SHAPING THE FUTURE OF PHYSICS IN SOUTH AFRICA

REPORT OF THE

INTERNATIONAL PANEL

APPOINTED BY THE

DEPARTMENT OF SCIENCE AND TECHNOLOGY
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EXECUTIVE SUMMARY

Preamble

It is recognized worldwide that physics is a basic science, vitally important to the development of mankind and to our understanding of the world - and universe - in which we live.

In South Africa, notable contributions to both fundamental physics and its applications have already been made, and, with the much-improved political situation, the subject is poised to make even more important contributions - on both the national and international stage. Such contributions relate particularly to improvements in the material well-being of individual citizens, to their health and safety and, at the national level, to its prestige and to the stability of the region.

In all this the maintenance, and enhancement, of the science base - of which physics is a key component - is vital.

In particular, physics often acts as a lead science - not only are the physics developments of today the technology of tomorrow, but, inter alia, it also plays the role of the canary in the mine. Thus, if Physics gets seriously ill, it is a warning that science and technology as a whole, and hence the growth of a knowledge-based economy, are in grave danger.

It is the Panel's view that at this stage, Physics in South Africa, although a small community, has a good international reputation, and exhibits significant strengths in a number of areas. However, it is in considerable danger, particularly in view of the ageing cohort of researchers, the trickle of input into the human resource pipeline, the slow pace of transformation in the physics establishments of universities and research institutes, and generally inadequate funding.

The International Panel is particularly impressed by the positive attitude of the present Government to science and is convinced that the physics community, enhanced in the many ways to be suggested, can make an important contribution.

Although not itemized as such, the five topics listed in the Terms of Reference (funding regimes, research capacity, human resources, consolidating existing reviews, and proposing strategies), are all covered by the Report.

In view of time constraints, the Panel has placed less emphasis on "the state of physics in South Africa", but concentrated on formulating "a strategy to revitalize physics in South Africa", and we believe that we had adequate information for the latter.

We regard the recommendations as robust.

After considerable exposure to the community and due deliberation we are able to respond to our brief, to review the state of physics in South Africa and to formulate strategy to revitalize it.

The current state of Physics in South Africa

The Panel is of the opinion that, considering the stresses of recent decades, the physics community is remarkably resilient. Despite the problems all along the line (poor preparation of physics students in schools, patchy support in universities, general under-funding, and the stresses of restructuring in the educational sector) there are some areas of research in universities and institutes that are internationally competitive. Many others are of good national standard. Most importantly, we discovered a physics research and teaching community that is talented and that will - when augmented by bright younger people - be able to take advantage of the new possibilities which are unfolding.

However, the physics community is small and spread over a large geographical area. There are a number of sub-critical research groups, and, apart from some notable exceptions, there is a lack of coherent collaborative research activity, whicht needs to be addressed. There is a perceived need for more collaboration and improved inter-personal communication at many levels, and some of our recommendations aim at removing structural difficulties that currently inhibit collaboration. But ultimately, the future of Physics lies in the hands of the Physics community, and its ability to grasp the opportunities for engaging with one another, with contiguous and related disciplines, with engineering groups, with industry and with the broader society.

A strategy to revitalize Physics in South Africa

Our terms of reference refer to the need to "formulate a strategy… to redirect Physics in South Africa." The Panel's view is that it is not so much a "redirection" that is required, as a serious and sustainable improvement in the many areas referred to below.

In what follows, we itemize the main recommendations. We regard their implementation as URGENT.
(We expect the institutions in parentheses to take the lead in taking action).

THE MAIN RECOMMENDATIONS

1. In many countries, elementary and secondary school teaching of mathematics and science is a considerable worry. In South Africa this situation is exacerbated in the historically black schools. Although beyond the scope of this inquiry, we must flag this very serious situation. We acknowledge that steps are being taken to address this matter, but urge the relevant authorities to pursue it with even more vigour, as it is a crisis situation. Individuals in the physics community are to be commended for their activity in this regard, but more involvement is needed, particularly at the structural level. [SAIP, NRF, Department of Education]

2. The long-term sustainable future of physics in SA depends on the country's commitment and investment in the development of a workforce that is representative of its demographic diversity. Evidence indicates that, while there is a rapidly growing cadre of physics students from previously under-represented groups, there are perceived difficulties that need to be addressed by the established physics community and by the funding authorities. Apart from financial barriers to both undergraduate and postgraduate study (addressed below), there are others matters of concern, such as that relating to the integration of students of different cultures into existing departments, particularly in regard to the transfer of students from HBU's to

HWU's. These questions need to be addressed urgently, and interpersonal communication is of the essence. [University community].

3. Job prospects in Physics are perceived by many young people to be poor, and this affects the take-up of the subject in schools and universities, but this is illusory. Both industry and business welcome them, for both technical and managerial careers, but this is not made apparent. The fault appears to lie on both sides, employers not making it clear that physicists are welcome to apply for their vacancies, and physicists not being sufficiently proactive. We recommend that SAIP mount a "connectivity-campaign". [SAIP]

4. The "Public Understanding of Science" is increasingly important, not least for a democratic nation where the wide appreciation of science is vital. Much is being done but we recommend more, particularly as "the public" consists of many constituencies, all of which are important. [SAIP]

5. There is considerable concern in the science community about the low level of remuneration in academe, school-teaching and student bursaries. In particular, we propose a revised bursary scheme with the intention of minimising the financial barrier for students to enter physics and to stay in physics, especially in comparison with competing career paths. The proposed bursary scheme is ideally based on the concept of free tertiary education for science students. We recognise the competing claims on national resources, but an upward revision of salaries and bursaries is essential. A serious "brain-drain" will result if salaries are kept low. [SAIP, NRF, Department of Education, Universities]

6. We recommend the creation of a fast, inexpensive, broadband National Research Information Network to support non-commercial research. This is vital not only for the National Research Digital Library suggested below, but in order to permit the maximum exploitation by South African scientists of data provided by national investments similar in scope to the proposed Square Kilometer Array. Projects of this type are likely to be the trend of the future and the lack of a system like the NRIN will mean that the dissemination of high value knowledge skills will, at a minimum, be severely constricted. [NRF, DST]

7. We recommend the creation of a National Research Digital Library Resource. Such a structure would provide subscription to electronic journals that will be accessible over the internet, and hence available to all universities (both staff and students), and selected non-commercial researchers. If the physics programmes of this nation are to be competitive, this is a vital need. It is clear that such a resource will have a transformational nature also, since even remotely located Universities will also be able to access the latest research findings, with the caveat of the necessity of ready internet access. [NRF, DST]

8. The Panel noted with pleasure the overall level of research and the existence of some excellent projects, although relatively few in number. Particularly impressive is the attitude of researchers towards the new "flagship projects" - projects that we applaud. We recommend that these projects be seen both to act as a focus for much of the scientific work in their respective areas, and to provide links to apparently unrelated branches of physics. [SAIP, DST, Physics community]

9. The onus is on the physics community to develop a long-term strategy for the subject, which addresses national developmental priorities as well as keeping the research internationally competitive. Such a strategy should, inter alia, aim at

optimising both access to and the efficient use of, expensive equipment, and to facilitate the use of existing expertise by encouraging collaboration, thereby reducing the barrier to innovation. This may lead to the establishment of a limited number of other "flagship" projects and/or National User Facilities (NUF's) on a scale more comprehensive than hitherto, and with an emphasis on facilitatory governance. Proposals for such projects should ensure a balance between funds for equipment, including its periodic updating, and those of staffing and maintenance. The concept of a NUF is decribed in more detail in Chapter 4 and Appendix 4 of the Report. [NRF]

10. Preoccupation with flagship projects and National User Facilities should not lead to the neglect of other areas of research. International experience has shown that "small science" has not only been a major training ground, and the forerunner, scientifically, of many large projects, but has also been a major vehicle for innovation and intellectual property development. Thus there is a need for strong support for "small science", preferably in the context of collaboration. [NRF, SAIP]

11. There is considerable concern about the state of the research infrastructure. According to the data received, much of the equipment in university departments is out of date or inadequate. The Panel recommends that SA makes a rational investment in modernizing its research infrastructure to meet the scientific requirements, as well as with the objective of training the future generation of young scientists and engineers with globally competitive skills. The Panel recommends that appropriate mechanisms for funding and optimal utilization of existing resources be put in place at all levels of the scientific needs. [NRF, DST, Department of Education]

12. The state of theoretical physics is characterised as internationally competitive in some areas, but there is fragmentation and a coherent policy is needed in the nation. We recommend the establishment of a National Theoretical Physics Facility (either real or virtual); the theoretical physics community will then be able to respond nimbly to national science policy initiatives. [NRF]

13. An important effect of physics research projects is technological spin-off. Advanced research projects not only bring immediate "rewards" to industry and commerce in the form of orders for technologically advanced equipment, but they also raise the possibility of new, previously unforeseen, developments. "Astro-technology" is an excellent example and we recommend that it be used as a prototype, and that physicists make use of the structures that encourage links to industry and innovation. [NRF, DST, SAIP]

14. We recommend that the Management and Policy Committee should remain in existence as a monitoring body, and that the SAIP, DST and NRF should report back to it in a year from now. The MPC should inform the community on the extent to which the Panel's recommendations have been implemented. [MPC]

It should be noted that some of above recommendations are presented in more detail, and with some variation in wording, in the main body of the Report, in addition to further recommendations.

In summary, we believe that South African society needs a strong Physics community in the interests of the overall science and technology sector; that South African Physics, although a small community, has considerable strengths; that Physics in South Africa is currently in danger; but that South African Physics can be saved, and indeed can grow.

We commend this Report to the community in general and to the initiators (SAIP, NRF and DST) in particular.

Our view is that if the recommendations are followed there will be an improvement in the areas where the initial concerns prompted the review, viz.

Student numbers will rise, at both undergraduate and postgraduate level;
The demography will be transformed;
Research funding will increase;
Funding for physics in general will increase,

in other words,

PHYSICS IN SOUTH AFRICA WILL BE REVITALIZED

April 2004

1. THE BACKGROUND

1.1 The Reasons for setting up the Panel

Many South Africans are aware of the CT or CAT (Computerized Axial Tomography) Scanner, a widely-used non-invasive medical diagnostic instrument. However, few realise that the first steps towards the development of this fundamental tool of modern medicine were taken in the Physics Department of a South African university.

About 50 years ago, Alan Cormack, a lecturer at the University of Cape Town, was interacting with medical colleagues from Groote Schuur Hospital, concerning the interpretation of X-ray pictures. The doctors complained that the pictures were “shadowgraphs”, and that they could not see the tissue that lay behind the shadowing objects. Using his knowledge and experience as a physicist, Alan Cormack devised an experiment, and developed the fundamental underlying theory required to interpret the pictures. His research article, published in the *Journal of Applied Physics* some years later, had the rather esoteric title “On the representation of a function by a set of its line-integrals, with some Radiological applications.” That paper led eventually to the award, in 1973, of the Nobel Prize in Medicine to Alan Cormack. And a couple of decades later, CAT scanners are found in every major hospital in the world. The Physics of today is often the technology or the instrumentation of tomorrow.

It is not common knowledge that in 2003, physics-trained people were not only awarded the Nobel Prize for Physics, but had shares in both the Nobel Prize for Medicine and for Economics.

And probably even fewer people realise that the commonly used touring, hiking and sailing tool, the GPS (Geographic Positioning System), requires, to provide accurate positioning, Einstein’s arcane General Theory of Relativity.

Thus it can be seen that Physics plays a fundamental role of “lead science” or “basic science”. Not only does it lead to technology, but it also enriches our lives, as it is a part of culture - it gives us a better understanding of our role and position in the Universe. Finally, Physics-trained people play a particularly useful role in today's technology-oriented society.

What is more, because of its basic role, Physics also plays the role of the canary in the mine. If Physics gets seriously ill, it is a warning that science and technology as a whole, and hence the growth of a knowledge economy, are in grave danger.

Right now, Physics in South Africa is ill. Although South Africa has considerable strengths in Physics (see below), there are also numerous warning signs that all is not well. ***Physics in South Africa is now under threat.***

The past decade or two has seen a decline in student numbers in Physics at all levels of study in tertiary education. University departments that once produced a torrent of excellent physicists, have been reduced to 3rd year classes of one or two. While student numbers at universities and technikons overall have risen during the last decade, what were major Physics departments can no longer guarantee that they will have an Honours class. The pipeline from school to profession is producing only a trickle of talented physicists. Pupils of Physical Science at school have declined in number. The teaching of Mathematics and Science at school is, in general, in dire straits. There is a shortage of teachers who have a thorough subject knowledge, as well as a love for the subject that they can transmit to their learners. The small pool of those students entering tertiary education with the required level of knowledge and understanding of Mathematics and Physics is skewed in its racial and gender composition (thereby leading to relatively slow transformation), and is attracted away from physics by the very real rewards to be found for a qualification in subjects such as Computer Science, Actuarial Science, and Business Science, apart from the long-standing attractions of Medicine and Engineering.

A couple of decades ago, the state had certain major missions, in which Physics played an important role. These included the broad fields of self-sufficiency in energy and defence, and in particular the development of a nuclear capability. National missions have now undergone changes.

However, many people have difficulty in identifying such missions facing the state now. And if they do exist, e.g. the fights against AIDS, poverty, crime, etc., they are seen as being based on "soft technology" and the social sciences, and a possible role for Physics is not recognised in them. Thus the role of Physics in the state, and indeed its importance to the state, is not as obvious as it was before.

Furthermore, large employers of physicists in the past, such as the CSIR and AEC, were radically restructured over the last 20 years. The National Physical Research Laboratory and other such laboratories disappeared, the role and number of physicists in the CSIR and NECSA were reduced, and they have become much more diffuse - less "visible". At the same time, the "scientific research" base of the CSIR was cut back, and replaced by a much more consultancy-oriented philosophy.

Outside academia, relatively few job advertisements are clearly designated as being for physicists. Even the Science Councils, once an area where many physicists were appointed, now employ relatively few physicists as such. Thus there is a perception amongst younger people of a lack of employment opportunities for those who study physics.

Overall, there is a relatively small base of active "visible" physicists, posts becoming vacant in academia are often frozen and not advertised, and there are strong indications that many of the most active researchers are approaching retirement. Although there are increasing numbers of students from under-represented groups coming through the ranks, the physics establishment is still largely composed of white males. Thus one must be concerned about the future of the physics research base.

Furthermore, as a school subject, Physics, as a part of Physical Science, is perceived as being a difficult subject, and unfortunately both learners and school authorities sometimes favour "easier" subjects, or possibly Physical Science at Standard Grade, so as to boost the resultant final performance in the Matriculation Examination, without consideration of the implications.

Thus, in summary, the superficial perception amongst those who are growing up is that Physics is a difficult subject at school and university, which does not lead to an identifiable job.

Within the Physics community there has been growing unhappiness regarding resource allocation, and in particular what was perceived to be the under-resourcing of Physics. There are inadequate funds for the replacement of ageing equipment, both from university sources and from central agencies (NRF). And there is the perception that funding emphasizes unduly the applications of science, without recognising (and funding) the role of the base sciences from which the applications come. The perceived lack of correlation between an individual's NRF rating and the actual funding awarded by the NRF has been a bone of contention, as has the fact that many physicists, doing "basic" research, seek support from the focus area "Unlocking the future", which appears to have higher standards imposed than some other (more applied) focus areas.

It is acknowledged that some of the concerns listed above are universal, in that other countries, too, have experienced a decline in student numbers in Physics, or at least a decline in the fraction of students taking the subject. Many, too find that inadequately-qualified teachers are responsible for the teaching of Physics at high school level. And no doubt, there is a general complaint about inadequate funding.

However, the situation is exacerbated in South Africa because of the racial imbalances within the pool of incoming students, thereby endangering the long-term sustainability of the discipline, and the extremely serious situation in regard to the teaching of science and mathematics at school level. There is also a perception in some quarters that at this stage of the country's development, the full emphasis of research support should be directed at "applied" research, in which the engineering fraternity are seen as being far more valuable than those with a physics training.

The above, and related, concerns led the South African Institute of Physics (SAIP), over a period of some years, to carry out a review of Physics, and to engage with the National Research Foundation (NRF) and the Department of Science and Technology (DST). The latter two bodies, recognising the seriousness of the situation, joined hands with the SAIP in setting up the International Panel to "Shape the Future of Physics in South Africa."

The three principals referred to above (the DST, NRF and SAIP) set up a Management and Policy Committee (MPC) that represented all stakeholders (i.e. higher education, industry, science councils, government, the biophysics and medical physics community, research students) with delegated authority to Prof EC Zingu, Chairman of the MPC.

The MPC was given overall charge of the process. It was their task to elicit the views of the physics community and the broader stakeholders, select the International Panel and convenor (subject to approval by the Director-General of DST), draw up the Terms of Reference of the Panel, approve the work plan for the review/foresight process, select and make available documentation that should be considered by the Panel, plan the programme of the Panel (in particular, which parties to interview, sites to visit, etc.), and to advise and manage the Technical Committee, the body responsible for the actual detailed arrangement of the logistics.

The International Panel submits its report to the MPC, who in turn will present it to DST and NRF, after soliciting responses to the report (review and strategic plan) from the relevant stakeholders.

1.2 Terms of Reference

The International Panel was appointed to carry out a **review/foresight process,** the purpose of which was to:

- review the state of physics in South Africa
- formulate a strategy to revitalize physics in South Africa.

The more detailed scope of the review/foresight process is described as follows:

- reviewing the funding regimes which promote physics and technology developments through research efforts in the private sector, science councils, academic institutions and/or any other donor agencies
- reviewing institutional infrastructure for the development of physics research capacity
- reviewing the human resources and skills development in physics
- consolidating existing reviews of physics
- proposing strategies to revitalize physics.

Specifically, the International Panel was to review the state of physics in South Africa and propose strategies with the aim of stimulating a revitalization and redirection of physics in South Africa by:

- reviewing the reports and minutes of previous assessments of physics in South Africa
- assessing submissions received regarding strategies for developing physics in South Africa
- undertaking a review and foresight of the state of physics based on an interpretation of the documentation provided by the TC (as well as on information obtained during interviews with relevant stakeholders.)
- undertaking on-site visits to and discussions with stakeholders, including academics, scientists in national laboratories, government representatives and industry with the objective of determining the potential to do physics
- formulating a strategy for future implementation to redirect physics in South Africa
- reporting verbally to the MPC and other stakeholders at the end of the review/foresight process
- compiling and submitting a written report on its findings and recommendations to the MPC within the stipulated format and timeframe.

In particular, the review/foresight process was to focus on physics in the tertiary education sector in South Africa. The Panel was advised not to dissipate its energies by attempting to deal in detail with the school education situation, other than possibly in regard to the training of science teachers. Nevertheless, it was made clear to the Panel, that stakeholders all recognized the fundamental importance of the school situation, and that it should not necessarily be ignored completely.

1.3 The Constitution of the Panel

At first sight it is anomalous to the foreign members of the International Panel that there should also be local (viz. South African) members of such a Panel, in view of its remit. However, in view of a greater emphasis being put on the future rather than assessing the present individual strengths and weaknesses of particular Departments, the anomaly disappears. In fact, the local knowledge has been extremely useful and the non-South African members express their gratitude to the local members for their input and for many kindnesses.

The members of the Panel are as follows:
Prof Krish Bharuth-Ram (University of KwaZulu-Natal), Nuclear and Condensed Matter Physics
Prof Martial Ducloy (Université du Paris-Nord, France), Atomic and Laser Physics
Professor Jim Gates (University of Maryland, USA), String Theory and Particle Physics
Dr Igle Gledhill (Defencetek, CSIR), Applied Physics
Prof Manfred Hellberg (University of KwaZulu-Natal), Plasma Physics - Convenor
Dr Kenneth Evans-Lutterodt (Brookhaven National Laboratory, USA), Condensed Matter and Applied Physics
Prof Guebre Tessema (Clemson University and National Science Foundation, USA), Condensed Matter Physics
Sir Arnold Wolfendale (Durham University, UK), 14th Astronomer Royal, Cosmic Rays and Astrophysics

The Panel members brought to the process a wide range of experience and knowledge, and their skills complemented each other well, both in regard to areas of Physics, and in other activities, such as Public Understanding of Science, operations of national funding bodies, industry, and education.

1. 4 The Process

As indicated above, the MPC provided the Panel with a wide range of material. These materials included policy documents (for instance, the government's Research and Development strategy), review reports (e.g. a review (2002) embodying the analysis of two comprehensive surveys of the identifiable physics community, completed in 1999 and 2000, a review of physics research activities in South African higher education institutions and National Facilities (1999)), submissions from the physics community (viz. responses to a very recent survey amongst SAIP members regarding perceptions of the level of research in South Africa), data on student numbers, and data on NRF awards made to the physics community in different guises.
The Panel requested some additional information that was made available through the kind offices of the Technical Committee and the Secretary of the SAIP. This included information on NRF-rated physicists, the value and age of expensive equipment in higher education institutions (HEI's), and student numbers at all institutions in 1998 and 2003. A request for bibliometric data could unfortunately not be fulfilled. In addition to the documentation made available to the Panel by the MPC, it also consulted the minutes of regional meetings held in 2002-3, the "chat site" set up at the time, and South African documents such as the recent HSRC report on R&D mobility,

together with reports of various public policy activities of the Institute of Physics (UK) and in the USA.

During the twelve-day period of the work programme drawn up by the MPC, the Panel paid visits to 7 cities and to 17 National Facilities, academic and industrial sites. Approximately 250 people were interviewed, covering a wide range - executive management of some universities and technikons, science councils and government departments, CEO's or senior managers of companies, researchers, physics academics in universities and technikons, physicists in industry and physics-trained individuals in management, self-employed people in business, post graduate students (without the academic staff), etc. In addition a large number of interviewees augmented their interaction by supplying further information to the panel by email.

It was a pleasure to meet these people, and we gratefully acknowledge the important inputs that they provided to this study.

Unfortunately, it was not possible to meet all those in the physics community who may have wished to have their voices heard directly, but it should be recognised that the whole process had provided ample scope for the entire community to submit inputs.

Also, it was disappointing that a number of individuals and bodies that were deemed by the MPC to be important, including some government departments and science councils, were not available to meet the Panel.

It should be said at the outset that the Panel does not feel that it is in a position to make a comprehensive comparative evaluation of the standard of research and activity in the different sub-disciplines of physics. By its nature, the process and the available data did not provide for a detailed critical review of the state of physics in South Africa. It was a rushed tour, with very limited access to research laboratories in universities, concentrated interviews, inadequate information on current research activity, and no bibliometric information.

However, from the first interactions with the MPC, it became clear to the Panel that the "foresight" aspect of the process was deemed to be the more important segment of the process, with the "review" part being necessary, so as to have a basis on which to devise the strategies for the future.

Although the work of the Panel was, by its very nature, rushed, and "spotty" (it was not possible to interview all sectors of the physics community in equal depth), the Panel is convinced that it has collected sufficient evidence to be able to make comments on the level of the Physics that it has seen, and it regards its knowledge base in regard to "the state of Physics" to be sufficiently well founded that its recommendations for the foresight exercise are robust.

2.PHYSICS, SCIENCE POLICY AND ECONOMICS

2.1 The Context - South African Science and Technology Policy

Since the election of the first democratic government in 1994, there has been a series of important policy papers that guide or affect the practice of science and technology, and thereby the practice of physics. This is the context within which the Panel has operated.

Major initiatives from various government sources affecting S&T, include:

South Africa's National Research and Development Strategy (2002), Government of South Africa (2002)
Preparing for the 21st Century (1996), DACST: The Green and White Papers on Science and Technology (1996)
The National Research and Technology Audit, DACST (1996/8)
The System-Wide Review of the Science Councils and National Facilities, DACST (1998)
The National Research and Technology Foresight Project, DACST (1999)
The National Plan for Higher Education, Department of Education (2001)
The National Strategy for Mathematics, Science and Technology Education in General and Further Education and Training, Department of Education (2001)
The Skills Development Strategy for Economic and Employment Growth, Department of Labour: The Green Paper (1997)
Human Resource Development Strategy for South Africa: A nation at work for a better life for all, Departments of Education and Labour (2001)
Accelerating Growth and Development: The contribution of the integrated manufacturing strategy, Department of Trade and Industry (2002).

The Foresight exercise carried out by the Department of Arts, Culture, Science and Technology (DACST) did not appear to focus particularly on fields that were of prime interest to the Physics community, many of whom in some ways felt left out of developments. However, that feeling may have arisen because of a lack of flexibility in the thinking of the community. It needs to adapt to the framework that is provided by government structures and policy if it is to survive.

Subsequently, a number of major scientific research areas were identified by DST (palaeo-anthropology, fynbos and biodiversity, the Antarctic, and the southern skies), where South Africa has a competitive advantage that it should pursue. It will be noted that in at least two of these, Physics plays an important role, viz. astronomy of the southern skies, and research conducted in Antarctica (that includes a long-standing programme in ground-based space physics). That does not mean, of course, that physicists cannot make a contribution in the other two research areas, too!

It is obvious that the recommendations of the Panel must be aligned with the National R&D Development Strategies, adopted by the Government of South Africa in August 2002, the context of which is outlined by President Thabo Mbeki :

"We have to exert maximum effort to train the necessary numbers of our people in all fields required for the development, running and management of modern economies. This again must be a national effort in which we should consider the necessary expenditures not as cost but as an investment in our future."

Further, we may quote Dr Rob Adam, Director-General, Department of Science and Technology:

"In July 2002 the Cabinet considered and approved the National R&D Strategy. The R&D Strategy ….represents the way forward for publicly financed science and technology and for creating an enabling environment for the National System of Innovations as a whole. The strategy operates at the level of major interventions and, therefore, it will lead to a wide range and variety of more detailed implementation activities. Organisations and groups are invited to approach the DST or its agencies if they wish to participate in specific strategy initiatives or contribute to the detailed implementation phases. The Department will make every effort to align such approaches with existing processes and, where necessary, establish new ones to achieve the objectives of the National R&D Strategy."

During South Africa's years of isolation and the pursuit of the associated technology missions of defence and energy self-sufficiency, the country spent more than 1% of its Gross Domestic Product (GDP) on Research and Development (R&D). However, after the abolition of the energy and military programmes, R&D spending dropped. By 1994 it had dropped to 0.7%, and it has stayed at about that level ever since. Figures for 2002 and 2003 show a small increase. It is encouraging to note that, in terms of the new R&D policy, it is the intention to double that figure by 2006.

The strategic objectives of the R&D Policy include

- Achieving mastery of technological change in our economy and society
- Increasing investment in South Africa's science base (human capital and transformation)
- Creating an effective government science and technology system (alignment and delivery).

Two questions thus arise.
Q1. What do we need to do to achieve these strategic objectives?
Q2. What is the role of Physics in this context?

The answer to the first question is clearly that we need to create and retain a pool of scientifically skilled and/or technologically competent, innovative and entrepreneurial people.

We attempt to answer question 2 below:

2.2 Physics and the Needs of the Nation

Physics, as a basic science, plays a fundamental role in underpinning technological development. Since technological development has a strong influence on a nation's economy, and its ability to provide for its citizens, Physics has a strong utilitarian role to play.

As Abdus Salam, the Pakistani Nobel Laureate in Physics in 1979, observed,
"In the final analysis it is basically mastery and utilisation of modern science and technology that distinguishes the South from the North." [1]

Given the strategic policy framework outlined above, we may ask: where does SA stand in economic terms, and how is this related to science and Physics in particular?

Indicators are quoted in the report “The State of Physics in South Africa”, 2002. The share of world wealth by country is illustrated in Figure 1.

