Nuclear Africa

DEFINING SOUTH AFRICA'S NUCLEAR TECHNOLOGY CAPABILITY

March 2017

Nuclear Africa

International Collaboration in Nuclear

Nuclear Africa 2017

Conference and Exhibition

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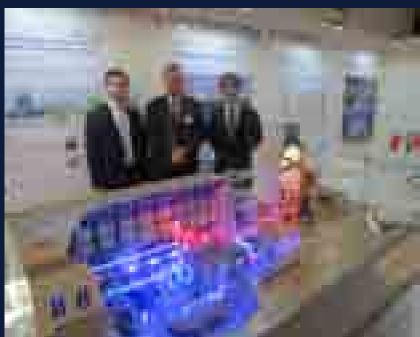







In Collaboration with

Media Partners

CONTENTS

PUBLISHER & EDITOR
Dr Kelvin Kemm
Nuclear Africa (Pty) Ltd
P.O. Box 74416, Lynnwood Ridge
Pretoria, South Africa, 0040
Email: exec@nuclearafrica.co.za

DEPUTY EDITOR
Carol van Niekerk
Nuclear Africa (Pty) Ltd
P.O. Box 74416, Lynnwood Ridge
Pretoria, South Africa, 0040
Cell: +27 (0)74 376 4519
Email: carolvn@nuclearafrica.co.za

ASSOCIATE PUBLISHER
Rachel Tladi
RNG Communications
Cell: +27 (0)79 691 8231
Email: rachel@rngcom.co.za

LAYOUT & DESIGN
Nadia Kruger
Email: nadia@thedesignfactory.co.za
www.thedesignfactory.co.za

Mr Phumzile Tshelane

CEO of Necsa

Nuclear Africa Conference 2017 "International Collaboration In Nuclear"

Necsa is excitedly looking forward to the nuclear developments which will unfold during 2017. These cover not only the major nuclear power build project but also include a wide variety of other nuclear-related issues that Necsa is involved with.

We are keen to link up with partners both foreign and domestic in furthering nuclear technology application to the benefit of all concerned.

The theme for this year's Nuclear Africa Conference is "International Collaboration In Nuclear"; we find it very appropriate to our activities of manufacturing nuclear and non-nuclear industrial components and we see it as an opportunity to once again engage with experts from various industry sectors. Just as we have conquered the nuclear medicine industry, we would now like to grow our presence in foreign countries through the manufacturing and export of power generation components.

The SAFARI-1 reactor continues to provide the world with modern scientific solutions and it is committed to enhancing the lives of millions of people worldwide through its nuclear medicine production capabilities. Nuclear medicine produced at SAFARI-1 is used in over 10 million medical procedures in more than 60 countries every year, saving millions of lives worldwide. Necsa has demonstrated very good business capabilities in the nuclear medicine industry, we have secured foreign nuclear medicine markets through collaborations with many international and South African companies, and we hope that during this conference we will establish more business ties. In 2017 our world market share has already increased substantially.

A significant goal that Necsa is now seeking to accomplish relates to our participation in the global manufacturing industry; Pelindaba Enterprises is a division of Necsa that specializes in heavy engineering and manufacturing of power generation components; it is the only manufacturing organisation in Africa that has acquired the ASME III Nuclear Certification.

The future of large-scale components manufacturing holds many opportunities for Necsa and the nuclear industry in South Africa. Obviously, contributing to South Africa's energy mix is an important factor and we have already started to provide large-scale power production components to local power stations, such as Medupi and Kusile, and we are ready to explore business beyond our shores and our borders. Our participation in the African continent is also of utmost importance and we are building ties with our African counterparts for collaboration in training, technology sharing and solving power generation challenges.

Looking abroad, we've made good progress in acquiring business bases for Necsa's high quality engineering products. We are looking at other opportunities elsewhere, to make sure we further integrate our production. Exploring export business is good for the economy, especially under the country's foreign currency exchange rates, so this is steadily becoming an area of focus. It is partnership which counts.

With government targets now in place to grow the nuclear contribution to the country's energy mix, we are looking forward to grasping this opportunity to further develop our expertise. The nuclear new build will allow Necsa to grow and to explore new business ventures offshore, thereby expanding our presence all over the world.

I would like to wish all the local and international Nuclear Africa Conference delegates a wonderful experience in our beautiful country. May you return many times? At Nt'Shonalanga Valley Resort look at the sunshine in the day-time and the stars in the night-time as you network and discuss how "International Collaboration in Nuclear" comes together; of course in the form of the partnerships needed to rapidly advance the nuclear power programme in South Africa, and beyond our borders.

Dr Kelvin Kemm

CEO of Nuclear Africa

Nuclear collaboration for the people of the planet

The South African progression towards the construction of a fleet of nuclear power stations was officially launched in December 2016 with the release of a Request for Information (RFI). This document asks for an indication of agreement on the ground rules for collaboration.

This RFI is a precursor document, before asking for formal bids which will include the financial quotations for the build of nuclear power stations. What is also most important in the RFI is that it is a message that South Africa requires a substantial local content collaboration. The emphasis is on the word 'collaboration.' Many companies which responded to the RFI have no intention of trying to supply a nuclear reactor; they are interested in an involvement in some sub-element of the whole process.

So the scope for construction and fabrication collaboration is vast. It is quite possible for fabricated assemblies be exported from South Africa, which themselves contain components made in two or more other countries. The name of the game is collaboration, so that all parties involved can clearly gain benefit.

Many companies in South Africa and in other countries which are currently not involved in nuclear fabrication can become part of the nuclear family. Many of these companies do not even realise this. There are companies currently involved in aerospace; oil and gas; food processing machinery; pharmaceuticals; and much more, which operate to an established culture of quality assurance in line with a nuclear fabrication culture. Many of these need to be invited to become part of the nuclear fabrication family, together with foreign partners.

Of course all of this has to link into financial viability, legal compliance, and more. We therefore need to also link up with the legal and financial institutions which are also a most important part of the whole mix.
In thinking on an international scale it is also most important to also look towards our African neighbours.

Nuclear power is not just a case of 'one-size-fits-all.' There are the large reactors of the size of about 1500MW output, but then there is also the class of Small Modular Reactor (SMR) of about 400MW, or less.

The South African concept of the PBMR falls into this class. Smaller reactors are not just for countries with smaller electricity demand. Smaller reactors can be strategically placed to service a specific nearby requirement; for example a mining complex; a harbour; or an industrial area, so they are applicable to all countries.

So we need to build collaboration at all levels with other African countries, plus many other interested countries. The time is now.

A conference like Nuclear Africa 2017 provides just such an opportunity for a variety of different organisations and individuals to get together to explore all possibilities for collaboration.

One then must not forget that all of this activity takes place in full view of the public. For that matter; the international public. Public opinion is an essential support structure within which the politicians and other decisions makers, such as the bankers, have to make their decisions. So it is essential that the nuclear science professionals constantly keep in mind that public understanding of what is going on during a nuclear build is most important. Talking to the public is not just a case of 'talking to the public.' A large measure of interpretation is required, so that complex issues are clearly understood.

The anti-nuclear fraternity, worldwide, will continue to muddy the waters as much as they can, so a careful and honest picture needs to be presented to the public, to produce genuine clarity.

Nuclear power, in all its forms, is the power of the future, so international collaboration is required right now, in the interests of all of the people of the whole planet.

Mr Alexey Likhachev

CEO of Rosatom

The nuclear industry remains at the helm of innovative and sustainable development

ROSATOM

It is my great pleasure to welcome you to this very prestigious event.

Nuclear faces very unique challenges globally, as I am sure you are all well aware, the common misconceptions about nuclear often makes it very difficult to communicate the good stories and the great achievements from our industry.

It is these misconceptions that as an industry we should work together to dispel, it is time that nuclear is demystified, it is time we all work together to deliver the good stories, the great stories and one day the nuclear industry will be celebrated for its grand achievement of bettering the lives of millions across the globe, rather than frowned upon for the simple reason of not being fully understood.

It is incredibly important for us to gather at events such as these, to celebrate achievements and acknowledge excellence in our unique industry. I would therefore like to extend our gratitude to Nuclear Africa for arranging this world class event, your dedication to the industry is valued globally.

The Russian nuclear industry has always placed great importance on international cooperation in the peaceful use of nuclear technology and over the past decades we have clearly demonstrated our ambitions to work with foreign partners to further develop the industry. I would like to take this opportunity to highlight several recent achievements from our industry.

