

# **REVIEW REPORT**

**on**

**THE CENTRE OF EXCELLENCE IN STRONG MATERIALS**

**by**



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## 1. INTRODUCTION

The DST/NRF Centre of Excellence in Strong Materials (CoE-SM) started in June 2004 at the University of the Witwatersrand (Wits). Although the main activities take place at Wits, the Centre has six major partner institutions, namely the Universities of Johannesburg, KwaZulu-Natal, Limpopo, the Nelson Mandela Metropolitan, Mintek and NECSA and a few other minor collaborators. At Wits the Centre conducts its work mainly in four schools within two Faculties: School of Chemistry, School of Physics, School of Chemical and Metallurgical Engineering, and the School of Mechanical, Industrial and Aeronautical Engineering. There is a particularly close relationship with research groups at the University of Johannesburg and Mintek. At these two institutions there are active groups participating in the Centre programmes.

*“Strong materials” are defined to be those that retain their distinctive scientific and applied properties under extreme conditions and have established or potential commercial applications.*

Although a wide range of materials properties and materials satisfy these criteria, the Centre focuses on six areas, namely Carbon Nanotubes and Strong Composites; Ceramics; Hardmetals; New Ultrahard Materials, Strong Metallic Alloys, Diamond and Thin Hard Films and Related Materials. These Focus Areas provide research themes, which allow considerable cross-fertilisation and collaboration especially in multidisciplinary projects.

According to the original proposal the Centre had a number of objectives, which included:

- Increased research output (publications, conference contributions, etc.) by the synergistic effect of cross-disciplinary research.
- Increased local collaboration – universities, science councils and industry.
- Increased collaboration with international role players and universities
- Increased funding to attract more students into the fields.
- Human capacity building in South Africa.
- Advancement of basic research, development and industrial use of these materials in South Africa and the rest of Africa.
- Establishment of a knowledge base, characterisation and processing expertise, techniques and equipment for the production, characterisation and testing of strong materials.
- Providing information, expertise, knowledge and technology in the field of strong materials to local industry, government, other research and educational institutions as well as the broader community.

The review of the Centre of Excellence in Strong Materials should and will report on the achievements of these goals by the Centre in the first 5 years of its existence.

The Review Panel consisted of three members, H. K. D. H. Bhadeshia (Professor of Physical Metallurgy, University of Cambridge, and Director and Professor of Computational Metallurgy, Graduate Institute of Ferrous Technology, South Korea), J. E. Field (Emeritus Professor of Applied Physics, University of Cambridge) with J. B. Malherbe (Professor in Physics and HoD, University of Pretoria) acting as

chairperson. The Panel conducted their duties over three days at the University of the Witwatersrand at the end of March 2009; practically being 5 years after the inception of the Centre. Prior to review these members received extensive documentation on the Centre, the Centres of Excellence and South African science policy. During this review the Panel received oral submissions from the present and past Directors of the Centre, the Deputy-Director, Focus Area leaders or deputy-leaders, students and other stake-holders namely different levels of university management, representatives of industry, members of the CoE-SM, CoE-SM Board members and representatives of other universities and scientific councils.

The report is in five sections: the above introduction is followed by a review of the performance of the Centre of Excellence of Strong Materials over the past 5 years in terms of the key activities and services, namely research, education and training, information brokerage, networking, service rendering, and management. Secondly, the future plans of the Centre are discussed in terms of the same key activities and services as above. In the next section, recommendations are made on the DST/NRF Centre of Excellence programme. Finally, the major recommendations are listed at the end of the report.

## **2. PAST PERFORMANCE**

### **2.1 General comments**

The Panel is of the unanimous opinion that the overall performance of the Centre of Excellence of Strong Materials over the past five years has been exemplary and that the Centre has largely achieved all its goals. The Centre has also fulfilled the key activities and services recommended by DST/NRF. Any comments and criticisms are meant to be constructive.

### **2.2 Research**

A key question is whether the establishment of this Centre has led to an increase in the research output over this period, bearing in mind that several members of the Centre were already established and highly rated scientists with a corresponding high output. This question was asked of all the senior members of the Centre and discussed with them. The overwhelming response was positive. All agreed that there has been a significant increase in publications, conference contributions and patents. More importantly, the existence of the Centre has led to a stimulation of activities and collaborations, some of which did not previously exist, particularly with Universities, National Laboratories and Industry within South Africa. There is evidence that there is international recognition of the cluster of excellence associated with the Centre. This has led to collaborations with leading scientists and organisations throughout the world.

