RESPONSE

to the

TENTATIVE FINDINGS

dated February 2016

of the

NUCLEAR FUEL CYCLE ROYAL COMMISSION

by

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1964:	Graduated B.Sc. (Honours) in Geology from the University of Adelaide.
1965-1995:	Geologist in the South Australian Department of Mines and Energy (now retired).
1979-1995:	Uranium Projects Officer in S.A.D.M.E.
1979-1983:	Secretary of the SA Uranium Enrichment Committee.
1979-1981:	Technical Advisor to the SA Legislative Council's Select Committee on Uranium Resources (Parliamentary Paper 154/1981)
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2. CONCLUSIONS

(1) In the 1970s and early 1980s the South Australian Uranium Enrichment Committee had firm plans for the development of uranium conversion (Port Pirie), uranium centrifuge enrichment (Whyalla) and the manufacture of centrifuges (Adelaide) and employing about 900 people. These industries would have approximately doubled the export value of the uranium oxide concentrate from our uranium mines.

(2) However, those plans were stymied by the Federal Labor Party who won Government in March 1983.

(3) In 2015 there may have been an opportunity for Australia to have conversion and centrifuge enrichment industries but, once again, Australian governments failed to capitalise on a value-adding industry.

(4) South Australia should store all levels of radioactive waste in the disused uranium mine (1952-1961) at Radium Hill.

(5) High level reprocessed radioactive waste from nuclear power reactors should be shipped to Port Pirie, converted into SYNROC and buried at Radium Hill.

(6) About 1740 million years ago there were six natural nuclear reactors at Oklo, Gabon, West Africa. They fissioned about six tonnes of uranium-235. Much of the uranium, plutonium and fission products have remained in or near those natural reactors despite being surrounded by hot groundwater.

(7) This natural demonstration of radioactive waste retention shows that the underground disposal of radioactive waste from nuclear power reactors would be safe because it would be chemically combined in SYNROC, encased in stainless steel and surrounded by clay in dry rocks.

(8) The Royal Commission discussed only the generation of electricity from a South Australian nuclear power reactor. They should consider a plant for electricity generation, desalination of sea water, and heating for industry and domestic purposes. Such a power reactor on top of cliffs along the west coast of Eyre Peninsula could supply electricity and potable water to Eyre Peninsula, and eventually to the huge open cut mine planned at Olympic Dam, north of Roxby Downs.

3. INTRODUCTION

This report will cover a general description of the nuclear fuel cycle, and then discuss the South Australian studies into uranium conversion, centrifuge enrichment and centrifuge manufacture by the Australian Mineral Development Laboratories (AMDEL) and the South Australian Uranium Enrichment Committee (SAUEC).

In addition it will describe the establishment in 1979 of the Uranium Enrichment Group of Australia and how it came to the same conclusion about centrifuge enrichment as had the SAUEC. However, this delay meant that no inter-Governmental agreements about technology transfer had been made by March 1983 when the newly elected Labor Prime Minister Bob Hawke prevented such agreements and thereby ended our chance of doubling the value of our uranium ore concentrate and denying South Australia and Australia high tech industries, 900 jobs and, together with their "Three Mines Policy", the loss of billions of dollars of export income.

I also propose that South Australia stores all radioactive waste in the former uranium mine at Radium Hill.

(1) The Nuclear Fuel Cycle

(a) Introduction

The 1981 report by the South Australian Legislative Council on Uranium Resources describes the basics of the nuclear fuel cycle, viz:

- mining
- milling to produce uranium ore concentrate (yellow cake)
- refining of yellow cake
- conversion of the refined yellow cake into uranium hexafluoride
- enrichment of the uranium hexafluoride
- production of uranium fuel
- the use of the uranium fuel in nuclear power reactors
- the handling and disposal of radioactive waste
- the recycling of unused uranium and plutonium back into new nuclear reactor fuel

(S.A. Legislative Council, 1981 p. 20-26, 51-95)

(b) The Nuclear Fuel Cycle – from Uranium Ore to Enriched Uranium to Nuclear Fuel and Radioactive Waste

These notes are based mainly on the Legislative Council of South Australia (1981).