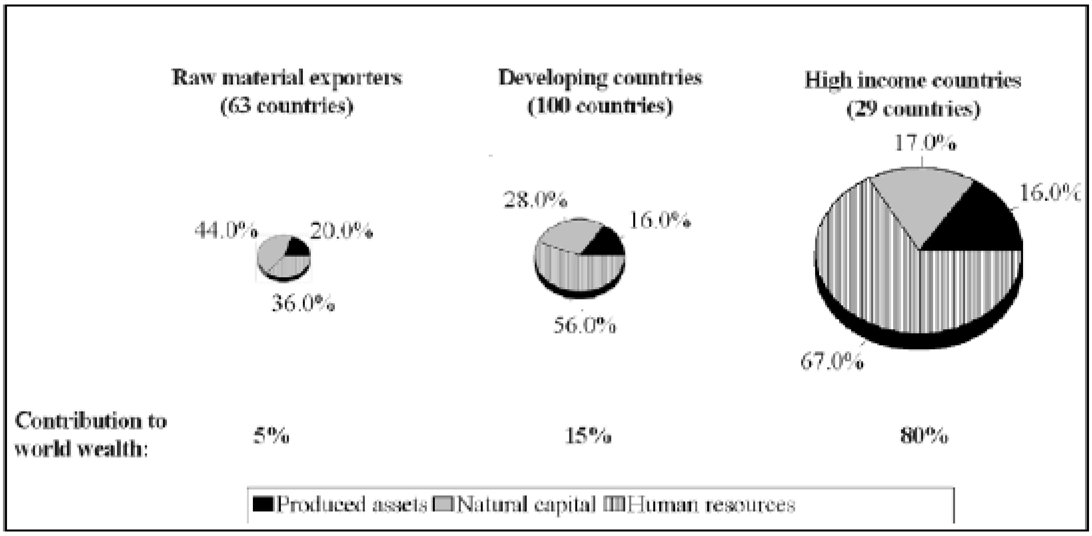


Fig. 1. Share of world wealth by type of country, illustrating the role of human resources, and thus innovation, in contributing to wealth. Data from the World Bank quoted in [2].

Of the 192 countries in the World Bank study (quoted in [2]), 63 are classified as raw material exporters, and contribute 5% to world wealth. At the other end of the scale, 80% of world wealth is produced by 29 high-income countries, relying on inputs from human resources. South Africa belongs to the middle group.

In Sachs’s classification of technological regions (quoted in [2]) into "innovators" (10 patents or more per million of population), "technology adopters" and the "technologically excluded", South Africa is observed to belong to the middle group.

The TAI or Technology Achievement Index (developed by the United Nations [2]) is a combined measure of creation of technology, diffusion of both recent and old innovations, and human skills levels. In attempting to answer the question “Does science and technology lead to national wealth and a better quality of life?”, the TAI may be correlated with other indices. The Human Development Index (HDI) is a summary measurement of life expectancy, literacy rate, education enrolment, and Gross Domestic Product (GDP) per capita. Figure 2 and Figure 3 show the dependence of national wealth and quality of life on TAI.

These figures lead one naturally to a key question for the future of South Africa.

SA is in the middle of the pack.

Will it move up to join the innovators, or down to the technologically marginalised countries?

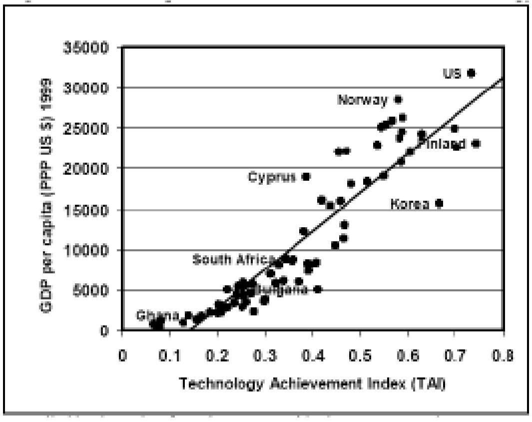


Fig. 2. National wealth in terms of the Gross Domestic Product (GDP) per capita and the TAI [2]

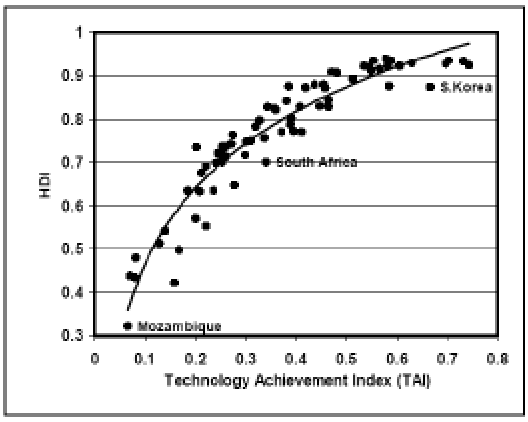


Fig. 3. Human Development Index (HDI) and the TAI [2]

Interestingly, South Africa is also found to be in the "middle of the pack" when one evaluates the ratio of population size to the number of PhD physicists - in East Africa, the number is about one PhD physicist per 2 million population, in South Africa one per 140 000, and in the USA one per 8 000[3].

One of the relevant indicators is the investment in Research and Development of the country. Figure 4 shows R&D investment in South Africa for the period 1983-2000, while Fig. 5 shows, on a global scale, the link of a nation's R&D investment to its national wealth, as measured by GDP per capita.

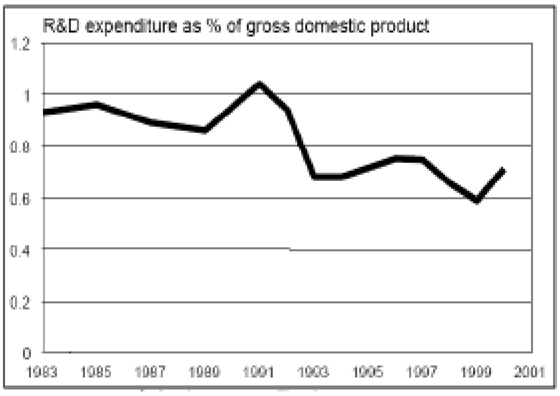


Fig. 4. Research & Development investment in South Africa for the period 1983 – 2000 [2]. The figures for both 2002 and 2003 were 0.76%

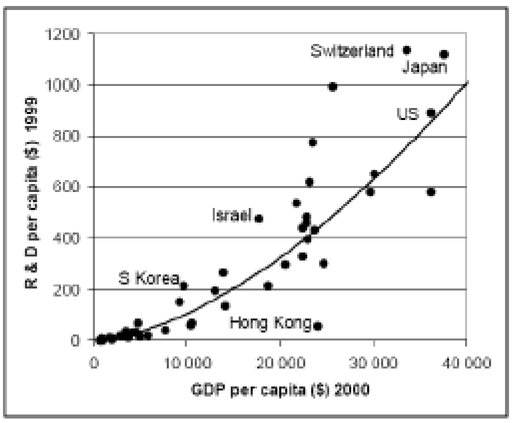


Fig. 5. Relationship between a nation's R&D investment per capita and its GDP per capita [2].

Although Figure 5 does not feature South Africa explicitly, the graph shows that economically more successful countries have a greater R&D spend per unit of GDP than is the case for poorer countries, with the "top" countries investing as much as 2% of their GDP in R&D.

Given these data, the answer to the question above may be **"SA is stagnating in terms of R&D investment, and it is likely that its national wealth and human development will remain stagnant unless action is taken".**

It is trite to say that South Africa is a nation in transition. Clearly, post-1994 there have been many changes, but many aspects of society are much as they were before that date. There are still many challenges that face the nation, and in overcoming these, further transformation needs to take place.

The above set of data indicates that South Africa's transition hangs in the balance - will it move up to the innovators or down to the technically marginalised? Although there are indicators of a possible positive outcome, the answer is not as yet clear!

This is where the future of Physics in South Africa can play an important role.

It is a role of physicists to act as indicators in science, as illustrated by the following quote [4]:
"Undergraduate physics is the miner's canary for all undergraduate science, technology, engineering and mathematics programs."

Unfortunately, Physics, as this report indicates, is suffering from severe illnesses in the pipeline of students coming through both to renew the academic community and to contribute to the economy. The canary is coughing; the science environment is unhealthy.

2.3 South Africa as a Part of Africa

Although South Africa is not one of the world's leading countries in science and technology, it is clearly the leader in sub-Saharan Africa, and indeed, in many areas of research and development, in Africa as a whole. Although there are some strong contributions in individual sub-disciplines of Physics in some African countries, this leadership role holds for the broad sweep of Physics, too. The government of South Africa has wholeheartedly endorsed the principles of NEPAD (New Partnership for Africa's Development). Indeed it has been responsible for much of the work towards its establishment. Thus the role of South Africa in Africa is a further important context that forms the framework for the thinking of the Panel.

2.4 Physics in Africa

"We believe that science and technology are key to development in Africa and that physics, which provides the foundation of so much else, has a special role to play in this development." [5]

South Africa was one of the thirteen founder members of the International Union of Pure & Applied Physics (IUPAP) when it was formed in 1922 to draw together the Physics enterprise throughout the world, and to foster international cooperation and collaboration in Physics. At the last General Assembly of IUPAP, Egypt and Ghana were the only two other African members, while Algeria, Morocco, and Senegal sent observers. That, to some extent, reflects the position of Physics in Africa.

In spite of difficulties in connection with resources, there are significant developments in some fields in a number of African countries. Apart from South Africa, Egypt appears to have the most advanced physics base on the African continent, while Ghana, Senegal, Algeria, Tanzania, Morocco, Tunisia, Nigeria and others each have strengths in certain sub-disciplines.

A particularly valuable contribution to the development of physics in Africa, has been the work of the International Programme in the Physical Sciences (IPPS), based in Uppsala, Sweden. The IPPS has worked mainly in East Africa (from Ethiopia to Mozambique, and particularly in Tanzania) and have provided equipment, arranged for academic staff to obtain higher degrees through study in Sweden, and generally contributed to capacity building. Nonetheless, there is still a long way to go.

During the years of isolation, South Africa was effectively cut off from the rest of Africa, in terms of physics as in other aspects. After the first democratic election, it was thus important for South Africa to build bridges into Africa. Building on a connection through IUPAP, it was possible to gain the support and cooperation of the IPPS, and thus in 1995, physicists from other African countries were for the first time invited to the annual conference of SAIP on a fully-funded basis. That link has since become a regular feature at SAIP conferences, and has been developed further with research collaborations and participation in International Conferences held in South Africa.

Since the first democratic election, South Africa has also been seen as an obvious country to assist in the training of postgraduate students and academic staff of countries north of the Limpopo. As a result there has been an influx of research students (and junior academic staff) from other African countries into South African universities. South African institutions have also been involved in the training of African medical and radiation physicists, under the auspices of the International Atomic Energy Agency.

A valuable recent development was the establishment of the African Laser Centre (ALC), a "virtual centre", which is based on six nodes, viz. South Africa, Egypt, Senegal, Ghana, Algeria and Tunisia. The official launch of the ALC took place late last year at a NEPAD Ministerial meeting, and a number of exchange and collaborative research programmes have been proposed. It is expected that the first programmes will roll out within the next year.

South Africa can make a significant contribution to the development of science and technology on the African continent. Valuable associates in such activities are the American Physical Society's (APS's) Task Force on Collaboration with Africa and the National Society of Black Physicists, a grouping of the African diaspora in the USA, both of whom are strongly supportive of efforts to develop Africa, and in particular, African physics.

2.5 The Contribution of South African Physics to International Scholarship

We should take care not to take a purely utilitarian view of Physics. Not only is it the precursor to much of technology, but over and above this Physics is also a major cultural activity of mankind, an activity that embraces intellects from all nations and persuasions, a discipline that enables us to understand Nature on a very fundamental level.

These two aspects of physics are interrelated. Two examples suffice to illustrate this. One example is Ludwig Boltzmann's fundamental research on the kinetic theory of gases, that provided the microscopic (molecular) underpinnings of the macroscopically known, but improperly understood, Laws of Thermodynamics. This has been said to be the greatest intellectual achievement of the 19th century. And yet Thermodynamics underpins such down to earth technology as the steam engine. A second example is the fundamental research on resonant absorption of energy by a nucleus, which underpins the development of NMR spectrometers and MRI scanners.

South African Physics is a part of the global enterprise of Physics, and it needs to bear in mind its responsibility to the global advancement of Physics, as well as to provide useful short-term deliverables. Because, even as South Africans pursue scholarship, so they are also enabled to share in the scholarship of others elsewhere, and thereby to bring to South Africa, and to interpret for South Africa, advances made elsewhere in the world.

Without diminishing the urgent needs of African countries, it should be stated that South Africans (and other Africans) can choose to take part in global research. The choice of problems undertaken should not be dictated by other continents as “appropriate to Africa”. To limit the scope of intellectual achievement allowed to the people of this nation would be as short-sighted as the education policies of former decades.

Thus scholarly activity, and the associated cultural growth, enables the fruits of Physics, too, to be plucked in a utilitarian fashion.

Interestingly, one of the strongest research areas in South Africa is Astronomy and Astrophysics, an area that, at first sight, has little economic value. Because the southern skies are important to world-wide astronomy, and because South Africa has certain geographical advantages, as well as technical and scientific strengths in this area, it has been able to make considerable contributions to the study of the Universe in which we live.

It has been gratifying to note that the government recognizes this value, and that it has invested heavily in the Southern African Large Telescope (SALT). But that investment has made economic sense, too, as the astronomical community has been able to obtain considerable financial leverage through strong international partnerships, so that, in fact, a larger fraction of the cost of building SALT has been spent in South Africa than has been invested by the South African government.

The government's support for the Square Kilometer Array (SKA) project, similarly, has both a scientific and an economic basis, as discussed below.

2.6 Physics in an International Context: The Growth Points

About 170 years ago, Michael Faraday demonstrated to the British Prime Minister his discovery of the principle of electromagnetic induction, that turned out to become the basis of all of electrical engineering, radio communications, and so on. The politician asked him "Of what use is this discovery, Mr Faraday?" His reply was telling: "Of what use is a baby, Mr Prime Minister? I do not know what use this discovery will be put to in the future, but I am sure that Her Majesty's government will find a way to tax it."

Where is Physics heading now, internationally? Where will future applications of Physics stem from? On the international scene, physics is characterized by a healthy momentum that is carrying it in a number of directions.

Prominent amongst these is the increasing migration of many physicists to the boundaries of physics where it meets other fields. These hybrid areas have names like bio-physics, econo-physics, info-physics, nano-physics and a host of others. This is a healthy development when one recalls that Nature and the problems facing continued progress, standards of living and physical well-being for humankind in a sustainable manner, are not divided into disciplines, but require multi-disciplinary solutions.

In a 1999 speech by Harold Varmus, Nobel Laureate in Medicine and the then Director of the U.S. National Institutes of Health (NIH), it was estimated that NIH then supported physics research at a level of 287 million dollars (US). The Human Genome Project, the European initiatives in Genomic and Biotechnology for Health, European Bio-informatics Institute, Bio-nanotechnology and the Sanger Institute and other such efforts have presented areas where the traditional methods, techniques, tools and the very ethos of the field of physics have important potential contributions to make. Indeed, cosmologists and elementary particle physicists are collaborating with molecular biologists in these studies. Through their joint efforts, this field has made substantial contributions to the fundamental knowledge base of our species by providing methodology for analysing large sets of data, extracting meaningful correlations, utilizing the power of mathematical models of such data and correlations which then provide the basis for innovation and technological advance. This combination of traits seems vitally needed as technology has allowed more and deeper probing of the structures around us that have consequences for the human condition.

The Human Genome Project is an example. The discovery of the structure of DNA had as two of its co-discoverers the physicists Francis Crick and Maurice Wilkins, 50 years ago last year. Although our species can now read its own genome, we face the challenge of learning how to safely re-write it to standards of the highest ethics, safety and common interest. Establishing meaningful correlations in the data from the genome and its final expression in form and function of the human body, improving the understanding of form and structure of proteins (with folding as an example) and a number of other such tasks seem well in the range of similar tasks that the physics community has carried out during the last several centuries with regard to physical structures in the realm of the inanimate.

Physics has been the great unseen hand behind most of the technological progress of at least the last century. Physics-trained individuals continue to make valuable contributions to diverse fields. The 2003 Nobel Prize in Medicine was shared by physicist Peter Mansfield for his work on Magnetic Resonance Imaging, while the Nobel Prize in Economics was shared by Robert Engle (M.S., Physics). And of course, like Alan Cormack, Aaron Klug (Nobel Prize, Chemistry, 1982) is another South African physicist who applied his physics training to solving problems of relevance to Medicine. His award was for his development of crystallographic electron microscopy and his structural elucidation of biologically important nucleic acid-protein complexes.

Another international stage that seems poised for the participation of physics-trained persons is that of developing enhanced materials and processing. In this realm, scientists face the challenge of meeting the needs for creating both materials and substances that have never existed previously as well improving upon the cost and quality of traditional materials. Examples of the previous nature include the exploration of new ways to store and transmit information (e.g. spin-tronics, improved electro-optical devices and networks). For several decades the computer industry has provided ever-increasing power and ability to manipulate data according to Moore's Law. (Gordon Moore was one of the founders of Intel, an international leader in computer chip manufacturing.) The law roughly states that computing power doubles every two years and this has been valid since its first pronouncement in 1965. During this entire time great exploitation has been made in manufacturing technology, materials improvement, etc. However, this field is now rapidly approaching limits that are imposed by the very laws of fundamental physics arising from quantum mechanics.

The impact of greater computing power has perhaps had its most powerful societal impact in the creation of the Internet and the World Wide Web. Physicists played a particular role with regard to the Web. In fact, the Web was actually created by groups of physicists at CERN (European Nuclear Research Centre in Geneva) concerned with high-energy particle experiments, who were looking for more powerful and effective ways to transmit data within their community. In South Africa the first steps towards the Internet were taken by a group of physicists (at Rhodes University). The wealthiest man in the world (Bill Gates) and the first African to fly in space (Mark Shuttleworth) both owe their fortunes to the existence of the Internet and/or the World Wide Web. The impact of these sorts of developments continues to evolve in opening totally new models for economic development that have been most spectacular in India. Low cost, broadband access connectivity has been critical in this case.

In order for this type of progress to continue, unique materials, processing techniques, etc. will be required. A forty year-old suggestion by Richard Feynman (Physics Nobel Laureate) has led to studies into the possibility of "quantum computing" as one way to by-pass the quantum limits that will ultimately invalidate Moore's Law. Should such studies be successful, their implementation would be as profound as the technology transformation from vacuum tubes (room-size computers) to integrated circuits (desktop-size computers). Nano-scale physics, which seeks to understand the laws of physics at scales of sizes smaller than ever previously contemplated, is poised to open the doorway to the manufacture of micro-sensors and micro-machines. For example, physicists are now able to measure masses as small as one billionth of one billionth (10^{-18}) of a gram. The ability to measure the mass of a single (large) molecules is just around the corner - something that promises the possibility of surprising applications in identifying drugs, explosives, and so on, in a variety of environments. This and other such developments have implications in areas as distinct as biological and medical applications, communication and information technology, smart materials and ubiquitous computing applications.

The same holds true for research into superconducting materials (that would lead to machines using very low levels of electrical power) and to the study of ultra low-temperature conditions. With the aid of lasers and other delicate tools, it has been possible to cool down materials to hitherto unreachable low temperatures, where the behaviour of matter is changed, and predictions made by Einstein and others 80 years ago have been verified. As yet we do not know how these strange conditions associated with Bose-Einstein condensation will be exploited, but one thing is certain, society will benefit from the results.

In the processing of traditional materials, too, fundamental studies that improve the understanding of the physical processes at work could underpin improved techniques, thereby holding the promise of allowing more energy efficient and environmentally benign technologies that support the goal of sustainability.

One of the greatest technological challenges facing humankind is the provision of sustainable energy. Nuclear fusion holds the promise of a relatively environmentally-friendly solution, and physicists and engineers of the world-wide community are currently awaiting a political solution to the question of the site of the International Tokamak Experimental Reactor (ITER). This device, which was designed by a team of physicists from throughout the world, will exploit the nuclear source that powers the sun, and the physics of ultra-high temperatures. ITER should provide a major step forward towards an economically viable nuclear fusion reactor, and lead to the culmination of a 50-year international programme of physics-based research.

Large facilities, such as neutron and synchrotron facilities, have become an important and common physics tool for research in a wide range of disciplines. The facilities have become user-friendly and have reached a point where a scientist with little knowledge of the machines can in a few days gather data that (s)he would not have been able to acquire otherwise. The user community of synchrotons alone has grown in recent years to a number in excess of tens of thousands. In Europe there are already more than 5 000 synchrotron users, and the number is comparable in the USA. With the construction of new synchrotrons in several regions (e.g. Australia, Brazil, Jordan), the community world-wide is bound to grow further. Because of their cost, regional and international cooperation is needed to establish such tools. However, once built, the facilities act like magnets for various disciplines, forcing physicists, chemists, geologists, engineers, materials scientists and biologists to interact in one location, leading to the advancement of science at the intersection between the disciplines. The 2003 Nobel Prize in Chemistry is the best illustration of the impact of such a large physics tool on a discovery with significant societal impact.

Within the traditional core areas of physics, with regard to fundamental physics, the international scene seems poised to reach levels where vistas of new revelations are expected to emerge both on the largest of scales (the universe itself) and the smallest of scales (elementary particles, superstring/M-theory, and space and time).

One such obvious nexus is Astroparticle Physics/Cosmology/General Relativity. Within this there has been a paradigm shift. Particle Astrophysics is the latest distillation of non-accelerator based particle physics which has a decades long history. However, the new feature that has changed within recent times is the increasing torrents of new data. It is now possible to speak of a "precision cosmology". Some of this new data has up-ended our view of the large-scale structure of the universe. A new picture has emerged suggesting a phase of an exponential expansion followed by an accelerating universe, possessing both dark matter and dark energy.

New initiatives, utilizing both ground-based and satellite-based instrumentation of a number and variety of types never before envisioned will ensure the acceleration in data accumulation about the cosmos. One that is of particular relevance to South Africa is the proposed Square Kilometer Array (SKA). A unique super radio telescope, the SKA will be made up of an array of dishes covering a square kilometer at the core, with further carefully distributed radio telescopes trailing out from the core for thousands of kilometers along a set of spirals. South Africa is making a bold bid to have this single international device in the Northern Cape, with telescopes in a number of SADC countries. If the bid is successful, it will provide magnificent scientific possibilities, as well as an injection of billions of rands, and a great shot in the arm for South Africa's information technology and telecommunications industry.

At the opposite end of the scale of sizes, the initiation of new particle accelerators promises to unlock even more secrets in the area of the fundamental constituents of matter, energy, space and time. The result of the last century of study within the realm of the very small has led to the "Standard Model" (a mathematical model that is consistent with tens of thousands of experiments). However, the very mathematical structure of the Standard Model informs us that we have at best an incomplete picture of the world of the very small. New forms of matter and energy: Higgs particles, "super particles", axions, and even more esoteric forms may be uncovered. Deeper insights into already established forms of matter and energy will be sought in the realms of massive neutrinos, quark-gluon plasmas and possibly new multi-quark bound state systems.

The new tools for these searches are already on the horizon in the form of the Large Hadron Collider at CERN in Geneva and planning for the next generation of Linear Colliders (LC). In an elegant, but perhaps counter-intuitive manner, the physics of the very largest structures in the universe and the very smallest are becoming evermore intertwined. Our understanding of astroparticle physics, cosmology, elementary particles (and possibly even more fundamental structures - perhaps superstrings) all seem required to enable us to have the most comprehensive view of our home, the universe.

2.7 The Physics Graduate as a Member of Society

The Panel interviewed senior government officials, and asked them explicitly whether, if Physics were to disappear as a serious activity in South Africa, anybody would notice. The response was quite definite - it would be very serious for the country.

In response to the question of the effect of a possible doubling of the number of Physics graduates, we were assured that the country's economy could absorb them. One of the key reasons is that it is one of the government's strategic aims to develop a knowledge-based economy. For such an economic development, a sufficient pool of Physics-trained graduates would clearly be very important.

In this context, it is important to stress the many different ways in which Physics graduates can contribute to society. On the one hand, clearly, they form the pool from which the academics and researchers are drawn. But equally importantly, they bring with them skills, honed by their training, that enable them also to play alternative valuable roles. They may, at that stage, no longer identify themselves as "physicists", but nonetheless, society benefits from their training in physics.

An example to cite in this connection is Hendrik van der Bijl, best known in South Africa as the founder of such outstanding enterprises as ISCOR and Eskom, amongst a number of other major companies. Quite clearly a "captain of industry", Dr van der Bijl was not a chartered accountant, a lawyer or an engineer! He was an outstanding experimental research physicist, who made seminal contributions to the verifying of some of the early quantum theoretical work of Planck and Einstein as it related to the photoelectric effect. Subsequently, he moved into applied physics research in the United States (where he worked for Western Electrical Co. and Bell Telephone Laboratories) before being enticed back to South Africa, as "scientific adviser to the Department of Mines and Industry", reporting directly to the Prime Minister. In that capacity he led the first industrialization of South Africa.

What skills do physicists bring with them?
At the very least, they are trained on how to deal with complexity in problems, how to solve technical problems of various sorts, not simply by using a "rule of thumb" (applying existing technology), but, where necessary, by going back to first principles, and asking the fundamental questions. They think logically, with an emphasis on cause and effect. In addition, of course, they invariably have mathematical modelling and computational skills that are well above average.

Physicists can thus be extremely valuable members of interdisciplinary teams tackling problems in industry or in government, introducing a fresh, searching look at problems that cannot necessarily be solved by "standard methods" (what one interviewee referred to as "catalogue engineering"). The physicist's form of lateral thinking often "breaks the mould."

Skills such as these have seen them rise to the top in various technical environments, as well as in areas such as "econo-physics", and related financial management activities.

An unexpected area where government sees physics graduates as playing a valuable role, is in negotiations with bodies such as the World Trade Organization, or in bilateral negotiations. Having on the negotiating teams people with physics skills can be very important - the delegation is less likely to be hoodwinked on technical matters by "first world experts!"

2.8 Globalization

Any policy decisions have to be made within the context of globalization. By its nature, physics is a global subject, and in that sense, its pursuit has always been affected by its global environment.

Although applications of physics often have a strong local flavour, the environment may well be similar to situations elsewhere in the world, and thus physics-based industry, too, has to be globally competitive. That applies not only to possible export earnings, but also to the local sale of products in competition with imported goods from countries that have made themselves globally competitive.

As a result of the global nature of physics, global mobility of physicists has always been a factor, and many developing countries have suffered from the effects of the resulting brain drain. In the case of South Africa, the situation was exacerbated because of the political circumstances.

There are, however, indications that the brain drain may be reversing[6]. For that to occur, it has been suggested that the South African environment has to be made sufficiently attractive to encourage the return of the emigrants - "The flamingos migrate, only to return when the brackish waters are replenished"[6].

In the context of the future of physics, it is thus important to generate conditions that would make South Africa attractive, not only to retain physicists in South Africa, but also to attract back South Africans who are abroad, and even to draw outstanding scientists from elsewhere, i.e. for South Africa to experience nett benefit from the global mobility of physicists.

3. PHYSICS AND PHYSICISTS IN SOUTH AFRICA

3. Introduction

As we have seen above, the pipeline feeding South African Physics is not flowing freely, and the number of physicists produced is insufficient to provide for the needs of industry, research councils, academia, teaching, and broader society.

In this chapter we analyse aspects of the Physics pipeline, as well as providing a snapshot of the current pool of physicists. We then present an outline review of aspects of physics research in the country, as well as a brief discussion of the roles and contributions of bodies such as the National Research Foundation, and the South African Institute of Physics, and finally discuss aspects of the Public Understanding of Science in South Africa.

In particular we note a greater need for the, in some aspects sub-critical, community of physicists to embrace a greater culture of interpersonal communication over a wide spectrum of possible linkages.

3.1 School Education

The "pre-pipeline" starts in the primary school. Unfortunately, very few primary school teachers are properly equipped to convey to the young minds before them, some of the beauty of physics, and some of the thinking underlying physics, in particular the importance of causal thinking.

At the next level, secondary school, the picture is in general equally dismal. Poor high school teaching, and under-qualified teachers are an international problem. However, the problem is considerably worse in South Africa, than in the developed world. It is particularly serious in South Africa's rural and township schools, thereby underlining historic divides and inequities. Particularly (but by no means only) in those schools, there is often an under-qualified teacher who has to teach poorly understood material without the benefit of a laboratory, laboratory equipment, or trained laboratory assistance - under those circumstances, it is an almost impossible task to generate enthusiasm for a subject like Physics. Clearly, it becomes a very difficult subject for the learners.

Fortunately, there are some excellent, dedicated teachers, who are active in events such as the Science Expo. The Expo, which covers the full range of science and technology, has for a number of decades been a vehicle for stimulating high school learners to think laterally in regard to subjects such as physics, biology, engineering, and so on. That would not have been possible without the intensive activity of supportive schoolteachers, together with some academic staff from higher education institutions, who assist with the judging.

In 2001, the Department of Education established *The National Strategy for Mathematics, Science and Technology Education in General and Further Education and Training,* (2001), in terms of which the Department has targeted 100 "science schools" that are apparently being provided with both teaching and equipment support, and that are to form the nucleus of a programme to improve the teaching of science. This strategy still needs to bear fruit.

