ENGINEERS
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Submission to the Nuclear Fuel Cycle Royal Commission

Engineers Australia

An independent and comprehensive investigation into South Australia's participation in four areas of activity that form part of the nuclear fuel cycle

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Cover Photo: Image of CAREM small modular reactor courtesy of Argentinean National Atomic Energy Commission (Comisión Nacional de Energía Atómica: CNEA).

Introduction

Engineers Australia is the peak body for the engineering profession in Australia. With more than 100,000 members across Australia, we represent all disciplines and branches of engineering. Engineers Australia is constituted by Royal Charter to advance the science and practice of engineering for the benefit of the community.

Engineers Australia maintains the position that to create Australia's low emission future there is a need to consider the full range of energy technologies available, including nuclear energy. However, Engineers Australia believes the potential for nuclear energy in this country has been inadequately recognised. The Nuclear Fuel Cycle Royal Commission established by the South Australian Government is an encouraging step forward to consider the viability and feasibility, along with the risks and opportunities associated with the use of nuclear energy.

Engineers Australia welcomes the opportunity to provide decision-makers with the following technical findings and facts –under the Royal Commission's Terms of Reference– via the [four] issues papers, in order to make informed decisions pertaining to the future of nuclear energy in Australia.

In doing so, Engineers Australia recognises a wide spectrum of views and concerns surrounding nuclear energy among the general public. Such a diversity of views exists equally across the membership of Engineers Australia. Thus, in preparing this submission, Engineers Australia sought to draw on expertise across the membership, and consequently received contributions from various groups within the organisation. In particular, Engineers Australia's Nuclear Engineering Panel drew on its broad experience, providing valuable input to the submission, which is reflective of the Panel's commitment to address all areas of the nuclear debate.

There is broad principle consensus from within Engineers Australia's groups that all externalities should be considered by proponents of all technologies including: health, mining and land degradation. A consistent approach should be applied to all potential sources, and the precautionary principle should prevail. A full life cycle assessment should be undertaken for all sources.

It is recognised that the scope of the Royal Commission is to consider issues associated with the nuclear fuel cycle and this submission speaks directly to that. There are matters relating to the structure of the electricity/energy market that are outside the scope of the Royal Commission, and should be considered within the overall framework of Australia's National Energy Policy. The findings of the Royal Commission are set to play an integral role in the shaping of Australia's National Energy Policy.

Engineers Australia wishes to reflect upon the nuclear power industry worldwide and the manner in which it has moved on from previous, serious accidents. Engineers have been at the forefront of vast improvement and technological advancement within the nuclear industry. Lessons of the past have been implemented into existing nuclear power stations and have helped shape the modern, safe designs of nuclear power plants that exist today. Engineers Australia notes misconceptions around nuclear energy are often based on confusion in public messaging, coupled with out-of-date knowledge and technologies. Engineers Australia sees the Royal Commission as an opportunity to instil community confidence in the nuclear energy sector and demonstrate the natural safety features of modern reactors, and their suitability for Australian conditions.

Australia already has a highly competent and well managed Commonwealth nuclear regulatory regime. The current legislation however requires revision to include the states and territories.

A summary of Engineers Australia's response to the four issues papers can be found on page 3. Engineers Australia welcomes the opportunity to participate and contribute further in the Nuclear Fuel Cycle Royal Commission inquiry.

The following is an overview of Engineers Australia's response to the four issues papers:

Issue Paper One: Exploration, Extraction and Milling

A response with respect to only one question in this issue has been provided. Australia has more than 60 years' experience of successfully managing uranium mining, milling and transport. With Australia's experience of uranium mining the risks are well understood. The internationally recognised International Atomic Energy Agency (IAEA) published Safety Standards that are used as the basis for legislation.

Issue Paper Two: Further Procession of Minerals and Manufacture of Materials Containing Radioactive and Nuclear Substances

A response has been provided to this issue relating to Australia's limitations around the processing of uranium ore to Uranium Ore Concentrate (UOC or "yellow cake"). The opportunity that Australia had to expand into this market area has probably been missed with respect to centrifuge enrichment as the world market is well supplied. However, there could be opportunities to undertake laser enrichment utilising the Australian invented SILEX laser enrichment technology that is being commercialised by GE (USA).