The uranium ore is extracted from the mine and taken to a mill where it is crushed, the uranium minerals are leached out and converted into uranium ore concentrate (UOC) which is about 80-90% uranium oxide. It is commonly yellow (and called yellow cake) but can also be green or red, depending on its composition.

The UOC is taken to a refining and conversion plant to be changed chemically to uranium hexafluoride. The UOC first needs to be refined (purified) to better than 99% uranium oxide because it may have contained impurities such as boron, cadmium and rare earth elements, etc. These, if present in nuclear reactor fuel pellets, would capture some of the neutrons which are needed to fission the uranium-235 (Kessler 1983, p. 55).

The purified uranium oxide is then “converted” chemically to uranium hexafluoride, after which it goes to the uranium enrichment plant.

In a centrifuge enrichment plant the centrifuges are vertical steel cylinders the internals of which are spinning at high speed. The slightly heavier uranium-238 hexafluoride tends to concentrate towards the periphery of the centrifuge from where it is removed as being “depleted” in uranium-235 hexafluoride, i.e. it has slightly less uranium-235 than the natural level of 0.72%.

The slightly lighter uranium-235 hexafluoride tends to concentrate near the middle of the centrifuge, from where it is collected as “enriched” uranium-235 hexafluoride, i.e. it has more uranium-235 than the natural level of about 0.72%.

After passing through about ten centrifuges in succession, a small amount of the uranium-235 hexafluoride has been enriched to about 3% uranium-235.

However, each centrifuge has only got a small capacity and so, in order to provide commercial (tonnes) quantities of 3% uranium-235, a very large number of centrifuges must be employed – hence the plans for the enrichment plant at Whyalla to have 100,000 centrifuges when at full capacity.

The enriched uranium hexafluoride is then taken to a fuel fabrication plant and converted chemically into uranium oxide. This is pressed into fuel pellets which are sintered at high temperature and pressure into a ceramic. These ceramic uranium oxide pellets are then fed into long zirconium alloy tubes which are fixed into fuel assemblies (metal frames) and put into a nuclear power reactor.

The heat of the reactor, to boil water and make steam for turbine electricity generators, is derived from the fissioning (splitting) of the nuclei of the uranium-235 (and plutonium-239) atoms.

The fission products are separated chemically from the used fuel pellets and become the high level radioactive waste.

This can then be combined chemically in SYNROC to be disposed of underground at (say) Radium Hill.

(Legislative Council of South Australia, 1981 p. 51-95)

(c) Uranium Conversion

In March 1981 the SAUEC recommended the establishment of a uranium conversion plant at Port Pirie - which would employ more than 200 people (SAUEC, March 1981). This document describes the technical and economic data of that conversion plant.

In a press release on 21 June 1981 the S.A. Premier David Tonkin announced that a group had formed a joint venture to study the economic viability of a uranium conversion plant at Port Pirie, using BNFL technology. The group comprised:

British Nuclear Fuels Limited: 30%
Broken Hill Associated Smelters Pty Ltd: 35%
Roxby Management Services Pty Ltd: 30%
S.A. Government: 5%
(S.A.U.E.C., 2 Sept 1981: Appendix A)

These decisions involved visits to the U.K. in December 1980 by the Minister of Mines and Energy (Roger Goldsworthy) and by Premier David Tonkin in April 1981.
(SAUEC March 1981; SAUEC, 2 September, 1981.)

(d) Uranium Enrichment

(i) The Need for Uranium Enrichment

Most nuclear power reactors are light water reactors, i.e. they use ordinary water as the coolant and moderator. Such light water reactors require that their uranium fuel has about 3% uranium-235 (Nero, 1979 p. 21).