The vast majority of schools, however, are still left in dire straits.

There is also a significant programme aimed at upgrading under-qualified teachers, but to put that into perspective, it should be noted that these courses are often attempting to bring the teachers' knowledge base to that of a first-level major stream Physics course. Thus this can at best only be a stop-gap measure. It is imperative that those who are teaching at Grade 12 level have a deeper understanding of the subject than can be provided by a crash course at first-year University level.

In some environments it is reported that there is no shortage of science teachers, the posts are filled. Unfortunately, that statement appears to rest on two very unfortunate circumstances. Firstly, there is the question of the level of subject knowledge of the teachers in place, alluded to above. Is an effectively under-qualified teacher (i.e. one with inadequate subject knowledge and understanding) who is filling the post something with which society should be satisfied?

The second problem is that because of the lack of adequate teaching and the resultant aura of "difficulty" surrounding Physical Science, many school learners prefer to choose what are perceived as "soft options", thereby reducing demand for the subject at school. That in turn has compounded the shortage of science and technology skills in the workforce, a situation that stymies economic development.

Returning to the serious problem of the level of the subject knowledge of teachers, it is pleasing to report that many institutions are trying to improve the situation through interaction with both teachers and scholars. Many universities and technikons have strong outreach programmes, as do all National Facilities, and the Science Councils. Inter alia, they take the form of so-called Saturday schools or vacation schools, site visits by schools to the departments or laboratories, or visits by staff to the schools.

Industry, too, has been very active in the support of such outreach programmes, both in regard to their funding (with the actual outreach being carried out by one of the higher education institutions or by consultants) and by arranging site visits, so as to engender a better understanding of science and technology in general.

As far as the Panel could ascertain, most schools do not have physics (or science) laboratories. Some schools do have items of equipment, but there is no state funding to provide for maintenance or purchase of equipment. A few isolated schools still have state-funded posts of laboratory assistant, but it appears that they are being phased out. And there does not appear to be any formal training course available to produce qualified school laboratory assistants for the future.

Thus a pivotal aspect of the learning of physics as a basic experimental science, viz. laboratory work, and the chance to "play" with equipment, is available only in a very limited number of secondary schools, and with virtually no state support for the activity.

One or two members of the physics community have vociferously suggested that it is time that the school subject of physical science should be split into its component parts of physics and chemistry. However, the Panel did not see its way clear to making a recommendation on such a step, as it had no evidence as to its effects.

The Panel identified problems with the construction of the school physics curriculum, that are dealt with in the next chapter.

3.2 University Education

3.2.1 Entry into the Physics pipeline

As far as could be ascertained, it appears that Physics as a major is available only in the universities - technikons (now universities of technology) offer Physics only as a service course, usually only at 1st-year level, in some instances also at 2nd-year level.

Entry into the tertiary Physics pipeline is in general restricted to those who have obtained appropriate school performance in Mathematics and Physical Science, at higher grade level. However, in many schools there is totally inadequate teaching, and most universities and technikons have introduced some form of academic support programme, so as to extract from the pool of those who have not satisfied initial entry requirements, those students who have the potential, but are held back by their poor schooling.

These programmes take a number of different forms. Amongst the best known are fully fledged Foundation Years, in which students take a number of science subjects, as well as communication and, say, computer literacy. An alternative approach is one in which students take a reduced number of full first-level modules, augmented by additional tutoring and foundational material - essentially the students have double contact time for half the subjects. A further approach has been to accept into the mainstream course students with relatively poor Matriculation results on a full academic load, and then to proceed more slowly, and provide additional tutoring in support of students who have difficulties.

Such a mix of approaches (and in particular the last option above) does, however, raise the question of relative levels attained by students at different institutions. Are the standards the same? This vexed question is of considerable importance for diversity management, as we shall see below.

Unfortunately the Panel had no data available that could provide an indication as to how successful the different academic support programmes are in bringing into the Physics pipeline those students who would, on the basis of the schooling alone, not qualify. However, anecdotal evidence appears to indicate that all of them yield a fair degree of success. They are important aids in attempting to "unblock" the pipeline into Physics - to overcome the difficulties produced by the school system.

3.2.2 University Throughput

A general concern in universities is the relatively high failure rate in subjects such as physics and mathematics, as opposed to, say sociology and history. This is something that certainly needs to be addressed. However, the simple answer, of dropping the standard, is certainly not desirable, and is, indeed, counter-productive. It has, however, been found in a number of departments that a concerted effort of regular tutorials, extra "open" tutorial sessions when necessary, personal contact between lecturer and students, and generally "tender loving care", does have a positive influence on the pass-rate, while not dropping the level of the examinations passed.

Data for the three years 2000-2002 supplied by the Department of Education indicate that about 85 to 100 students graduate annually as physics major students, making up about 7% of the total number graduating in the physical and life sciences.

The annual number of Honours graduates has fluctuated wildly over the last few year, the numbers lying between 40 and 70, Masters' graduates between 30 and 40 per annum, and there are between 10 and 25 new doctorates in Physics per annum.

It appears that at any one time, approximately 150 students are registered for a Masters' and about 110 for a PhD in physics.

Let us put these numbers of physics graduands at different levels into perspective by comparing them with other similar disciplines:

	Physics	Chemistry		Maths	CompSci	Biology	Geology
Bachelors	85-100	400	750	1100-1600	550	70	
Honours	40-70	200	280	300-500	400	100	
Masters'	30-40	100	60	80	220	35	
Doctorate	10-25	40-70	30	10	75-100	10-15	

Not surprisingly, Computer Science dominates the undergraduate numbers, but tails off rapidly at higher levels. It is apparent that Physics has a disastrously small part of the "science market" at present. The data that are most worrying are the very low numbers at Bachelors and Honours level. But even the number of recipients of research degrees is alarmingly low.

It was not possible to extract any historical trends over the 3 years of data, because of the fluctuations.

During the interviews, some departments indicated that student numbers at some levels had risen this year - quite sharply in some cases. However, when asked what they "were doing right", they had no obvious simple explanation for the effect, although it appeared that they had made conscious efforts to attract and retain students. Thus it is not clear whether this is a local statistical fluctuation, a trend (bottoming out), a short-term or long-term "Shuttleworth effect", or a regional effect arising from a possible shift of students from merging institutions to those that are unaffected by mergers (see below).

From student comments (see below), it appears that some departments are happy places, but in quite a few, departments don't make the students feel "at home". Furthermore, at a number of universities, the complaint came from students that the courses that they were being taught were too “theoretical", and that lecturers did not make an effort to link the physics to the "real world", be it the world of everyday experience, of industry, or of research.

It should be noted that in an attempt to bridge some of these gaps, as well as to generate more students, a number of departments have been innovative in setting up additional courses, over and above the main-stream physics course. Thus one finds higher-level modules, and indeed majors, in subjects such as Applied Physics, Environmental Physics, Electronics, Computational Physics, Astronomy, etc. These are to be applauded.

3.2.3 The Life of the Academic

The picture that some members of the public may have of the leisurely life of an academic in an ivory tower, enabled to relax and think, is unfortunately far from the truth.

The most common complaint of academics was a lack of available time.

Academics have over the last several years been working under a great deal of pressure, in part because of the instability of the higher education system. These pressures are particularly severe on young staff, who are trying to establish themselves as teachers and researchers.

In most parts of the world, Physics Departments survive through the service teaching that they have to do. That certainly applies in South Africa.

In this context, lecturers now have to contend with far more intensive teaching, as the number of under-prepared students entering tertiary education has risen quickly. Marking of tests has to be more detailed, and learning support provided to students has increased. With the restructuring of all university degrees over the past few years, a great deal of effort needed to be put into re-planning of degrees and of modules. Indeed many modules have had to be changed or generated anew, and so there has been a lot of both curriculum development and module development. A number of new bridging courses have been offered, sometimes without additional staff being provided. The same has sometimes occurred when the department took the initiative to offer an additional major (discussed above). Further, it was reported that in one formerly Afrikaans medium institution, courses are now being taught in both English and Afrikaans – almost doubling the total lecture load, without any additional staff.

At the same time, of course, academics are being encouraged to go into schools, so as to advertise physics and attract students, as well as to talk to the public, and to interact with industry. In addition, a number of institutions are currently beset by the pressures brought about by the merger of two (or more) very disparate institutions, each with its own history, ethos, and set of modules. This, too, consumes a great deal of time and energy.

And over and above all these pressures, most academics want to do research, and to publish. And then they are reminded to leave the comfort zone of their existing research and "go interdisciplinary". All in all, it does not leave much time for family life!

The above pressures have been most severe on young academics who are developing their careers, and the senior academics who are involved in management.

Other concerns raised by academics were the shortage of research students, lack of research funds, particularly for the purchase and maintenance of small equipment, and for travel to international conferences and workshops (vital, for keeping in touch), journal availability, and the lack of postdoctoral positions.

3.2.4 The Life of the Student

"We are the leaders we've been waiting for."[7]

The panel met approximately 70 postgraduate students from 15 departments in 9 meetings, in each case without any staff being present. These enthusiastic, articulate young people were asked to identify the major problems that they had experienced in their life as students. Clearly, a question of this sort invites comment on "problems". A number of students were very happy with their lot, or had experienced only minor difficulties, but others had much to talk about. It was noteworthy that a number of themes repeated themselves in different meetings across the country.

We listed the following top priority issues, and the list is ranked in approximate order of diminishing severity or the frequency with which the issue was raised.

Funding is a survival issue.

- The number of students who have children and/or are breadwinners for an extended family is significant, and rising.
- Awareness of information on the availability of grants appears to be low, particularly at some HBU's. Some students appear to be receiving less than the NRF grant values available.
- Awareness of "scarce skills funding" is lower than expected.
- A career in physics usually requires a postgraduate degree, and therefore requires a longer period of financial support than, for example, a commerce degree.
- Funding, including NRF funding, may be paid out late - frequently payment was received only well into the year, and an example of payment in September, 9 months late, was reported.
- In some departments, no students had funding problems. The majority of these were white students. Some students had been rescued by the department with jobs (tutoring, planetarium, observatory, technician) so that they could continue their studies.

The Student as Breadwinner

"There's pressure from my parents because I'm still at university - my school friends are bringing in money".

"I'm the breadwinner in a family of 5, and I have 2 children. The opportunity for me to tutor is lacking."

"If I had the choice again, I would only take physics if I had the funding, because of my special interest in it. With no funding, I have the need to survive."

"The department basically took care of me - I have 2 children and they found me the job at the observatory."

Awareness of career prospects is disturbingly low.

- While some courses are exciting and interesting, most undergraduates encounter few examples of physics in action, go on few site visits, see (hear) few alumni describing their experiences, and have very little idea of what physicists do or why physics is provided as a service course.
- In some cases, the students felt uninformed about what research was going on in their own department, let alone what might be happening elsewhere in South Africa.
- Insecurity about employment prospects influences choices of both students and parents, particularly where an extended family is being supported.
- Very few physics jobs are advertised as such. Some students go out and apply for a variety of jobs.
- Interdisciplinary content should be stressed.
- In some universities there are Student Physics Societies, which can make a difference in getting the message out. However, it appeared that that was not a common situation.

Equipment and libraries

- Equipment (for both teaching and research) was a third source of frustration frequently raised.
- Most HBU students expressed problems with access to computers, the internet, books and papers. This has to be provided if they are to make any progress and cross the information divide.

Departmental atmosphere

In general, the relationship between departmental staff and students - particularly physics major students - needs examination. (Some departments are happy ships, with postgraduate students who feel they are welcome in the tea-room, and that their futures are of concern to the staff members. Others are not.)
In some departments, the students felt cut off and ignored.

General remarks

Special problems exist for students with HBU qualifications moving to HWU. Some complained that they had been asked to repeat courses without being evaluated, and that when they repeated them, they had succeeded.
The problems of students supporting families are different from independent students or those being supported by parents, and need to be addressed as such.
Where universities have merged, facilitation may be needed to reconcile students from widely different backgrounds, who are expressing widely different problems.

Supervision of students at National Facilities raised particular problems. Both (university) supervisors and (research institution) co-supervisors need to take their supervision responsibilities seriously, and arrange regular communication either by formal report back/review meetings, or by other means.

It should be noted that we visited some departments where a significant number of students reported no problems at all when consulted.

3.3 The Pool of Physicists

3.3.1 Total Numbers

From the available data, it is estimated that there are about 220-250 academics at the universities, and smaller numbers at the (erstwhile) Technikons, where Physics is usually only a 1-year service course.

Unfortunately, no figures are available for physics-trained people in industry and in commerce, whether working as physicists or not. That is really a significant lacuna, and every effort should be made to gather a coherent estimate of the size of this group.

However, informal evidence was gathered from those who were interviewed by the Panel about the organizations that they represented, including most of the physics-based National Facilities and a number of Science Councils, as well as some industries and small businesses. In that particular sample, one may estimate that about 400 people are employed as "physicists" or identify themselves as "physicists".

These figures ignore significant numbers of people working as school-teachers, or in government, in industry or in business, as scientists, as "project engineers", as consultants, as computer boffins, as technical sales consultants or technical managers, not to mention those who have turned completely to management or are playing leading roles in the financial industry ("econo-physics") or are even in geocomputing (applying theoretical techniques to geological modeling).

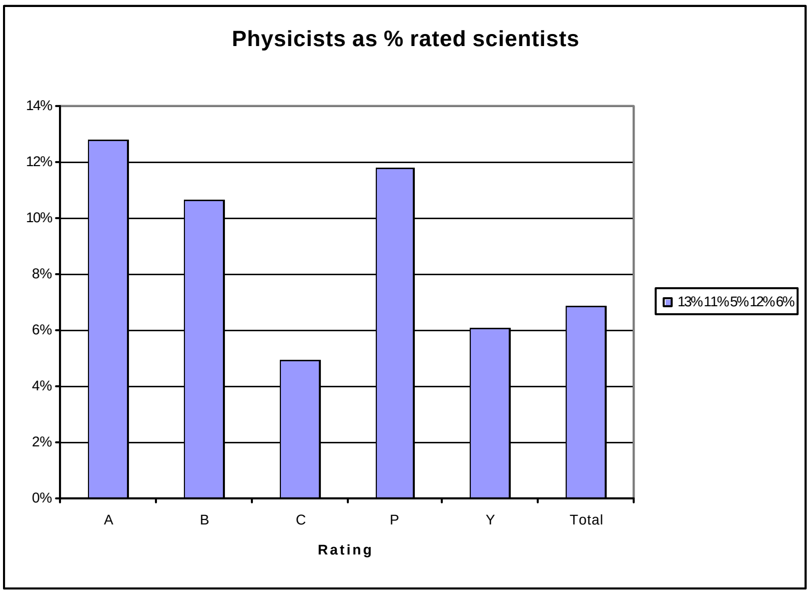
3.3.2 Measures of the Level of Physics Research

A measure of the level of Physics research may be obtained by comparing the performance of physicists with academics of other disciplines in terms of NRF ratings. The NRF ratings are based on national and international peer review, and may thus be taken as a relatively objective measure of international standing. However, this measure applies essentially only to the academic sector, as there is only a sprinkling of physicists from the National Facilities who have been rated.

According to NRF sources, there were about 100 NRF-rated physicists in 2003, i.e. slightly fewer than half of the academics at universities. Apart from the rated physicists, there are others who exhibit varying degrees of research activity - in fact, there are cases of active researchers who apparently have no need for an NRF rating to obtain adequate funding.

Of all NRF-rated scientists (natural and social scientists), physicists make up 6%.

Rating	Total	Physics
A	47	6
B	357	38
C	807	40
P	17	2
Y	165	10
Total	1393	96



Of the 47 researchers with an A rating, 6 are physicists (the highest number in a discipline, together with Animal and Veterinary Sciences (A&VS), closely followed by Engineering, Mathematical Sciences, and Microbiology & Plant Pathology with 5 each. Physics also has 38 of the 357 B-rated scientists (following closely on the heels of A &VS and Mathematics with 39 each).

However, while there is thus a reasonably high number of physicists who have a significant international reputation (A or B), it turns out that of 807 C-rated scientists, only 40 are physicists (compared with 99 in A&VS, 85 in Engineering, 68 in Health Sciences and 67 in Mathematics).

Amongst younger staff, it is pleasing that 2 of the 17 P-rated scientists are physicists, but only 10 of the 165 who are Y-rated come from physics.

The relatively low proportions of C- and Y-rated physicists presumably represents the fact that Physics Departments have been shrinking due to the freezing of posts.

Considering the distribution between different HEI's in 2003, it is worth noting that only three physics staff from the (pre-merger) HBU's, (one each from the Universities of Durban-Westville and Zululand, and Vista University) had a rating, and there were none from the technikons. Half of the rated physicists in 2003 were at the Universities of Witwatersrand, Cape Town, Natal and Stellenbosch.

3.3.3 Demographics

The demographics of the "visible" physics community are badly skewed. The overall picture is one in which white males dominate completely in the establishment. Secondly, half the respondents to the SAIP survey conducted in 1999 were over 50 years of age.

The NRF ratings, too, are dominated by white males. This underlines the need for transformation of the active physics community if the field is to survive.

The age-profile of the NRF-rated physicists shows that in terms of age, that particular group of physicists has a fairly flat distribution: about one quarter of them are in successive age-deciles, although there is an upward slope with age. More specifically, 20% are aged 30-39, 24% aged 40-49, 28% aged 50-59 and 28% aged 60 and above.

However, a closer look reveals that almost half of the rated physicists are 55 years or older. Furthermore, of the 6 physicists who have an A-rating, 4 are aged 60 and above, and of those with a B-rating, 14 out of 38 are 60 or older. Thus an alarming fraction of the top researchers are of "retirement age".

Of the respondents to the survey, 20% were women. However, considering only the sample of respondents below the age of 50 one finds that 30% are female.

Figures from the 2000 HSRC survey reported in [2] are reproduced below. The survey notes the trend break in the number of women at age 50, apparent in Figure 6, and attributes this break to a change in attitudes amongst those born after World War II. It is not, however, clear whether this distribution indicates a wave of women advancing in age, or a stable distribution with women exiting physics at about 50. A clear disparity in income median is apparent in Figure 7.

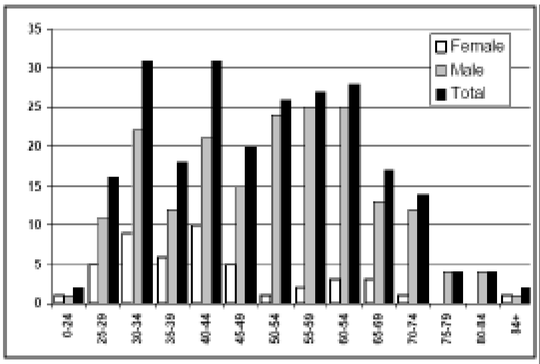


Fig.6 Age distribution of physicists, by gender

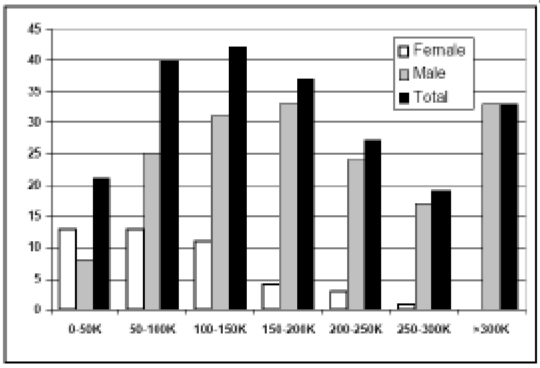


Fig. 7 Remuneration distribution of physicists, by gender

Further anecdotal evidence (e.g. participation at SAIP Conferences), indicates the presence of an apparently growing number of black and female graduate students. That is very clearly a distinctly positive feature for the future of the discipline. However, these graduate students still have to realize their potential to develop into the country's top researchers.

It is noted that of the 5258 NRF student bursaries awarded in 2003, 406 (i.e. 7.7%) were awarded to students of Physics. That figure is roughly in line with the fraction of NRF-rated scientists. According to NRF guidelines an upper limit of approximately 10% of the bursaries to research students may be awarded to "foreigners" (i.e. non-citizens who do not have permanent residence in SA). One may consider that, because of the "blocked pipeline" within the country, Physics should be allowed a higher proportion of foreigners. In fact the proportion of foreigners amongst physics bursars is higher than for most other disciplines (12%), but lower than, for instance, Earth Sciences, Chemistry, and Biotechnology.

3.4 Employment of Physicists and Physics-trained Graduates

A major concern is the perception, sometimes real and sometimes imagined, that jobs are scarce. Many aspects are relevant here but we only mention the more important ones.

As we have seen in Chapter 2, the authorities see a need for an increased output of physics graduates in the country's economy, to help steer and grow it into a knowledge-based economy. Again, it should be emphasized that the need was perceived as being both for those who continue working actively as physicists, and for those who, based on their physics training, skills and technical expertise, can take a lateral step into other areas of the employment market, e.g. in technical development, management, the financial sector or education.

The Panel wishes to underline the importance of the wide range of transferable skills developed through a physics education.

3.4.1 Unemployment

Whereas no university staff interviewed by the panel knew of any unemployed physicists, some students, notably at HBU's, were aware of “some” unemployed graduates.

Unemployment figures quoted in the State of Physics in South Africa Report of 2002 [2] showed that between 10 and 16% of respondents had experienced unemployment between 1995 and 2000, in comparison with the overall official unemployment rate for SA of 23%. The period of unemployment was not measured by the survey.

3.4.2 Jobs for Physics Graduates

According to the year 2000 HSRC survey[2] of graduates with a major in Physics, of the 16% sample who responded, almost half had a PhD degree. From this fact it appears that the sample had an inbuilt bias, in that there was a preponderance amongst those who did respond to the survey, of people who felt themselves to be "physicists". Thus it appears highly likely that the survey "lost" many who, having obtained a Physics degree, had moved onto other areas of employment. However, within the survey, one notes that academics made up about a quarter of the respondents.

A rough survey of Physics Departments at Universities leads one to an estimate of there being approximately 250 positions in the higher education sector. Hence, one can speculate that there are at least 1000 positions that physics graduates are currently filling in South Africa. And as we have indicated, that ignores a sizeable group who are no longer sufficiently involved in physics for them to bother to respond to such a survey being conducted on behalf of the physics community.

This figure is also in line with estimates extrapolated from the numbers of physicists employed by the various Science Councils, industries and businesses that were represented amongst those interviewed by the Panel.

Such an estimate does not, of course allow for the expected rise in posts that could follow the growth of projects such as SALT, HESS, PBMR and possibly the SKA, let alone if the hoped-for technological explosion should occur. And in thinking of the needs of the nation in such a case, one has to bear in mind the lag time that elapses between the time at which a high school learner decides to embark on tertiary study of physics and the production of a fully-fledged graduate.

3.4.3 The Physics-enabled CEO, contrasted with the Struggling Entrant

In exploring employment prospects after an education in physics, one of the considerations has been whether physics can lead to a lucrative career. The panel met 23 Chief Executive Officers and top managers of companies related to the study, of whom 16 were physics graduates, and 10 held physics PhD’s. Two run their own companies consulting in science policy and communication.

The “State of Physics” Report, 2002 [2], shows 33 of 221 respondents earning over R300k per year in 2000. Nine respondents had budget responsibility of over R20m. These data, and the people in the upper brackets encountered by the panel, indicate that physicists do find and occupy top positions.

At the other extreme, starting salaries for academic physicists, medical physicists and teachers are estimated, on the basis of interviews in this project, to be of the order of R60k to R70k, taxable. The survey of 2002 [2] shows a salary peak among the respondents in the band R150k to R200k.

Having said this, students regarded the starting salaries as unattractive - and we agree - but we would argue that it is worth waiting for “the big-time”.

3.4.4 Physics in Action: As an Education in Thinking

In comparison with technological and vocation-based training, physics provides a key to thinking about fundamentals, and to dealing with complexity.

The panel encountered many examples of decision-makers using rigorous critical thinking skills made available by a physics background in all walks of life, including the boardroom and the cabinet. A strong mathematical ability means that physicists are unlikely to be scared by intricate budgets or complex negotiations. Members of the panel recalled the quote by Abdus Salam:

“Physics is the liberal arts training of the 21st century”

Some people are concerned that physics graduates do not necessarily find employment "doing physics". However, it is commonly accepted that not all (relatively few?) English literature graduates are employed "doing literature", and the study of physics can lead to a career as a physicist, or be part of a broader (science-based) education leading to a variety of careers.

3.4.5 Physics in Action: Away from Knowledge Colonialism

The Panel was told by a prominent CEO, in essence:

“In SA we are living in a colonial knowledge economy era. My engineers will produce designs and make progress based on imported Intellectual Property, but I can’t re-export that IP. It’s the scientists who contribute to IP that is owned by South Africa, and for that reason I employ them. We need to generate unique technology in niche areas.”

One of the students expressed the view:
“We need to grow, to compete globally, and not just be users. It is very very very important for us to be trained as inventors.”

In this context, strong views about the nature of physics undertaken in Africa were expressed to the panel. Should South Africans refrain from getting involved in String Theory, and concentrate on problems with short-term immediate social or economic application?

We believe the portfolio should include both. It is not the case that people originating on the African continent should be restricted only to problems evaluated by someone else as "relevant"; Africans (including South Africans) should contribute to the global advancement of science.

3.5 “Flagship” Physics

One of the characteristics of certain sub-disciplines of physics is the reliance on big, relatively expensive machines to provide data. Such an iconic piece of equipment we call a flagship, and in this section we consider some flagship projects in South African physics.

3.5.1 Why are Flagship Projects important?

Flagships can act as a driver for leading the discipline, and as a catalyst to draw members of the discipline together, to join hands and to share both hardware and intellectual resources. Such a focus can play an invaluable role for a field. In addition, because flagship projects tend to be expensive and are very visible, they also provide an excellent vehicle for marketing.

However, flagships also have a potential down-side. Because of their cost and the associated economic inertia that they represent, they can, when belts have to be tightened in the economy, continue on their merry way while gobbling up all available funds, to the great detriment of smaller projects, and thus to science in general.

First we highlight some of the existing and in-progress flagship projects in South Africa.

3.5.2. Astronomy and Astrophysics

Insofar as Astronomy and Astrophysics has been a success story for South African science and it is a useful vehicle to convey the excitement and possibilities of flagship projects (and some potential hazards!), it is appropriate to examine this field in a little detail.

Astronomy is of particular relevance to Physics, in that it is generally regarded as being an integral part of Physics. Thus, advances in the subject are conditioned by development in Physics - in experiment and in theory.

A further, and increasingly important, aspect of Astronomy is its appreciation by the general population. There is a great thirst for knowledge astronomical by "the man in the street." Many young people are attracted into science and technology through Astronomy. Professional astronomers are fortunate to have strong support for their subject in this way from the general population and the long tradition of amateur astronomers.

There are many aspects of Astronomy that are of general relevance to the Panel's deliberations, and some will be considered here:

- At schools, the knowledge of teachers is often limited
- Planetaria - focal points for public interest - are rare (only two in the country) and apparently poorly funded
- Physics teaching in universities can benefit considerably from the use of examples from astronomy to illustrate physical principles. It is recommended that this aspect be fostered by university teachers - anecdotal evidence indicates that it is under-utilised
- With the increased expenditure on telescopes (SALT and, probably, SKA) there is great scope for research across sub-disciplines, e.g. condensed matter-astrophysics in order to develop competitive detectors. The link between the extreme conditions in space (e.g. in neutron stars) and those achievable in the laboratory (e.g. in superconductivity) is another related area of contemporary interest. Increased emphasis on these areas is important for

ensuring value-for-money for the large national spending. The Panel applauds such collaborations already in place but presses for more.

- An exciting new development is the spin-off from astronomy into industry – termed "astro-technology". The Panel was impressed by the work at the University of the North-West (Potchefstroom) and the progress at SALT.

The advantages of the Southern African Large Telescope (SALT) are well known and the Panel was impressed by the scope of the project and the progress so far. As a flagship project it satisfies all the requirements: good science, enhanced international perception, utilization of the "properties of the region", the presence of skilled practitioners, stimulus for local industry and excitement for the community.

All this is good but the Panel is concerned about a number of matters, mainly to do with staffing. Some are mentioned elsewhere, specifically the lack of adequate remuneration for all those involved: research students, post-doctoral fellows and staff, and their small number. Unless there is growth in the human resource provision to the support and utilization area there will be an inadequate return on the nation's very large expenditure on hardware.

