Nuclear Power Plants in Australia

Presentation by Detlef Sulzer to the Mining Monday Group on Monday 29th April 2024

Nuclear Power in a Box

- This was the title of my last presentation to you almost a year ago, when I tried to give you some information on the following:
- 1.) The history of Nuclear Power Plants
- 2) The process of the Nuclear Chain Reaction
- 3 The operation of a Nuclear Power Plant
- 4) The description of different Nuclear Reactors
- 6) The introduction to the Mini Modular Reactor.
- 7) A costs comparison between Nuclear - Alternatives.
- 8) Germany’s disaster in switching off their Nuclear Power Plants, having now the most expensive electricity in Europe.

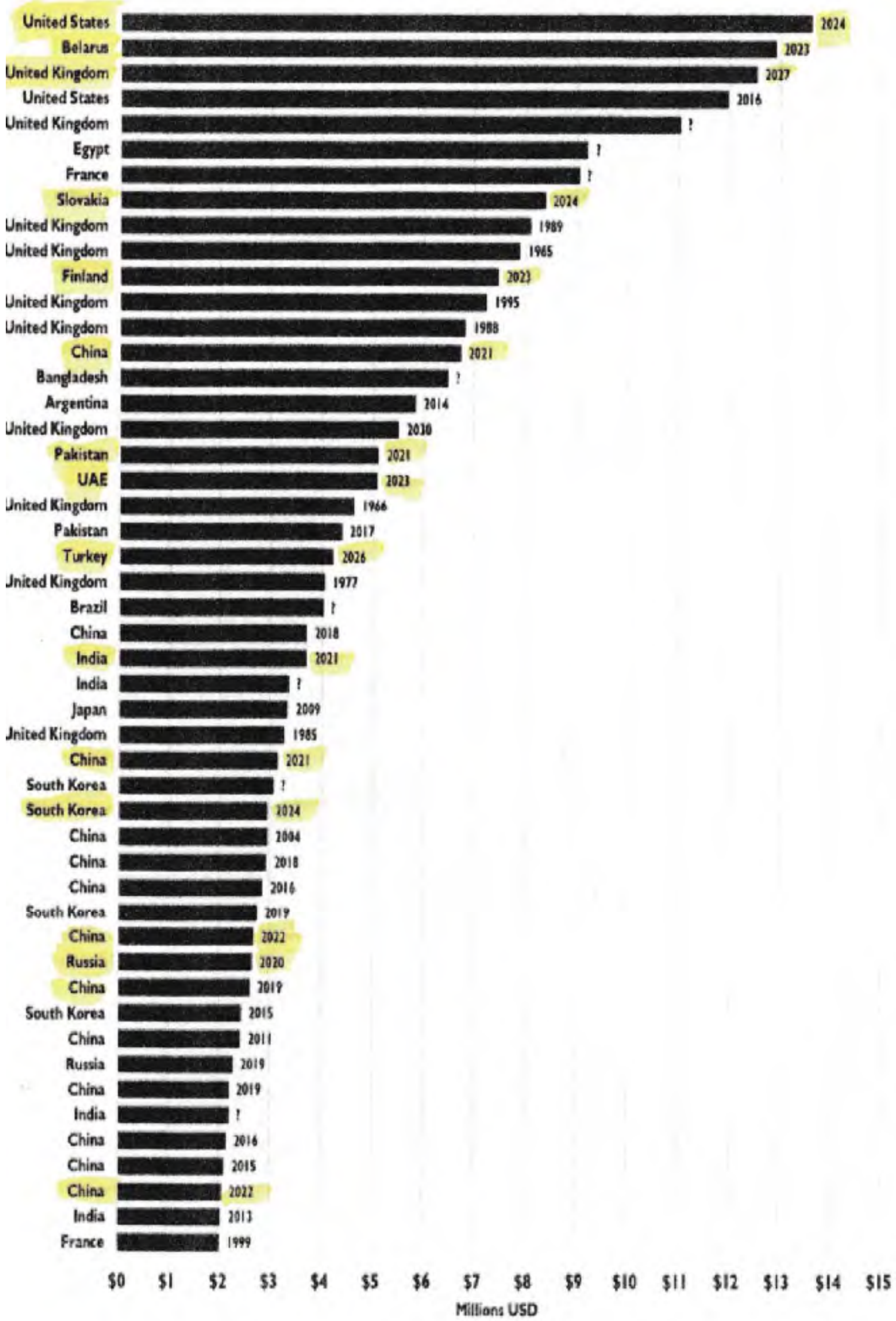
Australia’s Changing attitude to Nuclear Energy

- A year ago, about 18% of Australians were willing to consider having a Nuclear Power Plant in Australia.
- To-day this has grown to about 42% of the population.
- The Opposition considers Nuclear as being part of the transition to ZERO Emission by 2050.
- The Australian Minister for Energy, The Hon. Chris Bowen rejects Nuclear Energy, He declared it to being too expensive and taking too long to construct.
- His Point: Nuclear Plants will not be available in Australia by 2050 and CSIRO and The Institute of Engineers Australia are supporting his view.
- AEMO (Australian Energy Market Operator warns, replacing Coal with only Wind, Solar, Batteries and Pumped Hydro will give us Black-Outs by 2028.
- Major Coal Plants reach the end of their life span and are need major overhauls and repairs, which makes them too expensive to run. They need to be closed down.

Costs of large Nuclear Power Plants in the World, completed since 1970.

