

A South African Research Infrastructure Roadmap

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Executive Summary

South Africa is clearly taking a lead in developing its involvement with global projects such as the SKA, CERN etc. South African investment in astronomy has been impressive and the country has been successful in attracting a significant part of the SKA to be physically based in the country. Likewise the substantial investment in SALT as a global facility open to international users shows the importance that South Africa puts on doing and attracting world class science using a physical Research Infrastructure (RI).

There is a common acceptance that RIs are not just a large piece of equipment. They are part of a research eco-system involving whole communities either located in one or a number of places or dispersed but with some common elements which are:

- An open service to researchers within the country and outside
- A nationally governed organisation responsible for the RI
- Long term strategic plan for maintaining and upgrading
- Training both researchers and support staff in operating and maintaining the RI
- Outreach to researchers, industry, regional and national stakeholders
- Access by world class peer review
- Creating career development opportunities for all staff
- Ensuring that e-science is an integral component of the RI

Although the expert team has identified 17 potential RIs of interest to South Africa these must not be seen as either the last word or seen in isolation from each other since there is much to be gained in sharing management approaches, integrating outputs and even sharing some joint services in order that the research outputs will not be seen in isolation but rather contributing to the solutions to many of the challenges facing South African society.

For ease of undertaking the roadmapping exercise, a discipline based approach was taken, yet every effort should be taken to see the RI landscape holistically and for this reason each potential RI is identified with national priorities and links shown for the range of disciplines that they can bring together. Many of the distributed or virtual RIs exist in part and need relatively little extra effort to turn them from a series of discrete activities to a coherent RI that will deliver so much more than the sum of the parts.

There are a number of key features that need addressing at an early stage to make substantial investments in RIs value for money. These are:

- Training of personnel to realise and manage national RIs that are a service to the national community
- Initiating a review or stage-gate process for seeing RIs are under control from conception to the end of life including a rigorous internationally peer reviewed research case and a nationally reviewed business case (often termed the Conceptual Design and Technical Design Reports).
- Identifying a long term budget line for each RI to take into account realistic operating and upgrading costs
- Agreeing a governance structure that is transparent to all stakeholders and the public from the start
- Ensuring that there are sufficient numbers of personnel able to make use of the RI and to support them in their home institutions.

A small but significant amount of funding is needed to support these activities before a full commitment to fund a particular RI is taken. RIs are notorious for project drift if no proper monitoring system and delivery plan is agreed at the start. A good test as to the maturity of an RI proposal is whether the community can agree on a common conceptual design. This will need one or more “champions” to drive the project. The experience of the SKA should highlight that a person of sufficient tenacity and drive is necessary to effect a decision.

The roadmap focuses much more on the background to RIs rather than give significant technical detail to each project. There are two reasons for this. The concept of a national RI in South Africa is at an early stage and it is important that certain concepts such as service, RI eco system, governance, multi-disciplinarity are understood from the start. Secondly, the projects themselves are at an early stage and need more project definition before they can be described in more detail.

Any investment must be consistent with national priorities and the roadmap shows clearly how the RIs proposed contribute to these in a significant way. Likewise the impact of RIs in general in terms of socio-economic outputs and increasing the influence South Africa has internationally, not just in research, will be considerable. The largest impact, shown from every example around the world, will be human capacity building. Visible investment in physical RIs such as SALT shows young people that there is a long term commitment by the government and therefore good career prospects.

Another point that is assumed by the roadmap, although there is no specific section, is the relationship between the RI and the particular research community served. Part of this comes into governance but it is also an attitude of service that must be fostered among staff working at the RI. There are responsibilities on both sides. Researchers must give credit to the fact that people working on the RI for their sakes should gain recognition by being included in any outputs. All this is best achieved by regular open meetings and forming user groups.

Why are some obvious areas left off this roadmap? Some like SALT and SKA are already in progress so no more needs to be said other than South Africa continues to support them. Other areas such as space science, light sources, etc. are not well enough defined at this stage to warrant inclusion but are listed as potential RIs for the future.

This roadmap provides an exciting opportunity for South Africa to come further to the forefront in international research and therefore make the country more attractive to international stakeholders.

Summary of RIs highlighted by the roadmap

The RIs that are highlighted by the South African Research Infrastructure Roadmap are listed per scientific domain in the table below:

RI Domain	Identified RI
Humans and Society	The South African Network of Health and Demographic Surveillance Sites
	South African HSS Data Archive
	National Centre for Digital Language Resources (NCDLR)
Health, Biological and Food Security	Animal Bio Security Lab P4 Level (ABL-4)
	Distributed Platform for “Omics” Research (DIPLOMICS)
	Biobanks
	Nuclear medicine
Earth and Environment	A South African Marine and Antarctic Research Facility
	Biogeochemistry Research Infrastructure Platform
	An expanded National Terrestrial Environmental Observation Network
	Shallow Marine and Coastal Research Infrastructure
	The Natural Sciences Collection Facility
Materials and Manufacturing	Materials Characterisation Facility
	Nano-manufacturing Facility
Energy	SAFARI-2 Materials Research Reactor
	Solar Research Facility
Physical Sciences and Engineering	A national support centre for science

1. Introduction

Undertaking the production of the very first South African Research Infrastructure Roadmap in a very short time period with limited resources was a daunting task and will, inevitably be incomplete and require updating in due course. Why is such a roadmap necessary at all?

The idea of producing such RI roadmaps started just over a decade ago for both national and international RIs and they have now become a common feature of the research landscape. The first, and most obvious reason, is for funders to budget and know what is and what is not expected. Secondly and most importantly, it forces researchers to come together to share their ideas and work together for the national good. Thirdly it allows researchers to plan their own research in the reasonable hope of what will be supported and to alter plans if their area is not to be supported. Finally it lets institutions and other countries know what is likely to be coming and to plan their investments in human and support services accordingly.

The production of this roadmap is a joint collaboration between the South African Government and the European Commission and is informed by the experience gained in Europe both in the Union and in the Member States.

At this stage it is worth describing what a national Research Infrastructure is.

Research Infrastructure (RI) includes facilities, resources and services used by the scientific community across all disciplines for conducting cutting edge research for the generation, exchange and preservation of knowledge. It includes major facilities, equipment or sets of instruments, collaborative networks and knowledge-containing resources such as collections, archives and data- and biobanks. Research Infrastructure may be “single-sited”, “distributed”, or “virtual” (the service being provided electronically).

A national RI is thus a service to research which:

- Awards free open access to users selected through a world class peer-review competition
- Asks the users to publish/share their Research results in the public domain
- Manages access for proprietary and/or training activities as a different, and, in most cases, marginal activity
- Has, as a mission and goal, a clear national priority: e.g. to attract at least 30% of the selected users coming from non-host (non-owner) countries

The **European Strategy Forum for Research Infrastructure’s** definition introduces also the basic “rules of play” which a RI should fulfil: it must be built, managed, operated and funded to serve external researchers, chosen independently from the ownership (or the capability of the users to pay for the service) and only on the basis of the quality of their proposals as judged by independent and international peer review: The users, in exchange for being admitted free of charge, must share their research results in the public domain, and/or with the RI.

The concept of results encompasses both the specific results of the research performed with the use of the facilities of the RI and the possible results of developments performed to increase the technical capabilities while working at the RI. The first ones are normally shared in the public domain while the others are, in most cases are not and can lead to new technologies or ways of working that can be further exploited.

The general result for the local stakeholders in addition to undertaking their own research is a continuous improvement of instruments, technologies and training of technical and scientific

personnel, as well as in the quality of science produced. These are the effective results (or returns of investment) for the national and local funders, which justifies the free open access.

The advantages of opening national infrastructures to international use has become clearer only in the last 10-15 year sand this is now an established method to improve the national investments and both the national and international quality of research, while increasing the capability of South Africa.. This is not a new concept and has been employed by the astronomy community for sometime.

Why is good **governance** of RIs so important, and why in particular for South Africa?

- RIs are needed in all fields of science, and no single institution can provide them all.
- South Africa, as a nation cannot afford to have national facilities that are not open to all based on quality alone.
- By operating South African RIs with good governance will be attractive to international researchers and funders from other countries and show that South Africa is a major and respected contributor to world class research

In preparing this roadmap, it has been noticeable that the appreciation of good governance of national RIs is at an early stage and needs to be strengthened if the full advantages of investments are to be made.

2. The role of research infrastructures

2.1 An overview of the RI landscape

The **relevance and strategic value** of **research infrastructures (RIs)** comes from the multiple roles they play in all the selected S&T domains for a SARIR. These roles are as follows:

- **RIs are catalysts of the scientific development.** RIs become crucial instruments for conducting experimental research (in domains like astronomy, oceanography, particle physics, material sciences, etc.) because they accelerate or even make possible the creation or confirmation of scientific knowledge in one field.
- **RIs are catalysts of the technological development in advanced areas.** Usually, the development of a new RI also requires the development or optimization of new technologies and engineering processes during the construction and operation phases. Many of these technologies find useful applications later on in other fields such as in medicine or security applications.
- **RIs are catalysts for economic growth.** RIs (including those in the humanities and social sciences) are key determinants of competitiveness and essential to “*science-based innovation*” due to the advanced activities boosted in the rich ecosystem linked to RIs. Specific industrial programmes and stronger university-industry cooperation are basic components.
- **RIs are catalysts for international cooperation.** Some RIs are too big and expensive to be funded by a single country; furthermore, even when economic resources are available, the need to access world-wide scientific knowledge makes international cooperation a must and also an opportunity.
- **RIs are catalysts for strengthening territorial cohesion.** RIs constitute a source of economic development in the regions where they are located: they attract skilled people and high-tech investments. Then, they ensure an added value for boosting socioeconomic progress through additional investments in other complementary infrastructures like in transport, education, health, communications, culture etc.

This chapter focuses on the types of **research infrastructures** listed below. However, the development of a complex research infrastructure also implies the development or optimization of complex technologies. At the very least, information and communication technologies and data management services will constitute basic elements of every type of research infrastructure by sharing with other application domains; but the construction phase of a new RI could also require the development and testing of new materials, the robotic manipulation of scientific instruments in hazard environments, or the deployment of a distributed network of specialised sensors in a wide range of RIs.

Distinction between those RIs to be included in the SARIR and other types of smaller equipment used at the *research group level* is also necessary. Any RI roadmap focuses the attention on those RIs where their complexity, added value and cost require specific policy measures for the interest of the whole national community.

Figure 1 depicts the possible range of scientific equipment to be considered for the RI roadmap in South Africa diagrammatically. SARIR should focus on those RIs used for the whole scientific community in South Africa or, in some cases, with the participation of South Africa in other international RI. Some *departmental equipment* can also be included when they are used as components of a distributed RI and coordinated with other infrastructures available in other nodes of the network to be able to offer a global service at the scientific community.

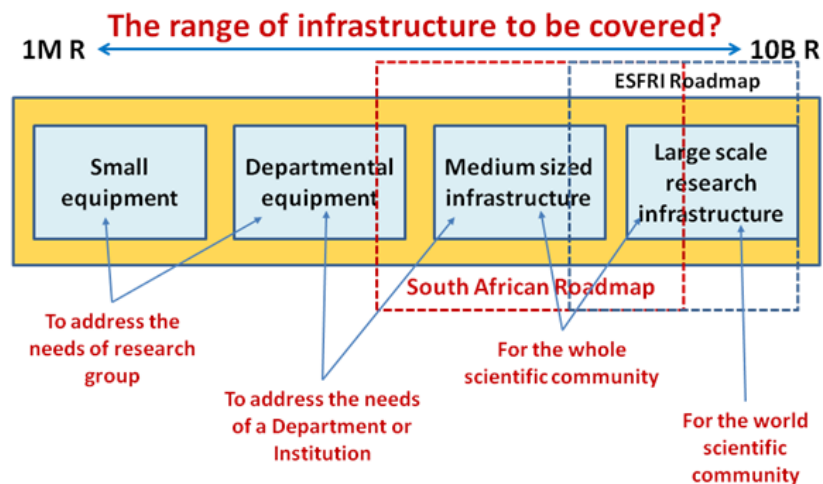


Figure 1: Range of research infrastructures for SARIR

The above mentioned **relevance and strategic value** gives RIs a mix of specific political and technical features as follows:

- *Strong investments.* The investment necessary should account for a relevant percentage of the available resources for supporting research activities in one specific S&T domain including the long term upgrading and operational costs.
- *Singular decision making process.* Political factors and external constraints influence decision making. Most countries have a project management control system whereby various stages or gates have to go through approval prior to political commitment. The UK's Gateway system is a good example.
- *Many years for the construction and operation.* The development of a new RI is a long process with frequent upgrades (including new IT technologies and software) to ensure its full usability over time. This fact requires a careful cost analysis during the whole RI life-cycle (from conceptual design to decommissioning).
- *Very high operation and maintenance costs.* Usually, the annual running costs of a specific single-sited RI are about 10% of the capital investment. This figure could be higher in case of distributed RIs due to the need of coordinating multiple nodes.
- *Specialised human resources.* Both for the maintenance and operation but also to support end-users, the RI needs highly specialised staff that are service focused.

RIs are not isolated elements in any *national innovation system*. They are closely related to the activity carried out by many other private and public actors by stimulating positive feedback amongst all of them. The actors, links and related activities associated to a specific RI constitute the **"RI ecosystem"**. As a consequence, Governments should articulate a set of closely related policy measures around the RIs in order to exploit their possibilities to benefit the national innovation system. The broad range of potential activities to be included could involve the participation of a number of ministerial departments, governmental agencies closely coordinated through specific policy structures.

Figure 2 places research infrastructures in the middle of the higher education, innovation and research landscape (*"knowledge triangle"*). The support to training of researchers, spin-off creation or scientific instrument development should be addressed from a **coherent policy programme** to generate RIs with enough highly skilled employees and users. In many cases, it is also necessary to coordinate it with other international organisations abroad. The definition of a RI roadmap is also an opportunity to rethink all these policy instruments.

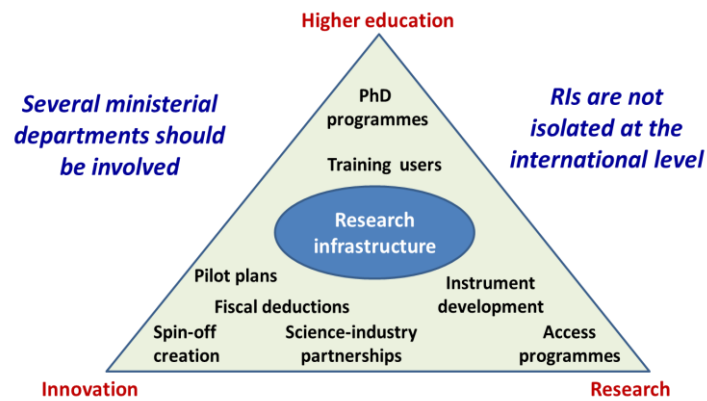


Figure 2: Elements of the RI ecosystem within the knowledge triangle paradigm

The **RI ecosystem** is not a static concept; it dynamically evolves through changes in the actors involved and by enriching their interactions at the national and international level with the signature of agreements and as a consequence of the evolution of the science case of the RI. It is also important to plan from the start the lifecycle and decommissioning of a RI. There can be big social consequences in doing this that need careful handling.

As Figure 3 indicates, the core of the RI ecosystem comprises the selected national RIs (both new RIs and the possible upgrade of pre-existent ones) included in the roadmap and everything which constitutes the operation & maintenance activities through a network of specialised providers. Attached to these main elements, there is a management and coordination structure at the policy level to give coherence and international support.

Furthermore, a *second ring* of policy measures includes human resources, outreach (including impact on schools) and industrial programmes. The **human resources programme** provides the necessary skilled people for the operation, maintenance, scientific use and service provision for the smooth running of the RIs included in the map. The outreach activities can take many forms from site visits to linking school curricula to the output from a RI. Young employees are excellent role models for school and other stakeholder engagement. The **industrial programme** is aimed at providing a set of high-tech enterprises which could provide components or services and also to facilitate the creation of spin-offs or start-ups to exploit the results obtained in the development and operation of RIs.

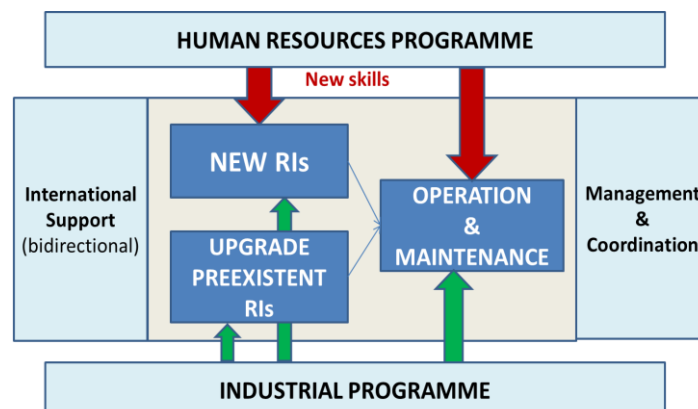


Figure 3: High level overview of the RI ecosystem

Due to the large variety of research infrastructures and the lack of a common terminology, the GSO (Group of Senior Officials from G8) agreed on **three broad categories of research infrastructures of global relevance** to be used in its discussions. These are:

- **Real single-sited global facilities are geographically localized unique facilities whose governance is fundamentally international in character.** The Large Hadron Collider (LHC) at CERN and ITER are current examples. Future projects of global interest and relevance need to be identified. ALMA and the Square Kilometre Array (SKA) are two of these; the International Linear Collider is potentially another one. The possibility of future opportunities of similar projects developed in different countries needs to be kept in mind, in order to ensure that there is scope for building only one such facility. In this context, the Cherenkov Telescope Array (CTA) could be an example.
- **Globally distributed research infrastructures are research infrastructures formed by national or institutional nodes, which are part of a global network and whose governance is fundamentally international in character.** LIFEWATCH for example can only function through a globally coordinated set of nodes; ARGO and GEOSS are two other examples. In Africa, the Africa Array (32m radio telescopes throughout Africa) is similar to the European VLBI Network and would potentially benefit the global VLBI system. Ocean, earth or seafloor observatories fit very well into this category, including oceanography fleets of research vessels and polar research facilities (both for the Arctic and Antarctic). Ad-hoc distributed facilities, linked with time-limited campaigns of observations, might also be considered for possible inclusion in this category. Scientific information exchange, data preservation and distributed computing infrastructures relying on open high-speed connectivity, provide new opportunities in terms of virtualisation of resources, advanced simulation environments and improved and wide access to research infrastructures.
- **National facilities of global interest are national facilities with unique capabilities that attract wide interest from researchers outside of the host nation.** Antarctic or ocean drilling facilities are typical examples. The Karoo Array radio Telescope or MeerKAT in South Africa could be another example, since it will remain an important instrument for a long time while SKA is being built. Existing research infrastructures with the potential for wide international utilisation (for instance, facilities that leverage geographical advantages or exhibit unique opportunities for advanced research) may fall under this category. For instance those that have geographical advantages or exhibit some singularities for advanced research. Countries may accordingly propose those national facilities that have the potential to be opened for global participation, taking due care of balancing international and national interests to think carefully which national facilities have the potential to be opened up at global level, taking due care of balancing international and national interests.

2.2 Relevance of distributed research infrastructures

Several research infrastructures proposed in SARIR are “**distributed RIs**”. This approach is very relevant in domains where there is no need for a single centralized RI but where researchers should have access to a range of specialized equipment located in several sites in a coordinated way. Typically, the concept of a “*distributed RI*” evolves from a situations found in many S&T domains where relevant equipment items are dispersed and resources under-optimized. A distributed RI should provide the following services:

- To offer researchers a **single entry point** to a set of related equipment located in different sites and institutions across the country.

- To serve as a tool to **reinforce cooperative multidisciplinary research** by creating synergies in complementary services by avoiding duplication of efforts and opening possibilities to address more complex research activities.
- To offer policy makers a **tool to define country-based or regional-based policies** in relation to the distributed RI within the domain, to obtain longitudinal data, to facilitate public-private partnerships and to support the internationalization of the South African innovation system.
- To allocate future resources to the **centralised coordination structure** and to give it the responsibility to distribute resources to different nodes according to strategic plans and quality of service.

Figure 4 schematically depicts this view. The **initial situation** is represented as a set of non-coordinated research equipment of different sizes and locations (some of them could be duplicated and not necessarily well maintained because responsibilities for that depend on individual institutions). The **final situation** implies a centralized coordination structure which provides a single window for researchers and the possibility to coordinate the allocation of resources for upgrading, for the purchasing and placement of new equipment and integration with pre-existent ones in order to optimize the available resources, and possible removal of obsolete equipment.

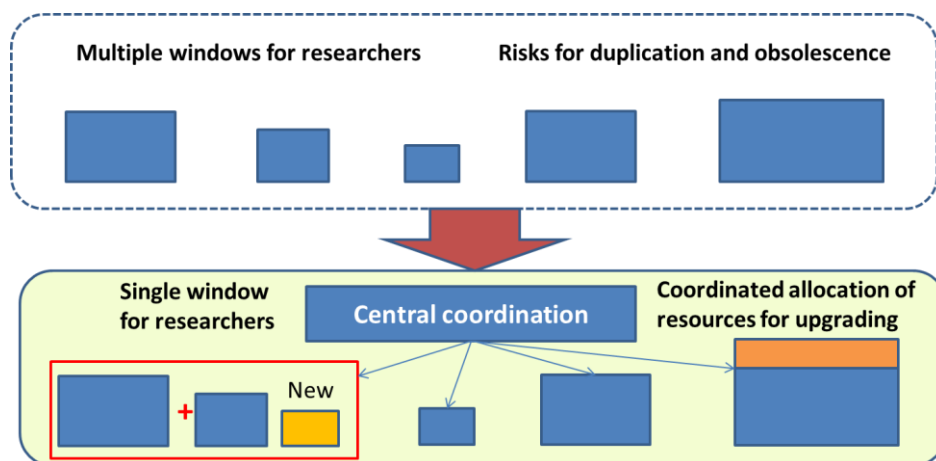


Figure 4: Transition from a dispersed set of equipment items to a coordinated structure as a distributed RI

The transition process is not necessarily easy to implement because the creation of a **national distributed research infrastructure** implies commitment of resources and to accept responsibilities on behalf of the whole scientific community. Any distributed research facility should be based on a *contract-based commitment* with the scientific community through the South African Government. Figure 5 indicates the main elements of such a process.

- **Agreement between all government departments** involved where appropriate. These departments should create a cross-coordination structure for fund allocation and high-level coordination.
- **Contract-based commitments between the participating entities.** This long-term contract should be monitored through key performance indicators (KPI) and agreed delivery plans to trace the evolution of the distributed facility and the possible reaction against deviations, the legal approach for liabilities, intellectual property issues and management of public funds, and the support for professional management.

- **Specific MoUs between individual nodes and the coordination structure.** These MoUs should have similar elements for all and specificities related to the type of equipment or services offered. All nodes will therefore have a double “governance dependence”, i.e. from the *host institution* to which they belong (university, research centre, etc.) and from the distributed RI network by accepting the external interface of the coordinator and the common rules as a member of the distributed RI.
- **Creation of a coordination structure** to serve as the interface with public administrations, to facilitate international cooperation, monitor the quality of the services offered to the scientific community, give visibility and centralised information and distribute users’ requests for access to specific nodes.
- **Access** As in the case of site specific RIs, the preferred mode of operation should be “free at the point of access,” so that all researchers have a right to use the facility depending on the quality of their application. This avoids unnecessary bureaucracy and complex trading between universities, but will require the availability of funds to support the activity.

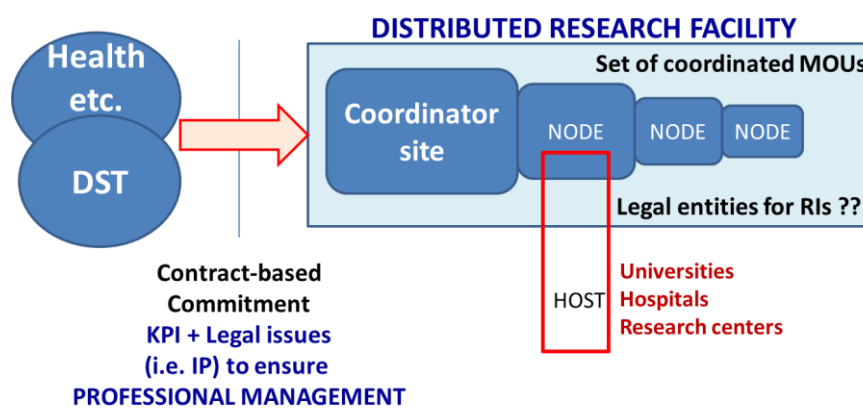


Figure 5: Structure of a national distributed research infrastructure

A final point is the **possible participation of private entities** in the distributed RI. The governance model could also attract the interest of private entities which could be interests to share the use of sophisticated equipment for research and commercial uses (this approach is not conceptually very far from the dual use of medical imaging systems for research and clinical use). Specific conditions should be addressed in the preparation of specific MoUs. For non-public bodies there would be an agreed charging system.

3. Methodology

The question is always asked of how RIs get onto a roadmap and what are the criteria? It is necessary to avoid just creating a “wish list” but on the other hand it should be far sighted and aspirational. However, it is a living document which will need revision as circumstances change. The emergence of e-science has probably had the most dramatic impact on the development of RIs in that it now makes possible e-humanities and other disciplines sharing data and surveys that would not have been possible in the past. Fast communication systems coupled with e-science have also led to the interactions between different communities such as the development of data analysis systems by physicists and engineers for those working in social sciences and the environment.

In many cases communities have built up cases for support over decades and several of the current international RIs being built now started off as a dream in the eye of researchers more than 20 years ago. The first and absolute criterion has to be for a person or community who will have the vision, patience and tenacity to see a project through despite all set backs and false promises that come their way. It is interesting to see, internationally, that certain communities find this easier than others to live with. Lessons from ESFRI are showing that projects with a firm backing from a community from the start are now coming through successfully while those that saw the roadmap as an opportunity to exploit have been less successful.

It was agreed with DST that the following criteria should be met for inclusion of an RI in the roadmap:

- Contribute to the total research ecosystem
- Be defensible to the public and excite them
- Be owned by a dispersed community
- Contribute to the sustainability of South Africa by economic, social, human capacity and international standing
- Bring together researchers and others from different communities
- Be acknowledged as world leading by the rest of the world

In the light of this the panel sought to gain evidence in a number of ways. First, pre-existing reports such as those mentioned in the first 3 chapters of this report confirmed those areas where South Africa was thought to have strength and a vibrant community and with some vision for the future. Secondly a survey questionnaire was sent to over 50 institutions and facilities that could be considered either as hosting current RIs or as being current RIs. Along with that a set of boundary conditions was agreed on what would and would not be considered for the roadmap. The questionnaire and boundary conditions are attached to this report. Finally a number of key people were approached to give an overview of their fields seen from a South African perspective. What became very apparent from this exercise was that the very concept of a national RI as an eco-system was not appreciated by most respondents. Some communities such as physics and environment had a very clear view of where they saw their subject developing and which RIs would be needed, while, for others there was no consistent view.

From the returned questionnaires it was clear that issues of governance, strategy and international interactions were not consistent with the concept of a national RI in most cases.

It was agreed to undertake further work to try and elicit a list of potential RIs for South Africa. These included interviews with key players who had the responsibility of overseeing their discipline area. These were arranged over several days both face to face and by telephone discussions. These were very informative and allowed the panel to run two workshops. The first was held in Cape Town in

June 2013 and the second in Pretoria in October 2013. Around a 100 attended the first workshop, by invitation. After presentations about the country's and DST's priorities and general presentations by the expert panel on what RIs are and are not, followed by a summary of the current South African position, the workshop divided up into 6 groups to reflect different disciplines and challenges. The 6 areas were:

- Health, Biological and Food Security
- Earth and Environmental Sciences
- Human and Social Sciences
- Physics and Space Science
- Energy
- Chemistry and Materials Science

The outputs from these groups were presented at a final wrap up session. The verbatim reports of the 6 sessions were recorded and were made available to those that attended the second workshop as was the interim report that had been sent to the Executive Committee of the DST in August which focused mainly on emerging policy issues. Further evidence was supplied after the first workshop by certain groups for clarification. At the second workshop the implications from the 6 areas for RIs were presented for discussion and feedback. This led to the expert group fixing the initial list of RIs on the roadmap and presented here which were largely self-selecting.