The broader astronomy community has organised itself well, and has shown a great willingness to collaborate and network. That is both to its and the country's benefit. A possible model for other collaborations within South Africa is offered by the National Astrophysics and Space Science Programme (NASSP[8]) that aims at developing postgraduate studies in astrophysics and space science on a national basis, and includes lecturers from 12 different departments.

In terms of an adequate return on investment it is recommended that increased efforts be made to interest the wider physics community in the opportunities at SALT, both in experiment and theory. Much is being done, but more is necessary. Areas of opportunity include input from theoretical physicists (e.g. at Stellenbosch and Cape Town).

An important aspect related to both SALT and other flagship projects is the need to plan for the updating of the instrument. For SALT, "Active Optics" is a must, with the laser community being involved. This area is another with important industrial connections.

Gamma ray astronomy is one of the "new astronomies" and South Africa is already amongst the world leaders in the important ground-based area. Although not yet a flagship project in terms of scale, the international HESS (High Energy Stereoscopic System) project in neighbouring Namibia is large by standards in the field, and SA is a major partner. All the virtues of a flagship are, in fact, here and the HESS results are already bringing rewards in the form of international prestige, spin-off to industry and training for research workers.

A major flagship development on the horizon is that of the proposed Square Kilometre Array (SKA). There is a fine tradition of research in radio astronomy in South Africa, albeit in a comparatively small way at the Hartebeesthoek Radio Astronomy Observatory. The subject does not have the same public appeal as optical astronomy (although there is a public outreach programme). However, a return on the funds invested is guaranteed by the involvement of local industry, as is the improved linkage of South African radio astronomers to the whole international community. Insofar as planning for the project is concerned, the matters of staff problems, etc., are as relevant here as they are in the SALT programme.

Important work is in progress which is on the periphery of "Astronomy and Astrophysics", most notably in relation to the World Space Observatory project (which will launch a UV space telescope in 4-6 years time), and space physics studies at the Hermanus Magnetic Observatory and at the South African Antarctic base, where a number of projects involving solar-terrestrial relations are being vigorously and successfully pursued in the context of international collaboration.

3.5.3 Nuclear Science

Another flagship project is iThemba LABS. Formerly the National Accelerator Centre, this, like SAAO and HartRAO, is a National Facility. Now a more generally based Laboratory for Accelerator-Based Sciences (TLABS), iThemba has an annual spend that is more than twice the cost of all the other National Facilities put together. The main accelerator is a 200 MeV separated-sector cyclotron, with associated beamlines and detector systems. It is used for medical purposes and isotope production during the week, and for nuclear physics at the weekends. In addition there is a van der Graaff accelerator that is used for nuclear-based materials research and neutron-induced reaction studies. The T-LABS thus draws together scientists from a wide range of disciplines.

The level of work being done in areas such as radiation studies, isotope production and nuclear medicine is high, and a number of important developments have emanated from iThemba, some of which are recorded below. It was, however, disappointing to the Panel to hear that the number of medical doctors who were using the facilities had apparently dropped from 3 to 1.2.

There was a further concern that arose from the hearings of the Panel, viz. it appears that while some users of the T-LABS were very happy with what they were being offered, others were very dissatisfied, to the extent that some allegedly preferred using facilities abroad to those at iThemba. That is a most unfortunate situation for a user facility to be in, and is a matter that requires urgent investigation. It is vital that better interpersonal communication takes place.

In the north of the country there are a number of smaller accelerator centres, including the Schonland Research Centre at the University of Witwatersrand, and facilities at the University of Pretoria and NECSA. A recent report on small accelerators has recommended to the NRF that the "northern" accelerators should either be drawn together into a new central facility or, alternatively, be absorbed into iThemba LABS as a northern component. A decision on this matter has not as yet been taken.

A further possible nuclear flagship project is the Pebble Bed Modular Reactor (PBMR). It appears that the PBMR company employs a number of reactor physicists, but that the thrust of the activity is directed at what might be termed nuclear engineering. If this project gets full international funding and government support, it could lead to exciting developments in the broader nuclear science scene in this country.

There was some lack of clarity regarding the needs of the PBMR project with respect to research developments. On the one hand it appeared that, unlike the academic engineers, the local physics community had not really "come to the party", as a result of which some of the nuclear reactor calculations had had to be outsourced to foreign institutions. On the other hand, members of the academic physics community reported that in their view there was great scope for a variety of aspects of physics expertise (including materials know-how, fluid flow, as well as nuclear and radiation expertise), and that discussions with the PBMR management in that regard were of great importance. Certainly, it would appear that better communication is of the essence.

It was, however, pleasing to note that the industrial partners involved in the PBMR project were collaborating with iThemba LABS, NECSA, the NNR and a number of universities in the training of graduates. This training covers a number of different appropriate courses, including a Masters' degree in radiation science. This course is a little controversial, however, in that questions have been raised regarding the content and level of physics knowledge in what appears to be more an interdisciplinary Masters' programme.

3.6 "Small" Physics

Big instruments (such as telescopes and accelerators) are often perceived, because of their visibility, as flagship banners for science and technology in many countries. Although such projects may be given a high priority, for good reasons, they are sometimes funded at the expense of smaller scale science. In physics, this tends to allocate a higher (scientifically unjustified) priority to particular fields: Astronomy and Astrophysics, Space Science, Particle and Nuclear Physics, Hot Plasmas, etc.

"Small physics", such as Atomic and Molecular Physics, Condensed Matter and Optics, do not get the same type of attention, although generally they provide the basic tissue for a distributed scientific environment throughout universities, institutes and schools. In addition they help to develop the conditions for the successful use of big instruments (e.g. Synchrotron Radiation Facilities).

To explicitly achieve balance between the two types of physics research, advanced countries (USA, European Union, etc.) have developed several original approaches including the provision of National Centres or Centres of Excellence (e.g. Laser Centres), research and/or training networks connecting universities, research institutes and centres (e.g. Nanotechnology networks). Nevertheless, quite often the funding of big science has caused severe strains. South Africa, starting from an almost "greenfield site", should avoid these strains.

In "small physics", it is important to maintain the equilibrium between the various subfields, as well as bridging links with other disciplines (e.g. Physics of Biological Systems, Physics of the Environment, Econophysics) and giving access to interdisciplinary fields, which are generally approached by small, but very dynamic groups. These small physics projects allow access to academic groups - which is not generally as well performed through big projects. In this way, one can find objectives which become the actual "property" of the academic community.

South Africa has already tackled with success the investment in large instruments for physics: several facilities have been realised, or are in the "pipeline", in fields such as astronomy and astrophysics (SALT, and the SKA project), nuclear physics, accelerator-based physics and interdisciplinary fields (iThemba). Other projects, such as the Synchrotron Radiation Facility (SASI), are under consideration by the community.

What are the strengths and weaknesses of South Africa in "small-scale" physics?

South African research is well represented in solid-state and condensed matter (CM) physics. This is one of the largest branches of physics where small, table top physics is performed. It is the branch of physics that studies the properties of large collections of atoms that compose both natural and synthetic materials, including electronic and optical properties of materials and all aspects of magnetism and magnetic materials. It is the subfield of physics that has the largest number of direct applications in everyday life, and which plays a key role in modern technology advances, such as, e.g. the transistor or, more recently, the discovery of colossal magnetoresistance which has led to a 100-fold increase in the capacity of the flash memories in modern computers and laptops.

Today the new opportunities in CM physics are the creation of new materials such as artificially structured materials (with their application in Information Science and Technology), but also at the boundaries where interdisciplinary interdependence with other fields of science and engineering is required. One of the growing areas is the boundary where physics meets biology. Also it should be noted that CM physicists constitute the largest cadre of users of large tools such as neutron and synchrotron facilities.

There is very good experimental and theoretical activity in condensed matter physics in SA. The activity covers modelling of materials, high pressure physics of materials, semiconductor physics, photovoltaics, surface physics, high-Tc superconductivity and magnetism. Solar cell technology (photovoltaic materials), which is actively pursued in several universities, should be "starred" particularly for the remarkable preliminary success obtained. Some of the research (hard materials) is directly relevant to local mineral industry and may have a short term impact.

Nanoscience and nanotechnologies are the object of a growing interest in SA, which should be pursued. Optics is also well represented, with the National Laser Centre (NLC) as well as in several universities. In all these topics, the need for a coherent approach to the research field, putting in synergy the various efforts, and networking groups of universities and national centres, is strongly needed. Such efforts have already started, e.g. for the solar cell technology, and nanoscience programmes.

In Optics, NLC is already present in the laser processing of materials (with the collaboration of some universities, as well as industry), in the devising of compact laser radiation sources (OPO), and it has started a programme of air pollution monitoring by LIDAR (Laser RADAR) techniques. The latter programme should be given its importance in the public outreach of science, in particular on the occasion of the 'World Year of Physics', by organising public demonstrations of this material in 2005. Links of the NLC with industry must be pursued and reinforced, as well as its pivotal role in organising the contribution of universities in a coherent way. Some weaknesses have been observed in optical communication technology; here, particular effort should be given toward the development of semiconductor laser sources, as well as to fibre optics technology (for which recent work, such as that in UPE, must be developed and supported). This is a strong case for developing the interplay between physics and engineering. The activity carried out on the application of optical methods and lasers in biology ("biophotonics") has to be pursued actively on a broad basis.

Another domain to be seriously considered is that of "Adaptive Optics", in relation to SALT. To take full advantage of the expected performance of this telescope, corrections of atmosphere-induced aberrations have to be done in real time. This needs the realisation of an artificial star in the upper atmosphere, taking advantage of the existence of sodium, at an altitude of order 60 km, which can be excited by a conveniently tuned dye laser.

A domain not covered in SA optical and atomic physics is the burgeoning field of laser cooling of atoms and molecules. South Africa has the capability to be present here, to keep international contact in this premier field, where low temperature records have been repeatedly broken, and Bose-Einstein condensations of low density atomic and molecular gases have been observed, opening the way to atom chips, quantum information and ultra-high-sensitivity atom interferometers, as well as to new frontiers in frequency metrology. This type of programme can be realised with a reasonable budget, which means that the field of ultra-cold atoms is within the realm of university physics. The NLC, in collaboration with the National Metrology Laboratory (for the optical metrology part), should start this programme and head some dynamical groups in well-chosen universities. This type of programme could be the object of a targeted recruitment of young scholars in universities, with an appropriately oriented funding.

3.7 Physics serves the Nation

There are very many examples of physicists working for the nation, in a way that the average "man in the street" is unaware of. As indicated, the Panel has seen only a fraction of the physics activity in the country, but from that limited experience we present below a few such examples:

The role of the National Metrology Laboratory (NML) of the CSIR as guardian of international length standards, has enabled it to assist the South African motor industry to manufacture engine blocks to micrometer accuracy, a prerequisite for the motor industry to have developed its very healthy export trade.

Amongst its regular tasks, the NML is also responsible for calibrating radiation dosimeters according to the international standards of which it is the guardian. The dosimeters, in turn, are used in hospitals throughout the country, and ensure that patients are given correct dosages of radiation during their treatment.

Medical physicists in hospitals across the country play vital roles in patient treatment by radiation, ensuring that patients' radiation doses are suitably calculated and applied. In addition, they are responsible for quality assurance and calibration of instrumentation used in patient treatment.

A number of academic and other research physicists are using their modelling skills to be part of South Africa's efforts to fight against HIV-Aids. This includes work as part of interdisciplinary teams, both in modelling biochemical molecules and their interactions, and in epidemiological studies. In fact, some physicists are also a part of the national Bio-informatics movement, or working in areas related to biotechnology, such as NMR and rational drug design.

The National Laser Centre (NLC), recently incorporated into the CSIR, is working on a sophisticated methane detection system for usage underground. Based on a dual absorption lidar, it will enable the user to identify localized pockets of enhanced methane concentration in mineshafts, as opposed to the standard detection systems, which can only provide information on a line-averaged basis.

The NLC has also built up pioneering high-power facilities to carry out three-dimensional laser forming of complex-shaped metal parts. This is being used by the motor industry to manufacture parts for the export market.

The Panel was shown some elegant work done using the nuclear microprobe at iThemba LABS to investigate the differential uptake and transport of metals by certain plants.

At NECSA, beneficiation of large quantities of silicon for Japanese industry, through neutron irradiation to get rid of inherent defects, contributes to our foreign exchange earnings.

Physicists at UWC have been commissioned by the National Nuclear Regulator to measure the levels of the radioactive gas radon in houses in Paarl, as the granite rocks in the vicinity might be associated with elevated levels of radon.

This list is by no means exhaustive, but merely presents a few illustrative examples. It does not reflect on groups or institutions whose work has not been mentioned.

3.8 Physics as International Scholarship

Much of the physics research conducted at universities is what may be termed “basic”, and does not directly benefit South Africa’s exchequer, but it is making contributions to international scholarship through their research. Indeed, it is noteworthy that much of it is being carried out in the context of international collaborations. Again, this listing is not an attempt to present "the best" work - it merely represents a few illustrative examples that have come to the attention of the Panel:

Theoretical work done at the Universities of the Witwatersrand and Stellenbosch has led to two fundamental experiments being carried out in Darmstadt, that point to an intrinsic connection between chirality and dissipation. Arising from extensions of this work, discussions are currently underway for possible experiments to study time reversal symmetry breaking and a possible experiment on quantum dots in the Netherlands.

The first measurement of the elastic properties of a solid material at high pressure using the technique of surface Brillouin scattering was carried out at the University of the Witwatersrand. This was recognised by the award for the most outstanding paper leading to a PhD degree at the international conference on high pressure science and technology.

The UCT-CERN Research Centre, who are a part of a collaborative group running CERN's ultra-relativistic heavy ion experiment called ALICE (A Large Ion Collider Experiment), has been selected as one of the nodes in the EU DataGRID project - the first such node in Africa and in the southern hemisphere. This project is a necessary step in the quest to deal with the large quantities of data generated by particle physics experiments. The new GRID protocol is envisaged to be the next level in data transfer and distribution, and is likely to revolutionize large-scale computing in the future.

High resolution vacuum ultraviolet laser spectroscopic studies at the University of Stellenbosch have measured (at a temperature of 4 K) the rovibronic spectra of isotopomers of the CO molecule, formed from some of the isotopes of the C and the O atom. The data for $^{12}C^{18}O$ and $^{12}C^{17}O$, together with measured absorption spectra in an interstellar cloud, have led to the determination of the heliocentric velocity of the interstellar gas – a neat application of laser studies to astronomy.

Physicists at the University of KwaZulu-Natal (Pietermaritzburg) have shown that the conventional formulation of multipole theory for **D** and **H** is unphysical when taken beyond electric dipole order, yielding, for instance, reflected intensities that depend on the choice of origin of coordinates. More recently, they have presented an alternative formulation that restores translational invariance to multipole theory.

The Hermanus Magnetic Observatory's studies of the geomagnetic field in Southern Africa indicate that the earth's dynamo is particularly active beneath South Africa and the Southern African Geomagnetic Anomaly.

Again, it should be emphasized that omission from this list does not result from a value judgement as to the standard of the research.

3.9 Equipment and Infrastructure

From data provided by the heads of university departments, it appears that much of larger equipment (costing more than R100k) in universities is ageing, a typical age for many items of equipment being 15-20 years. Although it was noted that there were some more recent acquisitions, it was not clear whether such instrumentation was being efficiently used, both regionally and nationally.

The Panel was concerned to find that the NRF fund for National and Regional equipment (essentially the vehicle for making state contributions to expensive equipment of any sort in universities, i.e. for physics or any other purpose) operated up to the year 2000, and at that stage was only of the order of R5m or so p.a.

It appears that since 2000, the NRF has not had a line item for expensive capital equipment. They have made available only ad hoc funds that arose from savings, these funds to be used only for maintenance, upgrading or usage (mobility grants) of existing equipment.

It was noted that, in terms of the DST medium term budget, an amount of R20m p.a. has been earmarked for expensive capital equipment for 2005 and the following two years.

Those pieces of new equipment that were purchased more recently would have been obtained through university funds, or via THRIP grants (shared funding with industry), as part of a successful Innovation Fund application, or through the ring-fenced funding that has been made available by DST for the development of laser science and technology in the country, in conjunction with the NLC.

Apart from equipment, there are two other expensive aspects of infrastructure that are a cause for concern. The first is the high, and rapidly escalating cost of journals, the lifeblood of research communication. Many university and Science Council libraries have had to reduce their holdings drastically.

The second expensive item is that of computing. Many HWU's have made a conscious decision to invest in computing connectivity, and most staff have good access to the internet, via what are usually fairly efficient internal LANs. However, that does not always apply to HBU's, where connectivity is a considerable problem, particularly, but not only, for students.

However, even in the best-endowed universities and research council facilities, the ultimate stumbling block of national and international connectivity is faced - a slow and expensive internet connection. This is particularly noticeable for those researchers who have large data sets that have to be accessed or transferred.

We shall deal with the issues of journal access and connectivity in Chapter 4, but will now comment further on the matter of equipment.

3.9.1 Tools for Physics in South Africa

The accelerated pace of advancement of science, particularly at the new and emerging frontiers, and those at the intersection of the different traditional disciplines such as physics, biology, chemistry and materials science, as well as astronomy, and the emergence of nanoscience and nanotechnology, has put tremendous pressure on the research infrastructure around the world. There is a need to modernize, and upgrade research tools everywhere. The pressure is even greater on SA, where the average age of typical equipment at the major research institutions is from 10 to 20 years. In addition, there has been many years of neglect of science infrastructure, particularly at historically disadvantaged institutions.

3.9.2 Equipment at the "Government" Laboratories

SA has some world-class instrumentation available at some of the national laboratories, such as neutron reactors, transmission electron microscopes, and high magnetic field and low temperature capability. The National Metrology Laboratory, for instance, has a 14 Tesla superconducting magnet system, and laser metrology capability; the National Laser Centre is well equipped with lasers of different types and powers, and so on. The laboratories are making good use of these instruments to fulfil their respective missions and work for the benefit of society. However, some instruments and capabilities appear to be under-utilized by the broader physics community. This appears to be due to a lack of a trained cadre of users (scientists), and a lack of awareness of the opportunities by the broader physics community, and in some cases there is ineffective governance. This situation needs to change if the nation is to reap the benefit of its investment.

3.9.3 Major Research Instrumentation at Universities

Physics departments have a range of instruments, some of which are quite modern (EM, -TEM, STM, AFM, XRD, Raman spectrometer, computer clusters….) and others are quite old. Departments are putting heroic efforts into keeping the new equipment well maintained and the ageing instruments operational, apparently at very considerable cost in terms of money and human resources. Lack of adequate instrumentation and the burden of repair and maintenance is high on students' lists of major obstacles to their research and training, sometimes prolonging the duration of a degree, and making it difficult to find funding. This has to be addressed in order to meet the country's objective of being competitive in the creation of knowledge, solving the challenging technical problems of the country and training a competitive scientific and technical workforce.

3.9.4 Medium and Small-scale Laboratory Equipment

There is the sense that the research award sizes are rather small and do not allow investigators to acquire small scale instrumentation costing between R30k and R100k. Many are forced to design and build even the smallest instrument that would have been available off the shelf with sufficient funding. Research is an internationally competitive endeavor in which time is a critical factor. Insufficient support in this area will clearly put SA scientists at a disadvantage.

3.9.5 Major Research Equipment

The panel applauds South Africa for its major undertaking in the Astronomy area. The partnership between the research community and the government agencies is exemplary. Other major items of equipment, such as a possible synchrotron, have been put forward for consideration by the community. The panel is encouraged by the fact that long range planning of such major equipment is taking place. Such big instruments will have an impact on a broad range of scientific disciplines, including physics, chemistry, materials science, biology and medicine. By bringing scientists from different disciplines into one location such facilities will help with cross-fertilization between the disciplines and lead to growth of multidisciplinary research. They have a great potential for capturing the nation's imagination and will contribute to societal awareness of science, outreach and the nation's scientific endeavor.

3.10 NRF

The National Research Foundation plays a key role in fostering research in physics, as it does for all disciplines. In general, it enjoys the trust and the confidence of the research community. However, there are some aspects relating to the work of the NRF that the Panel needs to report on:

3.10.1 Student Bursaries

From reports received by the Panel, there are a number of problems relating to transmission of information about and the administration of student bursaries. From our brief investigation, it is not clear where the bottlenecks are, i.e. whether the NRF, the university administration, the student, or the supervisor is at fault. However, there are problems somewhere along the line, and they seemed to be worse at HBU's. The problems relate not only to information about the existence of different types of bursaries (e.g. scarce skills bursaries), but also in regard to the payment of bursaries, that appeared often to be paid out well into the term (even as late as September!). In particular, one problem may relate to the fact that the NRF pays only after the student is registered, whereas at some institutions, the student cannot register until fees have been paid – a Catch 22 situation! Another difficulty arises from the fact that a student cannot apply for doctoral bursary once (s)he is registered. Thus, if a student registers first, (s)he is apparently excluded from NRF funding throughout the doctoral studies.

3.10.2 Expensive Capital Equipment

The problem in regard to the lack of funding for new expensive capital equipment over a number of years has been spelt out above. To put the amount of R20m p.a. envisaged for future years into perspective, it is noted that some universities are spending R10m to R18m of their own funds on equipment. It really is not a large amount of money in the context of national needs for new equipment.

3.10.3 Collaboration and Centres of Excellence

The Panel supports the notion of Centres of Excellence (both research CoE's and technology-based industrial CoE's), and believes that the condition of collaboration and networking that is imposed on such centres, together with similar requirements in regard to Innovation Fund, and to THRIP applications (collaboration with industry), is an important element in bringing about an increased amount of collaboration and networking that takes place in a national research environment in which many groups are, in their own right, sub-critical by international standards.

However, concern was expressed at the fact that the expected funding for a growing number of Centres of Excellence does not appear to be forthcoming.

The attention of the Panel was also drawn to an inconsistency in the NRF policy relating to collaboration other than in regard to the Centres of Excellence. It was reported that when a group is formed, the NRF funding to the group appears to be equal to or even less than the sum of the amounts that the individual researchers would have obtained. Thus, although the NRF recommends the forming of groups as a vehicle to encourage collaboration, there is no financial incentive to do so.

3.10.4 Ratings

Some foreign members of the Panel were concerned about the notion of rating, as carried out now for many years by the NRF. However, they observed that the process appears to enjoy the support of the academic research community, and they therefore accepted it. It was noted that the only comments regarding the rating system that members of the physics community brought to the Panel were complaints that there does not seem to be a correlation between rating level and funding level.

3.11 Fields associated with Physics

Here we consider a number of associated fields where physics plays an important role. Fields that were noted by the Panel, but which are not detailed here, include, for example, oceanography, meteorology, satellite technology, and defence.

3.11.1 Medical physics

The field of Medical Physics appears to be in crisis in SA. Medical physics is regulated in terms of the Atomic Energy Act, 1967, and the Hazardous Substances Act, 1973. The main areas of medical physics are radiation oncology, nuclear medicine, and radiation quality assurance and quality control. The World Health Organisation (WHO) and the International Atomic Energy Agency (IAEA) state that to provide radiation oncology medical service alone, 1.74 medical physicists are required per million of the population. Allowing for the other activities of medical physics (see below), about 150 medical physicists are required in South Africa. In fact, the number of registered medical physicists in full-time practice is only 41. In the Eastern Cape, 7 medical physicists are required, whereas 1 is practising[9].

Why are medical physicists needed? There are increasingly complex demands in diagnostic radiology, nuclear medicine and in radiotherapy. Dose simulation before treatment is a vital validation of treatment planning. These issues are related to medical safety; when radiation dose is not monitored, patients can suffer (Fig. 8.)

Fig. 8. An example of the effects of over-exposure to ionizing radiation, showing that exceeding radiation dose limits can lead to severe consequences

The bulk of medical physicists are employed in the public sector, but the growth of the private hospital sector (with better remuneration), as well as positions with the mines and in business, attract staff away.

SA has excellent and active medical physics departments working closely with the medical community. These are jeopardised by fragmented funding and their inability to appoint new staff. The problems of the student pipeline highlighted elsewhere in this report are increased by the fragmented nature of the funding sources.

3.11.2 Nanotechnology

Last year a South African Nanotechnology Initiative was started, with the blessing of (and some funding from) the DST. This is clearly an interdisciplinary area of study, embracing physicists, chemists, engineers of various persuasions, etc. The members of the initiative (self-nominated) total about 150, and include a significant number of physicists. A preliminary report has been drawn up, and plans are being developed for growth in certain strategic areas. It appears that the emphasis will be on technological deliverables. But one trusts that there will be scope for adequate funding for fundamental studies in this area of research, too, as it seems clear that a lot more fundamental understanding of the behaviour of bulk matter on this scale is required to optimise applications.

3.11.3 Biotechnology and Bio-informatics

Biotechnology and Bio-informatics are two growth areas on the South African scene, in which physicists can also play a role. The former discipline received a very large injection of funds a couple of years ago, and a number of regional incubators have been set up, so as to grow different aspects of biotechnology in different parts of the country, based on the (local) regional strengths.

Many aspects of biotechnology contribute to national causes, most particularly in the area of combating disease. In one disease alone, tuberculosis, South Africa faces the challenges of multi-drug resistance and multiple strain infections.

In Bio-informatics, the skills of mathematical and computational modelling that are highly developed amongst physicists are transferable to this field. The tools of rational drug design, molecular modelling, epidemiology, and analysis – for example NMR – either require physics or are closely related to physics. Assessment of decisions on Genetically Modified Organisms is among the many contributions that the field makes.

Although one is aware of several individual physicists who are involved in these areas of research, it is clear that there is scope for further fundamental developments in which physics skills can play an important role as part of an interdisciplinary team.

3.11.4 Geophysics

Geophysics plays an important role in mineral exploration. Only two universities offer an Honours in Geophysics, viz. Witwatersrand and Pretoria. Student numbers are small, but have jumped in recent years, mainly because bursaries have become available from the mining industry. It appears that there is a rapidly increasing need for geophysicists, in part because of oil exploration in Africa. For entry into study of geophysics at the Honours level, one requires physics at least at level-2 in the major stream, and preferably a major in physics.

Whereas the exploration side of geophysics is possibly less physics-intensive, the academic research aspect is intimately linked to physics. Topics such as the dynamo driving the geomagnetic field, reasons for and effects of changes in the field (such as the decay of the field, particularly in the vicinity of the South Atlantic Geomagnetic Anomaly, giving rise to enhanced radiation effects and resultant data losses in satellite communications), and satellite-based experiments that are linked to the evaluation of the gravitational constant, G, are examples of close links to other activities in physics.

3.12 Physics and Industry

Gibbons[10] has suggested that there has been a shift in how scientific research globally is carried out, away from the traditional form of academic research in a discipline, to more contract and applied research, and consultancy-type of research. Specifically, this has been designated as a shift from Mode 1 to Mode 2 knowledge production.

In contrast to the academic Mode 1 research that we are all familiar with, "Mode 2 knowledge is produced in contexts of application, it is trans-disciplinary knowledge, heterogeneous and organised in new and diverse ways"[11]. In particular this describes work that is carried out in (often multi-disciplinary) teams, at the boundaries of disciplines, and in industry or arising from industrial pressures.

There is relatively little evidence that such a shift in mode of research has occurred in South African physics, at least in the academic sector, and that is something that the university community should consider.

In general the Panel found that the academic Physics community in South Africa has relatively few links with industry. There are obvious counter-examples at a number of universities. But it is noteworthy that there are relatively few cases of THRIP awards going to Physics Departments (for instance, only two in 2002). The same goes for Innovation Fund awards, although we did note a large recent award to RAU for a pilot production line for photovoltaic modules.

If it is considered that many graduates would seek employment in industry, that industrial research problems can be challenging and also help fund research (and students), and that physics is the basis of much industrial development, it is disappointing that these links are as few as they appeared to be to the Panel.

Regrettably, the industrial response is sometimes equally negative - representatives of some large industrial corporations indicated that they did not think that they had a need to employ physicists. Clearly the image that they had of Physics graduates was that they were not very useful in solving their (engineering) problems. Fortunately, as alluded to in section 3.4 above, this did not apply to all our industrial interviewees.

Several industries have built their own links with universities and science councils. The panel encountered examples of industries with clear and successful physics links (e.g. Element Six) and of industries where, although considerable potential for the application of physics research exists, the primary emphasis has been placed on engineering approaches (e.g. ISCOR).