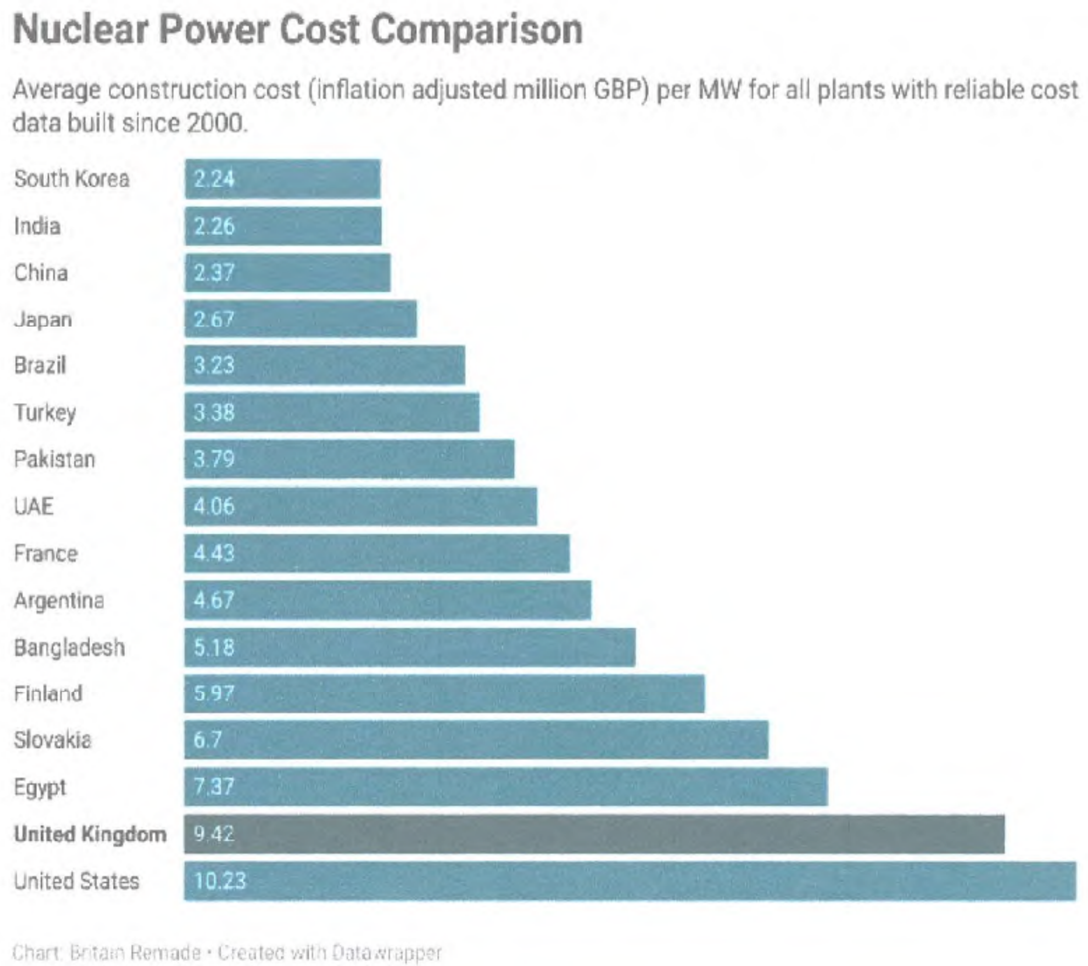
- Is it true, that Nuclear is too expensive for Australia? Do they need 25 years to built?
- On the next slide, each bar gives the costs of a completed power plant in the year of its completion.
- Plants completed between 2020 to 2024 are marked yellow, there are13.
- The large Cost variations are primarily caused by people’s attitude towards Nuclear Power in different countries and the research costs that are distributed on the number of plants being built in a particular country.
- Available Skills, Inflation, environmental requirements, vary greatly between countries, but play a major factor in the construction costs.
- South Korea, India, China and Japan are among the lowest costs countries at about GBP 2.2 Million/MW. The UK and USA were once low but are the most expensive with GBP 10.2 Million per MW now – **5 times higher - due to their Nuclear development cost, and not building Nuclear plants for 40 years.**
- The time to construct a Nuclear Power Plant has an equal large range of duration, from 5 to 25 years, dependent on the people's resistance to Nuclear Power Plant.

Capital Cost per MW Installed Nuclear Capacity per Plant
Constant 2023 USD, Source: Britain Remade

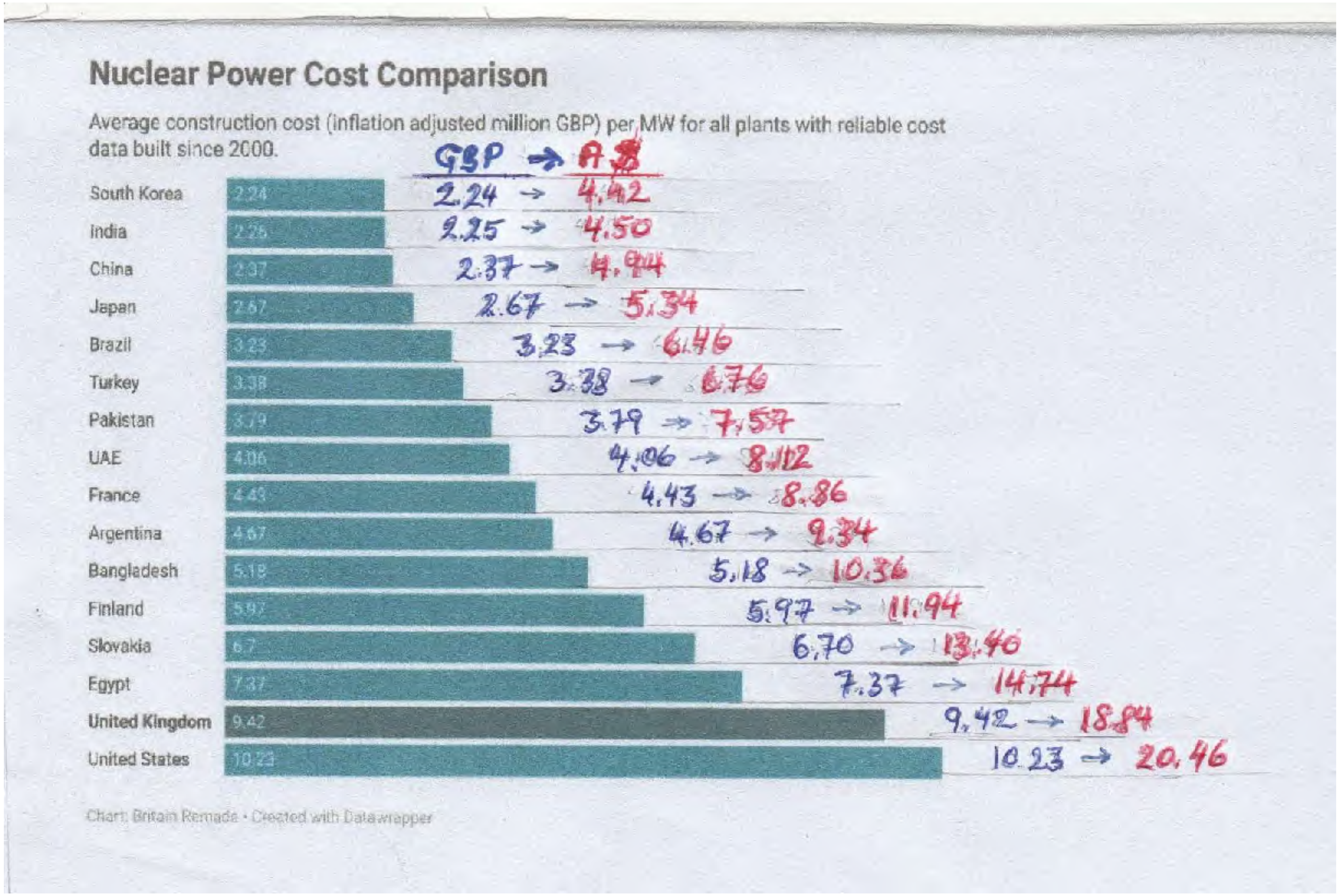


Nuclear Power Costs GBP/ MW by Country

For post 2000 completion. Cheapest South Korea @ GBP 2.24, most expensive USA @ GBP 10.23.