Firstly, I'd like to point out that the Nuclear Africa conference is taking place exactly one month after we commissioned our first ever innovative VVER-1200 nuclear power unit. Unit 6 of Novovoronezh Nuclear Power Plant (NPP) became the first Generation III+ power unit to be commissioned in the world. It provides for the highest level of operational safety and fully meets all post-Fukushima requirements. Its key feature is the combination of active and passive safety systems, which require absolutely no human intervention. More importantly this unit provides us with a referenced Gen3+ unit, the design of which will be used for Rosatom NPP construction projects across the globe.

In 2016, the Russian Research Institute of Atomic Reactors State Scientific Centre became the second global IAEA R&D Hub. The Institute was designated as an IAEA International Centre based on Research Reactors (ICERR) and will be made available for all IAEA member countries for R&D work.

Vitally important work on project ITER (International Thermonuclear Experimental Reactor, and is also Latin for "the way") continues. ITER will be the first fusion device to produce net energy for prolonged periods of time. It will also test the integrated technologies, materials, and physics necessary for the commercial production of fusion-based electricity. It is based on the Russian idea of Tokamak: an experimental machine designed to harness the energy of fusion.

Finally, nuclear energy will play a crucial role in solving the problem of global warming. Landmark COP 21 and COP 22 summits have set an ambitious goal to limit the rise in global mean temperatures to 2°C, which will not be possible without gradual decarbonization of the global energy mix. At present, nuclear reactors alone generate one third of all low-carbon power in the world, while the share of nuclear power in the global energy mix is about 11%. This figure set to increased to 18% by 2030 and 25% by 2050 in order to ensure that the goals set at COP 21 and 22 are achieved.

I would like to wish all participants the very best over the coming days.

Ms Agneta Rising

Director General of the World Nuclear Association

Nuclear Africa 2017
Welcome address

Electricity is the essential force that powers a better quality of life and drives economic growth and development. There is an urgent need to increase the provision of electricity worldwide, particularly in those regions where affordable and reliable supplies are not yet available to all.

Nuclear energy must have a growing role in the global generation mix, because we need to meet the world's needs from sources that are reliable and always available, but don't produce harmful air pollution or cause dangerous climate change.

To help meet these developmental needs sustainably the global nuclear industry has set a target to build 1000 GWe of new nuclear capacity by 2050. To achieve this will require an expansion of nuclear in countries such as South Africa that already benefit from nuclear generation. But it will also require nuclear to form part of the generation mix in more countries, particularly those with fast-growing economies.

World Nuclear Association is working to help realise these goals. The association, in partnership with the IAEA and OECD NEA, has welcomed fellows from Algeria, Côte d'Ivoire, DR Congo, Egypt, Ghana, Kenya, Namibia, Nigeria, Niger, South Africa, Sudan, Tunisia, Tanzania, Uganda, Zambia, and Zimbabwe to the World Nuclear University Summer Institute, an intensive six week course helping to train the leaders of our industry's future.

We will [also] need others to take action to enable nuclear energy to make the fullest contribution it can. Governments must establish policies and markets that allow nuclear generation to compete on a fair basis. Regulations should be efficient and effective. A new safety paradigm is needed to ensure that choices made on energy bring a genuine benefit to public wellbeing.

I look forward to discussing these issues with you at Nuclear Africa 2017.

Mr HOU Xuezhong

Senior Vice President of State Nuclear Power Technology Corporation

国家核电
SNPTC

As the developer of CAP1400, SNPTC has been always dedicated to the promotion and application of CAP1400 technology with its outstanding natures in safety, advancement and economics.

the GenIII passive pressurized water reactor nuclear power technology has drawn attention from countries aspiring to develop nuclear power generating capacity.

SNPTC has attached great importance to the nuclear energy cooperation with African partners, and is expecting to share its more than forty years successful experiences in nuclear power research &development, NPP construction and operation to its partners in Africa.

SNPTC and NECSA signed Agreement on Civil Nuclear Energy Training in 2014 and jointly implemented the agreement effectively. Up till now, SNPTC has provided 160 plus man-time GenIII nuclear power technical training to relevant organizations in South Africa, with content covering the whole NPP life circle including design, construction, operation and maintenance.

Besides, SNPTC has also carried out the communication and discussion with around fifty local enterprises in South Africa on cooperation of nuclear power localization development, achieving extensive consensus and willingness to cooperate.

In the future, SNPTC will continue to conduct mutually beneficial cooperation with friends among African countries to promote nuclear energy development and make joint contributions towards constructing a beautiful, low-carbon and environmentally friendly Africa with sustainable development achieved, so as to drive forward the economic development of Africa.

Message from

Mr. Hwan-eik Cho

President & CEO of KEPCO

Energy is an absolute necessity for national prosperity, quality life for people, and sustainable development. The importance of energy security is at its height as we face possible depletion and price instability of fossil fuel. Moreover, a stable supply of energy is also a prerequisite in fostering national economic growth.

Korea is highly dependent of foreign imports when it comes to natural resources such as coal and oil. Ever since it deployed its first nuclear-build in the 1970s for energy independence, Korea has continuously expanded its nuclear fleet resulting in 25 units currently in operation. Nuclear energy now accounts for more than 30% of total generation capacity in Korea, and is not only meeting the power demands of the country, but also contributing to the reduction of greenhouse gas emissions. The nuclear industry has become one of the important pillars bolstering Korea's national economy as well.

The Republic of South Africa among African states is the most advanced country in terms of social infrastructure including power supply, roads, communication systems, ports, logistics, etc., based on its economic power and geographical advantages. It also has positive outlooks for economic expansion with abundant natural resources, solid industrial foundation, and human resource potential. Gaining on this momentum, South Africa will need to provide stable supply power throughout the country to achieve further national economic development and to maximize its use of geographical advantages and abundant resources.

Nuclear energy will be the best way in accomplishing this for the Republic of South Africa, as it has been in the case of South Korea. Nuclear power plants(NPPs) are known for its high availability and economic feasibility suitable for stable power supply; and being an energy intensive technology, it is related to power generation, industrial technology refinement, and the enhancement of other isotope-related technologies regarding food, medicine, etc. These various applications give room for more local companies' participation in different industries, ultimately resulting in the improvement in South Africa's national competitiveness.

As such, NPP is the optimal solution as an alternative to fossil fuel, since it provides stable power supply as base load, guarantees high availability, responds to international environmental regulations, develops national economy and enhances industrial technology.

Through 40 years of continuous construction of NPPs with KEPCO, Korea has accumulated the technology and experience in all spectrums of nuclear power plant including design, construction, operation, nuclear fuel, waste treatment, and research reactor. It is also promoting various NPP projects at home and abroad under the One KEPCO team and is proving its high competitiveness around the globe.

The Barakah Nuclear Power Plant(BNPP) project in the UAE is a case in point of KEPCO's technology capabilities. Among all new nuclear-build projects around the world, BNPP project, constructing four units of APR1400, is the only one being carried out on-time and within budget.

At present, the standard APR1400 design is undergoing the most stringent NPP design evaluation in the world, conducted by NRC in the United States. NRC approval and certification of standard APR1400 design is expected in 2019, which would make APR1400 the third Gen III reactor technology to be certified by US NRC after WEC's AP1000, and GE's ESBWR. Moreover, APR1400 will be the first Gen III NPP technology that has an operating reference plant since unit 3 of Shin-kori in Korea officially entered commercial operation in December 2016.

KEPCO and the One KEPCO Team, with its outstanding nuclear technology and abundant experience, are the optimal and reliable partner for the Republic of South Africa in achieving its goal in securing stable energy source and industrial development through implementing nuclear new-builds.

KEPCO sends its heartfelt congratulations and support to the new nuclear-build program of South Africa, which will become an indispensable asset in the country. Moreover, we hope that the Nuclear Africa 2017 Conference serves as a window for exchanging various and valuable information, becoming a true foundation for the successful implementation of the new NPP project.

Dr Wolsey Barnard

CEO of NRWDI

Managing radioactive waste in South Africa

NRWDI
NATIONAL RADIOACTIVE WASTE DISPOSAL INSTITUTE

INTRODUCTION

With the introduction of a nuclear power program in South Africa during the 1970's it was realized that radioactive waste would have to be managed and that would require a national site for the disposal of the country's nuclear waste. In November 2005 Cabinet approved and published the radioactive waste management policy and strategy, which identified the need for the implementation of an independent radioactive waste disposal institute. The National Radioactive Waste Disposal Institute Act (No. 53 of 2008) was drafted and became effective on the 1st December 2009 endorsing the establishment of the National Radioactive Waste Disposal Institute (NRWDI). The Institute was established with the key responsibility to oversee the disposal and related waste management of radioactive waste, on a national basis.

