(\sim 4\% \text{ to } 7\%\) with increasing ion fluence corresponding to a mean sputtering yield of \(\sim 2.9 \times 10^2 \text{ at/ion}\) (see Figure 2). Significant sample surface topography changes occur upon ion irradiation consisting of grain growth and surface roughening, clearly observed in AFM and XRD analyses. Moreover, a close correlation is observed between the variations as a function of ion fluence of the measured sputtering yield, the determined Bi surface grain size and compressive strain. These moderate Bi surface effects are similar to those pointed out previously for thin films irradiated by MeV heavy ions. They can be mainly caused by inelastic electronic collision mechanisms taking place within the Bi material electronic stopping power regime below the threshold for latent track formation.

In the current case of 27.5 MeV \(^{84}\text{Kr}^{15+}\) ions incident on Bi, however, considering mainly the large magnitude of the measured sputtering yield not reproduced either by the linear or by the non-linear nuclear collision cascade theories, one is led to assume that the ion–solid interaction mechanisms due to inelastic electronic collisions are likely to dominate. This is consistent with the fact that for incident swift \(^{84}\text{Kr}^{15+}\) ions, the Bi electronic stopping power (increasing as \(\sim E^{1/3}\)) considerably dominates the target nuclear stopping power (decreasing as \(E^{-1}\), i.e. \(S_e \sim 8.08 \text{ keV} \text{ nm} \gg S_n \sim 0.18 \text{ keV} \text{ nm}\)).
References


2.5.4 Stopping power and energy loss straggling of thin Formvar foils for 0.3–2.7 MeV protons and alpha particles

S Mamerri1, H Ammi1, A Dib1, C A Pineda-Vargas2, S Ourabah3, M Msimanga4, M Chekirine5, A Guesmia5

1 Centre de Recherche Nucléaire d’Alger, 2 Bd. Frantz Fanon, B.P. 399, Alger-Gare, Algeria
2 iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa
3 Ecole Préparatoire en Sciences et Techniques d’Alger, B.P. 474, Place-des-Martyres, Algeria
4 iThemba LABS (Gauteng), National Research Foundation, Private Bag 11, WITS 2050, South Africa
5 Université Saad Dahleb, B.P. 270, Route de Soumaa, Blida, Algeria

In the present study, we report on stopping power and energy loss straggling measurements for H+ and He+ ions crossing thin Formvar foils (thickness of ~0.3 mm) over the ion incident energy range of 0.3 – 2.7 MeV. Notice that for this polymer only limited experimental stopping power data are available [1,2] for both H+ and He+ ions, while no measured straggling values are found in the literature. Through this investigation we would like also to provide useful information about the limited use of the Bohr classical theory to correctly describe the energy loss straggling process in the case of very thin foils. To carry out stopping power and energy straggling measurements, we have adopted a previously improved experimental method [3] based on Rutherford backscattering spectrometry and the transmission of the secondary produced ions for data analysis.

Stopping power and energy loss straggling data for protons (H+) and alpha particles (4He+) were measured in the energy range 0.3 – 2.7 MeV by using the indirect transmission technique. The determined stopping power data were compared to SRIM-2010, PSTAR or ASTAR calculation codes and then analysed in term of the modified
Bethe–Bloch theory to extract the target mean excitation and ionization potential $< I >$. A resulting value of $< I > \approx 69.27 \pm 1.8$ eV was deduced from proton stopping data. The measured straggling data were corrected for surface roughness effects due to target thickness inhomogeneity observed by the atomic force microscopy (AFM) technique. The obtained data were then compared to derived straggling values from the Bohr and Bethe–Livingston classical theories or from Yang’s empirical formula. A deviation of ~40%–80% from the Bohr straggling value has been observed for all reported energies, suggesting that the Bohr theory cannot be correctly applied to describe the electronic energy loss straggling process with the Formvar foil of the thickness used here. The inner-shell contribution of target electrons to the energy loss process is also advanced to explain the observed deviation from experiment in case of He$^+$ ions.

References


2.5.5 X-ray scattering and EXAFS studies of Pt$_{1-x}$V$_x$ alloys

A Gibaud$^1$, M Topic$^2$, G Corbel$^3$, V Briois$^4$, D Thiaudièrie$^4$, C A Pineda-Vargas$^2$, T Ntsoane$^5$

$^1$ Laboratoire de physique de l’état condensé, UMR-CNRS 6087, Université du Maine, Avenue Olivier Messiaen, 72085 Le Mans cedex 9, France
$^2$ iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa
$^3$ Laboratoire des oxydes et fluorures, UMR-CNRS 6010, Université du Maine, Avenue Olivier Messiaen, 72085 Le Mans cedex 9, France
$^4$ Synchrotron SOLEIL, L’Orme des Merisiers Saint-Aubin BP 48, 91192 Gif-Sur-Yvette cedex, France
$^5$ Necsa, P.O. Box 582, Pretoria 0001, South Africa

The research interest in this study focused on the Pt–V binary system as a potential candidate for catalytic applications. We studied this system as a function of vanadium concentration, which will serve as a model system for our further study of a variety of Pt- and Pd-based systems. In the present work we report on the determination of the lattice parameter and the distance between vanadium and its first neighbours in Pt$_{1-x}$V$_x$ alloys as a function of vanadium concentration in the range 0 < x < 50 at.% using X-ray scattering and extended X-ray absorption fine structure (EXAFS) methods.
Alloys of the Pt–V system between 0 and 50 at.% V have been investigated by X-ray scattering and EXAFS. The variation of the lattice parameter with the nominal chemical composition was measured and compared to previously reported values. The solid solution was observed in alloys containing up to 20 at.% V. In the alloy with a higher vanadium concentration of 50 at.%, we found that the alloy is not homogeneous and exhibits a segregation of Pt and PtV phases in addition to VO₂(M) phase. These experiments are complemented by EXAFS measurements made at the K-edge of V (see Figure 1) which clearly show the sensitivity of this technique to V content. Determination of the local environment of V and Pt is made via a basic model taking into account the first neighbours only.

![Figure 1: Left panel: Fourier inversion of the EXAFS data showing the evolution of the V first neighbours versus V concentration. Right panel: calculated and observed data in k space.](image)

### 2.5.6 Feasibility of PIXE in Lateral Diffusion of Ge Couples on Ni.

D Chilukusha¹, R Nemutudi², A Habanyama¹, C A Pineda-Vargas², C M Comrie³

¹University of Zambia, Department of Physics, School of Natural Science, P.O. Box 32379, Lusaka 10101, Zambia
²iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129 South Africa
³University of Cape Town, Department of Physics, Rondebosch, 7700, South Africa

Lateral diffusion couples have a unique advantage over thin-film couples in that the compound phases are formed on the surface and are therefore easier to resolve. The technique that is most commonly used in studies of lateral diffusion couples is Microprobe Rutherford backscattering spectrometry (μ-RBS). This technique however requires that the positions of the interacting species on the periodic table are not too close in terms of atomic number and therefore do not produce excessive peak overlap. A number of systems of technological importance have atomic numbers which are close. Notable examples are the Ni-Ge and Co-Ge systems which are very important for micro/optoelectronic applications. In order to satisfactorily characterise such systems, it is
imperative to find techniques which can complement μ-RBS. One of the objectives of this study was to determine the extent to which PIXE could be applied in the lateral diffusion couple study of a system with close atomic numbers.

The map in Figure 1 from Ge L X-rays shows the 2D-elemental distribution. At first glance, it would seem that the boundary that appears well-defined between regions A and B was the original island/thin-film interface. However, after careful analysis of the dimensions of the area that was darkened by the carbon-deposition (see optical micrograph in Figure 2), it was found that the original interface actually corresponded to the position indicated by the white line in the PIXE map of Figure 1. The five distinct regions, observed with other imaging techniques, are also discernible with PIXE. Whereas optical microscopy and SEM showed lucidly the boundary between regions B and C, PIXE could not resolve it very clearly.

There is a noticeable decrease in the intensity of the Ge as one move from region A to region B, while the difference in signal intensity between subsequent regions is barely visible. The substantial drop in the X-ray intensity between regions A and B suggests that there was a significant difference in the Ge content of the two regions, in agreement with the results found with μ-RBS.

Table 1 shows atomic calculations leading to the determination of the atomic ratio of Ni and Ge in the island region of the as-deposited sample. It was known that these atoms were not in compound form since the system had not yet been subjected to heat treatment. The thickness ratio of the two atomic species, as determined by μ-RBS, is also indicated in the Table 1. Good agreement is observed between the two techniques.
2.5.7 PIXE as a Characterization Technique in the Cutting Tool Industry

C S Freemantle¹,², N Sacks³, M Topic³, C A Pineda-Vargas³

¹School of Chemical & Metallurgical Engineering and DST/NRF Centre of Excellence in Strong Materials, University of the Witwatersrand, P/Bag 3, Wits, 2050, South Africa
²Pilot Tools (Pty) (Ltd), P.O. Box 27559, Benrose, 2011, South Africa
³iThemba LABS, National Research Foundation, P.O. Box 722, Somerset West, 7129, South Africa

Cutting tool materials have to withstand extreme process conditions in their application and require properties such as high hardness at elevated temperatures, high abrasive wear resistance, high deformation resistance, high fracture toughness, chemical inertness, and high stiffness [1]. Recycling of used tungsten carbide (WC) tools has become a problem in the cemented carbide industry. Cemented carbides account for approximately two thirds of the world’s tungsten consumption and if present production volume continues, the resources could be exhausted in 40 years [2]. In the present investigation, a tool grade (TG) material containing intentionally added, additional cubic carbide phases (TiC, TaC, NbC) and a zinc recycled grade produced for a mining application, that ideally should contain no cubic carbide phases in straight grade (SG) was studied. Micro-PIXE was used to determine 2D-elemental distribution within spray dried granules of each powder (TG and SG) in order to assess the levels of impurities unintentionally added in the recycling and manufacturing processes as well as those elements deliberately added during batch makeup.

A SEM micrograph and elemental maps for the recycled mining grade powder are shown in Figure 1. Similarly the tool grade powder is shown in Figure 2, in which the WL map (concentration of W from L X-rays) is also shown to demonstrate the dominant elemental distribution in PIXE mapping. Table 1 shows the overall elemental concentration comparison of the circular regions indicated for each powder.

Ti containing materials indeed appear to enter the scrap collection batch. Titanium should not be present at all in a ‘straight grade’. Titanium can be seen to be well distributed within the TG powder and the recycled SG powder, demonstrating that a satisfactory production process was employed in order to homogenize the powders. The level of Ti may alter the performance of the recycled SG products and ultimately the performance of the tool. Iron contamination from recycling and powder processing respectively is evident, indicating the build-up of iron in recycling (using the zinc method); similarly increased Ni concentration in the recycled grade was detected while none was detected in the tool grade powder (Table 1). Iron was also detected in the tool grade, and likely

<table>
<thead>
<tr>
<th>Region</th>
<th>Element</th>
<th>% Wt</th>
<th>Moles</th>
<th>PIXE ratio of Ni to Ge atoms</th>
<th>RBS ratio of as-deposited Ni and Ge layers</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Ni</td>
<td>9.5</td>
<td>9.5 g × (1 mol/58.69 g) = 0.162 mol Ni</td>
<td>1 : 2.72</td>
<td>330 : 1020</td>
</tr>
<tr>
<td></td>
<td>Ge</td>
<td>32</td>
<td>32 g × (1 mol/72.63 g) = 0.441 molGe</td>
<td></td>
<td>1 : 3</td>
</tr>
</tbody>
</table>

Table 1: Calculation of the atomic ratio of Ni to Ge in the island region of the as-deposited sample.
originated, at least in part, from ball milling in manufacturing. The same applies to nickel. Up to 0.3wt.% Fe can completely dissolve in the binder phase and recycling and milling have previously been identified to contribute to this.

<table>
<thead>
<tr>
<th>Element</th>
<th>W</th>
<th>Co</th>
<th>Ti</th>
<th>Ta</th>
<th>Nb</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SG</strong></td>
<td>89.77 ± 1.08 (0.05)</td>
<td>6.66 ± 0.01 (0.01)</td>
<td>0.13 ± 0.01 (0.01)</td>
<td>ND</td>
<td>ND</td>
<td>0.12 ± 0.01 (0.02)</td>
</tr>
<tr>
<td><strong>TG</strong></td>
<td>78.44 ± 0.09 (0.03)</td>
<td>7.59 ± 0.02 (0.004)</td>
<td>5.12 ± 0.02 (0.006)</td>
<td>2.65 ± 0.03 (0.04)</td>
<td>0.31 ± 0.05 (0.10)</td>
<td>0.15 ± 0.01 (0.01)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element</th>
<th>Fe</th>
<th>Ni</th>
<th>Cr</th>
<th>Cl</th>
<th>Ca</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SG</strong></td>
<td>0.21 ± 0.01 (0.01)</td>
<td>0.09 ± 0.02 (0.02)</td>
<td>0.02 ± 0.01 (0.01)</td>
<td>0.05 ± 0.05 (0.05)</td>
<td>0.04 ± 0.01 (0.02)</td>
<td>1.23 ± 0.11 (0.09)</td>
</tr>
<tr>
<td><strong>TG</strong></td>
<td>0.034 ± 0.002 (0.004)</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

Table 1: Extracted elemental composition (wt%) of the circular regions (Figures 2 and 3) with errors and minimum detection limits (in brackets) for the recycled straight grade and tool grade powders.

