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Understanding Progress (or lack of) in Nuclear Energy

Dr. Michael C. Clarke

CPEng, FIEAust, APEC Engineer, IntPE(Aus), FAusIMM, RPEQ (Mining & Chemical)

Infrastructure Development & Resource Management Engineer

A presentation to the Mining Mondays Discussion Group

This Presentation’s Scope

a. An overview of a recent interest; the use of new technology batteries as NPP backup, and
b. Where nuclear energy has come from, its present status and the future,
    a. The beginnings in the late 1940’s,
    b. The Development of First, Second and Third generation NPPs,
    c. Generation IV NPPs and beyond, plus an annexure,
c. Graham’s (Our Captain’s) Choice:- Thorium as a nuclear fuel, with reference to Australia being a major resource of monazite and thus Thorium.

Bataan Nuclear Power Plant 1

Stack

A Completed (1986) Light Pressurised Water Nuclear Power Plant that has never been fired up! Westinghouse – Burns & Roe.

Fukushima Learnings

- It is difficult to build TSUNAMI protection barriers large, heavy and high enough to give protection post major seismic events,
- Scramming the reactor only halts the fission reaction, but does stop high level decay of short-lived isotopes; about 6% of the heat generated in a reactor is Decay Heat, and on scramming those isotopes will decay and give off much heat,
- Hours of cooling post a scram will be needed to remove the short-lived isotope decay heat, and cooling for days/weeks for lower level heat production from spent fuel, and
- Emergency Diesel Generators (EDGs), designed to maintain power for cooling can be swamped.

Learnings from the Fukushima disaster with respect to Bataan NPP

- Although having seawater cooling is a major advantage for NPPs, it comes with significant risk of being a hazard factor in situations where the NPPs are located in high risk seismic/tsunami areas, e.g. Japan, The Philippines and California,
- For BNP a tsunami of even a few metres would have taken out EDGs, the switch-yard, the administrative building, possibly the turbine/generator hall, the and the ingress/egress ways, with the reactor and fuel handling building probably being spared, and
- If the tremor sensors were working the station would have successfully scrammed, but the decay heat could have caused great damage, as was the case for Fukushima.

Bataan Nuclear Power Plant 1
Tsunami Hazards

Areas of Immediate Hazard:

The EDGs,
Switchyard,
Admin Office &
Egress/Ingress Ways

Stack

A Completed (1986) Light Water Pressurised Nuclear Power Plant that has never been fired up! Westinghouse – Burns & Roe.

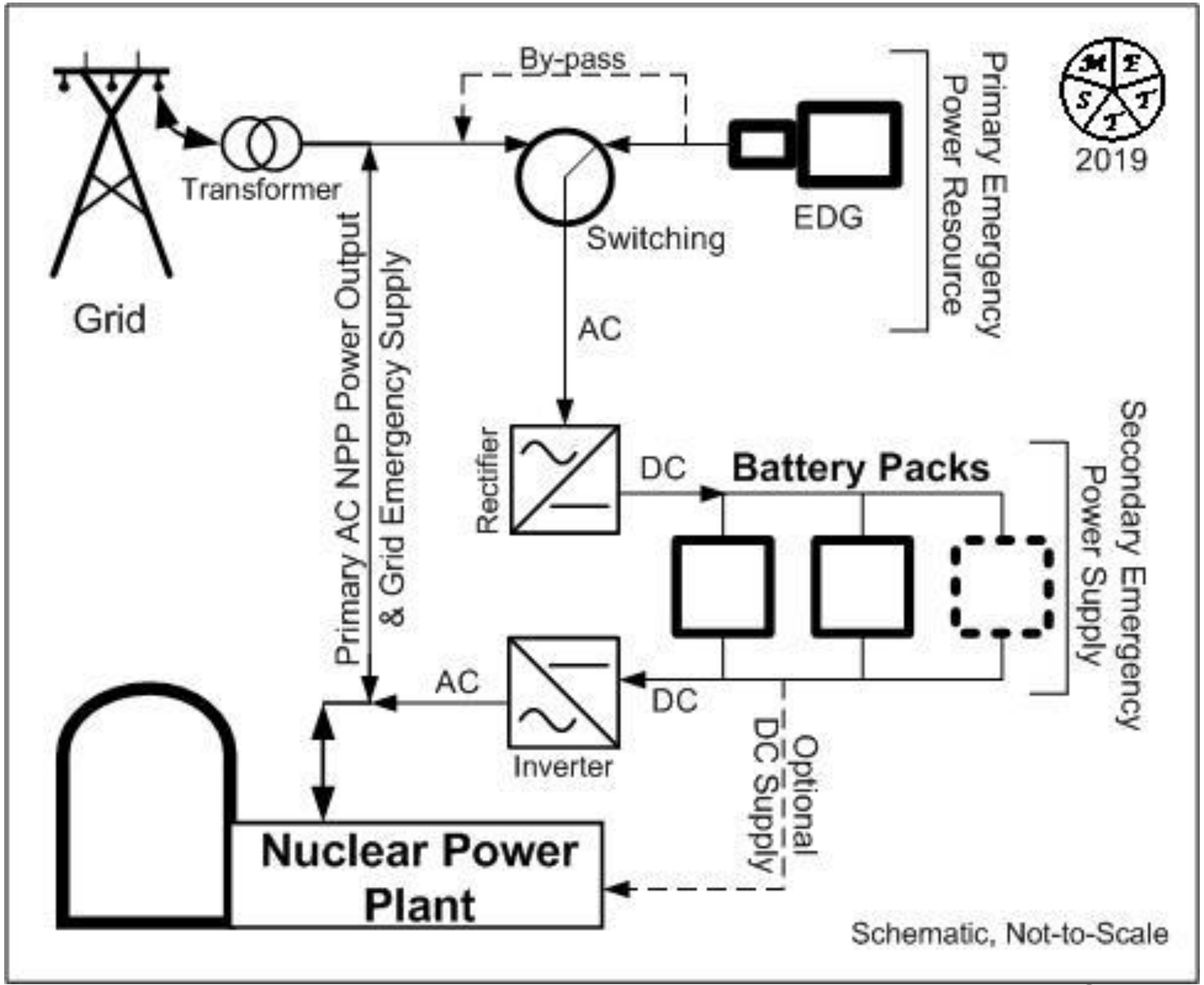
What to do to Create a Higher Backup Safety Level