3.13 Science Councils

The Science Councils were set up to provide national resources and national expertise in their designated areas. The economic realities of the past two decades, in terms of the money provided by the state have, in most cases, forced the science councils to seek alternative funding in order to maintain critical mass in areas that are deemed to be of national importance, and to close others. They have, in general, been both imaginative and successful in establishing and growing commercial markets, to the extent that income from these applications in many cases now outstrips the parliamentary grant.

Unfortunately, however, these financial pressures led to a reduction in a science culture in the science councils, and in particular, to a considerable reduction in the number of physicists employed. There was also a period during which relationships between universities and the science councils were distinctly cool.

Recently, however, things appear to have started changing. The current situation leads to a set of strategic decisions for the councils involved. The thinking from the CSIR, for instance, is that the enterprise and skills in the business interface should not be abandoned or compromised, since those skills have been built to contribute to crossing the gap to commercialisation. The strategy is rather to strengthen excellence in science, foster young researchers, and make contributions that stand up to rigorous scientific scrutiny.

Put differently, there is a wish to rejuvenate the science and technology base, and to build partnerships, for instance, with academia.

The funding support for these activities within the national mandate should come through the parliamentary grants to the science councils, summarised in [12]. Growth in commercialised income is significant and is driven by business principles, so that if funding for activities in the national interest is to keep pace with it, significant growth in science grant income is implied.

3.14 South African Institute of Physics

The South African Institute of Physics celebrates its golden jubilee this year. It has about 450 members, including 270 ordinary members, and a little over 100 student members. Unfortunately, many physicists, including some prominent academics, are not members of the SAIP.

The main activity of the SAIP is the annual conference, which is attended by between 280 and 350 physicists and physics students. An important aspect of the conference is its role in bringing (mainly postgraduate) students into the fold, and exposing them to the physics going on in South Africa. However, there has for a long time been a difficulty in making the conference something other than an exercise in academic physics. The challenge has been, and still is, to arrange a programme that attracts not only academic physicists, but also physics graduates working in industry. Numerous attempts have been made in this regard, but with little success. Another concern over the last decade or so has been the lack of attendance of physicists working with the Science Councils.

The dstribution of different sub-disciplines amongst them is a good guide to the spread of research interests, at least amongst the academic community. A total of 407 members have provided that information.

Solid state & materials science	136
Astro-, space & plasma physics	83
Nuclear, particle & radiation physics	64
Applied, industrial & general physics	34
Lasers, optics & spectroscopy	33
Physics education	31
Theoretical physics	26

Not surprisingly, the most common field of interest is solid state and materials science (33%) as first choice, with a further 9% indicating it as a second choice. Next comes astrophysics, space and plasma physics, with 20%, followed by nuclear, particle and radiation physics, with 16%. Other groups lie below 10%. It is noteworthy that the most common disciplines that are given as a second field of interest are applied and industrial physics (22%) and education (13%).

The SAIP does not publish a journal, but issues a quarterly electronic newsletter. That has a wide readership within the physics community, but has not yet been fully embraced as a vehicle for communication.

Advantages of SAIP membership, apart from a reduced registration fee for the conference, include a reciprocity agreement with the American Physical Society (attendance at APS conferences under the same conditions as for APS members), and joint membership with the UK Institute of Physics (including IoP membership at considerably reduced rates).

The SAIP has actively embraced the concept of the World Year of Physics in 2005, and a slew of meetings and other activities are being arranged. It is hoped that these will not only be for physicists, but will go out of their way to link with the wider public.

The SAIP represents physicists in a number of environments, e.g. on the national committee for IUPAP, but holds no lobbying role. Indeed, there is the concern that it is sometimes by-passed by authorities who probably should consult it.

However, the SAIP is hamstrung by the fact that it is dependent entirely on voluntary labour, with a small stipend being paid for secretarial assistance. To be able to do all the things that need to be done, it is necessary for the SAIP to have a full-time secretariat consisting of three or four staff.

3.15 Public Understanding of Science

As outlined above, virtually all higher education institutions, national facilities and science councils, as well as a number of industries, have active maths and science links to schools - the challenges of raising science awareness in the school-going community, and that of improving (augmenting) school-teaching in science are so great, that there is a widespread response to it.

Amongst the most successful such activities one may cite the Science Centre in Richards Bay, set up by the Physics Department at the University of Zululand, together with local industry. This has an annual throughput of the order of 20 000 schoolchildren.

But most of these activities that are directed at the Public Understanding of Science, Engineering and Technology (PUSET) tend to be restricted to schoolchildren and school-teachers.

There is some outreach to the "intelligent layperson", for instance, via astronomy projects (SAAO, SALT, Boyden Observatory), visits to iThemba LABS, and on a smaller scale, at most universities, where a variety of popular lectures are offered from time to time. However, it is not a major exercise, and more needs to be done.

Furthermore, there is very little targeted outreach to decision-makers and community leaders (both political and others). It is clear that this is an area of outreach which needs to be vigorously pursued.

Another area in which there is little physics activity is the media. Features on physics stories or achievements are rare. There are also large areas of South Africa where local newspapers do not have a science correspondent. Thus the whole question of physics in the media is a challenge for the physics community.

One of the serious problems facing physics as a career choice in South Africa is the lack of a clearly-defined "physics industry", akin to the chemical industry, computer industry, civil engineering industry, even the financial management industry.

However, in the UK, the Institute of Physics has, over a decade or so, been remarkably successful in a major PUSET drive that has spelt out the importance of the "physics based industries" (PBI's). Regrettably, the layperson, and the decision-maker do not always recognise the importance of the physics that underpins a large range of modern high-tech industry. According to a recent report[13], PBI's make up 43% of Britain's manufacturing employment, and 50% of its manufacturing enterprises, and they make a huge contribution to the GDP. The marketing of the concept of PBI's has been so successful that the nomenclature "PBI" has even been used in the House of Commons.

4. THE FUTURE

Introduction
In Chapter 3 the Panel has reported on various aspects of the state of Physics as gleaned from documentation and interviews. Bearing in mind the Terms of Reference, and the context that was set out in Chapter 2, the Panel now presents its views on the future of Physics, and strategies to bring about a better future for Physics in South Africa.

4.1. School Education

Although the Panel was instructed not to expend its energies unnecessarily on the school sector, the matter of School Education was raised by many of the interviewees, and the Panel is convinced that it cannot simply ignore that important part of the physics pipeline. It is therefore making some recommendations in this regard, and hopes that the relevant authorities will take them up and deal with them expeditiously.

4.1.1 The Further Education & Training Band

A number of changes to the Further Education and Training (FET) band are looming up ahead, and the Physics community faces these with some trepidation. For some time there have been questions as to the extent to which current teachers are adequately equipped to deal with the aims of Outcomes Based Education (OBE).

Over the last couple of years there has been a restructuring of the FET curriculum in Physical Science. The draft curriculum put forward by a panel appointed by the Department of Education was severely criticized by members of the Physics community, both by those who are researching in Physics Education, and by the broader academic group whose task it is to deal at university with the products of the school system. Various representations were made, including offers of assistance from the physics community, with limited results. At the eleventh hour, the expertise of the Physics Education community was called upon, to assist in producing an improved curriculum within a very short timeframe.

The Panel is pleased to note that in the end the Department of Education did accept assistance from the SAIP and some of its Physics Education experts. However, it seems to be imperative that in future the Department should call upon such expertise early in the curriculum development process. There is an obvious need for a structural link to be set up between the SAIP and the Department of Education in this regard, and the Panel calls upon the authorities to ensure that such a link is speedily established, and is made use of in future developments.

RECOMMENDATION 4.1.1
In many countries, elementary and secondary school teaching of mathematics and science is a considerable worry. In South Africa this situation is exacerbated in the historically black schools. Although beyond the scope of this inquiry, we must flag this very serious situation. We acknowledge that steps are being taken to address this matter, but urge the relevant authorities to pursue it with even more vigour, as it is a crisis situation. Individuals in the physics community are to be commended for their activity in this regard, but more involvement is needed, particularly at the structural level. [SAIP, NRF, Department of Education]

4.1.2 Attracting and Retaining Good Physics Teachers

It is our observation that those who have the ability to major in physics have a wide range of employment open to them, and few are encouraged to enter the teaching profession. In view of the shortage of suitably qualified science teachers to develop and sustain a science and technology-oriented economy, the Panel recommends that urgent steps be undertaken to attract more and better students into science teaching, and to retain them in that role.

RECOMMENDATION 4.1.2

(a) The state should introduce a bursary-loan scheme for students training as teachers of "scarce skills" such as physics. Students awarded a bursary to study towards a B.Sc. majoring in physics would be required to serve society by teaching for an equivalent number of years, failing which the bursary would be transformed into a loan.

(b) Differential salaries should be introduced, with science teachers being paid a premium over and above salaries paid to teachers involved in subjects that are not designated as "scarce skills". [Such teachers would need to prove their subject proficiency through some means of objective assessment.] [Department of Education]

4.1.3 School Laboratories and Laboratory Staff

As pointed out in Chapter 3, Physics is an experimental subject, and all schools should be provided with laboratories, equipment and laboratory assistance, and there is a need to provide for the training of school laboratory assistants. Based on international models, a suitable level of training could be as follows: Matriculation with a pass in Physical Science, followed by a one-year course, possibly spread over a two-year period in a "sandwich structure", ensuring that the candidate also benefits from experiential learning.

RECOMMENDATION 4.1.3

(a)The Panel recommends that the state should provide earmarked funds for the establishment of laboratories at all secondary schools teaching science, and ensure that the laboratories are adequately equipped and maintained to enable proper teaching of physics to take place.

(b) The state should establish a suitable number of posts of laboratory technician/assistant to provide the necessary support structure for the physics teachers.

(c) Finally, the state should, in consultation with the Physics community and Higher Education Institutions, ensure that a suitable training programme is set up for the optimal training of school laboratory technicians/assistants in different parts of the country. [Department of Education, SAIP, HEI sector]

4.1.4 International Physics Olympiad

Internationally, it has been found that the training for and participation in the International Physics Olympiad (IPhO) is a great way to boost the field amongst the most able of school-goers. For some time, consideration has been given (inter alia by the SAIP) to the question of possible participation in the IPhO.

There are in principle four difficulties standing in the way of participation:

- In most participating countries the level of physics knowledge in the final year of schooling is higher than in South Africa (e.g. A levels in the UK)

- The overall problems related to science teaching in South Africa are so serious that in the face of it, resources should not be spent ("wasted") on an elite group
- South Africa is a sparsely-populated, spread-out country, and hence there are severe logistics difficulties for the provision of training
- The activity would need to be funded, and a funding source would have to be found.

Notwithstanding the above, those who for some years have successfully organised the annual participation in the International Mathematics Olympiad would argue that it can be done, and it should be done. Furthermore, some spadework has already been done, and a proposal for a South African Physics Olympiad, as a precursor to participation in the IPhO, is on the table.

Interesting variations on this theme include the possible introduction of an Olympiad at a lower level (e.g. Grade 9), and the potential of setting up a Pan-African Physics Olympiad, PAPhO, with a view to unlocking the potential of the sub-continent. It has been suggested that it is possible, using existing infrastructure, to identify outstanding students (learners) in South Africa including rural and remote areas, as has been the case in the USA.

RECOMMENDATION 4.1.4
The Panel recommends that the physics community (led by the SAIP) should seriously take up the challenge of preparing South African schoolchildren for participation in the International Physics Olympiad. [SAIP, Physics community]

4.2 University Education

4.2.1 Foundation and Bridging Programmes

The discussion in the Chapter 3 has underlined the importance of foundation and bridging programmes, although they have hitherto not benefited from government subsidy.

RECOMMENDATION 4.2.1
The Panel recommends that the Department of Education and the SAIP should conduct an audit of academic support programmes in "unplugging the Physics pipeline", and on the basis of their success, the state should allocate targeted funding to HEI's for appropriate academic support programme to develop the necessary Physics base for the country. [Department of Education, SAIP]

4.2.2 University Teaching

We have noted in Chapter 3 that students criticized a number of aspects of the teaching that they had received. We recommend that University departments take note of these issues, and carry out some self-examination. In particular, a comment that came up repeatedly related to the fact that the "relevance" of the material being taught in the physics courses was not made clear.

RECOMMENDATION 4.2.2
We recommend that special effort be expended from the first physics lecture to expose students to applications, SA research opportunities and the role of physics in society. Examples from astronomy to illustrate physical principles are welcomed by students. We noted that where students had been encouraged to attend conferences

as undergraduates, contentment was relatively high. We recommend further that where they are missing, community projects, vacation jobs and internships be instituted to provide a better link between study and the possible workplace. [University community]
Medical physics students should be exposed to the practice environment from their first year. [Medical physics community]

In this regard, an attitude of mind towards applied or industrial physics needs also to be examined. There is a concern that many academics have a tendency, whether openly or indirectly, to denigrate "applied" physics or "industrial" physics. To such physicists, only academic physics is worthwhile. It is important that the Physics community should recognize the importance of educating physicists to work in school-teaching, government, industry or business, etc. Wherever they may be employed, they are still successful physics graduates, and benefiting society, based on their training.

Furthermore, it is an important sociological fact in South Africa today that any graduate is a member of a small elite group within society. A significant fraction of such an elite needs to be creating jobs for others, not themselves seeking employment. So entrepreneurial skills should be recognized and developed in undergraduate studies.

4.2.3 Internal Communication and Supervision

We have seen that in a number of Departments of Physics, there is a need to improve internal communication with students, in matters pertaining to financial support and other "environmental" matters that affect student performance. This is particularly important for postgraduate students, but is not restricted to them. We have also seen that there are situations (e.g. when students are working at other research institutions) when research supervision has been poor.

To this end we believe it to be important that departments develop effective communication systems with their students - at the personal level, through funding offices, through access to the internet (departmental, university, NRF web pages) and make sure that they are thoroughly informed about funding possibilities; that they resource assistantships and departmental jobs to those students in danger of dropping out; attempt to provide bridging funding where payment fails; and they keep the promises made to entice students into graduate courses in the first place.

RECOMMENDATION 4.2.3
We recommend that departments ensure that they, and through them their students, are kept well-informed about funding possibilities for students; that where possible they take steps to be of assistance to students in financial or other need; and that they ensure that their research supervision is of the highest possible standard, particularly in such situations where the student is not operating within the department, but is, say, at a research institution. [University community, Research institutions]

4.2.4 Attitudes in Departments

What departmental attitudes assist students and young professionals in gaining confidence and succeeding in physics? What are the elements of the environment that attract and retain under-represented groups?

The Mathematical Association of America mounted a project that searched for the common features of departments that are considered effective in their undergraduate programmes [14]. It was found that three states of mind underlie faculty attitudes in effective programmes:

- "respecting students, and in particular, teaching for the students one has, not the students one wished one had;
- caring about the students' academic and general welfare; and
- enjoying one's career as a collegiate educator".

Two further themes emerged repeatedly in the study:

- curriculum geared towards the needs of the students, not the needs of the faculty, and
- an interest in using a variety of pedagogical and learning approaches".

Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP)[4] investigated similar questions. Some points lifted from among many relevant findings are that

- successful departments have not "watered down" their curricula,
- one of the key elements is the sense of community established by faculty and students,
- the supportive, encouraging and challenging environment established in successful departments includes some obvious factors - such as mentoring of new faculty - and some perhaps surprising factors - such as the existence of a students' common room, or space controlled by the students,
- a sense of constant experimentation with, and evaluation of, the undergraduate programme to improve is important,
- flexibility in major programmes to meet the needs of students with a broad range of career interests is critical.

Both reports provide a great deal of useful material that may provoke changes in South Africa. In summary, being a "student-friendly" department goes a long way towards ensuring student - and departmental - success.

RECOMMENDATION 4.2.4

We recommend that, if they have not already done so, departments consult the references listed, undertake some soul-searching, and consider what they can do to ensure good staff-student relationships. [University community]

4.2.5 Student Initiatives

When interviewing students, the Panel was concerned about the fact that many students did not appear to be willing to take the initiative in dealing with their problems, e.g. in finding out about funding possibilities. While we recommend that staff take steps to assist them, the onus ultimately rests on the students to be proactive and take the necessary positive steps themselves, too. Students should play an important role in ensuring a successful future for Physics in South Africa.

It is suggested that, where they do not yet exist, students take the initiative to set up Student Physics societies. Furthermore, it could be of value to the societies, and to their future if these societies were in some sense nationally coordinated. It is recommended that the SAIP would be the appropriate organ to take the Student Physics Societies under its wing, and to foster them.

RECOMMENDATION 4.2.5

We recommend that students take the initiative in solving their problems, in conjunction with the department; further, that students be encouraged to form student physics societies on their respective campuses, and that the SAIP play a facilitatory and supportive role in this regard.[Physics students, university community, SAIP]

4.2.6 Student bursaries

We have seen that funding is a major problem for many students, and we recommend that the authorities take urgent steps to provide bursary-loans that will enable students to continue their studies in physics, as opposed to giving up on their studies, or being won over to a less scarce discipline where a prospective employer provides an attractive tied bursary.

Thus the intention of a revised bursary scheme would be to

- lower the barrier to enter science, and to stay in science, especially in comparison with competing career paths (commerce is an example); this is in view of the special needs of the S&T base as articulated above,
- meet the needs of the rising and significant fraction of students who are contributing to the support of a family, or who have other severe financial constraints, and who might be lost to science for this reason, and
- encourage the most able students to succeed in their studies, and encourage students to stay in SA.

In addition, we have identified a problem specifically with support of 3rd year and Honours students, since we understand that

- white students are excluded from support within the grant-holder linked bursaries programme, which can, according to reports, lead to discouragement of their pursuing further studies in Physics,
- support for other students is limited (and does not cover their tuition fees), and
- it appears that the Honours year in Medical Physics is not supported by either the Medical Research Council or the NRF funding programmes.

The following scheme is proposed specifically for students majoring in physics, but it could also be considered for other "scarce skills" sciences.

RECOMMENDATION 4.2.6
We recommend
(i) free education for all physics major students, and
(ii) the replacement of race discrimination in bursaries by means tests.
Realising that strong measures such as these may not be immediately implementable, but without abandoning the rigorous position, we suggest as interim measures
(a) providing tuition and accommodation loans for all 3rd year students in Physics, which are transformed into bursaries for those completing their degrees in the minimum period (three years),
(b) providing tuition and accommodation bursaries for all Honours students in Physics, including Medical Physics students, and
(c) that the bursaries should entail an agreement to remain in SA for a specified time, negotiable if a substantial opportunity opens for the student in another country.[NRF, MRC, Department of Education, Department of Trade & Industries]

Thus these bursaries would to some extent be competitive with employer-provided "tied" bursaries, that are common in Engineering, Commerce and Financial Mathematics.

4.2.7 South African Physics, Diversity & Transformation

An existential matter facing the South African physics community, along with the entire nation, is the creation of a genuinely multi-ethnic and non-discriminatory democracy. This task is the legacy of a miracle that occurred here about a decade ago. The miracle was the creation of a possibility - not an achievement of an actuality.

Perhaps uniquely in modern history, the success of this nation will be largely determined by the nation's embrace of diversity, respect and open access for all people in the country. The future of physics in SA lies in the country's commitment, investment and development of a workforce that is representative of its demographic diversity. With regard to the present situation for physics, there are two stark facts:

- Attention must be given to bringing historically under-represented groups into the mainstream of physics in SA. Otherwise there is little prospect for long-term support for physics activities at an optimal level.
- The demand that the standards and practices of physics within SA should be competitive with international norms requires that those standards and qualifications must remain at the absolutely highest possible levels.

Should the community not manage a successful balancing of these twin requirements of access and quality, there is less reason for optimism for this new frontier for humanity and the field of physics.

In the interviews held with the panel, these two challenges were muted presences that were often, at first, difficult to bring into discussion and focus. This perhaps was most dramatically the case in discussions held with students. Within this group, the panel heard concerns that varied depending on the characteristics of the speaker.

Among academics and those responsible for education, there was a commendable level of activity directed toward outreach and transformation. The Panel was satisfied that the community, although without a definitive development plan for providing open access and opportunity for all South Africans, was engaged on this problem. The lack of an overall or over-arching plan is a matter that all stakeholders ought to regard as a matter toward which efforts ought to be expended. The transformation issue is also powerfully interconnected with the decision to merge a number of institutions. Within the physics departments, essentially all participants seemed to be working towards making this a successful endeavour. In addition, foundation or bridging programmes are widely operative and this is acting to bring in increasing numbers of student from previously disadvantaged communities.

From the students, a wide range of comments was heard. Among groups who had historically enjoyed the full range of opportunity and advantages of the society, major concerns focused on the inaccessibility of advisors, the size of bursaries, concern for career options, etc.

Among groups who had not historically enjoyed the full range of opportunity and advantages of the society, the same issues occurred. However, there was a difference, especially from South African students who were from disadvantaged communities. Among this group the panel learned that such students often find themselves as bread-winners (sometimes the only one) for family, extended family members and even their own children. The economic stress on these students was tremendous. Their education cannot be viewed separately from their economic circumstances. This aspect is dealt with in section 4.2.6.

However, there was also an overlay of concerns having to do with what was perceived to be a lack of respect for – or confidence in - students from disadvantaged communities (especially directed toward Black South Africans). There is vast space for misinterpretation in such matters.

One area of particular concern is the rationalization of national curricula for the training of physics students, a concern arising from problems encountered by students transferring from a historically black university (HBU) to a historically white university (HWU). A number of students complained that they were required to retake courses which apparently covered the same material already completed at the HBU, without a proper evaluation of their knowledge base being carried out. Fortunately, in many (perhaps most cases) these students reported doing well, while experiencing a sense of having been disrespected. Apart from this potentially being a waste of resources, the process generates an initial impression of being unwelcome at the new university, the long-term effects of which cannot be underestimated with regard to a lack of progress toward the field's increasing diversity.

It is not uncommon, internationally, for students entering a new academic environment to face a mis-match of syllabi, and such students are often required to take courses to make up a perceived back-log for the proposed course of study. However, it is imperative that the registering institution should deal with such cases sensitively, communicate well with the students, consider carefully the knowledge base of the student, and where appropriate evaluate it objectively, before a reasoned decision is taken on whether the student is required to attend and/or obtain credit for one or more courses. The efficacy of articulation agreements between physics institutions (HBU/HWU) is a topic that requires attention immediately. It is not clear whether the Higher Education Quality Committee (HEQC) is the appropriate body to ensure such articulation.

Another feature that struck the Panel from its interviews with students was the apparent lack of formal mechanisms by which student concerns can be brought to their teachers, supervisors and other responsible administrators. This seemed to be a problem across the various groups. Once again, however, additional matters appeared with regard to Black students. More than one such student commented that there was a general fear that to become an identifiable advocate for transformation opened the way for such students to be "victimized".

The issues of access, diversity and transformation have no easy answers. This fact must be honestly and directly faced. There are no models from the international scene to which one can point as examples of complete success. The physics community is generally regarded as being composed of bright, innovative and thoughtful individuals. The only hopes for implementing a successful transformation are for South African physicists to rely on their being as engaged in this problem as they are in the physics problems on which they work. Communication, goodwill and a sustained commitment to the process are indicated to solve this extremely difficult problem. However, physicists collectively have a habit of solving difficult problems. The panel is confident that South African physicists are up to this task and ensuring both quality and access to all South Africans: Asian, Black, Coloured and White. To do less than this with regard to any and all of these communities is to walk away from a miraculous legacy of possibility.

RECOMMENDATION 4.2.7

The long-term sustainable future of physics in SA depends on the country's commitment and investment in the development of a workforce that is representative of its demographic diversity. Evidence indicates that, while there is a rapidly growing cadre of physics students from previously under-represented groups, there are perceived difficulties that need to be addressed by the established physics community and by the funding authorities. Apart from financial barriers to both undergraduate and postgraduate study (addressed above), there are other matters of concern, such as that relating to the integration of students of different cultures into existing departments, particularly in regard to the transfer of students from HBU's to HWU's. These questions need to be addressed urgently, and interpersonal communication is of the essence. [University community].

4.2.8 Women in Physics

The issues raised concerning women fall into two broad categories.

4.2.8.1 Parenthood, Family Concerns and Physics

Both women and men raised concerns around parenthood and family responsibility. An academic career in physics may not be family-friendly. To quote the NRF Thuthuka guidelines, “Women in particular may experience career advancement limitations [related to] the responsibilities of child rearing, care of the elderly or the relocation of a partner” [15].

- Women in science sometimes defer raising a family in order to establish their careers, but take personal risks in order to do so.
- It appears that the number of students with parental and family responsibilities may be rising; the panel does not have clear data on this point.
- In many cases, responsibilities for ageing parents and extended families are the deciding factor in career choices; the availability of funding is critical in these cases.
- The family support systems for South Africans may differ from those of their first world counterparts.

Some mitigating factors exist:

- Some special support exists for women returning to a research career after raising a family, but may only be obtained in the 5 years following PhD qualification [15].

Academic and business careers are competitive, and those with dominant family responsibilities may find it difficult to compete to establish or to re-establish their career.

4.2.8.2. Women as an Under-represented Group

In section 3.3.3 we saw that women are an under-represented group in the physics community. Issues that they may encounter in common with other under-represented groups may include

- prejudice
- low numbers of role models
- differences in family responsibilities, noted above.

A number of groups exist to support and encourage Women in Physics, and can be located on the Internet - for those who have access. Where the Digital Divide is a problem, this problem is likely to be exacerbated for women.

Submissions to the panel specifically from and concerning women also noted that excellence in publication is valued in academic advancement over service to students or to the nation, and that this may be a fundamental misconception in building a diverse S&T base for South Africa.

RECOMMENDATION 4.2.8

(a) Prejudice in all forms needs to be overcome. Opportunities to promote and encourage underrepresented groups, including women, should be given special attention.

(b) Departments should ensure that women students are aware of the special opportunities available to them through the NRF and other bodies.

(c) All students need to be aware of applications of physics and the career options available, and this may be even more critical for women.

(d) Where NRF rules make it difficult for women to advance, attention should be given to changing them. Specifically, the bar to re-entrants further than 5 years from their PhD should be removed. [University community, NRF, employers]

4.2.9 Postdoctoral Fellowships and Young Staff

At present there is inadequate funding for post-doctoral positions in South African institutions. Internationally, it is recognised that "post-docs" play a vital role in the research process in physics. They form an invaluable link between the upcoming postgraduate student and the established researcher, and often are involved in some of the student supervision.

We have earlier touched on some of the problems facing a new academic staff member. An important problem when one speaks about physics research funding is the way of providing young dynamic physicists with the potential to start new research themes at the cutting edge of world science. This funding for young physicists should be nationally managed, aimed at the 30-40 range (typically 35 years) and evaluated by independent referees. This should allow them to start a new research line without being dependent on older and more confirmed staff.

This fund should address physicists trained in SA universities, as well as SA physicists formed overseas (in America, Europe, etc.) and willing to come back to South Africa. This fund could be eventually coupled to a post-doctoral funding scheme, allowing such new research projects to be implemented on a short time scale.

RECOMMENDATION 4.2.9

We recommend that a much more vigorous policy of providing postdoctoral fellowships be pursued, and that special funds be made available for outstanding young scientists to develop new lines of research (existing funding for P-rated scientists does not provide adequately for equipment infrastructure). [NRF]

4.2.10 Physics Education

The Panel feels that, particularly in the developmental situation facing South Africa, there is great value in the current emphasis on educational aspects in the HEI physics sector, as reflected by the size of the Physics Education community. This group has played an important role in the development of bridging courses and of first year teaching, as well as in the upgrading of schoolteachers, and (particularly recently) in school syllabus development.

Clearly, the Physics Education specialists in the SAIP can act as a bridge between physics departments and the education community. Physics departments could, for instance, get more involved in both the training of pre-service teachers and the professional development of in-service physics teachers.

Looking through a list of research projects in physics departments, it is noteworthy that in virtually every department there is an activity in Physics Education. This is unlike the situation in some countries where such activities are dominated by sociologists, and housed in social science or education faculties.

The question was raised as to whether all the listed education research activities were properly founded as research, or whether they were, in some instances, a façade behind which academics who were not doing any physics research as such, were merely hiding.

In a nutshell, the view of the Panel was that physics education research belongs in a Physics department, but that it was imperative that such research be held to the usual standards of research in physics, i.e. that the same degree of rigour and reflection accompany it as are expected from research in any other branch of physics.

4.3 Redirecting Physics Research?

The enlarged Terms of Reference speak of the Panel coming up with recommendation for redirecting physics research in South Africa. After due deliberation, the Panel is of the opinion that there should not so much be a redirection of research, as an improvement over a range of activities that will make the research process more successful in future.