References

2.5.8 Structural and electrical characterization of printed metallic nanoparticles

C B van den Berg¹, B Magunje¹, D T Britton¹, M Harting¹, M Topic²

¹NanoSciences Innovation Centre, Department of Physics, University of Cape Town, Rondebosch, 7701, Cape Town, South Africa
²iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa

Printed electronics technology has attracted interest over the last few years as an alternative to conventional methods for the fabrication of electronic devices. Printing techniques such as screen, inkjet, and Gravure offset printing have been used for fabricating electronic devices. These techniques are advantageous because they are relatively simple, promise low production cost and can be adapted for large scale production. Another advantage is the wide variety of materials such as paper, plastics and ceramics that can be used as substrates [1,2]. One of the major challenges is to formulate suitable inks for the different printing techniques. Functional electronics inks consist of nanoparticles dispersed in a liquid medium. Printing the inks involves the selective deposition of the functional materials onto a substrate followed by a curing stage which may involve a number of processing steps [1,3]. For this reason metallic nanoparticles are of particular interest due to their applications in forming conductive tracks. Conductivity through the printed layer depends on how densely the nanoparticles are packed in the printed layer after curing [3]. The basic requirement is therefore that the concentration of the nanoparticles must be above the percolation threshold for charge transport [4]. The aim of this study is to characterize the structure of printed metallic layers to interpret the electrical transport through the metals.

Ag nanoparticles (APS~70 nm) was supplied by Sigma-Aldrich. Ag inks containing 40%, 50%, 55%, 60%, 70% by weight (wt%) with a commercially available acrylic ink base were prepared. The printing of the Ag inks was performed using an ATMA AT-60PD semi-automatic flatbed screen printer [4]. Scanning electron microscopy (SEM) studies on the printed layers were carried out on the Nova NanoSEM, operating in the backscatter electron mode with a beam energy of 10 keV. The surface topography for each sample was analysed using the Veeco NT 9000 series optical profiler. Electrical tests were performed on the samples using a LakeShore 7500 Series Hall Effect Measurement System. The sheet resistivity $\rho_s$ was measured in the van der Pauw geometry.

The SEM micrographs for the printed layers (Figure 1) show for lower particle loadings a layer that has generally lower particle density, and gaps between particles. As the particle loading increases, the particles begin to cluster and the gaps between individual particles decreases. At high particle loadings the density of the clusters increases and eventually giving the appearance of a uniform dense layer of connected particles. Sheet resistivity ($\rho_s$) is influenced by the packing structure and the roughness of the printed nanoparticulate layer. Below the percolation threshold the packing structure is more open and there are fewer conducting channels resulting in large roughness and high $\rho_s$. Above the percolation threshold the packing structure of the nanoparticles shows a higher density which gives rise to the reduced roughness and lower $\rho_s$. Observations made from SEM studies together with the electrical measurements show the percolation threshold for this particular system lies in the region of 55 wt% Ag.
2.5.9 Trace element zoning of sulphides and quartz at Sheba and Fairview gold mines: clues to mineralisation in the Barberton Greenstone Belt

A Agangi1, A Hofmann1, W J Przybylowicz2

1 Paleoproterozoic Mineralization (PPM) Res. Group, Department of Geology, University of Johannesburg
2 iThemba LABS, National Research Foundation, P O Box 722, Somerset West, South Africa

Hydrothermal fluids can mobilise a wide range of elements, including elements of economic interest (e.g. Au, Cu, Ag). These elements can then be deposited and concentrated following changes in physical-chemical parameters of the transporting fluids, such as boiling (separation of a vapour phase) and changes in oxidation state or pH. Fluctuations in chemical composition of these ore-forming fluids will result in varying chemical composition of the crystallising minerals (chemical zoning).
The chemical zoning of pyrite (FeS$_2$) and other sulphide minerals can record the evolution of mineralising fluids at widely varying P-T conditions ranging from diagenesis to medium metamorphic grade [1]. Chemical zoning of sulphides is invisible in optical microscopy, but can be studied by chemical etching, high-contrast back-scattering electron images, and compositional maps [2,3]. If preserved, zoning can reveal growth textures, brecciation and veining, resorption and recrystallization events, thus shedding light on the processes that contributed to ore formation [4].

Electron microprobe analysis (EMPA) and proton-induced X-ray emission (PIXE) analysis were successfully used as complementary methods to study chemical zoning of sulphide minerals. EMPA offers great spatial definition (down to 1 μm), which allows to map small-scale chemical variations. However, the number of elements analysed at the same time will be limited by the number of available detectors (up to 5). Further, the detection limit is relatively high (100 or a few hundred μg/g). In comparison, PIXE has a lower detection limit (down to a few μg/g), and allows the detection of most elements at the same time. Furthermore, PIXE analyses can be recalculated to give quantitative elemental maps. However, the spatial definition of PIXE is slightly lower (5 – 10 μm), which can result in “averaging” of compositions when analysing small-scale textures of less than 5 μm. Another difference between the two methods is that the electron beam has low penetration into the sample, resulting in shallow compositional information in EMPA maps. In contrast, protons can penetrate deeper into the sample, thus PIXE maps can provide information on mineral inclusions hosted within a few tens of μm from the surface.

PIXE and EMPA maps allowed the distinction of three stages of pyrite deposition at Farview mine, and two stages at Sheba mine. At both mines, the main stage of pyrite deposition is characterised by prominent chemical zoning, with oscillating As concentrations (Figure 1). The last stage of pyrite formation is mostly As-poor, and was deposited together with electrum (Au-Ag alloy) and other sulfide minerals (arsenopyrite, gersdorffite, arsenopyrite, and gersdorffite).
sphalerite...). Overall, compositional maps indicate a multi-stage mineralisation process, which involved different stages of gold deposition and remobilisation.

References


### 2.5.10 Towards characterizing fluid inclusions in mineralized pegmatites of the Damara Belt, Namibia

L Ashworth¹, J A Kinnaird¹, P A M Nex², W J Przybyłowicz³

¹ Economic Geology Research Institute, School of Geosciences, University of the Witwatersrand  
² Umbono Financial Services  
³ iThemba LABS, National Research Foundation, P O Box 722, Somerset West, South Africa

Namibia is renowned for its abundant mineral resources. A large proportion of these resources are hosted in the metasedimentary lithologies of the Damara Belt, the northeast-trending inland branch of the Neoproterozoic Pan-African Damara Orogen. Deposit types include late- to post-tectonic (~ 523 – 506 Ma) LCT (Li-Cs-Ta; Li-Be, Sn-, and miarolitic gem-tourmaline-bearing) pegmatites, and uraniferous pegmatitic sheeted leucogranites, which have a NYF (Nb-Y-F) affinity. In terms of mineralization, the pegmatites of the Damara Belt appear to display a zonation from LCT pegmatites in the southern Kaoko Zone, northern Central Zone and the north-western and central parts of the southern Central Zone to uranium-bearing NYF pegmatites in the south-western parts of the southern Central Zone of the Damara Belt. Although mineralization varies among these pegmatites, they share a common late-syn-tectonic to post-tectonic age of emplacement, ranging between ~ 510 and ~ 490 Ma [1-4].

Fluid inclusion studies reveal that although mineralization differs between the different types of pegmatites located at different geographic locations, and by extension, different stratigraphic levels, the fluid inclusion assemblages present in these pegmatites are similar. Thorough fluid inclusion petrography indicated that although fluid inclusions are abundant in the pegmatites, no primary fluid inclusions could be identified, and those studied are rather pseudo secondary and secondary. Fluid inclusions are aqueous-carbonic, carbonic, and aqueous.

Aqueo-carbonic pseudo secondary inclusions are the earliest fluid inclusions observed. They contain halite and an unidentified, acicular opaque phase. In the Li-Be and gem tourmaline-bearing pegmatites, these inclusions contain pure CO₂, however in the Sn-bearing pegmatites trace amounts of CH₄ are present. These inclusions
homogenize at temperatures ranging from 320 – 330°C, and their density is intermediate (0.7 – 0.8 g/cc). The presence of halite crystals in these inclusions indicates salinity in excess of 23.3 equivalent wt% NaCl [5]. Qualitative PIXE micro-elemental maps show the presence of Fe, Mn, Cu, and Zn, suggesting that the trapped fluids are far more compositionally complicated than indicated by micro thermometry alone (Figure 1). These elements have not commonly been associated with pegmatite systems.

![Figure 1: PIXE elemental map of an individual Type 1 fluid inclusion from an Uis Sn-bearing pegmatite. The green outline indicates the shape of the fluid inclusion, and warm colours indicate the presence and relative abundance of individual elements.](image-url)

Although it is widely accepted that mineralisation in pegmatites is a result of magma geochemistry and reactivity rather than of fluid activity [6,7], evidence for the late-stage exsolution of “exotic” metal-bearing fluids is present in the Namibian pegmatites. Their compositional heterogeneity indicates, along with stable isotope results not included in this report, that the pegmatites were derived from a meta-sedimentary crustal source, and the absence of any evidence for crustal contamination from emplacement into cold country rocks would suggest that these elements were derived from the source of the pegmatite magma. Late-stage exsolved fluids would thus have become enriched in elements incompatible with the melt, and become incorporated into late-stage minerals rich in those elements, such as cassiterite, chalcopyrite, and iron oxides in greissenised patches of the pegmatites.

**References**

2.5.11 Effect of Intermetallics on Pt-Al Surface Coatings Colour

M Topic¹, R. Vinci²,b, Z Khumalo¹3,c, C Mtshali¹,d

¹iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa
²Lehigh University, Materials Science and Engineering Department, 5 East Packer Avenue, Bethlehem, PA 18015-3195, USA
³University of Cape Town, Physics Department, Private bag, X3, Rondebosch 7701, Cape Town, South Africa

In addition to the attractive physical, mechanical and chemical properties of Pt alloys, it has been shown that many Pt-based intermetallics have reflection coefficients that are strongly dependent on wavelength in the visible region of the spectrum and are, therefore, coloured [1-2]. This raises the possibility of generating a specific AlₓPtᵧ phase with desirable properties within a deposited film, and the ability to tune the properties of a coated system.

Prior to annealing, the Pt:Al and Pt³:Al co-deposited coatings were smooth when observed by a scanning electron microscope. Increased surface roughness with rope- and ridge-like morphologies in the Pt:Al and Pt³:Al coatings, respectively, were evident after annealing. Visual observation showed that the colour of both coatings changed after thermal annealing. Prior to annealing, both coatings had shiny surfaces with almost no discernible differences from the original Al substrate colour. After annealing, the Pt:Al coating was “matt-silver” while the Pt³:Al coating displayed an “old gold” colour (Figure 1).

Phase analysis of both coatings primarily showed the expected Pt and Al peaks in the as-deposited condition. The differences in peak height reflect the differences in Pt and Al concentration. After annealing, the Pt:Al coating displayed new peaks associated with the presence of Al₂Pt₆ and Al³Pt phases. The Pt³:Al coating displayed only Al₂Pt peaks that were new. The Reitveld refinement results showed that the most dominant phase in the Pt:Al coatings were Al₂Pt₆ while the Al³Pt phase was the most dominant phase in the Pt³:Al coatings.

The RBS spectrum simulation shows that thickness of the Pt:Al layer increased by approximately four times during annealing, from 7200 x 10¹⁵ to 31070 x 10¹⁵ at/cm². A significant increase in thickness can be explained...
by formation of the Al$_2$Pt$_6$ phase, as the most dominant phase with a large number of atoms (116) per unit cell [3]. The Pt concentration varied through the thickness of the as-deposited coating between 50 at.% and 47 at.% which corresponds closely to the desired Pt:Al ratio. Thermal annealing, however, caused diffusion and redistribution of Pt and Al. The Pt concentration varied throughout the coating thickness, from 20 at.% in the near-surface region to 16 at.% and 8 at.% deeper in the coating. The concentrations correspond to the stoichiometry of an Al-rich phase (close to Al$_2$Pt$_6$ phase). However, two intermetallics, Al$_2$Pt$_6$ and Al$_2$Pt, were determined by XRD. This inconsistency is due to low penetration depth of alphas used in this experiment, and the fact that the Al$_2$Pt phase was most likely formed only in the interface region. The coating thickness of the other system (Pt3:Al) was doubled during thermal annealing: from 7480 x 10$^{15}$ at/cm$^2$ in its as-deposited condition to 13550 x 10$^{15}$ at/cm$^2$ after annealing. It is due to formation of the Al$_2$Pt phase (the most dominant phase) with 12 atoms per unit cell [3]. In the as-deposited condition, the Pt concentration was 70-77 at.% which is consistent with the intended composition of Pt3:Al. In the annealed coatings, the Pt varied from approx. 82 at.% down to 77 at.%, 57 at.%, 35 at.% and less than 23 at.%. This indicates the presence of several possible phases: a Pt-rich phase, AlPt, Al$_2$Pt, and an Al-rich phase. In contrast, the Al$_2$Pt phase was the only phase determined by XRD. It is probably due to small volume fractions of the other phases determined by RBS. Generally, the differences from XRD and RBS techniques come from different measurement depths and volumes of probed matter. Based on the results of this study, it is reasonable to assume that the structural characteristics of the most dominant phase determine the coating colour. Therefore, this study represents a step forward in tuning the coating properties depending on the conditions required by particular application.

The study of Pt:Al and Pt3:Al coatings deposited onto Al substrates and afterwards annealed at 500°C for 2 hours shows that formation of Pt-Al intermetallics affects the coating colour, the morphology, and coating thickness. More importantly, the differences caused by thermal annealing depend on the presence of the most dominant phase and its structural characteristics.

References

2.6 iThemba LABS (Gauteng)

2.6.1 Deposition of silicon nitride thin films by hot-wire CVD

A Adams1, C J Arendse1 and M Msimanga2

1 Department of Physics, University of the Western Cape, Private Bag X 17, Bellville 7535, South Africa
2 iThemba LABS Gauteng, National Research Foundation, Private Bag 11, WITS 2050, South Africa

Amorphous silicon nitride (a-SiNx:H) grown by hot wire chemical vapour deposition (HWCVD) has attracted the attention of researchers far and wide, mainly as a result of the superior film quality deposited at low temperatures [1,2]. Plasma enhanced chemical vapour deposition (PECVD) is the industrial technique of choice for device quality a-SiN:H films; due to its reproducibility. However, PECVD has its drawbacks in terms of film quality caused by ion bombardment, which results in void formation and undesirable oxidation [2-3]. HWCVD provides a means of reducing these voids by production of radicals as compared to ions in PECVD.