However, natural uranium has only 0.72% U-235, and most is U-238 (99.2745%) and a trace is U-234 (0.005%) (Holden, 1995, p. 11-135, 136).

Uranium enrichment is the (physical) process of separation of the uranium isotopes due to their very slight differences in weight. From the plant one stream of uranium hexafluoride has been “enriched” to about 3% U-235, and the other stream has about 0.2% U-235, i.e. it has been depleted in U-235.
(See SAUEC, 1980, p. 1, 2; Choppin et al., 2002, p. 36-37)

The conversion and enrichment of uranium approximately doubles the value of the Uranium Ore Concentrate from a mine (SA Legislative Council, 1981, p. 69; Hardy,2008, p. 137, Table 12 on p. 138).

(ii) Uranium Enrichment in South Australia

This is a summary of studies by the South Australian Uranium Enrichment Committee from 1975 to 1983. It is also a description of how South Australia and Australia lost the opportunity to enrich uranium when the Federal Labor Party stymied it in 1983. This, together with the Labor Party's subsequent "Three Mines Policy", which restricted the number of Australian uranium mines and therefore our production of uranium, has cost us billions of dollars in lost opportunities for uranium sales, value adding, and about 900 jobs in conversion and enrichment.

Between 1973 and 1983 successive South Australian Governments studied the feasibility of establishing uranium conversion, uranium enrichment and centrifuge manufacturing industries in this State.

The initial studies (of uranium conversion) were made in 1973-1974 by the Australian Mineral Development Laboratories (AMDEL) in Adelaide. In October-November 1975 Mr Ron Wilmshurst of AMDEL visited Europe and the UK to study uranium conversion and enrichment for the South Australian Uranium Enrichment Committee. Technical data, cost estimates and employment estimates are given in Wilmshurst (1975).

In 1975 the South Australian Uranium Enrichment Committee was established to advise the South Australian Government on the conversion and enrichment of uranium in South Australia (SAUEC, June 1980). This report describes the technical and economic aspects of uranium enrichment by centrifuge, suggests that centrifuges be manufactured in Adelaide and describes some environmental aspects of a centrifuge enrichment plant at Whyalla with 100,000 centrifuges and about 500 jobs.

The refining and conversion process would be those used by British Nuclear Fuels Limited in England.

The enrichment process chosen was the centrifuge technology developed in the UK, Holland and West Germany by URENCO-CENTEC. This centrifuge technology was chosen because it used only about 10% of the electricity required by other technologies (e.g. diffusion) and could be built in modules to keep pace with the demand.
(SAUEC, June 1980.)

During 1980-1981 the SAUEC received visits from representatives of a wide range of organisations including the Uranium Advisory Council, the UK Department of Energy, the US Department of Energy, British Nuclear Fuels Limited, British Petroleum, the Commissariat a l'Energy Atomique of France and Comprimo BV.
(SAUEC, 1980-1981, p. 2-3.)

In addition, members of the SAUEC visited UK and Europe to discuss conversion and enrichment as did the SA Minister of Mines (Roger Goldsworthy) in December 1980, and the SA Premier (David Tonkin) in April, 1981.

In 1975 the SAUEC concluded that a full feasibility study be initiated for uranium enrichment in South Australia and a number of companies were approached to take part.

In subsequent reports of February 1976 and November 1978 to the SA Government, the SAUEC added uranium conversion to their original recommendation for uranium enrichment (SAUEC, March, 1981: p. 4)

In its progress report of 5 August 1980, SAUEC recommended the structuring of a South Australian enrichment venture, with majority Australian shareholding for the establishment of an enrichment plant in South Australia.

In February 1981 this recommendation was accepted by the SA Liberal Government which informed the Commonwealth Government of South Australia's proposal for a uranium enrichment industry using URENCO-CENTEC centrifuge technology. This was done in a letter to the Prime Minister dated 18 February 1981. The same letter requested Commonwealth support for the necessary international agreements between South Australia and URENCO-CENTEC. (SAUEC, January 1982, p. 1, 2.)