Table 1 gives the consolidated numbers of publications and patents over the past 5 years with comments by the CoE-SM. This Table is repeated here because the 5 year report and the annual reports contain unconsolidated data.

**Table 1.** Publication statistics of the CoE-SM.

<b>Publication type</b>	<b>2004*</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008**</b>
Total Publications (published, in press or accepted – 2008 only)	19	56	56	54	51
Books / Chapters in Books	1	3	5	6	3
Articles in peer reviewed journals	9	19	27	39	25
Published	21				
In press	4				
Published conference pro- ceedings (published or in press)	7	28	18	12	19
Patents etc.	2	6	6	8	4

\* Only last quarter of 2004

\*\* Jan to Jun 2008

Over the years from 2004 to 2008, 11 full patents have been filed. The figure does not add up to the total in the table as some of these were provisional patents, for which the full patent was later filed.

Note: These figures are different from those in each Annual Report. At the time of writing the reports, some publications were still in press. However, these were usually published the following year, and have therefore been included in the figures for the year in which they were published, and not submitted. Thus, in doing this, the publications were not double counted, which would be the scenario if one were to add up the publication totals in each of the reports.

Although the number of members of the CoE-SM given in the Appendix of the 5 year report is very large, viz. 47, the actual number who contributes to the publications is much less because many of the members only contribute a small percentage of their time to the Centre. Consequently, the output in publications is very good. The most positive aspect is the relatively large number of patents.

One of the aims of this Centre is to do research, which is also of benefit to industry. During the interviews, the Panel was given several examples where this aim was reached. The fact that many patents have been filed during the past five years also attests to the applicability of the research. Evidence has been given of new industrial projects. In fact, the demonstrated synergy between basic research and applied (industrial) research is one of the main positive features of this Centre.

Furthermore, at least one of the Focus Areas originated at Mintek, with the leader still being based at Mintek. This project has benefited from being part of the Centre in that it used the expertise and facilities based at Wits.

The Panel was also informed about the benefit of mentorship by senior researchers within the Centre. It has at least helped to establish the group within this programme at the University of Johannesburg, which is now a viable research group where none existed before.

The Panel was asked to specifically comment on gender relevance. To answer this question one must consider the general trend in the world on this matter and in particular disciplines. In the physical sciences and engineering there are significant differences within the context of South African academia. Chemistry and its related engineering field attract significantly more females than pure physics. Until recently no gender parity in terms of numbers had been achieved even in chemistry. Taking this international trend into account, the Centre has done relatively well. There are several females in the senior ranks of the Centre with the Director also being female. The list of graduated students from the Centre contains 15 female students out of a total of 44, i.e. 34%.

### **2.3 Education and training**

The five year review report by the Director of the Centre states that 44 students have graduated from the Centre since its inception in June 2004. This is clearly an impressive number for South African standards and represents an increase in student number graduations compared to prior to the CoE-SM. There are several reasons for this:

- The number of CoE-SM bursaries available to students.
- The fact that bursaries are available makes it possible to choose the students with the best potential.
- The good reputation of the people involved with the Centre.
- The good reputation of the University of the Witwatersrand.
- The availability of many different pieces of equipment within the Centre for the students. In many cases this allows the students to complete their research faster.
- The connection to industry is also an attractive aspect for some students.
- The structure at the University of the Witwatersrand, which allows a student to progress from a BSc to a degree in engineering, is seen as an advantage.

The interview with students pointed out a number of other positive aspects of being part of this Centre. Belonging to a relatively large cohort of students helped them in their studies because they can help each other and also create opportunities for analysis on other equipment. Students find the fact that they could travel abroad to attend international conferences and/or work in other collaborating laboratories, an extremely positive one.

Additionally, the interview identified some generic areas for improvement. The Panel discussed these with the management of the CoE-SM. These areas are of a minor nature in terms of this report and are not necessarily particular to this Centre.