Nuclear Power Plants Costs/MW comparison by Counrty for Plants completed since 2000



Small Modular Reactors (SMR)

- Only Russia and China are constructing presently SMR's on land **for domestic** usage. **None have been built in USA or Europe on land, only on ships for their Navy's.**
- SMRs are in usage for the last 60 years by the US, UK, France and Russian Navy, but their design and performance **are secret.**
- South Korea, Japan, China, India, Russia, France, UK, Canada and USA are all developing now SMR's, for the coming eport market, to replace Coal fired Power Plants worldwide, with SMRs.
- Major Players developing land SMRs are Rolls-Royce (UK), China National Nuclear Corporation (China), NuScale Power (US). Holtech International (US), Westinghouse Electric Company (US), National Commision of Atomic Energy Argentina, Terrestrial Energy (Canada), Moltex Energy (Canada), GE Hitashi Nuclear Energy (US).

A World Nuclear Standard for SMRs; Australia's needs for its US Submarines

- The International Atomic Energy Authority located in Vienna, looks after the safety performance of Nuclear Power Plants worldwide.
- In addition, countries having their own Nuclear Safety Authority
- A Worlds Standard is needed for the produktion of Small Modular Reactors, similer to the International Standarts that are used in the Air Aviation Industry.
- The International Aviation Standarts are enfored , by not allowing planes to land at international Airports, when they are not constructed to these Standarts.
- Such an international Nuclear Standart is being developed presently for SMRs, to be used by countries that have no Nuclear Industry with Standarts of their own..
- Australia is in the delema of having laws prohibiting the development of a Nuclear Industry, but has purchased the most sophisticated US Submaribes power by latest SMR Technology. To operate, service and refuel these SMR‘s Australia needs a Nuclear Industry, because we cannot be dependant on another country to provid these services at time of war,.
- Australia needs to deelop a Nuclear Industry, not for the SMR, but for the Submarines.

Reasons for Developing SMRs

- SMRs produce electricity less efficiently than Larger Nuclear Power Plants. This may change in the future with high temperature SMRs.
- Nations which have developed a Nuclear Industry in building large Nuclear Power Plants, are now developing SMRs to export them to countries which have no Nuclear Industry themselves
- The advantage of the SMR is, that it is completely manufactured in a factory and when finished is transported as a single Unit to the Power Plant.
- While the Power Plant is constructed on site, the SMR is produced in the factory, reducing the Nuclear Power Plant construction time to about five years.
- The SMRs is extremely flexible and can be designed to produce steam for Electricity Production, or for towns heating demand, or at higher temperature for industrial processes, like the production of Hydrogen in the future.
- There will be a great demaned for SMRs, as long as the people believe in the elimination of CO_2 emissions by 2050
- China is now the world‘s greatest CO_2 emitter with about 35%, and has a population of 1,400 Million, 52 times larger than the 27 Million in Australia producing only 1.4% of the world‘s CO_2 Emission. However we are made to believe that we are the greatest CO_2 emitter in the world, by using the CO_2 emission per capita. It should not force us to reduce 70% CO_2 emission by 2030.

The present Development Status of SMRs

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- There are at present more than 80 SMR design and concepts on the market globally. They vary in size, type of Reactor, and using the different types of radioactive fuels and various types of coolant varying from gas to liquid metals.
- The experience of having over 500 Nuclear Power Plants operating for the last 40 years worldwide, has brought about reactors being cooled and moderated with gas and graphite, light and heavy water, and using Liquid metal such as Sodium and Potassium or a combinations of Lead and Bismuth.
- High performance reactors subject materials inside the reactor to extreme harsh conditions of intense Neutron bombardment, high Temperatures, quick neutron flux, irradiation exposure and corrosiveness, which requires long term experiments to evaluate the capacity and suitability of materials to withstand these conditions. For Fast Neutron SMRs liquid lead is favored for its low inclination to absorb or delay neutrons.
- Likewise, there are impressive developments in combining various radioactive elements as fuel source, which remind me of the development of the car engines during the time of my life.
- Most of the SMRs are in various stages of development. Only four SMRs are in the advanced stage of construction on land, They are in Argentina, China and Russia.

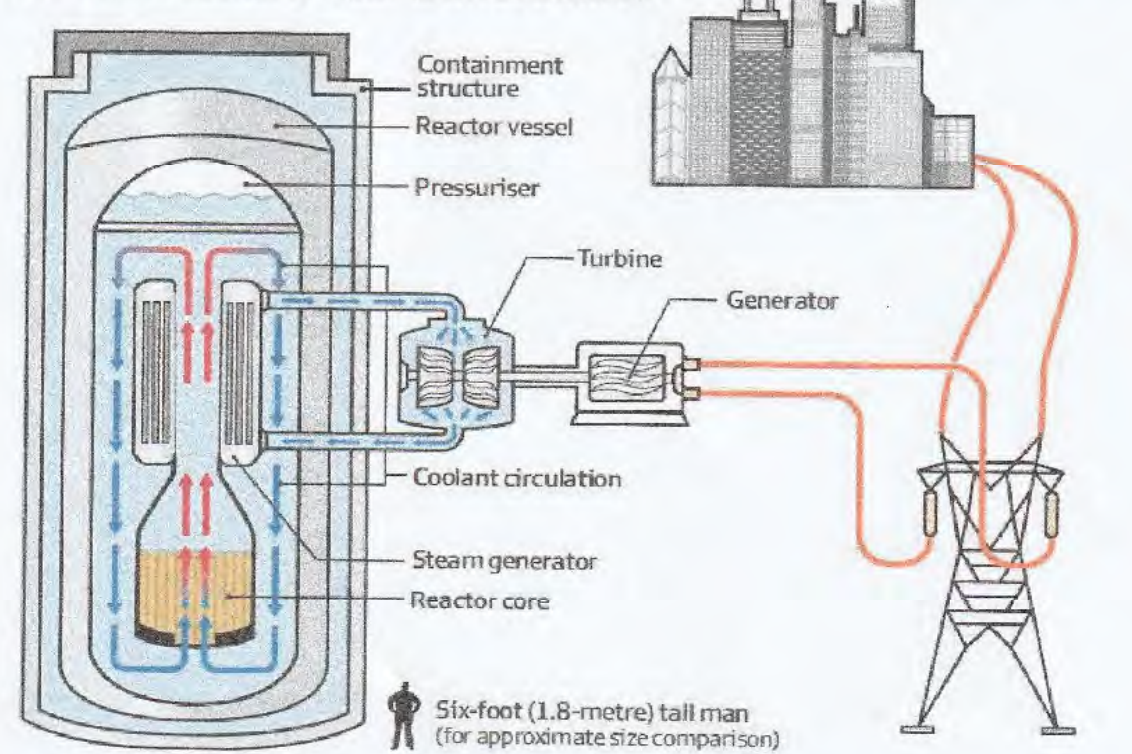
The China APC100 SMR – 126 MW elec. + 385MW therm. Heat - Under Construction.