RADIOACTIVE WASTE MANAGEMENT

The application of radioactive materials and nuclear radiation provides numerous benefits to people and society, and plays a significant role in everyday life. This includes scientific, medical, agricultural and industrial applications. It is a natural consequence of such processes that radioactive waste is generated, and as a result radioactive waste is a natural part of the consequence of the benefit which society is receiving as a result of the application of these technologies. The radioactive waste needs to be managed in a safe and secure manner. Radioactive waste management involves treatment, conditioning, transportation, storage and disposal of all categories of radioactive wastes, including administrative, operational and safety-related activities. The primary objective of the activities is to isolate the radioactive waste from people and the environment, for the period that the waste remains potentially hazardous.

VAALPUTS NUCLEAR WASTE REPOSITORY

The selection and characterization of a suitable disposal site commenced in the late 1970's and was concluded in the early 1980's. In this process the Vaalputs site was selected as the preferred site; from three candidate sites. Vaalputs was established as the national radioactive waste disposal facility; to serve South Africa's needs for disposing of the low level radioactive waste (LLW) and intermediate level radioactive waste (ILW) generated by the nuclear, industrial, medical and agricultural sectors. Vaalputs is situated in the Northern Cape Province.

The disposal concept for Vaalputs is a near surface, multi barrier concept, where waste packages are stored a few metres below surface. The license to operate Vaalputs was granted in 1986. The first shipment of the low level radioactive waste from the Koeberg Nuclear Power Plant arrived at Vaalputs in November 1986 and the first shipment from Necsa arrived in May 2011.

Currently only 1% of the vast site area has been utilized over the past 30 years of operations and Vaalputs can easily accommodate the additional projected Low Level Waste inventory stemming from the current nuclear industry, as well as the envisaged new nuclear build programme.

RADIOACTIVE WASTE - BACK END OR FRONT END?

In the nuclear industry value chain, radioactive wastes are called the "back end" of the fuel cycle. However at the end of the day this waste will become the "front end" since that will be the only evidence that will be left over after the original generators of the radioactive waste are no longer in operation, or in existence.

Therefore stakeholder confidence and trust in the Institute is of utmost importance. The Institute places a high premium on stakeholder empowerment, capacity building, communication and participation.

NRWDI is committed to providing innovative radwaste disposal and related services that are safe, technically sound, environmentally responsible, economic feasible and socially acceptable. This integrated and accountable radioactive waste management and disposal approach will ensure that no undue burden is placed on future generations; due to past, present and future involvement in nuclear programs.

NRWDI AT A GLANCE

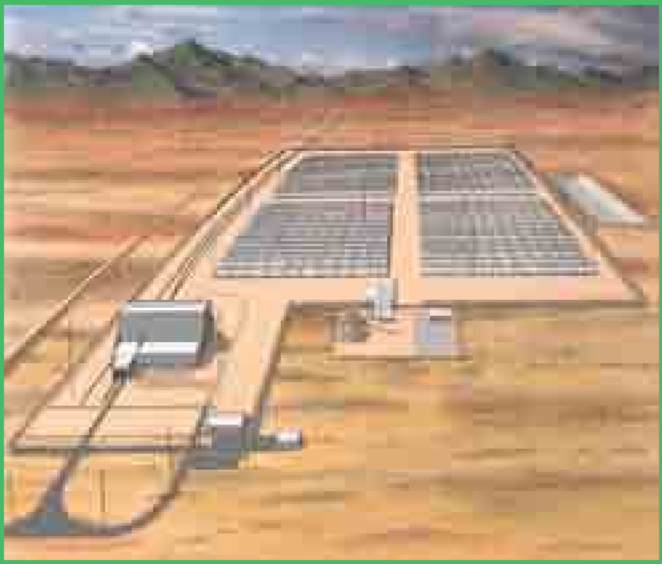
The National Radioactive Waste Disposal Institute (NRWDI) is a state owned entity established in terms of the National Radioactive Waste Disposal Institute Act (53 of 2008) and is responsible for discharging an institutional obligation, as defined in Section 1 of the Nuclear Energy Act (46 of 1999), which relates to the disposal and related waste management of radioactive waste, on a national basis.

DID YOU KNOW?

- Vaalputs is the national radioactive waste disposal site.
- The Vaalputs site, located in the Northern Cape, is 100km2 in extent.
- Vaalputs was the first Near Surface Repository in the world, to obtain ISO 9001 accreditation.
- Less than 1% of the waste disposal area has been utilised, over the past 30 years.
- Radiation levels measured on the outside of the radioactive waste containers are far less than the natural background levels found in various places in South Africa.

CONTACT DETAILS

National Radioactive Waste Disposal Institute (NRWDI)
Private Bag X1, Pretoria, 0001, Republic of South Africa.
E: Wolsey.Barnard@nrwdi.org.za
M: +27 084 321 7361



FUNCTIONAL MANDATE

The functions of the Institute are as follows, but not limited to:

- Manage radioactive waste disposal on a national basis;
- Operate the national waste repository at Vaalputs;
- Design and implement disposal solutions for all categories of radioactive waste;
- Assess and inspect the acceptability of radioactive waste for disposal and issue radioactive waste disposal certificates;
- Investigate the need for any new radioactive waste disposal facilities and to site, design and construct new facilities as required;
- Define and conduct research and development aimed at finding solutions for long-term radioactive waste management;
- Maintain a national radioactive waste database and publish a report on the inventory and location of all radioactive waste in the Republic, at a frequency determined by the Board;
- Assist generators of small quantities of radioactive waste, in all technical aspects related to the management of such waste.

NRWDI will consistently and continuously apply an integrated and accountable radioactive waste management and disposal approach, in order to ensure that no undue burden is placed on future generations due to past, present and future involvement in nuclear programs.

Dr Geoffrey Rothwell

Principal Economist, Organisation for Economic Cooperation and Development, Paris , France

South Africa participates in an international electricity market: the Southern African Power Pool. The purposes of this market are (1) to facilitate the development of a competitive electricity market in the Southern African region; (2) to give consumers a choice of electricity supply; (3) to ensure that the Southern African region is the region of choice for investments by energy intensive users; and (4) to ensure sustainable energy developments through sound economic, environmental and social practices.

Markets are powerful economic tools to encourage economic efficiency. However, energy markets fail to deliver on their promise of being both competitive and environmentally-friendly. First, electricity markets can fail if they do not take into account the external effects associated with electricity generation. For example, if air pollutants (including carbon dioxide) are not priced in the market, there can be an oversupply of pollutants compared to the economically optimal level. Second, in trying to encourage environmental-friendly generation, subsidies (for example, to renewables) can distort bid prices (assumed to be equal to incremental costs of generating electricity during specific hours of the day) for supply into a competitive electricity market. Market designers have been trying to address these problems, for example, with (1) the creation of tradeable carbon dioxide production permits that cap carbon dioxide within the market region, and (2) the creation of "capacity markets," that give a price incentive to provide future capacity.

However, once these secondary markets have been created, there is no guarantee that all of the markets will work together to provide competitive and environmentally-friendly generation, as well as low prices to consumers, particularly large industrial consumers. Given these sometimes conflicting demands, electric utilities are having financial difficulties. This has led to the down-grading of debt and equity issued by these companies. Debt refers to borrowing from banks, usually in the form of selling a contract to repay the debt at specific rates and at specific times, known as a "bond." The rate of return is generally known as the "interest rate." Equity refers (1) to the funds raised from the retained earnings of the utility, and (2) to funds raised in financial markets through the sale of "stocks," traded on stock exchanges. The rate of return on equity is known as the "rate of return on capital." Together the rates paid to debt and equity combine to form the "cost of capital," and are used to determine the rate at which to discount into the present future expenditures and returns on investments.

Agencies in the international financial markets evaluate the riskiness of debts and equities, and assume that the riskiness of the utility is at least equal to the riskiness of the country in which the utility resides, and that the riskiness of a generating project is at least as great as the riskiness of the utility. There are many firms rating debt, however, 95% of the financial instrument rating market is held by the "Big Three" credit rating agencies: Standard & Poor's (S&P) and Moody's in New York, and the Fitch Group, based in London. Their primary rating is between "investment grade" securities (Moody's rated AAA through BBB) and "speculative grade" securities (Moody's rated BB through C). Although they dominate the international market, they are fallible: they rated mortgage-backed securities before the financial crisis of 2007-2008 as investment grade, when, in reality, they were speculative. S&P is currently rating most electric utilities in Europe, the Middle East, and Africa at A- , BBB+, and BBB, where the minus sign implies that the rating could decline in the future and the plus implies that the rating could increase in the future. Presently, S&P rates bonds paid in foreign currencies by South Africans at BBB- and bonds paid in Rand at BBB, i.e., the same ratings as most of the electric utilities in Europe, the Middle East, and Africa.

Dr. Geoffrey Rothwell's Message Continues...