In addition to specific suggestions for RIs, a number of other features about the South African research community emerged from the interviews and workshops such as the need to maintain and support small scale facilities as feeding into larger RIs, trained technical support, project management experience of RIs, funding structures and the NRF rating system for those participating in running RIs and many other issues that relate to rethinking of a national RI contributing to the whole of South Africa rather than one particular institution.

4. South African political context and link with National Development Plan and other key policy documents

Two recent policy documents outline the immense challenges facing South Africa and a vision of what needs to be done to address these in order to place the country on a firm trajectory of growth, eliminate poverty and reduce inequality. These are the recently released National Development Plan (NDP)¹ by the National Planning Commission and the New Growth Path (NGP)².

The NDP refers to global drivers of change and emphasises the need for governments and companies to continuously adapt and adjust, not only to the risks and challenges of an ever changing and increasingly complex world, but also to optimally exploit the opportunities of such changes to substantially advance economic growth and to eliminate poverty and inequality. Africa, seen as a driver of change, provides a wealth of challenges and opportunities because of its vast mineral resources, its comparatively young population, massive urbanisation, explosion of consumer demand, its massive infrastructure deficit, huge renewable energy potential, its vast untapped agricultural potential and the threats of climate change. The threat to the world's environment by virtue of human activity is seen as a driver of change in its own right. A low-carbon future as the only realistic option is seen to offer exiting opportunities that will spur innovation to attain energy security, a cleaner and safer environment and the retention of greater biodiversity. The Plan furthermore highlights the importance of science and technology as a driver of change and key to development and sees this as the differentiator between countries that are able to tackle poverty effectively by growing their economies and those that are not. Hence, it emphasises that a competitive and sustainable economy will require a strong and effective system of science, technology and innovation. To achieve this, the core sites of research, i.e. universities, industrial laboratories, science councils and other sites of research and innovation need to function in a coherent and coordinated manner with broad objectives aligned to national priorities.

The country's higher education system is seen to make a critical contribution to achieve the desired outcomes, but emphasises the need to address the capacity and quality of staff to grow knowledge production and innovation in order for the universities to become world-class centres of excellence, capable of contributing to innovative answers and solutions to the challenges the country is faced with. The Plan acknowledges the need for more investment in R&D, to improve the link between innovation and the needs of business and society and to build the research infrastructure required by South Africa's development strategy. It furthermore calls for greater efficiency in terms of knowledge productivity, throughput, graduation rates and participation, with particular emphasis on the growth in PhD graduates, as these are the dominant drivers of new knowledge production within the national innovation system. It also recognises the need for a differentiated higher education system that takes cognisance of the need for universities to build on existing strengths and allows them to respond to needs they identify. Areas of strength should ideally be developed in response to the needs of the immediate environment, the African region and for global competitiveness. In this regard the funding must take into consideration the needs of a differentiated system, with adequate provision for both teaching and research, but with a greater emphasis on output based funding and strengthening of research excellence by way of performance based grants.

Although the goals of the NDP and the NGP are very similar, the latter places much more emphasis on the urgency of employment creation. As with the NDP, the NGP also recognises the importance of coordinating activities around core priorities rather than dispersing them to widely, activities which must respond to global imperatives and emerging opportunities. These include the markets

¹National Planning Commission, 2011, National Development Plan Vision 2030, 430p, ISBN: 978-0-621-40475-3

²Economic Development Department, 2011, The New Growth Path: Framework. 80p.

created by developing economies such as Brazil, India and China, opportunities in Africa as one of the fastest growing regions in the world, global warming and the need to reduce emissions particularly for South Africa as a carbon-intensive economy, and accelerating technological advances that impact on world economies. The NGP emphasises the need for Government to encourage stronger investment by the private and public sectors for rapid growth in employment-creating activities, whilst simultaneously maintaining and incrementally improving South Africa's core strengths and advanced skills base in several sectors. In this regard the NGP identifies various "jobs drivers", i.e. areas that have the potential for creating employment on a large scale, and which at the same time creates economic growth; i.e. the two key variables to monitor in attaining the targeted growth in employment - the rate of growth in employment relative to the rate of growth in GDP. Identified "jobs drivers" that impact on the country's R&D capacity includes:

- For infrastructure – The near doubling in capacity of electricity generation by 2030 with 33% of new generation coming from renewable sources and 25% from nuclear power.
- For the main economic sectors – A much stronger focus on the beneficiation of our mineral resources and support for the manufacturing sector to encourage activities that create employment on a large scale, while sustaining development of more knowledge-intensive industries for long-term growth.
- For knowledge and new economies - Major new opportunities for investment and employment linked to technological innovation, e.g. to meet targets for renewable energy, in manufacturing, in the knowledge intensive sectors of ICT, higher education, healthcare, mining-related technologies, pharmaceuticals and biotechnology.

The creation of new knowledge and technological innovation is clearly recognised in these two policy documents as being a key dimension in attaining the national development goals. Several of these are articulated in more detail in sector specific policy and strategy documents to which reference will be made in Chapter 4 with due emphasis of the importance of access to appropriate research infrastructures (RIs) to achieve these goals.

5. Socio-economic impact of RI

5.1 The context of the RI ecosystem

The development and operation of **research infrastructures** in a country constitutes an opportunity to **increase the quality of the national innovation system and its international visibility**. They are also extremely relevant tools to address the **long-term socio-economic challenges** identified by the country. While the main criterion for choosing one particular RI should be on scientific merit, it is important to assess other factors such as the creation of jobs and the other wider benefits that the RI can induce.

RIs form the anchor point for many national science, technology, social and economic plans. Most advanced countries have defined different R&D programmes or S&T activities to increase human capacity building, international mobility, the creation of new technology-based enterprises, public-private partnerships, and globally, the improvement of the interrelationships amongst all elements of the so called **“RI ecosystem”**. Figure 6 schematically depicts the concept of RI ecosystem with its main components.

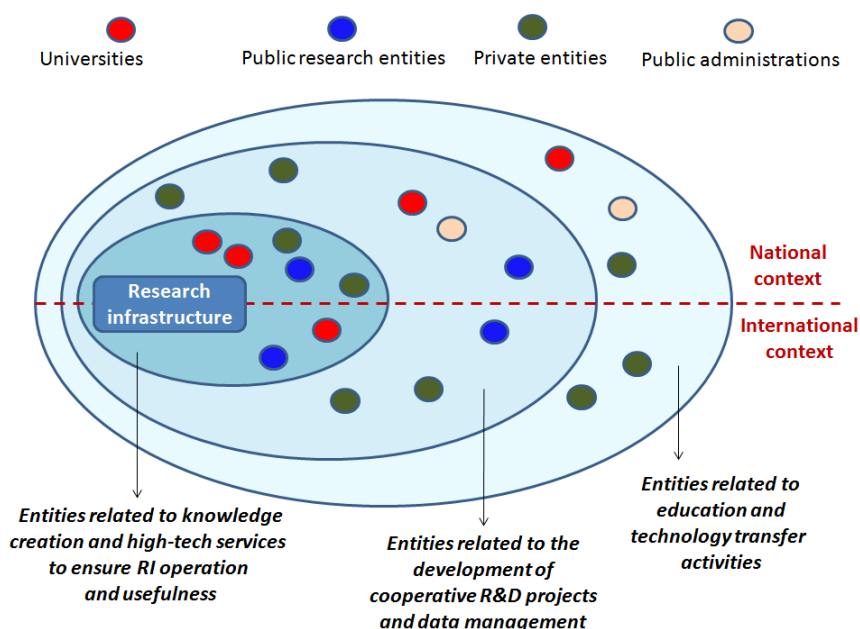


Figure 6: RI ecosystem

Figure 6 demonstrates the influence RIs have on different types of entities (universities, public research organizations, private firms and public administrations). All of them are related to the RI through the creation of knowledge and many other types of services and activities. These are represented in three circles, from which it is also evident that national RIs are only placed in entities best suited to manage and operate such infrastructures. A further aspect is the fact that such visible investments have on the public perception of science including influencing young people to follow a career in science.

Socio-economic factors which impact on research facilities can be classified in many different ways: from pure social factors derived from the RI impact on a city, region or country within a world perspective (as an example, the existence of a large RI has accelerated the transformation of the city-life and the intercultural relationships of their inhabitants) to pure economic factors like the increase of the economic transactions in the affected area, the development of the small business

sector and the growth of foreign investments. A good example is that of the so called “Medicon Valley” in Sweden, where the integration of the oldest University in Sweden with business incubators, large industrial research complexes and the building of the 4th generation synchrotron (Max IV), as well as the building of the European Spallation Source all within walking distance has attracted a very large number of biomedical industries to the immediate area.

Historically, the **socio-economic value** of the research infrastructures has been extensively discussed from three complementary perspectives:

- The **local benefits** associated with the provision of technical/scientific activities and services linked to the site where the RI is located. This value is more clearly assessed in single-sited research infrastructures or in nodes of a distributed RI (when the node activity also implies physical activity) but it also appears where users are located even if they access the facility remotely.
- The **added value for companies or research centres** belonging to the RI ecosystem which provide components or specialized services for the development and operation which also generates a concentration of qualified human resources. This intellectual and innovative environment has effects on the local schooling and culture among other aspects.
- The **long-term induced value** in the global innovation system which is related to the attractiveness for high-tech investments generated by the RI operation and the positive side effects on other actors. From this perspective, practically all socio-economic challenges are addressed.

The next section describes how these three types of benefits could apply in the construction of the South Africa RI roadmap.

5.2 Socio-economic benefits

5.2.1 Local benefits

A decision by government and other stakeholders to invest a relatively large amount of money for the development and operation of a RI should be based on the expected benefits that that decision could have for the whole innovation system of the country. These benefits are not exclusively limited to the place where the RI is located although it is true that they are mostly noticed in that place or region. For that reason, “*site decision*” constitutes one of the most important events in the RI lifecycle of a single-sited large RI. Even for virtual RIs the concentration of key personnel in a particular region can have a major impact.

5.2.2 Added value for the RI ecosystem

RIs are not isolated entities. Their influence pervades the local environment; hence the concept of an RI eco-system. Failure to see them from this perspective has often been the reason for notable failures. Thus the investment in a particular RI is only part of the picture, with the co-location of institutes, the relationship with local universities and innovative businesses interests also to be taken into account when considering investment.

The balance between economic contributions from the host country or specific institutions to develop or to operate a RI in its territory (usually, a substantial percentage of the total cost for international RIs) and the economic benefits generated (i.e. taxes from economic transactions or contribution to GDP) does not lend itself to vigorous financial analysis since the benefits are not always directly correlated. However, it is the case that an increase in economic activity surrounding

RIs is the norm (e.g. SKA). This added value requires strong coordination between all ministerial departments involved with an interest in the RI ecosystem.

5.2.3 Long-term induced value

Usually, research infrastructures are located in one geographical area where other research institutions or high-tech companies are or will also locate to benefit from the RI. The cases of Grenoble (France), Oxfordshire (UK), Hamburg (Germany), or Lund (Sweden) where several RIs, research centres, universities and high-tech companies coexist in the same place or in a limited area are well known and demonstrates the induced value of the RIs to boost economic growth and employment.

In other cases there may be specific scientific or technical requirements to locate the RI in special or remote places (i.e. the case of telescopes, Antarctic bases or underground labs for particle physics are well known) where the socio-economic impact is not “local” but **induced** in other parts of the country. The existence of supporting e-infrastructures in these cases also has an impact nationally.

In all cases, the **attraction of international funds** (for multilateral agreements) and **direct foreign investments** when the RI becomes a global RI can be easily measured. To this extent, governments should add the long-term benefits derived from the creation of spin-offs, industrial research labs, etc. because they will generate additional economic activity.

6. Lessons learnt from International Research Infrastructure Roadmaps

Creating roadmaps for research infrastructures has become a global phenomenon. There are many reasons for this but the effort is primarily driven by the following key factors:

- RIs are long term investments resulting in financial commitment often over several decades
- The RI ecosystem is complex and needs incubating and support in planning, often involving several areas of government. This includes the building up of sufficient expertise within universities and within government to make sure investment is properly managed and controlled.
- RI investment needs to be thoroughly assessed from several different perspectives and support is needed for preparation in addition to the creation and running of the particular RI. For large RIs this can take a few years.
- Investments in national RIs will be a significant part of any national research budget. Prioritising investments is difficult but should be open to the widest possible scrutiny.
- It may be necessary to reduce activity in some areas of research and restructuring plans should not be taken in isolation.
- Young people need to be able to see where it might be worth their while concentrating their academic activities.

A question that often arises is whether a roadmap should be integrated with a proposed financial budgetary plan. Even within one nation this is difficult without a firm commitment from all political parties not to interfere with the financial allocation for RIs over, at least, a ten year period. Therefore most countries separate the roadmap from the financial investment and inclusion of a particular RI on the roadmap does not guarantee that it will be created. The roadmap, as in this case, is the first step showing the need. Further processes are required to establish the full scientific and business cases that can justify investment.

Probably the best known roadmap is that created by the European Strategy Forum for Research Infrastructures (ESFRI). This forum was formed in 2002 to allow European Member States to share information on both existing and future RIs that could be of interest to more than one Member State. In 2004 it was decided that a long term (up to 20 years) roadmap was needed for RIs which were pan European in nature and not purely for national usage. The incentive for this came about by the creation of a roadmap for fundamental research published by the Department of Energy in the USA. Subsequently the European Council mandated ESFRI to officially create the roadmap. The first roadmap took two years of intensive work by over a 1000 scientists using specific criteria for selection. This first roadmap was published in September 2006 and subsequently adopted by the Competiveness Council. It was always acknowledged that the first roadmap would be incomplete and subsequently two further revised roadmaps have been produced.

The first roadmap resulted in two consequences. The first was that groups that had not previously considered forming a European RI started to look how they could benefit from working together including the humanities and social sciences. This was especially true for those working in the environmental and bio-medical fields which were not included in the first roadmap. That there was some opportunism taken by some groups is true, but these groups have not stood the test of time and have largely withered away through lack of leadership. The second consequence was that almost all Member States created their own national roadmaps for research in general resulting in

national research investment strategies. The ESFRI website³ has links to all these although the website is in need of updating.

Several lessons were learnt as a result of these exercises:

- If a group of scientists behind a particular RI did not already exist, forming one as a result of the roadmap exercise did not work. In other words the projects had to be fairly mature already. One of the criteria for inclusion was that the particular RI had to have its own website.
- There needed to be at least one champion for each RI (normally there were many) but if it was to be seen as an “add on” to someone’s portfolio then the chances of it succeeding would be slight.
- There was a distinct lack of managerial experience for running international RIs across Europe
- There were a number of ad hoc legal and financial structures including national laws preventing investment in not for profit companies in other countries that needed to be sorted out.
- Many policy makers and politicians did not understand the concept of the RI ecosystem and their impact on the socio-economic drivers.

As a result of these issues a number of follow on steps were taken. These included the creation of a skeletal legal structure (the European Research Infrastructure Consortium agreement, ERIC). This tackled issues such as taxation, employment rights, access policies etc. It was realised that funding of a “preparatory phase” was needed before any of the projects could go forward and be constructed. This was funded under an EC programme

To address the need to train suitable personnel and to inform policy makers the project “Realising and Managing International Research Infrastructures (RAMIRI)” was funded under two rounds by the European Commission. About 300 people have now attended this course which is focused on the day to day issues that need to be taken into consideration for setting up and running a RI. A handbook has been produced by the RAMIRI consortium and is available on their website. Another action was that many of the existing physical national RIs formed the European Research Facilities (ERF) group which complimented the international RIs such as CERN who were members of EIROFORUM. These two grouping started to share best practice, not only for managing RIs, but also in relation to public outreach and adopting appropriate methodologies for assessing socio-economic impact. It is likely that the ERF will take over the long term responsibility for RAMIRI.

Learning from the experience of other roadmaps, it is suggested that in the case of the South African RI Roadmap:

- This roadmap should be treated as a start of a process. Most of the RIs described are not at a sufficiently mature state to be taken forward without significant further work.
- This roadmap should be a tool to invigorate research and innovation in South Africa. It should be the object of creative discussion by all relevant stakeholders
- Both policy makers and researchers need training in preparing cases for support, realising and managing national infrastructures.
- It would be wise to consider a legal template that could be adopted by all national RIs with a specific emphasis on good governance.

³http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=esfri

- Lessons should be learnt from other countries that have shown that co-locating RIs with universities and industry results in economic regeneration.
- Staff should be seconded (e.g. to ESRF) for periods to learn how such facilities are managed and how the wider RI eco-system is encouraged
- All countries suffer from a lack of experienced personnel to run and manage national RIs. South Africa should consider an internal training programme including short secondments to RIs in other countries to build up a cadre of experienced leaders.

7. Relevance of research infrastructures to South African research priorities

This chapter summarises the more important government policies and strategies that define the national priorities for research and against which proposed RIs for inclusion in the roadmap need to be assessed. It commences with a brief account of an earlier assessment of research infrastructure requirements that has taken cognisance of policies and priorities prior to 2006, followed by an outline of subsequent policy developments that impact on research and research infrastructure.

7.1 The 2006 NACI Research Infrastructure Assessment

The first attempt to assess the research infrastructure requirements of South Africa's National System of Innovation (NSI) was commissioned in 2006 by the South African National Advisory Council on Innovation (NACI). The report entitled "A Study on the Required Physical Infrastructure to attain the Vision of the NSI", although not conceptualised as a roadmap, was identified as such by Stefano Fontana in his 2007 "Compendium of research infrastructure roadmaps and of the international dimensions of infrastructures"⁴. The NACI report was primarily an assessment of the research infrastructure required in support of the National Research and Development Strategy (NRDS) of 2002 in which priorities for the country were articulated under technology missions and science missions. The technology missions identified the need to meet key national and social objectives, such as poverty reduction, advanced manufacturing, resource based industries, new and emerging technologies and innovation. The science missions, on the other hand, emphasised the importance of making an impact on the global stage in specific areas where the country can contribute to leading-edge global knowledge. These include areas where there is an obvious geographic advantage, such as astronomy, palaeoanthropology, biodiversity, Antarctic research and unique geological features, as well as areas where South Africa has acquired a knowledge advantage such as indigenous knowledge, biodiversity, deep mining technology, technologies for diseases of poverty, an integrated approach to HIV/AIDS vaccine development, fluorine technology and others. However in assessing the research infrastructure needs the NACI investigation also took cognisance of various strategies developed by the DST and other government departments before and after publication of the NRDS such as e.g. the National Biotechnology Strategy (2001), the National Biodiversity Strategy and Action Plan (2004), the 2004 Indigenous Knowledge System policy of the DST, the Advanced Manufacturing Technology Strategy in 2003, the National Nanotechnology Strategy of 2006 and several others. In addition, cognisance was also taken of other policy developments such as e.g. the establishment of the South African National Biodiversity Institute (SANBI), a statutory body mandated by the National Environmental Management: Biodiversity Act 10 of 2004, to coordinate research and to monitor and report on the state of biodiversity in South Africa by way of policy advice.

The outcome of this NACI initiative had a significant impact on the development of research infrastructure in the country. Not only was the establishment of a Chief Directorate tasked with research infrastructure created within the DST, but ever since then Government's investment in research infrastructure has increased considerably and estimated to be in the order of R 5 billion. A part of this investment is through the National Equipment Programme (NEP) and the National Nanotechnology Equipment Programme (NNEP) managed on behalf of the DST by the NRF. These two programmes make provision for state-of-the-art research equipment on a competitive basis to universities and science councils. Both the NNEP and the NEP aim to ensure the establishment of

⁴<http://www.oecd.org/sti/sci-tech/41996708.pdf>

world-class research infrastructure in the National System of Innovation (NSI) that will not only enable researchers to perform cutting edge research and technology development, but also contribute to the advancement of human capacity development and the promotion of national and international research collaboration. Although sharing of this type of research equipment is encouraged wherever feasible, institutions with successful applications are generally obliged to make a one third contribution to the cost of the equipment, and must take full responsibility for housing, maintenance and operation of the equipment.

Important to note is that this type of equipment, owned and managed by the host institutions is not considered for inclusion in this RIR, although the possibility is not excluded that a collection of such equipment items presently distributed across several institutions may be reconfigured to become part of a distributed research platform under the RIR process.

7.2 The Ten-Year Innovation Plan

A major policy intervention that builds on the NRDS is the DST's Ten Year Innovation Plan (TYIP)⁵ which is designed to "drive South Africa's transformation towards a knowledge-based economy, in which the production and dissemination of knowledge leads to economic benefits and enriches all fields of human endeavour". It identifies five areas, the so called "Grand Challenges" of strategic importance for innovation. These are "Farmer to Pharma" (now generally referred to as Bio-economy), "Space Science and Technology", "Energy", "Global Change" science with a focus on climate change, and "Human and Social Dynamics". The plan recognises four cross-cutting drivers which will be key in assessing progress in these multidisciplinary priority areas, viz. human capital development; knowledge generation and exploitation; knowledge infrastructure; and enablers to address the "innovation chasm" between research results and socio-economic outcomes. The plan emphasises that economic growth of the country will accelerate with the right mix of investment in knowledge stocks and knowledge infrastructure and concludes that state-of-the-art infrastructure, modern laboratories and research institutions, and an NSI that is linked to the rest of the global scientific community are among the prerequisites for the successful implementation of the Plan. Regarding RI the Plan also highlights the need for:

- Life-cycle planning of R&D infrastructure, including depreciation, skills needs and running costs, as well as
- Strengthening South Africa's infrastructure development through appropriate international connections in order to become a preferred destination for S&T investment, with the location of major international research hubs across the grand challenge domains

This policy document does not spell out in any detail the type of research infrastructure required and only brief reference is made to some types to under different challenges, such as e.g.:

- Bio-economy – The establishment of appropriate technology platforms, and R&D and innovation infrastructure (including structural biology, functional genomics, etc.) that facilitate diagnostic and medical solutions and to bridge the gap between research and commercial implementation.
- Space Science - Observation satellites as RI and other RIs required for Earth observation.
- Energy – Pilot-scale plants for the production of hydrogen by water splitting, using either nuclear or solar power as the primary heat source.

⁵Department of Science and Technology, 2008. Innovation Towards a Knowledge-Based Economy: Ten-Year Plan for South Africa (2008-2018) 32p.

- Global Change - global monitoring capabilities on Marion Island, Antarctica and the Southern Ocean in partnership with other nations.

The reliance on research infrastructure is however spelt out in considerably more detail in challenge specific strategic and policy documents as well as through actions that have been developed and implemented since publication of the 10-Year Plan. First and foremost among these are the following:

7.2.1 The Bio-economy Strategy

This strategy builds on what was referred to in 10-Year Innovation Plan as the “Farmer to Pharma” Grand Challenge and even though the latter covers the whole spectrum of the bio-economy (health, agriculture and industry) the strategy recognises that the focus of the challenge was too narrowly focussed on biotechnology. The new strategy is inclusive of other disciplines such as information technology, social sciences and engineering and therefore embraces a more inclusive approach to research-based solutions for the agriculture, health and industry sectors.

The strategy is designed to create an enabling environment for the various stakeholders with the DST, as lead agent of this strategy, committed to engage on a continuous basis with the various stakeholders in government departments, the private sector and the research community to promote cooperation, facilitate the strategy’s broad implementation, and ensure synergy, alignment and better coordination of activities. It is recognised that the success of the Bio-economy Strategy is dependent on:

- The collaboration of the different government departments in setting the priorities, providing the necessary funding and developing the required human capital
- The full integration of R&D across sectors into the appropriate line departments in order to improve synergies within the national system of innovation
- Adequate funding for life sciences disciplines and large research infrastructure and platforms to raise the country’s production of patents in the life sciences.

The strategy emphasises that the competitiveness of the country’s bio-economy is underpinned by the need to develop strategic competencies and infrastructure. This can be achieved by providing a suite of incentives for innovation, which, from a RI perspective include the development of:

- Technology service platforms
- Pilot-scale infrastructure
- Incubation facilities

Regarding technology service platforms, the strategy identifies the need for these to be made centrally available by way of appropriate governance structures, rather than the various role players such as universities, science councils and others having to independently source the latest equipment and knowledge at great financial expense. Various specific areas are identified where investments are required to develop and or upgrade critical R&D infrastructure such as e.g. animal vaccine capabilities at Onderstepoort Veterinary Institute; the need for accredited R&D infrastructure to develop diagnostic, therapeutic and preventative healthcare products; investment in pilot and demonstration-scale units for bio-processing and wastewater treatment.

7.2.2 The 10-Year Global Change Research Plan for South Africa

This document⁶ provides a comprehensive account of the multidisciplinary research approach required to understand global change, its impact on the environment and society, and mitigation and adaptation for sustainability. The plan identifies a number of key research themes under four cross cutting knowledge challenges. The importance of RI for monitoring and observation features strongly under the knowledge challenge of “understanding a changing planet” with an emphasis on the need for:

- “building South Africa's existing monitoring networks and developing new networks to collect appropriate data at the right scales to identify the drivers of change, their effects and thresholds of concern. This will require observations of the land, oceans and atmosphere, using both in situ and remote-sensing technologies;
- acquiring the ability to coordinate and integrate the activities of different observation systems;
- developing information systems infrastructure which can ensure secure archiving, interoperability and accessibility of data collected through earth observation;
- securing existing data which may provide valuable baselines for detecting change;
- developing advanced systems analysis and modelling capability; and
- developing systems for monitoring the effect of adaptation and mitigation measures on global change.”

7.2.3 Human and Social Dynamic in Development Grand Challenge (HSDD GC) Science Plan

This science plan is based on two conceptual developments of this Grand Challenge⁷, viz. the *Concept Paper: Human and Social Dynamic Grand Challenge* and further elaborated upon in the *Strategic Framework: Human and Social Dynamics in Development*. According to this science plan the DST seeks to mobilize the scientific community around the following four core thematic areas of research which underscore the “Grand Challenge”

- Science, technology and society.
- The dynamics of human and social behaviour.
- Social cohesion and identity.
- Societal change and the evolution of modern society.

In doing so it will act as a catalyst, facilitator and coordinator, bringing together researchers, scholars, funders, policy-makers and decision-makers to promote authoritative research in the social sciences and humanities and augment the capacity to do so through effective collaboration. In this way the DST will enhance the production and use of reliable research and information supportive of effective decision-making and policy dialogue. Among the Instruments and modalities for implementing the plan the DST will support the following types of RI:

- Longitudinal Studies, of which not many exist in this ‘Grand Challenge’ area, are considered important in the social and behavioural sciences to understand the dynamics of change by describing, analysing and explaining the impact of social processes by repeated observation over time.

⁶Department of Science and Technology, 2010, 10-Year Global Change Research Plan for South Africa, 43p

⁷Department of Science and Technology, 2010. Human and Social Dynamic in Development Grand Challenge (HSDD GC) Science Plan, Final Draft, 34p

- Knowledge repositories and key e-infrastructures to promote usage and exploitation by a large community of scientists and other users. Support is envisaged for:
 - “The provision of a high-capacity and high-speed communications network interconnecting researchers and institutional networks, and support for the provision of computer and communications infrastructures.
 - The exploitation of such infrastructure to ensure critical mass, economies of scale and a cohesive approach to the development and deployment of social science data bases.
 - The promotion of their coherent use and development, in particular, through trans-national access, and support for researchers in accessing data bases internationally.
 - Research e-infrastructure by fostering the further development of global connectivity of high-capacity and high-performance communication and grid infrastructures and their adoption by user communities where appropriate.
 - Support the construction of new infrastructures and major upgrades of existing ones to promote the emergence of new research facilities.”