It is well-known that it is difficult, and sometimes dangerous, to place undue emphasis on the planning of research areas, if that should mean the total exclusion of other areas. Nonetheless, there is value in considering those areas of research that are most likely to make an impact in the future.

4.3.1 Focusing of Research Funding?

There are a number of categories of research funding that may be considered. First there is research that involves very large pieces of expensive equipment. A field that should certainly be supported in South Africa is astronomy in the broadest sense, i.e. optical, radio, cosmic ray. Here, in addition to existing research strengths, South Africa has great geographical and climatic advantages, which should be exploited. Indeed, DST has decided some years ago that research endeavours such as SALT, HESS and the SKA should be supported, and we welcome that.

A second general grouping is research that is recognized as being a national priority, possibly because of natural resources, and that involves a diverse array of equipment, each piece costing of the order of a few million rands. It is suggested that such research should be concentrated in a small number of centres, distributed across the country, but cooperating both formally and practically. Facilities have to be provided that enable, and indeed enhance such collaboration. An example that is already strongly active in South Africa is materials physics. This interacts strongly with materials engineering, and contributes substantially to the national economy.

Another example is laser physics and technology. Although there is limited research strength in this field in South Africa at present, the laser may be seen as an enabling technology that needs to be developed in South Africa, in the interests not only of physics, but of the broader S&T community, through laser-based applications.

There are similar fields that are coming into prominence internationally, but that are at this stage still inadequately developed in South Africa, such as biophysics (again in the broadest sense), and environmental physics.

Finally there is the research that is carried out in small groups -"small physics". Historically, most of South Africa's successes in physics have come from such groups. Not only the two Nobel Laureates, Cormack and Klug, who were trained by RW James at UCT, but also, for instance, Schonland's work on lightning, and others. It is vital that funding should make provision to maintain such groups, as long as they are active, and in particular to develop such groups when a leader emerges. Thanks to modern communication possibilities, such successful small groups are no longer as isolated as they were in the past, and their activity keeps South Africa in touch with the global advance of physics.

In considering funding, it is vital that the funding required by the "big spenders" should not eclipse the equally important needs of the small groups. It is imperative that funds for big projects, such as SALT, etc., come from a different pot from those that are needed for the small groups. Because of the scale of funding required, it is probably best if the funding for the intermediate category (centres working on national priorities) were lumped together with the "big equipment" group.

4.3.2 Collaborations and Networking

Both collaboration and fragmentation are characteristic of South African physics - contrasting communities were observed.

Collaboration begins within the department. There are a number of small departments that have decided to focus on a single or a couple of closely-related research areas. It turns out that they are successful, presumably because they are optimising resources - laboratory, library, and scarcest of all, human resources. It is recommended that small departments should optimise their research facilities through focussed research. In the case of large departments the need to focus is less urgent, and they can usually afford to have a number of successful research groups operating independently of one another.

Where there are small departments with mixed research interests, it is important for the members to seek research collaboration with other disciplines or with colleagues in other physics departments.

Some groups are in active collaboration with one another. A notable example is the astrophysics - astronomy - space physics consortium. Common interests have enabled the community to reap the benefits of involvement in big projects, and to access major national and international funding. The community has identified its skills shortages and has put a joint national graduate programme (NASSP) in place.

Spin-off technology - "astrotechnology" - is allowing the production and exploitation of intellectual property in pharmaceutical and engineering fields, and establishment of what might appear to be some unlikely alliances, e.g. between astronomers and solid state physicists at different universities, and between astronomers and industry. Such developments are exciting.

Similarly, the Panel was interested to hear of the interaction between research groups at RAU and the Universities of Port Elizabeth and Pretoria. Within the University of Witwatersrand, the pooling of expertise, across a wide front, in the field of materials science, has led to the establishment of the Wits Centre for Materials Science and Engineering, comprising 30 staff and over 50 postgraduates.

On the other hand, it is also apparent that there are fragmented departments, parochial tea rooms, and well-insulated walls between physics and mathematics departments (and even physics and astronomy departments). It may be that historical relationships and competition for scare resources are driving this situation.

Not surprisingly, opportunities are appearing for those physicists and astronomers who are prepared to cross boundaries and build on the ideas of others.

Without forcing unwelcome relationships, the panel would strongly encourage the collaborative attitude. This is particularly relevant to those members of the community who are struggling for resources.

Encouragement is being applied through funding; people are more likely to discover common interests when money is available as a result. As commented on earlier, the Centre of Excellence concept is welcomed, as it allows participants to put together a voluntary rather than a forced collaboration. Physicists are even collaborating with engineers through this mechanism. It is to be hoped that the collaborations proposed in CoE applications are continued with, even in the event that the proposals are not approved for funding.

However, the panel heard surprisingly trenchant criticism that in many cases engineering departments and overseas institutions seem to be more willing and eager to get involved in big new projects - PBMR and SKA are examples - than local physics departments. *The bread has been cast on the water but the community hasn't got all its ducks in a row.*

The Panel strongly recommends that more interpersonal communication be set up to encourage both inter-institutional physics collaboration and inter-disciplinary collaboration with colleagues in, say, mathematics, biochemistry or engineering, as well as between academic departments and science councils, industry, etc.

Finally, it should be emphasized that industrial collaboration is a vital and necessary connection for academic departments, with the obvious attractions of industrial funding, THRIP and the Innovation Fund, and possibly jobs for the students.

RECOMMENDATION 4.3.2
The Panel recommends that research groups take positive action to develop collaborative research, across institutions and disciplines, and particularly with industry, in order to strengthen the research endeavour in South Africa, and to benefit from the resultant advantages. [University community]

4.4 South African Physics & A Lack of Connectivity

The canary in the mine can show signs of distress well before gas levels have risen to a point of danger to the miner. Similarly, the field of physics is sensitive to conditions that in due course can have a severe impact on the knowledge-based economy. In meetings with diverse members of the South African physics community a common theme is the distress present with regard to access to a modern comprehensive information technology (IT) network whose principle component contains broadband Internet and Web access. In short, the existing network is too slow and too expensive by far.

Just as the Web was created by a group of physicists working at the CERN (a European physics research), the South African Internet was born principally due to the efforts of three physicists, viz. Francois Guillarmod, David Wilson and Michael Lawrie working at Rhodes University in 1988. The first link ran from Grahamstown, to Portland, OR, U.S.A. From Rhodes University, the email-only network spread to the University of Cape Town and the University of Natal. This story is one illustration of how the South African physics community, like its international counterparts, plays a leadership role in establishing often unrecognized innovative technological advances. It is not a coincidence that a significant fraction of the South Africa's first generation of computer science professors were, in fact, physicists.

The present lack of a modern cost-effective digital network in South Africa appears to be a choke point with regard to the health of the South African physics community. There are a number of apparent difficulties that could be ameliorated by the introduction of National Research Information Network (NRIN).

A modern cost-effective broadband NRIN would allow for the creation of virtual groups. Although the quality of individual researchers is often comparable to international norms, the relative isolation of these researchers produces groups that are sub-critical in size, leading to less effective interaction with colleagues than is the case internationally. A modern broadband and cost-effective IT network would allow the actual interaction to be replaced by virtual networking. There is much evidence in the international experience that suggests that after a required and initial face-to-face meeting, virtual collaborations (i.e. working via an IT medium) are quite effective.

Similarly, a modern NRIN would also allow the entire South African physics community (indeed, the science community) to solve the growing problem of timely access to scientific and technical journals, at a more affordable cost. This is discussed in more detail in the next section, but suffice it to say that the advent and increase of (cheaper) electronic publishing is leading to increasing costs of paper journals, and thus a national switch to electronic journals (really only possible with a faster, cheaper network) would bring about considerable national cost-savings.

A modern cost-effective NRIN would allow the physics community to engage in research areas where there will be increasing need for increasing exchange of large data sets, grid computing and data mining.

One possible project that potentially has an enormous impact on science in South Africa is the Square Kilometer Array (SKA). This involves the construction of a large radio astronomical facility of unique characteristics. Efforts to bring this international project to South Africa are already at a high level.

The data generated by this device may be used by scientists in many countries. If there is insufficient attention paid to the establishment of a broadband and cost-effective IT network, the scientific community of this country will be prevented from making full use of a facility built with significant South African investment and residing on South African soil - what some have called "knowledge colonialism". In fact there would be severe constraints on the operation of SKA as such, if it were to depend on the existing digital network.

The same argument above also applies to the national efforts in the area of Bio-informatics. The information contained in genomic type studies produces large data sets that must be analyzed, as is the case in many sub-disciplines of physics. This is often done in a collective manner via electronic means. Here, too, a broadband and cost-effective means of doing so is vital for South Africa's participation.

A new concept in the scientific world is that of grid computing. In this approach, the analysis of large data sets that have traditionally been analyzed by the use of supercomputers are instead sent out over a network to large numbers of desktop work stations for analysis and the results are then sent back to a central source. It is noteworthy that at least one South African group (at UCT) is actively collaborating with CERN on developing grid computing. Thus physicists are again taking the lead in this area. However, to be successfully integrated into the system, they require faster connectivity than is currently available. Other variations on this concept called data mining and the emergence of cyber-science are also coming to the fore internationally.

It should be noted that the need of the physics community with regard to the existence of a broadband and cost-effective national IT network mirror needs of the entire nation. This is especially true in the light of the government stated goal of establishing a knowledge-based economy. To succeed at this, the creation of such a network is a national imperative. This need was recognized as long ago as 1994. In the White Paper on Science and Technology[16], the following statement may be found:

- "*South Africa currently lacks a national policy to facilitate the country's optimal integration into the global information society and outlining clear responsibilities, goals and targets. This is a serious defect in our overall innovation drive and must be remedied immediately*."

From this point of view, the nation has already lost a decade. During this past decade, India has most spectacularly exploited a new model for national economic development. In the computer software field alone it has created a $12 billion/year industry starting from essentially nothing. That nation also effectively leveraged the fact that large numbers of its theoretical physicists travelled to the International Centre of Theoretical Physics (ICTP) in Trieste, Italy. This exposure had the vital function of cross-cultural exchange and linking many thinkers in that nation to the global conversation in science and technology. That nation's physicists played a role reminiscent of the South African visionaries at Rhodes University.

In order to build a knowledge-based economy, people must have the means to share information and knowledge. It does not seem prudent to lose yet another decade without a broadband and cost-effective IT network within South Africa. This will only increase the threat to the overall national strategy for economic development. The distress of the canary (physics) is loudly warning the miner (the national strategy for economic development based on knowledge).

RECOMMENDATION 4.4

We recommend the creation of a fast, inexpensive, broadband National Research Information Network to support non-commercial research. This is vital not only for the

National Research Digital Library suggested below, but in order to permit the maximum exploitation by South African scientists of data provided by national investments similar in scope to the proposed Square Kilometer Array. Projects of this type are likely to be the trend of the future and the lack of a system like the NRIN will mean that the dissemination of high value knowledge skills will, at a minimum, be severely constricted. [NRF, DST]

4.5 A National Research Digital Library Resource

The rapid rate of progress in areas of international competition necessitates the ready access to scientific and technical journals. If the physics programmes of this nation are to be competitive, even in carefully targeted areas, it is vital that there be created a National Research Digital Library Resource (NRDLR).

Information exchange has been a hallmark of progress in research for over one hundred years. For many years the method by which this exchange occurred in engineering, mathematical, technical and scientific fields, was not itself a dynamic medium: a system of journals held unchallenged domination in the area.

This began to change in the 1980's. In one area of theoretical physics, a move was made to establish an "electronic archive" or ArXiv (http://arxiv.org). The pioneer of this approach was U.S. physicist Paul Ginsparg. In this approach a central storehouse computer called a "server" is created where authors can submit their work. Other researchers then use either the World Wide Web or e-mail to access the contents from the server by downloading works of interest and printing out "hardcopies" (i.e. text on paper) at their location. In fact, many physicists' research, especially in theoretical physics, has become paperless.

This model has rapidly expanded beyond its initial area of physics and been adopted by most of the major publishers of physics journals in Europe and the U.S. In fact, it is such a successful model that the American Institute of Physics, publisher of the Physical Review and Physics Review Letters, by the middle of the 1990's had optically scanned its collection back to 1889 into a digital format. All major journals published have followed suit in the U.S. and Europe.

The approach of using servers has profound implications for the dissemination of advances in scientific and technological fields (and likely far beyond, thereby re-defining the concept of "the library"). This has been recognized by the U.S. National Institutes of Health, the largest research-funding agency in the world. It has adopted the server-model as its endorsed means for ensuring the transmission of research advances with the fields that fall under its responsibility via a program that has been named "PubMed" http://www.nih.gov/about/director/ebiomed/ebi.htm.

This in turn has had the effect of causing major European organizations charged with similar responsibilities to follow this course: http://www.thelancet.com/era
<http://www.library.yale.edu/~llicense/> ListArchives/0101/msg00001.html

So it is clear that this is the wave of next development in the leading centres of international research advancement.

A concentration on providing the South African physics community (indeed all S.A. research communities) with adequate access to a digitally-based system of journals also takes advantage of another trend apparent in the realm of paper-based journals. There has been a rapid rise in the price utilizing this traditional manner of data transmission. It seems likely that a digital-based system would likely allow for substantial cost-savings with regard to subscriptions. Indeed it has been a conscious decision by a number of physics journal publishers to utilize a differential price model that encourages migration to digital access over paper. As the market for the paper-based products decreases, this trend will become even larger as an ever smaller customer base is forced to shoulder more of the complete cost of production.

It would be a fundamental error for SA to ignore these trends by neglecting to create something along the lines of the NRDLR. It will be deleterious to the health of the national physics community and a fundamental threat to the national aspirations of growing a domestic knowledge-based economy. The present stress in the physics community over this issue is likely playing a predictive role of an impending threat to the overall national economic planning for the future.

RECOMMENDATION 4.5
We recommend the creation of a National Research Digital Library Resource. Such a structure would provide subscription to electronic journals that will be accessible over the internet, and hence available to all universities (both staff and students), and selected non-commercial researchers. If the physics programmes of this nation are to be competitive, this is a vital need. It is clear that such a resource will have a transformational nature also, since even remotely located Universities will also be able to access the latest research findings, with the caveat of the necessity of ready internet access. [NRF, DST]

4.5.1 The SARIS Project

After the Panel had completed its preliminary report and presentation, the SARIS (South African Research Information Service) came to its attention. This project, spearheaded by the CSIR, and funded by the Ford Foundation, appears to be operating along the lines alluded to above.

We quote from a recent article outlining the project:

- "*More and more research resources are becoming available through the Internet, but poor connectivity and expensive access rights present significant obstacles to many South African researchers. SARIS is a project aimed at creating a more concerted effort by Team South Africa to ensure that all researchers have effective and sustainable access. One of the project objectives is to gather information and ideas for innovative approaches from as wide a range of sources as possible*."

As SARIS came to the attention of the Panel so late, it has not had the opportunity to carry out an in-depth study of the project. It is important that the Physics community, through the SAIP, should investigate the SARIS project, and if, as appears to be the case, it dovetails with the thinking reflected in the previous recommendation, involve itself in the project.

RECOMMENDATION 4.5.1
The Panel recommends that the physics community, through the SAIP, should investigate the SARIS project, and, if appropriate, align itself with and be supportive of it, in its attempt to develop a Research Information system in South Africa that is appropriate to the needs of the new millennium. Furthermore, the Panel calls upon the Physics community to keep on the lookout for other such developments (e.g. for an improved digital network), as appropriate, and to act coherently as a community in support thereof. [SAIP]

4.6 Equipment - Tools for South Africa

4.6.1 Modernizing the Research Infrastructure

In Chapter 3 we have highlighted the need for more and newer equipment at a variety of cost levels. In this Chapter we list the resulting recommendations.

In particular we are concerned that with ageing equipment, and an imperative to be globally competitive, and hence to have access to new equipment, there is an overall need both to modernize the research infrastructure, and to ensure that the available equipment is used optimally in the interests of the country as a whole.

RECOMMENDATION 4.6.1
There is considerable concern about the state of the research infrastructure. According to the data received, much of the equipment in university departments is out of date or inadequate. The Panel recommends that SA makes a rational investment in modernizing its research infrastructure to meet the scientific requirements as well as with the objective of training the future generation of young scientists and engineers with globally competitive skills. The Panel recommends that appropriate mechanisms for funding and optimal utilization of existing resources be put in place at all levels of the scientific needs. [NRF, DST, Department of Education]

4.6.2 Equipment at "Government" Laboratories

We have seen that there are a number of laboratories in the science councils, national facilities and parastatals (which we shall call "government laboratories"), that have a wide variety of high quality equipment. However, that equipment is not always used optimally, and could be made available to a potentially wider user base.

RECOMMENDATION 4.6.2
The panel recommends that "government laboratories" enhance their user base through aggressive outreach effort to universities and other outside users in order to ensure full utilization of their unique capabilities. A more user-friendly facilitatory governance needs to be pursued. An increase in mobility grant and regular research grants are needed for this purpose. [NRF, Science Councils, National Facilities]

4.6.3 Major Research Instrumentation at Universities

It is a matter of considerable concern that NRF funding for major equipment purchases at universities has not been available over the last few years. The equipment situation is worsening, but is not yet irreversible.

RECOMMENDATION 4.6.3
The panel strongly recommends an increase in the nation's investment in university research infrastructure through upgrade and acquisition of major research instrumentation, as well as through support for instrument development. In order for SA's researchers to remain competitive and vibrant it is crucial to have a modern infrastructure that meets the demands of modern science and technology. Modern equipment at the universities is crucial for training purposes. Lack of training in the utilization of modern equipment will severely hurt South Africa's future generations. [NRF, DST]

4.6.4 Medium and Small-scale Laboratory Equipment

Funds for small-scale instrumentation, items costing between R30k and R100k, are critical for conducting research, repairing and upgrading existing equipment, and training students. The current mode of funding for such instruments is through the individual research grants. It appears to the Panel that these grants are, in general, too small.

RECOMMENDATION 4.6.4
The panel recommends an increase in the individual research grant to allow for the acquisition of these small but critical tools for research, and education and training, and that significant funds be provided for maintaining and upgrading of existing equipment.[NRF]

4.7 Flagship Science

4.7.1 What is a Flagship?

A long term strategy for physics would include identifying and pursuing a limited number of flagship projects. Flagship projects are high profile, often expensive projects and consequently there is only one project of any given type for the country. Choices of such projects must be considered carefully. In SA, research endeavours at some institutions and in some sub-disciplines are operating below critical mass. Key features of a flagship project are

- The project will be state-of-the-art, with the possibility of pushing back the frontiers of knowledge globally
- It raises the profile of science nationally, and has the potential to develop national pride
- It brings a focus to existing scientific enterprise, reducing the critical mass problem, for researchers, students and industry
- The successful completion of such a complex project requires many different skills at levels beyond their current competency. Consequently, there is a significant spin-off effect through such disciplines as engineering, information technology and other areas of science and industry
- There is the potential for attracting international funds
- It encourages international collaboration, and in particular provides a state-of-the-art research facility to be shared with scientists and students on the African continent

Furthermore, any proposal for a flagship project would have to be drawn up in the framework set by the National R & D Strategy, and would have more likelihood of success if it can make a cross-disciplinary impact.

We have seen that currently there are flagships in astronomy and in nuclear science. It is pleasing to note the community's reactions to these flagship projects.

RECOMMENDATION 4.7
The Panel noted with pleasure the overall level of research and the existence of some excellent projects, although relatively few in number. Particularly impressive is the attitude of researchers towards the new "flagship projects" - projects that we applaud. We recommend that these projects be seen both to act as a focus for much of the scientific work in their respective areas, and to provide links to apparently unrelated branches of physics. [SAIP, DST, Physics community]

4.7.2 The Next Flagship

In the South African context, given SALT, HESS and SKA, it seems reasonable to plan for a new flagship project that is not based in astronomy and astrophysics.

It is important that the physics community should identify possible flagship projects, carry out preliminary investigations on them, and then decide which it wishes to put forward, as a community.

Allowing for the preliminary investigations, feasibility studies, scientific planning, funding, development of a user base, machine design, manufacturing and commissioning, one needs to think on a timescale of about ten years.

On such a developmental timescale, there are a number of possible projects that would meet these criteria. However, one proposal was presented to the Panel, viz. for a synchrotron light source, and we will use this project, that meets the criteria, to outline the route to follow, to successfully implement such a project:

1. A study should be commissioned immediately
2. A user base, and user skills need to be developed
3. A scientific case needs to be presented, as well as a proposed machine design and layout
4. A management plan needs to be set up
5. Funding needs to be secured from national, regional and international sources
6. A detailed design will be needed, as well as an identified suitable site
7. Timetable for construction and commissioning

At first sight such an advanced light source, with its attendant costs, would appear to be an exotic wish for a country such as South Africa. However, it was noted that in both Brazil and Jordan synchrotrons will shortly be commissioned (built in part with international funding), there are the beginnings of a local user base already (using machines abroad), it would provide an extremely valuable tool for many condensed matter investigations, and it would be a tool not only for physicists, but would provide facilities for engineering researchers, materials scientists, chemists, biotechnologists, life scientists and nanoscientists. Further details on synchrotrons are provided in Appendix 5.

The Panel is not going to make a recommendation on the proposal to build a synchrotron, as it is of the view that a thrust of this nature should come from the user community mentioned above, and endorsed by the broader physics community. Should the decision be in favour of pursuing a synchrotron as the next flagship project, then it would be the role of the physicists, as representing the lead science, to draw in all the other potential users from the beginning. Such an interdisciplinary approach would make for a far more valuable tool for the nation, indeed for the continent.

RECOMMENDATION 4.7.2

The panel recommends that SA's physicists plan and prioritize their needs for a future large instrument. We recommend that funding agencies provide the necessary seed money to carry out these studies and to build up the user community in critical areas, such as, for instance, the South African Synchrotron Initiative. [Physics community, SAIP, NRF]

4.8 National User Facilities

In order to continue and extend the high quality of science in South Africa, we recommend that a variety of National User Facilities (NUF) be created. While it is clear that great effort is made in the training of students, it is also clear that at all levels, the quality of infrastructure for student training suffers. State-of-the-art tools are increasingly expensive, and in order to compete globally, one needs to train students on, and provide scientific staff with access to, appropriate equipment. We expect that a set of these NUF's will unleash and transform the creativity of the South African science and technology enterprise. Certain aspects of the proposed model exist already in SA; we are simply clarifying and extending the model.

A NUF is a location, real or virtual, with a thematically chosen set of tools/instruments that can be used by any South African researcher, academic or industrial. On the basis of an independently-reviewed, successful proposal, time is allocated on the NUF instruments/tools. Additionally, funding will be provided for consumables at the NUF, and funding for travel to and from the NUF. The equipment will be supported and maintained by the technical staff of the NUF.

These institutions will provide all South Africans with access to state of the art laboratory equipment, reducing the barrier to innovation in the country. Other key elements include user support, and a user-friendly governance, coupled with regular reviews by the NRF. Further details are provided in Appendix 4.

RECOMMENDATION 4.8.1
In order to optimize the utilization of the limited resources available, the panel recommends considering various mechanisms for sharing equipment. One possibility is the creation of a distributed network of National User Facilities (NUF's). [NRF]

The overall position regarding large facilities, including both flagship projects and National User Facilities, is embraced in the following recommendation, as recorded in the Executive Summary:

RECOMMENDATIONS 4.8.2 (note also 4.7.2, 4.8.1)
The onus is on the physics community to develop a long-term strategy for the subject, which addresses national developmental priorities as well as keeping the research internationally competitive. Such a strategy should, inter alia, aim at optimising both access to and the efficient use of, expensive equipment, and to facilitate the use of existing expertise by encouraging collaboration, thereby reducing the barrier to innovation. This may lead to the establishment of a limited number of other "flagship" projects and/or National User Facilities (NUF's) on a scale more comprehensive than hitherto, and with an emphasis on facilitatory governance. Proposals for such projects should ensure a balance between funds for equipment, including its periodic updating, and those of staffing and maintenance. The concept of a NUF is decribed in more detail in Chapter 4 and Appendix 4 of the Report. [NRF]

4.9. Small Physics

We noted in Chapter 3 that the pursuit of flagship projects should not be at the expense of "small science". A number of promising areas of "small physics" were put forward there; they should be taken seriously. The success of this research policy relies on a sound restructuring and networking of SA physics research between physics departments and national institutes. The role of the National Laser Centre can be pivotal in a number of areas and this fact should be widely recognised.

RECOMMENDATION 4.9

Preoccupation with flagship projects and National User Facilities should not lead to the neglect of other areas of research. International experience has shown that "small science" has not only been a major training ground, and the forerunner, scientifically, of many large projects, but has also been a major vehicle for innovation and intellectual property development. Thus there is a need for strong support for "small science", preferably in the context of collaboration. [NRF, SAIP]

4.10 Industry and Instrumentation Development

"The driver of technology is the need of science to make measurements for which there are no instruments." [17]

Physicists often have to develop their own instrumentation. Instrument development is an excellent mechanism for creating patents and intellectual property. South Africa has a cadre of skilled scientists and researchers capable of making contributions in this area, and it is important that, in the course of their research, physicists keep their eye open for the possible marketability of instruments (the intellectual property) that they have developed, and for associated links with industry.

RECOMMENDATION 4.10
An important effect of physics research projects is technological spin-off. Advanced research projects not only bring immediate "rewards" to industry and commerce in the form of orders for technologically advanced equipment, but they also raise the possibility of new, previously unforeseen, developments. "Astro-technology" is an excellent example and we recommend that it be used as a prototype, and that physicists make use of the structures that encourage links to industry and innovation. [NRF, DST, SAIP]

4.10.1 Industry and Science Councils

The relatively low involvement of the academic physics community with industry is described in section 3.12 above, with the observation that some strong and growing links do exist. Science Councils, notably the SABS, Mintek and the CSIR, are required by their mandate to perform this function, and physicists within these organizations are actively engaged with both industry and universities (section 3.13).

The relationship between business and universities through the employment of graduates has been described in 3.4.2, and it has been noted in 3.2 and 3.4 that employment and career prospects, and perceptions surrounding them, are critical factors in unblocking the student pipeline.

The intention of the CSIR to rejuvenate its science and technology base is welcomed and supported. Coupled with our recommendation that academic physics departments should seek closer ties with industry, we believe that the time is ripe for closer collaboration between universities and science councils.

4.11 A Role for Theoretical Physics in South Africa

The community of theoretical physicists in South African is one of considerable topical diversity and in many cases possessing a well-regarded international profile. While a small portion exists outside of traditional university physics departments, on balance its distribution of locations is not as broad as in countries higher up the Technical Achievement Index (TAI). To a very good approximation the nation’s theoretical physics community only exists within its universities.

This community, however, faces some challenges that inhibit its being more fully engaged in directions coupled to national goals and permitting it to have an even higher international standing. Although there are many quite accomplished individual investigators, in general, research groups in comparison to more highly placed TAI-scale nations are sub-critical in size. Individuals are often quite isolated within their physical environment. This difficulty has, in fact, long been recognized by the community and one of its responses has been to hold the "Chris Engelbrecht Summer School in Theoretical Physics." This has been the major attempt to permit the community to be kept abreast of the latest international developments.

The fractured status of this sort of existence seems to contribute to an overall lack of coherence in the South Africa's effort across an array of topics within theoretical physics. There is a pressing national need to assist this community maintain its international competitiveness and link more effectively to national needs. There is a model that might prove useful to alleviate this situation.

In other nations, centres have been created to gather groups of theoretical physicists together in order to meet pressing needs. In 1930, there was created near Princeton University in the U.S. an organization denoted as the Institute for Advanced Study[18]). This organization was envisioned as providing an environment dedicated entirely to the encouragement, support and patronage of learning through fundamental research and definitive scholarship across a wide range of fields. This institution became the home of Albert Einstein when he emigrated to the U.S. This model has been replicated at a number of locations around the world, with the newest such being the Stellenbosch Institute for Advanced Study [19]. However, a further distillation of this sort of model seems more appropriate to the specific needs of the South African theoretical physics community. In general the Institutes for Advanced Study direct their attentions to far broader areas of investigation.

National goals with respect to applied physics or engineering directions have a long history of requiring the nation to establish national laboratories facilities such as iThemba and NECSA. However, there is an obvious missing piece to efforts where theoretical physicists are expected to contribute.

There is no South African theoretical physics user facility. A similar situation existed in the U.S. until their National Science Foundation (the equivalent to the NRF) recognized the need for such a facility in the 1980's. This led to the establishment of the Institute of Theoretical Physics (ITP) affiliated with the University of California at Santa Barbara, now called the Kavli Institute of Theoretical Physics or KITP[20].