SMR Development by Rolls Royce,

470 MW costing A$3.4 Bn,($7,23mill/MW) available in 2029

Powering up

Could small nuclear reactors work in Australia?

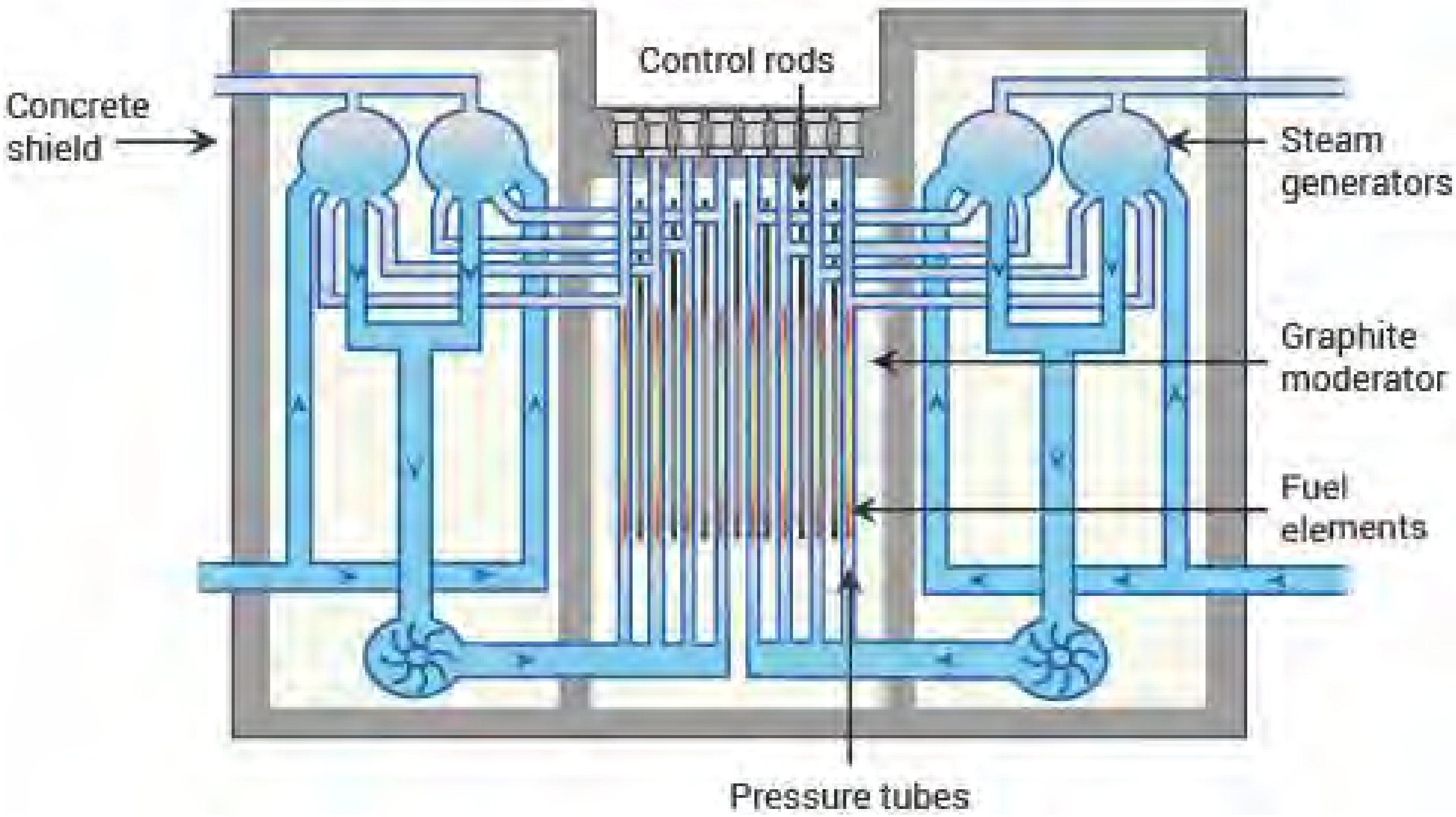


- Rolls-Royce expects regulatory approval in the UK by mid-2024 for a small modular nuclear reactor (SMR), which could come online by 2029.
- Each 470-megawatt unit costs about £1.8b ($A3.4b). It would be built on a four-hectare site, the size of around 10 soccer fields.
- SMRs are cheaper and quicker to build and can also be deployed on ships and aircraft. They would be shipped to site for installation.

SOURCE: US ENERGY DEPARTMENT, ROLLS-ROYCE

Russian SMR Development ready for the International Market

A Light Water Graphite-moderated Reactor (LWGR/RBMK)