7.2.4 Establishment of South African National Space Agency (SANSA)

The vision for the Space Science Grand Challenge of the Ten Year Plan is that the country should be among the leading nations in the innovative utilisation of space science and technology in order to enhance economic growth and sustainable development for the improvement of the quality of life. SANSA⁸ was established in 2009 to “provide for the promotion and use of space and co-operation in space related activities, foster research in space science, advance scientific engineering through human capital, and support the creation of an environment conducive to industrial development in space technologies within the framework of national government policy”.

With the establishment of SANSA two key RIs were placed under its jurisdiction, viz. the previous CSIR Space Application Centre (SAC) (now Space Operations) in Hartbeesthoek and the previous NRF Hermanus Magnetic Observatory (HMO) national facility (now Space Science), both major infrastructure platforms for space research. The following research infrastructure now constitutes part of SANSA:

- *Earth Observation* - The SANSA Earth Observation facility drives and coordinates space based earth observation activities. It collects and provides data and value-added services for earth observation research to support South Africa's policy, decision-making, planning, resource & environmental management, economic growth and sustainable development. This includes all the computer systems for storage, processing and delivery of satellite imagery to the consumer and also the Earth Observation Data Centre which houses the satellite imagery archive.
- *Space Observations* - SANSA Space Operations provides state-of-the-art ground station facilities and services, for satellite tracking, telemetry and communication activities, as well as launch support, in-orbit testing, mission control and space navigation.
- *Space Science ad Space Weather* - SANSA Space Science is responsible for monitoring the space environment over the Southern African region, the southern Indian and Atlantic Oceans as well as part of Antarctica, and is member of global networks of similar organisations throughout the world. Instruments are deployed throughout South Africa, Namibia, Antarctica, Marion Island and Gough Island. The Space Weather Centre provides an important national service by monitoring the sun and its activity to provide information, early warnings and forecasts on space weather conditions and its impact on communication satellites. SANSA Space Science is furthermore installing magnetotelluric stations in various

⁸<http://www.sansa.org.za/>

locations around South Africa to observe and study the variations in the ionosphere and in geomagnetically induced currents.

- *Space Engineering* - includes state-of-the-art satellite assembly, integration and testing services, satellite systems and sub-systems coordination and development conducive to industrial participation in satellite system development and sub-system development.

7.2.5 The National Hydrogen and Fuel Cell Technologies Research, Development and Innovation strategy

Although approved prior to the finalisation of the Ten Year Plan, its implementation is closely aligned with the objectives of the Energy Grand Challenge and branded as Hydrogen South Africa (HySA). The overall goal of HySA is to develop and guide innovation along the value chain of hydrogen and fuel cell technologies in South Africa. South Africa's rich endowment of the platinum group metals (PGMs), in particular platinum, provides it with a competitive advantage in the development of fuel cell catalysts. The strategic goals include the development of local cost competitive hydrogen generation solutions based on existing know-how; creating wealth through value added manufacturing of PGM catalysis and promoting equity and inclusion in the economic benefits of South Africa's resources. The strategy was implemented by way of a hub-and-spoke model which links science councils and universities with industry and international research, development and innovation centres. This approach saw the establishment of a distributed research infrastructure for hydrogen and fuel cell research by way of three centres of competence (CoCs) as a delivery model. The Hydrogen South Africa (HySA) CoCs are:

- HySA Systems: Systems Integration and Validation Centre of Competence
- HySA Catalysis: Hydrogen Catalysis Centre of Competence
- HySA Infrastructure: Hydrogen Infrastructure Centre of Competence

7.3 Other South African policy based R&D priorities

7.3.1 The South African Strategy for the Palaeosciences

South Africa unique geographical advantage from the perspective of the palaeosciences was already given due recognition in the National Research and Development Strategy of 2002 and subsequently in the African Origins Platform Strategy of 2006. This revised strategy is somewhat more embracing as it provides a holistic framework for the development of the palaeosciences, i.e. palaeontology, palaeo-anthropology, archaeology, and all related disciplines. Five interrelated goals are identified in the strategy two of which have a direct bearing on appropriate research infrastructure.

The first of these addresses the capacity of institutions to conduct research and to develop the required research capacity to do justice to the palaeo-heritage of the country which is impacted on by substantial recent technological advances in non-destructive imaging techniques, such as CT scanners and synchrotrons. These in turn generate a tremendous amount of data, with the result that data capturing, storage and management is becoming increasingly important for research and the competencies of researchers in the palaeosciences. The disciplines also require access to a variety of different accurate dating techniques, with the age dating of samples over the past 2 million years, i.e. the emergence of humans, of particular importance. However, the study of associated fossil material and geological environment is also key in understanding natural processes of climate change and their impact on life in the past for which purpose accurate biogeochemical analytical facilities have become indispensable. These needs will largely be addressed with the completion of the accelerator mass spectrometry (AMS) facility at iThemba LABS in Gauteng.

The other goal addresses the importance the of extensive palaeoscience collections as a basic resource that will support fundamental and applied research well into the future. Many of the collections are housed and curated in museums and universities, but these have seen the erosion of their human and infrastructural capacity over time, leaving many of them under-staffed and hence as suboptimal facilities. There is also no national set of minimum standards for the curation of collections, protocols to access these collections and no comprehensive centralised databank of material available in the various collections. This will, according to the strategy, require the organising of the disparate collections into a research infrastructure of clusters of mutually complementary expertise.

7.3.2 The Charter for Humanities and Social Sciences

The Charter for Humanities and Social Sciences⁹ was commissioned as a special project by the Minister of Higher Education and Training in 2010 to identify key interventions required in uplifting the status and quality of research and education in the Social Sciences and Humanities (SSH) in Higher Education in the country. This was prompted among others by the concerns voiced by the professional associations and stake-holders in the broader humanities, among others through the Academy of Science of South Africa (ASSAf), which initiated a consensus study on this topic in 2008¹⁰, of the downscaling of the importance of the human and social forms of scholarship for a variety of valid reasons. This downscaling has had a serious effect on the quality of the academic enterprise and on the quality of the research output in these disciplines. The Charter identified all the major shortcomings and proposes several key interventions to overcome these. Among these an institutional arrangement is proposed whose role it will be to enhance scholarship, research and ethical practice in the fields of HSS, including to “facilitate the process of gathering together and making available and easily accessible research and other data related to the HSS in South Africa”.

Ready access to data and information is seen as one of the key interventions referred to as “Catalytic Projects” and defined as having to produce “benefits to the research project for the higher education system, and indeed society as a whole, by dynamising the fields, the disciplines and interdisciplinary work, and thereby also increasing the capacity to research further, theorise better and contribute to the raising of our status in the global academic commons...” Although not considered as research infrastructure in the Charter, several of the recommendations under this key intervention to be successful will have to rely on the availability of heritage and the systematic collection of data over protracted periods of time to have maximum impact. Reference is made among others to the importance of heritage institutions and heritage sites as vital research-producing areas, such as e.g. local authority-linked museums; the need to work with rural communities in order to preserve heritage, oral performance and indigenous know-how; and in understanding and monitoring rural transformation, rural production and livelihoods, biodiversity and health.

7.3.3 Sustainable Development and the Environment

From the perspective of sustainable development and the environment, the Department of Environmental Affairs (DEA) has taken the lead in developing several government policy documents.

⁹ Department of Higher Education and Training, June 2011, The Charter for Humanities and Social Sciences, 68p

¹⁰ Academy of Sciences of South Africa, August 2011, Consensus Study on the State of the Humanities in South Africa: Status, prospects and strategies, ISBN-978-0-9814159-3-2, 50p

First and foremost of these are the National Framework for Sustainable Development (NFSD) of 2008 and the subsequent *National Strategy for Sustainable Development and Action Plan* (NSSD)¹¹ which builds on the NFSD. The NSSD identifies five strategic priorities, several of which require substantive S&T inputs for effective understanding, implementation and monitoring of the environment. Strategic Priority 3 e.g. refers in particular to the promotion of innovation, science and technology as one of the key enablers of implementation. It lists as a strategic goal the need to “grow and strengthen a portfolio of niche high-potential science and technology capabilities, as well as actively facilitate the exploitation of both existing and new capabilities to support sustainable development priorities and green economy ambitions” and identifies a number of interventions to achieve this goal. The strategic goals under Priority 4 to build sustainable communities, on the other hand, has a strong focus on the reduction of poverty, social cohesion and a decent quality of life for all. This will by implication require substantive involvement of the social sciences and humanities to provide evidence-based policy advice to Government on a host of pertinent issues for implementation.

In one of its concluding chapters the strategy highlights the necessity of targeted science and technology interventions in the achievement of the sustainable development priorities. It emphasises in this regard the need to develop strategic partnerships between government departments, industry, research institutions and communities.

*The National Protected Areas Expansion Strategy for South Africa 2008*¹², on the other hand, highlights the importance of expanding the existing network of areas where the majority of biomes and marine bioregions can be protected, as the present network of protected areas falls short of sustaining biodiversity and ecological processes. The identification and proclamation of additional areas is therefore considered essential for the conservation of South Africa’s biodiversity and in the mitigation of the impacts of climate change on biodiversity. The aim is also to secure the sustainable provision of important ecosystem goods and services, such as the production of clean water and natural products on which we all depend, even in the face of stresses such as climate change. Marine protected areas in turn are of particular importance for sustainable fisheries, e.g. by protecting nursery grounds for commercially important fish species. The implementation of this strategy will therefore ensure that protected areas play a central role in the country’s climate change adaptation strategy.

The significance in both the above two strategies from the perspective of research infrastructure lies therein that any assessment of the impact of climate change and other anthropogenic activities on biodiversity and ecosystem services can only be done with the aid of long-term observation and monitoring of the biodiversity within the various biomes and marine bio-regions.

7.3.4 Health

The National Health Research Committee (NHRC), a statutory body established in terms of the National Health Act, Act No. 61 of 2003, is mandated among others to:

- Identify and advise the Minister on health research priorities for the country
- Ensure that the health research agenda and resources focus on priority health issues
- Develop and advise the Minister on the application and implementation of an integrated national strategy for health research

¹¹Department of Environmental Affairs, 2011, *National Strategy for Sustainable Development and Action Plan*, 2011 – 2014, 43p

¹²Department of the Environment 2010, *Government of South Africa*, Pretoria, 41p, ISBN 978-1-919976-55-6

In accordance with this mandate, the NHRC convened a summit¹³ to set priorities for health research, and to identify the research requirements of the strategic priorities of the National Department of Health (DoH). The summit identified seven areas that need to be addressed to strengthen the health research system of the country. These include the stimulation and support of new and innovative research programmes that address the quadruple burden of disease (i.e. HIV/AIDS and TB; maternal and child health; non communicable diseases; and violence and injury), health systems strengthening and combating the social determinants of health, as well as the development of health research facilities and infrastructure in academic health complexes, which are required by the National Health Act of 2003 to conduct research into priority health problems of South Africans.

That these recommendations have by and large been accepted by the DoH is indicated by a subsequent announcement by the Minister of Health that the research budget of his Department is to increase to more than 2 % of its total budget over the next ten years¹⁴.

7.3.5 Energy

The Department of Energy's Integrated Resource Plan (IRP) for electricity¹⁵ is based on the consideration of several scenarios in order to provide a balanced approach to secure the country's electricity supply for the foreseeable future with due cognisance of South Africa's commitments to mitigating climate change as expressed at the Copenhagen climate change summit. Various key constraints and risks, such as reduction of carbon emissions, water, job creation and also the most recent technological developments for renewable energy resources and their costs were taken into consideration. The plan proposes a reduction of the present dependence of ~90% of the country's reliance on coal based generation sources to ~65% in 2030 by growing the share of nuclear energy, renewable sources and others such as hydroelectric as well as open and closed/combined cycle gas turbine generation. A host of areas where research needs to be conducted in order to meet the goals of the plan are referred to. This Plan will feed into the Integrated Energy Plan presently under development by the Department of Energy that will also address the challenges for the petrochemical sector responsible for the country's oil and gas based energy needs. Several of the challenges facing this sector are identified in the National Development Plan which highlights aspects of pertinence that impact directly on the future of this industry. This relates primarily to natural gas as an alternative to energy production in order to cut South Africa's carbon intensity and greenhouse gas emissions.

Government's resolve to considerably enhance efficiencies in the use of energy is highlighted by the recent publication for comment of a revised Energy Efficiency Strategy¹⁶. This strategy, benchmarked on international best practice, recognises among others that technological advances hold significant potential for improvements in energy efficiency and in this regard refers to the desirability of a dedicated R&D programme in energy efficiency.

¹³Mayosi BM, Mekwa NJ, Blackburn J, et al. 2011 National Health Research Summit Report: Strengthening Research for Health, Development and Innovation in South Africa. Department of Health, April 2012. 9p.

¹⁴Purposeful support for health research in South Africa, S Afr J Sci. 2012; 108 (5/6), Art #1268, 1 page, <http://dx.doi.org/10.4102/sajs.v108i5/6.1268>

¹⁵Integrated Resource Plan for Electricity, March, 2011, Department of Energy, Pretoria, 73p

¹⁶Department of Energy: Draft Second National Energy Efficiency Strategy Review, November 2012. Notice 1000 of 2012, Government Gazette No 35920, 50p.

7.3.6 Water

The proposed National Water Resource Strategy - 2 (2012)¹⁷ is a very comprehensive draft strategy document that outlines in great detail the complexities and challenges that South Africa faces in ensuring a sustained supply of water for the foreseeable future.

A number of technical and enabling strategies are identified that will guide the implementation of overarching core strategies and associated key strategic actions support the NWRS-2, with research and innovation being acknowledged as a fundamental contributor to understanding South Africa's water resources and developing many of the techniques and tools used for water management, and to inform the development of national water policy and enabling legislation.

The core objectives and actions of the strategy are as follows:

- Lead and direct solution-orientated research and innovation targeted towards challenges experienced within the water sector
- Align the water sector Research and Innovation Strategy, the National R&D Strategy and the National System of Innovation
- Promote maximum research impact, by providing mechanisms for support and uptake of innovative solutions within the water sector
- Ensure inclusive, coherent and well-coordinated participation by all role players in water-related research and innovation
- Ensure that water sector Research and Innovation is adequately resourced and that resources are used efficiently and effectively
- Draw on indigenous knowledge systems for research and innovation in the water sector

8. Research infrastructures in the context of scientific domains

Within the general context of RIs described earlier, the analysis of the main features found in the **S&T domains selected for the development of the South African RI Roadmap** where RIs should play a role will be described by using the following template:

- *Science domain characterisation.* It describes the rationale for the investments in RIs, main goal of the domain chosen and its possible interaction with other S&T domains to support interdisciplinary work.
- *Types of RIs needed to advance knowledge.* It addresses the rationale behind the use of RIs in that S&T domain and at what extent they are necessary in South Africa. General characterisation in terms of single-sited, distributed or global RIs is mentioned.
- *Identification of RIs available in South Africa.* A general identification of RIs available today or required in the future. This information will be completed with the individual description of specific RIs included in this report.
- *RIs in other countries with open access to the South African scientific community.* The roadmap can also include other RIs available outside South Africa with access to the South African scientific community. This access might exist today through previous agreements signed by universities, research centres or governmental units, or by signing up specific MoUs with other RI management entities or governmental agencies abroad.
- *Constraints to facilitate the exploitation of results in the RI.* This factor considers the relevance of collecting, accessing, recovering or processing scientific data and to facilitate remote access to other infrastructures; also, any other type of constraints (political,

¹⁷ <http://www.dwa.gov.za/nwrs/NWRS2012.aspx>

geographical or technical ones) which could hamper the full usefulness of the RI (or its launching) in the domain.

The **S&T domains identified for the South African RI road map** are depicted in Figure 7. The grouping was made for convenience purposes in order to manage a limited set of domains and is arbitrary in nature. The identified domains are not totally independent and it is expected that **interdisciplinary RIs** will become more common in the future, cutting across several of these domains.

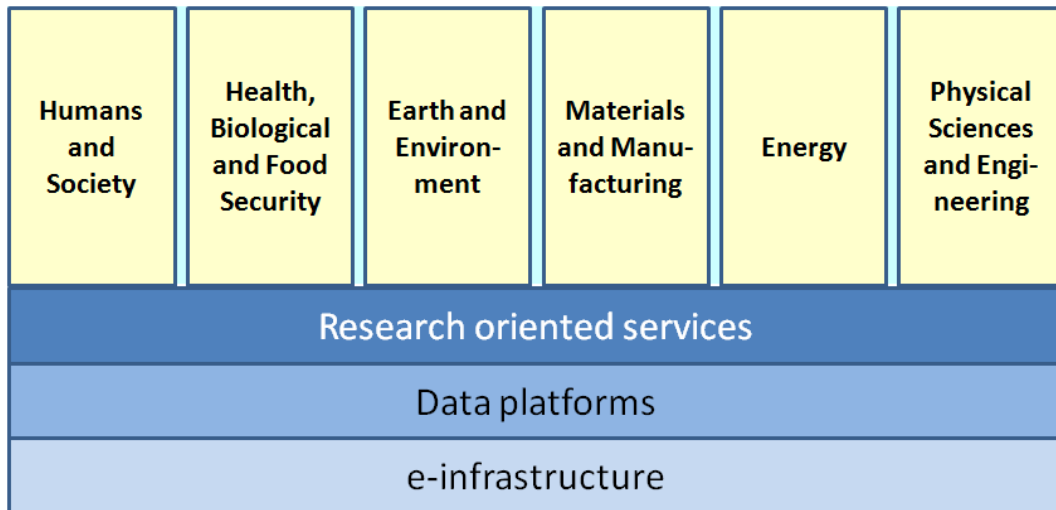


Figure 7: S&T domains of SARIR

The common goal of the **three horizontal domains** is to provide a common set of services to the scientific community in order to facilitate their work on across the range of RIs. This entails the following:

- *e-infrastructure*: Essential infrastructure to support data exchange, cooperative work and remote access. The very fast evolution of bandwidth based on fibre optics but also in the broadband mobile access networks can provide unlimited access from anywhere.
- *Data platforms*: The trend towards “*data-driven science*” implies that many of the research teams will base their scientific activity on the processing of collected data and remote accessed. Data management services therefore became essential ingredients today to ensure the competitiveness of research groups.
- *Research oriented services* are specific set of services linked to the RI to support not only data management but also the development of scientific instruments, capabilities for product development (moving from prototypes labs to industrial prototypes) and other general-purpose infrastructures. In all these cases, data services and broadband networks are needed to facilitate the remote use of those facilities.

8.1 Humans and society

Research in the Human and Social Sciences (HSS) is essential for social, economic and cultural development and transformation in South Africa. Yet a number of recent studies, such as the Consensus Study on the State of Humanities in South Africa: Status, prospects and strategies¹⁸ and

¹⁸Academy of Science of South Africa, 2011.Consensus Study on the State of Humanities in South Africa: Status, prospects and strategies. ISBN- 978-0-9814159-3-2, 160p

the Charter for Humanities and Social Sciences¹⁹ have highlighted the diminishing role of these disciplines in academia and emphasised that they should be enabled to play a stronger role in the development of society, the economy and intellectual life in South Africa. The need for an elevated role of the HSS in the country's development has also been recognised by the Department of Science and Technology in their Ten-year Plan²⁰ by highlighting human and social dynamics as one of the grand challenges of the plan. The objective of this grand challenge is stated to increase and deepen research to improve scientific understanding and practice in a range of fields, while contributing to the development of evidence-based public policy that improves human wellbeing. The science plan developed for this grand challenge²¹ mentions specifically the need for research infrastructure and longitudinal studies to achieve this objective.

An important issue raised at the workshop sessions on HSS in July 2013 is that many academics in the HSS do not think in terms of national research infrastructure and the need to be moved to a culture of sharing and co-operation on a national and even international level. The need for a national workshop/conference was expressed to alert academics of the importance of research infrastructures as well as sharing of data and collaboration to elevate the quality and impact of research in the HSS in the country.

- *Types of RIs needed to advance scientific knowledge.*
 - Digital libraries with every historical or artistic document in museums or public and private collections of research interests including provenance and other data for identification.
 - Platforms for socioeconomic surveys and post-processing (socio-economic and anthropological observatories)
 - Satellite monitoring of urban evolution, migration, teledetection, etc. data continuously updated.
 - Other common services like dating facilities or preservation of cultural heritage.
- *Identification of RI in South Africa.* They are disseminated and dispersed across the country in several universities, research centres and entities.
 - Health and Demographic Surveillance Sites as a distributed platform of observation sites primarily kinked to the Medical Research Council (MRC) but with significant potential to the social sciences dimension. Existing sites are Agincourt, Mpumalanga (Wits), Africa Centre, KZN (UKZN), Dikgale, Limpopo (UL)
 - A few data repositories such as those managed by the HSRC the SADA of the NRF, Stats SA, and others.
 - A centralised repository for archiving and re-use of digital language resources the Resource Management Agency was recently established at NWU.
 - Some social surveys are presently conducted from time to time by the HSRC for various customers, primarily in government.
- *Other RI available in other countries with open access to the South African scientific community.* Practically, all countries have RIs in this field and research cooperation between countries should be encouraged. The European CLARIN is an example where there are already strong linkages with South African scientists.

¹⁹Department of Higher Education and training, 2011, Charter for Humanities and Social Sciences, Report commissioned by the Minister of Higher Education and Training, 68p

²⁰Department of Science and Technology, 2008, Innovation towards a Knowledge-Based Economy: Ten-Year Plan for South Africa (2008-2018) 32p

²¹Department of Science and Technology, 2010, Human and Social Dynamic in Development Grand Challenge (HSDD GC) Science Plan, 34p

- *Constraints to facilitate the exploitation of results in the RI.* A crucial component is the access to digital information disseminated in many sites where data interoperability is a basic requirement. Digitisation takes time and is costly. Several international IT companies have shown a willingness to cover such costs in exchange for usage of the data.

8.2 Health, Biological and Food Security

This domain groups three main areas related to live beings: health, biology and food security. Five sub-domains have been identified: **Agro-food** (crops production, food security, GMO, fight against plagues, biobanks, etc.), **Identification and processing of life beings** (genomics, proteomics and metabolomics), **Health systems** (medical imaging, health services including telemedicine, micro-robotic surgery, brain simulation, nuclear medicine, etc.), **Biodiversity** (identification and preservation of endangered species) and **Structural biology** (use of synchrotrons and neutron sources for analysis of synthesis of life beings components like proteins).

These sub-domains are not isolated and research and innovation activities are moving very rapidly towards multidisciplinary support by a combination of centralized and distributed RIs. A commonality found in potential research infrastructures related to this field is that the use of very large centralized equipment is not necessary.

Multidisciplinary affects this domain and links to research facilities in other domains are very relevant. Specifically, examples could be found with energy (i.e. biomass), human and society (i.e. with the development of epidemiological studies), physics and engineering (i.e. with microscopy or synchrotron facilities), etc.

- *Types of RIs needed to advance scientific knowledge.* The wide range of activities included is also reflected in the large variability of RIs which can be needed in S&T development. RIs from other domains could be also used. (e.g. “synchrotrons” are also used in life sciences).
 - GMO facilities for controlled growth (greenhouses, growth chambers, etc.)
 - Security labs (P3, P4 levels) Animal experimentation facilities
 - Genomics/proteomics/metabolomics platforms
 - Bio-banks (plants, animals, seeds, genomes)
 - Nuclear medicine and medical imaging
- *Identification of RI in South Africa.* Many South African universities and research centres have updated facilities in this domain but they are not necessarily open to the whole community or they do not facilitate its use as a “national research facility”.
 - In the health sub-domain a distinction between medical use and research use of some facilities is needed to be considered part of the roadmap. In many cases, large imaging machinery (i.e. Magnetic Resonance Imaging (MRI), Magnetoencephalography (MEG), etc.) could be used for diagnostic purposes and not for research.
 - Cyclotron-based short-life radioisotopes generators closer to clinical research and practice in hospitals. iThemba LABS have one but the dual use for research is not well solved.
- *Other RI available in other countries with open access to South African scientific community.* RIs like the above mentioned are common in many countries. Furthermore, the access to **international facilities and programs** in the field are also relevant (i.e. EMBL, EDCTP, ESRF, etc.). The irrelevance came to the need to support South African research groups and the training of new generations of scientists in close contact with other international teams. Then, is relevant to increase the interaction with other facilities by strengthening the participation of South Africa in international networks.
 - Nanotechnology facility (or part of it) for medical purposes (i.e. in connection to international efforts like IMEG in the EU)

- Facilities for structural biology in EMBL
- Access to beam lines in synchrotrons available in other countries.
- *Constraints to facilitate result exploitation.* The lack of coordinated structures at the national level constitutes the most important constraint (these facilities usually adopt the form of “service platforms” for specific uses or distributed networks). These equipment are not very large but with very fast obsolescence (and a continuous decrease in purchasing price). Two additional aspects are also relevant:
 - Growing importance of **bioinformatics resources** (and also on the training of life-sciences scientists in exploiting these techniques).
 - The **dual use** (research and medical use) of advanced equipment medical imaging systems, cyclotrons or robotic systems available in hospitals to support translational research

8.3 Earth and Environment

South Africa is particularly vulnerable to the unprecedented loss of biodiversity ascribed to anthropogenic activities as it is one of the most biologically diverse countries in the world. Its unique biodiversity and its exceptional geological record and associated ore deposits, as well as its extensive palaeontological and palaeo-anthropological heritage are globally widely acknowledged and make it an ideal laboratory to study important geological and evolutionary events in the earth’s history from the origin of life on earth to present day Earth systems processes.

- *Types of RIs needed to advance scientific knowledge.* Due to the large diversity of topics covered in this domain, RIs are also very different but not all of them are of interest to SA:
 - Oceanographic research vessels and associated equipment (i.e. research submarines)
 - Arctic/Antarctic bases
 - Distributed network of sensors for climate change and the monitoring of natural hazards (both on the sea and on land)
 - Balloons, instrumented aircrafts, etc. for atmospheric studies
 - Earth observation satellites (specific payloads such as high precision cameras)
 - Drilling probes (deep-sea and on land)
- *Identification of RI in South Africa.*
 - A platform for Marine and Antarctic Research, incorporating a state-of-the-art research vessels and research bases in Antarctica and on Marion and Gough Island.
 - Very limited facilities for shallow marine and coastal research exist at SAIAB (NRF), with others located at the marine unit of the CGS and the CSIR not readily accessible to researchers.
 - The South African Environmental Observation Network (SAEON), established within the last decade as a national facility of the NRF consists of several key sites spread across the country for long-term monitoring of the environment.
 - Instrumentation for geochemistry and dating as well as the chemical characterisation of biological material is scattered across the country in an uncoordinated way. The accelerator mass spectrometer (AMS) facility close to completion at iThemba LABS Gauteng will add an important dimension to the country’s capabilities in this domain.
- *Other RI available in other countries with open access to the South African scientific community.*
 - Access to oceanographic research vessels owned by other countries is negotiated by scientists on an individual basis but dictated by the research interests of that country and very infrequently negotiated in support the South African priority (i.e. to explore the continental platform).

- Many international facilities and platforms exist for Earth observation and South Africa already has close linkages with several of them, e.g. ILTER, GEOSS, GBIF, GOOS and GEO-BON.
- *Constraints to facilitate the exploitation of results from the RI.* As in many other domains, there is a general need of archiving and accessing data generated in scientific campaigns and also the ability to share them with similar information available in other countries. Furthermore, research on atmospheric, ocean-air interactions, climate change models, etc. requires the access to very advanced HPC facilities.