- Not rely on vulnerable EDGs as much as is shown for PNPP,
- Consider using the new battery technologies for a near instant backup,
- Have greater backup in depth in terms pf capacity and geography,
- Have batteries that can take earthquakes, tsunamis and impacts, and
- Down-rate the role diesels(EDGs).

Battery's Future Role in NPP Backup

The conversion from Alternating Current (AC) to Direct Current (DC) and then the reverse requires sophisticated electronics; electronics that would require duplication for safety and security.

The EDGs could be run in charging mode during the initial period of a scram and then in direct energy supply mode to the plant's cooling system.



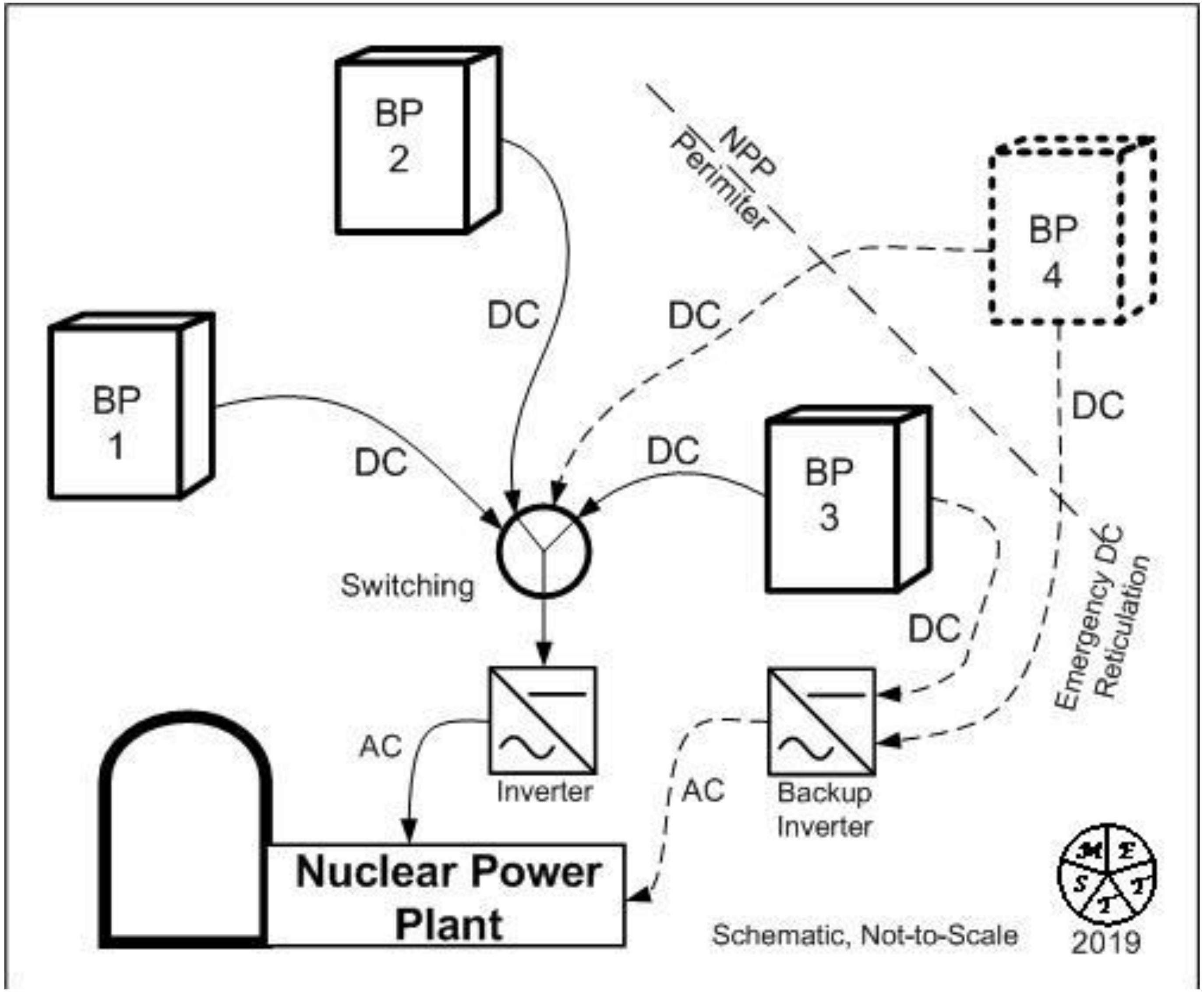
Inside and Outside the NPP's Perimeter

Battery Packs

Backup can include direct linkages to secondary power transmission sources, EDGs, hydro-plants and gas-turbine plants, however batteries will deliver greater security and safety if wisely installed.