The following aspects need to be investigated by DST/NRF:

- The restriction on the number of foreign students allowed bursaries. These are often very good students who inspire their South African counterparts.
- The bursary amounts should be increased to more realistic levels.

### **2.4 Information brokerage**

The Panel feels that this aspect has been satisfactorily attended to during the past five years. The CoE-SM is a multi-disciplinary programme with basic science disciplines of chemistry and physics participating with engineering sciences using strong materials. This interaction played a vital role in identifying new areas of research. The Centre undertakes dissemination of knowledge via the mechanisms of publications, conferences, seminars, workshops (presentations by students from the Centre), collaborations and some interesting outreach activities at schools. The students particularly appreciated seminars by focus group leaders and international participants, and requested more such activities.

## **2.5 Networking**

The CoE-SM has been very strong in this field. It has many networking contributions through its collaborations. A large and impressive list of international and local collaborative institutions is given in the five year report. These include extensive collaboration within South Africa with some members of CoE-SM coming even from the Cape Province.

## **2.6 Service rendering**

As with the previous section, members of the CoE-SM have provided extensive scientific service to their home institutions, other institutes, and industry. They have served on review committees, conference organising committees, Boards and Editorial Boards, they have compiled reports, refereed papers and assisted on accreditation visits. As well as being members of distinguished societies, many serve on committees in their home institutes and act as external examiners.

## **2.7 Management of the CoE-SM**

### **2.7.1 Leadership**

During the past 5 years there have been two Directors of the CoE-SM, Prof J.D. Comins and the present Director, Prof. L.A. Cornish. The Director is assisted by the CoE-SM Executive which meets monthly to discuss the running, funding and future of the CoE-SM. Most of the decisions are consensual, including those involving funding. The Focus Area Coordinator is responsible for the efficient running of his/her Focus Area. There is also a monthly meeting of the Director with the Deputy-Vice-Chancellor, Prof B Bozzoli. The Board of the CoE-SM meets bi-annually to review the past activities and to endorse major decisions. The practical running of the Centre is done by Dr T. Capecchi, the Administrative Manager, who checks the accounts and is responsible for reporting them to the DST/NRF.

The Panel is of the opinion the CoE-SM is well-managed with enough mechanisms to allow transparency and participation by all members.

Given the limitations on available space, it is clear that the purchase of major equipment should be preceded by planning for space in association with the

appropriate university officials. It is inevitable that this problem will be exacerbated as the CoE-SM grows in numbers.

### 2.7.2 Staffing

Apart from a Director, 95% of whose time is devoted to the Centre, the CoE-SM employs an Administrative Manager, a Bookkeeper and a Senior Administrative Secretary. The verbal presentations by members of the CoE-SM to the Panel indicated that the staff is necessary and that they are very professional.

A recurring theme during the interviews had been the need for the appointment of technicians to manage, repair, develop and refurbish sophisticated equipment. There is clear evidence of significant financial savings from the refurbishment of donated equipment. The Panel recommends that DST/NRF investigates the issue of technician appointments as a necessity for any research on the scale of the CoE-SM. This matter was also raised with the Deputy-Vice-Chancellor of Wits, Prof B Bozzoli – see the next section. She suggested that the matter might be resolved between Wits and DST/NRF. The Panel suggests that the management of DST/NRF meets with Prof Bozzoli to discuss the issue.

### 2.7.3 Commitment of institution hosting the CoE-SM

The Panel had a frank discussion with the Deputy-Vice-Chancellor (DVC) of Wits, Prof B Bozzoli on various matters concerning the CoE-SM, the most important being the continuation of the Centre after the 10 year period of funding by DST/NRF. The University is applying its mind to this matter. It is, however, clear that the University is totally committed for the Centre to succeed and is very proud to be hosting one of the first DST/NRF Centres of Excellence. Some of the other matters discussed with the DVC include the lack of technicians (refer to the previous section), intellectual property, space and administration problems.

### 2.7.4 Location of the CoE

The CoE-SM is ideally placed.

### 2.7.5 Funding

The Panel was satisfied on how the budget was spent (see Table 3 in the 5 year report) – a reasonable amount (25 – 30%) is spent on bursaries, and the running expenses are not excessive. The most positive aspect of the funding given to the CoE-SM has been the growth of funding by sources other than the DST/NRF CoE funding.