8.4 Materials and Manufacturing

Material science is a very versatile domain which serves many others domains; the domain evolution is driven today by two main forces: nanoscience and nanotechnology to characterise or develop new materials, and better instruments to “see” the matter interactions at a nano-scale. For example, the interface between bio-medicine and nanostructures is a very vibrant area for research now. **Materials RIs** are focused at understanding, developing, measuring, modifying and application improvement of materials from nano-scale to macro-scale. **Manufacturing RIs** support the design, development, processing, testing, integration and packaging of structural or functional materials from demonstration and pilot phase to full commercialisation

- *Types of RIs needed to advance scientific knowledge.* Main effort in the last years was focused towards the development of a new generation of: synchrotrons, neutron sources, nuclear microscopy systems, electron microscopy, surface science or nanotechnology facilities.
- *Identification of RI in South Africa.* South Africa has many components which could evolve towards national distributed facilities:
 - **Advanced electron microscopy facilities**, including HRTEM and aberration corrected HRTEM, SEM and electron and X-Ray analytical facilities to analyse materials at the atomic level, etc.
 - **State-of-the-art surface science facilities**, including SIMS, XRD, XPS, SAM, AFM, LEED, etc.
 - **The National Centre for Nano-structured Materials**, including electron microscopes, scanning probe microscopy, XRD, X-Ray scattering, optical characterisation, electrical characterisation and surface analysers, etc.
 - **Centre of Excellence in Strong Materials**, including electron microscopy, micro-analysis, materials strength analysis, optical spectroscopy, materials preparation facilities, thermal analysis, etc.
- *Other RI available in other countries with open access to the South African scientific community.*
 - XFEL (under construction in DESY, Hamburg)
 - Synchrotrons (i.e. ESRF, Grenoble, France)
 - ESS (under construction in Lund, Sweden)
 - Nanotechnology facilities for research on materials design and characterisation are available in many countries (i.e. IMEC facilities in the EU)
- *Constraints to facilitate the exploitation of results in the RI.* The development of a new physical RI is very expensive (lack of a large user community to compensate for the costs). It seems more feasible to enter as partner in RIs under development allowing experience in construction, usage and management. In this way, the internal community will be built up until such time as a decision to build a dedicated facility in South Africa is reached. Many future RIs will be located abroad and remote use becomes a relevant approach to facilitate their by the South African scientific community.

8.5 Energy

Energy RIs are focused at understanding, developing, measuring and application improvement of conventional and renewable energy and energy systems. In this sector, many of the potential research infrastructures could adopt the form of a “*pilot plant*” if the industrial sector were interested in. The following subdomains are identified from the RI perspective: **Nuclear energy** (fusion and fission) research facilities, **techniques for fossil energy** (shale gas extraction, biodiesel, CO₂ sequestration, etc.), **Renewable energy** (photovoltaic, concentrated solar power, wind, biomass, tide energy, fuel cells), **Energy efficiency** (in housing, factories, etc.), and **Energy distribution** (smart grids, distributed generation, etc.).

- *Types of RIs needed to advance scientific knowledge.*
 - Solar cells development capabilities.
 - Pilot plans for thermo-solar (CSP) or photovoltaic systems (with or without solar concentration (CPV))
 - Pilot plants for wind turbine testing.
 - Smart grid testing facilities
 - Nuclear reactors for fission energy research and for materials testing.
 - Participation in fusion RIs.
- *Identification of RIs in South Africa.*
 - SAFARI-1. A fission research reactor that serves mainly as a source of neutrons. A research reactor is essential to any country with an active nuclear power industry to support research in the front and back end of the nuclear fuel cycle. The reactor is also applied in medical isotope production.
 - Distributed energy research laboratories focusing on generation, transmission and distribution, as well as energy efficiency and smart grids.
- *Other RI available in other countries with open access to the South African scientific community.*
 - Concentrated Solar Power (CSP) in Almeria (Spain)
 - ILL (Institute Laue Langevin)
 - Fusion research reactors (JET, ITER, PETAJOULE, NIF, etc.) to allow the access to South African researchers.
 - Experimental fission reactors and nuclear waste treatment plants in several countries
- *Constraints to facilitate the exploitation of results in the RI.* Fission research is mainly linked to the evolution of nuclear plants while South Africa is not active in fusion research.

8.6 Physical Sciences and Engineering

This domain includes both the RIs required for space, astronomy, and equipment to support physical experiments (accelerators, optics, light sources, etc.) and also the engineering capabilities to serve the construction of sophisticated equipment in this field.

From the first dimension, it is composed by platforms, payloads and data archives from deep space missions to optical and radio telescopes. Contribute to the *knowledge of deep space* (solar system, planetology, galaxies, astrophysics, cosmology, etc.) through the use of space probes or telescopes or from the ground through specialised instruments in terrestrial (optical or radio) telescopes.

- *Type of RIs needed to advance scientific knowledge in space science and astronomy.* Due to the specific nature of this domain, experimental science requires sophisticated machinery to facilitate long distance observation and astrophysics theory confirmation. In terms of potential RIs there is a rough distinction between:

- Optical telescopes (ground based), Space based telescopes, (Array of) antenna for radio astronomy (millimetres range),
- Satellites: Earth observation satellites or space probes (to the Sun, near objects, planetary research, deep space)
- Scientific instruments (visible/infrared camera, SAR, particle detectors, etc.) and e-infrastructures for obtaining and processing data remotely obtained from several facilities on space and on ground based RIs.
- *Identification of RI available in South Africa.* South Africa is playing a prominent role in the international arena. MeerKAT in a previous phase and the future South African contribution to SKA (Square Kilometre Array) constitute a key milestone for South African astronomy. In the space sector, there are not scientific satellites in operation neither capacity for launching. The satellite launched in 2007, is not in operation although there are new plans for another observation satellite.
- *Other RIs available in other countries.* Apart from the access to ESO facilities, there are several countries with state-of-the-art telescopes which have some percentage of time open for international cooperation and others where a specific intergovernmental agreement is possible. In the satellites subdomain, the following assets are relevant for SA: Copernicus (ex-GMES) and contributions to GEOSS, access to ESA, NASA or other space agencies facilities through specific agreements
- *Constraints to facilitate results exploitation.* The cost of a new telescope to compete over the world with other countries is very expensive and South Africa should rely on agreements with other organisations to access to those facilities. South Africa has not a research satellite for Earth observation and there are many opportunities to re-launch a programme based on the current capabilities.

From the **science-driven engineering** vision, the needs came from the ability to concentrate engineering capability to support experimental science. Most advanced countries have one or more centres to support national and international activities in science (e.g. Rutherford-Appleton Laboratory in the UK, Grenoble Science Park in France or Lund in Sweden). Initially set up, in the main, to undertake fundamental physics, they have now transformed into centres of expertise to cover virtually all areas of research from biology to humanities.

Accelerators are currently employed for medical therapies, manufacture of isotopes and as possible means for nuclear fission. Light and other similar sources from 4th generation synchrotrons to free electron lasers require both accelerators and advanced beam line optics and sensors for use in biology and testing engineering components

Such facilities generate huge data sets and these centres are often the source of expertise and experience for other RIs. Furthermore, they tend to attract industries to co-locate and they also act as training institutes for skilled technicians. South Africa has the opportunity to create one of these in a national effort during the next 10 years.

9. The role of Technological Infrastructures in a South African Research Infrastructures Roadmap (SARIR)

In considering the RIs proposed for the SARIR in this report the focus has mainly been in providing the framework for those research infrastructures which address national challenges and which could serve to increase the global competitiveness of the research community in SA.

Nevertheless, even with the main goal as stated above as guide, *competitiveness* also depends on the capability to move the scientific activity to the innovation realm through deeper involvement of high-tech industrial sectors from the start.

The relationship of industry with RIs is outlined below (see Chapter 12 on Industrial Involvement) where the role of industry as provider of components and services but also as user of those RIs is discussed.

To complete this scenario, this chapter pays attention to those **infrastructures led by industry to serve their own interests to accelerate innovation**. They will be termed here as "*technological infrastructures (TI)*". The role of these TIs cannot be limited to a given national innovation system because in many cases they are promoted by multinational companies serving their global interests in a highly competitive world market where the pressure to offer new advanced products or services, or to conduct large and sophisticated engineering projects is growing very fast. To become competitive in this field, high-tech industries need to explore new technological solutions, to create and test sophisticated prototypes, to deploy experimental services and to expose them to selected users, and to be able to continuously absorb new materials and manufacturing processes. The attraction of South Africa to such companies to locate TIs here will depend on tax incentives in addition to a trained labour force and other considerations.

Within this highly competitive context, the border between "*research*" and "*technological*" infrastructures to support industrial testing and prototyping is blurred. However it is clear from other international contexts that investing in TIs in conjunction with leading research is another attraction (Medicon Valley in Sweden is a good example).

This situation is extremely relevant in many engineering areas such as wind tunnels for fluid dynamic measurements, wave tanks for coastal experimentation, pilot chemical plants, hydrodynamic testing channels, seismic testing facilities, engine/turbine testing, crash testing facilities, high-speed experimental transport lines (i.e. magnetic levitation railways, solar planes, etc.), nano-manufacturing facilities, industrial robotics, etc. All of them are very complex and expensive facilities to be designed and built by using multidisciplinary teams in large multi-annual industrial-driven projects.

Some of these kinds of facilities are also related or motivated by scientific research. The case of studying the effect of climate change on coastal areas, the testing of atmospheric pollution models, new ideas for innovative propulsion techniques or moving 3D printing techniques to actual component manufacturing, etc. benefit from close interaction with scientific research. In some cases, it has been the basis for a flourishing science-driven industrial sector.

The relevant aspect in the context of a SARIR is to decide if it is necessary or not to address this issue or, after clarifying the scope, to set up a clear fence between RIs and TIs as defined in this chapter.

This type of discussion is not totally new. For many years the discussion about the way to include some TIs in national roadmaps has appeared in many countries with different approaches depending on local factors. This discussion deals with the possibilities to use public funds for some of these TIs and the requirements to allocate experimental time with a shared scientific/industrial use, and who will pay for that. An example is that of lasers constructed for both defence and fundamental research purposes.

From the experience gained in other countries, South Africa could support some TIs based on the following conditions:

- The need for a new TI should be backed by a group of companies (not an individual one) and, if possible, by whole industrial sectors on the basis of their potential competitive gains, and scientific organisations to demonstrate the common interest in the facility and the benefits for closer ties.
- The involvement of SMEs in the proposal (including high-tech spin-offs and start-ups) should be a prerequisite.
- Evaluation would require a specific process with analysis of the benefits for the country's capacities and the alignment with governmental priorities on industrial sectors.
- Industries should cover part of the costs for the construction and operation.
- Time for scientific research on the infrastructures should be, at least, 50% of the total available time.
- The governmental support for investment cost should be based on a combination of loans and subsidies.
- Mobility and access programmes for researchers and SMEs should be expanded to cover the use of this kind of facilities.
- The funding for TIs should come from a different and additional budget in order to avoid conflict with any budget allocated for the RIs of the SARIR.

10. Criteria for prioritisation

Picking winners is not an easy game especially when the RIs proposed cover such a diverse range of disciplines and cross disciplinary areas. If money and resources were no object then perhaps there would be no need for prioritisation but the reality is that funds will be finite at any point in time. In looking at the 17 RIs included in the roadmap, they can be divided up into those that can be brought to realisation in the short, medium, long and very long term. So, for example, if the RI consists of bringing a coordinated approach to existing facilities this can be done relatively modestly and quickly. However for something like a research nuclear reactor the planning and realisation even if a decision to proceed was made now would be long to very long term before researchers could access it.

Some countries like the UK, have an agreed capital budget line over 10 years into which projects can be fitted in. This is good for policy makers since capital spend on large physical RIs is lumpy often with one or two peak spending years during construction. The ability to fit other RI spending around these high spend years is relatively easy if there is a long term commitment over a decade.

Among the other factors that have to be taken into consideration before a final decision on priorities is made are:

- Size, reputation and dispersion of the particular research community in South Africa that will use or take part in the RI
- Potential for growing a particular community
- Leadership
- Proposed governance and business model
- The maturity of the case for support
- Access
- Active data management plans
- Building on the obvious research strengths of SA
- Relevance to national priorities
- Contribution to solving grand challenges
- Stakeholder engagement plans
- Implications in embedding South Africa into international programmes
- Possible impact in terms of quality of life, economy, attracting overseas researchers, local communities etc.
- Value for money

While these may all be quantified in a more or less objective way, it has to be accepted that there are strategic reasons which have little to do with the scientific case but might be related to fairness of distribution, security reasons and local political reasons.

What is clear from the 17 chosen is that much more work is needed to prepare most of them for a final decision. The communities involved need support to make the cases robust and funds should be made available for this purpose. In the EC, so called “preparatory phase” funding has allowed aspects such as the legal and governance issues to be sorted out for European RIs in addition to preparing the scientific and technical documentation needed.

For complex proposals there are some acknowledged ways of proceeding. First a **Conceptual Design Report (CDR)** is presented outlining the general approach, the research to be undertaken, potential governance structure, societal implications and many other factors including ball park costs. The CDR is internationally refereed (the number being consistent with the size of the project) and if it passes

this stage it moves on to a much more detailed report (**Technical Design Report - TDR**), which will outline far more detail including exact design work, further experimentation where necessary to support a particular way forward and a detailed life time costing and impact analysis. Again the TDR will require reviewing including by finance and legal experts to ensure the case is robust and there are no hidden surprises (especially financial ones) that may lead to the RI not being successful. In the UK's Gateway process, the CDR is labelled "Gateway 0 – the science case" and the TDR "Gateway 1 – the business case." The verdict on Gateway 1 will either be red or amber but never green until the funds are finally committed. The project then moves to Gateway 2 which looks at how the RI will be procured. Gateways 3 and 4 look at completion of the RI for service, and then the operating mode. Finally at the end of an RI's life, Gateway 5 looks back at the contribution of the RI over its lifetime and final dispersal of staff, curation of outputs, and many other aspects of shutting a facility down.

It can be readily seen that the expertise required is not naturally found in traditional academics and is more in line with project management in general. However academic leadership is required and those taking a lead on realising and running a national RI probably have to set aside their own research ambitions at least for the time they are running the RI. One presenter at the Cape Town workshop stated he had committed "academic suicide" to lead part of an international RI.

Apart from the science case it is vital that a good and transparent governance model is adopted. There are a number of reasons for this. First, significant amounts of public money are involved and any taxpayer/funder must be able to see that the money is well spent. Secondly the funds are generally from the same source as for funding individual research areas and there is always a tension between direct funding to universities and to RIs. The management have to be held to account for the delivery plans of the RIs and external audits needed to assure the governing body that all is under control. Such delivery plans should be agreed on the basis of taking notice of what the appropriate user base community want. Once an RI is set up, it is quite difficult to shut it down since there is an assumption that it is easier to let it continue. The governance structure should be able to take a difficult decision like this on the basis of the research agenda alone. In many countries a not for profit company is set up to run the RI consisting of board with an independent chair and non-executive directors plus the chief executive only from the RI. It is not necessary to have a separate board for each RI and a number in related fields can be bunched together for efficiencies sake.

11. Candidate RIs selected

Given the analysis in Chapter 8, also based on the stakeholder inputs into this roadmap, the identified RIs for potential inclusion in the SARIR are clustered under the indicated science domains:

RI Domain	Identified RI
Humans and Society	The South African Network of Health and Demographic Surveillance Sites
	South African HSS Data Archive
	National Centre for Digital Language Resources (NCDLR)
Health, Biological and Food Security	Animal Bio Security Lab P4 Level (ABL-4)
	Distributed Platform for “Omics” Research (DIPLOMICS)
	Biobanks
	Nuclear medicine
Earth and Environment	A South African Marine and Antarctic Research Facility
	Biogeochemistry Research Infrastructure Platform
	An expanded National Terrestrial Environmental Observation Network
	Shallow Marine and Coastal Research Infrastructure
	The Natural Sciences Collection Facility
Materials and Manufacturing	Materials Characterisation Facility
	Nano-manufacturing Facility
Energy	SAFARI-2 Materials Research Reactor
	Solar Research Facility
Physical Sciences and Engineering	A national support centre for science

11.1 Humans and Society

11.1.1 The S A Network of Health and Demographic Surveillance Sites

The Facility

A distributed platform of observation sites for health and demographic surveillance systems, designed for the collection of standardised longitudinal population (i.e. socio-economic-demographic) and health data, through multi-round household-based enquiry among specific communities representative of larger sectors of the country's population.

Background

The National Research and Development Strategy highlights under the priority area "Science and Technology for Poverty Reduction" the importance of understanding social circumstances surrounding poverty and disease in processes of social and technological innovations to address these with the aim of enhancing economic activity and wealth creation. This is taken a step further by the DST in its Ten-year Plan for South Africa with a strong focus on innovation to solve "our society's deep and pressing socioeconomic challenges". A better understanding of human and social dynamics at all levels is highlighted specifically as one of five key challenges to meet the objectives of this plan. In a subsequent elaboration captured in the HSDD GC Science Plan of 2010 human and social dynamics refers to humanity's behaviour and development in the face of continuous change and highlights the need for a multidisciplinary research approach to understand behaviour of individuals and societies over time which includes how individuals, families and communities grow, learn, change and adapt; the interplay between generations; the influence of organizational, community, and environmental processes; etc. In this regard the funding of research and the support of longitudinal studies on migration, poverty, health care, childhood and social cohesion are key for empirical evidence in science-led policy making.

For reasons similar to these, research sites with Health and Demographic Surveillance Systems (HDSS) have emerged as critical research infrastructure globally in understanding trends and transitions over a period of time, evaluating policy and implementing trials. In addition, they provide opportunity to undertake genetics and genomics research. Their contributions towards producing high quality data in a range of disciplines have been recognized by leading international agencies such as the World Health Organisation and various United Nations entities. HDSS contribute to research in multiple disciplines across the sciences, health sciences and humanities as fertile training ground for postgraduate training and providing a critical research platform to impact on policies and intervention programmes, particularly those targeting vulnerable groups.

There are three such Health and Demographic Surveillance System (HDSS) sites in rural South Africa at present, viz. Agincourt in Mpumalanga, the Africa Centre in KwaZulu-Natal and Dikgale in Limpopo, that collect standardised longitudinal population (i.e. socio-economic-demographic) and health data, through multi-round household-based enquiry, and with a strong site-specific research, policy evaluation, research training and science outreach agenda. These platforms for multi-level research receive some funding from the Medical Research Council and their respective host institutions, i.e. the Universities of Witwatersrand, KwaZulu-Natal and Limpopo respectively, but rely on the bulk of their funding for their activities on third stream income such as the Wellcome Trust, UK, National Institutes of Health (NIH), USA, and private donor organisations. The sites have been instrumental in providing understanding of the multiple inter-related transitions that have led to marked changes in population structure and health outcomes ever since their establishment two decades ago. In addition to having been pivotal the training of research students, the research

based on the data from these sites has been instrumental in calibrating national datasets, and in informing policy at national, provincial and local level.

Research Infrastructure required

Given South Africa's socio-economic and cultural diversity, there is an imperative to (i) secure the ongoing activities of the three existing surveillance sites, and (ii) expand the number of surveillance sites in order to improve our understanding of health and socio-economic transitions affecting the wellbeing and development of vulnerable populations in different environments of the country, test appropriate interventions and evaluate policy. The existing three centres have proven invaluable in better understanding health and social transitions in a South African context, but this would be enhanced considerably by additional HDSS centres in other areas across the country and critically at least one HDSS centre in an urban environment. Akin to the tasks of the existing centres, a network of centres collectively would be tasked to:

- Collect data and facilitate and conduct policy-relevant health and population research, in an ethical manner, in partnership with the communities within which they operate.
- Act as a major research platform that enables multidisciplinary research with students and experts from key disciplines in the humanities and social sciences, as well as statistics and computational mathematics in addition to health sciences.
- Foster effective collaborations and ensure that common standards are applied in data generation and manipulation for cross-site compatibility of common variables.
- Ensure that data capturing, analyses and sharing are as efficient as possible, hence optimizing access to HDSS data, by advocating for the provision of faster, cheaper bandwidth in rural areas of South Africa.
- Foster better working relationships with government entities at local, provincial and national level to ensure that key findings are translated into policy and implementation. Critical to these endeavours, as the research becomes increasingly cross-disciplinary, are other key stakeholders in addition to the Departments of Health, such as the national and provincial departments responsible for social development, education, human settlements, rural development, traditional affairs, agriculture and others.
- Encourage capacity development of data scientists with mathematical and computational abilities to ensure the availability of effective data analysis capabilities in Health and Demographic Surveillance Systems.
- Foster partnerships with global initiatives to share multi-centre data such as the INDEPTH-iShare data repository²².

Impact

Longitudinal socio-demographic and health surveillance data, collected across a range of South African contexts, is essential to address the following three core issues:

- The impact of poverty and disease, which includes issues such as: survival of children, early cognitive development and performance at school, nutrition, ability to productively enter the workforce, securing the livelihoods of family and households, resilience to economic or social 'shocks', etc. This in turn is key in:
- Understanding context-specific pathways of how disease (and compromised function) relates to poverty, and poverty to disease, as prerequisites to developing appropriate innovative interventions to improve quality of life. These in turn are important in

²² www.indepth-ishare.org

- The design of core and support strategies for implementation of interventions, monitoring their outcome to adapt implementation strategies if required, and finally assessment of the impact of these interventions over time.

In addition, the establishment of such a network opens up a number of new avenues for research and innovation if networked appropriately within the NSI. Examples include the following:

- Connectivity between SAEON and local demographic surveillance sites for new multi- and inter-disciplinary research opportunities that interrogate specifically the understanding of the interaction between human activity and the function of ecosystems under conditions of stress induced by disease and poverty on the one hand, and for wealth creation (sustainable use and exploitation) on the other hand;
- The diversity of environments in Africa and the speed of social change, accentuated by e.g. the impact of global climate change, provide a unique platform to study the inter-relationship between biological (including genetic) and socio-economic imperatives. To follow such an approach in Africa to find answers, rather than in the “North”, provides an exceptional opportunity to lead and not merely to follow in a very topical and emerging new area of scientific enquiry;
- The integration and use of multiple methods from different knowledge systems, i.e. indigenous knowledge (traditional beliefs and practices) and the qualitative-quantitative interface that could lead to new and innovative insights and technologies.

Linkages with other research infrastructures

The three existing HDSS are already part of the International Network for the Demographic Evaluation of Populations and Their Health (INDEPTH – www.indepth-network.org) and it stands to reason that future sites of this nature should also be integrated in this global network. Locally the network of HDSS can derive much benefit through linkages with SAEON referred to above, but also other RIs in HSS such as the proposed SAHSSDA and the proposed country –wide Longitudinal Social Surveys.

Type

A distributed platform of observation sites for longitudinal health and social surveys in site specific communities.

11.1.2 South African HSS Data Archive

The Facility

The facility comprises a distributed research infrastructure that provides and facilitates access for researchers to high quality data in the Humanities and Social Sciences (HSS) and supports their use. It promotes the acquisition, archiving and distribution of electronic data, and encourages the exchange of data.

Background

Several studies in recent years, such as e.g. by the Academy of Science of South Africa (ASSAf)²³ have highlighted a downscaling of the importance of the Social Sciences and Humanities over several years. This downscaling has had a serious effect on the quality of mind of senior graduates, on the academic enterprise itself and on the quality of research output in these disciplines. This prompted the Minister of Higher Education and Training to commission a task team to identify key interventions required to uplift the status and quality of research and education in the Social Sciences and Humanities (SSH) in Higher Education. The outcome of this investigation, the Charter for Humanities and Social Sciences²⁴ identified all the major shortcomings and proposed several key interventions that will be required to overcome these shortcomings and elevate the quality and impact of research in these disciplines. One of these refers to the establishment of an institute or entity that should be tasked among others to “facilitate the process of gathering together and making available and easily accessible research and other data related to the HSS in South Africa” (p18). Furthermore, ready access to data and information was seen as another of the key interventions and defined as having to produce “benefits to the research project for the higher education system, and indeed society as a whole, by dynamising the fields, the disciplines and interdisciplinary work, and thereby also increasing the capacity to research further, theorise better and contribute to the raising of our status in the global academic commons...” (p37). Important to note in this regard is that the science plan of the Human and Social Dynamic in Development Grand Challenge (HSDD GC) of the DST’s Ten Year Plan has identified a need for the support of research infrastructure to ensure a cohesive approach to the development and deployment of social science data bases and support for researchers in accessing data bases internationally.

Many important datasets in the Social Sciences and Humanities have been lost in the past because of the tendency within these disciplines to work in isolation and to be possessive about the data generated by them. The establishment of a national facility where data gathered and used by researchers can be archived and accessed by others, implies sharing and encourages collaboration, particularly where a dataset are being reinterpreted. A culture of sharing and collaboration around datasets therefore needs to be engendered as this will not only promote optimal utilisation thereof but also enhance the quality and impact of the research.

Research Infrastructure Required

A national research infrastructure platform that allows users to locate datasets, as well as questions or variables within datasets, stored at data archives or repositories in South Africa. Such data collections should include a variety of data from e.g. sociological surveys, election studies, longitudinal studies, opinion polls, and census data. These data archives should constitute a network of accredited repositories, where certain standards of curation and data validation are strictly adhered to.

²³ Academy of Sciences of South Africa, August 2011. Consensus Study on the State of the Humanities in South Africa: Status, prospects and strategies, ISBN-978-0-9814159-3-2, 50p

²⁴ Department of Higher Education and Training, June 2011, The Charter for Humanities and Social Sciences, 68p

Such a national platform needs to be driven by a team of experts in the management of Social Sciences and Humanities datasets who have among others, the skills and capacity to:

- Provide advice and assistance to researchers and students in the development of a data management plan prior to commencement of data collection, in order to ensure that data being collected can be used in future. This implies adherence to appropriate standards in terms of data structure and format, consideration of documentation format and content as well as metadata to address archival implications from an early stage;
- manage, archive and disseminate data;
- deal with and advise researchers and research students on confidentiality of data and data protection, intellectual property, maintaining ethical standards and the adherence to codes of ethics across the spectrum of disciplines as and when required;
- assist with the integration of different datasets on related topics so as to add value to the information to be extracted from them and thereby their use for research of quality and impact; and
- to actively promote the benefits of data archiving and sharing to the HSS research community of the country.

It should be obligatory to place any data collected by way of publicly funded research in such a data repository.

Storage of and access to data should be free to research students and researchers affiliated to universities, science councils and NGOs. Requests for data should however be strictly reviewed to ensure that usage thereof adheres to ethical and confidentiality considerations which may apply to any specific datasets. The same needs to apply to commercial concerns requiring access to data, but in such instances a fee needs to be levied with the proceeds shared with the originator of the data concerned.

Staff and users of the facility should work together to continually improve the quality of data for storage and access to researchers and students. To this extent, the facility may design research projects and conduct expert seminars in order to enhance the exchange of data and technologies among data organizations. In this regard the facility should align itself with the Manifesto of the New Global Data Generation to simplify and guarantee access in e-science scenarios.

The South African Data Archive (SADA) already has many attributes of a research infrastructure required by the Humanities and Social Sciences²⁵ and hence would constitute an ideal core facility of a proposed research infrastructure of a South African Humanities and Social Sciences Data Archive. Its data holdings are from a wide range of areas primarily in the HSS, such as from census and household surveys; demographic and health related studies; substance abuse; crime; inter-group relations; labour and business; education and training, and on political perceptions and attitudes. It furthermore offers a variety of value adding services such as ensuring data integrity, integration of datasets, development of electronic search and retrieval systems. In addition it is member of a number of international data organisations such as the International Federation of Data Organisations (IFDO), the International Association for Social Science Information Service & Technology (IASSIST), and an associate member of the Council of European Social Science Data Archives (CESSDA).

²⁵ <http://sada.nrf.ac.za/>

Linkages with other Facilities

Apart from the linkages to global data archiving organisations already referred to above under the SADA, the proposed SAHSSDA can link into all the other proposed facilities that generate HSS data, such as the proposed demographic surveillance sites, the periodic social surveys and the National Centre for Human for Digital Language Resources.