The establishment of such an entity in South Africa would offer the possibility of providing a long-term coherent stability to the community. There must be some attributes from which this organization cannot stray:

a. The overall reach of this organization must be national in scope.

b. It must not become the "property" of any subgroup of the South African theoretical physics community. It should provide for establishing an end-to-end linkage of the community. At the minimum it should be charged with the responsibility of ensuring the information technological basis for supporting collaboration between members of the community.

c. The organization must coherently engage the theoretical physics community with areas of national needs and goals.

This point perhaps can be best illustrated by an example drawn from the experience of the KITP. The programme of KITP provides programmes of study that bring together groups of physicists to study recent developments of rapidly developing areas. One of the most active of these areas has been in biophysics. These programmes have become major avenues by which theoretical physicists in the U.S. have become contributors to investigations in the area of biophysics.

An additional need of this envisioned entity is to maintain very close links to members of the general physics community who are not themselves theoretical physicists. One of the repeated statements made to this panel was how isolated university physicists are from the needs of the nation. The proposed national theoretical physics user facility ought to possess mechanisms that can be used to break down this isolation.

The organization should be charged with maintaining the coherence of the national theoretical physics community. There is a likelihood that groups of theoretical physicists may develop within the country, who are not affiliated with the university system. STIAS is one possible model, but not the only one on the horizon for the nation.

One other model has recently been initiated in South Africa, the African Institute for Mathematical Sciences[21]. Although at present this is principally an entity that is educationally focused on the entire continent, it has been created principally by theoretical physicists,and should it (or an as yet to be created entity) evolve in a manner that establishes new communities of theoretical physicists, efforts should be made to engage them for purposes of national goals and needs through the national theoretical user facility.

RECOMMENDATION 4.11
The state of theoretical physics is characterised as internationally competitive in some areas, but there is fragmentation and a coherent policy is needed. We recommend the establishment of a National Theoretical Physics Facility (either real or virtual); the theoretical physics community will then be able to respond nimbly to national science policy initiatives. [NRF]

4.12 Related Fields

4.12.1 Medical Physics

Section 3.12.1 above has described a documented crisis in the supply of registered medical physicists (radiation oncology, nuclear medicine, and radiation quality assurance and quality control) to meet WHO and IAEA requirements. Available data indicates that about 150 medical physicists are required, but that only about 40 are available.

In the medical physics field, funding sources include the Department of Health (for undergraduate courses) and provincial governments (for intern posts). However, Medical Physics Departments are not eligible for NRF grants.

There is a special problem in that no funding source exists for Honours students.

It was apparent that this area is potentially rich in Intellectual Property, and that the links between disciplines have to a large extent already been made. Ideas are waiting to be exploited.

The medical physics, radiation oncology and nuclear medicine communities have proposed solutions to authorities in the field. We recommend that the SAIP support them in their endeavours to have these proposals urgently considered. These are summarized here.

RECOMMENDATION 4.12.1
(a) Medical physics (including radiation oncology, nuclear medicine, and radiation quality assurance and quality control) should be designated as "scare skills" professions.
(b) An urgent training programme to provide an adequate number of registered graduates, particularly to public service, is required. Funding is a major factor in this programme. Increased funding from the sources involved is required to provide staff and student numbers, but consolidated and well-coordinated use of the funds is an important factor.
(c) Funding from the NRF or MRC should be provided to Medical Physics Departments, particularly in order to resolve the problems of funding for Honours students, transformation, the development of research and the development of young staff members.[DTI, Department of Health, Provincial governments, NRF, MRC, SAIP]

4.12.2 Cross-disciplinary Links

All physics-related fields depend on a throughput of physics students for success and for growth. Furthermore, as we have seen in Chapters 2 and 3, there is much exciting physics at the boundaries, where disciplines meet. It appears that in South Africa academic physics has not yet made a significant shift towards Mode 2 knowledge production. Thus it could be in the interests of physics in South Africa if there were closer interaction with practitioners in these physics-related fields.

In Chapter 3 we discussed particular related areas, viz. biosciences, geophysics and nanotechnology, but it is not intended that collaborations might only be sought in those areas. Nor is it intended that the impression should be given that physicists would only find rich areas at the interfaces of disciplines. However, particularly where stagnation is occurring, collaborations can be a fruitful source of stimulation, funding, and the development of Intellectual Property.

RECOMMENDATION 4.12.2
The panel recommends that South African physicists consider establishing closer links and collaborative research endeavours with biophysics, geophysics, medical physics, bio-informatics, engineering, etc. and similar physics-related disciplines.[Physics community]

4.13 The Public Understanding of Science

It is well known, and self-evident, that the Public Understanding of Science (an abbreviation for the Public Understanding of Science, Engineering and Technology - PUSET) is an increasingly important topic. In South Africa - a country in rapid change - the importance is even greater. A great deal of outreach is being done by virtually all sectors of the physics community, and that is welcomed. However, much still needs to be done.

It appears that most of the outreach hitherto has targeted children and teachers. These are, for the future development of scientists in general, vital groups. However, it should be appreciated that there are many facets to this topic and many branches of “the public” – not only children and teachers, but also policy-makers and leaders, engineers and industrialists, and adults in general - and their needs vary, particularly in view of the great inequalities across the society.

With 2005 being the International World Year of Physics, the SAIP is already actively engaged in planning activities to raise awareness of physics in the community at large. Indeed, this is an opportunity for every physicist in the country to play a role in this area, and the panel would urge all physicists to do so. It is vital that the celebrations of Physics are not restricted to physicists – this is the ideal vehicle to “go public”.

An important consideration that should feature in the thinking of all who are in receipt of public funds, is that they have a responsibility to the public.

Funding bodies, appointment and promotion committees alike should all require input on this topic from candidates, and allocate “points” for expertise and activity in this area.

In planning their teaching programme, universities should make provision for senior undergraduate and postgraduate students to gather experience and obtain training in making presentations to the public, be it on a research topic or a more general one related to their discipline.

RECOMMENDATION 4.13.1
The "Public Understanding of Science" is increasingly important, not least for a democratic nation where the wide appreciation of science is vital. Much is being done but we recommend more, particularly as "the public" consists of many constituencies, all of which are important. [SAIP, Physics community]

The role of the SAIP could be important here. If augmented as recommended in §4.14, it could act in a coordinating fashion, being responsible for initiating collaborative efforts and acting as a political lobby - not least to secure greater funding.

RECOMMENDATION 4.13.2
Job prospects in Physics are perceived by many young people to be poor, and this affects the take-up of the subject in schools and universities, but this is illusory. Both industry and business welcome them, for both technical and managerial careers, but this is not made apparent. The fault appears to lie on both sides, employers not making it clear that physicists are welcome to apply for their vacancies, and physicists not being sufficiently proactive. We recommend that SAIP mount a "connectivity-campaign". [SAIP]

There are two very important groups that have in general been ignored by South African physicists. These are the opinion-formers and policy-makers, and the engineers and industrialists.

It is vital that the physics community builds closer links to industry and engineering. Better links to that sector could, inter alia, lead employers to accept physics graduates as suitable candidates for employment opportunities that appear at present to be restricted to engineering graduates. That in turn would clarify the fact that physics graduates are indeed employable, thereby breaking down one of the major obstacles that turns away young people from the study of physics. The personnel offices of industrial and engineering firms need to be alerted to the value and versatility of physicists.

The building of bridges to industry can begin, in the case of academics, through taking up closer links with engineering colleagues in many and various ways. There is in general a lack of research collaboration with engineers. Further, it is a concern that the amount of physics that is being taught to engineering students is being cut back step by step, in an era in which engineering is becoming more high-tech. That matter should possibly be taken up at an institutional level, between SAIP and the Engineering Council of South Africa (ECSA).

A second important link into industry could be provided by physics graduates now working in industry. It is imperative that the physics community access this "diaspora". A possible route would be for departments to gather information about the graduates of yesteryear, and for SAIP to coordinate the exercise. A number of physicists in industry responded positively to the Panel's question as to whether they would assist in such a networking exercise.

Once there is an improvement in the "job situation", that fact needs to be publicized to schools, parents and others who influence study choices.

There is a link with expanded resources and responsibilities for the SAIP; see Recommendation 4.14.

RECOMMENDATION 4.13.3
With the assistance of physics departments, the SAIP should urgently build up a database of physics graduates who are not working in academic physics or research organizations, with a view to re-establishing contact with them. Such a network could form the basis for improving physics-industry linkages, and wider employability of physics graduates. In addition, it could lead to regular contact with decision-makers who influence science. [SAIP, Physics departments]

4.14 The South African Institute of Physics (SAIP)

The SAIP has to date been hamstrung by the fact that it is essentially a group of enthusiastic volunteers. In spite of this, it has made considerable contributions to the SA physics community. It is clear that the Institute can play a major role in the future of physics (and more generally, of science) in South Africa, but that to do so, it needs resources.

The Institute could play a special role in liaising with government representatives and stakeholders, policy-makers and decision-takers, contacting, in the first instance, particularly those with a science background, and alerting them to opportunities and dangers at a national strategic level.

SAIP may offer access to expert assistance when required by government, in conjunction with other base sciences. Such a request for advice might come from, for example, the Parliamentary committee on Science and Technology.

It would be desirable if the SAIP were to establish an interface to schoolteachers of physics, so as to be able to provide support to them where appropriate.

A database of physics career opportunities on the SAIP website would be a valuable aid to students planning their future. At the same time, it could turn out be an important marketing tool for physics.

To accommodate physics graduates now with the Science Councils or industry, it would be valuable if the SAIP electronic newsletter had a section devoted to "the industrial physicist".

RECOMMENDATION 4.14
It is recommended that funding be made available (from DST) for a restricted period (say 5 years, renewable) to enable an office with a full-time secretariat of a small number of "employees" to be formed. They would be responsible for implementing the programme of the Council of the SAIP, which would include serving physics and physicists nationwide. Special emphasis would be placed on:

- developing a national strategy for physics;
- increasing public awareness;
- interfacing with government departments on science issues;
- interfacing with and improving the lot of physics teachers, particularly in schools;
- forging stronger links between universities, national facilities, science councils, industry and commerce;
- ensuring a greater acceptability of a physics training for posts in industry and commerce;
- improving students' access to information on both bursary sources and employers;
- making sure that both the joys of physics and the availability of jobs are known in schools and elsewhere; and
- monitoring the implementation of reviews such as this and reporting back to the community.[DST, NRF]

4.15 Financial Incentives

This study has identified the lack of financial incentive to develop the S&T base through several key remuneration systems. We list below some of the most important such comments (the recommendation number is provided in brackets where applicable).

The student pipeline requires attention in the following areas:

- bursary-loan scheme for science teachers (4.1.2)
- differential salaries for teachers of scarce skills such as physics (4.1.2)
- school laboratory assistants and their salaries (4.1.3)
- bursary-loan scheme directed at free education for physics students (4.2.6).

Section 3.3.3 has offered some data on salary expectations for physicists. The attractiveness of academic careers is severely limited by

- university salaries.

Smaller but significant interventions that have been identified are

- the removal of the limit of 5 years from PhD for re-entrance for Women in Research (4.2.8)
- better post-doctoral funding (4.2.9)

Salary differentials between scientists and others, for example engineers, are subject to market forces. Section 3.4.3 has shown that there are highly-placed, and presumably well-rewarded, physicists in South Africa.

Although we note that many financial incentives have been incorporated in other recommendations, we nonetheless provide a single overall recommendation on financial incentives.

RECOMMENDATION 4.15 (note also 4.1.2, 4.1.3, 4.2.6, 4.2.8 and 4.2.9)
There is considerable concern in the science community about the low level of remuneration in academe, school-teaching and student bursaries. In particular, we propose a revised bursary scheme with the intention of minimising the financial barrier for students to enter physics and to stay in physics, especially in comparison with competing career paths. The proposed bursary scheme is ideally based on the concept of free tertiary education for science students. We recognise the competing claims on national resources, but an upward revision of salaries and bursaries is essential. A serious "brain-drain" will result if salaries are kept low. [SAIP, NRF, Department of Education, Universities]

4.16 Epilogue

4.16.1 The Extent to which the Purpose and Scope of the Review/Foresight have been Covered

As pointed out in Chapter 1, the Terms of Reference included both a Review aspect (the "state of physics in South Africa") and a Foresight aspect ("formulate a strategy to revitalize physics in South Africa"). The first topic has been covered in scant detail, due to the limited duration (less than 2 weeks) of the process, which did not allow for a complete review.

However, the Panel is convinced that the study of the "state of physics in South Africa" was sufficient to enable the Panel to "formulate a strategy to revitalize physics in South Africa". This strategy is, we believe, firmly based, although "peripheral areas" (e.g. "Defence-physics", Meteorology, Physical Oceanography, etc.) have not been covered in detail.

Thus we believe that we have covered the purpose of the process envisioned.

We regard the recommendations as robust.

Although not itemized in the five topics given in the Terms of Reference (funding regimes, research capacity, human resources, consolidating existing reviews, and proposing strategies), all these topics have been included in the Report, and we are thus confident that we have covered the scope of the Review/Foresight process, as desired by the Management and Policy Committee.

4.16.2 Relevance of our Report to other fields of Science: the role of the Academy of Science of South Africa

It is obvious that physics cannot be taken in isolation and that a number of the analyses and proposals that we have presented impinge on other sciences. We are thus very mindful of the need to inform those working in other areas of science.

We propose that a way forward would be to send this Report to the Academy of Science of South Africa, whose mandate includes the health of science in general, and ask it to both help with the monitoring process and use it to improve the health of the other areas of science. This we hereby do.

RECOMMENDATION 4.16.2
We recommend that the Management and Policy Committee should forward this Report to the Academy of Science of South Africa for its consideration and possible action in the broader context of science in South Africa. [MPC]

4.16.3 Monitoring the Implementation of the Proposals

It is important that the principals who instituted and guided this Review/Foresight process should continue to interact with each other on these proposals over the next year.

RECOMMENDATION 4.16.3
We recommend that the Management and Policy Committee should remain in existence as a monitoring body, and that the SAIP, DST and NRF should report back to it in a year from now. The MPC should inform the community on the extent to which the Panel's recommendations have been implemented. [MPC]

5. RECOMMENDATIONS

Here we list all the recommendations in detail.
They are numbered according to the section in Chapter 4 in which they appear. The abbreviation (Exec *) designates recommendations that appear in the Executive Summary.
Partial duplication arises from the presentation of abbreviated and combined recommendations in the Executive Summary.
It is expected that action should be initiated by the bodies listed in brackets at the end of each recommendation.

RECOMMENDATION 4.1.1 (Exec 1)
In many countries, elementary and secondary school teaching of mathematics and science is a considerable worry. In South Africa this situation is exacerbated in the historically black schools. Although beyond the scope of this inquiry, we must flag this very serious situation. We acknowledge that steps are being taken to address this matter, but urge the relevant authorities to pursue it with even more vigour, as it is a crisis situation. Individuals in the physics community are to be commended for their activity in this regard, but more involvement is needed, particularly at the structural level. [SAIP, NRF, Department of Education]

RECOMMENDATION 4.1.2
(a) The state should introduce a bursary-loan scheme for students training as teachers of "scarce skills" such as physics. Students awarded a bursary to study towards a B.Sc. majoring in physics would be required to serve society by teaching for an equivalent number of years, failing which the bursary would be transformed into a loan.
(b)Differential salaries should be introduced, with science teachers being paid a premium over and above salaries paid to teachers involved in subjects that are not designated as "scarce skills". [Such teachers would need to prove their subject proficiency through some means of objective assessment.] [Department of Education]

RECOMMENDATION 4.1.3
(a)The Panel recommends that the state should provide earmarked funds for the establishment of laboratories at all secondary schools teaching science, and ensure that the laboratories are adequately equipped and maintained to enable proper teaching of physics to take place.
(b) The state should establish a suitable number of posts of laboratory technician/assistant to provide the necessary support structure for the physics teachers.
(c) Finally, the state should, in consultation with the Physics community and Higher Education Institutions, ensure that a suitable training programme is set up for the optimal training of school laboratory technicians/assistants in different parts of the country. [Department of Education, SAIP, HEI sector]

RECOMMENDATION 4.1.4
The Panel recommends that the physics community (led by the SAIP) should seriously take up the challenge of preparing South African schoolchildren for participation in the International Physics Olympiad. [SAIP, Physics community]

RECOMMENDATION 4.2.1

The Panel recommends that the Department of Education and the SAIP should conduct an audit of academic support programmes in "unplugging the Physics pipeline", and on the basis of their success, the state should allocate targeted funding to HEI's for appropriate academic support programme to develop the necessary Physics base for the country. [Department of Education, SAIP]

RECOMMENDATION 4.2.2

We recommend that special effort be expended from the first physics lecture to expose students to applications, SA research opportunities and the role of physics in society. Examples from astronomy to illustrate physical principles are welcomed by students. We noted that where students had been encouraged to attend conferences as undergraduates, contentment was relatively high. We recommend further that where they are missing, community projects, vacation jobs and internships be instituted to provide a better link between study and the possible workplace. [University community]

Medical physics students should be exposed to the practice environment from their first year. [Medical physics community]

RECOMMENDATION 4.2.3

We recommend that departments ensure that they, and through them their students, are kept well-informed about funding possibilities for students; that where possible they take steps to be of assistance to students in financial or other need; and that they ensure that their research supervision is of the highest possible standard, particularly in such situations where the student is not operating within the department, but is, say, at a research institution. [University community, Research institutions]

RECOMMENDATION 4.2.4

We recommend that, if they have not already done so, departments consult the references listed, undertake some soul-searching, and consider what they can do to ensure good staff-student relationships.[University community]

RECOMMENDATION 4.2.5

We recommend that students take the initiative in solving their problems, in conjunction with the department; further, that students be encouraged to form student physics societies on their respective campuses, and that the SAIP play a facilitatory and supportive role in this regard.[Physics students, university community, SAIP]

RECOMMENDATION 4.2.6

We recommend

(i) free education for all physics major students, and

(ii) the replacement of race discrimination in bursaries by means tests.

Realising that strong measures such as these may not be immediately implementable, but without abandoning the rigorous position, we suggest as interim measures

(a) providing tuition and accommodation loans for all 3rd year students in Physics, which are transformed into bursaries for those completing their degrees in the minimum period (three years),

(b) providing tuition and accommodation bursaries for all Honours students in Physics, including Medical Physics students, and

(c) that the bursaries should entail an agreement to remain in SA for a specified time, negotiable if a substantial opportunity opens for the student in another country.[NRF, Department of Education, Department of Trade & Industries]

RECOMMENDATION 4.2.7 (Exec 2)
The long-term sustainable future of physics in SA depends on the country's commitment and investment in the development of a workforce that is representative of its demographic diversity. Evidence indicates that, while there is a rapidly growing cadre of physics students from previously under-represented groups, there are perceived difficulties that need to be addressed by the established physics community and by the funding authorities. Apart from financial barriers to both undergraduate and postgraduate study (addressed above), there are other matters of concern, such as that relating to the integration of students of different cultures into existing departments, particularly in regard to the transfer of students from HBU's to HWU's. These questions need to be addressed urgently, and interpersonal communication is of the essence. [University community].

RECOMMENDATION 4.2.8
(a) Prejudice in all forms needs to be overcome. Opportunities to promote and encourage underrepresented groups, including women, should be given special attention.
(b) Departments should ensure that women students are aware of the special opportunities available to them through the NRF and other bodies.
(c) All students need to be aware of applications of physics and the career options available, and this may be even more critical for women.
(d) Where NRF rules make it difficult for women to advance, attention should be given to changing them. Specifically, the bar to re-entrants further than 5 years from their PhD should be removed. [University community, NRF, employers]

RECOMMENDATION 4.2.9
We recommend that a much more vigorous policy of providing postdoctoral fellowships be pursued, and that special funds be made available for outstanding young scientists to develop new lines of research (existing funding for P-rated scientists does not provide adequately for equipment infrastructure). [NRF]

RECOMMENDATION 4.3.2
The Panel recommends that research groups take positive action to develop collaborative research, across institutions and disciplines, and particularly with industry, in order to strengthen the research endeavour in South Africa, and to benefit from the resultant advantages. [University community]

RECOMMENDATION 4.4 (Exec 6)
We recommend the creation of a fast, inexpensive, broadband National Research Information Network to support non-commercial research. This is vital not only for the National Research Digital Library suggested below, but in order to permit the maximum exploitation by South African scientists of data provided by national investments similar in scope to the proposed Square Kilometer Array. Projects of this type are likely to be the trend of the future and the lack of a system like the NRIN will mean that the dissemination of high value knowledge skills will, at a minimum, be severely constricted. [NRF, DST]

RECOMMENDATION 4.5 (Exec 7)
We recommend the creation of a National Research Digital Library Resource. Such a structure would provide subscription to electronic journals that will be accessible over the internet, and hence available to all universities (both staff and students), and selected non-commercial researchers. If the physics programmes of this nation are to be competitive, this is a vital need. It is clear that such a resource will have a

transformational nature also, since even remotely located Universities will also be able to access the latest research findings, with the caveat of the necessity of ready internet access. [NRF, DST]

RECOMMENDATION 4.5.1

The Panel recommends that the physics community, through the SAIP, should investigate the SARIS project, and, if appropriate, align itself with and be supportive of it, in its attempt to develop a Research Information system in South Africa that is appropriate to the needs of the new millennium. Furthermore, the Panel calls upon the Physics community to keep on the lookout for other such developments (e.g. for an improved digital network), as appropriate, and to act coherently as a community in support thereof. [SAIP]

RECOMMENDATION 4.6.1 (Exec 11)

There is considerable concern about the state of the research infrastructure. According to the data received, much of the equipment in university departments is out of date or inadequate. The panel recommends that SA makes a rational investment in modernizing its research infrastructure to meet the scientific requirements as well as with the objective of training the future generation of young scientists and engineers with globally competitive skills. The panel recommends that appropriate mechanisms for funding and optimal utilization of existing resources be put in place at all levels of the scientific needs. [NRF, DST, Department of Education]

RECOMMENDATION 4.6.2

The panel recommends that "government laboratories" enhance their user base through aggressive outreach effort to universities and other outside users in order to ensure full utilization of their unique capabilities. A more user-friendly facilitatory governance needs to be pursued. An increase in mobility grant and regular research grants are needed for this purpose. [NRF, Science Councils, National Facilities]

RECOMMENDATION 4.6.3

The panel strongly recommends an increase in the nation’s investment in university research infrastructure through upgrade and acquisition of major research instrumentation, as well as through support for instrument development. In order for SA's researchers to remain competitive and vibrant it is crucial to have a modern infrastructure that meets the demands of modern science and technology. Modern equipment at the universities is crucial for training purposes. Lack of training in the utilization of modern equipment will severely hurt South Africa’s future generations. [NRF, DST]

RECOMMENDATION 4.6.4

The panel recommends an increase in the individual research grant to allow for the acquisition of these small but critical tools for research, and education and training, and that significant funds be provided for maintaining and upgrading of existing equipment.[NRF]

RECOMMENDATION 4.7 (Exec 8)

The Panel noted with pleasure the overall level of research and the existence of some excellent projects, although relatively few in number. Particularly impressive is the attitude of researchers towards the new "flagship projects" - projects that we applaud. We recommend that these projects be seen both to act as a focus for much of the scientific work in their respective areas, and to provide links to apparently unrelated branches of physics. [SAIP, DST, Physics community]

RECOMMENDATION 4.7.2
The panel recommends that SA's physicists plan and prioritize their needs for a future large instrument. We recommend that funding agencies provide the necessary seed money to carry out these studies and to build up the user community in critical areas, such as, for instance, the South African Synchrotron Initiative. [Physics community, SAIP, NRF]

RECOMMENDATION 4.8.1
In order to optimize the utilization of the limited resources available, the panel recommends considering various mechanisms for sharing equipment. One possibility is the creation of a distributed network of National User Facilities (NUF's). [NRF]

RECOMMENDATION 4.8.2 (note also 4.7.2, 4.8.1) (Exec 9)
The onus is on the physics community to develop a long-term strategy for the subject, which addresses national developmental priorities as well as keeping the research internationally competitive. Such a strategy should, inter alia, aim at optimising both access to and the efficient use of, expensive equipment, and to facilitate the use of existing expertise by encouraging collaboration, thereby reducing the barrier to innovation. This may lead to the establishment of a limited number of other "flagship" projects and/or National User Facilities (NUF's) on a scale more comprehensive than hitherto, and with an emphasis on facilitatory governance. Proposals for such projects should ensure a balance between funds for equipment, including its periodic updating, and those of staffing and maintenance. The concept of a NUF is decribed in more detail in Chapter 4 and Appendix 4 of the Report. [NRF]

RECOMMENDATION 4.9 (Exec 10)
Preoccupation with flagship projects and National User Facilities should not lead to the neglect of other areas of research. International experience has shown that "small science" has not only been a major training ground, and the forerunner, scientifically, of many large projects, but has also been a major vehicle for innovation and intellectual property development. Thus there is a need for strong support for "small science", preferably in the context of collaboration. [NRF, SAIP]

RECOMMENDATION 4.10 (Exec 13)
An important effect of physics research projects is technological spin-off. Advanced research projects not only bring immediate "rewards" to industry and commerce in the form of orders for technologically advanced equipment, but they also raise the possibility of new, previously unforeseen, developments. "Astro-technology" is an excellent example and we recommend that it be used as a prototype, and that physicists make use of the structures that encourage links to industry and innovation. [NRF, DST, SAIP]

RECOMMENDATION 4.11 (Exec 12)
The state of theoretical physics is characterised as internationally competitive in some areas, but there is fragmentation and a coherent policy is needed. We recommend the establishment of a National Theoretical Physics Facility (either real or virtual); the theoretical physics community will then be able to respond nimbly to national science policy initiatives. [NRF]

RECOMMENDATION 4.12.1
(a) Medical physics (including radiation oncology, nuclear medicine, and radiation quality assurance and quality control) should be designated as "scare skills" professions.