Amorphous silicon nitride films were deposited by HWCVD using a heated tantalum filament at 1460°C at a fixed pressure of 100 mbar and a gas flow ratio varying from \( R = \Phi_{NH3}/\Phi_{SiH4} = 0.2 – 1.4 \), where \( \Phi \) refers to the flow rate. All thin films were deposited using a constant H2 flow rate of 20 sccm and a substrate heater temperature of 240°C. Heavy Ion ERDA was performed using a 26 MeV Cu\(^{7+}\) beam at a scattering angle of 30° using a Time of Flight (ToF) detector system in order to determine the N content within the film.

![Figure 1: N/Si ratio as a function of NH3 flow rate](image)

The influence of NH3 gas flow rate is illustrated in Figure 1. The N content is observed to increase as the NH3 flow rate increases. When considering variation in NH3 flow rate the result can be trivially explained as the increased presence of ammonia, which results in an increased presence of nitrogen containing radicals, such as Si(NH2)4 and thus result in an increase in nitrogen incorporation. These aminosilanes are the species responsible for the incorporation of N into the a-SiN:H thin films. Since NH3 is mainly dissociated by secondary gas phase
reactions from the decomposition of SiH₄ [4], the increased presence of NH₃ enhances these secondary gas phase reactions and thus results in an increased N incorporation. The relationship shown in Figure 1 was also observed by Romijn et al. [5]. The figure illustrates that these a-SiN:H films are in the silicon-rich regime, where silicon is the dominant species in the amorphous matrix.

The depth profiles of the films obtained from the Heavy Ion ERDA data showed little to no oxidation in the bulk, which indicates that the films prepared are of good quality and also shows that HWCVD can be used in the production of device quality a-SiN:H thin films with uniform composition.

References


2.6.2 Effect of compositional profiles of thin hard films of transitional metal nitrides, carbides on stress evolution by surface Brillouin scattering. Cr₃C₂ case study

D Wamwangi¹ J Kuria¹, D Comins¹, M Msimanga²

¹ School of Physics, University of the Witwatersrand, Johannesburg 2050, South Africa
² iThemba LABS Gauteng, National Research Foundation, Private Bag X11, WITS 2050, South Africa

Thin hard films of transitional metal nitride, boride, carbides and carbon nitrides have been widely used as protective coating and in cutting tools due to their excellent mechanical properties [1]. However, stress evolution and relaxation remain a key research question on the film substrate adhesion and wear resistance properties, which limit the application potential. The deposition of thin films under varied power and working gas pressure as well as the substrate temperature based on the structural zone model enables the determination of the evolution and relaxation of residual stress. The changes in deposition conditions such as sputter power (selective adatom dispersal) and substrate biasing have been used to influence the stoichiometry of thin hard films during growth. Such variations induce residual stresses in thin hard transitional metal nitrides carbides and boride films, which are deleterious to film substrate adhesion especially in cutting tools due to instances of film fracture or delamination over the entire substrate. The evolution of intrinsic stress due to substrate bias and its correlation to stoichiometry variation form the key objective of this project.

In this work, thin films of transitional metal nitrides, borides and carbides have been grown on (100) Si substrates using RF magnetron sputtering at a substrate bias of -60 V and working gas pressure of 5x 10⁻³ mbar. Argon was used as the inert gas for all thin film depositions. The determination of stress relaxation and evolution has been
studied by several researchers using a variety of techniques such as wafer curvature, X-ray and neutron diffraction. One key method that has not been used before to observe the mechanisms of residual stress evolution and relaxation is surface Brillouin scattering. This technique determines the elastic properties of bulk materials and thin single- and multi-layer films by the frequency shift induced by inelastically scattered light due to acoustic phonons. The determination of stress relaxation was carried out by establishing the acoustic wave propagation using surface Brillouin scattering measured in the backscattering geometry. An \( \text{Ar}^+ \) laser was used as the probe at 514.5nm. The determination of film stoichiometry was carried out using time of flight – energy (ToF-E) Heavy Ion Elastic Recoil Detection Analysis (HI-ERDA). The stoichiometry determination was carried out for transitional metal nitrides and carbides. The summary of some of the results of the composition determinations are discussed below.

Figure 1 shows a 2D scatter plot of the ToF-E measurement of recoil ions from a \( \text{Cr}_3\text{C}_2 \) thin film on a (100)Si substrate. The projectile beam was of 26 MeV \( \text{Cu}^{+5} \) ions, with the detector system fixed at 30° to the beam direction. The velocity dispersion curves of the \( \text{Cr}_3\text{C}_2 \) thin films obtained from the Rayleigh wave (RW) of phase velocity 7500 m/s appear in Figure 2. The determined phase velocities are much lower than that of the bulk phonon velocity propagating parallel to the surface (8500 m/s).

Slow propagating symmetric film guided modes which are displaced throughout the layer are also evident in this plot. The increase in the phase velocities upon substrate biasing is attributed to the in-situ incorporation of \( \text{Ar}^+ \) ions and defect formation leading to an increase in the intrinsic stress within the film. That the phase velocity is correlated to the elastic constant shows an increase in phase velocity due to stiffening in the film upon stress evolution. These preliminary results present the first evidence of stress determination with surface Brillouin scattering. The project is on-going to establish the correlation of intrinsic stress and stoichiometry by Heavy Ion elastic recoil detection analysis.

Figure 1: 2D ToF-E scatter of recoils from the Chromium Carbide thin film, RF sputter deposited on a Si substrate at -60 V bias. The scatter plot also shows presence of nitrogen impurity in the film.
2.6.3 The effect of thermal annealing on the diffusion behaviour of Iodine and Silver co-implanted into 6H-SiC

T Hlatshwayo, M Msimanga

1 Department of Physics, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa
2 iThemba LABS Gauteng, National Research Foundation. Private Bag 11, WITS 2050, South Africa

The success of modern nuclear reactors depends on their ability to contain all the radioactive fission products that are produced leak during operation. In such reactors this is achieved by coating the fuel kernel with chemical vapour deposited layers of 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 [1, 2]. Consequently, the diffusion of the important fission products in SiC has been investigated extensively over the past two decades. The early studies [3, 4] already pointed out that the silver isotope ¹¹⁰Ag seems to diffuse more easily through the SiC layer than the other major fission products during reactor operating conditions. This finding has been confirmed by several other studies – see reviews [5-7].

A recent review [7] pointed out that there are many contradictory studies in the diffusion of silver in SiC. The exact mechanism causing the transport of silver in polycrystalline SiC is also a central problem. Most of the studies have shown that silver does not diffuse in crystalline SiC [4, 8-11]. Implanting silver ions (or other heavy ions) into single crystalline SiC at room temperature causes the SiC to become amorphous even at relatively low fluences – see [7] for a review. However, if the implantation is done at temperatures above 350°C into single crystalline SiC, the SiC remains single crystalline [8–10]. For the room temperature implantation, limited
diffusion is detected during the initial annealing steps [8-11] suggesting that this diffusion is due to defects created during the implantation process. During reactor operation several fission products are produced which may influence their migration behaviour. This study focuses on the effects of thermal annealing on Iodine and Silver co-implanted into 6H-SiC at room temperature.

The starting material was hexagonal 6H-SiC from Intrinsic Semiconductors®, $^{109}$Ag⁺ and $^{127}$I⁺ of 360 keV were implanted into 6H-SiC at room temperature to fluences of $1 \times 10^{16}$ cm⁻² and $2 \times 10^{16}$ cm⁻², respectively. Some of the implanted samples were annealed under vacuum at 1500°C for 30 hours using a computer controlled Webb 77 graphite furnace. The as-implanted and annealed samples were analysed by Heavy Ion ERDA at iThemba Labs Gauteng, using a 26 MeV $^{63}$Cu⁺ beam.

From the raw 2D ToF-Energy spectra obtained from the heavy ion ERDA mass-dispersive detection system [12] it was possible to distinguish the co-implants from each other and to obtain separate elemental energy spectra. The sample depth profiles calculated from the energy spectra are shown in Figures 1 and 2. The results suggest that annealing induces diffusion of both the $^{127}$I and $^{109}$Ag species towards the surface. The fact that both the $^{127}$I and $^{109}$Ag content retained in the SiC each drop by an order of magnitude points to appreciable loss of the diffusing species once they reach the surface region. Further studies on diffusion mechanisms of ion species implanted at 350°C and then annealed are in progress.

References


**2.6.4 The use of isotope hydrology to characterize and assess water resources in South(ern) Africa: Towards a management model for the exploitation of groundwater from the Taaibosch Karoo graben, Limpopo Province, employing environmental isotopes, chemistry and hydrogeological data**

M. Butler¹, B.Th. Verhagen²

¹iThemba LABS Gauteng, National Research Foundation, Private Bag 11, Wits 2050, South Africa
²School of Geosciences, University of the Witwatersrand, Johannesburg 2050, South Africa

A Water Research Commission study of the graben between the Blouberg Mountains and the Tshipise fault in the Alldays area, Limpopo Province, was undertaken to more firmly establish the basic geohydrologic parameters and the inter-relationships of a basalt aquifer and the deeper Tshipise sandstone aquifer in the Taaibosch Karoo graben. Previously thought to be unproductive, an earlier isotope study motivated deeper drilling. This produced high yields of excellent quality groundwater from the sandstone, which suggested its potential as a major regional potable water resource.

A further aim was to generate an integrated exploitation management concept and model in order to maintain the exceptional quality of the sandstone groundwater. Isotope and field measurements from further boreholes drilled in the north-western portion of the study area suggest lower sandstone transmissivities than elsewhere, underlining the importance of assessing the aquifer conditions in various areas in order to arrive at a realistic integrated overall conceptual hydrogeological model.

Satellite images illustrate the dramatic expansion of agriculture development in the north-eastern portion of the study area. Complaints of illegal water use and interference with monitoring boreholes raise concerns about uncontrolled extraction from the sandstones enhancing contamination from the overlying, more mineralised basalt with its often high nitrate concentrations.

A database of all available data for the study area was used for contouring on a regional scale, illustrating relationships between the rural villages and higher E.C., Na, SO₄, Cl as well as NO₃-N. Tritium and carbon-14 contours illustrate the potential of the Terveen Lineament as a source of recharge to both aquifers. In all cases, the influence of the fault lines and the Terveen lineament are clearly discernible, confirming the model of localised recharge through the southern fault zone and partial discharge along the Tshipise fault. Elevation and
depth to base of basalt were used to establish the regional range of aquifer parameters for this highly heterogeneous aquifer, as well as illustrating the considerable topography of the sandstone erosional surface.

Once ground water abstraction for the town of Alldays commenced from the three high yielding sandstone boreholes on the farm Kromhoek, water levels declined severely (Figure 1). Calculated abstraction rates from this Kromhoek wellfield proved too high, probably due to uncontrolled extraction from the agricultural development.

![Figure 1](image)

**Figure 1**: Monitoring boreholes H26-0442 and H26-0604 on the farm Kromhoek indicating dramatic decline in ground water levels since abstraction in October 2010.

### 2.6.5 Characterization of Au and Ag nanostructures in implanted sapphire and MgO crystals

A G Kozakiewicz¹, T E Derry¹, S R Naidoo¹, C Pineda², E J Olivier³ and J Neethling³

¹DST/NRF Centre of Excellence in Strong Materials and School of Physics, University of the Witwatersrand, Private Bag 3, P.O. Wits, Johannesburg 2050
²iThemba LABS, National Research Foundation, P O Box 722, Somerset West 7129, South Africa
³DST/NRF Centre of Excellence in Strong Materials and Centre for HRTEM, Nelson Mandela Metropolitan University, Port Elizabeth 6031, South Africa.

Silver and gold metal nanoparticles embedded in MgO and sapphire single crystals have been synthesized by high fluence ion implantation using keV and MeV ion beams. In the 150 keV silver implanted specimens, optical absorption spectra show an intense surface plasmon resonance peak corresponding to the Ag metal nanoparticles formed in the crystalline matrix in both oxides. The surface plasmon resonance peak position varies depending on the crystal orientation, from 406 nm to 426 nm in silver implanted sapphire (Figure 1).

Electron microscopy of Ag implanted Al₂O₃ was carried out by implanting into nanoflakes of the material, and also by using Focused Ion Beam cross-sectioning of both materials. An example of the profile of the damage and nano-particles produced by 150 keV Ag⁺ ions is shown in Figure 2.
High resolution transmission electron micrographs indicate that the nanoparticles are crystalline – see Figure 3. RBS-channelling analysis and high resolution TEM images provide the surprising result of retained crystalline structure of the sapphire substrate extending from the buried implanted layer to the surface.

An entirely different picture is observed in crystals damaged by energetic MeV Au ions. The surface plasmon resonance band of gold in optical absorption spectra develops only after annealing at 1100°C. RBS-channelling analysis shows the presence of a highly disordered structure of random level for both as-implanted and annealed material. Many of the nano-particles have a cubical habit (Figure 4).

The electronic energy loss mechanism is responsible for creation of damage in high energy (15-20 MeV) gold implanted crystals while in keV silver implanted specimens the defects are produced by nuclear energy deposition of the implanted ions.
2.6.6 Ion Beam Modification of the Structure and Properties of Hexagonal Boron Nitride

E Aradi, S R Naidoo, D Billing, D Wamwangi and T E Derry

Cubic boron nitride (c-BN) nanocrystals have been produced by boron ion implantation of hexagonal boron nitride (h-BN) at various fluences and implantation energies. The optimum fluence was found to be $5 \times 10^{14}$ ions/cm$^2$ at 150 keV. The presence of these nanoparticles was investigated using grazing angle XRD and Fourier Transform Infrared Spectroscopy.

The grazing angle XRD pattern after implantation exhibited c-BN diffraction peaks with high intensity at the grazing angle of 3° whose penetration depth corresponded to the implantation depth. After implantation, Fourier...
Transform infrared spectroscopy indicated a peak at 1090 cm\(^{-1}\) which corresponded to the vibrational mode for nano-c-BN.

Fourier Transform infrared spectroscopy was used to identify the local structural order and composition of the material before and after implantation.