Type of Research Infrastructure

The envisaged research infrastructure will be a distributed data-platform with the existing SADA as a central hub and a limited number of distributed data nodes linked to institutions that generate high volumes of HSS research data, including the HSRC. Each of the nodes will have a small core staff to manage the data acquired within the node and to provide assistance to students and researchers in the region of the node. The central SADA hub will coordinate and facilitate the activities of the network, establish criteria for data storage and access to the distributed repositories, initiate various value adding activities referred to and also liaise with global data networks of which SAHSSDA will be a member or associate member.

Impact

The overall impact of data archives and the sharing of data is apart from enhancing optimal utilisation of data also the overall enhancement of quality and impact of research in the HSS, among others by reinforcing open scientific inquiry which allows effective self-correction of research; secondary analysts can verify, refute, or refine original results; it facilitates high-quality, policy-relevant research; it encourages diversity of analysis and opinions; it opens up the pursuit of new research avenues; it allows for the creation of new datasets through the merging or integration of several existing sources of information; allows analysis of data in ways not envisioned by the original investigators; and improves methods of data collection and measurements through the scrutiny of others.

11.1.3 National Centre for Digital Language Resources (NCDLR)

The Facility

A centralised repository for the archiving and re-use of digital language resources such as text and speech data for all the official languages of South Africa and to provide the technology to assist individuals to carry out their research.

Background

Human language technology (HLT) has an important role to play in a multilingual society such as South Africa. This has been recognised in several policy documents such as the Foresight Report of the Department of Arts, Culture, Science and Technology (DACST) in 1999, the National Language Policy Framework of the Department of Arts and Culture (DAC) in 2003, and in a study of the Department of Trade and Industry entitled “Benchmarking of Technology Trends and Technology Development”, wherein human language technology (HLT) was regarded as one of eight technologies of importance in the development of the ICT sector globally and locally. However, for the advancement of HLT ready access and availability of language resources is of critical importance, an aspect that was recognised in the European context with the establishment of a Common Language Resources and Technology Infrastructure (CLARIN). CLARIN is a large-scale pan-European research infrastructure of the ESFRI (European Strategy Forum for Research Infrastructures) family, with the aim to make language resources and technology available and useful to scholars of all disciplines, in particular the humanities and social sciences.

In South Africa the establishment of a national centre for language resources was mooted more than a decade ago already by an advisory panel on HLT appointed by the Minister of Arts, Culture, Science

and Technology. However, it was only in 2008 that the proposal to establish a National Centre for Human Technologies was approved by Cabinet. In practice, this became a virtual centre under the auspices of the HLT Unit within the DAC which, with the assistance of an expert group on HLT, devised strategic plans and on funding of various projects on HLT. As funding for HLT projects became available from the DAC and the DST the necessity of a central repository of language resources became crucial, and with financial support from the DAC a language Resource Management Agency (RMA) was established at the Centre for Text Technology at North-West University in 2012.

The scientific purpose of the RMA is to acquire, manage and distribute reusable digital text and speech data for all official languages of South Africa for a large variety of applications underpinned by research such as e.g.:

- The development of language based applications in the field of HLT to facilitate automated communication between humans and computer systems in a language of choice
- Commercial development of software tools in local languages such as spelling and grammar checkers for all local languages, intelligent tools for e-learning in these languages, automated interactive speech-to-speech translation services for interpersonal communication, etc.
- Development of the official African languages by providing large corpora to assist official bodies tasked with terminology and lexicographic development; to standardise spelling and language use; to assist private publishing houses in publishing educational material in African languages in a standardised format, etc.

Research Infrastructure required

The RMA is currently being viewed as a three year project (2012-2014) and hence its sustainability as such is not guaranteed. As its existence forms the backbone of many HLT activities its future status needs to be guaranteed in one way or the other as a national research infrastructure.

Given the fact that the development of HLT is regarded as a high priority within the South African scientific community, and given that digital language resources form the backbone of HLT application development, it follows that a sustainable language resource centre is of the utmost importance to facilitate these developments. The RMA with presently guaranteed funding for only three years must therefore be seen as a precursor to the establishment of a national facility for digital language resources. This will be the first national facility in the domain of the humanities and social sciences, as all of the existing facilities are situated outside this domain.

In line of the initial thinking a fully fledged nationally facility will have the following functions:

- Act as a central repository for all digital text and speech data and applicable software tools generated through projects directly and indirectly sponsored with public funds, as well as speech and text data from other sources;
- The management of this data by e.g. migrating from different storage platforms as technologies change, and distributing the data as reusable resources for R&D purposes;
- To assist researchers to store their resources (e.g. corpora, lexica, audio and video recordings, annotations, grammars, etc.) in a sustainable way, by offering a depositing service and assisting with the technical and organisational curation of the data, e.g. password-protection in respect of legal, privacy and ethics constraints.
- Assess sponsored projects conducted within the broad domain of HLT to promote standardisation in terms of ISO or other applicable standards in the industry;

- Act as a link between other national and international resource centres – e.g. linking users to speech archives such as that of the South African Broadcasting Corporation and eventually expanding its scope to include other languages spoken in the rest of Africa;
- Creating and annotating corpora of different types and registers in each of the official languages of South Africa; annotation is a specialised activity which will create a number of jobs, especially for mother tongue speakers specialised in African languages and linguistics;
- To provide a technology platform for the support of the humanities and social sciences more generally as an infrastructure supporting knowledge creation through digitally enabled research across the different disciplines, by highlighting potential relationships that may exist between different studies, either directly or at the meta-level.

Linkages with other Research Infrastructures

Linkages to digital language technology networks and facilities globally such as CLARIN, the open language resource facility Meta-share of the Multilingual European Technology Alliance (META-Net), the Language Technology World (Lt-world), and Evaluation and Languages Resources Distribution Agency (ELDA) of the European Language Resources Agency (ELRA) would greatly benefit a local research infrastructure, particularly to stay abreast of technological developments. Locally linkages with the proposed South African HSS Data Archive, as well as any other research infrastructure with a focus on datasets in the HSS are indicated.

Type

A central, expanded RMA facility is envisaged as a technology platform that makes language resources, technology and expertise available to the HSS research communities by way of single sign-on access to all available digital data collections. This will require specialised skills in computational linguistics, linguists with language proficiencies in the official languages of the country and support staff, as well as the necessary computer infrastructure to store and manipulate large datasets.

Impact

A technology platform as envisaged will greatly enhance the development of HLT specifically and digital humanities more generally, which is of particular interest given the multilingual nature of South African society. It will open up new avenues for research through the integration of language-based resources and also raise the status of the official African languages of the country. As the only facility of the kind on the African continent it can play a significant role in the advancement of HLT on the continent.

11.1.4 Contribution to National Challenges of RI for Humans and Society

RIs Challenges	Health and Demographic Surveillance Sites	SA HSS Data Archive	Digital Language Resources
Global Change Mitigation and Adaptation	x		
Poverty eradication	x		
Nutrition, health and wellbeing	x		
Access to quality education	x	x	x
Conservation of National Heritage		x	
Migration, urbanisation & rural development	x		

11.1.5 Stakeholder Departments of Humans and Society RI

Identified RI	DST	the dti	DBE	DAC	DEA	DoH	DSD
The S A Network of Health and Demographic Surveillance Sites	x		x		x	x	x
South African HSS Data Archive	x			x			x
National Centre for Digital Language Resources	x	x	x	x			

11.2 Health, Biological and Food Security

11.2.1 Animal Bio Security Lab P4 Level (ABL-4)

Description of the facility

A biological security lab oriented to animal communicable illnesses and their potential risk to humans. It would become the centre node of a network of other P3 bio security labs in the country oriented to animals and other P4 and P3 labs for humans.

Background

Today, South Africa has in operation a P4 biological security laboratory mainly devoted to human infection diseases located in the National Institute for Communicable Diseases (NICD). It provides reference microbiology, virology, epidemiology, surveillance and public health research to support the government's response to communicable disease threats.

The NICD has established co-operatives agreements with partner national public health institutions such as the Centre for Disease Control (CDC) and NIH/NIAID of the USA, the European Centre for Disease Control (ECDC) and the Health Protection Agency (HPA) of the United Kingdom, as well as other internationally recognised public health institutions.

Nevertheless, it is important to increase the capacities to act on animal communicable illnesses which could be potentially dangerous for humans by building and operating a second biological security lab P4 specifically devoted to this kind of problems. The new lab should be also the central node of a South African network of other P3 labs located in the country and, if possible, by coordinating a network of similar labs in Africa.

Experimental infrastructure required

Three main elements:

- Contained lab with a minimum of 100 m² of maximum security working area (level 4) built in a separate building. This area should be equipped with state-of-the-art scientific instruments.
- Animal housing (mainly for those endangered species or more dangerous for human transmission) with the capacities to isolate individuals (quarantine requirements). Specific attention should be paid to primates.
- A specific animal bio-bank facility in order to preserve isolated and characterized pathogens.
- A bioinformatics section linked to South African bio-banks facilities in order to preserve data related to relevant specimens to be accessed by the scientific and clinical community.

Linkages with other RI

The proposed ABL-4 Biological Security Lab should be closely related to other biological security labs located in the country and it should be a relevant component of international networks for rapid action against emergencies.

It is also closely related to the bio-banks available in the country and, more specifically, with the proposed national research facility.

Connection to other facilities in the health sector (i.e. for GMO) is also necessary as a part of the coordination scheme in the field of research infrastructures.

Type

ABL-4 will be a single sited research infrastructure, located in the NICD premises.

Impact

ABL-4 will have strong regional impact, whilst it will form part of an international network of biological security labs, which will increase the global security against new communicable diseases. As a side effect, it will become an essential tool to preserve animal biodiversity in a very rich region of the world.

11.2.2 Distributed Platform for “omics” Research (DIPLOMICS)

Description of the facility

DIPLOMICS is conceived as a set of updated equipment distributed across the country to provide the infrastructure required to perform competitive research in genomics, proteomics, metabolomics and metabolomics in the human health, animal health and the agro food biotech sectors. It would be coordinated by a central organization to become a national distributed facility and to offer advanced external services based on the use of the infrastructure.

Background

Today, there are many research centres and some research units in hospitals scattered through the whole country. In some cases, they are open to external researchers but in other cases they are mainly used by internal research groups without a concept of service behind.

In South Africa, the Centre for Proteomic and Genomic Research (CPGR) is a specialist not-for-profit contract research organisation established in South Africa to provide support and services to the life science and biotech community. The organization, based in Cape Town combines state-of-the-art information rich genomic and proteomic (*'omics'*) technologies with bio-computational pipelines to create unique solutions for biological problems. The CPGR is situated in laboratories within the Institute of Infectious Disease and Molecular Medicine (IIDMM), University of Cape Town.

Other facilities in this area are located in other South African universities (e.g. the Central Analytical Facilities of the University of Stellenbosch or the ARC and UWC National Proteomics Research & Services Unit, the facilities for genomics and proteomics at the University of Free State, or Centre for Human Metabolomics of the North-West University etc.).

In implementing the National Biotechnology Strategy (2001), South Africa has created 9 Biotechnology Research and Innovation Centres (BRICs) with three principal performance areas: (i) new products; (ii) new companies; and (iii) technology platforms relevant to the creation of new products and companies. In addition, several companies in the country or abroad offer services for genomics or proteomics analysis by using state-of-the art equipment by using gel-based or liquid-based proteomics and mass spectrometry. Then, researchers need to use and pay external services.

Experimental infrastructure required

The sharp reduction in size, cost and the continuous improvement in the performance of associated equipment make necessary to adopt a very flexible approach where the trade-offs between in-house services or external provision of services should be regularly evaluated. If possible, this infrastructure could also provide services to other African countries.

The following set of facilities is required:

- High end mass spectrometry
- DNA/protein microarraying
- High density gene chip analysis
- High-quality microarray hybridisation and scanning
- Real-time RT- High-throughput liquid handling
- Standard DNA/RNA analysis
- Atomic Spectroscopy
- Automated Electrophoresis
- Bioanalyser
- Gas Chromatography

- Liquid Chromatography
- Molecular Spectroscopy
- Nuclear Magnetic Resonance

Nevertheless, the equipment will evolve very rapidly over time and the list should be updated under the criteria established by the coordination structure of the facility.

Linkages with other RI

The proposed DIPLOMICS distributed research facility should be closely related to the proposed P4 and other P3 biological security labs located in the country and it should be a relevant component of international networks in the field. Specific attention could be paid to strengthening the links with EMBL and EMBO in the EU. The proposed RI is also closely related to the bio-banks available in the country and, more specifically, with the proposed national research facility.

Type

DIPLOMICS will be a distributed research infrastructure, with a central node located in CPGR premises and nodes located in several universities of the country.

Impact

DIPLOMICS will have strong regional impact, whilst it will form part of an international network of biological security labs, which will increase the global security against new communicable diseases. As a side effect, it will become an essential tool to preserve animal biodiversity in a very rich region of the world.

11.2.3 Distributed Platform for Biobanks and GMO Facilities

Description of the facility

The concept of **biobanks** both for plants and animals is becoming a crucial element to support fundamental and applied research in life sciences. A BioBank is a system for the management of a facility for the conservation of genetic resources, sustainable utilization of genetic resources, management system for archival collections, advancement of scientific knowledge, bio-discovery and biosecurity.

The suggested distributed RI for Biobanks and GMO facilities implies the coordination, curation and enhancing of a set of coordinated biobanks and GMO facilities of controlled growth on the basis of the pre-existent facilities in SA.

Background

South Africa has several disconnected biobanks with biological samples including blood, hair, sperm, egg-cells, embryos, and tissue samples in relation to animals or human beings; additionally, there are also a number of biobanks with seeds for production or endemic plants both for commercial and preservation processes. In connection to that, and specifically for plants, the development of advanced facilities for controlled design and growth of GMO is also a very useful research infrastructure along with genomic information of relevant species.

In June 2010, the National Institutes of Health (NIH) and the Wellcome Trust launched a joint project called “Human Heredity and Health in Africa” (H3Africa). This project aims to identify the genetic and environmental factors that contribute to common diseases in Africa which will ultimately improve the health of African populations. Central to this project is the establishment of biobanks in Africa which will store and make available DNA, tissue samples and medical information to researchers. This will not only improve the infrastructure and promote research in Africa, but may also lead to increased collaborations both within Africa and across the world.

A number of biobanks related to animals are disseminated across the country. Two examples are mentioned:

- The Pretoria-based **BioBank South Africa** (SA). It is funded by the Department of Science and Technology, as well as some funds from each consortium member. The biobank is based on a centralised service centre facilitating biomaterials information to a multidisciplinary research and management audience, regionally and globally. The consortium managing BioBank SA is led by the Endangered Wildlife Trust, with other members being the University of Cape Town, the Agricultural Research Council, Taurus Livestock Improvement (a private company), and the South African National Parks Board.
- The Africa Centre’s Virology Laboratory in Durban. It has built up an extensive collection of biological specimens of various kinds. The results of tests carried out on these specimens are generally stored in the main databases of the various studies involved, and are linkable back to the demographic and other data collected from the individuals concerned.

Other biobanks for agricultural research and crop improvement exist in other entities of the country.

Experimental infrastructure required

The RI is conceived as a distributed facility composed by three main elements:

- Biobanks for humans and animals

- Biobanks for plants
- GMO facilities for controlled growth and biosecurity

Linkages with other RI

This RI is strongly related to two other RIs proposed in the SARIR:

- the ABL-4 RI to be able to manage samples of different species
- the DIPLOMICS RI to obtain genome information of relevant animals or plants.

Type

Distributed RI with several nodes and a centralised coordination structure. The Department of S&T, the Department of Health and the Department of Agriculture and fisheries should coordinate their efforts to implement the suggested distributed RI.

Impact

Biobanking has great potential to build research capacity in Africa. However there is currently a lack of research into the attitudes of research participants towards the storage and secondary use of tissues in Africa. New regulations are necessary to ensure that basic legal and ethical principles are adhered to at a national level and also in accordance with other African nations.

11.2.4 Distributed Platform for Nuclear Medicine

Description of the facility

The proposed **RI for nuclear medicine** consists in a set of advanced equipment for diagnosis and treatment of human illnesses based on the use of nuclear technology for medical imaging and radioisotope generation. It is based on the effort around NTeMBI in SA. NTeMBI functions as a high level RD&I initiative providing a framework to consolidate expertise and to implement new strategic initiatives relating to R&D on nuclear technologies in medicine.

Background

Nuclear medicine in South Africa, including PET (Positron Emission Tomography) and SPECT (Single-photon Emission Computed Tomography) modalities, is widely established in both public and private sectors in South Africa. The South African capacity to produce radioisotopes is very high although the combination of research and production objectives on the same platform is not solved.

The Necsa subsidiary NTP Radioisotopes (SOC) Ltd is one local pharmaceutical company with regular exports of radioisotopes and related products to more than 50 countries with an estimated 25% world market share in radiochemicals. iThemba LABS is also supplying significant amounts of radioisotopes both locally and internationally. Local support for PET facilities is provided by NTP, iThemba LABS and PET Labs Pharmaceuticals (Pty) Ltd.

Experimental infrastructure required

The establishment of a facility to perform pre-clinical imaging is needed as a matter of urgency and is seen as hampering the progress of many of the projects. The development of the facility could be phased according to availability of funding. The acquisition of a microPET is considered most important.

Medical imaging in support of drug discovery is a niche application for NTeMBI and should be strengthened. A national pre-clinical imaging facility should be established at the Pelindaba site at Necsa. At least 600m² building space (Building 2100) adjacent to the cyclotron facility operated by NTP, has been allocated by the Necsa for the facility.

A consortium consisting of Necsa, NTP Radioisotopes Pty (Ltd) (NTP), North West and the University of Pretoria has been established to develop the current Business Plan of NTeMBI. The consortium will be able to offer a comprehensive service to external clients in synthesizing, radiolabelling, scanning of new compounds and interpretation of clinical data.

Linkages with other RI

The proposed facility complements the DIPLOMICs distributed RI for obtaining additional data for medical purposes (i.e. genetic-based cancer diseases). From the nuclear perspective, the facility is also related to the proposed SAFARI-2.

Type

We propose the creation of a centralized structure located in iThemba Labs with the maximum facilities from Necsa.

Impact

It is envisaged that this will lead to the development of significant additional RD&I capacity in South Africa and the introduction of new products and services into the African and international markets

11.2.5 Contribution to National Challenges of RI for Health, Biological and Food Security

RI Challenges	Animal Bio- security P4	Platform for “omics”	Biobanks and GMO support	Nuclear Medicine
Food security	x	x	x	
Energy supply and efficiency			x	
Global change mitigation and adaptation			x	
Improvement in nutrition, health and well-being	x	x		x
Strengthening local industry and economic growth & sustainable livelihoods		x	x	x
Environmental sustainability	x		x	

11.2.6 Stakeholder Departments of Health, Biological and Food Security RI

Identified RI	DST	DoH	DAFF	DoE	DEA	the dti
Animal Bio-security Lab P4	x	x	x			
Distributed platform for “omics” research (DIPLOMICS)	x	x				x
Biobanks and GMO support	x	x	x	x	x	x
Nuclear medicine	x	x				

11.3 Earth and Environment

11.3.1 A South African Marine and Antarctic Research Facility

The Facility

A platform for Marine and Antarctic Research that incorporates the research bases in Antarctica, Marion Island and Gough Island, for multi and interdisciplinary research in the biological, oceanographic, atmospheric, geological and space sciences.

Background

A key consideration of the Global Change Grand Challenge in DST's Ten Year Plan²⁶ is the recognition that South Africa's geographic position, given its proximity to the Antarctic, the Southern Ocean, and the Agulhas and Benguela currents, provide it with a unique laboratory to play a leading role in climate change science and one in which South Africa can become a world leader.

South Africa has a long track record in Southern Ocean and Antarctic research largely as a consequence of its obligations as a signatory of the Antarctic Treaty Systems and other related conventions and agreements. To meet these obligations Government has in recent years made substantial investments in the acquisition of a purpose-built ice capable research vessel, the SA Agulhas II and a new base at Marion Island, which have greatly expanded opportunities for cutting edge research. However, for many years now the research endeavour in the Southern Ocean and Antarctica has been bedevilled by numerous problems which have been highlighted by Treasure et. al. (2013).²⁷ In this paper the authors refer among others to the disjuncture between research funding provided by the DST through SANAP and the logistics of the research vessel which is controlled by the Department of Environment Affairs. The biggest concern is the lack of available ships time which is presently consumed largely by the logistics of annually servicing the bases on Marion and Gough Islands and on Antarctica. There is no funding for dedicated scientific ship time beyond the standard voyages to the bases or during different seasons, with the result that the substantial investment made in the new vessel is lying fallow for more than 6 months of the year. This problem has also been highlighted in two reviews of the SANAP and in the 2006 NACI report on research infrastructure²⁸, with the two reviews referred to having proposed the establishment of a national facility for marine and ocean research. This proposal was pursued by the DST in conjunction with the NRF who have commissioned a study into the establishment of a South African Polar Research Entity in 2009.²⁹ The prevailing state of affairs seriously compromises the country's aims of exploiting its geographical advantage in developing a leadership role in climate change and Antarctic research and in its ability of making substantive and leading contributions in global treaties and conventions affecting climate change and the extensive ocean territories under its jurisdiction.

The Research Infrastructure

For world-class scientific research that addresses key issues of global and fundamental importance South Africa's position in relation to the Southern Ocean and Antarctica needs to be fully exploited.

²⁶The Department of Science and Technology 2008, Innovation towards a knowledge-based economy: Ten-year plan for South Africa (2008–2018)

²⁷Treasure AM, Moloney CL, Bester MN, McQuaid CD, Findlay KP, Best PB, et al. 2013. South African research in the Southern Ocean: New opportunities but serious challenges. *S Afr J Sci.* 109(3/4), 2-5.

²⁸NACI 2006, A Study on the required physical infrastructure to attain the vision of the NSI, National Advisory Council on Innovation, South Africa. <http://www.naci.org.za/index.php/naci-resources/studies>

²⁹National Research Foundation 2009. An investigation into an optimal model for the establishment of a South African polar research entity, 96p (unpublished).

This by implication requires, apart from the research vessel and research bases on the islands and in Antarctica, appropriate technical support to scientists and the availability of resources to acquire a variety of different instruments such as floats, autonomous underwater vehicles and gliders for the continuous monitoring of changes within the ocean, ocean floor monitoring and core drilling facilities, as well as a variety of installations and equipment for space science.

Cooperation with national and international institutions and the integration of activities with global networks will require infrastructure for the collection and archiving, manipulation and sharing of long-term scientific data series on Antarctica and the Southern Ocean. This will also enable South Africa to properly discharge its responsibilities under the Antarctic Treaty System and other related conventions and agreements by providing sound, evidence-based policy advice to Government.

The research infrastructure is furthermore also required for scientific work of practical, economic and national significance that relates to obligations of state agencies in terms of national legislation pertaining to the Exclusive Economic Zone and the expanded territories under the extended continental shelf claim. This relates specifically to the needs of the Department of Environmental Affairs, the South African National Biodiversity Institute, the Council for Geoscience, the Petroleum Agency of South Africa and the South African Weather Service.

As a research vessel with ice-breaking capabilities, the Agulhas II is ideally suited for research in far off-shore deep ocean environments. The deployment of a vessel of this size in shallower, continental shelf waters would be uneconomical and for this reason access to a smaller ~50m vessel with blue water capabilities for research in deeper continental shelf environments would be ideal. Research vessels of this nature have in the past been made available by the Department of Agriculture, Forestry and Fisheries on an ad hoc basis. An agreement should however be reached with this Department to make these vessels more readily available for research until such time that a dedicated research vessel can be justified for this facility.

Linkages with other facilities

A facility of this nature would, together with the envisaged Shallow Marine and Coastal research infrastructure effectively covers the entire marine environment. Close linkages will need to be established with this facility as well as with the SAEON marine node as South Africa's contributor the international Argo Float array facility and SADC the Southern African Data Centre for Oceanography hosted by the CSIR. Globally linkages need to be nurtured with a host of ocean and climate change infrastructures and networks, in particular GOOS through its regional alliances for Africa, the Southern Oceans and the Indian Ocean.

Type

A national facility akin to those managed by the NRF in order to serve the very different stakeholders with vested interests in marine and polar research, both in the public sector and in higher education.

Impact

The impact of the facility will be nationally and globally. Nationally in that it will provide considerably improved facilities for accurate weather forecasts, our ability to predict the impact of climate change on the sub-continent, preservation of marine terrestrial island biodiversity, and the assessment and exploitation of natural resources in the territories under the extended continental shelf claim. Globally there are several opportunities for South Africa to lead in Southern Ocean and space science research, the latter among others also in relation to the unique features of the geomagnetic field over the southern Atlantic and to the south of the sub-continent.

11.3.2 Shallow Marine and Coastal Research Infrastructure

The facility

A platform of at least three research vessels and various instrument arrays for “bay-scale” research aimed at studying physical, biological, geological and geophysical features of coastal marine environments to a depth of ~100 meters.

Background

South Africa has a coastline close to 3000km in length with an offshore continental shelf area to a depth of 200m covering an area of about 300 000 square km or roughly a quarter of its land surface area. 20 marine protected areas have been proclaimed along the coast in recent years by the Department of Environmental Affairs to preserve the pristine and unique marine biodiversity along our shores which are host to an estimated 15% of known marine species; hence ideal sites to observe and monitor the impact of global change on marine life over time.

Coastal and shallow marine research has traditionally been undertaken using the fairly large ocean-going ships of the former Marine and Coastal Management of the Department of Environment and Tourism, now the Fisheries Management Branch of Department of Agriculture, Forestry and Fisheries. These research vessels, up to 50m long and costing upwards of 150 Million Rand, can berth up to 10 scientists and undertake cruises of 10 to 30 days. Successful research has been undertaken on these platforms, however they are costly to run (R80 - 150k per day), have long lead-time needs in terms of planning, and as they primarily serve the mandate of fisheries management are often not readily available for research during some critical seasonal observational requirements, and hence not suitable for bay-scale research.

A core infrastructure platform dedicated to shallow marine and coastal research has, however, in recent years been acquired by the South African Institute for Aquatic Biodiversity (SAIAB) largely as a direct consequence of the “rediscovery” of the Coelacanth in comparatively shallow marine waters off the northern coast of KwaZulu-Natal in 2000. This has led to a comprehensive, interdisciplinary and multi-national flagship research programme of SAIAB, referred to as the African Coelacanth Ecosystem Programme (ACEP), a programme that has filled a void in oceanographic and marine ecological sampling on the continental shelves of the east coast of southern Africa and the southwestern Indian Ocean. ACEP focused on several sub-projects in the fields of marine geoscience; physical and biological oceanography; marine ecology; coelacanths and biodiversity; isotope, genetic and genome studies; etc., but was in its formative years very depended on research infrastructure (ship time and submersibles) provided by collaborators from abroad. This changed in 2009 when the DST made available funding to SAIAB for the acquisition of a marine and coastal research platform which is comprised of a 13m Research Vessel (the Ukwabelana), a Remotely Operated Vehicle (ROV), a CTD (conductivity, temperature, density) profiler, and other specialised oceanographic and biological sampling equipment as well as the skilled personnel required to operate much of the equipment. Although primarily acquired for ACEP, the facilities have been made available to a large number of researchers from various universities, research institutions and museums as well as the Departments of Environment Affairs and of Agriculture, Forestry and Fisheries.

Currently, barely three years after its acquisition, the research platform is totally oversubscribed for research and the training of the next generation of researchers. It demonstrates the demand for a research infrastructure of this nature among researchers from various institutions and the success with which the platform has been managed by a national facility. Serious consideration must therefore be given to substantially grow this platform and make the infrastructure even more readily available to the research community.

Parallel to these developments was the acquisition of a near shore survey and research vessel by the Council for Geoscience, designed as a scientific platform for marine geological research, mineral resource exploration, and fisheries- and habitat-management programmes. The vessel is equipped with an entire suite of marine geophysical equipment for near shore marine surveys with an operational water depth window ranging from ~ 3m to ~100m. The vessel is however comparatively small (8.5m) which impacts on its capabilities of readily venturing into somewhat deeper waters.