Russian Safety Records in using SMRs for Ice-breakers and atomic Submarines

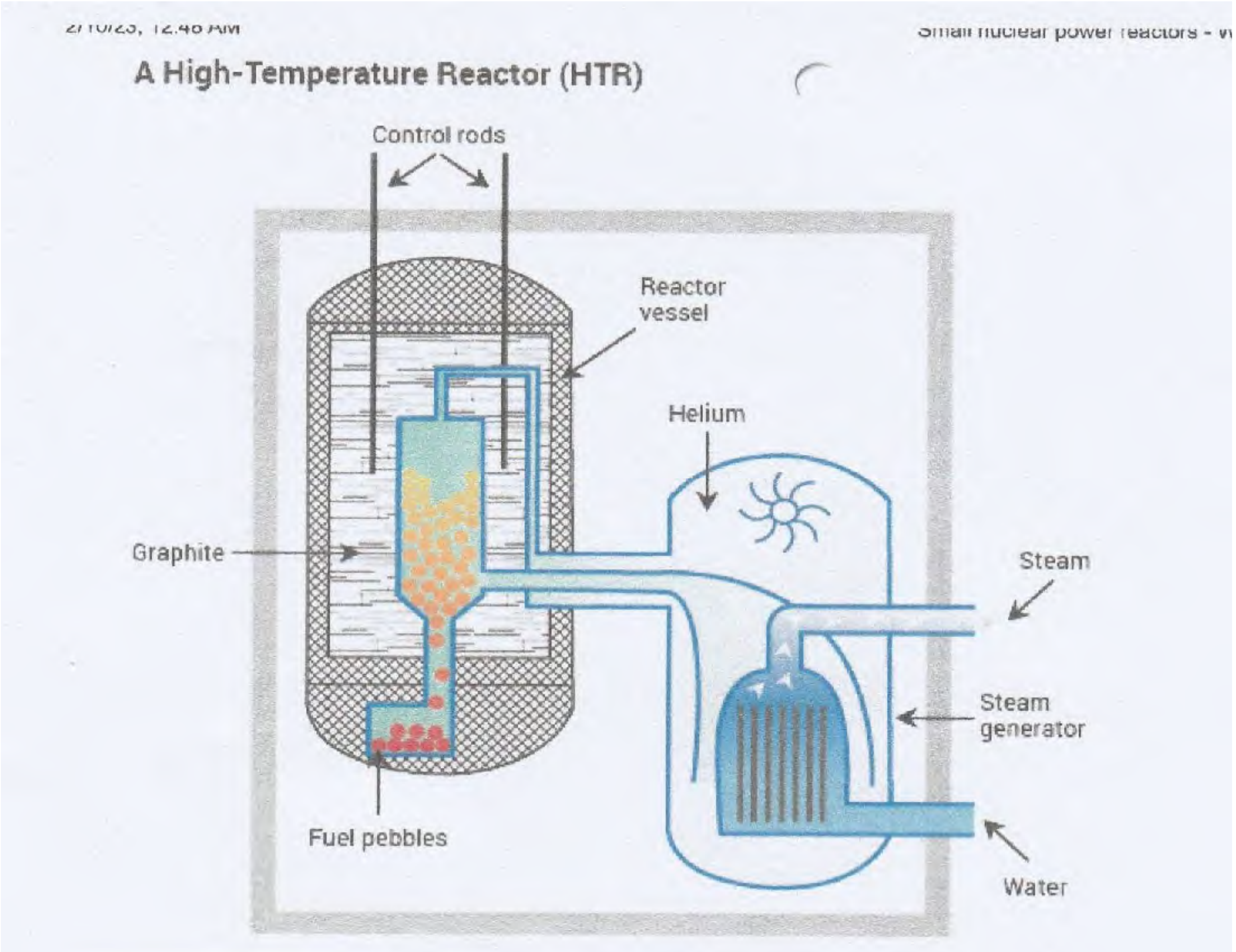
SHIPS DESIGNING AND CONSTRUCTION TECHNOLODIES AS A PROJECT BASIS

- Russian safety experience of ship reactors operation exceeds 7000 reactor-years

- Accident-free operation of 15 reactor units for the ice-breakers and the lighter with total operating time of 260 reactor-years

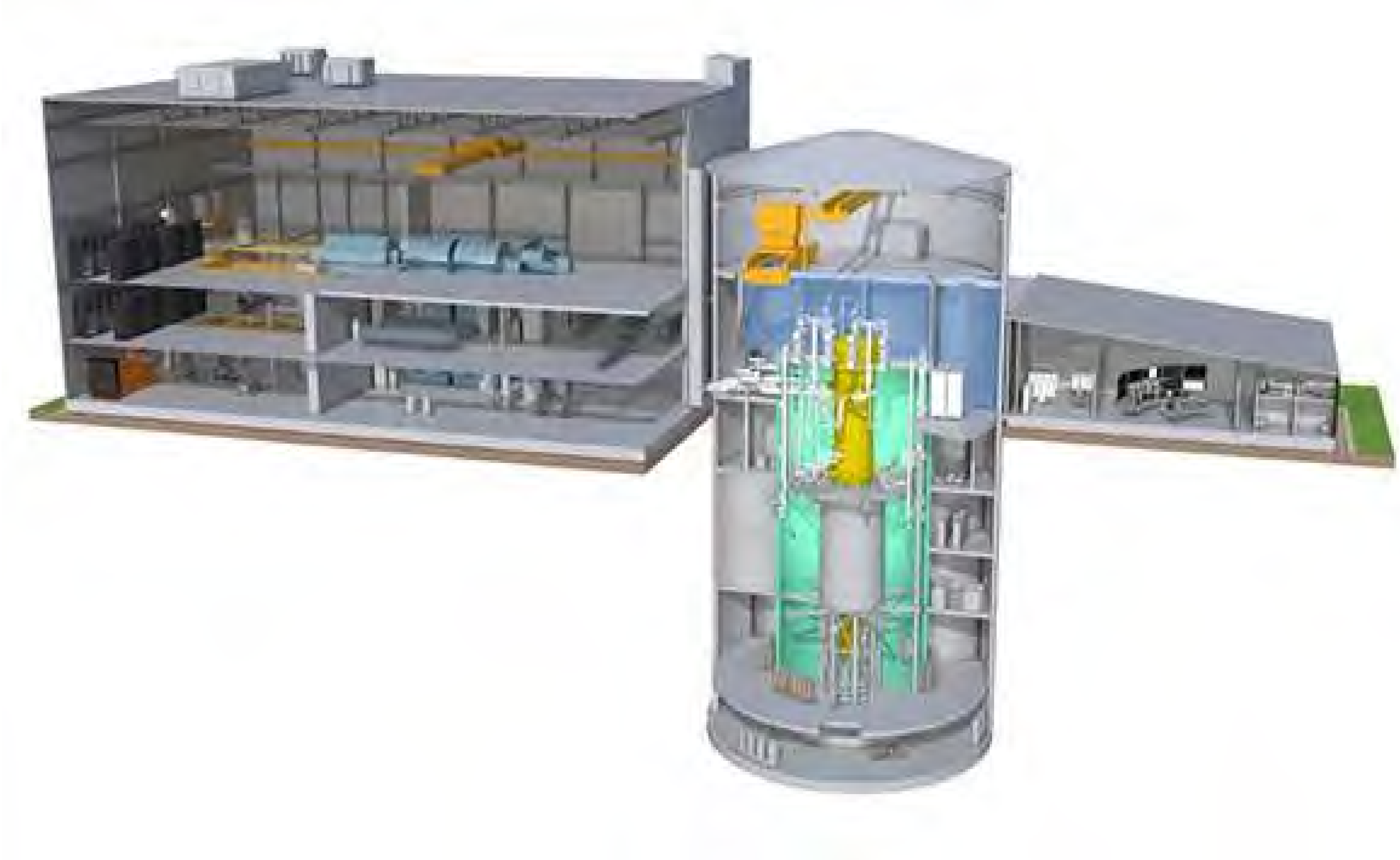
- Totally it is constructed about 460 reactor units for atomic submarine which have proved high reliability

High Temperature Reactor using Thorium Pebbles can be used for SMR. In Germany material failure of the thorium encasement.