![Figure 1: Fourier Transform infrared spectrum for (a) unimplanted h-BN and (b) for h-BN implanted with boron ions at 5x10\(^{14}\) ions/cm\(^2\) and the energy of 150 keV.](image)

The spectrum before implantation shows the A\(_{lu}\) out-of-plane bending mode for h-BN at 780 cm\(^{-1}\) and the E\(_{lu}\) in-plane stretching mode for h-BN at 1380 cm\(^{-1}\). After implantation, together with the h-BN vibrational modes, another peak is observed at 1090 cm\(^{-1}\), which represents the TO mode for c-BN nanoparticles indicating that h-BN was transformed into c-BN by ion implantation.

![Figure 2: Grazing angle XRD diffraction pattern for (a) unimplanted and (b) implanted h-BN with boron ions at 5x10\(^{14}\) ions/cm\(^2\) and the energy of 150 keV.](image)

Glancing incident XRD was also used to identify the morphology of the material before and after implantation. Figure 2(a) shows the different diffraction peaks for h-BN at various planes. Calculations show that the initial material was high quality h-BN. After implantation, new peaks at 60.3\(^{\circ}\), 74.37\(^{\circ}\) and 89\(^{\circ}\) are observed. The peak at 60.3\(^{\circ}\) has been associated to the (015) plane of rhombohedral phase BN. It has been observed initially to be
produced as a transitional phase during the h-BN to c-BN phase transformation. The other two peaks have been calculated and found to represent the (002) and the (311) planes for c-BN respectively, with lattice parameter $a=3.614\text{Å}$. Using the Scherrer equation, the particle size for c-BN was found to be $\sim 9\text{ nm}$.

Both Fourier Transform Infrared Spectroscopy and grazing angle XRD showed that h-BN was transformed into nc-BN.

### 2.6.7 High resolution transmission electron microscopy investigation of implantation damage in carbon implanted and annealed diamond

E K Nshingabigwi$^{1,2}$, S R Naidoo$^1$, T E Derry$^1$, J H Neethling$^3$, E J Olivier$^3$ and J H O’Connell$^3$

$^1$DST/NRF Centre of Excellence in Strong Materials and School of Physics, University of the Witwatersrand, WITS 2050, Johannesburg, South Africa.

$^2$Department of Physics, National University of Rwanda, P O Box 117, Huye, Rwanda.

$^3$DST/NRF Centre of Excellence in Strong Materials and Centre for HRTEM, Nelson Mandela Metropolitan University, Port Elizabeth 6031, South Africa.

The doping of diamond by ion implantation is a promising technique for the fabrication of diamond-based electronic devices [1]. Previous studies on the ion implantation doping of diamond using the Cold Implant Rapid Anneal technique have indicated that if the critical dose of about $5.2 \times 10^{15}$ carbon ions are exceeded, diamond transforms to graphite [1,2]. Below the critical dose, the implantation damage in diamond anneals out and the diamond structure is retained [3]. The understanding of the nature of lattice defects generated during ion implantation and subsequent annealing is therefore important for the optimization of electronic devices. This paper presents results of a high resolution transmission electron microscopy (HRTEM) and electron energy loss spectroscopy investigation of the damage layer in diamond implanted with carbon ions using a dose which exceeded the critical dose defined above.

Slices of $\sim 40 \mu\text{m}$ thick natural diamond with $\{110\}$ orientation were implanted edge-on, at liquid nitrogen temperature, to a maximum dose of $7 \times 10^{15}$ carbon ions cm$^{-2}$ and annealed for 30 minutes at 1600K in argon. The ion implant energy was varied between 50 and 150 keV as described elsewhere [2]. HRTEM specimens were prepared by using a Helios Nanolab 650 FIB/SEM and investigated in a double Cs-corrected JEOL JEM-ARM200F HRTEM equipped with a Quantum Gatan Image Filter.

Figure 1 (a) is a bright-field TEM image of carbon implanted and annealed diamond, showing the implanted region extending from the diamond surface to the interface between the damage layer and diamond substrate (arrowed). Figure 1 (b) shows an electron energy loss spectroscopy spectrum image map obtained by using a window centred upon the $\pi^*$ peak (284.1 – 289.9 eV) in (c), which is an electron energy loss spectrum of the carbon K-edge obtained from the implanted layer. Although the $\pi^*$ peak is an indication of the $\text{sp}^2$ character of the carbon layer, the overall electron energy loss spectrum in Figure 1(c) is characteristic of highly disordered carbon [4] and the spectrum image map of the implanted layer shown in Figure 1(b) indicates that the implanted layer consists of disordered carbon. These findings were confirmed by HRTEM imaging across the implanted
region shown in Figure 2(a). This typical image of a section of the implanted layer clearly shows the presence of
regions with bent (002) graphitic fringes and regions of amorphous carbon. The HRTEM image in Figure 2(b)
shows the interface between the implanted layer and the diamond substrate. Diamond crystallites (D),
terspersed between regions of amorphous carbon (A) and partially graphitized carbon (G), are visible in this
region. An interesting observation is the lattice images of extended defects (arrowed) visible in the diamond
structure at the interface between the implanted region and the diamond substrate shown in Figure 2(b). These
defects, which are responsible for the dark diffraction contrast visible in Figure 1(a) and indicated by the arrow,
were produced at the tail of the projected range of the carbon ions where the ion dose was too low to render the
diamond amorphous. The peak of the implanted-ion damage is around 100 nm [1].

![Figure 1. (a) Bright-field TEM micrograph of carbon implanted diamond. (b) electron energy loss spectroscopy image map obtained by using the π* peak (284.1 – 289.9 eV) shown in (c), which is an electron energy loss spectrum of the carbon K-edge obtained from the implanted layer.](image)

![Figure 2. High-resolution TEM images of carbon implanted diamond showing (a) the implanted layer and (b) the interface between the implanted layer and diamond substrate.](image)

This investigation has illustrated the value of HRTEM and electron energy loss spectroscopy to determine the
nature of defects generated by ion implantation in diamond and the micro- and nanostructure of the implanted
layer. These techniques are also very useful to determine the critical implantation and annealing conditions for
the transformation of diamond to graphite.

References

2.6.8 Back Surface Influence on Brillouin Scattering in Ion-Implanted Chemical Vapour Deposited Diamond.

I Motochi, B Mathe, S R Naidoo and T E Derry

DST/NRF Centre of Excellence in Strong Materials and School of Physics, University of the Witwatersrand, WITS 2050, Johannesburg, South Africa.

Brillouin scattering measurements on thin opaque films seem to work nicely as long as the scattering surface is optically smooth. In transparent materials the measurements become complex due to the combination of surface ripple mechanism and elasto-optic scattering occurring within the sample bulk. The condition for observing a Brillouin spectrum is an optically smooth surface. Even in transparent surfaces the surface at which light interacts needs to be optically smooth. For materials that transmit light like diamond, the reflection from the back side plays an important role in obtaining a meaningful spectrum. Brillouin scattering measurements have been made to find out how the nature of the back surface for both pristine and ion-implanted diamond affects the spectra. While the spectra for a diamond sample polished on both sides and fixed to an aluminium holder using a double sided tape had other features (see Figure 1(a)), the same sample lacked them when fixed without the tape (see Figure 1(b)). In the case where the unpolished side was held to the back side, no spectrum for both pristine and heavily ion implanted samples was observed (see Figure 1(c)).

![Figure 1: Surface Brillouin scattering measurements on C implanted diamond. Figures (a) measurements taken with diamond held on the Al holder with a double sided tape, (b) diamond held on holder without a tape and (c) diamond polished on side held on same slot as for case (b), the unpolished side is on opposite side of the laser beam. No peaks are seen in case (c).](image)

This implies that the nature of the surface, front and back, plays a vital role in what can be measured in Brillouin scattering. Using Green’s elastodynamic functions, further analysis has been done to calculate sound velocity in the different samples.
3. Appendices
3.1 Publications and Reports

3.1.1 Publications in Refereed Journals

*(Publications and reports on research done (fully or in part) at iThemba LABS by external users and/or members of staff, as well as work done elsewhere in which members of staff participated)*

Radionuclide Production Department


Medical Radiation Department


Radiation Biophysics Department


Materials Research Department


15. ALICE Collaboration. Neutral pion and η meson production in proton-proton collisions at √s = 0.9 TeV and √s = 7 TeV. *Physics Letters B* 717 (2012) 162.


17. ALICE Collaboration. Production of K*(892) and φ(1020) in pp collisions at √s = 7 TeV. *European Physical Journal C* 72 (2012) 1.


21. ALICE Collaboration. Transverse sphericity of primary charged particles in minimum bias proton-proton collisions at √s = 0.9, 2.76 and 7 TeV. *European Physical Journal C* 72 (2012) 2142.

22. ALICE Collaboration. Underlying event measurements in pp collisions at √s = 0.9 and 7 TeV with the ALICE experiment at the LHC. *Journal of High Energy Physics* 7 (2012) 116.


Appendices

Publications and Reports

iThemba LABS (Gauteng)


3.1.2 Conference Proceedings

Materials Research Department


**Medical Radiation Department**


**Nuclear Physics Department**


**iThemba LABS (Gauteng)**


Accelerator and Engineering Department


3.1.3 Chapters in Books

3.2.1 Conference Contributions

**ECRIS Workshop 2012, Sydney, Australia**

1. R W Thomae, J L Conradie, D T Fourie, D Küchler, Beam experiments with the Grenoble Test Electron Cyclotron Resonance Ion Source at iThemba LABS.

**16th International Conference on Positron Annihilation, Bristol, UK, 19-24 August 2012**

1. C Naidoo, N P van der Meulen, C Vermeulen and R Krause-Rehberg, The production of $^{22}$Na Positron sources at iThemba LABS.


1. D D Rossouw, D Prince, C Davids and C Naidoo, Evaluation of a 50 mCi $^{68}$Ge/$^{68}$Ga generator produced by iThemba LABS.

**52th Annual SAAPMB Congress and Summer School, 17 - 19 September 2012, Port Elizabeth, South Africa**


2. V Vandersickel, P R Beukes, J P Slabbert, A Vral. Evaluation of $^{3}$H2AX foci after exposure of human lymphocytes to gamma-rays or high energy neutrons.


4. P R Beukes, V Vandersickel, J P Slabbert. Variations in radiosensitivities of different individuals to 60Co cobalt gamma rays and high energy neutrons.


**International Symposium on Exotic Nuclei Vladivostok, Russia 1 – 6 October 2012**


**Symposium for North Eastern Accelerator Personnel, SNEAP 2012, INFN, Legnaro, Italy, 1 – 5 October 2012.**


**13th International Conference on Nuclear Reaction Mechanisms, Varenna Italy, 11 – 15 June 2012.**

1. W A Richter - Review of nuclear structure calculations in the sd shell for the rp process.

2. J J van Zyl Angular distributions of the analyzing power in the excitation of low lying states of $^{56}$Co.

**Thirty First International Workshop on Nuclear Theory, Rila Mountains, Bulgaria, 25 – 30 June 2012.**

1. AA Cowley - Dominant Reaction Mechanisms of Nucleon-Induced Particle Emission into the Continuum

2. JJ Van Zyl, - Incident-energy Dependence of the Analyzing Power in the $^{58}$Ni(p,3He)$^{56}$Co Reaction between 80 and 120 MeV

**International Conference on Nuclear Structure and Related Topics (NSRT12), Dubna, Russia, 3 - 7 July 2012.**

1. AA Cowley - Proton-induced composite particle emission in inclusive reactions in the range of 100 to 200 MeV

**57th Annual Conference of the South African Institute of Physics, 9 – 13 July 2012**


3. E Z Buthelezi, Physics with muons in the ALICE experiment at the LHC.
4. J Cleymans, Quarkonium and light flavour production in pp and Pb-Pb collisions studied with ALICE at the LHC.


7. D Negi, Statistical gamma-decay studies of atomic nuclei at iThemba LABS.

8. N Ndlovu, Air pollution studies using biomonitor.


10. F Nemulodi, Investigation of the 11.16 MeV state of 13C.

11. C O Kureba, Effects of nuclear deformation on the fine structure of the ISGQR.


14. A Sehone, Using simulations to design a Medusa calibration facility.

15. R Botha, Using RAD7 to measure the radon levels in hot springs.


17. G Steyn, A saturation boiling model for an elongated water target operating at a high pressure during 18F production bombardments.

18. L Donaldson, Fine structure of the isovector giant dipole resonance using the (p,p') reaction at zero degrees: Effects of strong nuclear deformation.


Nuclear Structure 2012 (NS12), Argonne National Laboratory, USA, 13 - 17 August 2012


8'th International Conference on Nuclear and Radiochemistry (NRC8), Cernobbio, Italy, 15 - 24 September 2012

1. G Steyn - Cyclotron production of radionuclides with medium-energy proton beams and high-power targetry.

10th International Conference on Clustering Aspects of Nuclear Structure and Dynamics, Debrecen, Hungary, 24 - 28 September 2012

1. AA Cowley. Alpha-cluster structure in the ground state of 40Ca displayed in a (p,p⁰) knockout reaction


1. R Neveling, The K600 at iThemba LABS


6. J Swartz, Search for the 0⁺⁵ α-Cluster State in 20Ne.

7. F Nemulodi, Characterization of the 2⁺ Excitation of the Hoyle State in 13C.

8. R Bark, Future Development of iThemba LABS

3rd South Africa - JINR Workshop (Few to Many Body Systems: Models, Methods and Applications), Stellenbosch, South Africa, 27-30 November 2012

1. Application of the Isobaric Mass Multiplet Equation to the rp process in Nuclear Astrophysics.
International Workshop on Discovery Physics at the LHC (Kruger2012), 3 – 7 December 2012

1. E Z Buthelezi, Summary of ALICE at the LHC results from heavy flavour measurements in p-p and Pb-Pb collisions at LHC energies
2. J Cleymans, The Tsallis Distribution at the LHC

2nd China-South Africa Joint Symposium on Nuclear Physics, Stellenbosch, South Africa, 3 – 7 December 2012

1. M Wiedeking, The Up-Bend in Radiative Strength
2. D Negi, Statistical gamma decay studies at iThemba LABS
3. B V Kheswa, Statistical Decay of 74Ge at iThemba LABS
4. J Swartz, Search for the 0+ cluster state near the 5-alpha breakup threshold in 20Ne with the (p,t) reaction.