Research Infrastructure Required

To meet the needs of the research community the existing research platform of one vessel plus ROV and instrumentation needs to be expanded with at least two additional fully equipped research vessels. This will allow for one vessel to be stationed in Durban and service the needs of research conducted essentially along the KwaZulu-Natal coast. The existing vessel, stationed in Port Elizabeth will be available for research on the south-eastern and southern Cape coast, with a further vessel stationed in the Cape to service research conducted on the coastal waters around the Cape and along the Cape west coast.

Ideally both additional research vessels should be somewhat larger than the existing vessel, i.e. 15 plus metres in order to increase the capacity to carry a larger selection of standard marine research instrumentation, including the capability of conducting marine geological and geophysical surveys in waters that the current capabilities of the comparatively small research vessel of the CGS cannot achieve.

In addition to the vessels, a variety of different anchored underwater instruments are required for deployment in various arrays within the coastal waters. Some such instrument arrays have already been deployed on a limited scale. One is SAEON's "sentinel site" in Algoa Bay for intensive study and sustained observations to detect and understand physical and biological changes in the ecosystem. The other is the SAIAB's acoustic telemetry array platform (ATAP) consisting of receivers deployed around the South African coastline by SAIAB as part of the global Ocean Tracking Network (OTN) project. Both need to be expanded and apart from the instrumentation require regular access to service the instruments and to upload data.

Linkages to other Facilities

For effective coverage of the entire marine environment linkages need to be established and nurtured with the proposed Marine and Antarctic Research Institute. SAEON has, by virtue of its mandate of long term observation, a direct interest in the expansion of this platform through its coastal and shallow marine node. Conversely, through linkage of the facility to SAEON will enhance South Africa's participation in and contribution to global networks such as GEO-BON and GEOSS. Furthermore linkages with SADCO, SANBI and SABIF, and the proposed Natural Science Collections facility will be required.

Type

Largely a mobile observation platform, but with static (anchored) elements.

Impact

With a coastline of 3000 Km and host to an estimated 15 % of known coastal marine species, 25% of which are endemic to South African waters, our shallow marine and coastal environments can rightfully be regarded as globally one of the most biologically diverse regions. A research infrastructure platform as envisaged will considerably enhance the extent of observations on understanding the impact of climate change on the country's unique shallow marine and coastal biodiversity. The shallow marine and coastal environments do however also constitute rich and diverse natural assets that are continually under pressure from economic and social activities such as commercial line fishing, recreational activities and coastal developments. A research infrastructure

platform will therefore also enable research focussed on understanding measures required to safeguard the sustainability of these resources. All of this will place the country in a very strong position to make conceptually leading contributions to global debates and policy interventions through the Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES), the Intergovernmental Panel on Climate Change (IPCC) and others.

11.3.3 An expanded National Terrestrial Environmental Observation Network

The Facility

A country-wide distributed terrestrial observation platform to understand and forecast the impacts of climate change, land use change, and invasive species on ecological change at sub-continental scales. It must have an open access approach to its data and information products so that scientists, educators, planners, and decision makers can map, understand, and predict primary effects of humans on the natural world and effectively address critical ecological questions and issues.

Background

The present unprecedented loss of biodiversity in terms of the extinction of species and loss of genetic variation is estimated to be up to 1 000 times more than the "background" or natural rate. These declines, ascribed to habitat destruction, climate change, pollution, and the spread of invasive species largely due to anthropogenic activities, reveal that the natural world cannot support the pressure that humanity is placing on it. South Africa is particularly vulnerable in this regard. It is one of the most biologically diverse countries in the world as it is home to nearly 10% of the world's plant species, 7% of the reptiles, birds and mammals and 15% of known coastal marine species but occupies only about 2% of the world's land area. Because of the close inter-linkages between biodiversity, ecosystem services and human well-being, there have been many initiatives among the scientific and policy communities to establish mechanisms to better understand biodiversity and to provide information on the causes and consequences of environmental change.

In South Africa this has manifested itself in the establishment of the South African National Biodiversity Institute (SANBI), a statutory body mandated by the National Environmental Management: Biodiversity Act 10 of 2004 to coordinate research and to monitor and report on the state of biodiversity in South Africa by way of policy advice. Some key research infrastructure facilities under the jurisdiction of SANBI are the biosystematics and collection facilities and the National Botanical Gardens, as well as the South African Biodiversity Information Facility (SABIF).

A parallel and complementary activity was the establishment of the South African Environmental Observation Network (SAEON). It has been designed to deliver long-term reliable data to monitor environmental change for scientific research and to enable formulation of adaptive and mitigating management policies and practices. SAEON has grown over the years and has now six well established observation sites. Four of these are located within specific eco-climatic domains, one node focuses on coastal systems and another one on marine system. A centralised facility caters for the collection, storage and dissemination of data collected at the various nodes and also hosts the data portal for the South African Earth Observation System of Systems (SAEOSS).

Research infrastructure required

An imperative of an environmental observation network is its capacity to observe both the human causes of environmental change, i.e. climate change, land use patterns and invasive species, and the biological consequences of environmental change, i.e. the impact on biogeochemical changes, biodiversity, eco-hydrology and diseases. The observation infrastructure should furthermore also support experiments that accelerate changes toward anticipated future physical, chemical, biological or other conditions to enable testing of ecological forecast models, and to deepen understanding of ecological change.

Ideally, an expanded terrestrial observation platform should entail nodes that can effectively cover the nine eco-climatic domains or biomes in the country. The location of the four existing terrestrial SAEON sites is such that this could readily be achieved if the critical mass of the existing nodes were to be strengthened in order to effectively service all the biomes. Sites of this nature should be arranged in a hub and spoke model that will enable them to identify and include land use types

across eco-climatic domains. This should include urbanization as ecologically intense but little studied uses of land, agricultural sites with a range of different production systems, eco-hydrological areas, as well as areas of intense pollution e.g. nitrogen deposition.

Akin to the National Ecological Observation Network in the United States the expanded terrestrial observation system should have the capabilities of monitoring, sampling and analysing the different components of the sites, i.e. terrestrial, aquatic, and atmospheric by using different observing methods. These should include among others a variety of terrestrial biological measurements and observations, including the identification of sentinel or indicator taxa; fixed instrumentation to measure terrestrial changes in key physical and chemical parameters in order to assess ecosystem-level responses to such changes such as in the diversity and function of organisms in both terrestrial and aquatic systems; facilities for the observation of basic stream ecological structure and function, the abundance and roles of nutrients and pollutants and their impact on consumers; and airborne observation facilities with a remote sensing instrumentation package, e.g. LIDAR surveys, as well as spectral radiances and photographic images that bridge the scales from surface and tower observations to that of satellite based remote sensing.

Regarding the latter, the South African Weather Services several years ago developed a state-of-the-art airborne research facility involving three aeroplanes. This state owned facility seems underutilised at present largely as a result of funding difficulties. Serious consideration should be given to resurrect this infrastructure and to place it under the jurisdiction of regular users such as e.g. the proposed terrestrial environmental observation network and simultaneously have it available as a research and observation platform for other users both in academia for atmospheric research and science councils, such as e.g. the Council for Geosciences for airborne geophysical and other surveys.

The collection, archiving and curation of samples, including digital images to provide a record and reference for future studies of biological change is already being undertaken by SAEON, as is the collection and dissemination of data in accordance with established standards and protocols through SAEOSS. SAEOSS is mandated to provide unifying access to a wide variety of earth and environmental observation data sources, both remotely sensed and in situ and providing tools to share this with the rest of the world through the Global Earth Observation System of Systems (GEOSS). However, SAEON should also be able to play a more proactive role on behalf of the research community to negotiate access to data for research, particularly from those state agencies that are hesitant to release their data or only make it available on a commercial basis. This includes data for weather, air quality and radar network data from the South African Weather Services, as well as weather data from the ARC and the Department of Water Affairs (DWA), soil data from the ARC, water quality data from the DWA, air pollution data from various institutions, etc. etc. all of which will, in an integrated way, considerably benefit any research aimed to understanding their impact on the environment.

Linkages to other facilities

This facility is seen largely as an extension of the existing SAEON facility, but will require continued close linkages to a variety of other facilities to achieve its objectives. Locally this will primarily be to the SANBI facilities referred to above, the scientific services and research centres of SANParks and the South African Institute for Aquatic Biodiversity, as well as the proposed national facility for natural science collections and the biogeochemistry infrastructure.

Globally linkages already exist to various RIs such as ILTER, GEOSS and through the SABIF of SANBI to GBIF. However, consideration should be given to establish linkages with other RIs' should these not exist, such as LifeWatch, the European e-infrastructure for biodiversity and ecosystem research, the Integrated Carbon Observation System (ICOS), the Global Terrestrial Observing System (GTOS), etc.

Type

A static terrestrial observation platform consisting of a network of nodes strategically located to cover the different biomes of the country. Each node can have various secondary observation sites depending on land use patterns, extent of invasive species, eco-hydrological considerations, etc.

Impact

An expanded RI as envisaged will considerably enhance the extent of observations on understanding the impact of climate change on the country's unique terrestrial biodiversity, a key outcome of the Global Change Grand Challenge of the DST's Ten Year Innovation Plan. As globally one of the most biologically diverse countries, observation based insights of an expanded RI it will place the country in a very strong position to make conceptually leading contributions to global debates on essential policy interventions on adaptation and mitigation, among others through the Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES), the Intergovernmental Panel on Climate Change (IPCC) and others.

11.3.4 A Natural Sciences Collection Facility

The Facility

Designed to consolidate the large number of widely dispersed and under resourced natural science collections into a limited number of collection institutions with the mandate to manage and curate these in accordance with international best practice and to ensure optimal availability and accessibility of the material for scientific research.

Background

A recent audit of the country's natural science collections commissioned by the NRF³⁰ has shown that there are at least 120 collections in more than 40 institutions across the country. These collections, amassed over the past 170 years, hold a vast amount of largely irreplaceable material and related information, covering most of South Africa and reflect the tremendous wealth of the country's biodiversity and as well as other parts of the continent. Globally, information associated with the specimens in collections of this nature are increasingly accessed by researchers for primary biodiversity data that has many applications of societal relevance, such as conservation considerations, land use decisions, climate change and several others. Yet the bulk of our natural science collections have over the years lapsed into a serious state of neglect. This was highlighted in some detail by the audit referred to and which has identified the major shortcomings in the curation of this valuable asset. Aspects highlighted include among others:

- A split mandate regarding the responsibility for curating and using natural science collections. Natural science collections within museums resort under the Department of Arts & Culture, biodiversity is the responsibility of the Department of Environmental Affairs, while research is supported mainly by the National Research Foundation which falls under the Department of Science & Technology. Several large collections are also housed in universities, within the Agricultural Research Council, provincial museums, within National Facilities of the NRF, SANBI and the Council for Geosciences.
- A lack of national curatorial policies for collections management procedures and standards covering the South African natural science collections.
- Lack of an adequate and critical number of staff, appropriately trained. This was seen as the most pressing threat to the future survival of the collections. Ideally, collections should be curated in a dynamic, appealing environment and supportive of research on the collections, involving researchers, curators and technical support staff.
- Both the collections and their staff are hampered by funding constraints.
- A new mindset needs to be fostered among collections staff to think nationally rather than locally and to promote an understanding that the collections' major value is for scientific research.
- Utilisation of some of the larger collections for research is limited or absent in the museums falling under the Department of Arts and Culture, which does not have a mandate for natural science research.
- Lack of facilities to enable researchers to access many of the collections or data pertaining to the collections remotely.

Collections of this nature constitute, according to an OECD Global Science Forum report on Scientific Research Collections, an essential component of the research infrastructure of a country. For a country such as South Africa as one of the earth's most biodiverse countries, collections of this nature are of particular importance and essential for developing a proper understanding which is critical to biodiversity conservation, global climate change adaptation, biotechnology development

³⁰National Research Foundation, 2011, Audit report of South Africa's Natural Science Collections: collecting now to preserve the Future. 236p. Unpublished.

and other societal benefits. However, unlocking of the valuable information enshrined in them, will only be achieved if they were well managed and well-resourced.

Research Infrastructure Required

According to the NRF audit report, optimal utilisation of this unique asset will require drastic interventions with major structural and governance alignments and the consolidation and restructuring of collections. Several options were considered in this regard, with the preferred model referred to as “Natural Science Collections Hub” as having the most potential for addressing the current problems, and for achieving maximum value from the collections. The major change focus would be at a political level with substantial changes at the collections/institutional levels.

The model makes provision for a central management and co-ordination hub and the consolidation of biological collections into five regional collections institutions, each one of which established around a strategic research focus. The focus of another institute would be the palaeosciences, including palaeoanthropology, whereas the BioBank SA consortium already operates as a biomaterials ‘hub’ which could readily be integrated into the proposed Collections Hub. Consolidation of the numerous, dispersed collections would be informed by the research focus areas, with the regional institutes themselves organised in a node and spoke model where appropriate. Uniform processes and procedures will need to be put in place across all the envisaged collections institutions to ensure optimal usage of the material and the unlocking of the valuable information enshrined in them. Collection institutes should furthermore have state-of-the-art facilities to undertake systematic work on the identification and classification of species within and additions to the collections.

The proposal is seen as a medium-to-long-term solution which would improve cost effectiveness through economies of scale by having fewer institutions holding collections, streamlined governance, funding and reporting structures, a critical mass of staff for research, curation, mentoring and staff training. The strategic co-ordination of data from collections, access to and research on collections would be at the national, i.e. central hub level and ensure that all information on collections are not only accessible to the network of institutions but also to the broader community through appropriate information portals such as the South African Biodiversity Information Facility (SABIF).

Linkages with other facilities

Locally linkages will primarily be with other research infrastructures that support research in biodiversity and environmental sciences such as SAEON, SAIAB and SANBI, although linkages with the biogeochemistry and the characterisation facilities will be required to access latest techniques with which to study specimens in greatest possible detail. In a consolidated form the collections will take their rightful place among the great collections of the world and part of a global network accessed by scientists.

Type

A centrally coordinated repository of knowledge vested in a limited number of natural science collection facilities located in the main centres of the country.

Impact

Collections do have the potential to be used in answering a wide range of questions relating to climate change, sustainable use of resources, biodiversity conservation and human health and well-being. It is here where the proper utilization of the collections for research can have its greatest impact, given that South Africa is one of the earth’s most biodiverse countries. The impact of a facility as envisaged will primarily be in opening up the vast collections for research aimed at exploiting the wealth in biodiversity for the benefit of the country, and through appropriate data

portals and linkages into global collection networks create opportunities to participate in the generation of scientific solutions to global concerns.

11.3.5 Biogeochemistry Research Infrastructure Platform

The facility

The facility comprises a platform facility that will cover a broad spectrum of state-of-the-art analytical techniques for high quality trace element analysis, isotope and radiogenic isotope analysis and dating for the geological, biological and environmental sciences.

Background

South Africa's unique biodiversity, its exceptional geological record and associated ore deposits, as well as its extensive palaeontological and palaeo-anthropological heritage are globally well recognised and have been accorded due recognition as a geographical advantage in its National R&D Strategy and through the Global Change Grand Challenge also in DST's 10-Year Innovation Plan. However, our scientists never had a comprehensive research infrastructure to do justice to this uniquely competitive advantage. A research infrastructure designed to provide our scientists with the essential tools to explore in considerably greater detail biogeochemical processes in different eco-climatic domains during present conditions of climate change, as well as important geological and evolutionary events in the earth's history from evidence locked up in the wide array of geological sequences of different ages on the sub-continent. These include the origin of life on earth, the evolution of multi-cellular organisms, the evolution of mammals, several mass-extinctions, and the origin of humans. Instrumentation essential for such a comprehensive, multi-disciplinary approach are in part available but scattered in different institutions.

Research infrastructure to be included

Present facilities

Present facilities that should constitute part of such a research infrastructure include:

- *Accelerator Mass Spectrometry (AMS) at iThemba LABS (Gauteng).* AMS has developed into a major analytical tool in recent decades and with the AMS facility close to completion at iThemba, South Africa will be well served in an array of capabilities that will rank among the best in the world. These range from carbon dating to high precision analyses for light stable isotopes, and some elements of higher atomic number. The importance of the technique lies in its sensitivity (which is as much as a million times better than conventional mass spectrometry), the small sample size (up to 1 000 times smaller than that required for other decay counting techniques), and high throughput. The AMS techniques have application in a large variety of disciplines, such as environmental sciences, climatology and climate change, palaeoclimatology, palaeosciences, oceanography, hydrology, archaeology, space physics, material sciences and several others.
- *Luminescence dating* was closed down at the CSIR but has been re-established at the University of the Witwatersrand and is working well. However, running such a laboratory is costly in terms of personnel, and university funding model are usually such that the lab is unsustainable in the long term. It will be wise to incorporate it into the envisaged national facility. Of importance to note is that the combined luminescence and AMS dating facilities are required to cover the critical period of evolution of humans.
- *Isotope and dating facilities.* The University of Cape Town has in recent years acquired and installed two Multi-collector Inductively Coupled Plasma Mass Spectrometers (ICP-MS) machines with the aid of an Innovation Fund (IF) grant. This facility has been conceptualised as a national facility although there are costs involved for all users (with some preferential tariffs for users from UCT) to cover operating expenses. One of the machines is designed for solution ICPMS and a tool for normal isotope analysis at trace level and ideal to study Rb/Sr, Sm/Nd, Lu/Hf, U/Pb/Th, and other systems. It can also be used for environmental studies on

various other isotopes such as Si, Fe and Mg the significance of which in environmental research and understanding of processes in nature is being recognised more and more. The second instrument is equipped with a shorter wavelength laser for dating by means of laser ablation techniques. It is ideal for U/Pb and U/Th dating on U bearing minerals. The available instrumentation is under the jurisdiction of a dedicated instrument scientist and technical staff, and supported by existing clean laboratory facilities.

A laser ablation ICP-MS facility for dating is also available at the University of Stellenbosch and similar to the UCT facility access has certain cost implications.

Facilities to be added to the Platform

- *Expanded facilities for radioactive isotopes.* Lacking in South Africa is the ability to use a range of radioactive isotopes to trace geological processes. The use of radioactive isotopes as geological tracers is a powerful tool applicable to most fields in the geosciences, but for most purposes researchers need to perform these experiments at overseas labs. A state of the art facility capable of analyzing a range of radioactive isotope would need to include:
- *An ultra-clean, low contamination metal-free chemistry laboratory* for the separation of the elements/isotopes of interest. Importantly this laboratory must have the capability first, to separate a range of elements including Sm-Nd, Rb-Sr, Lu-Hf, Pb-Pb, Re-Os and the PGEs with potential for work on non-traditional isotopes, as well elements such as e.g. Fe, Cr and Si, and secondly, have isotope dilution capabilities for precise determination of isotopic ratios on old rocks.
- *A Thermal Ionization Mass Spectrometer (TIMS)* to complement the Multi-collector ICP-MS facilities available. Different isotopes are ideally analyzed in different ways and a combination of two different mass spectrometers will provide a powerful and effective tool of analytical capabilities able to analyze many of the elements and their isotopes for geological and biological applications.

Sensitive High Resolution Ion Microprobe (SHRIMP) is a non-destructive technique that provides a better resolution than the conventional dating techniques referred to above. Whereas the latter service the need for the large number of “good” age dating of rocks in Africa, these do in most cases not provide the level of precision required for highest quality research outputs. Recent advances in SHRIMP techniques have expanded capabilities to higher precision and expansion to a wider spectrum of isotopes. Given the uniqueness of our geological and palaeontological heritage a stage has now been reached where serious consideration needs to be given to add SHRIMP as a facility to this platform. The Council for Geoscience or iThemba (Gauteng) could be considered as a host for such a facility.

Remote access to a new high resolution Secondary Ion Mass Spectrometer (SIMS) is being installed at the Geoforschungszentrum (GFZ), a Helmholtz Facility in Potsdam Germany. This will require a skilled off-site operator of such a facility with direct remote control workstation and sufficient bandwidth to access the facility abroad, as well as local, specialised sample preparation and investigation facilities, such as an Electron Microprobe, before these are sent abroad. This will provide an ideal opportunity for very detailed analyses of many elements and isotopes in the parts per billion range, and will meet some of the interim requirements especially for the geosciences until such stage that a SHRIMP facility is acquired.

Linkages with other facilities

Within the context of the Earth and Environmental Sciences this RI will of necessity have close linkages with the proposed expanded terrestrial environmental observation network, the proposed

national materials characterization facility, the GFZ referred to above and for the interim also maintenance of existing sound working relationships with the SHRIMP facility in Canberra, Australia.

Type

In essence a national RI platform of diverse, distributed items of scientific instrumentation, hosted by different institutions and with linkages to select research infrastructures abroad.

Impact

A RI of this nature will not only elevate the quality and impact of research in the earth and environmental sciences conducted in South Africa to new levels, but it will also provide opportunities for conceptualising interdisciplinary research approaches in earth systems science hitherto not possible in South Africa. It will also counter the migration of students and researchers to better equipped laboratories abroad.

11.3.6 Contribution to National Challenges of RI for Earth and the Environment

Challenges	RIs	Marine and Antarctic Research Facility	Shallow Marine and Coastal Research Infrastructure	Terrestrial Environmental Observation Network	A Natural Sciences Collections Facility	Biogeochemistry Research Infrastructure Platform
Food Security		x	x			
Global Change, Mitigation and Adaptation		x	x	x		
Strengthening Industry, economic growth						x
Environmental Sustainability		x	x	x	x	x
Access to water				x		
Conservation of National Heritage					x	

11.3.7 Stakeholder Departments of Earth and Environment RI

Identified RI	DST	DWA	DAC	DEA	DoH	DMR	DoE	DAFF
Marine and Antarctic Research Facility	x			x		x	x	x
Shallow Marine and Coastal Research Infrastructure	x			x		x	x	x
An Expanded National Terrestrial Environmental Observation Network	x	x		x	x		x	x
A Natural Sciences Collections Facility	x		x	x		x		x
Biogeochemistry Research Infrastructure Platform	x	x		x		x	x	x

11.4 Materials and Manufacturing

11.4.1 Materials Characterisation Facility

The facility

The Materials Characterisation Facility comprises a future central hub for specialised state-of-the-art materials characterisation instrumentation, supported initially by a distributed network in South Africa that binds together several identified specialisation centres in materials characterisation. Together they present a broad base of characterisation techniques such as electron microscopy, surface analysis, materials testing, nuclear magnetic resonance, nano-scale characterisation and advanced sample preparation facilities.

Background

The need for a centralised advanced materials characterisation facility has been expressed by materials science and technology stakeholders. However, historically, such instrumentation and facilities were placed at institutions that represent strong expertise and knowledge in the specific characterisation techniques. This has resulted in a fragmented capability that is not always readily accessible to researchers. No formal network management model was adopted and individual institutions often neglected maintenance and upgrading, since there was no national plan. There is a strong case to centralise future advanced and state-of-the-art equipment and facilities under a national characterisation facility. However, the existence of the distributed capability cannot be negated and a hub-and-spoke model is desirable, under one nationally coordinated and planned characterisation facility. Such a model represents cost saving by optimising placement; provide properly managed maintenance and access; open opportunities for specialist research and technique development and equipment improvement by dedicated teams; and builds critical mass and knowledge in advanced materials characterisation. Most of the equipment in such a centralised facility will be accessible virtually for controlling instruments and experiments over the Internet. Although centralisation is often a contested subject, South Africa cannot continue to fragment such an expensive investment environment any further and this roadmap provides the vision that with time, all future advanced investment of this nature should be in a central facility. The existing advanced instruments at separate locations will remain at location and as part of the network, but be phased out with time as they reach end of life, or be replaced by a more modern generation. This model does, however, not preclude institutions from acquiring their own characterisation equipment used for training students, supporting own preparatory research before it is taken to a national facility and to gain experience in sample preparation and analysis techniques. In essence the facility is initially a relative small hub with large nodes and will migrate with time to a large hub with small nodes.

Research infrastructure required

The Materials Characterisation Facility is made up of the following activities:

The Central Advanced Characterisation Facility

This facility will form the core of future materials characterisation platforms in South Africa, planned and managed to support the large variety of materials science and engineering projects undertaken by the various research institutions in the country. It will assume a corporate management function of the nodes that make up the distributed facility in terms of upgrading, maintenance and access.

Electron microscopy facilities

Major investments have been made in modern electron microscopes (TEM and SEM) over the last decade resulting in institutions owning relative state-of-the-art instruments with some

complementarity and some overlap. These include, amongst others, facilities at Nelson Mandela Metropolitan University (HRTEM), the University of the Western Cape, and the National Centre for Nano-Structured Materials (NCNSM) at the CSIR, the University of the Witwatersrand.

Surface science facilities

Although several research institutions have surface analytical instruments such as XPS (ESCA), SIMS, EELS, LEEDS, scanning probe microscopy, etc. the University of the Free State and the NCNSM host the most complete platforms.

Materials testing

A national Centre of Excellence in Strong Materials at the University of the Witwatersrand hosts a variety of materials testing infrastructure and provides leading research in this field.

Ultra-high Field Nuclear Magnetic Resonance (NMR)

Future acquisition of an ultra-high field NMR (1 GHz and beyond) spectrometer should be on a national basis and such an instrument and its supporting platforms belong in a centralised characterisation facility.

Advanced sample preparation facilities

Each of the characterisation environments provided for by the central research facility requires advanced sample preparation. Such laboratories will form part of the larger research infrastructure, grouped with the techniques on offer.

Linkages with other RI

Other materials characterisation platforms exist, but are dealt with elsewhere in SARIR:

Ion beam analysis

Although several materials characterisation techniques fall under this category, it is taken up in the Laboratory for Accelerator Based Science.

Neutron based materials analysis

This falls under the Materials Research Reactor.

Synchrotron based materials analysis

These activities are addressed by the national synchrotron roadmap and utilises synchrotron beams elsewhere in the world.

Type

This research infrastructure is distributed with a single-sited hub to be developed for the future, linked with existing nodes of state-of-the-art instruments. All instrumentation under the auspices of the Materials Characterisation Facility will be virtually linked to a large variety of researchers involved in materials science and technology projects in South Africa. It thus has a mixed character of single-sited, distributed and virtual research infrastructure.

Impact

Access to such a well planned, equipped and managed research infrastructure will make the materials science and engineering research fraternity in South Africa globally competitive. Industry in South Africa will find advantage in utilising knowledge on their doorstep and will have an opportunity to have their researchers trained on world class facilities to prepare them for expanding their own in-house research laboratories. The research infrastructure will form part of an international network of similar research infrastructures.

11.4.2 Nano-manufacturing Facility

The facility

The nano-manufacturing facility comprises a state of the art clean laboratory with photo-, e-beam and x-ray lithography, steppers, etchers, ion beam sputtering, Molecular Beam Epitaxy (MBE), on-chip materials processing and materials characterisation equipment, etc. to enable micro-electronics and nano-structure manufacturing and micro- and nano-systems engineering for advanced sensors and devices.

Background

South Africa has been a minor player in the area of high volume, low cost micro-electronics and has ceased all commercial operations in this area, but has led in several areas of dedicated device design and manufacture and low volume production. It has built a significant knowledge base in semiconductor and nano-materials, but lacks the capacity to make modern devices required by local industry for integration with locally designed systems, many of which for the export market. Significant local communities have been built around semiconductor materials, nano-materials, micro-electromechanical systems (MEMS), sensors, microfluidics, mechatronics, and associated technologies. These communities do not have access to a state-of-the-art manufacturing facility to take their research to commercialisation. In 2009 a roadmap and business plan were drawn up under the guidance of these communities, in close collaboration with the electronics and optronics industry that suggested the establishment of a microsensor initiative and a MEMS micromanufacturing activity in South Africa. Fragmented activities in microsystems development and manufacturing are taking place in a variety of clean laboratory facilities that are dated and not state-of-the-art. A modern new clean laboratory with the capacity to provide device and systems development to these communities at the nanoscale has been identified as a national need for some time. Especially in the field of MEMS, locally manufactured products are integrated into systems that represent a large export market. There is, however, in the current facilities a need to upgrade to technologies that include on-chip materials growth and processing and for larger scale integration capacities. The competitiveness of South Africa as a player in this technology field is under pressure with the lack of modern facilities.