A major issue with regard to the budget is the financial sustainability after the 10 year funding period by DST/NRF. The vision is that the Centre should become financially independent after this period. This matter was discussed with Deputy-Vice-

Chancellor of Wits, Prof B Bozzoli, and the Panel also made some general comments on this matter.

## **2.8 Strategic positioning of the CoE and future plans**

It is obvious to the Panel that the CoE-SM is best placed at the present location and that it should not move elsewhere.

## **3. FUTURE PLANS**

### **3.1 Research**

#### **3.1.1 Focus Area on Carbon Nanotubes and Composites**

Strong materials are said in the scientific brief of the Centre to be those *that retain their distinctive scientific and applied properties under extreme conditions and have established or potential commercial applications.*

The work on carbon nanotubes and associated carbon shapes seems to lack balance with excessive emphasis on synthesis and the characterisation of physical properties, which do not seem to have particular relevance to strength. The panel has not seen evidence for applications in which the large longitudinal modulus of such tubes, or the huge strength of nanotubes has been exploited or even considered in depth.

There are general statements that the carbon tubes will be incorporated in polymer matrices but it is not clear how the problem of transferring stress from the matrix will be tackled. There are studies in the literature, which show that there is no particular advantage in making composites with the carbon nanotubes unless alignment problems are solved and uniform dispersion is achieved (M. Paradise and T. Goswami, *Materials and Design* 28 (2007) 1477-1489). There is also clear evidence that the strength of the tubes collapses dramatically as their size is increased. The literature suggests that the performance of nanotube composites falls short of those made using carbon fibres. There may be an improvement in other properties but the need for this work needs greater justification.

Nanotubes have recently been incorporated at the Centre in a membrane for water treatment and this may be an encouraging development although the role of the tubes has not been made transparent to the Panel. Furthermore, this activity is not a part of the mission statement of the CoE-SM.

It has been stated that carbon nanotubes may help increase the electrical conductivity of ball bearings in an effort to reduce dust collection through the build up of static electrical charge. However, the Panel was also informed that this is not a major issue in ball bearings and structural reinforcement using boron nitride nanotubes may be a better option.

The Centre may also investigate work on long carbon tubes for structural applications (*Science* 304 (2004) 276) although it is also clear that entropy considerations require



a dramatic drop in mechanical properties on scaling beyond a millimetre (Materials Science and Technology 21 (2005) 1293-1302).

The Panel is not clear whether this focus area fits within the brief of the Centre and urges that a greater emphasis is placed in the next five years to understanding whether such materials have a role in engineering applications.

### 3.1.2 Diamond composites, ceramics, hard metals

These areas are ones in which South Africa is in a strong position following decades of research on diamond and tungsten carbide ceramics.

The Centre has a well-developed programme involving both theoretical modelling (Prof J. E. Lowther) and experimental exploitation (Prof I. Sigalas). In addition, there is strong support from industry, notably from Element Six, who funds a Chair for Prof Sigalas, several bursaries and also helps with the preparation of patents.

Prof Lowther's *ab initio* modelling allows new materials to be predicted and the moduli calculated. Prof Sigalas is then able to attempt synthesis and evaluation. In some cases the predicted structures were successfully identified (BC5) and in others not, meaning that the modelling needs further development. It is worth emphasizing that the "gap" between theory and experiment has narrowed significantly in recent years. This is a world-leading approach.

In addition to the boron sub-oxide research, Professor Sigalas has also made significant advances into SiC/diamond composites and their toughness; patents have been filed. The aim is to synthesise these methods at low pressures since this cuts costs.

The Panel emphasises that "hard" materials are not necessarily strong. A long-term aim of the *ab initio* calculations should be to predict "tough" structures, i.e., those which absorb substantial energy on fracture.

There is a potentially important worldwide application of the materials developed at the CoE-SM in the context of friction stir welding of high-melting point metals such as titanium and steel (Progress in Materials Science 53 (2008) 980-1023; see also the April 2009 special issue of Science and Technology of Welding and Joining). The major issue is the life of the tools used in this process and the ceramics focus group is well-suited to make a seminal contribution to this area.