When building electricity generation capacity, the cost of capital rises as the bond rating falls. In other words, bank's buy bonds only if the rate is competitive with comparable bonds for all countries and firms, and investors only buy stock if the rate of return is competitive with investments of comparable risk. This is a problem in the electricity generating market, where all carbon-free generation technologies are capital intensive. This includes nuclear power, hydro, wind (on and off shore), and solar (distributed and centralised). Banks and investors are considering short-term returns, but investments in carbon-free electricity generating technologies pay off in the long-term. High costs of capital mean that the needs of future generations are not considered by the financial markets. This implies that governments must intervene to ensure that investments "meet the needs of the present generations without compromising the ability of future generations to meet their needs" (World Commission on Environment and Development, 1987). This problem becomes acute when considering investments in nuclear power capacity that could provide electricity for three generations.

Dr Pascal Colombani

Special Envoy of the French President for the South Africa-France nuclear partnership

A balanced energy mix is a key factor to ensure a country's energy independence and to contribute to its economic growth. At the same time, in line with COP21 agreements, an energy mix including low-carbon technologies as nuclear and renewables will ensure a reliable production of electricity and a reduction of greenhouse gas emission. Nuclear energy, when exploited with technologies compliant with the highest safety standards, is part of the solution to tackle climate change.

For decades, the French nuclear industry and Eskom and Necsa have been partners. For more than 30 years, Koeberg is a reliable source of electricity for the South-African Republic and an example for the African continent and the world.

As South Africa goes ahead with its nuclear procurement process, France commits itself to scale-up this successful cooperation into a long term strategic partnership.

For over 60 years, France has developed a safe, secure and sustainable nuclear industry and acquired an extensive experience in the field of industrial localization in various countries. Such a partnership has been implemented with China (skills development, staff training, partnerships at all levels of the value chain with now around 100 French nuclear companies working closely with local partners). This partnership has accelerated China's self-reliance in the nuclear energy field.

Another example relates to the recent decision of the British Government to approve the construction of two EPRs reactors at Hinkley Point (HPC). This decision is the result of ten years of rigorous preparation. It is good news for British consumers and a huge boost for British industry competitiveness, in particular with the development of the UK supply chain (64% of the value will be created in the UK). The project will also deliver thousands of high quality jobs and apprenticeships for people locally and all across the UK. It confirms the maturity of EPR, a proven design meeting the highest standards of nuclear safety and environment protection.
France is eager to implement the same depth of cooperation with South Africa.

Our ambition is not only to provide the technologies to meet South Africa's energy needs, but also to fully support employment opportunities and skills development at all levels of the society (workers, managers, technicians, engineers, researchers, scientists).

Embarking on a nuclear program is not only related to electricity production. It is a part of an ambitious industrial, research and social development that will result in economic growth, industrial localization and social transformation for the benefit of the whole South-African population. The development of a self-reliant industrial capacity will also help to develop cutting-edge expertise relevant for various fields such as electrical engineering, piping, welding....

The nuclear programme will strengthen the position of South Africa as the clear leader of the African continent for all civilian nuclear applications (from electricity production, radioisotopes production to health applications or nanotechnologies...). Beyond the construction of power stations, it will benefit to the national transformation of South Africa and of the whole African continent.

Dr. Geoffrey Rothwell's Message Continues...

The problem with investments in nuclear power is that they are expensive only in artificial, and intrinsically flawed, electricity power and financial markets. Given these market failures, governments must step in to provide capital. At a cost of capital of 3% (also, known as the "social discount rate," and approximately equal to the rate of the growth of the population and the infrastructure depreciation rate), nuclear power on a long-term average basis (also known as the "levelised cost of electricity," LCOE) is cheaper than coal, natural gas combined cycle, residential and commercial photovoltaics, concentrated solar, and offshore wind (see Nuclear Energy Agency/International Energy Agency, *Projected Costs of Generating Electricity, 2015 update*). The only technology that is competitive with nuclear power at a 3% cost of capital is onshore wind. Hence, the optimal sustainable combination of technologies is intermittent onshore wind backed with reliable nuclear power.

Finally, honoured participants of the Nuclear Africa 2017 Conference, do not hesitate to ask me questions during and after the conference through email: geoffrey.rothwell@oecd.org!

Thorium

The Other Nuclear Fuel

By Dr Kelvin Kemm

Nuclear Africa

Produced by Nuclear Africa (Pty) Ltd for general public information.

Thorium mine in the Western Cape

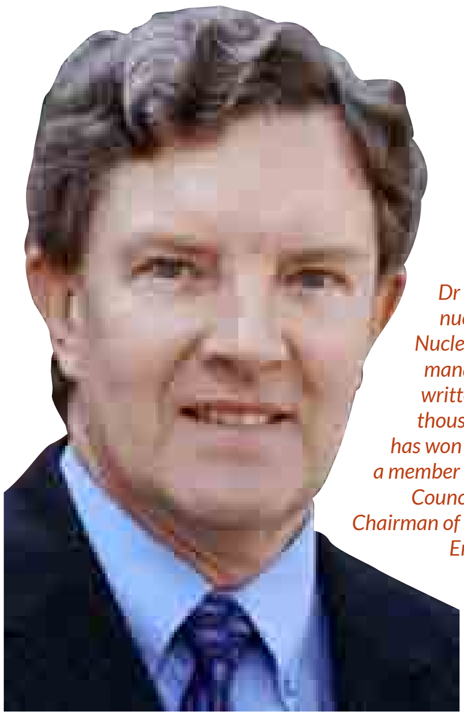
Way back in 1905 a young, unknown scientist by the name of Albert Einstein proposed a radical new physics theory called the Simple Theory of Relativity. It was anything but simple, but it turned out to be much simpler than his General Theory of Relativity, which followed some years later. Einstein's ideas would change the world.

The Simple Theory of Relativity produced a startling equation:

$$E=mc^2$$

This equation shows that energy produced (E) from some mass of anything (m) is equal to the mass, multiplied by the speed of light (c) squared. The speed of light is a very large number, so the energy that this equation predicted would result from a small mass, would be enormous.

Most people just did not believe it, and the young Einstein was mostly criticised and treated with distain.



Dr Kelvin Kemm has a PhD in nuclear physics. He is CEO of Nuclear Africa, a nuclear project management company. He has written two books and over one thousand published articles. He has won a number of awards and is a member of the Ministerial Advisory Council on Energy. He is also the Chairman of The South African Nuclear Energy Corporation (Necsa).

It was known that the energy carried by something like a cannonball was related to its velocity. Today, cricket players know very well that it is much more painful to be hit in the chest by a ball bowled by a fast bowler, than by a slow ball bowled by a spin bowler. That comparison 'feels' logical to any observer. High speed, big impact.

However, in the $E=mc^2$ equation the mass was not even moving. It turned out that the energy that Einstein predicted was nuclear energy. The nuclear energy comes from mass actually turning into energy, something that was considered impossible at the time.

This famous equation tells one that the nuclear energy released from a mass about equal to a standard building brick will drive the largest ship in the world around the earth about 100 times.

It turns out that trying to convert a standard brick into nuclear energy is not very practical. What we need to do is to use carefully selected atoms which are already inherently unstable, so that they will start to break apart easily, with the correct nuclear inducement. Such atoms include Uranium, Plutonium, and Thorium.

Plutonium is so unstable that all the plutonium that was in the earth, as it cooled from a molten ball of lava, has long since decayed away. So today if one wants plutonium, it is necessary to make it using a nuclear reaction. Uranium and Thorium are the two nuclear fuels that are found naturally in the ground, and which can be mined.

Fissile and Fertile

The U-235 atom is known as a 'fissile' atom, because it splits quite easily when struck by a neutron. The word 'fission' means - to 'break apart'. So 'fissile' means – 'can break apart'.

In contrast, Thorium-232 is called 'Fertile'.

The nucleus of a fertile atom will not split, but a small alteration to the nucleus makes it unstable, and then it will split. So a Th-232 is fertile because it can easily be converted into U-233 which is fissile.

For the technically-minded,
this is the nuclear transformation:

$$n + {}^{232}_{90}Th \rightarrow {}^{233}_{90}Th \xrightarrow{\beta} {}^{233}_{91}Pa \xrightarrow{\beta} {}^{233}_{92}U$$

South Africa possesses the world's richest thorium mine, Steenkampskraal in the Western Cape. It is approximately 350km north of Cape Town. The mine was discovered in the late 1940s and produces valuable Rare Earth materials, plus thorium. Small quantities of Rare Earths are used to make items like super strong magnets which are used in cellphones.

Steenkampskraal is owned by STL (Pty) Ltd, a Centurion-based company near Pretoria, in South Africa. STL is working on processing the thorium to nuclear grade purity.