Although the finding of SAUEC was made available to UEGA, the September 1981 report of UEGA (UEGA, 1981) made no reference to the SAUEC conclusions and nor to the colossal amount of work done by AMDEL and SAUEC under Labor and Liberal Governments over the previous seven years. (SAUEC, January 1982, p.2.)

If these plans by the South Australian Uranium Enrichment Committee had come to fruition South Australia would have had in the 1980s:

- a centrifuge manufacturing plant in Adelaide
- a uranium conversion plant in Port Pirie
- a centrifuge uranium enrichment plant in Whyalla

The Adelaide factory would have made the most advanced URENCO-CENTEC centrifuge enrichment machines in the world, which would have supplied 100,000 centrifuges for the Whyalla plant, and replacement centrifuges for the already established enrichment plants in England, Holland and West Germany.

South Australia would have been "centrifuge central" with an integrated industry involving the mining and milling of uranium, conversion to uranium hexafluoride, the enrichment of the uranium hexafluoride and the manufacture of centrifuges – and employing about 900 people in conversion, enrichment and manufacture,

In addition, uranium conversion and enrichment would approximately double the value of our Uranium Ore Concentrate (see Hardy, 2008, p. 137 and Table 12 on p. 138).

Unfortunately, all this work and planning over many years came to nothing when, in March 1983, Federal Labor came into Government and stopped all work on uranium enrichment by SAUEC and UEGA.

(e) Uranium Enrichment Group of Australia

In 1979 four companies set up a joint venture known as the Uranium Enrichment Group of Australia (UEGA). The companies were:

- Broken Hill Pty Ltd (BHP)
- Colonial Sugar Refining Ltd (CSR)
- Peko-Wallsend Operations Ltd
- Western Mining Corporation Ltd (WMC)

On 2 January 1980 the Commonwealth Government announced that UEGA was to carry out a “Pre-feasibility Study” to assess the commercial viability of establishing a uranium enrichment industry in Australia. Their main studies took place in 1980-1981 and delivered their final Pre-feasibility Report to the Commonwealth Government on 30 April 1981 (Hardy, 2008: p. 83-88; SAUEC, January 1982).

That is, UEGA was in direct competition with the South Australian Uranium Enrichment Committee – they made similar visits overseas, interviewed similar people and came to the same conclusion – that URENCO-CENTEC centrifuge enrichment was suitable for Australia.

The delays caused by UEGA meant that no Government-to-Government Agreements for technology exchange had been made when, in March 1983, Federal Labor won Government and stymied all further uranium enrichment studies by both UEGA and SAUEC – and so we lost a value-adding industry.

(f) Uranium Enrichment in Australia in the 21st Century – Another Lost Opportunity

Apart from my Conclusion the following description of the potential for an Australian uranium centrifuge enrichment plant for 2015 is taken from a 2008 perspective in Hardy (2008: xii, 130,131, 133, 134, 138, 153-161).

In February 2007 Dr Clarence Hardy was instrumental in establishing the public Australian company Nuclear Fuel Australia Ltd (NFA). One of its main objectives was to carry out a feasibility study into the construction of a multi-national centrifuge enrichment plant (and the associated conversion plant) in Australia using URENCO-CENTEC centrifuge enrichment technology. This feasibility study would use as a model the National Enrichment Facility, then under construction near Eunice, New Mexico (USA), using URENCO-CENTEC centrifuge technology.

The NFA "Preliminary Feasibility Study Report" was completed in March 2008. It concluded that because nuclear power capacity world-wide was expected to increase significantly, probably between 20% and 40%, by 2030 (see p. 153) a corresponding increase will be required in the supply of uranium and in conversion, enrichment and fuel fabrication services. Considerable changes had occurred around 2008 in the supply of enrichment services with uneconomic gaseous diffusion enrichment plants being closed, or in the process of being replaced by the more economic centrifuge technology.