### 3.1.3 Research Gaps

The Panel noticed the lack of work on concrete and very little on steels. These are key structural materials, which are of vital importance to the economy of a country such as South Africa, and there may be some urgency in developing these areas given the imminent expansion in nuclear power as an energy source in South Africa. Irradiation damage and life assessment are then likely to be of strategic importance both in design and in ensuring long-term safety and structural integrity.

South Africa has a huge mining industry, which makes a large use of wear-resistant steels. The Centre could develop a research area based on a recent novel, bulk nanostructured steel which is cheap enough for wide application on a large scale (Current Opinion in Solid State and Materials Science, 8 (2004) 251-257).

The Focus Area on metals is moving more towards steels and it would be advantageous to review some of the latest developments in steel technology in order to define its purpose. There have been a number of exciting developments, which is at a sufficiently early stage of existence to require detailed research and a wide range of applications in the context of South African Industry.

The Panel makes these comments without assessing research in these fields in other locations within the South African academia. It would be useful for the DST/NRF to assess these areas nationally. We also do not suggest that these areas should be included in the CoE-SM programme but we point out that they are natural areas of investigation for the Centre, provided that there is enough expertise within the group or outside experts who would like to become part of the Centre.

### **3.2 Education and Training: Student Recruitment**

It is clear that the Centre has succeeded in recruiting and training more students than would have been possible without its existence. At the same time it has broadly met the quotas of race and gender consistent with national policy.

There are nevertheless new opportunities to take advantage of its current and growing reputation to develop recruitment methods to better suit the financial and family pressures facing those who choose to pursue further education in South Africa:

- **Direct Funding:** The **CoE-SM** could work towards the establishment of sponsorships with international industries such as Rolls-Royce (major user of rhenium, ruthenium and small quantities of platinum). These would offer the full cost of a Ph.D. programme for work related to their technology but at a stage which is pre-competitive.
- **Indirect funding:** The **CoE-SM** could work towards establishment of secondments from Industry of staff to conduct Ph.D. programmes in a University environment, with the full costs being borne by the industrial partner.
- **Binding Sponsorships:** The **CoE-SM** could work towards the substantial enhancement of bursaries with additional support from industry, with an obligation for the candidate to commit to employment for a period of three years with the industry concerned.
- The University of Witwatersrand has a Research Fund, which, according to the Acting Head of the School of Physics, can be used by the **Centre** to supplement contributions from industrial partners in the sponsorship of students.

- Indirect Funding: The **DST/NRF** should establish an Industrial CASE (cooperative awards in science and engineering) programme, which fund Ph.D. studentships where businesses take the lead in arranging projects with an academic partner of their choice. One third of the cost would be borne by industry and the student would typically spend three months per annum working in the industrial laboratory. There is a possibility of employment following completion of academic work.

It may be the case that the THRIP programme could be adapted towards these principles as a long-term commitment with ring-fenced resources.

- It is recommended that the **DST/NRF** should consider continuing the support of students, the most important output of the Centre, beyond the ten year period of the current funding.

### **3.3 Information Brokerage: Dissemination**

The Centre undertakes dissemination of knowledge via the mechanisms of publications, conferences, collaborations and some interesting outreach activities at schools.

A greater use of the world wide web to disseminate teaching materials, theses, publications, slide presentations and data would enhance the visibility of the CoE and permit a wider audience to benefit from the work of the Centre. One example where this could be readily implemented is the proposed new course on powder metallurgy.

An example of the effectiveness of this medium in communicating the principles of materials is <http://www.msm.cam.ac.uk/phase-trans> created by one of the panel members (HKDHB). This consists of a digital library, containing complete textbooks courtesy of the publishers, movies of metallurgical processes, worked examples, computer programs, calculators, reviews, podcasts, factual reporting and a myriad of resources, all of which could be taken freely from any geographical location in the world at any time.

The materials are accessed typically by 60,000 students each month, who take three times as many documents each month along with other formats. The access is free, anonymous and unlimited.