BWRX-300 the GE Hitachi Nuclear Energy SMR

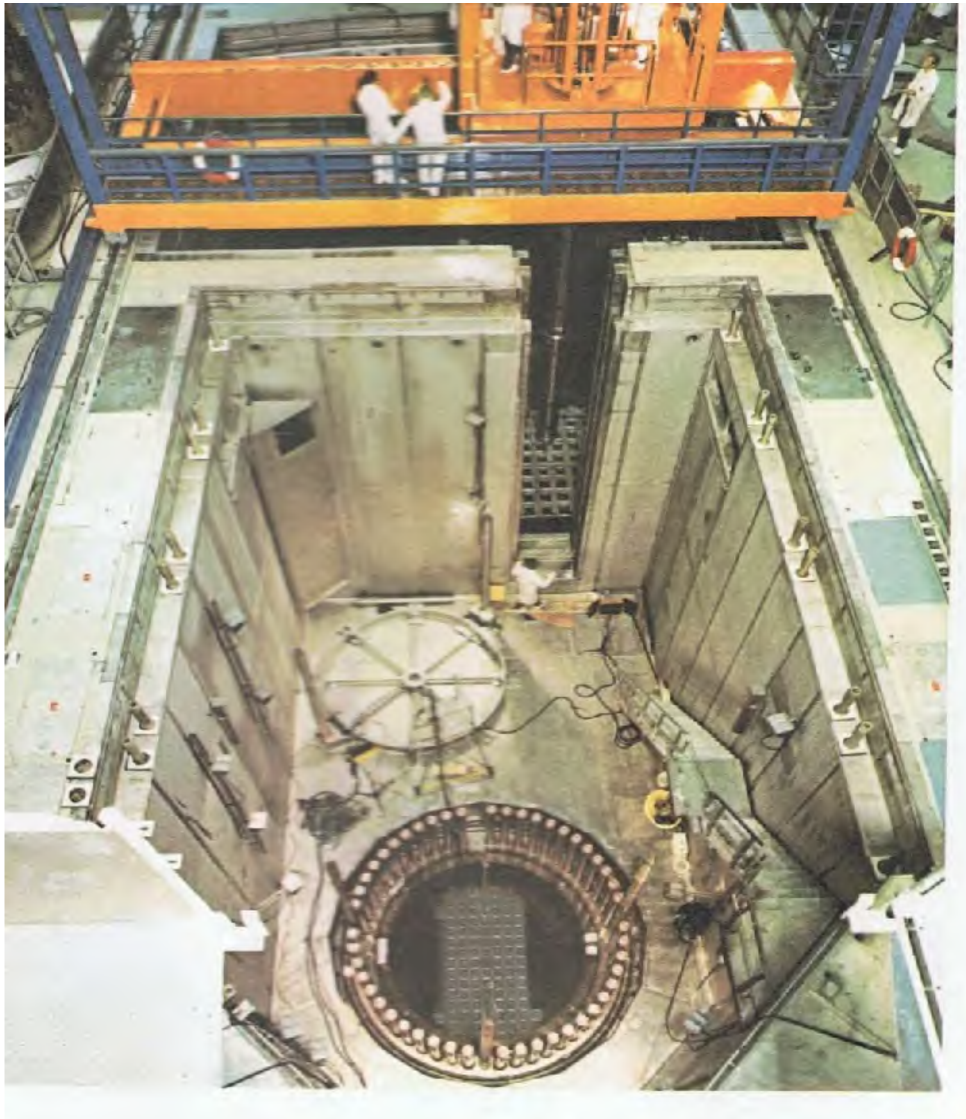
One of the most economic SMR designs available – 60% capital cost reduction



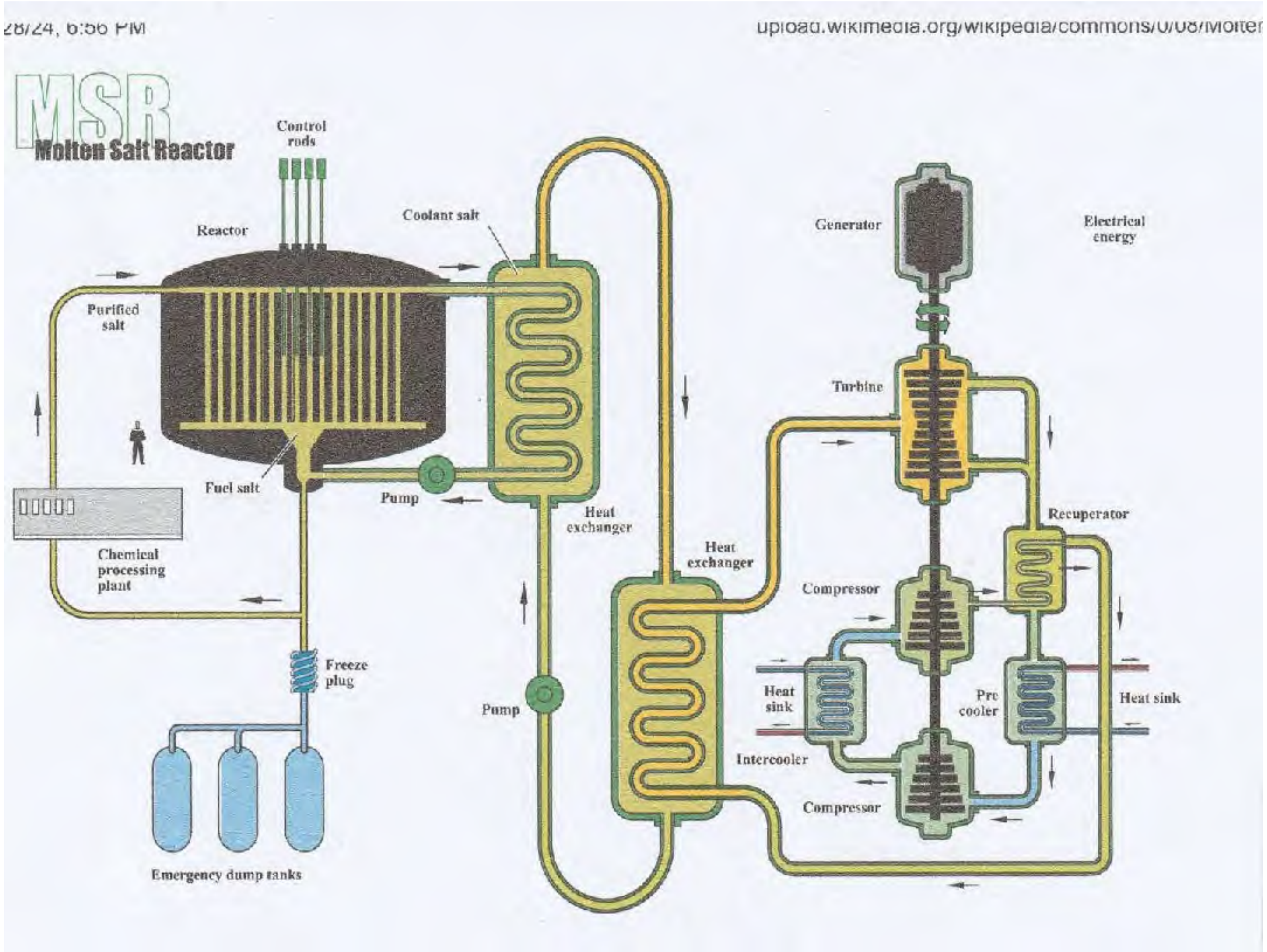
Key Advantages of the BWRX-300

- The Reactor Building is placed below ground level
- Concrete quantity is reduced by 50%
- Construction time only 24 to 36 month
- Product-specs-bwrx-300-vessel-300px.png (GE‘s10th BWR design)
- Reactor type: Boiling water reactor
- Electrical capacity: 300 MW(e) net to the grid
- Primary circulation: Natural circulation
- Fuel enrichment: 3.81% (avg)/4.95% (max)
- Refueling cycle: 12-24 months
- Approach to safety systems: Fully passive
- Design life: 60 years
- For emergency supply of additional cooling water to remove residual reactor heat for seven days.
- Can be installed at a Coal fired Power Plants using local water supply and Grid connections.