The installation of battery backup should primarily be inside the nuclear plant's perimeter however additional units could be situated at some distance from the NPP.

Batteries packs (BP) outside the perimeter would need to comply with nuclear maintenance and security standards.



Which Battery Technologies are Best for NPPs?

This is still NOT known, however existing Lithium-ion batteries appear to be not in the race, and

Criteria for backup battery uses in NPPs should be developed.

Nuclear Energy, where is it going?

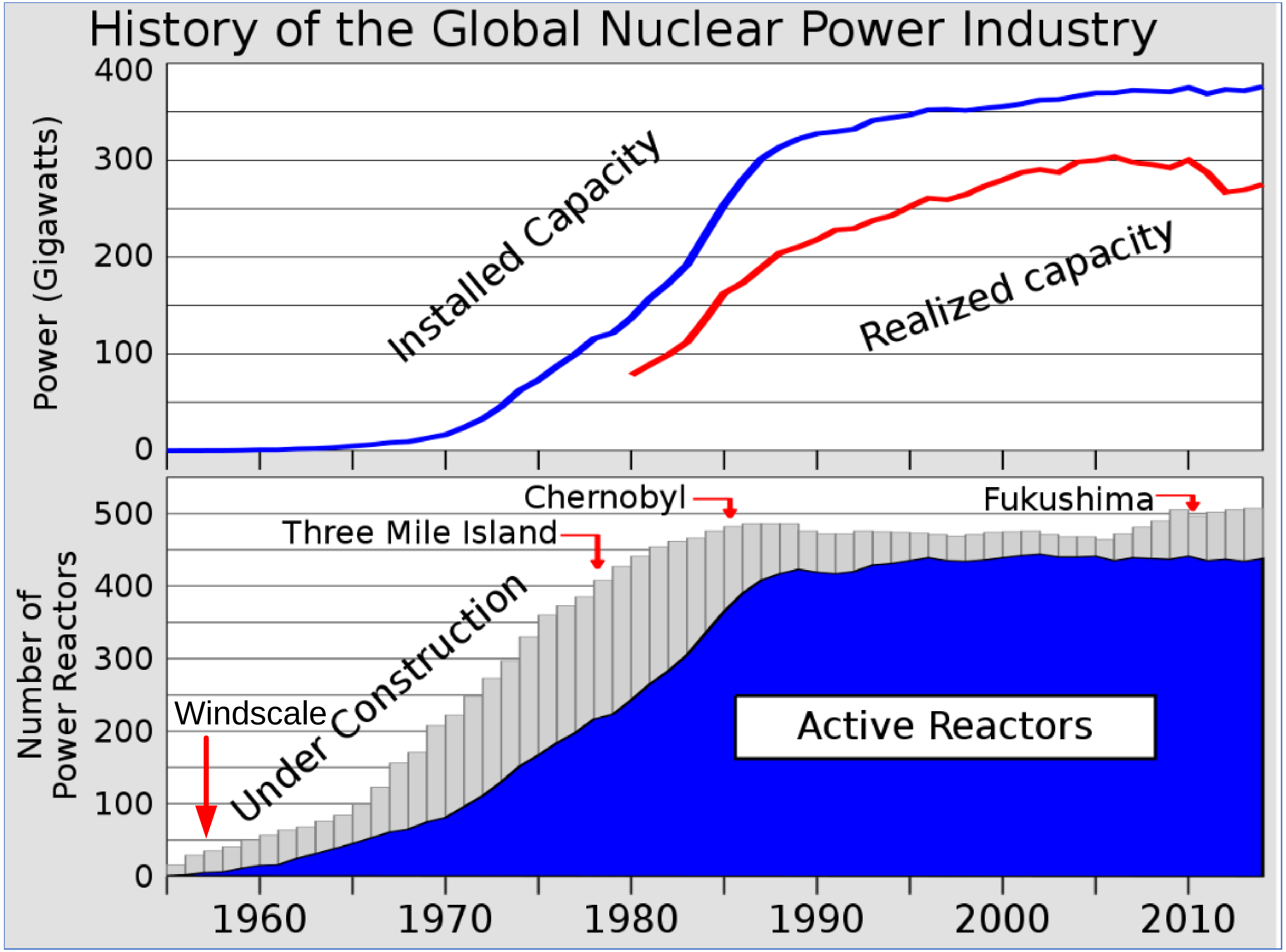
- Internationally,
  - China and India are the main proponents,
  - New Nuclear Power Plants have been built, are under construction, or planned,
  - Research on Nuclear Energy Systems,
    - India is interested in developing Thorium fuelled systems,
    - China is pushing ahead with NPP (Gen III+) designs that have a wide range application, are large, > 1100 Mwe, and Gen IV reactors,
- The West,
  - A Few Replacements (e.g. The UK is installing new commercial reactors), &
- Australia,
  - We will be lucky to continue to be a yellow-cake exporter.