A list of the main enrichment plants in operation, under construction or being decommissioned in USA, France, Russia, China, UK, Holland and Germany, and minor plants in other countries, are to be found in Hardy (2008 p. 132, 154-161).

Another conclusion by the NFA study was that there will be a decrease in the supply of enrichment services from the main countries in the period 2012-2020 due mainly to the decommission of old gaseous diffusion plants and the completion of the US-Russian Highly Enriched Agreement in 2013. In this agreement Russian weapons-grade uranium-235 (from nuclear weapons) is bought by the USA, its uranium-235 diluted with uranium-238 down to about 3% and then fabricated into nuclear reactor fuel.

The new centrifuge plants under construction will not replace the lost capacity for several years. In Table 9 on page 133 there is a deficit in enrichment supply in 2015 [however an Australian plant would have had to have been in operation in 2015].

The NFA study also concluded that the construction of an enrichment plant and associated plant in Australia would require professional, skilled and semi-skilled employment during the construction time (5-7 years, 800 people) and 210 full- time and contract people during operation.

Dr Hardy concluded that in about 2015 the potential demand over supply "provides a window of opportunity for an Australian enrichment plant to enter the market and effectively gain market share mainly at the expense of Russian enrichment services". This because "several countries could prefer the added security of dealing with Australian uranium, conversion and enrichment supply companies".

Conclusion – from a 2016 perspective it can be seen that once again Australian Governments have failed to capitalise on a value-adding industry – just as Labor did in 1983.

(g) Recommended Reading

There are two good and accessible books describing the efforts to establish a uranium enrichment industry in Australia during the 1970s and early 1980s, viz. Hardy (2008) and Alder (1996).

Clarence Hardy's book "Enriching Experiences" describes the development of ideas about atoms in the 1890s and before World War II, the uranium enrichment technologies developed by the US Manhattan Project during WW II, centrifuge theory and technology in the UK and Europe (URENCO-CENTEC) after WW II, the experiments with centrifuges starting in 1965 by the Australian Atomic Energy Commission (now the Australian Nuclear Science and Technology Organisation) and the parallel plans for uranium enrichment for South Australia (by the South Australian Uranium Enrichment Committee) and for Australia (by the Uranium Enrichment Group of Australia) during the 1970s and early 1980s.

In addition, the subtitle of Keith Alder's book "Australia's Uranium Opportunities – How Her Scientists and Engineers Tried to Bring Her into the Nuclear Age but Were Stymied by Politics" exactly summarised the situation (Alder, 1996).

The 1982 Biennial Conference of the Labor Party had endorsed a uranium policy which stated that if the Labor Party was in Government it would not permit the enrichment of nuclear materials in Australia (Hardy, 2008: p. 93).

In March 1983 the Australian government changed from Liberal/Country Party to Prime Minister Bob Hawke's Labor Party, and the word was passed to UEGA that there would be no Government-to-Government Agreements relating to uranium enrichment technology from that Labor Government. Without such agreements there could be no technology transfer and that stopped dead the prospects of establishing a worthwhile industry based on upgrading our natural resources for export. (Alder, 1996: p. 76)

4. NUCLEAR POWER REACTORS – Electricity Generation, Desalination and Water for Olympic Dam

The Tentative Findings of the NFCRC only considered the generation of electricity for South Australia and concluded that it would not be economic at the present time (p. 2, 11-14). However, the Findings failed to consider that the electricity from a nuclear power reactor could also be used to desalinate sea water, or that its waste heat could be used for industrial or domestic heating or heating glass houses for vegetables and flowers.

They should consider the need and economics of a nuclear power reactor on a cliff site on the west coast of Eyre Peninsula. A cliff top locality would place the reactor above any ocean waves (unlike those at Fukushima in 2011) and sea water could be used to cool the steam in the turbine circuit.