Fuel Assemblies

Thorium can be placed into High Temperature Gas Reactor (HTGR) fuel such as the South African fabricated fuel ball shown in the picture, but can also be placed into conventional metal fuel reactor assemblies, with very little modification required.

Experimental work is currently underway internationally, testing thorium fuel in various configurations. Most Smaller Modular Reactor (SMR) systems are formed from HTGRs.

How does a thorium reactor work?

Well, like this: Thorium-232 is mined from the ground where it is extracted from one of its naturally occurring minerals, such as monzonite. This Thorium-232 is later placed in a nuclear reactor, usually in the form of thorium dioxide ThO_2. At this point the thorium atoms are referred to as 'fertile' atoms, their nuclei will not split.

Then one has to arrange to bombard these fertile thorium nuclei with a stream of neutrons. The neutrons can come from various sources, such as Plutonium or U-235. A neutron from such a source penetrates a Th-232 nucleus, where it is captured, turning the nucleus into a Th-233 isotope.

This isotope is unstable and a nuclear decay reaction takes place and it turns into another element Protactinium-233. Another nuclear decay soon occurs and this Pa-233 transmutes into U-233.

Another neutron then strikes the U-233 which fissions like the U-235 in a conventional uranium fuelled reactor. Energy is released and more neutrons are produced which keep the whole chain reaction going.

Uranium Enrichment

(see Isotopes on Pg. 4)

When uranium comes out of the ground it is a mixture of two isotopes; U-238 and U-235. The important isotope of the two, for nuclear power, is U-235 but it constitutes only 0.7% of the natural mixture. The remaining 99.3% is U-238. To use the uranium in a nuclear reactor it has to be enriched, which actually means removing U-238 atoms so that the percentage of U-235 atoms in the remaining mixture rises. For power reactors an enriched mix of 5 to 10% U-235 is required. For the production of nuclear weapons an enrichment of uranium of 90% or better is required. So there is a clear distinction between nuclear power grade uranium and nuclear weapons grade uranium. In the case of thorium, enrichment is not necessary and it can be used as is, after being extracted from mined ore. Thorium is not suitable for use in nuclear weapons.

Thorium - An Abundant Nuclear Fuel

World electricity consumption doubled in approximately the past 25 years. There is every reason to believe that it will double again in the next 25 years, if not sooner. One only has to look at the low electrification figure for many African countries, to receive a psychological jolt. Many African countries are only 5 or 10% electrified.

It is well known that one of the fastest economic accelerators which can be used to improve the living conditions of low socio-economic societies is to provide an inexpensive, reliable, electricity supply. Such an energy supply almost instantly brings with it the development of schools, clinics, communications, adult education, food preservation, lighting and much more.

Commercial nuclear power has been in operation for more than half a century and has shown itself to be the safest form of electricity production. It is clean and reliable. In the public mind, nuclear power is viewed as being composed of large plants run by sophisticated First World countries. This image is largely true, but considerable research and development being carried out right now is set to change this view.

Reactors known as SMRs or Small Modular Reactors are under development, and are close to deployment. They are only 5% to 10% the size of the current large reactors and are ideally suited for large-scale deployment in developing countries. For that matter, in First World countries as well, where they can be strategically positioned near to areas of high electricity demand. SMRs do not need large volumes of water for cooling, so they don't have to be built on large bodies of water, like oceans or large lakes. So SMRs can be placed wherever you like.

As far as the existing large reactors are concerned, there are currently some 440 in operation around the world, with about another 70 under construction. So the visible market which can be internationally penetrated for nuclear reactor fuel sales is approximately some 500 nuclear reactors.

Thorium Properties

Thorium was discovered by Jöns Jacob Berzelius, a Swedish chemist, in 1828. He discovered it in a sample of a mineral that was given to him by the Reverend Has Morten Thrane Esmark, who suspected that it contained an unknown substance.
Esmark's mineral is now known as thorite ($ThSiO_4$).

When it is pure, thorium is a silvery white metal which is air-stable and retains its lustre for several months. When it is exposed to air, thorium slowly oxidises and tarnishes, becoming grey and finally black.

Thorium oxide has a melting point of 3300°C, which is the highest of all oxides. Only a few elements such as tungsten, and a few compounds such as tantalum carbide, have higher melting points.

Thorium is named after Thor, the ancient Norse god of war.

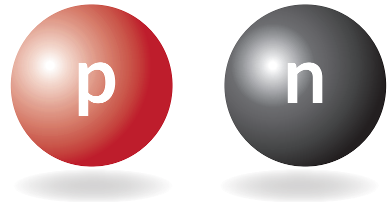
What flashes to mind is the magnitude of the uranium demand, which is looming. The optimists rub their hands in glee and talk of the foreign exchange which will be earned, from major uranium exports. The predictors of doom and gloom shake their heads, with looks of despair, and say that nuclear power will never last, because world supplies of uranium will run out in a century or less.

Well, in technological terms, ten years is a very long time. Just think of the technology changes of the last ten years. Think of email, internet, cell phone banking, genetic modification, satellite TV transmission, and more. Behind the scenes, less visible to the public, there are advances in mining technology and mineral processing; the uranium is certainly going to last a lot longer than the doomsayers predict.

Nuclear power is going to expand a lot faster than many now imagine. Nuclear power technology is expanding at a rapid rate. There is also another major playing card in the pack, which is the other powerful nuclear fuel...thorium.

There is even more thorium in the world than there is uranium. The potential for thorium as a nuclear fuel has been known about for as long as that of uranium. Thorium can be used in the existing conventional reactors, and in the new generation reactors.

Isotopes



For now let us consider that the nucleus of an atom consists of neutrons and protons. They are about the same size and mass, but the proton is positively charged and the neutron is electrically neutral. In fact many other particles can come out of an atomic nucleus at times, like beta particles, muons, and more, but that is higher level nuclear physics and we will ignore those complex details for this discussion.

The number of protons in a nucleus determines what the material is. For example carbon has 6 protons, oxygen 8, gold 79 and uranium 92. If you also then add the neutrons to the nucleus, this then gives the total mass of the element. (In shopping centre jargon 'the weight', but we don't use 'weight' in this context in physics.) Adding the neutrons to a carbon nucleus gives a typical mass of 12, whereas uranium comes out at 238. However the number of neutrons in a nucleus is not necessarily fixed at an exact number and it can vary a bit, so some carbon atoms can have two additional neutrons, to be carbon-14 and uranium can have a few less to be uranium-235 or uranium-233.

All isotopes chemically react the same way, so carbon-12 and carbon-14 both form charcoal and burn exactly the same way, when oxygen is present. Scientists did not know that isotopes existed until the atomic age was underway and then this tiny mass difference was detected, and explained.

For virtually all scientific applications in our daily life, the existence of isotopes makes no difference. However one important attribute of the differing numbers of neutrons in a nucleus, is that this determines how tightly bound the nucleus is. This is like the amount of 'glue,' so a U-238 nucleus is more tightly 'glued' than a U-235 nucleus. In physics this is known as the Binding Energy. This means that it is easier to split a U-235 nucleus in a nuclear reactor, so releasing its nuclear energy. A U-233 nucleus also splits easily, but you don't find U-233 in nature, you have to specially make it, by using thorium.

However there is a thorium isotope which does exist naturally in the ground, and it is very close to what we are looking for, it is Thorium-232. But it will not split in a nuclear reactor, because the packing arrangement of 232 particles is more strongly bound (more binding energy) than the packing arrangement of 233 particles.

So we have to make a plan to change the 232 atom into a 233. *(See page 2: Fissile and Fertile)*

Research into using thorium in nuclear reactors was carried out in the United States in the late 1950s and also in Germany and the United Kingdom in the early to mid-1960s. In the US, several demonstrations of the use of thorium reactors were performed.

In Germany and the UK, thorium was used in their early demonstration High Temperature Gas Reactors (HTGR) such as the AVR and THTR reactors in Germany, and DRAGON in the UK.

Most of the thorium used in all of these reactors came from the Steenkampskraal mine.

Nuclear Africa

Produced by:
Nuclear Africa (Pty) Ltd
Pretoria, South Africa
Tel: +27 (0) 12 807 3920
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First nuclear power unit with VVER-1200 reactor was comissioned at Novovoronezh NPP II in Russia. Construction of new VVER-1200 reactors is underway in Russia and Belarus. This design is also to be implemented at Hanhikivi-1 NPP in Finland, Paks NPP Units 5-6 in Hungary, Akkuyu NPP in Turkey, Rooppur NPP in Bangladesh, and El-Dabaa NPP in Egypt.