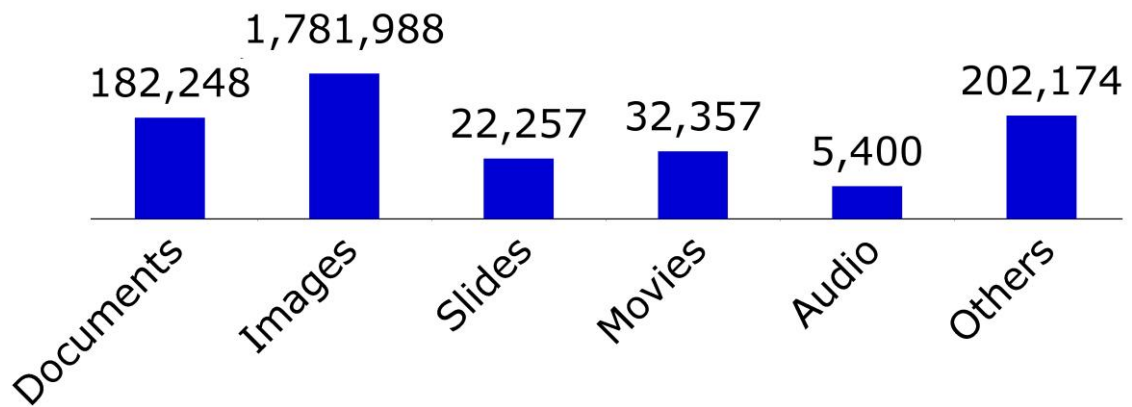


Figure 1. Monthly access of electronic resources at <http://www.msm.cam.ac.uk/phase-trans>

The transparency in making the teaching materials available has advantages. Any mistakes discovered in the contents are reported back and amendments made, perhaps making this the most comprehensive quality control system imaginable. There are complete courses which have been adapted and used by others; an approach like this would have clear benefits for the educational system of South Africa in general.

### 3.4 Networking

The Centre has a highly effective strategy on networking and continues to develop stronger links, particularly with academia in Germany and Japan. We applaud this and have nothing to add to what they already achieve.

### 3.5 Service rendering

We believe that service rendering can be enhanced with the effective use of the world wide web, where the dissemination of knowledge once implemented on the web does not require active intervention, and yet is of use to many.

### 3.6 Management

The Centre is aware of the need for succession planning and the Panel felt that adequate planning is in place.

The Panel recommends the setting up of a staff-student committee, which would serve the role of impersonal communication of issues via student representatives. In addition, the student body could, via this committee, be kept informed about the future programmes of the Centre, and any teaching, space, equipment and other issues. A bi-annual meeting would be appropriate.

It is essential for the smooth running of the Centre to compile a web-listing of available equipment, with each piece of equipment associated with a contact person

who can help use the facility. The list would also be of interest to external parties interested in the activities of the Centre.

#### **4. DST/NRF CoE PROGRAMME**

The Panel is left in no doubt that the CoE scheme is a remarkable tool to inspire collective activity in chosen areas, leading to synergies, which would not otherwise have happened. The Centre reviewed by this Panel has demonstrated the ability to inspire a young generation of highly qualified people who are enthusiastic about what lies ahead and who feel a responsibility to serve the South African society of the future.

The following comments are based on experience on similar ventures in the United Kingdom, from which important lessons can be learnt and implemented at this early stage in the evolution of the CoEs.

The U.K. implemented similar schemes some time ago under the title of Interdisciplinary Research Centres (IRCs) with each Centre focussing on a specific topic. The word “interdisciplinary” is particularly important since several Departments were typically involved, either from the same University or from neighbouring ones. Cambridge University had the first IRC in the U.K. with five participating Departments, each of which contributed staff and students. The topic was “hot superconductors” and the funding was allocated for ten years. When it was set up, there was tremendous interest and the press predicted, and the general public expected, industrial benefits on a short-time scale. The fact is that this topic of “hot superconductors”, as with many scientific areas, needs a longer period than ten years to mature. A well-known example of this is energy from fusion where success in the next ten years has been predicted for decades! The Panel suspects that nano-technology will also require a long time-scale.

In Cambridge, the funding was, as intended, stopped after ten years and funding from “other sources” was not large enough to support the IRC once the Engineering and Physics Research Council (EPSRC) ceased its contributions. As a result, the Centre collapsed and the researchers dispersed. The lessons are that funders of research must be sensitive to different areas needing different time-scales for research to mature. Also it must be made absolutely clear that the funding will stop after ten years. The managers of the Cambridge IRC had wrongly thought that some further funding would be given by EPSRC after the ten-year period.

