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CHALLENGES AND OPPORTUNITIES IN THE DEVELOPMENT OF SAFER NUCLEAR TECHNOLOGIES

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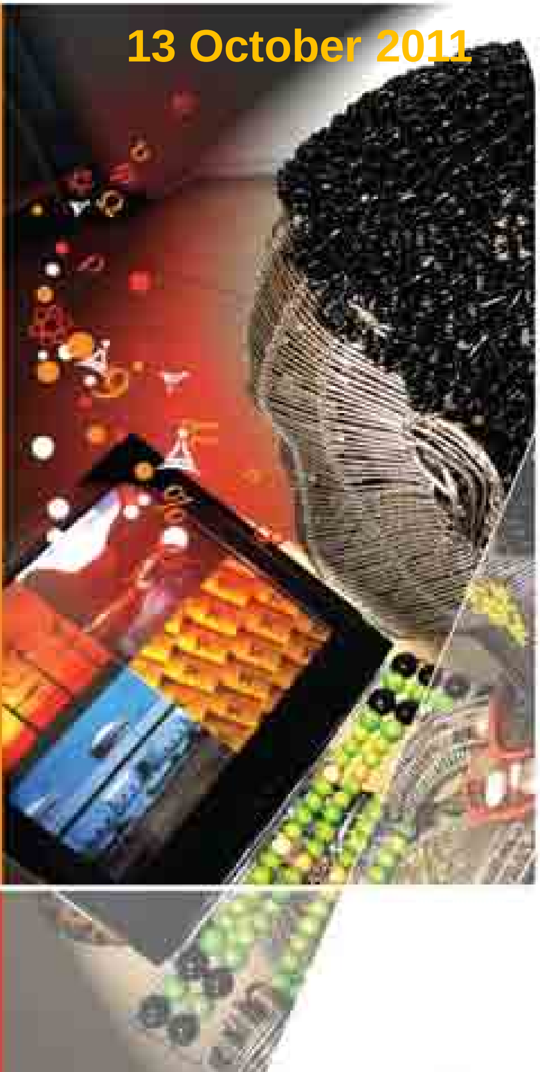

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Presentation Plan

- Challenges for nuclear power
- Where we are now
- What is being done
- The opportunities

Challenges for Nuclear Power

Nuclear Fuel Resources

Challenge: Global uranium resources are only enough to supply fuel for the next 100 years or so.

- New discoveries are being made on a yearly basis, e.g. 50 000 tons in Andra Pradesh this year.
- Extract uranium from sea water? There are about 25 billion tons of U in the earth's oceans. This is enough to keep the world's current nuclear fleet going for about 7 million years!

Nuclear Fuel Resources

- Thorium can be used to breed ^{233}U. Doing this will roughly double current nuclear fuel material reserves, as well as removing many safeguards challenges. India is making progress here.
- Currently only ^{235}U is used in fuel. But only 0,7% of natural uranium consists of ^{235}U. The other 99,3%, which is made up of ^{238}U, goes “unburnt”. Fast Breeder Reactors convert ^{238}U into ^{239}Pu, thereby increasing the world’s burnable uranium stocks by a factor of over 100.

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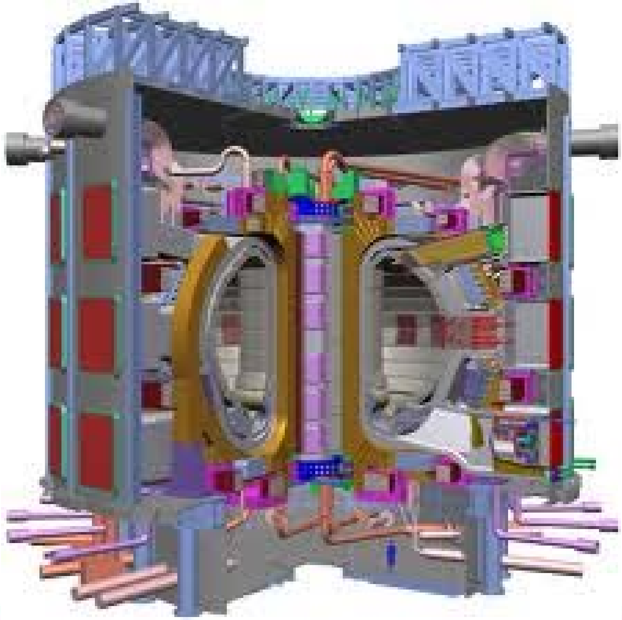
Nuclear Fuel Resources

- All current nuclear electricity generation is fission based. Nuclear fusion, however, offers almost limitless fuel reserves in the form of lithium and water. The global research collaboration ITER is the world's response to the fusion challenge



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Nuclear Fuel Resources

- The big challenge in fusion is that, at the very high temperatures needed to overcome the electrostatic repulsion between tritium and deuterium nuclei, these nuclei generate their own magnetic fields, which cause "leaks" in the applied field confining them. Solution: fuse ^3He and neutrons from a fission reactor? Unfortunately naturally occurring ^3He is extremely rare. However, there are millions of tons on the moon, occluded in ilmenite rock. Mining boom in the 22nd century!?
- Another use of ^3He: a radiation-free nuclear fuel!

$$^3He + ^3He \rightarrow ^4He + p + p$$

Requires very high temperatures though.