1st SA – USA AstroNuclear Physics Meeting, iThemba LABS, Somerset West, South Africa, 11 – 13 December 2012

1. R Bark, New Physics with RIB
2. R Neveling, Nuclear Astrophysics with the K600
3. M Wiedeking, Photon Strength Function at Astrophysical Energies

51st International Winter Meeting on Nuclear Physics. Bormio Italy, 21 - 25 January 2013

1. F Bossú, Heavy Flavour production with ALICE at the LHC


1. W Richter, Shell-model calculations of rp-process rates for the P-29(p,gamma)S-30 and P-30(p,gamma)S-31 reactions

International Conference on Nuclear Data for Science and Technology 2013 (ND2013), New York City, New York, USA, 04 – 08 March, 2013

1. M Wiedeking, The Photon Strength Function at Low Energies

3.3.2 Colloquia and Talks

1. D D Rossouw, Progress report on collaborative project on 68Ga, IAEA 2nd RCM 68Ga generator workshop, Vienna, Austria, Dec 2012.
2. A Baeyens. Chromosomal Radiosensitivity of HIV positive individuals before and after ARV treatment. Research day and Postgraduate expo of WITS Faculty of Health Sciences, 19 September 2012.
5. F Francies. Chromosomal radiosensitivity of triple negative breast cancer patients with poor prognosis. Research day and Postgraduate expo of WITS Faculty of Health Sciences, 19 September 2012.
10. M Wiedeking, Mysteries of Red Nuclear Matter, NIF Seminar, Lawrence Livermore National Laboratory, Livermore, California, USA, 19 March 2013
11. M Wiedeking, Oslo Cyclotron Laboratory and iThemba LABS, Department of Physics, University of Oslo, Oslo, Norway, 18 June 2012.
3.3 Postgraduate Training

3.3.1 Degrees Awarded

Radionuclide Production Department

MTech
1. M van Rhyn, The separation of radioactive contaminants from waste water, Cape Peninsula University of Technology, Bellville 2012.
2. C Perrang, The separation of $^{88}$Y from $^{88}$Zr and its Nb target material, Cape Peninsula University of Technology, Bellville.
3. C Liu, Further development of the radiolabelling of particles with $^{68}$Ga and $^{18}$F for positron emission particle tracking (PEPT) measurements, Cape Peninsula University of Technology, Bellville.
4. M van Heerden, The performance analysis of AG MP-1 anion exchange resin $^{68}$Ge/$^{68}$Ga generators and the radiolabelling of ion exchange resins for PEPT studies, Cape Peninsula University of Technology, Bellville.
5. S Dolley, Radiochemical aspects to resolve a problem in the determination of cross section of the $^{68}$Zn(p,$\alpha$)$^{64}$Cu nuclear reaction, Cape Peninsula University of Technology, Bellville.

Materials Research Department

MSc
1. N N Nyangiwe, Graphene based nano-coatings: Synthesis and physical-chemical investigations, University of the Western Cape.
2. S Songo, Nonlinear optical properties of natural dyes based on optical resonance, University of the Western Cape.
3. I G M Madiba, Thermochromic properties of VO$_2$ nano-coatings by inverted cylindrical magnetron sputtering for space applications. University of the Western Cape.
4. Z Khumalo, The effects of annealing on the phase transformation in Pt-Mo system, Department of Physics, University of Cape Town.

PhD
1. S Khamlich, Nano-Structured Cr$_2$O$_3$ and opto-electronic applications, Tshwane University of Technology.
2. J Sithole, ZnO nanostructures by hydrothermal processing and multi-functionality, University of the Western Cape.
3. S Kanu, Studies of nodule formation and N$_2$ fixation in the tribe Psoraleae, Tshwane University of Technology.
4. P Sibuyi, Irradiation effects on SiC nanostructures: Physical properties, University of the Western Cape.

Nuclear Physics

MSc
1. N Y Khewsa, University of the Western Cape

PhD
1. J J van Zyl, Analyzing power angular distributions in the excitation of low-lying states of $^{56}$Co, University of Stellenbosch

Accelerator and Engineering Department

1. B Lomberg, University of the Western Cape.

E I T Department

MSc
1. M Mokhomo, University of Cape Town.

iThemba LABS (Gauteng)

Postgraduate Diploma in Nuclear Science and Engineering (North West University, Potchefstroom)
1. O Mayaapelo
2. A Bopape
3. P Lolwana
4. T Sibiya
5. J Mahlase
6. S Masike
7. K Bosilong
8. M Khuzwayo
### Appendices

#### Medecical Radiation Department

**MSc**
1. S Qhobosheane, Implementation of a proton therapy supervisory system for iThemba LABS, University of Stellenbosch.

#### Radiation Biophysics Department

**MSc**
1. X Mueller, Breast cancer radiosensitivity, University of the Witwatersrand.
2. P Beukes, Inherent radiosensitivities of different individuals to $^{60}$Co $\gamma$-rays and p(66)/Be neutrons, University Stellenbosch.

**M Med Radiotherapy Registrars**
1. L Fourie, University of Stellenbosch.

#### Hons
1. F Francies, University of the Witwatersrand

#### 3.3.2 Postgraduate Students

**iThemba LABS (Gauteng)**

**PhD**
1. K Sekonya, University of the Witwatersrand
2. Makgato, University of the Witwatersrand
4. R Machaka, Sliding friction and wear properties of ion implanted ultra-hard boron-based materials, University of the Witwatersrand
5. A Kozakiewicz, Ion irradiation effects on the formation of nanoparticle colloids in crystals, University of the Witwatersrand
6. H Saeze, Delineation of deep groundwater flow regime in the Table Mountain Group, University of the Western Cape
7. A Duah, University of the Western Cape
8. S Victor, University of Johannesburg
9. D Umwuchola, University of Johannesburg
10. E Nshingabigwi, Cross-section transmission electron microscopy of radiation damage in diamond, University of the Witwatersrand
11. M Gomo, University of the Freestate

**MSc**
1. E Aradi, Heavy-ion modification of soft hexagonal boron nitride to ultra-hard cubic boron nitride by ion implantation, University of the Witwatersrand.
2. I Mayida, University of the Witwatersrand.
3. T Tshuma, University of the Witwatersrand.
4. M Mutheiwa, The assessment of the causes of high nitrate in ground water in Bochum District, Limpopo Province, University of the Witwatersrand.
5. F N Shangase, Environmental isotopes and evaluation of bio-markers for pollution in Mozambique tilapia (oreochromis mossambicus) at Lake Mzingazi, University of Zululand.
6. T Roussow, Geochemical characterization of basement aquifers within the Limpopo Province, South Africa, University of Pretoria.
7. B Maqabuka, Characterization of Incomplete Fusion Reactions with DIAMANT and AFRODITE, University of Johannesburg.
9. K Leketa, University of the Freestate.
10. T Shakhane, University of the Freestate.
11. D J Hagen, University of Stellenbosch.
12. M Peche, University of Johannesburg.
13. M G Sani, Ahmadu Bello University, Zaria, Nigeria.
14. M B Samaila, Ahmadu Bello University, Zaria, Nigeria.
15. S Siwawa, University of the Western Cape.
16. A Umeakubuike, University of the Witwatersrand.

**Hons/BTech**
1. F Hendjala, University of the Witwatersrand.
2. M Bamuza, University of the Witwatersrand.
3. F Rhoda, University of the Western Cape.
Appendices

Postgraduate Training

5. S Z Sibiya, University of KwaZulu-Natal.
6. C Rikhotso, Tswane University of Technology.

M'SONE, University of Johannesburg
1. R Brayshaw
2. E Chinaka
3. B Maqabuka
4. T Moipolai
5. T Ndanduleni
6. S Shongwe
7. K Tsatsi
8. M Tshisekedhi
9. H Vilakazi
10. T Khumalo
11. L Maseko
12. S Mothwa
13. I Nxumalo
14. Oluwalye
15. R Ramabulana
16. J Ndlovu
17. L Masevhe
18. M Mashua
19. P Mudau
20. S Chifamba
21. T Seakamela
22. T Gwayisa
23. T Mahafa
24. B Seanego
25. N Nkosi
26. A Masaure
27. G Zimba
28. D Seepamore
29. T Gina
30. E Omogiate
31. L Msebi

M'SONE, University of Johannesburg
Postgraduate Diploma in Nuclear Science and Engineering (North West University, Potchefstroom)
1. O Manyaapelo
2. A Bopape
3. P Lolwana
4. T Sibiya
5. S Masike
6. K Bosilong
7. J Mahlase
8. M Khuzwayo

Radionuclide Production Department

PhD
1. G Greyling, Development of novel metal-complexing ligands suitable for labelling with metallic radionuclides, University of Cape Town.
2. C Vermeulen, Development and modelling of bombardment facilities at iThemba LABS, University of Stellenbosch.
3. D Prince, Radiolabelling somatostatin peptide derivatives 1,4,7,10-tetraazacyclododecane-N,N',N'',N'''-tetraacetic acid-D-Phe1-Tyr3-octreotate (DOTATATE), 1,4,7,10-tetraazacyclododecane-N,N',N'',N'''-tetra-acetic acid-D-Phe1-Tyr3-octreotide (DOTATOC) and 1,4,7,10-tetraazacyclododecane-N,N',N'',N'''-tetraacetic acid-1-NaI3-Octreotide (DOTANOC) with 68Ga, using the iThemba LABS SnO2-based 68Ge/68Ga Generator, University of Stellenbosch.

MSc
2. I Schoeman, Qualification of in-house prepared, GMP compliant 68Ga RGD in healthy monkeys and subsequent molecular imaging of αvβ3 integrin expression in patients, North-West University.
Appendices

Postgraduate Training

**MTech**

1. M van Rhyn, The separation of radioactive contaminants from waste water, Cape Peninsula University of Technology, Bellville.

2. C Perrang, The separation of $^{88}$Y from $^{88}$Zr and its Nb target material, Cape Peninsula University of Technology, Bellville.

3. C Liu, Further development of the radiolabelling of particles with $^{68}$Ga and $^{18}$F for positron emission particle tracking (PEPT) measurements, Cape Peninsula University of Technology, Bellville.

4. M van Heerden, The performance analysis of AG MP-1 anion exchange resin $^{68}$Ge/$^{68}$Ga generators and the radiolabelling of ion exchange resins for PEPT studies, Cape Peninsula University of Technology, Bellville.

5. S Dolley, Radiochemical aspects to resolve a problem in the determination of cross section of the $^{62}$Zn(p,$\alpha$)$^{64}$Cu nuclear reaction, Cape Peninsula University of Technology, Bellville.

**Medical Radiation Department**

**PhD**

1. B-M van Wyk, Automatic intensity based multi-modal registration of CT and MRI images of the head, University of Stellenbosch.

**MSc**

1. N J Matjelo, Organ Identification from digital X-rays, University of Cape Town.

2. M Mokhomo, Automated abnormality identification in CT images, University of Cape Town.

3. S Qhobosheane, Implementation of a proton therapy supervisory system for iThemba LABS, University of Stellenbosch.

**Radiation Biophysics Department**

**PhD**


**MSc**

1. X Mueller, Breast cancer radiosensitivity, University of the Witwatersrand.

2. P Beukes, Inherent radiosensitivities of different individuals to $^{60}$Co $\gamma$-rays and p(66)/Be neutrons, University Stellenbosch.

3. B Alexander, Investigate the radiosensitization influence of prostaglandin treatment on cancer cells, University of Western Cape.

4. T T Sebeela, A rapid method to do biological dosimetry to enable the triage of workers in the event of a nuclear incident, North West University.

**Hons**

1. F Zita, Chromosomal Radiosensitivity of triple negative and young breast cancer patients, University of the Witwatersrand.

**Hons. Medical Physics Stellenboch University**

1. Hein Foureir
2. Collin Fakazi Nachissambe

**Postgraduates in Oncology Nursing, Cape Peninsula University of Technology**

1. A Udembah
2. J Egbera
3. T Weber
4. S Croy
5. N Swartbooi
6. F Flandorf
7. B Ohlsen
8. L Fredericks
9. M Daniel
10. A Hendrickx
11. E Fugar
12. C Beukes

**MARST**

1. B Modukanele
2. N Nsibandze
3. K Bojosi
### Appendices

**Postgraduate Training**

| 4. | T Basinyi |
| 5. | M Zwane |
| 6. | M Mazibuko |
| 7. | D Thulani |
| 8. | T Lesele |
| 9. | M Maake |
| 10. | M Magagula |
| 11. | S Dlamini |

**Materials Research Department**

**MSc**

| 1. | A Adams, University of the Western Cape |
| 2. | T Adonisi, University of the Western Cape |
| 3. | S Allies, University of Cape Town |
| 4. | A Bangisa, University of the Western Cape |
| 5. | D Chilukusha, Study of Ni-Ge interactions in thin films and lateral diffusion couples, University of Zambia |
| 6. | A Emmanuel, University of the Western Cape |
| 7. | A Field, University of Cape Town |
| 8. | N Hanief, Phase transformation in Pt-Cr coated system, Centre for Materials Engineering University of Cape Town |
| 9. | B Javu, University of the Western Cape |
| 10. | J Khoele, University of the Western Cape |
| 11. | Z M Khumalo, The effect of annealing on the phase transformation of platinum coatings, University of Cape Town |
| 12. | I Madiba, UNISA |
| 13. | L Mathevula, Synthesis of VO$_2$ nano-coating by pulsed laser deposition for thermal solar heat management in space/aircrafts units, UNISA |
| 14. | R Missengue, University of the Western Cape |
| 15. | S Mkhwanazi, University of the Western Cape |
| 16. | P Mokone, University of Limpopo |
| 17. | D Neveling, University of Stellenbosch |
| 18. | K Nukwa, Deep space radiations like induced damages in materials for space applications: Case of graphene |

| 19. | N N Nyangiwe, Graphene based nano-coatings: Synthesis and physical-chemical investigations, University of the Western Cape |
| 20. | Ch Okafor, Nafion nano-fiber mat membrane for fuel cell application, UNISA |
| 21. | Z Sentsho, Hydrogenation of Pd and Pd-based alloys, Physics Department, University of the Western Cape |
| 22. | K Shingange, University of Limpopo |
| 23. | T Totito, University of the Western Cape |
| 24. | S Zongo, Nonlinear optical properties of natural dyes based on optical resonance, University of the Western Cape |

**PhD**

| 1. | J Alegbe, University of the Western Cape |
| 2. | A K H Bashir, University of the Western Cape |
| 3. | J Gaumbe, University of Cape Town |
| 4. | A Ibrahim |
| 5. | S Kanu, Studies of nodule formation and N2 fixation in the tribe Psoraleae, Tshwane University of Technology |
| 6. | S Khamlich, Nano-Structured Cr$_2$O$_3$ and Optoelectronic applications, Tshwane University of Technology |
| 7. | N Magqi, University of the Free State |
| 8. | A Mahmoudi |
| 9. | N P Mongwaketsi, Synthesis and characterization of porphyrin nanorods, University of Stellenbosch |
| 10. | C B Mtshali, Investigation of physical properties of C$_6$ nanorods synthesized by self assembly and molecular recognition, University of Zululand |
| 12. | Z Y Nuru, Platinum-Aluminium oxide for application as solar absorbers, University of the Western Cape |
| 13. | G Philander, VO$_2$ based nanocomposites for thermal shielding applications in satellites, University of the Western Cape |
14. T P Sechogela, Synthesis and characterization of VO\(_2\) implanted in ZnO by ion implantation, University of the Western Cape.