The Nuclear Power Industry, Past, Present & Future

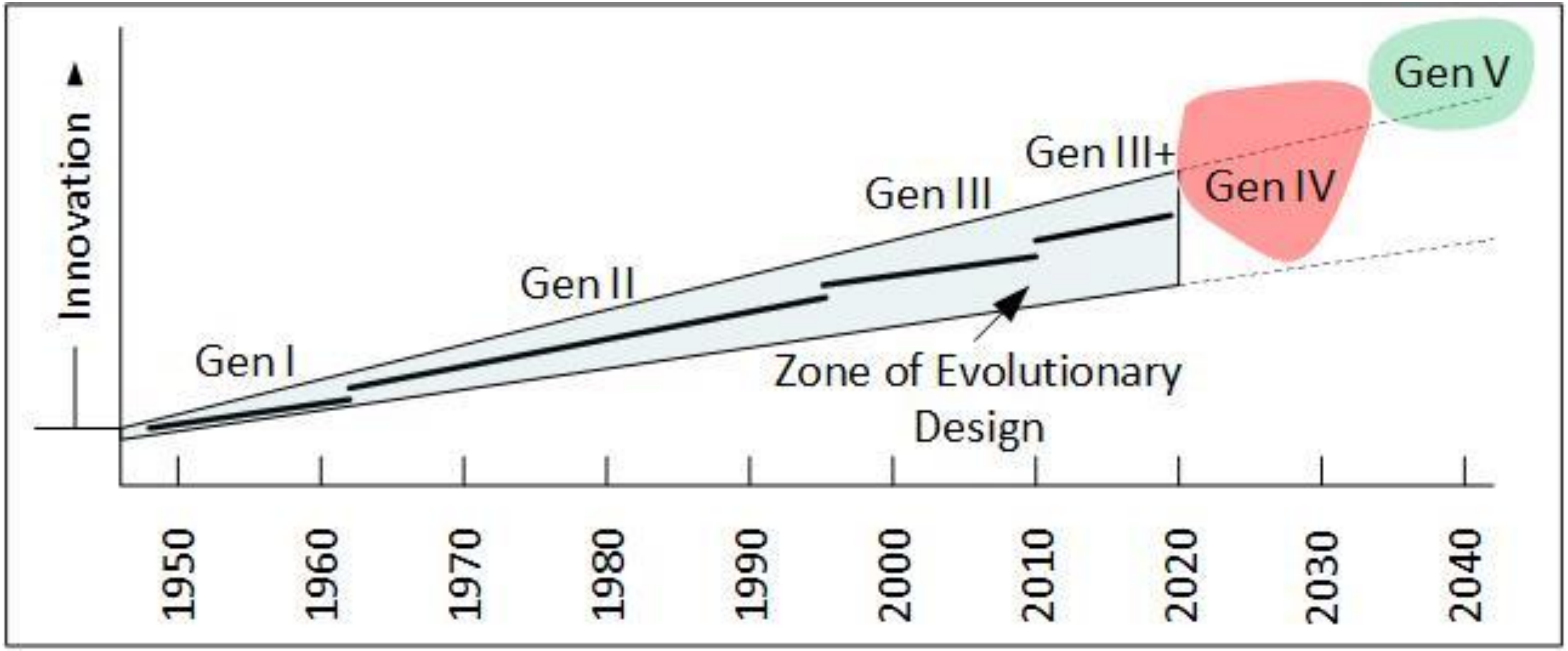
- Start, early 1940's as an offshoot of weapons research and production,
- First commercial nuclear reactor, Calder Hall, UK, 1956, 50 MWe,
- Second plant, 1957 , Shippington USA, 60 MWe,
- The Units were examples of Generation I NPPs,
- Bataan, a pressurized water reactor, 620 MWe, is a Generation II plant, and
- Generation III and III+ are essentially Generation II evolutionary design improvements, including with higher conversion efficiencies, improved safety systems, better fuel handling and modularized construction; the extension of plant working lives of ≥ 60 years. Source: Goldberg & Rosner, Nuclear Reactors, Generation to Generation, 2011

The number and aggregated capacity of civilian fission electric nuclear reactors operating and under construction over the period 1960 – 2015. Source Wiki

Nuclear generation produces around 11% of the World's electricity



Getting out of the Evolutionary Rut, When (or If?)



Acknowledgement to the late Dr Clarence Hardy

Examples of Gen III+, Gen IV and Gen v

Gen III+

- European Pressurised Reactor,
- Advanced CANDU Reactor – ACR 1000 (heavy water),
- AP 1000 (based on the AP 600, e.g. the Bataan Reactor),

Gen IV

- Very High Temperature Reactor (VHTR),
- Pebble bed modular nuclear reactor (PBMR),
- Gas Cooled Fast Reactors (GCFR)

Gen V

- Accelerator Driven Reactor (ADR), SUB-CRITICAL, non-fission collision, and
- Sequential fuel systems, e.g. PBMR – HTGR – APWR – AHWR (CANDU).

Sequential fuel systems, e.g. PBMR – HTGR – APWR – AHWR (CANDU) future BIG Nuclear Engineering Projects

- PBMR Fuel >9% Enrichment with U-235 (expensive),
- HTGR Fuel say 5 – 7% enriched, and is composed of PBMR spent fuel,
- APWR Fuel say 3·5% enriched, and is composed of HTGR spent fuel,
- AHWR Fuel say 1·5% enriched, and is composed of APWR spent fuel, &
- AHWR burns its fuel down to 0·35% enrichment (half the U-235 of natural Uranium) and a relatively benign final waste is produced.
- Here with have a nuclear complex of FOUR different types of reactor and FOUR fuel processing units; total power to grid >8000 MWe, and
- This is TOO big for Australia, but how about India, China, Brazil & Japan.

Accelerator Driven Subcritical Reactor (ADR), sub-critical, non-fission collision energy

- First build a nuclear accelerator like the CERN unit in Switzerland,
- Use Uranium-238 (non-fissile) and/or Thorium-232 as a target,
- Use high energy protons to bust-up the U/Th and release energy,
- Collect the energy given off and make electricity – easy done.