Continues…

A Spent Fuel Plan is Required

- Although the amount of spent fuel is much tinier (by a factor of about a million) than ash and greenhouse gas emissions from coal-fired plants, concerns remain that there is an incomplete business plan.
- Technologies exist to almost close the fuel cycle (burning all nuclides to non-radioactive products). What remains are the few percent of shorter-lived non-fissionable nuclides (e.g. ^{137}Cs with half-life 30 years).
- Using a particle accelerator, remaining radioactive nuclides can be transmuted to non-radioactive nuclides.

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Issues Related to Public Perceptions

- We are our own worst enemies, we apologize for everything, thereby appearing to take the blame.
- OTT syndrome: When you apply for a license to bury something 800 metres underground, will anyone believe you when you tell them that it is more or less harmless?
- Learn from nuclear accidents, and from how other industries manage their accidents. Each accident is different. Do not promise that there will never be another accident.
- Place matters in perspective. Are we afraid of catastrophe or just of fear itself?

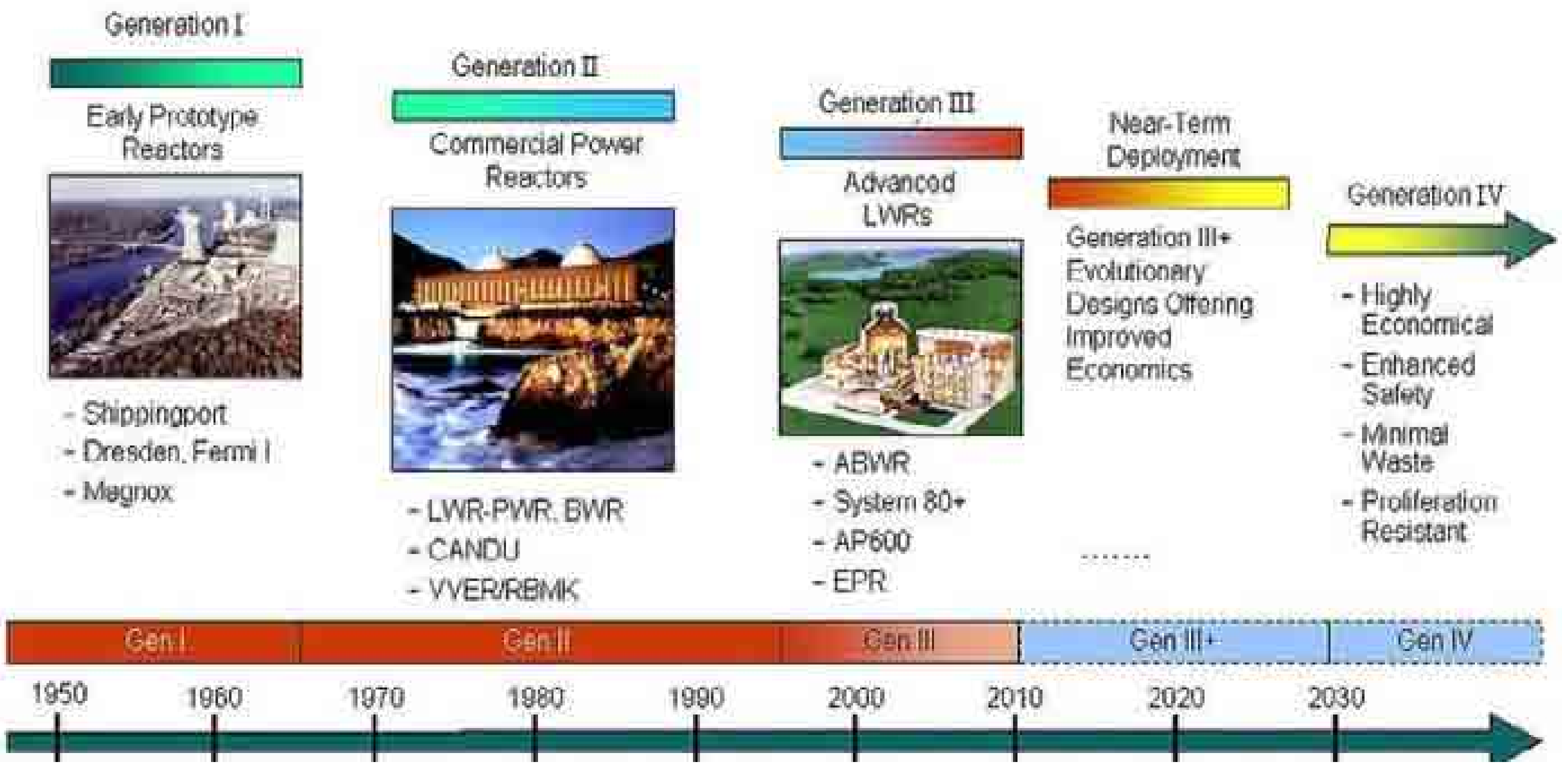
Where We Are Now

Generations of Nuclear Reactors

- Generation 1 — Prototypes and early power reactors
- Generation 2 — Commercial designs built on Gen 1 experience up until the end of the 1990s.
- Generation 3 — Evolutionary safety improvements. Much lower core damage frequency. Either multiple redundancy or passive safety.
- Generation 4 — 8 objectives, including full passive safety and closed fuel cycle.

Generations of Nuclear Reactors

Generation IV: Nuclear Energy Systems Deployable no later than 2030 and offering significant advances in sustainability, safety and reliability, and economics



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Where are the Existing Reactors

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Power Reactors Currently Operating

Pressurized water reactors	265
Boiling water reactors	94
Pressurized heavy water reactor	44
Gas cooled reactors	18
Light water graphite reactors	12
Fast breeder reactors	4
Other	4

Continues…

Where are the new reactors being built?

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Power Reactors Currently Under Construction

▪ Pressurized Water Reactor	51
▪ Advanced Boiling Water Reactor	4
▪ Pressurized Heavy Water Reactor	7
▪ Fast Breeder Reactor	2

Continues…

Trends