15. J Sibanyoni, University of the Western Cape

16. A Simo, Investigation of properties of VO\(_2\) for application in infrared modulators, University of the Western Cape.

17. J Sithole, ZnO nanostructures by hydrothermal processing and multi-functionality, University of the Western Cape.

18. B T Sone, Nano-scale WO\(_3\) for hydrogen sensing, University of the Western Cape.

19. I S Tadadjeu, Deep space radiations like induced damages in materials for space applications: Case of diamond like carbon nano-coatings, Cape Peninsula University of Technology.

20. W Vardien

Nuclear Physics

MSc

1. M E A Elbashir. Test of fast neutron detectors for spectroscopy with \(^{3}\text{He},n\) two-proton stripping reactions, University of Stellenbosch.


PhD

1. P L Masiteng. Gamma spectroscopy of oblate nuclei in A = 190 mass region, University of the Western Cape.

2. J P Mira. Correlation of \(^{8}\text{Be}\) fragments and alpha particles emitted in the interaction of \(^{12}\text{C}\) with \(^{197}\text{Au\ and \ }^{89}\text{Nb\ at\ an\ incident\ energy\ of\ 400\ MeV, University\ of Stellenbosch.}\)

3. M A Stankiewicz. Nuclear structure and reaction dynamics with AFRODITE and DIAMANT, University of Cape Town.


5. M Jinga. Fine structure of the isovector giant quadrupole resonance: a survey with the \((p,p')\) reaction at 0 degrees, University of Witwatersrand.

6. C O Kureba. Fine structure of the isoscalar giant quadrupole resonance and 2\(^+\) level densities in spherical to deformed nuclei across the isotope chain \(^{142,144,146,148,150}\text{Nd}\) using the \((p,p')\) reaction, University of Witwatersrand.

7. T Dinoko. Search for low spin collective structures in \(^{150}\text{Er}\) and \(^{159}\text{Er\ University\ of the Western Cape.}\)

8. J Ongori. Radon escape from mine tailings dams, University of the Western Cape.


10. J J van Zyl. Analyzing power angular distributions in the excitation of low-lying states of \(^{56}\text{Co\ University\ of Stellenbosch.}\)

11. F Nemulodi. Further characterisation of the 2\(^+\) cluster state in \(^{12}\text{C}\). University of Stellenbosch.


13. D Geduld. Measurement of \(^{235}\text{U\ and \ }^{238}\text{U\ neutron fission cross-sections in the energy range from 40 MeV to 100 MeV, University\ of Cape Town.}\)

14. N B Ndlovu. Atmospheric deposition of trace elements in the Western Cape, South Africa, studied by the biomonitoring techniques; NAA, ICP-MS and GIS. University of Stellenbosch.


18. J Ndayishimye. DSAM in $^{193}$Tl. University of Stellenbosch

19. Z Ngcobo. The development of the neutron converter for the production of radioactive beams at iThemba LABS. University of Cape Town


21. P Sithole. Gamma spectroscopy
3.4.1 International Users and Collaborators

COMENA, Commissariat a l’Energie Atomique, Algiers-Algeria
M Izzroukouen
L Guerbouz
M Guitoum

Université des Science et de la Technologie H Boumediene, Algiers, Algeria
D Moussa
W Yahia-Cherif
S Ouchaoui
A Belhout
M Debabi
A Chafa

CRNA, Centre de Recherche Nucléaire de Algérie, Algiers, Algeria
H Ammi
S Mammeri
A Dib
H Hanoudi
C Benazzouz
N Ait Said
Z Lounis-Mokrani

Université des Sciences et de la Technologie H Boumediene (USTHB), Faculté de Physique, Algiers, Algeria
S Ouichaoui

CDTA, Centre de Développement des Technologies Avancées, Algiers, Algeria
T Kerdja
S Lafane

University of Bab Ezzouar, Chemistry Dept Algiers, Algeria
H Amara

University Mohamed Belkaid, Physics Dept, Tiemcen, Algeria
Gh Merad

International Atomic Energy Agency, Austria
F Muelhauser
A Markowicz

Linz Institute for Organic Solar Cells (LIOS), Johannes Kepler University Linz, Austria
A M Egbe

Sustainable Minerals Institute, University of Queensland, Brisbane Australia
A van der Ent

School of Physics, University of Monash, Victoria, Australia
M R Dimmock

PEMS School, University of New South Wales at Australian Defense Force Academy (ADFA), Canberra, Australia
A Abiona

Department of Lithospheric Research, Center for Earth Sciences, University of Vienna, Vienna Austria
C Koeberl

Catholic University Louvin, Brussels, Belgium
J Gueulette
J Martinez
B de Coster
V Grégoir
J-M Denis

University of Ghent, Ghent, Belgium
A Vral
P Willems
B Thierens
L de Ridder
V Vandersickel

Chemistry Department, University of Botswana, Botswana
B Abegaz
P Koosaletse-Meswela

Environmental Sciences, University of Botswana, Botswana
O Totolo

Biological Sciences Department, University of Botswana, Botswana
M Setshogo

University of Campinas, Brazil
C Giles

Physics Institute, the Federal University of Rio Grande do Sul (IF-UFRGS), Porto Alegre, Brazil
C Iochims dos Santos
R Debastiani
<table>
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<th>L Boufleur</th>
<th>Physics Department, National University, Bogota, Colombia</th>
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<td>J Dias</td>
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<tr>
<td>Dept De Physique, Universite de Yaounde 1, Yaounde, Cameroon</td>
<td>Charles University, Czech Republic</td>
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<td>J M Ndjaka</td>
<td>M Krticka</td>
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<tr>
<td>Sunnybrook Health Sciences Centre, Toronto, Canada</td>
<td>Department of Molecular Biology, Aarhus University, Aarhus, Denmark</td>
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<tr>
<td>J-P Pignol</td>
<td>C Cvitanich</td>
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<tr>
<td>Department of Earth and Planetary Science, McGill University, Canada</td>
<td>A Jurkiewicz</td>
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<td>S Fuchs</td>
<td>J Stougaard</td>
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<tr>
<td>INRS, Centre des Énergies, Matériaux et Télécommunications, Quebec, Canada</td>
<td>EØ Jensen</td>
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<td>B Ngom</td>
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<td>University of Western Ontario, Canada</td>
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<td>C L Cupelli</td>
<td>N Sandal</td>
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<tr>
<td>Shanghai Institute of Ceramics, Chinese Academy of Sciences, Materials Sciences Department, Shanghai, China</td>
<td>K Laszczyca</td>
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<td>Y Yanfeng Gao</td>
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<tr>
<td>School of Physics and Nuclear Engineering, Beihang University, Beijing, China</td>
<td>Institute of Anatomy, University of Aarhus, Aarhus Denmark</td>
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<td>L H Zhu</td>
<td>D Orłowski</td>
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<tr>
<td>School of Physics, Peking University, Beijing, China</td>
<td>Department of Agricultural Sciences, Faculty of Life Sciences, University of Copenhagen, Denmark</td>
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<td>S Q Zhang</td>
<td>Faculty of Sciences, Addis Ababa University, Addis Ababa, Ethiopia</td>
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<tr>
<td>School of Space Science and Physics, Shandong University, Weihai, China</td>
<td>J Teketel</td>
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<td>Central China Normal University, Wuhan, China</td>
<td>University of Strasbourg, Strasbourg, France</td>
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<td>J Zhu</td>
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<td>International Centre for Tropical Agriculture, Cali, Colombia</td>
<td>A Altmeyer</td>
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<td>Institut de Physique Nucléaire (IPN), Orsay, France</td>
<td>S Raous</td>
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<td>Institut de Physique du Globe, France</td>
<td>S Groeber</td>
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<td>L Carpozen</td>
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<tr>
<td>Faculty of Sciences, University of Le Maine, Le Mans, France</td>
<td>Laboratoire Environnement et Mineralurgie, CNRS-Nancy Université-INPL, Vandoeuvre les Nancy, France</td>
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<td>A Gibaud</td>
<td>E Montarges-Pelletier</td>
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<tr>
<td>Physics Department, University of Brest, Brest, France</td>
<td>SUBATECH, Nantes, France</td>
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<td>G Vignaud</td>
<td>P Pillot, ALICE Collaboration</td>
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<td>DAPNIA, Saclay France</td>
<td>D Stocco, ALICE Collaboration</td>
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<td>H Borel</td>
<td>L Aphecetche</td>
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<tr>
<td>Institut de Recherches Subatomique, France</td>
<td>G Martinez-Garcia</td>
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<tr>
<td>G Duchêne</td>
<td>Centre de Recherche sur la Matière Ultradivisée, CNRS-Orlean, Orlean, France</td>
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<td>F Gunsing</td>
<td>ML Saboungi</td>
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<tr>
<td>Centre de Recherche sur la Matière Ultradivisée, CNRS-Orlean, Orlean, France</td>
<td>ESRF Synchrotron Laboratory, France</td>
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<td>B Sahraoui</td>
<td>G Martinez-Criado</td>
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<tr>
<td>The Synchrotron SOLEIL, France</td>
<td>Centre d’Optique et Photonique, Université d’Angers, Angers, France</td>
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<td>P Dumas</td>
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<td>F Jamme</td>
<td>Centre de Recherche sur la Matière Ultradivisée, CNRS-Orlean, Orlean, France</td>
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<td>Y Ibraheem</td>
<td>E Montarges-Pelletier</td>
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<tr>
<td>University de Picardie, Amiens, France</td>
<td>Subatech, Nantes, France</td>
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<td>I Lukyanchuk</td>
<td>P Pillot, ALICE Collaboration</td>
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<tr>
<td>National Institute for Agricultural Research (INRA) INRA-BIA, Nantes, France</td>
<td>D Stocco, ALICE Collaboration</td>
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<td>L Aphecetche</td>
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<tr>
<td>Institut de Recherches Subatomique, France</td>
<td>G Martinez-Garcia</td>
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<td>F Gunsing</td>
<td>National Centre for Health and Environment (GSF), Germany</td>
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<tr>
<td>Laboratoire Sols et Environnement, INRA Université de Lorraine, Vandoeuvre-lès-Nancy, France</td>
<td>E Schmid</td>
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<tr>
<td>G Echevarria</td>
<td>Abteilung Medizinische Physik in der Strahlentherapie, Deutsches Krebsforschungszentrum, Heidelberg, Germany</td>
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<td>Physikalisch-Technische Bundesanstalt, Germany</td>
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<td>Technical University, Dresden, Germany</td>
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<td>Bundesamt fuer Strahlenschutz und Gesundheit, Oberschleissheim, Germany</td>
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<td>Forschungszentrum Jülich GmbH, Jülich, Germany</td>
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<td>Departmental Reports</td>
<td>Users and Collaborators</td>
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<td>Technical University of Clausthal, Clausthal-Zellerfeld, Germany</td>
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<td>Technische Universität Darmstadt, Germany</td>
<td>Ghana Atomic Energy Commission, Ghana</td>
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<td>P von Neumann-Cosel</td>
<td>D Achel</td>
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<tr>
<td>A Richter</td>
<td>Physics Department, University of Cape Coast, Ghana</td>
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<td>V Yu. Ponomarev</td>
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<td>J Wambach</td>
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<td>I Poltoratska</td>
<td>Biological Research Center, Hungarian Academy of Sciences, Szeged, Hungary</td>
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<td>R Nasiru</td>
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<tr>
<td>Chemistry Department, Obafemi Awolowo University, Ife, Nigeria</td>
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<td>G Eghareva</td>
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Departmental Reports

Centre for Energy Research and Developmentn
CERD, Ife, Nigeria
A Fasasi
J Ajao
E Obiajunwa
G Osinkolu

Physics Department, University of Nigeria
Nsukka, Nsukka, Nigeria
R Osuji
F Ezema

Chemistry Department, University of Zaria,
Zaria, Nigeria
L Edomwonyi-out

Chemistry Department, University of Oslo,
Norway
G Wibetoe

University of Oslo, Norway
S Siem,
M Guttormsen,
A-C Larsen,
A Goergen,
T Renstroem
F Giacoppo