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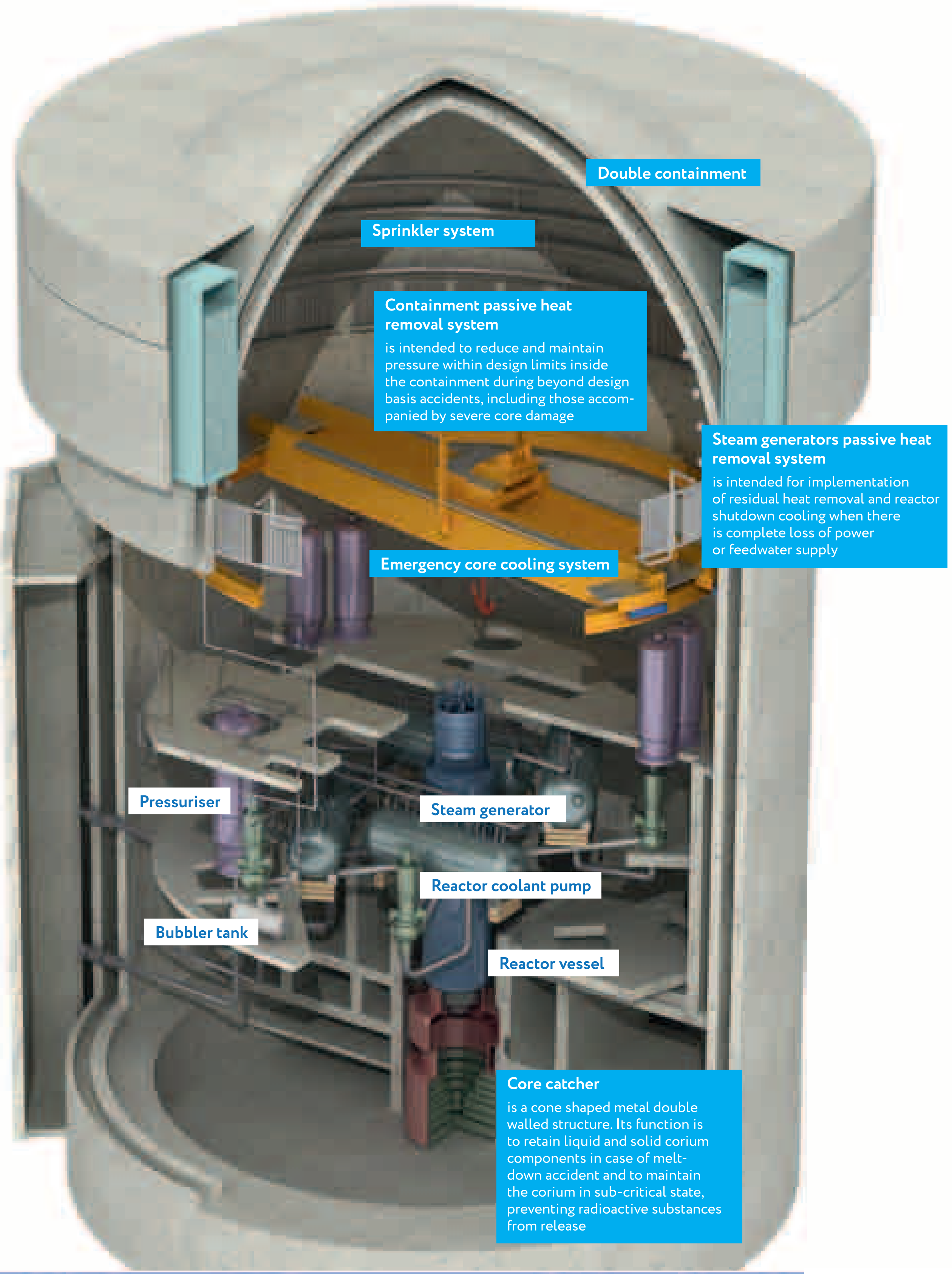

ROSATOM

Eskom

Koeberg Power Station celebrates 33 years of safe nuclear operation

ABOUT KOEBERG

Eskom is one of the top 20 utilities in the world by generation capacity (net maximum self-generated capacity: 41 194MW). It generates approximately 95% of the electricity used in South Africa and approximately 45% of the electricity used in Africa.

On 4 April 1984, Koeberg contributed the first nuclear-generated electricity to the National Electricity Grid, ushering in a new era for Eskom, South Africa and Africa. Koeberg Nuclear Power Station, one of 27 power stations in Eskom's fleet, is situated at Duynefontein, approximately 30km north of Cape Town. Koeberg is a base load power station, which means that it generates electricity until it is shut down either for refuelling (approximately every 18 months per unit), or for maintenance purposes. The station has two pressurised water reactors (PWRs) which supply in the region of 1 860MW - nearly 5% of South Africa's electricity needs.

The power station plays a pivotal role in ensuring the security of the Cape power network as most of the power generators – which are predominantly coal-fired stations - are concentrated in the northern part of the country due to the location of coalfields. In all its years of operation, the one most consistent priority on the Koeberg plant has been safety – not only of the people who work at the plant, but also of the public.

How does it work?

Koeberg operates on three separate water systems (primary, secondary and tertiary circuits). The primary system is kept under pressure by a pressuriser to prevent boiling of the primary coolant, hence the name Pressurised Water Reactor (PWR). Very little fresh water is consumed in the nuclear process. The cooling water system uses seawater at the rate of 80 tons/sec to cool the steam in the two condensers - 40 tons/sec for each unit. It is important to note that at no time does the seawater come into contact with the demineralised water that is used in the primary system. The reactor core is contained in the reactor vessel, which is 13m high and 25cm thick. All internal surfaces of the vessel are clad with stainless steel to avoid corrosion.

OUR SAFETY

At Koeberg, safety is critical in all operations and decision-making. Koeberg's quality and safety culture has been in place even before the project began in 1976 and has been recognised locally and internationally with numerous awards.

Regulating nuclear safety is a national responsibility. South Africa, including its regulator, nuclear operators, and the government, has an obligation of diligence and duty of care to its people and environment, and is expected to fulfil its national and international undertakings and obligations. A global nuclear safety regime is in place and is being continuously improved. IAEA safety standards, which support the implementation of binding international instruments and national safety infrastructures, form the cornerstone of this global regime. The IAEA safety standards constitute a useful tool for contracting parties to assess their performance under these international conventions. These safety standards have recently been updated to capture the events associated with the Fukushima Dai-ichi incident in Japan. The nuclear industry is subject to stringent safety standards due to the acknowledgement of the consequence of any potential safety incident. Design basis changes, especially those that have an impact on nuclear safety, require proper justification and are reviewed and approved by the national nuclear regulator. In addition, there is joint collaboration between nuclear operators worldwide in ensuring the implementation of industry best safety practices by way of safety audits carried out by WANO.

The National Nuclear Regulator (NNR) provides not only requirements and guidelines, but also periodically monitors the facilities in operation in accordance with the safety standards specified in the facility's approved licence. In addition, Koeberg works with an approved supplier list, which grades suppliers' capability to supply and work in certain areas of the plant in accordance with the applicable safety criteria.

Additionally, routine self-assessments are conducted, as well as peer reviews by institutions such as WANO, OSART, and INPO. The golden thread that permeates the nuclear industry is a strong safety and security culture, which is also a prerequisite for safe operations. All work is executed in accordance with specific precompiled and authorised procedures.

Koeberg continuously strives to improve on its performance. Consequently, the station regularly undergoes peer reviews, which places it under scrutiny by international and local experts to benchmark its performance against international best practises. In 2017, Koeberg celebrates 33 years of safe operation – over the years, the station has received numerous accolades, amongst others, becoming the first nuclear power station outside the United States to receive initial accreditation and retain accreditation for its Operator Training Programmes from the Institute of Nuclear Power Operations (INPO).

Koeberg invites external organisations to regularly audit the station's performance in order to meet its objective of delivering world class nuclear energy. 2017 saw Koeberg being commended by the World Association of Nuclear Operators (WANO) during the two-yearly Peer Review, which took place at the end of January 2017 - the results of the review were the best in the station's history. This is a reflection of the station's high standards of operation. WANO evaluations are a major milestone for any nuclear power station, as international nuclear experts assess the station and performance, and at the end of the evaluation, a report card indicates how the station measures up against the best in the world. The National Nuclear Regulator (NNR), which is the oversight body assigned by government, makes sure that Koeberg operates within set national and international standards.

The Koeberg Integrated Emergency Plan

National legislation (NNR Act No. 47 of 1999) requires Koeberg Nuclear Power Station to have an established integrated emergency plan to protect the public in the unlikely event of a nuclear accident. The Act also requires that the effectiveness of the Integrated Koeberg Nuclear Emergency Plan be tested by the National Nuclear Regulator (NNR) every two years.