- The locus of nuclear power is moving east. The west is de-industrializing and can therefore address its CO_2 emission targets by other means. Given the long period to achieve positive NPV, unregulated markets are a challenge for new build.
- New build is overwhelmingly PWR. The diversity of designs is disappearing.

What is being done?

Generation 4 Reactors

- An international task force is developing six nuclear reactor systems for deployment between 2020 and 2030. Three are fast neutron reactors.
- All of these operate at higher temperatures than today's reactors. In particular, four are designated for hydrogen production.
- All six systems represent advances in sustainability, economics, safety, reliability and proliferation-resistance.
- South Africa is one of the 10 members of the Generation IV International Forum (GIF).

Generation 4 Reactors

Relative to current nuclear power plant technology, the claimed benefits for 4th generation reactors include:

- Nuclear waste that lasts a few centuries instead of millennia
- 100-300 times more energy yield from the same amount of nuclear fuel
- The ability to consume existing nuclear waste in the production of electricity
- Improved operating safety
- Economically more competitive than current generation

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Types of Gen 4 Reactor

Thermal reactors

- Very-high-temperature reactor (VHTR)
- Supercritical-water-cooled reactor (SCWR)
- Molten-salt reactor (MSR)

Fast reactors

- Gas-cooled fast reactor (GFR)
- Sodium-cooled fast reactor (SFR)
- Lead-cooled fast reactor (LFR)

Overview of Gen 4 Systems

System	Neutron spectrum	Coolant	Temperature °C	Fuel cycle	Size (MWe)
VHTR (very-high-temperature reactor)	thermal	helium	900-1 000	open	250-300
SFR (sodium-cooled fast reactor)	fast	sodium	550	closed	30-150, 300-1 500, 1 000-2 000
SCWR (supercritical water-cooled reactor)	thermal/ fast	water	510-625	Open/ closed	300-700 1 000-1 500
GFR (gas-cooled fast reactor)	fast	helium	850	closed	1 200
LFR (lead-cooled fast reactor)	fast	lead	480-800	closed	20-180, 300-1 200, 600-1 000
MSR (molten salt reactor)	fast/thermal	fluoride salts	700-800	closed	1 000

Opportunities

Opportunities

- Huge opportunity to bootstrap South African science and technology on the back of a R 1 trillion (?!) spend.
- Opportunity to be part of a global effort to reduce carbon footprint.
- Opportunity to use the uranium value chain to attract investors.
- Opportunity to develop local high spec manufacturing.
- Opportunities for the social sciences in the realm of public opinion and understanding.

Thank You!!!