The reactor would produce electricity – some of it for the power grid on Eyre Peninsula and some used to desalinate sea water to be fed into the present pipeline system. In the future some of this water could be used in the huge open cut expansion planned for the Olympic Dam mine at Roxby Downs.

Such a scheme would reduce the reliance of people and industry on Eyre Peninsula for their electricity from Port Augusta power stations or from a more distant source. It would also reduce their present reliance on water from the Todd River scheme and from the River Murray.

5. RADIOACTIVE WASTE

(1) Management, Storage and Disposal of Radioactive Waste

I agree with the Royal Commission's Tentative Findings on page 3 that the storage and disposal of radioactive waste in South Australia is likely to deliver substantial economic benefits to the South Australian Community. However, I make the following proposal:

(2) Proposal To Store All Radioactive Waste In The Disused Uranium Mine At Radium Hill, Eastern South Australia

The Tentative Findings of the South Australian Nuclear Fuel Cycle Royal Commission were released on Monday 15 February 2016. Among other subjects these Findings described the potential billion-dollar bonanza arising from the storage of radioactive waste in South Australia.

However, the **ROYAL COMMISSION** has made **TWO POOR PROPOSALS REGARDING THE STORAGE OF RADIOACTIVE WASTE.**

The **FIRST POOR PROPOSAL** is that **RADIOACTIVE WASTE COULD BE STORED UNDERGROUND NEAR KIMBER OR PORT AUGUSTA** following suggestions from a report commissioned by the Commonwealth Department of Industry, Innovation and Science (see Littley, Starick and Dillon, 2015). In addition, a site near Woomera was recommended in a 2002 Commonwealth Report on a National Radioactive Waste Repository (Commonwealth Department of Education, Science and Training, 2002).

The Kimba or Port Augusta storage is proposed to be in a purpose-built underground repository involving a new secure port and railway, a temporary storage on the surface and taking up to 25 years to construct with up to about 4,500 jobs (Nuclear Fuel Cycle Royal Commission, February 2016, p.18, 19, 26).

HOWEVER, WE ALREADY HAVE A SUITABLE UNDERGROUND REPOSITORY AT THE FORMER URANIUM MINE (1952-1961) AT RADIUM HILL IN THE OLARY

REGION OF EASTERN SOUTH AUSTRALIA AND SOUTH OF THE BARRIER HIGHWAY.

Radium Hill is already a gazetted low-level radioactive waste repository (S.A. Government Gazette, 2 April 1981). It is owned by the South Australian Government and managed by the Mining Branch of the S.A. Department of State Development (personal communication, Mr Kevin Kakoschke, Kurralta Park, 16 February 2016). It could also store intermediate- and high-level radioactive waste.

The low-level waste could be stored in the upper drives (tunnels) and the high-level waste in the deep drives (tunnels) at about 365 metres.

The Radium Hill site already has a 1.6 km long aircraft runway (which would need upgrading) but requires a bitumen road from the Barrier Highway, surface facilities for staff and to handle waste, reconstruction of the headframe and winder to deliver equipment and waste underground, installation of equipment to ventilate the mine, electricity and water.

However, before such works are undertaken the Mine will need to be assessed underground for safety (e.g. loose rocks, rock falls, radon gas levels, etc.), ground water levels, the quality of the steel sets supporting the walls of the shaft and any timber supporting drives, etc., and what would be required for services such as electricity, water, railway lines, etc.

These assessments of the underground workings and geology would be aided by the detailed plans drawn up when the Mine was in operation from 1952 to 1961. These plans are presumably held in the archives of the SA Government.

The recommissioning of the Radium Hill Mine for the storage of radioactive waste would be far cheaper than the proposals of the Commonwealth and the Royal Commission.

The **SECOND POOR PROPOSAL** of the Royal Commission is that **WE STORE THE USED FUEL RODS FROM NUCLEAR POWER REACTORS** (Nuclear Fuel Cycle Royal Commission, February 2016, p. 16-19, 26). Those fuel rods still contain much of the nuclear energy in the unused uranium and plutonium, and all of the radioactivity, which will last for millions of years.