Advantages:

  - Turn the accelerator on and off as required (little decay heat),
  - Use relatively common (and cheap) target fuels, and
  - Produce relatively low-level nuclear wastes,

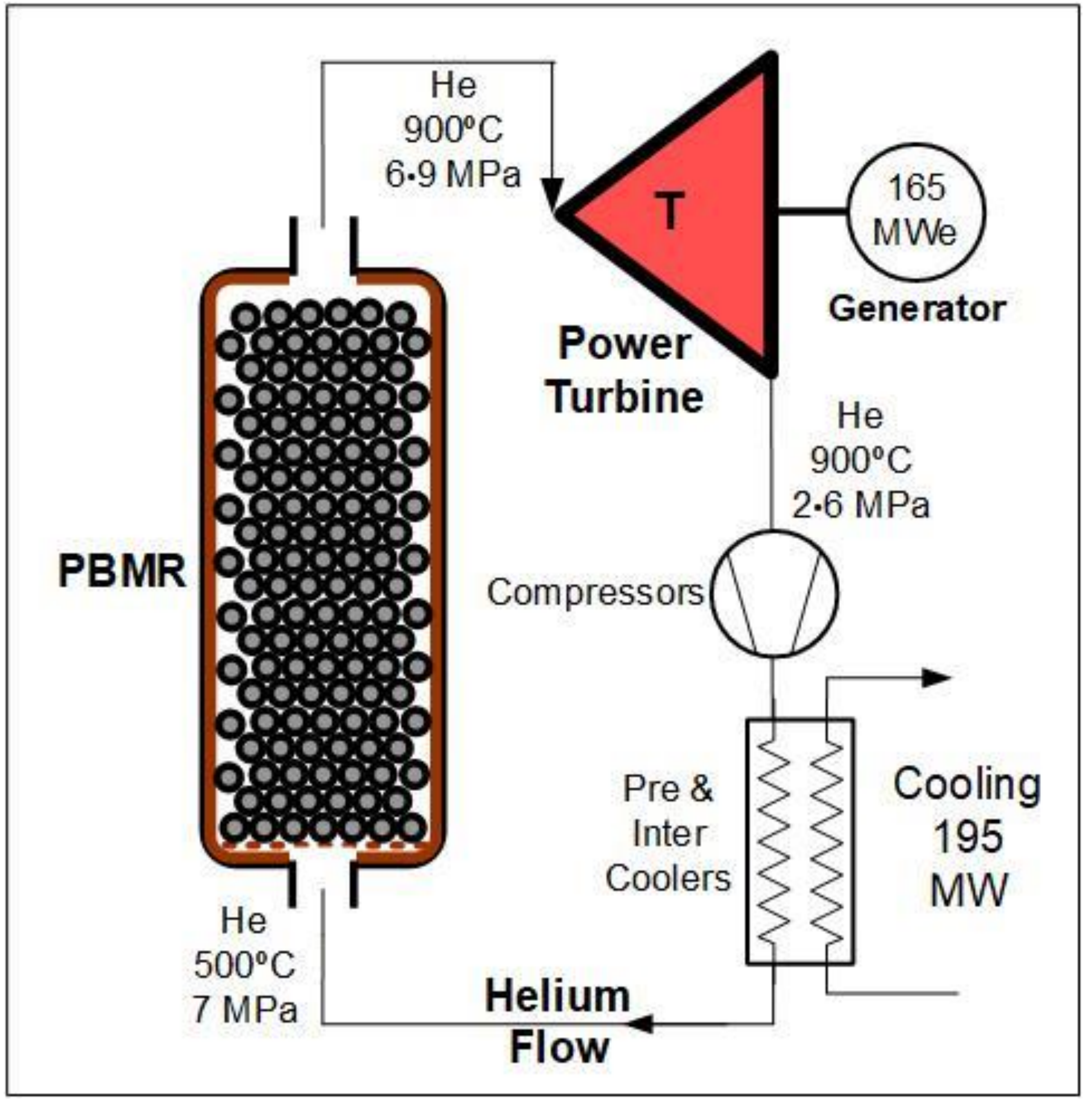
- Principal Disadvantage:
  - Finance, build and run a bloody big and energy hungry accelerator!

Pebble Bed Modular Reactor (PBMR) essentials

This information in this diagram is extracted from ESKOM (Electricity Commission of South Africa) documents.

The ESKOM HTGR programme has unfortunately been shutdown for budgetary reasons.

As well as being an example of Gen IV technology, it is also an example of smaller scale, relocatable nuclear technology that is slowly being introduced.



Combined Cycle PBMR NPP

The Primary Cycle is a PBMR (a Very High Temperature Gas Reactor) using HELIUM as the heat exchange medium.

The Secondary Cycle is a Carbon Dioxide (CO_2) cycle that takes from the heat exchangers and uses that heat to produce significant secondary power generation.

Major internal users of power will be the compressors of the Primary Cycle and the Pump(s) of the Secondary Cycle.

All heat flow, temperature and energy output figures are only rough calculations and need to be confirmed by detailed cycle modelling.