In order to ensure that the Koeberg Emergency Response Organisation is prepared for any emergency at any time, the power station arranges for annual training, which tests the readiness of the key roleplayers within Koeberg's emergency organisation. This is in addition to the NNR Exercises, which independently test the emergency preparedness and emergency response capabilities of Koeberg Power Station and all the intervening organisations involved in Koeberg's Integrated Emergency Plan.

A team consisting of members from Eskom, the local authorities, and other support organisations are available around the clock to handle any emergency at the power station. In the unlikely event of an emergency at Koeberg, Eskom will recommend appropriate protective actions to the relevant authorities, and National, Provincial and Local Government will authorise and implement the protective actions, as appropriate.

OUR ENVIRONMENT

Hikers and cyclists are encouraged to enjoy the clean air and healthy natural environment surrounding the power station. The 3000ha, Koeberg Nature Reserve, which surrounds the present Koeberg Nuclear Power Station, was proclaimed in October 1991 and officially opened in September 1992.

Great care has been taken to conserve and restore the coastal landforms, wetlands and different vegetation of the area, as well as the animal life. There is a biking trail and several hiking trails through the reserve, which visitors are welcome to explore. The Dikkop and Grysbok Hiking Trails varies from 2.5 km to 22.3 km taking the hiker through widely varying terrain, and one can experience the splendour of the many moods of the West Coast. The Mountain Bike Trail leads the visitor through two naturally occurring veld types, Strandveld and Duneveld. On the route there is a bird hide, which allows visitors and birdwatchers to view the spectacular variety of birds in the reserve.

The reserve is used by a number of students to conduct research, including sampling and recording of fauna and flora, and it serves as an integral part of outdoor educational programmes from visiting schools and interest groups.

The purpose of the Koeberg Nature Reserve is to:

- create an environment in which development of the area can take place, within the context of Koeberg Nuclear Power Station and conservation requirements;
- protect an ecologically viable, representative area of Fynbos and its associated biodiversity;
- protect the ecological integrity and functioning of wetlands, their catchments;
- protect the biodiversity of the area; and
- provide sustainable access by the public to the area and its resources

The reserve plays a pivotal role in the conservation of the area which is being threatened by the fast expanding Cape Town metropole, coastal developments, farming and mining. The Koeberg Nature Reserve is a fine example of a preserved and responsibly managed natural resource. This will be so for decades to come.

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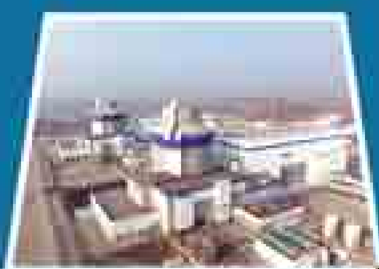

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- To achieve localization of China AP1000 standardized design
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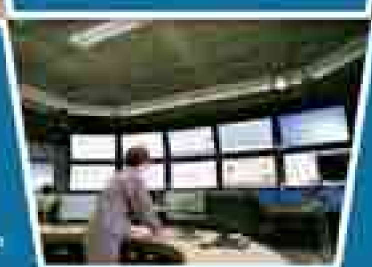
- CAP1400 FOAK NPP
- Siting



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- Build the Nuclear Energy R&D base platform

Renewables

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- EPC of renewable energy projects
- The operation and service of renewable energy projects

Nuclear Fuel
Its Nature and Disposal

Produced by Nuclear Africa (Pty) Ltd for general public information.

Spent nuclear fuel under water exhibits a blue glow

by Francois Mellet

Uranium in nature is a slightly radioactive metal that occurs throughout the Earth's crust. It occurs in most rocks, in concentrations of 2 to 4 parts per million. Uranium is about 500 times more abundant than gold, and is as common in the Earth's crust as tin, tungsten and molybdenum. It is also naturally present in most soils, as well as in many rivers and in sea water. It is found in concentrations of about four parts per million (ppm) in granite, which makes up 60% of the Earth's crust. Uranium concentration can be as high as 400 ppm (0.04%) in fertilizers, and in some coal deposits the Uranium concentrations can rise to greater than 100 ppm (0.01%).

In South Africa and Namibia where the concentration of Uranium in the ground is sufficiently high, the mining of various ores to process and to extract uranium for eventual use as nuclear fuel, is economically feasible.

Francois Mellet is an electrical engineer whose career started in Eskom. He progressed to spend ten years in Koeberg Nuclear Power Station as a commissioning and project engineer. He later spent a year in the nuclear environment in France, Germany, Belgium and the United Kingdom. He then spent five years as maintenance manager at the coal-fired Matimba Power Station. Francois then spent nearly a decade in International Risk Control Africa where he worked in a diversity of sectors. From 2002 he has been working on a project in France to design and develop an underground research laboratory, leading to the construction of a longterm storage facility for high level nuclear waste. The client is ANDRA (National Agency for Nuclear Waste Storage).

The earth's Uranium (chemical symbol U) was apparently formed in supernovae up to about 6.6 billion years ago. Its radioactive decay provides the main source of heat inside the earth, causing convection of molten rock and consequent continental drift. As decay proceeds, Uranium eventually becomes lead, so the lead in the final product progressively increases in relative abundance. Rather interesting is that lead is scientifically used to shield living organisms from the radio-active effects of different nuclear sources

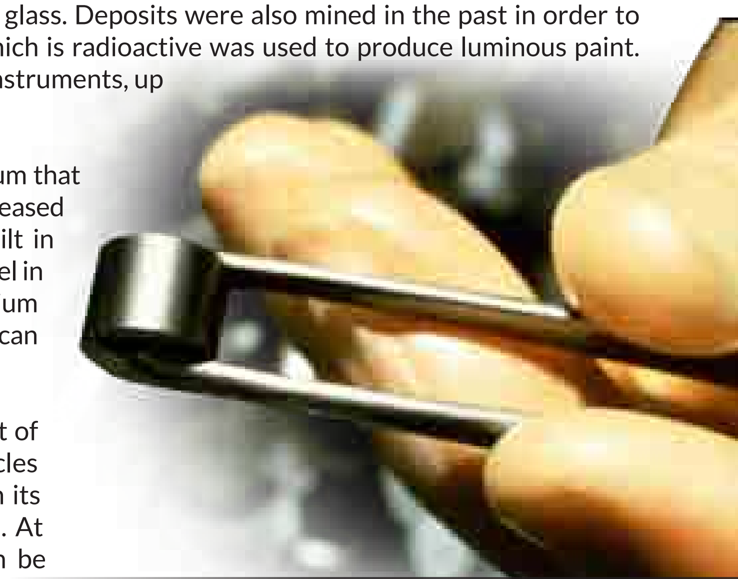
Uranium was discovered by Martin Klaproth, a German chemist, in 1789 in the mineral pitchblende, and was named after the planet Uranus. Being relatively soluble, in contrast to thorium, it is also found in the ocean, at an average concentration of 3 parts per billion.

Light elements such as hydrogen and helium are found in abundance all over the universe. However for the heavier elements to form, such as Uranium and gold, the giant gravitational fields found amongst stars are required. As layers of matter are crushed together by gravitational force, a star can explode, forming many of the heavier elements. Such an explosion is known as a supernova. Fragments from such an explosion can later be drawn together by gravity to form planets, containing materials 'like uranium and gold.'

In the past, from as early as 79AD, Uranium was also used to colour glass. Deposits were also mined in the past in order to obtain its decay product, Radium. From the later 1800's, Radium which is radioactive was used to produce luminous paint. This paint was used particularly on the dials of watches and aircraft instruments, up to the 1950's, so that they could be read in the dark.

For many years after the Second World War, virtually all of the Uranium that was mined was used in the production of nuclear weapons, but this ceased to be the case in the 1970's when nuclear power reactors were built in significant numbers. Today the only substantial use for Uranium is as fuel in nuclear reactors; mostly for electricity generation. The isotope of Uranium called Uranium-235 is the only naturally-occurring material which can sustain a fission chain reaction, releasing large amounts of energy.

Small amounts of radioactive fission products in the fuel can leak out of the fuel cladding into the reactor water, in the form of small particles and debris. These can lodge on surfaces of the reactor vessel and in its internal structures, and also in those of adjoining pipes and vessels. At decommissioning, much of this radioactive debris is loose and can be washed or scrubbed away to form a sludge that can then be disposed of. Some of it is more firmly stuck and cannot be so easily removed.



A pellet of Uranium Oxide which goes into the Zirconium tubes which makes up a fuel element.

- Thorium (Th) is more abundant in nature than Uranium.
- Thorium is fertile rather than fissile, and can only be used as a fuel in conjunction with a fissile material such as recycled Plutonium.
- Thorium fuels can breed fissile Uranium-233 to be used in various kinds of nuclear reactors.