The fuel rod storage pool 12x12x12 m, provided already in1970 additional cooling water above the Reactor. When all systems fail, and pressure within the Secondary Containment rises to danger level, the membrane between pool and containment is pierce by the pressure and the pool-water flows into the Secondary Containment, cooling the Reactor, preventing its melt-down like in Fukushima.



Molten Salt high Temperature Reactor with two Heat Echangers

- 

Advantages and Disadvantages of Molten Salt Reactors (MSR)

- MSR use a fluid fuel in the form of a very hot Fluoride or Chloride salt mixed with Thorium or Uranium or other radioactive fuels.
- **Advantage:**
- The liquid is Fuel and Coolant the same time.
- To re-fuel more liquid is add, while the reactor stays in operation.
- The continuous removal of fission products and other undesirable byproducts, like Protactinium (Pa) during Reactor operation
- MRS operate at high temperature like Fast Breeders, with radioactive fuel concentration of 20% to 25%
- **Disadvantage:**
- Half the periodic table of elements dissolve in the salt used.
- The removed Protactinium Pa-233, decays to U-233 which is weapon grade Uranium, from which Atomic booms can be made, almost undetectable for the IAEA.
- All maintenance is done by remote control, due to the high radioactivity everywhere, which is difficult and expensive.

The Development of Future SMRs

- Not only have there been great developments in the all-important cooling cycle of Reactors, making it impossible for reactors to overheat and explode, using Lead for SMRs, but there have been fascinating developments in the composition of the radioactive fuel used in Reactors.
- Fast-neutron reactors (FNR) are to become the fourth largest segment of SMRs. These Reactors are smaller and simpler than LWR, HWR or BWR, as they do not need moderators to slow down the neutrons to split other atoms. The immense quantity of Neutrons keep the chain reaction going
- Fast Neutron Reactors (FNR) have longer-fueling intervals and have better fuel performance. The core can burn used LWR fuels, or Plutonium and Thorium fuels that are enriched to about 15%-20% This technology is an advancement of the Fast-Breeder Reactor Technology, which can transform U-238 to Pu-239 to U-233, and abundant Thorium-232 to U-233

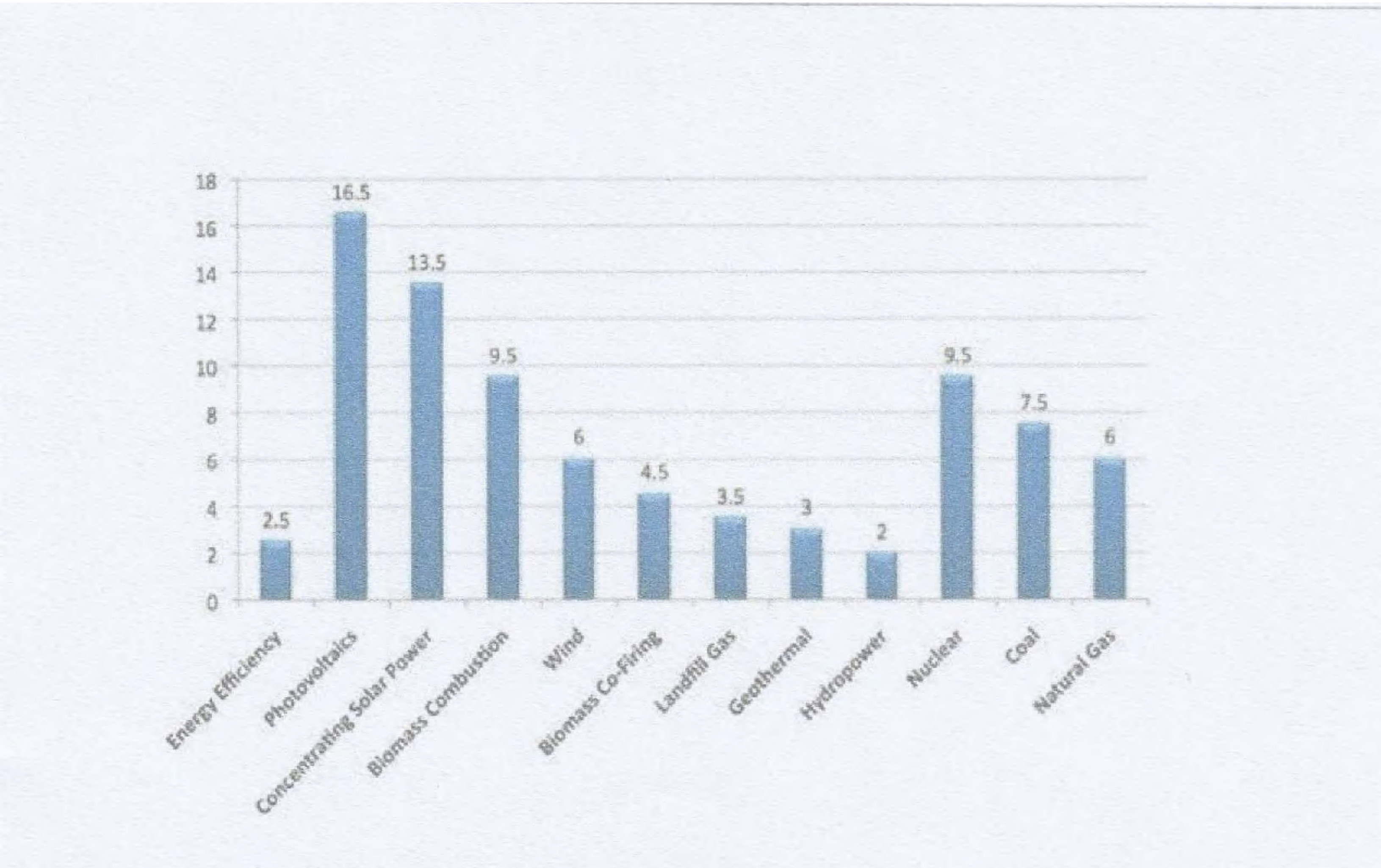
Potential Fuels used in Modern SMR

- The fast reactor has no moderator and relies on fast neutrons alone to cause fission, which for uranium is less efficient than using slow neutrons.
- Hence a fast reactor usually uses plutonium as its basic fuel, since it fissions sufficiently with fast neutrons to keep thchain reaction going.
- At the same time the number of neutrons produced per plutonium-239 fission is 25% more than from uranium, and this means that there are enough neutrons (after losses) not only to maintain the chain reaction but also continually to convert U-238 into more Pu-239.
- Furthermore, the fast neutrons are more efficient than slow ones in doing this breeding, due to more neutrons being released per fission. These are the main reasons for not using of a moderator to slow neutrons down, as is needed in present Reators.