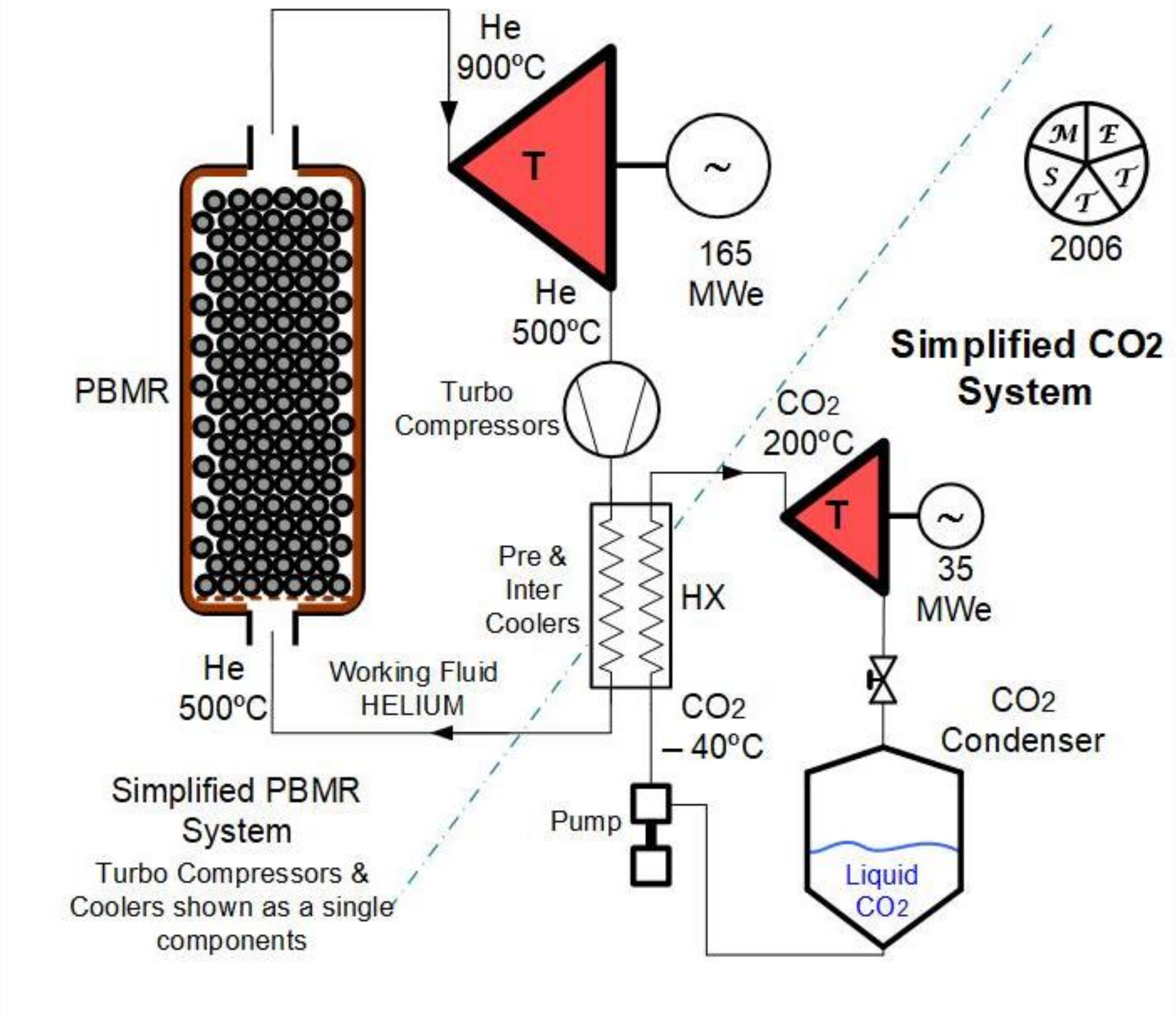


Figure. Waste Heat Recovery from a Pebble Bed Modular (Nuclear) Reactor using a CO_2 bottoming cycle

Graham's Pet – Thorium as a Precursor for a Nuclear Fuel

- Thorium is a radioactive natural element,
- It is 2 to 3 more plentiful than uranium, and in found in the common beach sand mineral, Monazite (3 – 11% Th), in a phosphate matrix $(Ce,La,Th)PO_4$,
- Thorium-232 (Atomic Weight 232) can be converted to Uranium-233, a fissile material; like the bomb making isotopes U-235 & Pu-239,
- The nuclear conversion equation is:

$$ {}_{90}Th^{232} + {}_{0}n' \rightarrow {}_{90}Th^{233} -\beta\rightarrow {}_{91}Pa^{233} -\beta\rightarrow {}_{92}U^{233} $$

- U-233 is FISSILE; you can use it in nuclear reactors, and make BOMBS like the Hiroshima (Uranium - 235) and Nagasaki (Plutonium - 239) devices.

Conclusion: A Nuclear Future for Australia?

- Medium load plants, PWRs of 600 MWe in twos or possibly threes to replace coal-fired power stations,
- Smaller reactors of say 100 – 200 MWe to power specific industrial applications such as remote water desalination plants and aluminium smelters,
- Small reactors in a pod to provide stable base-load power in remote areas, and to complement renewable power generation, and
- Very small reactors, 3 – 15 MWe to run remote small to medium size production facilities such as mining, mineral processing and agricultural pumping; the reactors may be surplus submarine power units.

Thanks & Questions

michael.clarke@metts.com.au

Annexure: Thorium

- Thorium can be a source of nuclear fuel, that fuel being U-233,
- U-233 can be used in Mixed Oxide fuels, as a replacement for U-235,
- Its use and development expands the possibilities and democratisation of nuclear energy,
- U-233 production does however need a high level of nuclear sophistication, and thus it use (or abuse) has been limited to states with superior nuclear capabilities,
- Australia's role in developing the Thorium Cycle will be raw mineral mining and concentration and possible waste management, and
- Australia's principal benefit in Th mining may be Rare Earths co-production.