Research infrastructure required

The nano-manufacturing facility that will address the local needs requires the following components:

New clean laboratory facility

At least 1 000 square meters of clean laboratory space is required, of which 200 m² will be class 10 000, 500 m² class 100 and 300 m² class 10 supported by about 200m² of office space. A three-storey building, with the basement and upper level used for services and the middle section containing the clean laboratory shells is required.

Specialisation in the clean laboratory

Three areas of specialisation will be established in the clean laboratory facility: academic R&D; shared production and a commercial section.

- Academic R&D: Facilities required include Molecular Beam Epitaxy reactors (often materials dependent); ion beam etching; thermal diffusion furnaces; Low Pressure Chemical Vapour Deposition (LPCVD); Reactive Ion Beam Etching (RIE); ion implanters; wafer alignment and bonding equipment, chemical-mechanical polishers; lithography (optical, electron beam and X-ray); characterisation equipment. Such an area is highly dependent on ultra-high vacuum environments, ultra-clean laminar flow conditions and the use of specialised gasses.

- Shared production: In this section facilities for inspection and metrology; ion beam etching; chemical vapour deposition; physical vapour deposition; cleaning and solvents and lithography, coating, masking spinning and steppers are the main constituents.
- Commercial section: Businesses can rent specialised clean laboratory space and bring in their own equipment. The manufacturing of microbolometers which is a commercial activity in South Africa will largely benefit from such a lease. This may also cover the fields of specialised MEMS such as microfluidics and emerging devices.

Linkages with other RI

Several local research initiatives are undertaken in nano-and micro-electronic systems, devices and materials. This will be a national facility where such research can be taken closer to demonstration and final devices that could be integrated in commercial components and systems. The facility will also be closely linked with the Materials Characterisation research infrastructure that forms part of this roadmap.

Type

This research infrastructure is single-sited, but will be virtually linked with materials and device characterisation facilities. It is high end, since it needed to bridge the gap between research and development and commercialisation on the innovation value chain.

Impact

The impact on the local micro-electronics and optronics industry will be to ensure that it remains globally competitive. It will also enable the start-up of a nano-electronics industry aimed at dedicated devices and systems required by the South African and global defence and civil industry. The research infrastructure will form part of an international network of similar research infrastructures.

11.4.3 Contribution to National Challenges of RI for Materials and Manufacturing

Challenge	RI	Materials Characterisation Facility	Nano-manufacturing Facility
Energy Supply and Efficiency		x	x
Global Change Mitigation and Adaptation			x
Poverty eradication		x	x
Improvement in nutrition, health and wellbeing		x	x
Strengthening local industry and economic growth & sustainable livelihoods		x	x
Access to quality education		x	x
Access to water		x	
Conservation of national heritage		x	
Peace, safety and security		x	x

11.4.4 Stakeholder Departments of the Materials and Manufacturing RI

Identified RI	DST	the dti	DoE	DAC	DoH	DPE	DMR	DSD	DoD
Materials Characterisation Facility	x	x	x	x	x		x		x
Nano-manufacturing Facility	x	x				x			x

11.5 Energy

11.5.1 SAFARI-2 Materials Research Reactor

The facility

A research reactor is a fission nuclear reactor that serves mainly as a source of neutrons.

Background

The current SAFARI-1 reactor at Pelindaba, Necsas is 48 years old and is well maintained and used, but according to estimates could work efficiently for another 10 to 12 years. For South Africa to maintain a competitive position in nuclear science and isotope production it has to be replaced before its end of life.

SAFARI-2, like its predecessor, will be used as a major source of neutrons for research, the production of isotopes, of which Molybdenum-99 for medical nuclear diagnostics is the highest demand and the doping of silicon wafers through neutron transmutation for the semiconductor industry. Neutron fluxes are applied in a variety of analytical research setups.

A research reactor is essential to any country with an active nuclear power industry to support research in the front and back end of the nuclear fuel cycle. It is an important analytical tool for materials science.

Experimental infrastructure required

Ancillary to the reactor, three basic types of infrastructure are required:

- Neutron production infrastructure
- Neutron guides
- Irradiation facilities

Basic neutron production infrastructure

A *Cold Neutron Source (CNS)* provides very low energy neutrons with long wavelengths for neutron scattering. Using a CNS allows researchers to study the structure and properties of materials such as plastics, ceramics, magnetic materials, pores in rocks and biological materials at the nanoscale. The CNS is generally a volume of liquid deuterium cooled to a few degrees above absolute zero, located close to the reactor core. The reactor core produces about 20 Megawatts (MW) of energy when fully operational, so a substantial cooling plant is needed to remove the heat from the CNS to keep it cool and the deuterium liquefied.

A *Thermal Neutron Source* provides medium range energy neutrons in an energy range comparable to room temperatures. Thermal neutrons are used to peer inside metallic objects such as aircraft and engine components and to investigate the atomic and magnetic structure of materials including minerals, pharmaceuticals, cement and superconductors. These neutrons come directly from the fission process and need no additional equipment.

A *Hot Neutron Source* operating at temperatures around 1 000^oC, hot (high velocity) neutrons can be used to study the structure and behaviour of glass and glass-like materials, liquids and the molecular interactions in materials for the energy industry (including hydrogen storage materials). A hot moderator generally contains a graphite block which is thermally insulated and positioned in the moderator tank in the vicinity of the maximum thermal flux density distribution. The graphite cylinder is heated by gamma radiation and, to a small extent, by neutron radiation from the reactor.

Neutron guides

Neutron guides carry the neutrons from the reactor core towards the neutron guide hall instruments. The neutron beams are used by scientists to conduct neutron research. The instruments will vary, depending on the experiments being conducted.

There are separate guides for cold, thermal and hot neutrons. Neutron super-mirrors in the guides transport, bend and focus the neutron beams and take them to the experimental area.

Irradiation facilities

These fall into different classes:

- General purpose irradiation facilities, for example for fuel or waste testing
- Bulk irradiation facilities, used for the irradiation of uranium plates to produce Molybdenum-99 and the irradiation of other materials such as Iodine-131
- Large volume irradiation facilities, used for irradiating silicon
- Neutron activation and delayed neutron activation facilities, used for determining the content of samples and the amount of uranium in samples, respectively

The irradiation facilities are contained in various tubes within the reflector vessel that access neutron fluxes of varying wavelengths as required for the material being irradiated and its end purpose.

Linkages with other RI

The research reactor is an essential research infrastructure to complement accelerator based sciences, high resolution electron microscopy, synchrotron research and laser based materials analysis.

Type

SAFARI 2 will be a single sited research infrastructure, based on the Pelindaba site of Necsa.

Impact

SAFARI 2 will have strong regional impact, whilst it will form part of an international network of research reactors, supplementing the global reactor based research and isotope production capability.

11.5.2 Solar Research Facility

The facility

The solar research facility comprises a platform for research, development and testing of concentrating solar technologies as well as other technologies such as photovoltaics and solar water heating

Background

South Africa is richly endowed with solar irradiation that is not optimally applied in the energy mix yet. The Integrated Resource Plan indicates a significant contribution to electricity generation by concentrated solar power (CSP) and photovoltaics (PV). Given that South Africa has amongst the highest solar direct normal irradiation in the world, it presents an ideal opportunity to develop a solar research platform with world class research potential. Feasibility studies are being undertaken for solar parks of up to 1 GW in the Northern Cape and Eskom is in the process of developing a 100 MW CSP project in the same area. A photovoltaic roadmap is under development and the role of concentrator PV has been identified in a future energy mix for the country. A research facility is required for concentrator solar power to study materials, mirror (heliostat) design, parabolic dish design, heat conversion, heat transfer fluids, and energy storage. Significant research is being undertaken in CSP all over the world and with a Solar Research Facility in South Africa, it can offer unique contributions based on the geographical advantage of solar irradiation patterns in the country.

Research infrastructure required

The facility requires about 10 hectare of suitable land and grid connection for both own consumption and feeding electricity back into the grid. Specialised research platforms include:

Tower

The tower, typically 50 meter high, hosts solar receivers and custom experiments.

Heliostat field

Heliostats provide solar flux onto the tower and typically includes 5 000 heliostats with two square meter mirrors each.

Thermal storage test facility

This is an open area with concrete base and walls, ducts, fans and heating elements situated close to the tower.

Heat transfer fluid test facility

The facility includes heating elements, pumps and supply tanks for optimising heating fluids and for developing next generation materials and systems.

Photovoltaic test facility

The facility comprises an open area with electrical infrastructure to connect PV modules. Testing can be done on large scale PV panels as well as PV concentrator layouts.

Solar water heater test facility

This is an open area for placement of different solar water heater systems under development with access to water and measurement instrumentation.

General test facilities

Solar resource measurement equipment and optical characterisation and electrical and thermal test facilities are required in laboratories and in the field.

Linkages with other RI

Several local research initiatives are undertaken in solar energy. This is, however, taking place at a small scale and has not been brought close to the application phase. The Solar Research Facility represents an environment for scaling up on this knowledge to transfer it to commercial applications. In particular, the proposed research infrastructure will link with Sandia National Laboratory Solar Test Centre in the United States and the Plataforma Solar de Almeria (PSA) in Spain. Linkages on parabolic dish design with the SKA programme are evident.

Type

This research infrastructure is single sited and high end, since it needed to bridge the gap between research and development and commercialisation on the innovation value chain. It will be located in an area of high solar incidence, preferably sharing facilities with one of the solar parks envisaged for South Africa.

Impact

The research infrastructure will form part of an international network of similar research infrastructures. It will provide a unique opportunity for testing CSP systems and improving materials, components and energy management under conditions of high solar irradiation. It will support the local demonstrator and commercial generation initiatives in CSP that are under way.

11.5.3 Contribution to National Challenges of RI for Materials and Manufacturing

Challenge	RI	SAFARI-2 Materials Research Reactor	Solar Research Facility
Energy Supply and Efficiency		x	x
Global Change Mitigation and Adaptation			x
Poverty eradication			x
Improvement in nutrition, health and wellbeing		x	
Strengthening local industry and economic growth & sustainable livelihoods		x	x
Access to quality education		x	x
Environmental sustainability			x
Conservation of national heritage		x	
Peace, safety and security		x	

11.5.4 Stakeholder Departments of the Materials and Manufacturing RI

Identified RI	DST	DoE	DoH	DPE	DMR
SAFARI-2 Materials Research Reactor	x	x	x		x
Solar Research Facility	x	x		x	

11.6 Physical Sciences and Engineering

11.6.1 A national support centre for science

Background

There is an increasing use made of accelerators and light sources in science and medicine from the understanding of protein structures to the treatment of cancer tumours in addition to their use in a wide range of materials science and engineering. Many countries have one or more national laboratories which act as centres for a wide range of expertise and as the national representative in international activities. This avoids duplication of effort among universities and ensures there is critical mass of skills which can be utilised to build components and whole instruments needed by a great variety of sciences. Critically it would be a training ground for building human capacity.

What is it?

A centre which has critical mass expertise in accelerators, magnet design, optics, sensors and testing facilities with the ability to micro-fabricate components for instrumentation and devices for medical diagnosis

What is it for?

A very wide range of applications would be served. The most immediate would be to gain expertise in the building of beam lines for light sources elsewhere (e.g. ESRF in Grenoble) or for future 4th generation light sources such as hard X-ray free electron lasers which might be required once South Africa has built up sufficient need for its own light source in a decade or so. With an accelerator science and technology centre superconducting cavities and diagnostics can be designed and built adding very high value to South African raw materials. Such accelerators are used for several applications from particle physics to proton therapy. A further addition would be focused on acceleration by lasers which could substantially lower the cost and increase the availability of medical treatment facilities. With such a centre the country would be a credible bidder to take part in large international experiments such as the proposed "International Linear Collider" (ILC) or could contribute to the upgrade of the Large Hadron Collider in 2019.

A critical output would be the training of a cadre of high quality design and technical staff who, if the experience of other countries is repeated, will go on to create several hi-tech companies or attracting hi-tech companies to locate in South Africa.

Who would use it?

It would be a resource for researchers from a wide range of backgrounds and be open to work in conjunction with universities to build hi-tech instruments and devices for a very wide range of programmes including new medical devices.

Linkages

Although primarily a civil centre there will be synergies with defence establishments especially in the fields of lasers and instrumentation. It would also be the resource centre for building new lasers, light and ion beam sources whether they are co-located or elsewhere. International experience has shown that partnerships with key universities and the sharing of academic staff are essential. Ideally this would be a national centre co-located with an active science centre such as the iThemba LABS or somewhere similar.

The facility would be governed by an independent council reporting directly to NRF consisting of industrial and academic members with an International Science Advisory Board assessing priorities

for support. There would also be a linked training school which could work with the Department of Education to train apprentices and administrators at the highest level. Where “in kind” contributions are made to international facilities, teams could be sent elsewhere in order to gain further experience and to “buy” a share in the science. (This is very common).

The building up of such a centre would depend upon the funding and timescale decisions for other facilities such as a radioactive ion beam facility or a future light source such as a synchrotron. It is very important that the centre remains flexible and does not create a life of its own outside national needs or in competition with universities. Experience elsewhere has shown that approximately half the costs are for core staff while the other half is for winning competitive projects either with universities or other partners. This does not include any one off capital build.

Impact

In addition to training high quality personnel, other similar institutions attract hi-tech industry to their immediate vicinity because of the innovative nature of the work being undertaken. This has further knock on effects on local schools and culture. As an example, high quality components as part of South Africa’s contribution to CERN can be miniaturised and used for medical diagnostics. At the Rutherford-Appleton Laboratory, the UK set up a venture fund run by a professional fund manager to license or create spin outs based on the technology being developed.

A diagram showing line up with national priorities is not shown since such a centre (possibly with outposts) would cover all priorities.

11.7 Potential projects for inclusion in future RI roadmaps

One outcome of the first ESFRI roadmap was that other groups who saw new potential organised themselves to define future RIs. While the panel cannot anticipate what might happen there are four areas where it would be expected that an RI (new or upgrade) will become necessary.

RI Domain	Identified RI
Humans and Society	<ul style="list-style-type: none"> • Longitudinal Social Surveys • A Social Sciences and Humanities Collections Facility
Physical Sciences and Engineering	<ul style="list-style-type: none"> • A South African or Southern African Light Source • <i>Space Science</i>: A South African Space Science Centre • <i>Astronomy</i>: <ul style="list-style-type: none"> ▪ 4m class optical telescope and SALT 2 ▪ VLBI 2010

11.7.1 Humans and Society

- ***Longitudinal Social Surveys***

Longitudinal Social Surveys are typically used for collecting data relating to social, economic, labour, educational and health-related issues and serve as an important research tool for economists, sociologists, and other researchers. Within the European ESFRI context, the European Social Survey (ESS) “an academically driven long term pan-European distributed instrument” has been accepted as a research infrastructure. For South Africa some longitudinal social surveys as research infrastructure aimed at building capacity and to elevate the quality and impact of HSS research in the country and with optimal impact in addressing societal challenges, should ideally also be conceptualised and driven by academics. This would however require detailed discussions amongst the larger SSH community of the country, a process of planning that could be facilitated by the NRF with due involvement of the HSRC as a partner in such a venture due to its mandate “to gather, analyse and publish data relevant to developmental challenges in the Republic...” and its experience in conducting such studies for clients.

- ***A Social Sciences and Humanities Collections Facility***

South Africa with its cultural diversity and rich, albeit controversial, history has a vast collection of irreplaceable cultural and heritage material and art in many museums and institutions scattered across the country and in institutions abroad. Globally, information associated with the material in collections of this nature is increasingly accessed by researchers for research data that has many applications of historical and societal relevance. The question invariably arises to what extent information on the diversity of material in these collections is freely accessible for research, the extent to which this material is professionally curated and catalogued in accordance with internationally accepted norms and standards, and whether this material is generally accessible for research? Akin to the recent audit of the natural science collections commissioned by the NRF, it is proposed that a detailed audit is conducted of collections of relevance for research in the human and social sciences, prior to any decision being taken whether collections of this nature or specific parts thereof could become constitute as a research infrastructure for inclusion in the research infrastructure roadmap.

11.7.2 Physical Sciences and Engineering

- A South African or Southern African Light Source. This has been alluded to several times in the report and does depend on the growth of both the user base and learning from existing and future partnerships such as the one with ESRF. Given the time delay for agreeing a design and funding, planning for this should start within the lifetime of this roadmap and not left too late.
- Upgrading the South African laser centre. Again this needs definition and links with the European Laser lab and other international projects should be exploited
- A South African Space Science Centre. The overview of space related research in South Africa has hinted that such a centre would be good but as yet there is no adequate definition to bring it into this roadmap
- Research Infrastructures in the Humanities and Social Sciences for future consideration

12. Human capacity building, the need for sensitive project management - how to train the workforce?

The roll-out of a Research Infrastructure Roadmap to support a successful and competitive research base in a country requires two necessary ingredients:

- Human capacity development
- Good management of the RI

Viewing RI as more than facilities built to service researchers from owner institutions requires a new paradigm in training and management of the custodians and the users of such RI. With the exception of the existing national facilities in South Africa, such a culture of broad access and fulfilling a critical role in the international ecosystem of RIs does not yet exist.

12.1 Human capacity development

Human capacity development refers here to those people that will plan, develop, manage, operate, use and evaluate the national RI brought about by this roadmap. Perhaps the most important task is to identify and train RI managers and their management teams. Staffing the RI over its entire life cycle requires a variety of professional skills. This life cycle includes the initial conception for inclusion in the roadmap; the conceptual and technical design phases; the construction phase; commissioning; operation; maintenance and expansion and eventually the decommissioning phase.

RIs are as good as their champions. It is therefore critical to identify potential champions, often from foreign sources, that can lead in the initial phases and to develop some local talent at the same time. Working at a RI deserves a particular status and standing in the scientific community. This needs to be taken into account in defining the responsibilities of staff, ensuring and acknowledging visibility of their contributions and in rewards and benefits. Being on a RI management or technical team needs recognition at the same level as the researchers that utilise the facilities provided by the RI. To create this as a sought-after career environment requires careful human resource planning, often using a different set of rules than those applying to current government or academic environments.

Many RIs lend themselves to exciting the youth to consider a career in science, often in the immediate vicinity of where a RI is located. Offering outreach programmes to communities and involvement with local education and training institutions requires skills in popularising science and communication to ensure that RIs play a major role in creating the next generation of scientists in a country.

One of the most important aspects to ensure a highly skilled and motivated corps of users around RI is the creation of an environment of free movement of knowledge within which the bright minds using the RI can grow and flourish. Apart from creating exciting career opportunities and stimulating interest in science, RIs are fundamental in developing human capacity in science, engineering and technology in a country over their entire lifespan. They complement the higher education system by providing platforms where students interact with other users, often at a global level, and become motivated to advance their studies for the purpose of taking up research as a career or to be ready for employment in industry. In a South African context race and gender equity are important considerations in human capacity development, be that for own management, scientific and technical staff or for training and preparing students for the job market.

12.2 RI management

Research infrastructure management along the entire life cycle is complex and requires different skills sets. Taking over from the policy makers once it has been agreed that a particular RI will be developed first requires an involved negotiation period with funders. Once funding is in place, the RI development and construction projects need to be pursued which involves the alignment of construction crews with suppliers, some of which (like local SMEs) will often have to be capacitated to be able to supply in accordance with the detailed and frequently unique specifications of the RI.

Governance structures have to be set up and maintained, including the identification and involvement of stakeholders and shareholders and the development of appropriate partnerships. This includes the decision on a legal form for the RI that will own it, be accountable for it and have authority over it. Ownership relates strongly to the position and role of the RI in the national innovation framework. Since it is a facility for the good of a broad base of researchers, it should ideally be owned by an independent entity, not being part of the existing government, research council or academic environment. A holding agency, along the line of the European Research Infrastructure Consortium (ERIC) in Europe could be considered as a legal framework.

Research strategy and priorities will be set by an advisory body consisting of world class experts in the fields of research serviced by the RI. Priorities for use will be decided on merit, based on a peer review process. Both external users and internal researchers that are permanently employed by the RI will compete for research time.

An important governance issue is the development of communities around the RI and defining and executing, apart from science outreach activities, collateral benefit programmes associated with the RI. This, together with socio-economic development that also includes local supplier and services development will ensure the acceptance of RI by the public. Finally, every good governance system requires a thorough evaluation and monitoring process.

Strong financial management capabilities are required. This involves the identification of funding sources and clients. Estimating, costing and budgeting for the RI over its entire life span is a continuous process, both for short term and medium term expenses and revenue. In addition, communication with both industry and stakeholder communities, keeping users informed, marketing and public feedback of outcomes and impacts is critical to a well-functioning RI.

The building of a flexible national base that has the ability to manage single sited, distributed and virtual RI is critical to realise this roadmap strategy. Successful RI are built on good collaboration, not only among researchers and research institutions on a national and global scale, but also with other RI that complement the entire competitive base in a national innovation framework and for competitiveness of a world-class research base.

13. Implementation and the implications of open access

The term “open access” can refer to publications and also to data. It can also refer to the way research is undertaken and is often termed “Science 2.0.” It is fair to say that all three aspects are interrelated and highly emotive since they affect, not only how research is done but also the traditional publication models on which research depends (namely, citeable publications after peer review). This roadmap report is not the place to debate the merits or demerits of the open access drivers but to acknowledge that they will have an ever increasing impact on access to information from RIs and that RIs in many cases will be the places with the greatest concentration of expertise as they have to manage so much information. This expertise will be built up, for example, as South Africa becomes a Tier 2 centre for the LHC in Switzerland.

If and when full open access to data and publications become available then decisions will have to be taken on whether all access is free and what should be done about politically sensitive information such as that on animal testing. The so called “Citizen cyber-science” movement already has many adherents in South Africa and more should be encouraged. Making information openly available and crowd-sourcing analysis of those data is a form of democratisation which the ESPAS report “Global Trends 2030” calls a polycentric world where the concept of nationhood starts to break down. This is difficult for politicians to grasp and especially so in a country which is so young democratically. It is even a huge problem for established democracies.

One aspect of this phenomenon is the huge rise in Massive Open Online Courses (MOOCs) which are having a major impact on universities around the world. Linking course material back to original papers and data is starting to occur and is causing universities to look at course delivery afresh.

While certain countries try and restrict citizens from accessing all open content for various reasons, recent examples of secure information leakages show that this position will not be sustainable in an open access world.

As has already been said, RIs are going to be the places of expertise in this new environment and can help develop national best practice policies to ensure openness while preserving sensitive personal data and data that would jeopardise national security. Likewise they can also act as training centres for “data scientists” and for those developing online research content for crowd sourcing.

14. Role of industry in management, supply and use

The economic efforts behind the construction and operation of a research infrastructure are pressing governments over the world to maximise the benefits or the spill-overs generated by this investment during its life-cycle to different stakeholders. In other words, RIs are often considered drivers for economic growth. One of the perspectives is the potential **strengthening of the industrial sector** which can be derived as a consequence of this process.

The potential **involvement of industry in research facilities** has three complementary perspectives:

- The **industry as a provider** of components, systems or the civil works in the construction process of the RI or as provider of advanced services³¹ during the operation and maintenance phase.
- The **industry as a user** of the research facility with their own equipment (installed in the RI) or by using the general facilities provided by the RI.
- The **industry in the management** of the research facility through the offer of professional management services.

The relative importance of these (compatible) approaches generates a different perception of the way that the research facility can facilitate the improvement of the national innovation system. More specifically:

Industry as RI Provider

The construction, the major upgrading or the participation of South Africa in RIs located abroad offers many opportunities to create or to improve a national “science-driven industry” in close cooperation with research centres and universities. To address this goal it is necessary to consider an appropriate balance between in-cash and in-kind contributions based on the technical and managerial capabilities of the nation. Whatever dimension an in-kind contribution may take, it should be addressed from a very professional perspective to ensure that they satisfy the quality rules of international tenders.

Afterwards, industry can participate in the operation and maintenance phases of the suggested RIs of a SARIR by providing advanced services related to sophisticated components, testing of new elements, etc. in close relationship with the technical staff of the research infrastructure and according to open international tenders.

Industry as a RI user

In many cases, industry could also benefit from the use of the RI to complement its research efforts carried out on their own premises. For a specific industry to use one research facility two different approaches are possible:

- Competing for the use of the instruments available for the scientific community in one RI. As time-allocation for the scientific use of the facility is made through the presentation and evaluation of specific research proposals, industry participates in this case as any other scientific user regardless the cost which can be charged for that use in case of a successful proposal.
- Through specific agreements to use the RI exclusively for specified periods of time under some financial arrangement. Alternatively a specific industry can be the owner of some

³¹ We are not considering here the provision of general services (security, cleaning, electricity, water, etc.) not related to the S&T domain of the RI.

equipment (i.e. a dedicated beam line in a synchrotron) installed as a separate asset of the research facility or in the co-owner with public institutions.

The accumulated experience indicates that a proactive role of industry to use the RI as independent user is very low. Usually, it requires the participation of academics to conduct state-of-the-art research with the RI concerned. Joint proposals between research groups and industries to use a RI are relatively common.

Industry as a RI manager

The management of a complex RI requires sophisticated skills which can be addressed by recruiting skilled and experienced people or by subcontracting part of the involved processes to other enterprises with the required knowledge. Some areas related to non-technical advanced services (like legal aspects or IPR) are easier to facilitate with the involvement of industry than others where management has to rely on the RI personnel with scientific background.

From this previous discussion, the following **policy recommendations** can be extracted:

- **To involve industry from the very beginning of the definition process** of one RI in order to facilitate early feedback on the scientific case or in the preliminary design and also to help in the positioning process of the national industrial sector at the international level. This recommendation implies the identification of interested industries which should receive enough information about the intended specifications. Obviously, only pre-qualified industries could participate in this phase.
- **To create a governmental support programme to increase the capacity of the industry in the provision of sophisticated components.** The support of pre-identified interested industries to increase the possibilities of success in open tenders for component provision is a long-term goal which should be addressed through governmental programmes where industry can obtain the qualification degree to participate and to win in international tenders.

This programme is especially pertinent to SMEs because the possibilities to finance the development of specific industrial prototypes are very difficult to get; for that reason, the creation of public procurements to provide a prototype-based component in order to anticipate future international tenders introduces a short-term extra cost but long-term benefits.

For many industries the participation in the construction of a RI implies availability of some experience which is not possible to obtain unless they could explore the use of the technology in low risk projects. In this case, the involvement of industry should also be organised from the first steps in the construction phase. In some countries this goal was supported by financing the development of prototypes by selected industries.

- **To open the research infrastructure for industrial users.** This objective can be addressed by defining the access conditions and cost in a compatible way with the scientific use of the RI. Generally speaking, it is necessary to distinguish between the considerations of the industrial user as another scientific user (with the same working conditions and time-allocation based on the quality of submitted research proposals) or to allow for a commercial use of the RI.

This second possibility is rather more difficult to manage for the need to sign up contracts between the legal entity of the RI and the enterprise with confidential requirements, the use of own space lab

and components, etc. which can be difficult to accept in an open environment. This alternative is easier to implement when the equipment for industrial use is different (i.e. the case of a “beam line” in a synchrotron) and/or the maximum time of use is limited. In this case, it is necessary to establish a **cost of the facility** linked with the percentage of use and indirect costs.

15. Cyber-infrastructure and Data Management

15.1 Cyber-infrastructure

As shown throughout this report, cyber-infrastructure (sometimes referred to as e-infrastructure) is critical to all aspects of running successful RIs. There are four distinct areas where cyber-infrastructure support is needed to exploit the full potential of other RIs.