Issues Paper Three: Electricity Generation from Nuclear Fuels

The matter of electricity generation from nuclear fuels should be considered as one of the potential options of the mix of energy sources.

Low emissions nuclear power could potentially play an important role in South Australia's electricity generation mix. A timely start to a South Australian nuclear power program will have widespread economic benefits. The development of nuclear power could;

- improve the resilience of South Australia's energy system making energy supply more reliable and affordable;
- provide South Australia with long-term energy security;
- help South Australia move to a low carbon society and reduce its greenhouse gas emissions over the short, medium and long term in the most cost effective manner;
- have the potential to provide high-quality manufacturing skills and outputs support for similar programs in other States and south-east Asian countries;
- and help South Australia to become an innovative state by introducing new technologies and new industries, therefore creating more jobs.

Small Modular Reactors (SMRs) are well suited to the South Australian system however investment in any new generation in the NEM is subject to acceptable long-term market pricing. Ultimately the analysis and quantifying of the advantages and disadvantages of the introduction of nuclear power in South Australia will come down to a careful evaluation of all of the key factors noted throughout this submission as part of a feasibility study before any final decision can be made. Many of the factors require substantial technical experience in the nuclear engineering field to evaluate. The outcomes will require careful communication to a wider audience.

While unit cost is certainly an important consideration it is notoriously difficult to ensure that the cost implications of all factors can be quantified or even fully assessed without a site-specific assessment. Only a rigorous feasibility study of the nuclear power option for South Australia would lead to credible unit cost scenario from this source of power generation.

Issues Paper 4: Management, storage and disposal of nuclear and radioactive waste

Storage of radioactive materials and chemical processing to extract medical radioisotopes have been carried out safely at Lucas Heights, near Sydney, for over 50 years.

There could be a financial incentive for South Australia to establish a Low Level Waste Repository (LLW) within the state. The technology of a near surface repository is well understood and the risks to people and the environment are very low. If a LLW repository was established, a co-located Intermediate Level Waste store should also be considered. The risks are again low.

A deep geological repository for High Level Waste would not be needed until at least 50 years after the start of a nuclear power program in Australia.

The possibility of an Integral Fast Reactor (IFR) project using PRISM or a similar type of reactor could be investigated by a feasibility study. If spent fuel was imported from abroad for an IFR project, interim storage in dry storage casks is well understood and low risk.

Transport of radioactive materials is one area where there is very good international agreement and standards, because the whole of the nuclear fuel cycle, from ore to waste involves transport, in many cases between countries. Australia has experience of transport of spent fuel.

Radioactive materials are transported worldwide to international standards. South Australia has extensive experience of the safe transport of uranium ores. Transport of LLW and ILW to a site in South Australia would be low risk.

Issues Paper 1: Exploration, Extraction and Milling

Question 1.10

Would a future expansion of exploration, extraction and milling activities create new environmental risks or increase existing risks? If so, are current strategies for managing those new risks sufficient? If not, in what specific respects? How would any current approach need to changed or adapted?

Response

Australia has more than 60 years' experience of successfully managing uranium mining, milling and transport.

Australia has 31% of the world's resources of uranium, but only supplies 12% of the world's demand so there is room for expansion.

With Australia's experience of uranium mining the risks are well understood. The internationally recognised IAEA publish Safety Standards are used as the basis for legislation. An example in the mining area is the IAEA Management of Radioactive Waste from the Mining and Milling of Ores Safety Guide WS-G-1.2.

ARPANSA has issued the Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing RPS 9, based on the IAEA Safety Guide. The objective of this code is to provide a regulatory framework to manage the protection of workers, members of the public and the environment from harmful effects of radiation exposure arising from mining or mineral processing and from the waste resulting from these activities both now and in the future. The Code details the requirements of the Radiation Management Plan and the Radioactive Waste Management Plan which control the risks. The plans must be approved by the regulatory authority.