The Henryk Niewodnicanski Institute of Nuclear
Physics, Polish Academy of Sciences, Poland
P Olko

Department of Animal Physiology and
Ecotoxicology, University of Silesia, Katowice,
Poland
P Migula
M Augustyniak
M Nakonieczny
M Tarnawska

Department of Animal Histology and
Embryology, University of Silesia, Katowice,
Poland
J Klag
M Rost-Roszkowska
I Poprawa

Institute of Geological Sciences, Jagiellonian
University, Krakow, Poland
M Michalik
I Jerzykowska

Users and Collaborators

Chemical Physics Department, Faculty of
Chemistry, Jagiellonian University, Krakow,
Poland
M Baranska
M Roman
T Wróbel

Department of Ecological Microbiology, Institute
of Environmental Sciences, Jagiellonian
University, Krakow, Poland
K Turnau
P Ryszka
T Anielska

Department of Cell Biology and Imaging,
Institute of Zoology, Jagiellonian University,
Krakow, Poland
G Tylko

Polish Academy of Science, Warsaw, Poland
A Wisniewski

Instituto Technologico Nuclear, Portugal
A Belchior

GIP CYROI, Sante Clotilde, Reunion
E Jestin
C Mériaux

Joint Institute for Nuclear Research, Dubna,
Russia
O Meshkov
S Yakovenko
A Ogloblin
S Shishkin
A Efremov
S Bogolomov
A Yeremin
V Chepigin
O Malyshev
D Kamanin
M Frontasyeva

A F Ioffe Physico-Technical Institute, St
Petersburg, Russia
A A Pasternak

Kigali Institute of Technology, Kigali, Rwanda
E Minani
C Museruka
C Inezia

Faculty of Engineering, National University of
Singapore, Singapore
O Adeyeye
Slovak Office of Standardisation, Metrology and Testing, Bratislava, Slovak Republic
J Ruzicka

Institute of Physics, Slovak Academy of Science, Slovak Republic
M Venhart

Jožef Stefan Institute, Ljubljana, Slovenia
P Pelicon
P Kump
M Nečemer
P Vavpetič
B Povh
M Lipoglavšek

Department of Biology, Biotechnical Faculty, University of Ljubljana, Ljubljana, Slovenia
M Regvar
K Vogel-Mikuš
P Pongrac
I Kretf

Korea Atomic Energy Research Institute, Jeongup-si, Daejeon, South Korea
S D Yang
J Kim

Korea Institute of Radiological and Medical Sciences KiRAMS, South Korea
J Kim

Hospital Universitario Virgen Macarena, Departamento de Fisiología Medica y Biofisica, Universidad de Sevilla, Spain
F Sanchez-Doblado

Faculty of Engineering, Univ of Castilla-La Mancha, Almaden, Spain
T Cuberes –Montserrat

Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas CIEMAT
J I Lagares

Fysiska institutionen, Lunds Tekniska Högskola, Lund, Sweden
K Malmqvist
J Pallon
P Kristiansson
M Elfman
C Nilsson
B Jonsson

Lund Institute of Technology, Sweden
B G Carlsson
I Ragnarsson

CERN (European Organization for Nuclear Research), Genève, Switzerland
D Küchler
F Cerutti
A Ferrai
ALICE collaboration

CSM Instruments, Switzerland
G Favaro

Paul Scherrer Institute, Villigen, Switzerland
R Schibli
A Lomax
E Pedroni

Centre de Recherche et Technologies sur les Energies, Tunis, Tunisia
R Chtourou

The Cyclotron Trust, Oxford, UK
D J Grocott

University of Oxford, UK
A Korsunsky
B Buck,
A C Merchant

University of Surrey, UK
P Evans
W Catferd
A Matte

STFC Daresbury Laboratory, UK
N Rowley

Kings College, University of Cambridge, UK
J F McKenzie

University of Birmingham, United Kingdom
M Freer.
T Kokalova
C Wheldon

University of York, United Kingdom
C Diget
B R Fulton
S P Fox
A Laird
P Joshi
D G Jenkins
N Navuzkanat
F Johnson-Theasby
R Wadsworth  
**Dept of Earth Science and Geography, Keele University, United Kingdom**  
NJ Keel  
B O’Driscoll  

**UAE University, Abu Dahbi, United Arab Emirates**  
K Meehan  

**Argonne National Laboratory, Chicargo, USA**  
J Greene  

**Michigan State University, USA**  
B A Brown  
A Fryday  

**Lawrence Livermore National Laboratory, USA**  
L A Bernstein  
D L Bleuel  
R Hatarik  
D H G Schneider  

**Lawrence Berkeley National Laboratory, USA**  
P Fallon,  
I-Y Lee,  
R B Firestone,  
M S Basunia,  
L Phair  

**University of California Berkeley, USA**  
B L Goldblum  

**Midwest Proton-Therapy Facility, Bloomington IN, USA**  
D F Nichiporov  

**Pro-Cure Treatment Centres Inc, Bloomington IN, USA**  
A N Schreuder  

**Massachusetts Institute of Technology, USA**  
B P Wiess  

**Arizona State University, USA**  
A Pommier  

**University of Utah, USA**  
J R Bowman  

**Stanford University, USA**  
J Wooden  

**Positron, Texas, USA**  
J Kitten  
S Kittem  
P Rooney  

**Los Almos National Laboratory, USA**  
FM Nortier  

**University of Washington, Medical Centre, USA**  
G Laramore  
R Risler  

**Cornerstone University, Michigan, USA**  
N Crompton  

**University of Notre Dame, USA**  
G Berg  
M Wiescher  
M Couder  
J Görres  
A Long  

**Department of Materials Science & Engineering, University of Arizona, Tucson, USA**  
J B Kana Kana  

**NSF CoE CMFN, Clark Atlanta University, Atlanta, USA**  
I Khan  
A Msezane  

**Brighnam Young University, USA**  
G Hart  

**Lehigh University, USA**  
R Vinci  

**Brookhaven National Laboratory, USA**  
K Lutterodt  
F Camino  
E Sutter  

**Arizona State University, Arizona, USA**  
J Wetmore  
M Harsh  

**Georgia Tech University, USA**  
T S Woodson  
D Soumonni  
S Cozzens
Rutgers University, New Jersey, USA
E Garfunkel

Department of Pediatrics, Baylor College of Medicine, USDA-ARS Children's Nutrition Research Center, Houston, TX, USA
M Klein
A Grusak

Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, USA
T Tyliszczak

Departments of Science Education and Biology, Boston University, Boston, MA, USA
D Zook

Plant Biology Division, The Samuel Roberts Noble Foundation Inc, Ardmore, Oklahoma, USA
A Valentine

Department of Biological Sciences, San Jose State University, San Jose, USA
N Rajakaruna

Department of Biological Sciences, Auburn University, Auburn, Alabama, USA
R Boyd

Kansanshi Mining PLC, Zambia
V Masedi

Physics Department, National University of Zambia
S Htwaambo
M Thembo
G Kalonga
3.4.2 South African Users and Collaborators

AGES
M Hill

ARC-Infruitec, Stellenbosch
B Barnes

Aurecon
M Levin

Cape Peninsula University of Technology, Cape Town
T N van der Walt
L Taleli
W Solomons
Z Jalali
B Wyrley-Birch
C le Roux
R Pienaar
S Rhoda
D Gihwala
J Esterhuizen
S Khan
P Basson

CSIR
National Metrology Laboratory – Rosebank
B Simpson
F van Wyngaardt
M Railton

Biosciences & Synthetic Biology, CSIR, Pretoria-South Africa
M Mhlanga
F Saiman
R Sparrow

Constantiaberg Mediclinic
R Mellvill

Council for Geosciences
J Leshemo
H Saeze
H Mengitsu
U Nzotta
S Lenong

Department of Health
Western Cape
S Olivier
E Snyman
S Nel

Department of Water Affairs
N. Netshiendeulu

Digby Wells
L Smith
G Moukodi

Radiation Oncology Department, Durban
T Mazibuko

Eerste River Hospital,
C Antonie

Eskom
M Alard
L Msengana

Frere Hospital
Department of Radiation Oncology
B Pochare
V Reddy

Geomeasure
R Sebire
T Swalles
K Gravelet-Blondin

Groote Schuur Hospital Division of Radiation Biology
A Hunter

Ground Water Squared
L Botha

Health Professions Council of South Africa
Professional Boards
S Munyuku

Jones & Wagener
L Potter

Medical Research Council
N Bhagwandin
J Seier
J van Heerden

Mintek
E van der Lingen

Molteno Brothers, Elgin
E Louw
C O’Brien
National Institute for Communicable Disease, Johannesburg
G Munhenga
B Brooke
L Koekemoer

National Laser Center (NLC)
S Federico

National Nuclear Regulator
W J Speelman
T Tselane

National Research Foundation
K Bahruth-Ram

Necsa
V Z de Villiers
N Jarvis
J-R Zeevaart
T Ntsoane
A Venter
M Andreoli
S Sello
C Wagener

Nelson Mandela Metropolitan University
P McGrath
S Baron

Centre for HRTEM
J H Neethling
E J Olivier
J H O'Connell

Netcare Limited
Netcare Oncology and Interventional Centre
Radiotherapy Department
N Willemse
A Groenewald

North West University,
N Mumba
D Serfontein
M Modise
I Schoeman

Department of Chemistry
A Grobler

NTP Radioisotopes (Pty) Ltd
S Maage

Provincial Hospital Port Elizabeth
Department of Radiation Oncology
E Jansen

Rhodes University, Grahamstown, South Africa
N Torto
S Chigome

Dept of Physics and Electronics
D G Roux

SASOL
E Du Plessis
H Assumption

SRK Consulting
N Sutria
C Terrel
D Duthe
J Van der Walt

Tshwane University of Technology, Pretoria-South Africa
R McCrindle
L Cele
J Ndambuki

Chemistry Department
F Dakora

Department of Crop Science
L Maja
S Kanu

Umvoto Africa
R Hay

University of Cape Town
J Visser
A Hunter
D Hendricks
J Womersley
K Hadley
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Centre for Materials Engineering
C Lang
R Knutsen

Department of Chemistry
G Smith
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| H Hawkins                          | Department of Geology    |
| M Cramer                           | C D K Gauert             |
|                                   | A Wildau                 |
|                                   | M Tredoux                |

| Electron Microscopy Unit          |                         |
| M Jaffer                           |                         |

| Molecular and Cell Biology Department |                         |
| J M Farrant                        |                         |
| R Ingle                            |                         |
| M Wolf                             |                         |

| Department of Zoology,            |                         |
| H L Malan                          |                         |

| Department of Radiation Oncology  |                         |
| E A Murray                         |                         |
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| A L van Wijk                       |                         |
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| S Dalvie                           |                         |

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| A Morrison                         |                         |
| S Bremner                          |                         |
| J-P Franzidis                      |                         |
| A van der Westhuizen               |                         |
| S Harrison                         |                         |
| L Bbosa                            |                         |
| M Brighton                         |                         |
| D Parker                           |                         |
| J Cilliers                         |                         |

| School of Electrical, Electronic and Computer Engineering |                         |
| A L L Jarvis                                   |                         |

| University of Limpopo/ Dr George Mukhari Hospital Medical Physics |                         |
| F Daniels                              |                         |

<p>| University of Pretoria |                         |
| R Lakier               |                         |</p>
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<th>G Mathurine</th>
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<td>M Diale</td>
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<tr>
<td><strong>Department Of Nuclear Medicine, Steve Biko Hospital</strong></td>
<td><strong>Division of Medical Physics</strong></td>
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<td>M. Mouton</td>
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<td><strong>Department of Botany &amp; Zoology</strong></td>
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<td>A Valentine</td>
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<td>S Siqueira Turketti</td>
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<td>A A Cowley</td>
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<tr>
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<td><strong>University of the Witwatersrand</strong></td>
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<td>J Carter</td>
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<td>I T Usman</td>
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<td>E Sideras-Haddad</td>
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<td>S R Naidoo</td>
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<td>D Commins</td>
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</tbody>
</table>
Users and Collaborators

T Mophaltlane  
R Goba  
T Makgato  
D Wamwangi  
A Kozakiewicz  
E K Nshingabigwi  
I Motochi  
B A Mathe  
R M Erasmus  
S Shrivastava

School of Geophysics  
G R J Cooper

School of Chemistry  
T Lerotholi

School of Geosciences  
B Th Verhagen  
L Ashworth  
J A Kinnaird  
P A M Nex

School of Molecular and Cell Biology  
C Straker  
M. Zamxaka

Metallurgy Department  
N Sacks

Department of Nuclear Medicine, Charlotte Maxeke Hospital  
W Vangu

University of Zululand  
Department of Physics and Engineering  
O M Ndwandwe  
O Nemraoui  
S Ntshangase

Tygerberg Hospital, Cape Town  
S Rubow  
J W Warwick  
J Pelser

Water Geosciences Consulting  
M Holland

West Rand Oncology Centre  
R de Mûelenaere  
S Baistow  
L van Zyl

XSIT Citrusdal / Citrus Research International  
H Hofmeyr  
M Hofmeyr

T Mophaltlane  
R Goba  
T Makgato  
D Wamwangi  
A Kozakiewicz  
E K Nshingabigwi  
I Motochi  
B A Mathe  
R M Erasmus  
S Shrivastava  
S Groenewald  
Rob Stotter
3.5.1 iThemba LABS Organizational Structure
3.5.2 Staff List (as at 31 March 2013)

**DIRECTORATE**
Z Z Vilakazi - Director  
J J Lawrie - Deputy Director & Head of Research  
A Raman (Personal Assistant)

**HUMAN RESOURCES**
N Africa - Division Head  
M Plaatjies-da Silva  
M van der Meulen (till Dec 2012)  
A Haggland (from Nov 2012)  
T Ramosie