Uranium – 233

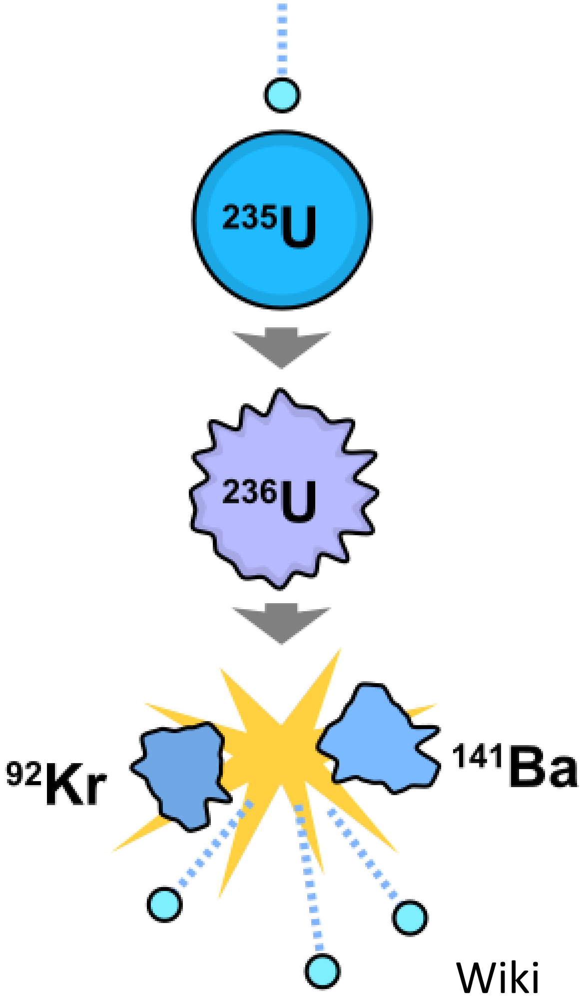
In the production of U-233, U-232 is co-produced

U-232 is not Fissionable, it is very radioactive, is a neutron poison (absorbs neutrons without benefit) and is very difficult to separate from U-233.

The presence of U-232 has slowed the development of Thorium derived nuclear energy and prevented its ready use in nuclear weapons; however it has been reported that the US exploded a U-233/Pt-239 test weapon, and India has tested a 'small device' (possibly a nuclear artillery shell) using U-233 as the fissile material?

It is reported that U-233 can be purified to over 95% (the U-232 having been removed) and is being used with Plutonium as a Mixed Oxide (MOX) Fuel in a 300 MWe Indian research reactor.