Australia has all three different types of uranium mines – open pit, underground and ISL (In-Situ Leach) and they each have different risks. All radiological risks are subject to control by professional Health Physicists. There are also risks associated with the particular location.

Ranger in the Northern Territory is an example of an open pit mine. This has the largest surface impact as there is a lot of rock to remove to access the ore. Ranger is located in the Kakadu National Park so there are particularly sensitive environmental issues. The risk to the environment is primarily from the chemicals, as in mining for many other minerals, rather than from radioactive materials. The processing plant uses chemicals to extract the uranium from the ore and a "defence in depth" multiple barrier system is required to ensure that spillages do not cause damage to the environment. For example a leach tank ruptured in 2013, but the contents were retained by the plant containment system. The waste left after extracting the uranium ore is neutralised and held in tailing dams. Open cut mining finished at Ranger in 2012 after more than 30 years and contracts are now met by uranium from stockpiles. It is a condition of any uranium mine licence that the site is rehabilitated after the completion of mining. The first open pit at Ranger has been refilled and rehabilitation is in progress.

Olympic Dam in South Australia is an example of an underground mine. This is the world's largest deposit of uranium being mined, but Olympic Dam is primarily a copper mine with uranium a by-product. As with Ranger, there is a need to manage the processing on site the tailings dam. The risk from inhalation of radon gas is significant in underground mining and is controlled by the ventilation systems. As with all mining, there is a risk from inhalation of dust.

BHP's proposals for expansion as a very large open pit received environmental approval, but are on hold due to current low mineral prices.

BHP is trying the heap leach process to reduce ore processing costs. Ore is mined, crushed and 36,000 tonnes (one days' production) heaped on an impermeable pad. It is treated with sulphuric acid for 300 days and the uranium and copper dissolves and is extracted. The tailings will have to be neutralised before they are stored in a tailings dam. This process has been used at BHP's Spence copper mine in Chile.

The third mining method is In-Situ Leach (ISL) which is now the dominant uranium mining process worldwide. Acid is pumped down boreholes and dissolves the uranium. The liquid is extracted via recovery wells and processed on the surface to extract the uranium. This is the most economical way of extracting uranium underground; no need to remove the rock; minimum tailings management; minimum remediation. However it is only applicable to certain geological formations. The ore must be located in permeable sands within sediments that allow effective confinement of the leach solution. The wells have to be cased where they go through aquifers. Australian examples of ISL are Beverley, Honeymoon and Four Mile East in South Australia. The particular risks from ISL are managed by Australia's In Situ Recovery Uranium Mining Best Practice Guide issued in 2010 by DRET.

After the ore is processed on site, the uranium ore concentrate (UOC), commonly known as "yellow cake", is transported in drums to ports for shipment overseas. Transport of nuclear material worldwide is governed by the IAEA Transport Regulations TS-R-1 and the ARPANSA Safe Transport of Radioactive Material Code RPS C-2 (December 2014) which is based on the IAEA Regulations. UOC is low radioactivity and the transport risks are minimal.

In summary, the risks with uranium mining differ from those associated with nuclear power plants. Australia has extensive experience of managing the risks from uranium mining, milling and transport.

Issues paper 2: Further Processing of Minerals and Manufacture of Materials Containing Radioactive and Nuclear Substances

Question 2.1

Could the activities of conversion, enrichment, fabrication or reprocessing (or an aspect of those activities) feasibly be undertaken in South Australia? What technologies, capabilities or infrastructure would be necessary for their feasible establishment? How could any shortcomings be addressed?

Response

Australia currently mines uranium and processes it on the mine sites to remove impurities. It is shipped abroad as Uranium Ore Concentrate (UOC or "yellow cake").

For UOC to be used in a typical nuclear power plant, the UOC has to be converted to uranium hexafluoride (UF6) gas for the input to an enrichment plant where the naturally occurring 0.7% U-235 is enriched to 3-5%. Enriched uranium hexafluoride is converted to high density uranium dioxide (UO2) pellets, which are fabricated into fuel assemblies and loaded into the reactor.