**FINANCE AND BUSINESS MANAGEMENT**
V Spannenberg – Department Head  
N Oliver (Secretary)

**N Moshenyane (Manager: Finance)**
A Tyhali  
C Saaaiman  
D Smith  
F Wallace (till Dec 2012)  
E Majiet

**N Pietersen (Manager: Supply Chain & Support Services)**
L Sabsana  
I Antonie – Stores Supervisor  
A Ntunzi (till Jun 2012)  
L Davids  
R Hendricks  
G Christians  
E Theunissen  
R Masiza

**Safety, Health & Environment**
F Daniels (Division Head)
J Fredericks  
B du Preez  
A Lombard  
M Lots  
J Mncube  
N M Marks  
M R Mentsyisi  
S Magwa  
Z Diba  
E D Knoop (Supervisor: Housekeeping)  
J Aron  
L Mcoteli  
D Theunissen  
E Sono  
S Silwanyane

**COMMUNITY INTERACTION & TRAINING**
G Arendse - Division Head
A Yaga  
L Sidukwana  
E Mabotswa (from Sept 2012)

**ACCELERATOR**
L Conradie (Department Head)  
D Fourie (Deputy Head)  
P van Schalkwyk (Deputy Head)  
V de Jongh (Secretary)

**Cyclotron & Beam Transport**
R Thomae  
J G de Villiers  
JP Mira  
C Ndlangamandla (from Nov 2012)  
R Pylman

**Cyclotron Operation**
M Sakildien (Division Head)
B Greyling  
N Khumalo  
E van Oordt  
T Baloyi  
O Combo  
C Williams  
H Anderson  
M Dire  
N Klaasen

**Van De Graaff Operations**
K Springhorn (Chief Operator)  
S Marsh  
C Doyle

**Radio-Frequency**
J van Niekerk (Division Head)
H du Plessis  
W Duckitt  
G Price  
D April

**Diagnostics & Vacuum**
P Rohwer (Division Head)
R McAlister  
C Antonie  
H Klink  
G Pfeiffer  
L Anthony  
O Smith
Electronic Engineering  
SJ du Toit (Division Head)
M Chirindo  
C Lussi  
C Baartman  
P Davids  
P Shoedass  
K Solomons  

Information Technology Support  
I Kohler – Deputy Department Head
J Krijt  
A Phillips  
M Robertson  
M Bark  
W Tapleni  
G de Vaux  
H Gargan  

Electrical  
M C Bakkes  
L Swartz  
M Isaacs  
R Hendricks

Mechanical Engineering
D Wyngaard (Division Head)
P Paulsen (Supervisor: Workshop)
S Bizwaphi  
L Adams  
M Williams  
J van der Walt  
N Ndalyvane  
A du Plessis  
M Adams  
W Kearns  
J Broodryk (from Aug 2012)
J Augustine  
C Alexander  
M Davids  
K Kunana

RADIONUCLIDE PRODUCTION  
C Naidoo - Department Head
D Christians  
V Jackson  

Radiopharmacy  
D Prince - Division Head
S Dolley  
C Davids  
X Mncedane  
A Pakati  
M van Rhyn  
C Perrang  
J Abrahams (till Feb 2013)
P Hobongwana (from Sept 2012)
M Ntoy (from Aug 2012)
S Buwa  
R Anthony

ELECTRONICS & INFORMATION TECHNOLOGY
J Pilcher - Department Head
S Watts (Secretary)
N Rabe  

Radiochemistry  
N Rossouw - Division Head
N Van Der Meulen  
E Isaacs  
P Louw  
S Losper  
C Vermeulen  
S de Windt  
G Swarts  
D Saal

Library & Information Systems
N Haasbroek - Division Head
A Sauls  
W Zaal

MEDICAL RADIATION  
J P Slabbert - Department Head
E van Ster (Secretary)

Software Engineering
M Hogan - Division Head
C Oliva  
C Pieters  
L Pool  
S Murray  
M A Crombie  
A Sook  
M Mvungi

Operations & Treatment  
J Nieto-Camero –Operations & Treatment
S Schroeder (Supervisor)
S Rhoda  
M Loubser  
P C du Plessis

Electronic Engineering (R & D)
N Stodart - Division Head
H Mostert  
J van der Merwe  
S Stefanov  
P Jones
Departmental Reports

Treatment Planning & Development
E de Kock (Division Head)
J Symons
N Muller
B Martin
C vanTubbergh
C Callaghan
S Qhobosheane

Clinical Research
D Commin (Supervisor)
S Fredericks

Hospital
A Lawrence -Division Head
L Faviers
E Booysen
J Fuller
W Abrahams
L Arendorff
E van Zyl
S Daniels (Supervisor: Kitchen)
J Petro
M Bond
C Diba
J de Morney
E Knoop
A Rhoda
S Daniels
A Steyn
F Fredericks (Supervisor: Housekeeping)
T Lavery

RADIO-BIOLOGY DEPARTMENT
A Baeyens
V Vandersickel (postdoctoral researcher)

Radiation Protection Division
D McGee - Division Head
T Modisane
N E Mzuzu
W J Fredericks
J Otto
S Sam
F Beukes (Contract)
X Muller (Contract)

NUCLEAR PHYSICS DEPARTMENT
M R Nchodu – Department Head (from June 2012)
S V Förtsch
E A Lawrie
M Wiedeking
F D Smit
G F Steyn
E Z Buthelezi
R Neveling
P P Maleka
P Jones (Contract)
D Negi (postdoctoral researcher)
F Bossu (postdoctoral researcher – from Aug 2012)
S Ntshingana
N Y Kheswa
F Gonglach
O Shirinda (PDP)
T D Singo (PDP)
J Swartz (PDP)
D Geduld (PDP)
F Nemulodi (PDP)
J Easton (PDP)
B V Kheswa (PDP)
S Majola (PDP)
S P Noncolela (PDP)
Z Ngcobo (PDP)
J Cleymans (Research Associate)
A A Cowley (Research Associate)
S M Perez (Research Associate)
W A Richter (Research Associate)
S M Perez (Research Associate)
W A Richter (Research Associate)

MATERIALS RESEARCH DEPARTMENT
C Pineda-Vargas – Department Head
L Nyusani
J Crafford
W Przybylowicz
J Mesjasz-Przybylowicz
M Maaza
M Topic
M Nkosi
R Bucher
P Sechogela
C Mtshali (Contract)
Z Khumalo (Contract)
R Minnis-Ndimba (Contract)
A Barnabas (Contract)
T Doyle (Contract)
C Comrie (Contract)
L Kotsedi (PDP)
G Philander (PDP)
B Ngom (postdoctoral researcher)
Y Wang (postdoctoral researcher) (till Dec 2012)

iThemba LABS (GAUTENG)
S M Mullins – Department Head
D D Monyamane (Secretary)
M Msimanga
M Madhuku
K G Sekonya (Contract)
A M Kwelilanga
M D Mahlare
M Maloma
T C Mashego
J E Padavatan
P Chuma
M A Mthembu
N V Radebe

**Technical Division**

C G Badenhorst – Division Head
K F Balzun
O Pekar
A Miller (from Aug 2012)
R K Chirwa
T T Matsibiso
S Selinyane
H Shipalana

**Environmental Isotopes Division**

M J Butler – Division Head
M J Mabitsela
O H T Malinga
### 3.7 Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ADC</td>
<td>Analogue to Digital Converter</td>
</tr>
<tr>
<td>AFM</td>
<td>Atomic force microscopy/microscope</td>
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<td>AFRODITE</td>
<td>The iThemba LABS gamma-detector array</td>
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<td>AFS</td>
<td>Andrew File System</td>
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<tr>
<td>ALI</td>
<td>Annual limit of Intake</td>
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<td>ALICE</td>
<td>A Large Ion Collider Experiment - one of seven detector experiments at the LHC, CERN</td>
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<tr>
<td>AMS</td>
<td>Accelerator Mass Spectroscopy</td>
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<td>BGO</td>
<td>Bismuth Germanate – Bi$_4$Ge$<em>3$O$</em>{12}$</td>
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<tr>
<td>CAMAC</td>
<td>Computer Automated Measurement And Control – modular crate electronics standard for data acquisition</td>
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<tr>
<td>CDCC</td>
<td>continuum-discretized coupled channels</td>
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<tr>
<td>CERN</td>
<td>European Organization for Nuclear Research</td>
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<tr>
<td>CPUT</td>
<td>Cape Peninsula University of Technology</td>
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<tr>
<td>CSIR</td>
<td>Council for Scientific and Industrial Research</td>
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<tr>
<td>CT</td>
<td>Computed Tomography</td>
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<tr>
<td>CVD</td>
<td>Chemical Vapor Deposition</td>
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<tr>
<td>DAC</td>
<td>Digital to Analogue Converter</td>
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<tr>
<td>DAQ</td>
<td>Data Acquisition System</td>
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<tr>
<td>DDR</td>
<td>Digitally Reconstructed Radiograph</td>
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<tr>
<td>DMC</td>
<td>Dose Monitor Controller</td>
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<tr>
<td>DST</td>
<td>Department of Science and Technology</td>
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<td>ECRIS</td>
<td>Electron Cyclotron Resonance Ion Source</td>
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<td>EEC</td>
<td>Electrostatic Extraction Channel</td>
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<td>EPICS</td>
<td>Experimental Physics and Industrial Control System</td>
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<td>EPMA</td>
<td>Electron Microprobe Analysis</td>
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<tr>
<td>ERDA</td>
<td>Elastic Recoil Detection Analysis</td>
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<td>ETX</td>
<td>Embedded Technology eXtended - a highly integrated and compact computer-on-module form factor</td>
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<td>EXAFS</td>
<td>Extended X-Ray Absorption Fine Structure</td>
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<td>FDG</td>
<td>Fluorodeoxyglucose</td>
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<tr>
<td>FPGA</td>
<td>Field Programmable Gate Array</td>
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<tr>
<td>FWHM</td>
<td>Full Width at Half Maximum</td>
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<td>GMP</td>
<td>Good Manufacturing Practice</td>
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<tr>
<td>GTS</td>
<td>Grenoble Test Source</td>
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<td>HMI</td>
<td>Hahn Meitner Institute</td>
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<td>HPGe</td>
<td>High Purity Germanium</td>
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<td>HPLC</td>
<td>High Performance Liquid Chromatography</td>
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<td>HWCD</td>
<td>Hot Wire Chemical Vapour Deposition</td>
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<tr>
<td>IAEA</td>
<td>International Atomic Energy Agency</td>
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<tr>
<td>mIBG</td>
<td>metaiodobenzylguanidine</td>
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<td>IOC</td>
<td>Input/Output Controller</td>
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<tr>
<td>ITLC</td>
<td>Instant Thin-Layer Chromatography</td>
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<tr>
<td>KIRAMS</td>
<td>Korea Institute of Radiological Medical Sciences</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>LBNL</td>
<td>Lawrence Berkeley National Laboratory</td>
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<tr>
<td>LEPS</td>
<td>Low Energy Photon Spectrometer</td>
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<td>LET</td>
<td>Linear Energy Transfer</td>
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<td>LHC</td>
<td>Large Hadron Collider</td>
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<td>LIS</td>
<td>Library and Information Service</td>
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<tr>
<td>MANuS</td>
<td>Masters in Accelerator and Nuclear Science</td>
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<tr>
<td>MatSci</td>
<td>Masters in Materials Science</td>
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<tr>
<td>MBE</td>
<td>Molecular Beam Epitaxy</td>
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<tr>
<td>MEC</td>
<td>Magnetic Extraction Channel</td>
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<tr>
<td>MEDM</td>
<td>Motif Editor and Display Manager</td>
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<tr>
<td>MODBUS</td>
<td>a serial communications protocol originally published by Modicon</td>
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<tr>
<td>NIM</td>
<td>Nuclear Instrumentation Module (an instrumentation standard)</td>
</tr>
<tr>
<td>NRF</td>
<td>National Research Foundation</td>
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<tr>
<td>NTeMBI</td>
<td>Nuclear Technologies in Medicine and the Biosciences Initiative</td>
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<tr>
<td>PCI</td>
<td>Peripheral Component Interconnect (a local computer bus for attaching hardware devices in a computer)</td>
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<td>PDP</td>
<td>Professional Development Programme</td>
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<tr>
<td>PECVD</td>
<td>Plasma Enhanced Chemical Vapour Deposition</td>
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<tr>
<td>PEPT</td>
<td>Positron Emission Particle Tracking</td>
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<td>PET</td>
<td>Positron Emission Tomography</td>
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<td>PIXE</td>
<td>Particle Induced X-ray Emission</td>
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<td>PTCOG</td>
<td>Particle Therapy Co-Operative Group</td>
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<tr>
<td>PXI</td>
<td>PCI Extensions for Instrumentation</td>
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<tr>
<td>RBS</td>
<td>Rutherford Back Scattering</td>
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<tr>
<td>RF</td>
<td>Radio Frequency</td>
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<tr>
<td>RIB</td>
<td>Rare Isotope Beam</td>
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<td>RIMS</td>
<td>Research Information Management System</td>
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<td>RPD</td>
<td>Radionuclide Production Department</td>
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<td>SANReN</td>
<td>South African Research and Education Network</td>
</tr>
<tr>
<td>SEM</td>
<td>Scanning Electron Microscopy/Microscope</td>
</tr>
<tr>
<td>SPC</td>
<td>Solid Pole Cyclotron</td>
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<tr>
<td>SPG</td>
<td>Stereophotogrammetric</td>
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<td>SSC</td>
<td>Separated Sector Cyclotron</td>
</tr>
<tr>
<td>TEM</td>
<td>Transmission Electron Microscopy/Microscope</td>
</tr>
<tr>
<td>TOF</td>
<td>Time of Flight</td>
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<tr>
<td>UPS</td>
<td>Uninterruptable Power Supply</td>
</tr>
<tr>
<td>USB</td>
<td>Universal Serial Bus</td>
</tr>
<tr>
<td>VBTS</td>
<td>Vertical Beam Target Station</td>
</tr>
<tr>
<td>VME</td>
<td>a computer bus standard</td>
</tr>
<tr>
<td>VPN</td>
<td>Virtual Private Network</td>
</tr>
<tr>
<td>XRD</td>
<td>X-ray diffraction</td>
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