*The Panel recommends that the DST/NRF makes a firm and public decision about its views on continued funding at this stage of the existence of CoEs so that the latter have a clear strategy for the future.*

The Panel comments now on some details regarding the planning aspects of the funding of CoEs assuming a cessation of contributions from the DST/NRF at the 10 year point.

The present funding is for ten years with a review after five years.

The Panel felt that the use of committed funds could be better implemented as follows, to take account of the limited span of the funding:

- (i) An initial period with a rapid increase in funding for students, followed by a decrease in the final three years. (Though DST/NRF may consider maintaining some funding by **bursaries** to students beyond the ten year time scale, as described previously.)
- (ii) A policy of increasing the budget for equipment funding to a peak around about the five year stage, essentially so that the Centre of Excellence would have maximum benefit of equipment at an early stage.
- (iii) Finally, the budget from DST/NRF would begin its decrease towards the end of the ten years so that the Centres of Excellence would have to plan properly for increased funding from other sources. Effectively this means that the end-of-term funding should be partly be advanced to an earlier stage.

This is not a request for extra funding but a recommendation for a different profile of funding which would hopefully help both the Centres of Excellence and DST/NRF.

On another issue, the teaching of science in schools, in particular Physics and Mathematics, is a world-wide problem. The quality of the teaching, both in terms of equipment and the training of teachers, appears to be in a particularly chronic state in South Africa. This reflects in the number of applicants who choose science for graduate and post-graduate education.

## 5. Recommendations

The following recommendations are made in the light of the opinion of the Panel that the performance of the CoE-SM over the past five years has been exemplary and that it has largely achieved its goals.

1. The DST/NRF should conduct a cost-benefit analysis on the restriction placed on the number of foreign students permitted bursaries (section 2.3).
2. The magnitude of the student bursaries should be reviewed regularly by the DST/NRF and University authorities (section 2.3).
3. The DST/NRF may wish to formulate a policy on the funding of technicians in the context of large projects involving sophisticated equipment. In the context of the present CoE-SM, DST/NRF and the Deputy Vice-Chancellor for Research at Wits should meet to discuss possibilities (section 2.7.2).
4. The Carbon Nanotubes focus group needs to fit better to the mission of the CoE-SM (section 3.1.1).
5. The excellent link between the *ab initio* and ceramic synthesis groups can be strengthened by attempting to develop models for the toughness of hard

compounds. It is also recommended that the groups look at the potential for making a seminal contribution to the development of friction stir welding tools using the technologies they have created. (section 3.1.2).

6. The development of focus areas in concrete and of steels research should be assessed by DST/NRF and CoE-SM in the context of activities and needs within the whole of South Africa (section 3.1.3).
7. The Panel recommends that the CoE-SM and DST/NRF look at other methods for the funding of greater numbers of post-graduate students, particularly those involving financial contributions from industries both within South Africa and in other parts of the world (section 3.2).
8. The Panel recommends that the DST/NRF should consider continuing the support of students, the most important output of the Centre, beyond the ten year period of the current funding (section 3.2).
9. The CoE-SM should make greater use of the world wide web as an effective method of disseminating knowledge to a wider audience (section 3.3).
10. The Panel recommends that the CoE-SM should establish a staff-student committee to enhance communications on a broad range of issues (section 3.6).
11. The CoE-SM should make visible a list of equipment and support staff associated with that equipment on its web site (section 3.6).
12. DST/NRF should draw on the experience of the interdisciplinary research centres which were established in the U.K. to see how to manage better the end of the ten year period of funding (section 4).
13. The Panel strongly recommends that the DST/NRF makes a firm and public decision as soon as possible, about the continued funding of the CoE's beyond the ten year stage (section 4).
14. The CoE's should consider a profiled spend of resources over the next five years so as to best manage the ten year span (section 4).
15. The issue about the teaching of science in schools is outside of the brief of the Panel, but the Panel recommends that DST/NRF, CoEs and universities should look carefully at how this problem might be mitigated.

## **ACKNOWLEDGEMENTS**

The Panel would like to thank the secretariat of the NRF, in particular Ms Anke Rädcl, for their outstanding help and support throughout this exercise. We further acknowledge the complete cooperation and help from the management, staff and students of the CoE-SM and Wits.