Australia could "add value" to their exports of uranium by conversion, enrichment and fuel fabrication facilities in Australia. The typical breakdown of fuel costs is 42% uranium, 4% conversion, 31% enrichment, 8% fuel fabrication. Current world prices for uranium, conversion and enrichment are low.

Conversion by itself would not be economic and uranium hexafluoride is a highly toxic material that is not ideal for transportation and shipping. Combined conversion and enrichment is a better option. Conversion is a chemical fluorination process and a suitable factory could be built in Australia. However the world market is dominated by Cameco (Canada), Converdyn (USA), AREVA (France) and Roseatom (Russia) and there is currently over-capacity in the market.

The only commercial enrichment technology currently employed is centrifuge (all the old gaseous diffusion plants are now shutdown). ANSTO's predecessor the Australian Atomic Energy Commission carried out extensive research into centrifuge technology in the period 1965-1983 and successfully developed centrifuges [1].

The South Australian Government set up a Uranium Enrichment Committee in January 1975 to advise it on the possibility of establishing uranium conversion and enrichment facilities in the State [1]. They concluded that a conversion/enrichment plant was feasible. The enrichment plant envisaged centrifuges based on URENCO design. The project was overtaken by other Australian studies, none of which eventually progressed.

Although centrifuge enrichment sounds a simple technology, in practice it is very difficult and the market (apart from Russia) is now dominated by URENCO technology (owned by the Governments of The Netherlands, Germany and UK). If Australia wanted to build an enrichment facility it would most likely have to be under licence from URENCO. Even AREVA had to do this with their new George Besse II enrichment plant in France. Again, there is currently over-capacity in the enrichment market.

A future possibility is laser enrichment. The SILEX laser enrichment technology was invented in Australia and in 2006 an agreement was signed with GE (USA) to commercialise the process. This has taken many years, but a small demonstration plant is now operating in the USA.

There was a lot of interest in enrichment plants in Australia in the 1970/80s, but no projects proceeded beyond the feasibility stage. Australia has probably now “missed the boat”, but there could be opportunities in the future. The technology is available, but commercial technology would have to be licenced.

References

[1] Enriching Experiences, Uranium Enrichment in Australia 1963 – 2008, Clarence Hardy (2008)

Issues Paper 3: Electricity Generation from Nuclear Fuels

Introduction

The matter of electricity generation from nuclear fuels is an option that should be considered as one of the potential options of the mix of energy sources. Clearly the world needs to progressively move away from fossil fuels towards low emission electricity. In the search of viable energy sources that provide secure supply and have a low carbon footprint, the nuclear power generation option has already been recognised by many nations as an energy source that provides secure, reliable supply.

The progressive development and security of human civilisation has in large part been based on technological advance and we see no real change in that process today. Across the world we observe various countries at all development stages from early to advanced, moving forward at varying rates of progress. The success of planned technological development and community welfare over the last few decades is best illustrated by South Korea with China currently the outstanding case study.

A major factor has been the development and utilisation of energy, with availability and progressive lowering of cost of electricity to all community sectors being a key factor. The fact that large scale base load generation of electricity from nuclear power provides one of the lowest cost options for overall control of all forms of pollution and carbon dioxide reduction has been understood by most progressive nations but lost or ignored by many others.

It has always been the case that only a small proportion of the population has sufficient technological education or understanding to be fully comfortable with complex technical developments. We can look back on many visionary developments which were derided, deemed unsafe, or rejected at the time of early introduction but are now acceptable mainly through familiarity if not full understanding. The history of technological rejection is resplendent with many examples from the printing press to the motor car. The generation and distribution of electricity itself was deemed unsafe but is now acceptable with a range of well understood safeguards and safety principles.

Edison himself claimed that: “Fooling around with alternating currents is just a waste of time. Nobody will use it, ever. It’s too dangerous.... It could kill a man as quick as a bolt of lightning. Direct current is safe”

Low emissions nuclear power has an important potential role in South Australia’s electricity generation mix. The development of nuclear power would:

- improve the resilience of South Australia’s energy system making energy supply more reliable and affordable,
- provide South Australia with long-term energy security,
- help South Australia move to a low carbon society and reduce its greenhouse gas emissions over the short medium and long term in the most cost effective manner, and
- help South Australia to become the innovative State by introducing new technologies and new industries.