Fast Nuclear Reactors can produce Hydrogen more cost effectively

- Hydrogen can help to decarbonize electricity generated from gas fired power plants. Also, in transportation it can be used in Hydrogen fuel-cell cars, fuel cells trains, ships and aeroplanes, without the fire risk of Lithium-iron batteries.
- Hydrogen can be produced using a fast-neutron reactor, molton salt reactor and high temperature reactor all capable of producing not only electricity but also high temperature procces steam.
- Hydrogen production using the Thermochemical cycles process or the high-temperature steam electrolysis method, require both heat and electricity.

Capital Costs in GBP/MW for various types of Power Generation providing Electricity in Great Britten



What makes Solar and Wind Power so expensive, to provide Electricity 24/7.

- The Sun shines 12 hours not 24 hours, and the Solar glas pannels last only 20 to 25 years and likely to be replaced by new technology within next 10 years.
- When Clouds cover the sun temporarily, Batteries have to supplement the electricity supply to stabilize the Net.
- For the night electricity, Pumped Hydro Power Plants need to be built, require 15% to 25% more electricity, to pump water up than is obtained from the water flowing down through the turbine.
- When the sun does not shine for several days, no water is pumped up to the Pumprd Hydro. To prevent black-outs, a gas fired power plant has to be built. They can be changed from Gas to Hydrogen at a later stage when aailable.
- The transport of Electricity from Sun-Fields, Wind-Farms to the Hydro Power Plants and the capital cities of Australia costs 10% loss for every 300 km. Of a 1,000MW from sunny Queensland only 500MW will arrive in Melbourne.
- To link the various places of power Generation, it is estimated that the Australian Electricity Network for 25,000MW has to be extended by 10,000 km costing A$ 100 Billion. Which is $100,000Million/25,000MW = A$ 4.0 Million/MW
- Batteries are exspected to last 12 to 13 years in the future, requireing to be replaced 3 times over a 40 year live span

Capital Costs requirments for Alternatives in Australia

- Solar plants have to be built to 2.5 times of the design size to load batteries, pump up water, and compensate for energy losses occurring during electricity transportation.
- Batteries to compensate solar intensity variations
- Construction of a Pumped Hydro Plant (Snowy 2 cost increase from $2 Bn to $15 Bn for 2,000 MV seven days)
- Construction of a Gas fired Power Plant
- Building a new National Grid to connect all power facilities and bring electricity to the users in cities
- And all this should be cheaper than obtaining electricity from a Coal fired Power Plant ? – Only environmental scientist can achief to come to such a conclusion, not Engineers. Government has to pay for it all.

Capital Cost to make Solar available 24/7

- The capital cost to provide 1MW of solar electricity for permanent consumption over a period of 40 years, requires the following cost components:

1) Solar plant costing $1.5 Mill/MW + new solar panels @ $1.0 Mill/MW	= $ 2.5 Mill/MW
2) Additional sole panels to produce electricity for the night-time supply	= $ 2.5 Mill /MW
3) Additional sole panels for 25% energy loss at Pumped Hydro Plant	= $ 0.61 Mill/MW
4) Additional solar panels, 25% to charge Batteries to stabilize network	= $ 0.61 Mill/MW
5)Construction Costs of the Pumped Hydro Power Plant for night power	= $ 2.0 Mill /MW *($ 5.0 Mill)
6) Battery-Set for 0.25 MW at $3.6 Mill/MW for emergency power supply	= $ 0.9 Mill/MW
7) Three replacements of battery-Sets at $ 0.9 Mill x 3 = $ 2.7 Mill	= $ 2.7 Mill/MW
8) Construction of a supplementary gas combined cycle power station	= $ 1.7 Mill/MW
9) Additional 10,000km Grid Lines for 25,000 MW at $100 bn/25,000 MW	= $ 4.0 Mill/MW
Total	**$ 17.52 Mill/MW**

Estimated capital cost to develop a Mini Nuclear Power Plant (CSIRO 2022)	$ 16.0 Mill/MW
Estimated capital cost for Mini Reactor Plants when mass produced	**$ 9.0 Mill/MW**

Electricity Production Costs per MWhour

Listed are the general electricity production cost of different types of electricity plants, within a variable range. No Grid losses are considered

Solar at full sunshine .... \$ 40 to \$ 60/MWh

Wind at average good wind speeds .... \$ 70 to \$ 90/MWh

Coal fired Power Plants .... \$ 80 to \$100/MWh

Hydro Power Plants .... \$ 40 to \$ 70/MWh

Pumped Hydro Power Plant .... \$ 80 to \$160/MWh

Gas fired Power Stations 20% of time (\$120/5=\$24) \$120 to \$200/MWh

Battery Power for 0.25MW (\$300x0.25=\$75/MWh) ... \$300 to \$500/MWh

Solar electricity stored (40+40+10+10+80+24+75) .... \$ 279 to 475/MWh

Large Nuclear Reactors .... \$ 50 to \$120/MWh

Mini Nuclear Reactors (CSIRO by 2030) .... \$129 to \$336/MWh

Conclusions

- The present Government election promised that our annual electricity costs will reduce by $275 when going for Wind and Solar did not happening.
- Now over 40% of the Australian population want the Government to include Nuclear in their mix of Alternatives to replace Coal
- The construction cost of Nuclear Plants is subject to how much environmental scientist hinder their construction.
- The new generation of Mini Modular Reactors presently in development are based on 40 years experience of operating of over 500 Nuclear plants. The SMR design ensures that accidents like at Chernobyl and Fukushima are impossible to reoccur.
- The electricity Generating costs from Nuclear Plants are considerably cheaper than solar and wind made available 24/7. If Nuclear is used for the 30% of basic day and night electricity demand it would reduce the costs of making solar and wind available 24/7 considerably.
- Australia has to develop its own Nuclear Industry in the future to have an independent fuel supply for its Nuclear Submarines. It is not needed for the construction and operation of SMR.
- Until this Nuclear Industry is developed Australia would be well advised to include SMR in their change from Coal to Alternative green Energy.
- Australia should have a very close look at what is happening in the field of Nuclear Energy in the world today. Japan, China or South Korea are developing their own SMRs to supplement their change to a CO2 free energy production. America and the UK are restarting their Nuclear Power Plant program again Germany having switched off all their Nuclear Plants which once produced their 30% of its electricity demand, has now the highest electricity and gas prices in Europe, Many German Companies relocate their production facilities to East European countries with cheaper gas and electricity.
- Australia had the advantage of cheap electricity and gas. Do we want to ruin this totally by not considering Nuclear Power Plants in Australia??