- Accessible and cheap large bandwidth connectivity between users and the RI and with links to international users. This allows virtual access to data and the potential for virtual operations.
- Sufficient local and national supercomputing capability for undertaking simulations and for data analysis.
- A critical mass of researchers at both the RI and institutions that access the RI to ensure that all aspects of cyber-science are exploited according to commonly agreed standards.
- Storage requirements for very large data sets, their curation, preservation, protection and services in relation to access and analysis of very large datasets.

In parallel with this roadmap has been the conceptualisation of a National Integrated Cyber-Infrastructure System (NICIS) by a committee consisting of local and international experts. This team has addressed in some detail the needs expressed above in a report submitted to the DST in October 2013, entitled “National Integrated Cyber-Infrastructure System: A framework for the establishment and maintenance of a sustainable NICIS”. The text below is a brief summary of the findings in their report and, although not a roadmap in the sense of the SARIR, the investigation was prompted by a number of large science projects that drive the need for a substantive growth and expansion of the cyber-infrastructure (CI) and the interdependent infrastructure needs for high-performance computing, fast networking and large datasets.

Their report, benchmarked against CI systems in other countries, proposes the establishment of a sustainable NICIS that can “exploit the enormous synergies that can be derived from integrating national CI into a cluster of mutually supporting activities which leverage high-level financial and strategic planning, as well as oversight and management.” This in essence entails an amalgamation of existing separate organisations supported by the DST at present into a single integrated CI organisation, i.e. NICIS, which would involve the Centre for High Performance Computing (CHPC), the Data Intensive Research Infrastructure for South Africa (DIRISA), the South African National Research Network (SANReN), and possibly also the university driven TENET. These would collectively be supported as centralised “Tier 1” facilities and provide the backbone for several institutional “Tier 2” resources provided through programmes such as the NRF, DHET and others.

The establishment of the proposed NICIS would be in accordance with the following principles:

- Joint planning and budgeting
- Good governance principles such as transparency, accountability, efficiency and effectiveness
- Visibility of CI services
- Sustainability
- Constructive stakeholder engagement

Contrary to the proposals in this report on a SARIR, the CI report recommends that NICIS becomes a legal entity fully owned by the DST, with the DST deciding the vision and overall aims, as well as the funding and budgetary aims. A NICIS Board is envisaged to maintain an independent control function

on behalf of the DST, to develop a strategic plan, to have real decision-making powers and the ability to hold the CEO to account. An alternative option proposed is a NICIS as a national facility under the NRF.

It is furthermore proposed that the activities of the NICIS will be organised in service areas such as Networking, Computing, Data, Skills and Training, and Administration. In this regard it is envisioned that the Networking Services should be recognised as the National Research and Education Network (NREN) servicing all research and educational sectors, including the Further Education and Training Colleges and schools, that the CHPC should take on the role of the Computing Services, that the present DIRISA programme should be transformed into a more vigorous expanded Data Services, and that the targets of the Skills and Training Services should target both CI professionals for the management and operation of NICIS and other CIs, as well as researchers that use and benefit from using CI services to enhance their research and collaboration capabilities.

Other recommendations, aligned with those of national RIs of a SARIR are:

- The importance of participating in international CI initiatives to ensure high quality of the NICIS enterprise
- The need for long-term funding security
- That access and the allocation of cyber-resources by researchers should be on a merit-based competitive process
- The recognition for the need of innovation projects within the NICIS, but that these should largely be performed by research communities outside the NICIS. NICIS should however not serve as a funding agency.

Members of the CI team have pointed out the importance of understanding quantitative growth requirements to meet projected future demands in networking capacity and bandwidth requirement of the SANReN backbone, as well as the need for up to exascale high performance computing facilities on completion of the SKA. However, it should be up to the Board of the proposed NICIS to initiate the development of detailed CI roadmaps in accordance with an approved strategy for NICIS, rather than giving undue attention prematurely at this stage before the DST has responded to the recommendation of the CI task team.

15.2 Data Management

Although the SKA expects to create more data flow than any other activity in the world, many other areas of research especially from RIs will not be far behind. Both the “omics” platform and the X-ray tomography of the fossilised brains of prehistoric skeletons coupled with the diversity of the plant and animal life in South Africa will put great demands on data storage, curation, protection, authentication and access. This will no doubt be addressed if the proposals regarding the establishment of a NICIS referred to above come to fruition.

In common with many countries, an open data policy will require easy access for all researchers from whatever discipline to interrogate the data. Indeed it is only by allowing such access that many of the solutions to grand challenges will be found, particularly where data sharing takes place across different disciplines. There is now a world-wide movement in the form of the Research Data Alliance who are trying to ensure that common approaches to data sharing across the globe are adopted, the “rd-alliance.org”. There are now a large number of international groups looking at aspects from persistent identifiers, metadata, marine studies, structural biology, social sciences, wheat production and the impact of the cloud on development as examples of the diversity of activity in this area.

It is important that South Africa mandates an active data management plan that is adopted and implemented for all national RIs consistent with global access to data. This evidently seems to be the mandate of the proposed Data Services of the NICIS and it is encouraging to note that CI report considers it essential that the Data Services area of NICIS participates in international forums such as the Research Data Alliance in order for South Africa to be an effective player in world class research.

16. Identified RIs in an international context

As mentioned in previous chapters the coordination, participation and cooperation at the international level is a key component of the SARIR planning process. As the **Group of Senior Officials (GSO) on Global Research Infrastructures of G8** has shown³², many countries were ready to start a progressive opening of their national facilities to the participation of other countries (even in the governance schemes) by reciprocity schemes. As stated in the approved GSO framework: *“it becomes crucial to make concerted efforts at the international level for the realization of “global research infrastructures”. The interest in a “global research infrastructure” relies on its capacity to address the research needs of world-wide scientific communities by combining the best available knowledge, human capital and resources in one specific scientific area with multi-source funding”*.

The objective of this chapter is to identify those **national or multilateral RIs** located in other countries (“international RIs”) which could be of significant interest to the South Africa S&T system in each priority S&T domain. The rationale for identifying such RIs is twofold:

- **South Africa cannot locate all possible RIs necessary for their scientific community within the country.** In many cases, the only possibility will be to access other RIs available abroad or created by international organizations to keep its scientific competitiveness. The consequence is the need to agree with other stakeholders (governments, entities or international organizations) on access to selected research infrastructures and to create specific mobility programmes for South African researchers.
- **South Africa could participate as partner in the development of other RIs** (or part of them) by contributing to the advance of S&T domains and to improve its international position. The formal participation of South Africa as a partner country is usually a pre-requirement to facilitate the participation of the South African industry in international tenders.

Within this context, several international RIs were identified as priorities for South Africa in relation to the priorities for the domains presented in this document. First, a set of criteria for the identification of relevant international RIs is proposed; these constitute the basis for specific actions which will be described in a second phase.

16.1 General criteria

The number of RIs available at the national level which are **open to international participation** is growing very rapidly. This development is necessitated by the need to attract the interest of the international community in order to increase the funding sources or simply the number and quality of researchers using those facilities; but also the existence of international partners was found useful to accelerate internal decision making processes at the national level (i.e. the interest of the research facility under discussion at the national level is reinforced by the interest demonstrated by external stakeholders).

In the scope of SARIR development, four scenarios were identified to serve as a guide for the identification of key international RIs:

1. **Cases where some international RIs can be located at sites in SA.** The rationale for this case is to **attract the interest of the world scientific community** to places where South Africa can

³²“Framework for a coherent and coordinated world-wide development and operation of global research infrastructures”. Group of Senior Officials on Global Research Infrastructures (2013).

compete with other sites. The investments made in the country (not only by South Africa but also by other partners) will boost R&D in the area and in other related domains. The most relevant case in this group is **SKA** under development where South Africa has committed resources as the host country; however, other potential cases could be found in e.g. environmental or evolutionary sciences (i.e. palaeoanthropology or biological diversity) areas where South Africa has unique sites for world-class research.

2. **Cases where need exists for South African researchers to access international RIs.** In order to facilitate access to world-class RIs where the international competition or even the total time available is not sufficient to guarantee fair access or to cover the demands of the South African scientific community, specific MoUs with the entities owning or managing such international RIs are necessary. In order to facilitate the access under better conditions, South Africa should commit resources to cover a percentage of the running costs of the facilities concerned. Usually, this type of MOU does not make provision for participation in the governance structures of the research RI.
3. **Cases where South Africa could create their own laboratories (or to conduct complex experiments) in RIs located in other countries.** This case constitutes an option in order to push forward the South African industry and the competitiveness of research groups and to increase cooperation with other researchers without the need to create a new RI from scratch in SA. In some cases, the option to develop a national RI is not possible due to the lack of funding, local knowledge or critical mass but the creation of some facilities abroad can be an option. One example of this case is the possible construction of a specific **beam line in one of the latest generation synchrotrons** available in other countries (i.e. ESRF). Today, many of these synchrotron facilities could accept South African researchers as international users (on the basis of allocating time for excellent individual peer-reviewed proposals) but this approach does not allow for the South African industry and technological research groups to acquire the experience in the provision of sophisticated machinery or to obtain experience in the management of complex scientific instruments. In other cases the percentage of time open to international users may be very limited with very high international competition to allow insufficient time to meet the needs of South African research groups.
4. **Cases where South Africa has the opportunity to join international networks of RIs.** This case implies the availability of in-situ facilities in South Africa as nodes of an international network of nodes with state-of-the-art equipment and to accept international coordination. This approach is becoming common in cases of **distributed international RIs** where South Africa can also modulate the effort and timing to participate in those networks when local/national interest is assumed.

In all these four cases, criteria to participate in international RIs can be classified in two main groups:

- **S&T criteria** pertain to the capacity of the South African science and technology system either from the point of view of the existence of sufficient critical mass of researchers of international quality to access to other facilities abroad, or from the assessment of its positive impact of the effort on the quality improvement of research activities in SA.
- **Positioning of the innovation system.** The existence of political reasons to increase the cooperation with other countries or to belong to international networks of facilities to increase the visibility of the South African S&T system. Here, decision-making is being modulated by “science-diplomacy” reasoning and prioritization.

A **cross-cutting additional criterion** to be taken into account refers to the relative weight of the capital investments and running costs in each domain compared to the planned local investments in South Africa. Even when scientific criteria could support the allocation of the available resources in one S&T domain in international RIs, that decision should be carefully assessed against the benefits to locate the investments in South Africa.

In summary, **the international dimension of SARIR is a necessary condition and it should be addressed as an integral part of the RI strategy**. The consequence is the need to consider international RIs in the priority allocation of resources for the SARIR to cover participation in the chosen mode of engagement with international RIs.

The rest of this chapter details international RIs of relevance to the identified RIs for each of the S&T domains. A set of recommendations is included in the final section.

16.2 Identified international RIs in the SARIR domains

16.2.1 Humans and Society

Historically, no large RIs at the international level were considered necessary. This situation is rapidly changing due to the importance gained by data management in conducting research activities. From this perspective, South Africa should participate in pre-existent international networks or in the creation of new ones. Such international networks where South Africa already participates are INDEPTH and CLARIN. Others should include the creation of South African nodes for data archives and language resources in international distributed networks.

Final conclusion: SARIR is not only the roadmap *in South Africa* but a roadmap *for South Africa*. If the final goal is to improve the national S&T system the international dimension is an essential part which should be addressed simultaneously with RI identification in selected domains.

The identification of possible actions at the international level made in this chapter must be periodically updated because new RIs or opportunities will continuously appear in the international context. Based on that, the following recommendations are extracted.

16.2.2 Health, Biological and Food Security

This area is characterized by the need of relatively small equipment (compared to physical sciences) but with a very high degree of obsolescence in short periods of time. For this reason, it is very important to be closely connected to other international entities and partners in order to access sophisticated scientific equipment.

The following actions at the international level were identified:

- Construction of a **beam line for structural biology** in any of the national synchrotrons opens to international participation. Cases of Soleil, Alba, Diamond could be considered.
- Strong participation in **EMBL/EMBO**. EMBL institutional partnerships are close cooperative affiliations between EMBL and external institutions of comparable standard, vision and international orientation. They are working relationships at the institutional level that are based on shared institutional goals and scientific synergy or complementarity. The role of EMBL by coordinating ESFRI "*Elixir*" and "*EuroBioimaging*" projects is also useful to SA.

Although not explicitly related to any RI, the South African participation in the second phase of EDCTP-2 for clinical trials in Africa has huge relevance to join effort to public and private entities.

16.2.3 Earth and Environment

Data collection and management for Earth observation and climate change monitoring is a world-wide challenge where South Africa should contribute and participate as actively as possible. Several of these are already identified under the individual RI proposed for the SARIR, but more emphasis can be placed on e.g.:

- The use of satellite data concerning the South African environment for monitoring and preservation is an essential part in addition to terrestrial networks. For that reason, South Africa should consider the use of Copernicus (Earth observation satellite network) data in the near future.
- Building on the existing collaborations and coordination of research programs on Antarctica and the southern oceans with other countries.

16.2.4 Materials and Manufacturing

RIs in this domain are very expensive and usually they are built with the cooperation of several countries which commit resources in variable percentages of total costs. Then, there are good opportunities to cooperate in the development of new RIs.

More specifically, South Africa should continue its participation in **CERN** (cooperation agreement) and to consider the strengthening of its position in the **ESRF** (today a 0.3%). Furthermore, two RIs under construction in the EU could be considered because they will represent the state of the art once finished and South Africa should be closer to them: **XFEL** (Hamburg, Germany) and **ESS** (Lund, Sweden). The expert team proposes to sign up specific MoUs in both cases to be able to create or empower research groups participating on those facilities. It is not necessary to wait until finishing the construction phase to sign up the MoUs because training of scientists should start well before in partner entities. It constitutes an excellent base for increasing the critical mass and to gain technological experience.

On the other hand, part of the South African quota in future international RI cases could be satisfied “*in-kind*” (if South African partners had the technical capabilities for the provision of some components and budgets are accepted). This possibility is lower when research facilities are well advanced in their construction phase and major components have been allocated (case of XFEL).

To support the suggested **nano-manufacturing facility**, suggested as a new RI of SARIR in this domain, it is relevant to get agreements with international partners in the field. In the EU, the case of **IMEC** (Belgium) could be specifically addressed to support the South African industry although many centres of excellence on nanoscience spreads over the world and South Africa can find potential partners to facilitate training of researches and access to very advanced services.

16.2.5 Energy

The structure of this domain at the international level covers four types of subdomains where research can benefit of the availability of RIs: nuclear research (both in fission and fusion), generation of renewable energy (solar, wind, marine, biomass, etc.), energy efficiency (in housing, transport, etc.) and energy distribution (smart grids). At the international level, huge efforts are being addressed in all of them with emphasis on pilots and demonstrator projects to accelerate the innovation process.

With respect to South Africa the following aspects need to be taken into account:

- South Africa should not be involved in the ITER construction (Cadarache, France) but it could participate in additional activities in relation to IFMIF (material research for nuclear fusion) and related issues in close contact with the Material characterization facility suggested in SARIR.
- Participation in thermo solar plants (i.e. like PSA in Spain) or in large photovoltaic solar infrastructures are very useful in the development of the suggested Solar pilot plant proposed in SARIR.

16.2.6 Physical Sciences and Engineering

Astronomy is well addressed with the participation in SKA and other facilities available in the country. This is a very international sector where facilities are open to researchers. The development of SKA could be also the basis for a possible time-exchange agreements with other ESO programs like VLT or ALMA.

With respect to space research the signature of long-term agreements with ESA and NASA will open the possibility to the South African industry and research groups.

In the area of physics and engineering the creation of the **national support centre for science and engineering** as proposed in SARIR constitutes an excellent opportunity to consolidate the South African links with two or three main centre located in other countries. Anyway, this is a long-term effort (more than ten years) which should be supported by specific agreements.

17. Recommendations

In addition to the 17 potential RIs listed in the roadmap there are some general recommendations that are important. These are listed here.

1. To construct a world class RI (anything less would not be justified) needs not only to attract the best RI but also to look at how schools, universities, culture etc., can be integrated to be an attraction for industry. *Investment in any RI should look at the ecosystem in a holistic way.*
2. RIs are not the same as research project, however, worthy. *It is important that national research infrastructures should be distinguished from institutional or departmental facilities or equipment or research projects. The RIs present research oriented services to the national research community and focus on national RIs.*
3. Focus on excellence and areas where South Africa has a distinct advantage. A major aim of RIs is to raise the standard of research and innovation in South Africa. The other criteria should be where critical mass is needed to find solutions to the challenges facing South Africa. *It is recommended that a limited number of world class RIs are created rather than spread funds too thinly. The Roadmap should highlight these opportunities and be updated as new areas grow.*
4. Current paradigms in research infrastructure contain a fragmented view and personal institutional ownership. *A culture shift towards sharing, collaboration and service needs to be fostered.*
5. Building human capacity: There is a critical need to build the right levels of management, users, technical staff and future human capacity to ensure RIs are planned, constructed and operated optimally:
 - *In considering the RI investment it is important to be able to attract the best people internationally to manage these RIs by paying attention to the local placement environment and communication systems in addition to offering career development and attractive remuneration packages.*
 - *South Africa should build up a cadre of researchers, administrators and managers who could take charge of national and international RIs based in South Africa*
 - *It is more difficult to attract skilled technical staff and the potential training role of an RI in this regard should be part of the RI ecosystem.*
 - *It is essential that students and postdoctoral fellows are supported through studentships and fellowships allocated to RIs.*
6. An agreed robust and transparent procedure for taking RIs forward from the roadmap and funding them need to be developed for all RIs. *This should be a phased process from concept (science case) to detailed design, business case and governance.*
7. Conceptualise and plan the RI and making the socio-economic case. *In the conceptualisation phase the broader socio-economic impacts, internationalisation and linkages with industry and technological infrastructure need to be taken into consideration linked to global learning experiences.*

8. There is a need for consistency in approach before a funding decision is made: *High level people to be involved in the planning should preferably be trained beforehand on how to handle the various planning phases and in management and governance issues relating to RIs.*
9. The provision of RIs can have large impact on public perception in increasing the scientific interest in the population especially of young people. *All RIs should have a rigorous public and media engagement programme.*
10. Cyber-infrastructure is critical to all RIs whether virtual or physical. This ranges from virtual access to physical sites, data sharing, curation, provenance, protection, developing metadata standards and interoperability among other issues. *e-Science and cyber-infrastructure need to be planned from the start of any RI programme allowing virtual access and open access to national and international data.*
11. Almost all RIs are bound to have an international dimension. *Where appropriate and to attract international investment the legal and financial basis of the RI should be set up to encourage participation.*
12. Research infrastructures are a long term commitment and often take several years to be planned, developed and operated. *Government should agree to an overall minimum budget line with a 10 year horizon for capital expenditure on RIs. Operational, upgrading and decommissioning costs should be factored into RI budgets.*
13. Many research infrastructures address the needs more than one government department. *A cross ministerial group should be formed to allocate a lead ministry and funders to support each research infrastructure in order to ensure efficiency and best use of financial resources.*
14. Governance of RIs is a critical success factor. *It should be nationally agreed that independent governance structures are put in place that guarantees good management, financial accountability, risk management, and can give the assurance to government and/or the funders that the RI is run appropriately for the national good.*
15. There is evidence that industry is attracted to RIs because of the intellectual environment and the possibility of knowledge transfer. *It is recommended that RIs, where appropriate should be proactive in interacting with industry to ensure the maximum return for South Africa in its investments.*
16. This is an active roadmap. *Update the SARIR on a regular basis to take account of changing requirements and priorities.*

Appendix 1: List of Acronyms

Acronym	Meaning
10B R	Ten Billion Rand
1M R	One Million Rand
ABL	Animal Biosecurity Laboratory
ACEP	African Coelacanth Ecosystem Programme
AFM	Atomic Force Microscope
ALMA	Atacama Large Millimeter/sub-millimeter Array
AMS	Accelerator Mass Spectroscopy
ARGO	System for observing temperature , salinity , and currents in the Earth's oceans
ASSAf	Academy of Science of South Africa
BRIC	Biotechnology Research and Innovation Centre
CDC	Centre for Disease Control
CDR	Conceptual Design Report
CERN	European Organization for Nuclear Research
CESSDA	Council of European Social Science Data Archives
CGS	Council for Geoscience
CHPC	Centre for High Performance Computing
CI	Cyber-infrastructure
CLARIN	Common Language Resources and Technology Infrastructure
CNS	Cold Neutron Source
CoC	Centre of Competence
CPGR	Centre for Proteomic and Genomic Research
CPV	Concentrated Photovoltaics
CSIR	Council for Scientific and Industrial Research
CSP	Concentrated Solar Power
CTA	Cherenkov Telescope Array
DAC	Department of Arts and Culture
DEA	Department of Environmental Affairs
DHET	Department of Higher Education and Training
DIPLOMICS	Distributed Platform for Omics
DIRISA	Data Intensive Research Infrastructure for South Africa
DoH	Department of Health
DST	Department of Science and Technology
DWA	Department of Water Affairs
EC	European Commission
ECDC	European Centre for Disease Control
EDCTP	European & Developing Countries Clinical Trials Partnership
EELS	Electron Energy Loss Spectroscopy
EFDA-JET	European Fusion Development Agreement - Joint European Torus
EIROFORUM	Partnership between: CERN, EFDA-JET, EMBL, ESA, ESO, ESRF, European XFEL and ILL
ELDA	Evaluation and Languages Resources Distribution Agency
ELRA	European Language Resources Agency
EMBL	European Molecular Biology Laboratory
EMBO	European Molecular Biology Organisation
ERF	European Research Facilities
ERIC	European Research Infrastructure Consortium
ESA	European Space Agency

ESCA	Electron Spectroscopy for Chemical Analysis
ESFRI	European Strategy Forum on Research Infrastructures
ESO	European Southern Observatory
ESRF	European Synchrotron Radiation Facility
ESS	European Social Survey
ESS	European Spallation Source
EU	European Union
GBIF	Global Biodiversity Information Facility
GEO-BON	Group on Earth Observations Biodiversity Observation Network
GEOSS	Global Earth Observation System of Systems
GFZ	Geoforschungszentrum
GMES	Global Monitoring for Environment and Security
GMO	Genetically Modified Organism
GOOS	Global Ocean Observing System
GSO	Group of Senior Officials
GTOS	Global Terrestrial Observing System
H3Africa	Human Heredity and Health in Africa
HDSS	Health and Demographic Surveillance Systems
HLT	Human language Technology
HMO	Hermanus Magnetic Observatory
HPA	Health Protection Agency
HPC	High Performance Computing
HRTEM	High Resolution Transmission Electron Microscopy
HSDD GC	Human and Social Dynamics for Development Grand Challenge
HSRC	Human Sciences Research Council
HSS	Human and Social Sciences
HySA	Hydrogen South Africa
IASSIST	International Association for Social Science Information Service & Technology
ICOS	Integrated Carbon Observation System
ICP-MS	Inductively Coupled Plasma Mass Spectroscopy
ICT	Information and Communication Technology
IF	Innovation Fund
IFDO	International Federation of Data Organisations
IFMIF	International Fusion Materials Irradiation Facility
IIDMM	Institute of Infectious Disease and Molecular Medicine
ILC	International Linear Collider
ILL	Institut Laue-Langevin
ILTER	International Long Term Ecological Research
IMEC	Interuniversity Microelectronics Centre
INDEPTH	International Network for the Demographic Evaluation of Populations and Their Health
IPBES	Intergovernmental Platform for Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
ITER	International Thermonuclear Experimental Reactor
KAT	Karoo Array Telescope
KPI	Key Performance Indicators
KZN	KwaZulu-Natal
LEED	Low Energy Electron Diffraction
LEEDS	Low-energy Electron Diffraction Spectroscopy

LHC	Large Hadron Collider
LIFEWATCH	e-Science European Infrastructure for Biodiversity and Ecosystem Research
LPCVD	Low Pressure Chemical Vapour Deposition
Lt-world	Language Technology World
Max IV	4 th generation synchrotron in Sweden
MBE	Molecular Beam Epitaxy
MeerKAT	Karoo Array Telescope Demonstrator (precursor to SKA)
MEG	Magnetoencephalography
MEMS	micro-electromechanical systems
META-Net	Multilingual European Technology Alliance
MOOC	Massive Open Online Course
MoU	Memorandum of Understanding
MRC	Medical Research Council
MRI	Magnetic Resonance Imaging
MW	Megawatt
NACI	National Advisory Council on Innovation
NASA	National Aeronautics and Space Administration
NCDLR	National Centre for Digital Language Resources
NCNSM	National Centre for Nano-Structured Materials
NDP	National Development Plan
NEP	National Equipment Programme
NFSD	National Framework for Sustainable Development
NGO	Non Governmental Organisation
NGP	New Growth Path
NHRC	National Health Research Committee
NIAID	National Institute of Allergy and Infectious Diseases
NICD	National Institute for Communicable Diseases
NICIS	National Integrated Cyber-Infrastructure System
NIF	National Ignition Facility, Lawrence Livermore National Laboratory
NIH	National Institutes of Health
NMR	Nuclear Magnetic Resonance
NNEP	National Nanotechnology Equipment Programme
NRDS	National Research and Development Strategy
NRF	National Research Foundation
NSI	National System of Innovation
NSSD	National Strategy for Sustainable Development
NTeMBI	Nuclear Technologies in Medicine and the Biosciences Initiative
NWU	North-West University
OECD	Organisation for Economic Cooperation and Development
OMICS	Metabolomics; Genomics, Proteomics
PET	Positron Emission Tomography
PGE	Platinum Group Element
PGMs	Platinum Group Metals
PSA	Plataforma Solar de Almeria
PV	Photovoltaics
R&D	Research and Development
RAMIRI	Realising and Managing International Research Infrastructures
RD&I	Research, Development and Innovation
RI	Research Infrastructure
RIE	Reactive Ion Beam Etching

RIR	Research Infrastructure Roadmap
RMA	Resource Management Agency
ROV	Remotely operated vehicle
RT	Reverse Transcription
S&T	Science and Technology
SA	South Africa
SABIF	South African Biodiversity Information Facility
SAC	CSIR Space Application Centre
SADA	South African Data Archives
SADCO	Southern African Data Centre for Oceanography
SAEON	South African Environmental Observation Network
SAEOSS	South African Earth Observation System of Systems
SAFARI	South African Research Reactor
SAHSSDA	South African Human And Social Sciences Data Archive
SAIAB	South African Institute for Aquatic Biodiversity
SALT	Southern African Large Telescope
SAM	Scanning Auger Microprobe
SANAP	South African Antarctic Programme
SANBI	South African National Biodiversity Institute
SANParks	South African National Parks
SANReN	South African National Research Network
SANSA	South African National Space Agency
SARAH	South African Heritage Resources Agency
SARIR	South African Research Infrastructure Roadmap
SEM	Scanning Electron Microscopy
SHARE	Survey of Health, Ageing and Retirement
SHRIMP	Sensitive High Resolution Ion Microprobe
SIMS	Secondary Ion Mass Spectroscopy
SKA	Square Kilometre Array
SME	Small, Medium Sized Enterprise
SOC	State-owned Company
SPECT	Single-photon Emission Computed Tomography
SSH	Social Sciences and Humanities
TDR	Technical Design Report
TEM	Transmission Electron Microscopy
TENET	Tertiary Education Network
TI	Technological Infrastructure
TIMS	Thermal Ionization Mass Spectrometer
TYIP	Ten Year Innovation Plan
UCT	University of Cape Town
UK	United Kingdom
UKZN	University of KwaZulu-Natal
UL	University of Limpopo
UWC	University of the Western Cape
VLBI	Very-long-baseline interferometry
Wits	University of the Witwatersrand
XFEL	X-ray Free Electron Laser
XPS	X-ray Photo-electron Spectroscopy
XRD	X-ray Diffraction

Appendix 2: People involved

The expert panel would like to thank all people involved in the interviews, private discussion and the two stakeholder workshops.

Workshop 1: 26 and 27 June 2013, Cape Town

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Workshop 2: 23 October 2013, Pretoria

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