Nuclear Fission

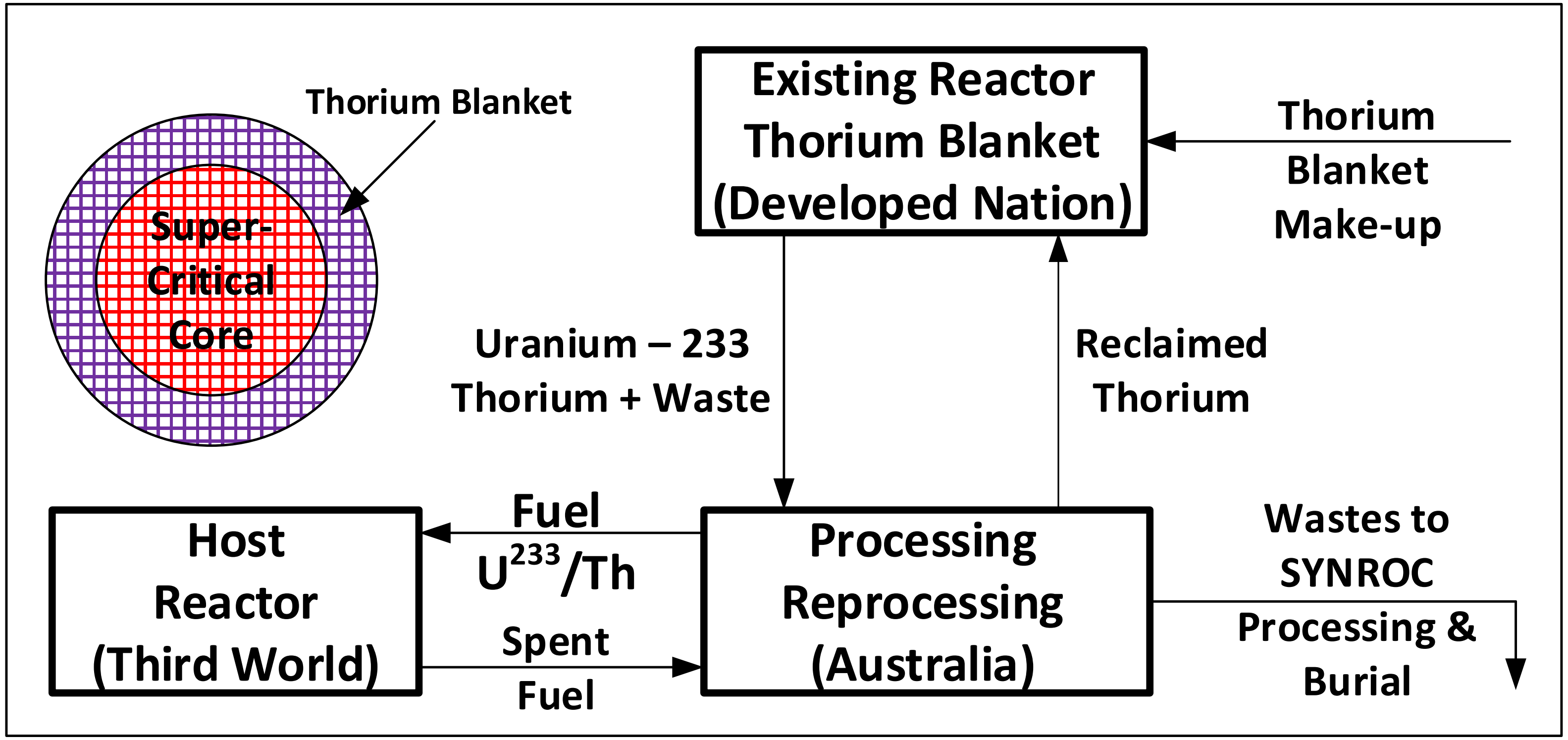


Wiki

The Thorium Cycle: Materials Flow

Safer Energy for the Third World

Published: Chemical Engineering in Australia,
Volume 12, No 3.
September 1987



This paper reiterated the Nuclear Industry's mantra that the U-233 road to nuclear weapons was very challenging because the co-production of U-232, a 'nuclear – neutron – poison' and a source of very high energy gamma radiation. Advances in nuclear chemistry probably have changed this assumption.

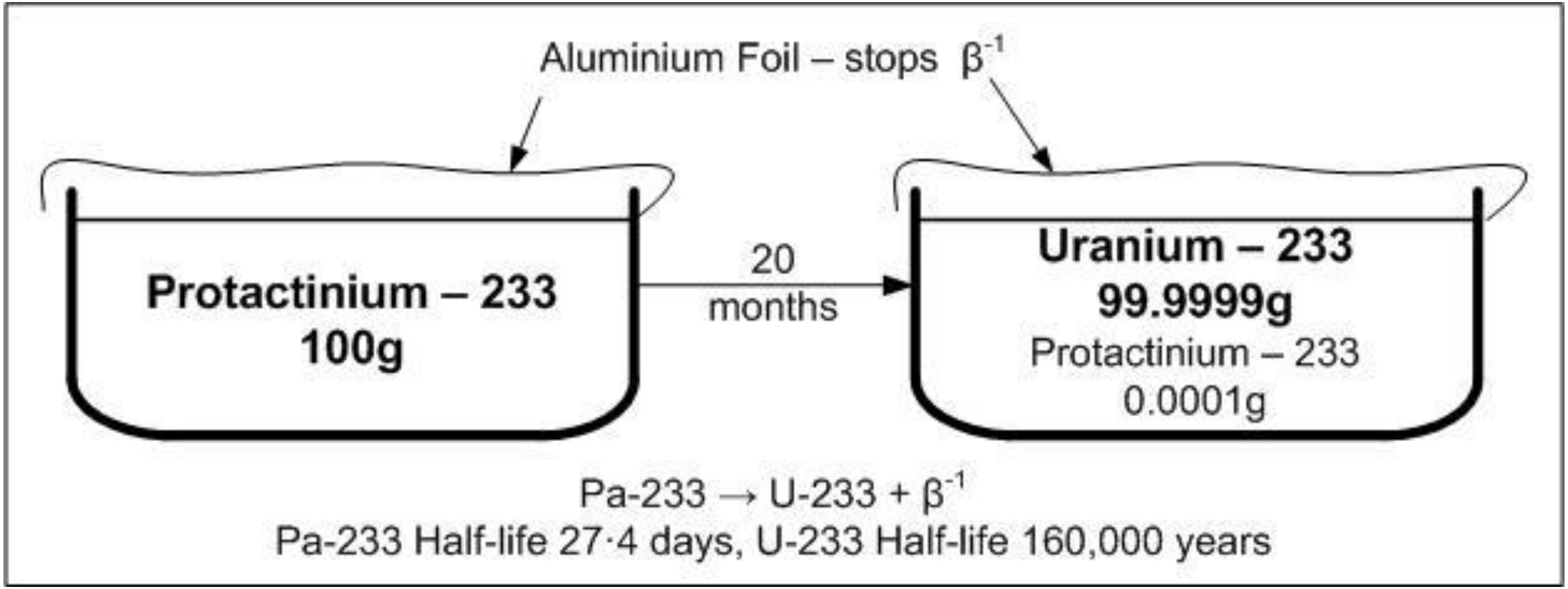
Nitric Acid Technique to Produce 'Pure' U-233

See:- http://universe-review.ca/F14-nucleus05.htm

- Expose Th-232 to short periods of radiation (1 month),
- Remove canisters from the reactor and dissolve the contained zirconium capsules containing Th, U-233 and small amounts of U-232 in nitric acid (note: all this Uranium will go to waste), filter,
- Co-precipitate the Protactinium (Pa), the U-233 precursor, from the filtrate with potassium permanganate (as MnO_2), and again filter,
- Post the third stage filtration, separate the Pa – Mn residue and react it with Iodic Acid to remove the manganese and oxidise the Protactinium (Pa), to PaO_2, producing a PaO_2 residue, and
- Allow the Pa-233 to decay to U-233 over say 18 to 24 months, to produce fertile and fissile U-233 (>99.999 pure).

Quote: An 'under-the-counter' method of producing U-233?

Protactinium to Fissile Uranium



β^{-1} (beta particles) are high energy electrons; they are stopped by a metre of air or aluminium foil

Is this or similar methods being used to produce fissile U-233?

If this is so who is doing it?

Is this U-233 being used responsibly in nuclear power production as a supplement to or replacement of U-235 or Pu-239?