IT WOULD BE BETTER THAT WE STORE THE RADIOACTIVE WASTE FROM CHEMICALLY REPROCESSED FUEL RODS (from which the uranium and plutonium have been removed) leaving the highly radioactive (i.e. short-lived) fission-products waste to be stored at Radium Hill. It will decay to low levels in 300 – 1000 years or so (see Legislative Council of South Australia, 1981, p. 25, figure 26.12)

This reprocessed waste would come from overseas reprocessing plants.

In addition, this reprocessed waste should be solidified here in to SYNROC (an Australian technology, (see Legislative Council of South Australia, 1981 p.78, 79 and Ringwood 1982, 1985) which will render it more chemically and thermally stable than the ancient crystalline basement rocks at Radium Hill.

I SUGGEST THAT OVERSEAS REPROCESSED RADIOACTIVE WASTE BE SHIPPED TO PORT PIRIE, CHEMICALLY SOLIDIFIED INTO SYNROC THERE AND THEN TRUCKED TO RADIUM HILL ON THE EXISTING ROADS.

This would be safe, would provide employment, would minimise the need for a new port, transport, mining infrastructure and site characterisation, and would thereby minimise establishment costs and maximise financial returns to South Australia.

It would also avoid unnecessary stress to people in Kimba and Port Augusta.

(3) Oklo – Natural Nuclear Reactors and Natural Retention of Much Radioactive Waste

When the Earth formed about 4,500 million years ago natural uranium was then composed of about 83% uranium-238 and about 17% uranium-235 (Durrance, 1986: p. 92). U-238 has a radioactive half-life of about 4,500 million years and U-235 a half-life of about 700 million years (Walker et al., 1984: p. 47). Therefore since the formation of the Earth about half of the U-238 has decayed to lead and most of the U-235 (now it is only 0.72%).

However, at about 1,740 million years ago the amount of U-235 was about 3% of uranium, i.e. the amount required to maintain nuclear fission in nuclear power reactors.

Between about 1,900 – 1,850 million years ago uranium was deposited and buried in a river delta in an area which is now Oklo in Gabon, West Africa. By about 1,740 million years ago some of this uranium became highly concentrated in about six areas of the deposit to the extent that six natural nuclear reactors commenced operating on and off for at least 500,000 years.

The neutron moderator was the hot (up to 200^o C) groundwater. About six tonnes of U-235 was fissioned, which is about the same amount as consumed in four years in a large nuclear power reactor.

Of the fission product elements formed, about half were leached from the reactor zones. These include krypton-85, zenon, rubidium, barium, cadmium, possibly caesium-137 and some strontium-90. However, at least half of the 30-odd fission product elements remained immobilised in the ore. These include the rare earth elements, and yttrium and most or all of the zirconium, ruthenium, rhodium, palladium, niobium, silver, molybdenum, some iodine and most of the strontium-90. In addition plutonium remained.

Since the large bulk of the radioactive products of the natural reactor decayed away in the reactor site, then this adds confidence that man-made wastes can be expected to behave in a similar way, particularly since they will be deliberately protected from underground water. They will not be in contact with hot underground water as were those at Oklo for at least 500,000 years.

In the case of SYNROC the radioactive waste elements will be chemically combined in three calcium and barium titanium oxide minerals, at about 1150^o C, encased in stainless steel and stored in dry rocks and surrounded by clay. At Radium Hill the ancient crystalline basement rocks would melt at about 300-400^o C lower temperature than SYNROC (see Legislative Council of South Australia, 1981: p. 78, 79, 94; Choppin et al., 2002: p. 538-540; Durrance, 1986: p. 90-96, 390-393; and references therein to papers by Brooking and Cowan; Ringwood, 1982, 1985).

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