Uranium

is one of the heaviest of all the naturally-occurring elements and has a density of 18.7gm/cm³. Its melting point is 1132°C.

While nuclear power for the production of electricity is the predominant user of Uranium, one can also use the heat from nuclear fission directly for industrial processes, and for marine propulsion, such as in nuclear submarines and nuclear powered surfaced warships. Another class of specialist nuclear reactors is important for making a range of commercial radio-isotopes, such as our own South African SAFARI-1 reactor which produces life-saving medical isotopes. SAFARI-1 has been in operation for over 50 years.

In nature, Uranium produces so little radio-activity that its ore can be safely handled with bare hands. Before it can be used in a reactor for electricity generation, however, the ore must undergo a series of processes to produce a useable nuclear fuel.

Like many other natural elements, Uranium occurs in slightly differing forms known as isotopes. These isotopes differ from each other in the number of neutrons in the nucleus. Natural Uranium (Unat), as found in the Earth's crust, is a mixture of three isotopes: Uranium-238 (U-238), accounting for 99.275%; U-235 at a concentration of 0.720%; and traces of U-234 at 0.005%. Uranium ore is processed in South Africa into a yellow oxide power which is then exported. It is known as: Yellowcake. Its chemical composition is U_3O_8. In popular and commercial literature it is something written like this: U3O8.

For most of the world's reactors, the next step in making a useable fuel is to convert the uranium oxide into a gas, Uranium Hexafluoride (UF_6). Since this form of Uranium is a gas, it can be fed into enrichment devices that require a gas flow, such as a centrifuge or the South African developed Vortex tube system. The process of Uranium enrichment increases the proportion of the U-235 isotope from its natural level of 0.7% to 3 to 10%, depending on the type of reactor it will be used in. This enrichment enables greater technical efficiency in reactor design and operation, particularly in larger reactors, and also allows the use of ordinary water as a process controller or moderator. Submarines and ships operate using enrichment levels ranging all the way up to 96%. Note that weapons-grade Uranium is typically 80%-95% enriched.

Illustration of a PWR fuel element of an array of 17x17 zircalloy tubes of 3.4m in length. Illustration shows Uranium oxide Fuel Pellets being loaded into the tubes.

The World Nuclear Association predicts that global Uranium demand will increase by 48% by 2023, as a result of the approximately 70 nuclear reactors currently under construction globally.

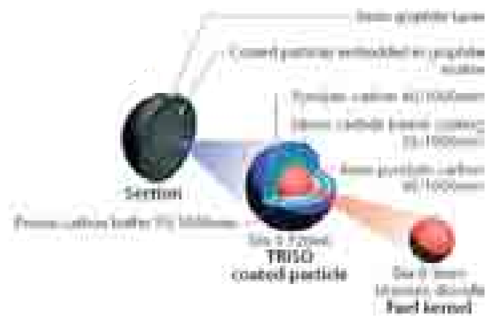
The Pebble Bed Modular Reactor (PBMR) type of power plant is fuelled and moderated by graphite fuel spheres, each containing Tri-structural-isotropic (TRISO) coated, low-enriched, Uranium Oxide fuel particles. TRISO fuel is a type of micro fuel particle, coated with four layers of three materials. These particles are less than 1mm in diameter. They are all embedded in a graphite ball about the size of a cricket ball.

TRISO fuel particles are the size of poppy seeds. Break one open, and it looks like the inside of a tiny jaw-breaker sweet. An outer shell of carbon coats a layer of silicon carbide, which coats another layer of carbon and the uranium centre — where the energy-releasing fission happens.

TRISO fuel particle

A TRISO particle of Uranium has its own containment layers. It is about 1mm in diameter.

60mm in diameter



PBMR fuel ball containing 9gm of Uranium, made at Necsa

There are 15000 fuel particles per fuel sphere, called a Pebble. It is the size of a cricket ball. Each fuel pebble contains 9gm of Uranium, and this Uranium contains enough electrical generation capacity to sustain a family of four for a year. Five tons of coal would be required to generate the same amount of electricity as one pebble's energy.

In South Africa, much of the productive ground for Uranium production is the gold fields in the Witwatersrand Basin. Uranium is frequently found as a by-product of gold mining. Klerksdorp, Welkom, Carletonville, Parys and Evander are towns strongly associated with gold mines.

A 1000MW nuclear power plant will produce 20 tons of spent fuel per annum, compared to a typical similar coal-fired unit in South Africa, which would produce 1.4 million tons of ash in a similar period. Therefore a nuclear plant produces 70 000 times less waste by volume.

Nuclear Waste

Operational nuclear waste is produced at any facility which uses radioactive material, such as a power station, research reactor, or nuclear medicine center.

Low Level Waste (LLW) is produced from ongoing operational and maintenance activities, as well as the de-commissioning of certain equipment during or at the end of power station life. This consists of gloves, jackets, swabs and anything which may have come into contact with radioactive material, and so may have some smear of radioactive material on it.

Intermediate Level Waste (ILW) is based on concentrations of radioactive materials in liquids or filter materials. These materials are deposited in pipes or similar and are then normally placed in high-density concrete containers, which are then stored in near-surface disposal facilities. "Near-surface" means: some 30 to 50m below ground.

For a power station reactor, once the inner fuel elements in the centre of the reactor core are exhausted (due to higher neutron flux in the core centre) the reactor commences a power coast-down towards a re-fuelling outage. The spent fuel elements are then removed and replaced with new fuel elements. The spent fuel should not be regarded as nuclear waste at this stage, since there are still very valuable materials in the spent fuel. This spent fuel can then be reprocessed, to separate the various valuable materials such as Plutonium-239, in the spent fuel. This Plutonium can be further used in other types of reactors.

Spent fuel is referred to as High Level Waste (HLW) and it is extremely dangerous if not handled correctly. The governments of most countries in the world have not yet authorized the long-term storage of HLW in their countries. The first two countries to gain government authorization were Finland and Sweden. Their repositories are underground, in ground that is permanently wet, so the regular pumping out of water is required, while the tunnels are filled with spent fuel. In South Africa's case the likely ground for such a High Level Waste repository is extremely dry, so no water pumping would be necessary.

During the early years of Koeberg Nuclear Power Station, fuel elements were being imported from the USA and France. In order to secure the sustainable operation of our only nuclear power production unit, a strategic decision was made to manufacture South Africa's own fuel assemblies.

Production of low-enriched Uranium (3.25%) commenced in August 1988 at Valindaba, part of the Pelindaba site of Necsa near Pretoria. There was also a Zircaloy Tubing facility at Pelindaba used to produce the cladding tubes for the fuel assemblies fabricated for the Koeberg reactors.

The first complete Koeberg fuel loading with locally manufactured fuel, took place in 1991 on Koeberg Unit 2, when a third of the 157 fuel assemblies were replaced during a re-fueling outage. This was an extremely proud moment for South African nuclear engineering!

Enrichment activities at the plant were terminated in October 1995, due to political and economic reasons.

Reprocessing

When highly radioactive spent fuel is produced, two options face the government concerned. One is to store the spent fuel underground, while the other is to reprocess the spent fuel to extract the remaining valuable materials. Of course the spent fuel is highly radioactive, so reprocessing is a complex and dangerous process.

Once all materials of value have been removed from the spent fuel; the remaining material may then be considered as "nuclear waste".

Spent fuel can be safely handled and transported in a controlled manner under the supervision of nuclear professionals.

At present South Africa has an operational nuclear waste repository site at Vaalputs in the Northern Cape, for Low and Intermediate Level Nuclear Waste storage. This facility is ideally located 100km south-east from the town of Springbok in a very dry region, with rainfall of 74mm per annum. With low inhabitance of less than 1 person per km², low seismicity and a stable weather system, the area is ideal. Over the last 30 years there has been a utilization of only 500-1000 hectares of the extremely large site of 10 000 hectares. This is a very economical site, run since 1986 by a South African team from the local region.

First South African made fuel element for Koeberg Nuclear Power Station, 1989.

France has their low and intermediate level nuclear waste facilities located within 5 km of populated towns, in very wet regions by European standards, where extensive concrete and clay-engineered solutions are required.
For the High Level Waste, high cost experimentation has been ongoing for the last 16 years in France, to find a solution to store the waste in sedimentary clay rock. This Underground Research Laboratory (URL) is at a depth of 500m and is located within 2.5 km of surrounding villages. The final solution design is now complete and is planned to also be at a depth of 500m, covering an area of 15km² of tunnels. The budgeted cost is a figure of some 25 billion Euros over the next 150 years.

Nuclear Africa

Produced by:
Nuclear Africa (Pty) Ltd
Pretoria, South Africa
Tel: +27 (0) 12 807 3920
Email: exec@nuclearafrica.co.za
www. nuclearafrica.co.za

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