(b) An urgent training programme to provide an adequate number of registered graduates, particularly to public service, is required. Funding is a major factor in this programme. Increased funding from the sources involved is required to provide staff and student numbers, but consolidated and well-coordinated use of the funds is an important factor.
(c) Funding from the NRF or MRC should be provided to Medical Physics Departments, particularly in order to resolve the problems of funding for Honours students, transformation, the development of research and the development of young staff members.[DTI, Department of Health, Provincial governments, NRF, MRC, SAIP]

RECOMMENDATION 4.12.2
The panel recommends that South African physicists consider establishing closer links and collaborative research endeavours with biophysics, geophysics, medical physics, bio-informatics, engineering, etc. and similar physics-related disciplines.[Physics community]

RECOMMENDATION 4.13.1 (Exec 4)
The "Public Understanding of Science" is increasingly important, not least for a democratic nation where the wide appreciation of science is vital. Much is being done but we recommend more, particularly as "the public" consists of many constituencies, all of which are important. [SAIP, Physics community]

RECOMMENDATION 4.13.2 (Exec 3)
Job prospects in Physics are perceived by many young people to be poor, and this affects the take-up of the subject in schools and universities, but this is illusory. Both industry and business welcome them, for both technical and managerial careers, but this is not made apparent. The fault appears to lie on both sides, employers not making it clear that physicists are welcome to apply for their vacancies, and physicists not being sufficiently proactive. We recommend that SAIP mount a "connectivity-campaign". [SAIP]

RECOMMENDATION 4.13.3
With the assistance of physics departments, the SAIP should urgently build up a database of physics graduates who are not working in academic physics or research organizations, with a view to re-establishing contact with them. Such a network could form the basis for improving physics-industry linkages, and wider employability of physics graduates. In addition, it could lead to regular contact with decision-makers who influence science. [SAIP, Physics departments]

RECOMMENDATION 4.14
It is recommended that funding be made available (from DST) for a restricted period (say 5 years, renewable) to enable an office with a full-time secretariat of a small number of "employees" to be formed. They would be responsible for implementing the programme of the Council of the SAIP, which would include serving physics and physicists nationwide. Special emphasis would be placed on:

- developing a national strategy for physics;
- increasing public awareness;
- interfacing with government departments on science issues;
- interfacing with and improving the lot of physics teachers, particularly in schools;
- forging stronger links between universities, national facilities, science councils, industry and commerce;

- ensuring a greater acceptability of a physics training for posts in industry and commerce;
- improving students' access to information on both bursary sources and employers;
- making sure that both the joys of physics and the availability of jobs are known in schools and elsewhere; and
- monitoring the implementation of reviews such as this and reporting back to the community.[SAIP, DST, NRF]

RECOMMENDATION 4.15 (note also 4.1.2, 4.1.3, 4.2.6, 4.2.8 and 4.2.9) (Exec 5)
There is considerable concern in the science community about the low level of remuneration in academe, school-teaching and student bursaries. In particular, we propose a revised bursary scheme with the intention of minimising the financial barrier for students to enter physics and to stay in physics, especially in comparison with competing career paths. The proposed bursary scheme is ideally based on the concept of free tertiary education for science students. We recognise the competing claims on national resources but an upward revision of salaries and bursaries is essential. A serious "brain-drain" will result if salaries are kept low. [SAIP, NRF, Department of Education, Universities]

RECOMMENDATION 4.16.2
We recommend that the Management and Policy Committee should forward this Report to the Academy of Science of South Africa for its consideration and possible action in the broader context of science in South Africa.[MPC]

RECOMMENDATION 4.16.3 (Exec 14)
We recommend that the Management and Policy Committee should remain in existence as a monitoring body, and that the SAIP, DST and NRF should report back to it in a year from now. The MPC should inform the community on the extent to which the Panel's recommendations have been implemented. [MPC]

APPENDIX 1

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APPENDIX 2

Glossary of Abbreviations

AEC	Atomic Energy Corporation
AFM	Atomic Force Microscope
APS	American Physical Society
A&VS	Animal and Veterinary Sciences
CAT	Computerized Axial Tomography
CEO	Chief Executive Officer
CERN	European Nuclear Research Centre
CM	Condensed matter
CoE	Centre of Excellence
CSIR	Council for Scientific and Industrial Research
CT	Computerized Tomography
DACST	Department of Arts, Culture, Science and Technology
DNA	Deoxyribonucleic Acid
DST	Department of Science and Technology
ECSA	Engineering Council of South Africa
EM	Electron Microscope
FET	Further Education and Training
GDP	Gross Domestic Product
GPS	Geographic Positioning System
HartRAO	Hartebeesthoek Radio Astronomy Observatory
HBU	Historically Black University
HDI	Human Development Index
HEI	Higher Education Institution
HEQC	Higher Education Quality Committee
HESS	High Energy Stereoscopic System
HIV	Human Immunodeficiency Virus
HMO	Hermanus Magnetic Observatory
HSRC	Human Sciences Research Council
HWU	Historically White University
IAEA	International Atomic Energy Agency
IoP	Institute of Physics
IphO	International Physics Olympiad
IPPS	International Programme in the Physical Sciences
ISKOR	Iron and Steel Corporation
ITER	International Tokamak Experimental Reactor
iThemba LABS	iThemba Laboratory for Accelerator-Based Sciences
ITP	Institute of Theoretical Physics
IUPAP	International Union of Pure & Applied Physics
KITP	Kavli Institute of Theoretical Physics
LAN	(Computer) Local Area Network
LC	Linear Collider
LIDAR	Light Radar

MPC	Management and Policy Committee
MRC	Medical Research Council
MRI	Magnetic Resonance Imaging
M.S.	Master of Science
NASSP	National Astrophysics and Space Science Programme
NECSA	Nuclear Energy Corporation of South Africa
NEPAD	New Partnership for Africa's Development
NIH	National Institutes for Health
NML	National Metrology Laboratory
NMR	Nuclear Magnetic Resonance
NLC	National Laser Centre
NNR	National Nuclear Regulator
NRF	National Research Foundation
NUF	National User Facility
OBE	Outcomes Based Education
OPO	Optical Parametric Oscillator
PAPhO	Pan-African Physics Olympiad
PBI	Physics-Based Industry
PBMR	Pebble Bed Modular Reactor
PUSET	Public Understanding of Science, Engineering and Technology
RAU	Rand Afrikaans University
R&D	Research and Development
R…k	multiples of R1 000
R…m	multiple of R 1 000 000
SA	South Africa
SAAO	South African Astronomical Observatory
SADC	Southern African Development Community
SAIP	South African Institute of Physics
SALT	Southern African Large Telescope
SARIS	South African Research Information Service
SASI	South African Synchrotron Initiative
SEM	Scanning Electron Microscope
SKA	Square Kilometre Array
SPIN-UP	Strategic Programs for Innovations in Undergraduate Physics
SRC	Schonland Research Centre
STM	Scanning Tunnelling Microscope
S&T	Science and Technology
TAI	Technology Achievement Index
TC	Technical Committee
TEM	Transmission Electron Microscope
THRIP	Tertiary-level Human Resources in Industry Programme
T-LABS	iThemba LABS
UCT	University of Cape Town
UK	United Kingdom
USA (US)	United States of America
UWC	University of the Western Cape

WHO	World Health Organisation
XRD	X-Ray Diffractometer

APPENDIX 3

List of People Interviewed by the Panel

Although a serious attempt was made to keep a record of all the people who were interviewed, the list below is unfortunately incomplete.
We apologise sincerely for any errors or omissions in this list.

Management and Policy Committee
Dr N Chetty
Prof FJW Hahne
Prof MG Lotter
Dr PA Nevhutalu
Mr MJ Pasha
Dr J Sigalas
Mr P Tshelane
Dr ZZ Vilakazi
Prof EC Zingu (Chair)

NRF Executive Management
Dr AM Kaniki
Dr TS Marcus
Dr KDK Mokhele (President)
Dr PA Nevhutalu
Dr NSR Skeef
Dr G von Gruenewaldt
Dr PA Whitelock

Council of the South African Institute of Physics
Dr SH Connell
Dr N Chetty
Prof DJ Grayson
Prof WD Heiss
Prof H Moraal
Dr PA Whitelock
Prof EC Zingu

Technical Committee
Ms L Kleingbiel
Mr N Masindi
Ms A Radel
Ms GU Schirge

Department of Science and Technology
Dr R Adam (Director-General)

Department of Education
Dr N Badsha (Deputy Director-General, Tertiary Education)
Dr L Lange (HEQC)

Department of Trade and Industry
Dr J Potgieter
Mr A Tau

South African University Vice–Chancellors and Deputy Vice-chancellors
Prof CWI Pistorius (Vice-Chancellor, U Pretoria)

Prof RM Crewe (Deputy Vice-Chancellor, U Pretoria)
Prof F van Niekerk (Deputy Vice-Chancellor, North-West University)

Deans of Science of Universities and Technikons
Prof C Wright (Dean, U Witwatersrand)
Prof A Stroh (Dean, U Pretoria)
Prof PJJG Marais (Dean Tshwane University of Technology)
Mr J Moraki (Physics, Tshwane University of Technology)

SABS
Dr R Carolissen (Group MD, SABS Holdings)

MINTEK
Dr FW Petersen

Private Sector
Dr AP Botha
Dr HJ Strydom
Dr LR Botha

Council for Scientific and Industrial Research
Dr S Sibisi (President and CEO)

National Metrology Laboratory
Ms ZLM Msimang
Dr F Hengstberger

National Laser Centre
Dr P Mjwara

University of the North
Prof NM Mokgalong (Vice-Chancellor)
Prof NM Mollel (Dean)
Prof P Ngoepe
Prof G Djolov
Dr KE Rammutla
Mr FM Phala
Dr HR Chauke
Mr MJ Phasha
Ms R Maphanga
Ms MM Mokagane

University of Venda
Dr I Matamba

NECSA
Mr LDS Thobejane (CEO)
Dr WvZ de Villiers
A Joel
Dr CB Franklyn
Dr G Nothnagel

National Nuclear Regulator
Adv LB Zondo (CEO)
Dr A Tsela
Dr D Kgwadi

ISCOR

Dr L Strydom

Kentron
Dr G Viljoen

University of Pretoria
Prof FD Auret
Prof JB Malherbe
Prof AR Plastino
Mr R Andrew
Mr WE Meyer
Mr RQ Odendaal
Mr M Diale

University of South Africa
Prof DJ Grayson
Prof M Braun
Mr GJ Rampho

University of Zululand
Prof AT Davidson

University of KwaZulu-Natal
Prof C Graham
Prof TB Doyle

Medical University of South Africa
Prof DM Mafokwane
Mr ME Sithole
Dr V Nolting
Mr M Lucky
Ms R Mhlongo
Ms Mseshabela
Mr C Adams
Mr L Mosibi

University of the Free State
Prof HD van Schalkwyk (Dean)
Prof GN van Wyk (Director, Entrepeneurial and Academic Projects)
Prof HC Swart
Prof WD Roos
Dr MJA Hoffman
Dr PJ Meintjies
Dr JJ Terblans
Dr RE Kroon
Mr M Ntwaeaborwa
Mr J Asante
Mr E Wurth
Mr B Dejene
Mr OM Ntwaeaborwa
Mr JKO Asante
Ms I Claassens
Mr H Joubert
Mr MS Dhlamini
Mr GJ Olivier
Ms Ramoshebi
Mr S Cronje
Mr RA Harris

Ms L Coetsee
Ms S Niewoudt
Ms R Conradie
Mr H Calitz

Medical Physics
Prof G van Zyl
Prof CA Willemse
Prof CP Herbst
Prof MG Lotter
DR FCP du Plessis
Dr H du Raan
Ms S Acho
Mr S Makgere
Mr J van Staden
DR FCP du Plessis
Dr H du Raan
Ms S Acho
Mr S Makgere
Mr J van Staden

University of Port Elizabeth
Prof JAA Engelbrecht
Prof J Neethling
Prof A Leitch

Mr NG Hashe
Mr N Kaschula
Mr A Gxasheka
Mr G James

Port Elizabeth Technikon
Prof DW Sharwood (Dean, Applied Sciences)
Mr M Ackermann
Mr R Mulder
Dr OJ Lombard
Dr FJ Vorster
Mr CD Riddin
Dr D Hattingh
Ms A Els-Botes
Dr T van Niekerk (Dean, Engineering)

Rhodes University
Prof J Jonas
Dr P Nathanson
Ms K McAlpine
Ms L Richter

CSIR Centre for Fibres, Textiles and Clothing
Prof L Hunter
Dr A Douglas
Ms T Joubert
Mr AF Botha

Private Sector
Mr PE Viljoen

SAAO

Dr D O'Donoghue
Prof J Jonas (HartRAO & Rhodes University)
Prof OC De Jager (North-West University)
Dr P Sutcliffe (Hermanus Magnetic Observatory)
Dr P Martinez
Dr L Balona
Prof P Dunsby (UCT - NASSP)
Prof T Fairall (UCT)
Prof M Feast (UCT)
Dr C Nxomani
Dr K van der Heyde
Mr C Rijsdijk
PLUS approximately 8-10 NASSP students

University of the Western Cape
Prof J van Bever Donker (Dean)
Prof R Lindsay
Dr R Madjoe
Dr T Marais
Prof D Knoesen
Dr B Julies
Prof RJ de Meijer
Dr D Pugh
Dr D Marshall
Dr TK Marais
Prof D Marshall
Dr MR Nchodu
Dr S Wyngaardt
Mr W Damon
Ms S Johnson
Mr T Muller
Ms S Halindintwali
Mr R Maclons

University of Stellenbosch
Dr EG Rohwer
Prof AA Cowley
Prof FG Scholtz
Prof WD ös
Prof K Muller-Nedebock
Dr GJ Arendse
Dr GC Hillhouse
Prof B van der Ventel
Prof FWJ Hahne (Director, AIMS)
Mr I Snyman
Dr CM Steinmann
Mr NM Jacobs

University of Cape Town
Prof D Reddy (Dean)
Prof J Cleymans
Prof RD Viollier
Dr SS Vilakazi

iThemba Labs
Prof J Scharpey-Schafer
Dr SM Mullins
Dr PJ Celliers

JL Conradie
Dr C Theron
TP Ntsoane
SP Segonjane
S Murray
Dr R Bark
Dr S Förtsch
J Ncapayi
Z Buthelezi
GF Steyn
E Vermeulen
J Guambe
Dr J Lawrie
M Eisa
Dr RT Newman

Rand Afrikaans University
Prof V Alberts
Prof H Alberts
Dr CA Engelbrecht
Mr F Dhlamini
Ms K Tolessa
Mr CJ Sheppard
Ms HA Derrett

University of the Witwatersrand
Prof BJ Cole
Prof P Du Plessis
Prof JD Comins
Prof FRN Nabarro
Dr M Mujaji
Dr S Connell
Prof J Rodriques
Ms R Gwyn
Mr R Erasmus
Mr K Tjebane

North-West University
Prof H Moraal
Mr J Minnie

Private Sector
Dr K Kemm
Dr B Fanaroff (Also Project Manager, SKA Bid)

Element Six
Dr J Sigalas
Dr FA Koch

Eskom
Dr J Gosling
Mr D Nichols

The Innovation Hub
Dr N Comins

APPENDIX 4

National User Facilities (NUF's)

4.8.2 What is a NUF, and how does it work?

A NUF is a location, real or virtual, with a thematically chosen set of tools/instruments that can be used by any South African researcher, academic or industrial.

- The NUF's will be networked, and will have a central accessible database/website to serve as a point of access for all potential users.
- On the basis of an independently-reviewed successful proposal, time is allocated on the instruments/tools at the Facility.
- In order to reduce barriers for research, a successful proposal will additionally include funding for both travel and consumables.
- The equipment at the facility will be supported by technical staff of the NUF, whose responsibility it will be to guarantee that the required instrumentation is functioning, and to assist users in its use - this user support is a key element of a NUF.
- The choices of new equipment and upgrades will be made by the user organization/governing body, and not by a centralized governmental authority. For example, as instruments get over-subscribed, additional items will be purchased.
- There will be NUF's with different themes located where necessary, and to take advantage of local resources/environments. Certain themes may occur in more than one geographical location. However, the expense of certain instruments is such that it may well be that only one of that item may exist in the country.
- NUF's may be located anywhere: in or near an academic institution, in National Laboratories or Science Councils, or in a completely stand-alone setting, as the particular theme or geographical needs require.
- NUF's need not be as big or as costly as the existing National Facilities
- The NUF's will run frequent training sessions/summer schools for the scientific community, and with current and emerging scientific topics. Periodic user meetings of the facilities will enable the sharing of ideas and the improvement of the performance overall. Leading international scientists can be invited occasionally.
- Competitive research activity of the NUF staff is necessary in order to keep in touch with the state of the art.
- The NUF's will be regularly reviewed by NRF.

4.8.3 What are the advantages of NUF's in general and in particular for SA?

The advantages for SA are numerous and we list a few key advantages.

- The primary advantage is the ability to deliver world-class tools/instrumentation in a cost effective manner.
- Counter-intuitively, science is a social enterprise, and there are important social features and advantages of NUF's. They allow scientists and students from many geographically disparate universities to interact. Additionally, the interaction with industrial users will enable students to see practical applications of their skills, and will provide industry with a ready source of trained students.
- NUF's will encourage multi-disciplinary science. Many pieces of equipment can be used by very different branches of the sciences, and the sharing reduces duplication and saves money. For example, X-ray diffractometers can be useful to physicists, biologists, chemists, geologists and materials scientists.

- There are long-standing variations between the quality of the infrastructure at different universities. Levelling these differences can be a long, expensive and complicated undertaking, and will require much more than simply purchasing instruments. For the greater benefit of the country, we must provide an alternative for the talented and motivated science students present at those disadvantaged institutions; we cannot wait for the institutions to act. The NUF can play a transformational role by levelling the field for research equipment for the different universities.
- In all countries, and in SA, the quality of student mentoring is uneven. The NUF's provide an alternative to bad mentoring and guidance by providing interactions with other students, staff, and industrial users, and hence change potentially career-ending situations into opportunity. This is in fact quite often how very successful research groups in the US actually operate. The actual skills and knowledge are passed from student to student, often with little or no supervision from the professor. The SA problem here is that there are too few graduate students, and hence too few groups big enough to allow an effective student-to-student transfer of knowledge. To restate: the NUF's provide an alternative to uneven mentoring and small groups, and the student becomes part of the support structure of a "super group". Note that this does not replace the responsibility of proper supervision by the faculty, and adequate level of mobility grants would be required to allow maintaining effective supervision. Enhanced connectivity is also an important element.
- Students should be required to go to the NUF's early in their research studies.
- SA has a particular problem in lack of awareness of the existence of resources, and efforts should make all students aware of facilities available, and this should occur preferably in the undergraduate programmes, and certainly early in the graduate programmes. NUF's should be able to allocate resources to structure internships/temporary employment programmes geared at utilizing and exposing students to the facilities.

4.8.4 Governance of the NUF

Governance of the NUF's is an important issue.
NUF's are at the minimum a taxpayer-funded institution and so every effort should be made to ensure that the resources are utilized to the benefit of the country. There are many existing models for user facility governance around the world, and we leave it to the stakeholders to construct a detailed plan appropriate to SA.

However we can identify some issues: transparency, accountability of the facility to the users, accountability of the users for the resources given to them, and outreach.

Additionally, while these facilities are seeded by the Government, it is by no means the only source of funding. The NUF can apply to international organizations for funding of certain equipment. Furthermore, local industries can also take advantage of the synergy and donate tools to these facilities. While cost recovery from the industrial users can be considered, we note that cost recovery may be a net loss to the country. The benefits of increased intellectual property and creativity, and the interaction of human resources will vastly outweigh the fiscal gains from cost recovery.

The funding stream should be protected such that the essential ability to support and maintain these facilities does not get diverted into other laudable goals. In particular University administrations have other pressing needs that we have observed often result in reduced support for maintenance.

The labs should be held accountable for serving all communities.

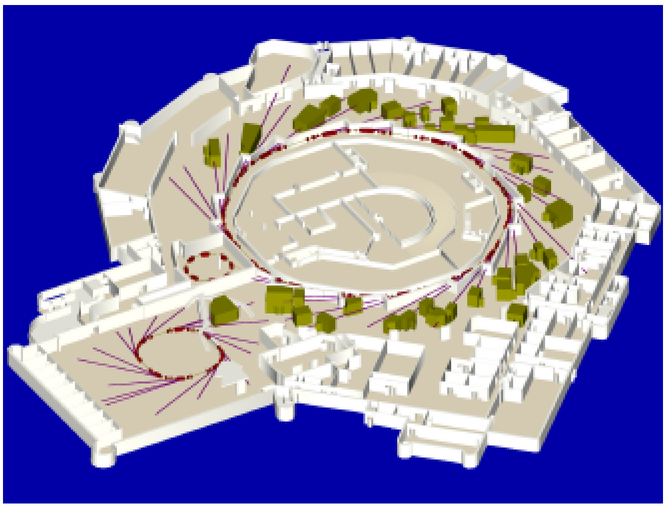
APPENDIX 5
A Synchrotron Light Source

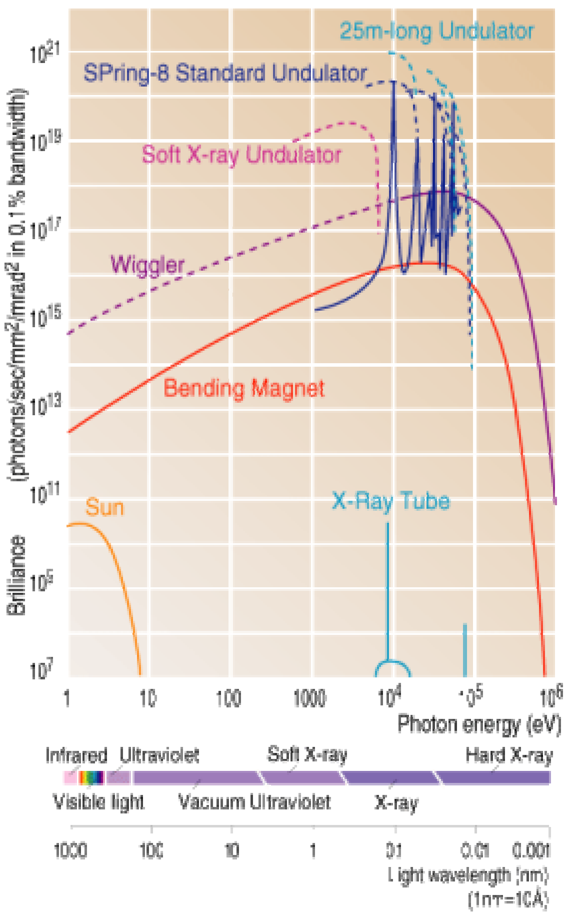
Why do we consider a synchrotron?

While we leave it to the physics community to choose the flagship projects of their choice, we feel it is worthwhile to show how a synchrotron light source satisfies our criteria for flagship projects. In particular, it was clear that there has already nucleated an interest group pushing this project, under the tentative name SASI (South African Synchrotron Initiative), and there are already South African scientists and engineers using synchrotrons in other parts of the world.

What is a synchrotron?

Briefly, using relativistically accelerated charged particles, typically electrons circulating in a ring, one can create a source of radiation with photon energies that span the range from the infra-red to the hard X-ray. Due to the broad range of energies, the brilliance of the source, and numerous other considerations and advantages, the number of synchrotron sources in the world and the number of scientists using them is increasing rapidly. Consequently, the scientific impact they have continues to grow. It is difficult to find an area of experimental science in which synchrotrons do not have an impact, from the more traditional uses in physics, chemistry, engineering and biology, to the rapidly developing applications in archaeology, environmental sciences, geology and other fields. Synchrotrons are expensive projects, and naturally fall into the category of a "Flagship" project.





Left: A cut-away view of a synchrotron showing the ring.
Right: The resulting emitted photon spectrum.

Can South Africa use such a Synchrotron effectively?

The base skills required to use such a facility already exist in South Africa. South Africa does not have a synchrotron source now, and one might incorrectly assume that the experience base, and interest to use such a facility effectively might not exist. In fact many of the basic techniques in use at synchrotron facilities are already in use in South Africa.

For example, standard X-ray crystallography of biological molecules, uses laboratory sources of fixed energies of hard X-ray photons to determine crystal structure. The method, and laboratory-based instruments already exist, and are in use in South Africa. The synchrotron can extend the capabilities of South African scientists at the minimum, by providing a more intense source than a laboratory source, allowing rapid collection of better quality data. However, by taking advantage of the broad range of energies available at a synchrotron source, one can introduce new techniques that most South African scientists cannot currently use in their existing laboratories, but are being routinely used elsewhere in the world. Furthermore, other laboratory-based tools such as infra-red microscopes, and XRF (X-ray fluorescent) laboratory tools exist in South Africa, which implies that there will be an existing user base when these techniques become available at a local synchrotron. To summarize, (a) South Africa has an existing knowledge base for many of the techniques typically used at synchrotrons, and (b) synchrotrons provide a single brilliant source of photons, which allows for the use of a variety of state of the art instruments.

Does the synchrotron satisfy the guidelines for flagship projects?

Below, we show on a point by point basis, how a synchrotron satisfies the main guidelines we suggest for flagship projects:

- **"The projects will be state-of-the-art, with the possibility of pushing back the frontiers of knowledge globally."**

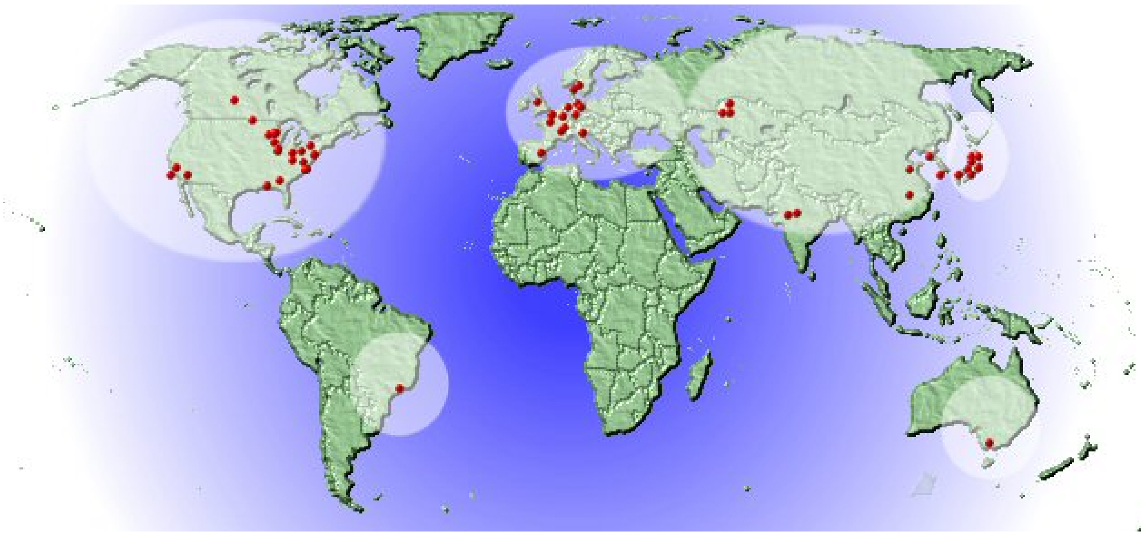
Synchrotrons are state of the art facilities, for example the most recent Nobel prize in chemistry was based on experiments performed at a synchrotron.

- **"Raises the profile of science nationally, and has the potential to develop National Pride."**

A large project such as this will raise the profile of science nationally, and South Africa's profile internationally. Furthermore, since the tool is state of the art, the potential exists for globally significant discoveries to be made at such a facility. This could be a source of National Pride. In particular, by choosing scientific problems for which South Africa has a natural advantage, one increases significantly the possibility that such an advance might happen locally. An additional point worth noting is that this would be the first synchrotron radiation user facility on the African continent, and the third in the Southern Hemisphere.

- **"Brings a focus to existing scientific enterprise, reducing the critical mass problem, both for researchers and students."**

One of the difficulties South Africa faces is the number of research activties that are below critical mass. A synchrotron would bring a focus to the scientific enterprise, and would increase interactions between various sub-critical groups across the country, and enable new areas of research.



The locations of synchrotron facilities worldwide, showing absence of a facility in Africa; Courtesy of Spring8

- **"The successful completion of such complex projects requires many different skills at levels beyond their current competency. Consequently, there is a significant spin-off effect through such disciplines as engineering, information technology and other areas of science and industry."**

The skills required to build and assemble such a project will clearly be a major boost locally, as one can deduce from previous flagship projects, like SALT.

- **"Potential for attracting international funds."**

From the example of the SESAME project, which was established in Jordan with international funding, e.g. from UNESCO, it is clear that the potential exists to obtain funding from outside South Africa.

- **"Encourages international collaboration, and in particular provides a state-of-the-art research facility to be shared with scientists and students on the African continent."**

A South African specific science case

While the general case for synchrotrons as a basic research tool can be made and have been made elsewhere, we will highlight the specific areas that will uniquely benefit South Africa, and the scientific resources and problems that are uniquely South African, and can be brought to the synchrotron. South African scientists would have a natural advantage in these areas, in a manner analogous to the role of the Southern Skies for South African astronomy.

1) Archaeology

By performing CT (computed tomography) scans of solid objects one can "see" inside rocks and artifacts in a non-destructive manner. In fact this field has not yet developed fully internationally. It seems that laboratory-based instruments are used more often, and these laboratory-based tools have poorer spatial resolution. It seems clear that higher spatial resolution studies, and compositional and structural information of South African samples could potentially yield major breakthroughs.

2) Aids research

One of the standard tools in biological research and biotechnology is crystallography. In this field the limiting step is often the choice of molecule to be studied, and the ability to crystallize the chosen molecule. There is no natural advantage for the crystallization, and consequently the South African scientists are at no disadvantage, if they have rapid access to a local synchrotron. Some crystals do not travel well, so international synchrotrons while feasible could prove difficult.

3) Mining and geology

An important part of South Africa's economy is mineral extraction. High temperature and high pressure studies of mineral systems should improve understanding of geological processes, and this improved understanding may result in improved exploitation of these natural resources.

4) Catalysis

There are existing industrial processes that use catalytic methods, and synchrotrons are well suited to this field. The structure, composition and chemical state of the catalysts can be determined by appropriate synchrotron techniques.

While this is not a complete list, we think that it is clear that there are potential scientific areas in which South African scientists, with the assistance of a local synchrotron, could have a global impact. Finally it is worth pointing out that the presence of such a facility would help to retain talented scientists in South Africa.

It is important that action be taken to build the user base in parallel with the longer-term planning and construction.

Does South Africa have the technology to build and operate such a tool?

iThemba LABS and similar accelerator facilities will have the knowledge to design and build much of such a machine, but consideration should also be given to buying one off the shelf.