Nuclear power would provide South Australia with an additional measure of energy security. In the long-term, South Australia may by example also be able to support other Australian States and help countries in the south east Asian region increase their own energy security through the adoption of nuclear power generation programs.

The development of large power stations, nuclear or otherwise, is unlikely to be required in South Australia in the near future, at least until existing baseload high emissions plant is retired and carbon reduction policies become mandatory. There is an international effort, particularly in USA, China, Russia, South Korea and Argentina to develop smaller, inherently safe, decentralised power stations with Small Modular Reactors (SMRs). The Introduction of SMRs is a technological evolution that is particularly suitable for South Australia. SMRs can provide a reliable and cost-effective source of baseload electrical power with incremental installation to suit increasing demand. Strategically located SMRs with unit outputs in the range of 25 to 300 MWe would provide system resilience and enhance South Australia’s energy security.

Electricity generation in South Australia suffers from the lack of reliable, dispatchable, baseload low emissions generation. The adoption of nuclear power would provide this generation.

Previous governments have taken significant steps to understand and consider nuclear energy. A federal parliamentary inquiry chaired by Geoff Prosser in 2006 found that “For the generation of continuous reliable supplies of electricity on a large scale, the only alternative to fossil fuels is nuclear power. Nuclear plants offer very low operating costs, security of energy supply and electricity price stability. Nuclear power is cost competitive with gas and coal-fired electricity generation in many industrialised countries.”

In 2006 the Uranium Mining, Processing and Nuclear Energy Review Taskforce, headed by Dr Ziggy Switkowski, also reported positively on nuclear opportunities. It considered nuclear energy to be practical, sustainable and able to be delivered in Australia within 10 to 15 years. The task force criticised complex overlapping State and Federal regulations for inhibiting industry efficiency and suggested simplifying the regulations.

The Howard Government sought to encourage the nuclear industry, seeing it as potentially viable even without a carbon penalty. The government committed to policies repealing legislative prohibition and supporting mining, research, new technologies including advanced generation four (Gen IV) reactors, skills increase and most importantly public communication. With the change of government in late 2007, work on nuclear options ceased and the focus shifted to climate change and emission reduction policies.

As chairman of the NSW Legislative Assembly Public Accounts Committee recent review of NSW energy policy, Jonathan O’Dea MP noted- “New energy technologies take time to develop and implement. Australia will suffer significant energy shortfalls over time, increase costs and greater pollution unless new technologies disrupt the current trends. It makes no sense for governments to arbitrarily rule out any form of power generation. Yet that is exactly what we have done to nuclear energy, which is relied on around the world to safely and effectively generate base load electricity. Governments at every level must work together to make sure legislation does not block possible answers to present problems.”

The following responses to the Issues Paper 3 questions and those noted in the appendix provide a summary of relevant information.

References

[1] World Federation of Engineering Organisations (WFEO), "Feasibility of Nuclear Power, revision 2" (2015); published by WFEO.

Question 3.1

Are there suitable areas in South Australia for the establishment of a nuclear reactor for generating electricity? What is the basis for that assessment?

Response

By Australian standards, South Australia has a massive land area with low population density. Many areas would be well suited for a nuclear power plant. Fig 2 in the issues paper shows that the extensive grid system in South Australia provides many opportunities for nuclear generation close to existing transmission lines.

Careful siting of nuclear facilities is an important part of a nuclear power program. It is one aspect that requires thorough analysis and interactions with local communities well ahead of any building decision. Any analysis supporting site suitability, although established at the onset of the project, needs to be revisited periodically throughout the life-cycle of the facility to confirm that the design continues to be adequate in the face of any changing site characteristics. Characteristics may also change resulting in a requirement for new analysis techniques.

Three significant factors distinguish sites suitable for nuclear plants from sites suitable for electricity generation by other means, as follows:

1. Nuclear plants require minimal ground space per MW of generation – in particular, much less area than wind farms or solar thermal power stations. This is illustrated by the example below of a NuScale Small Modular Reactor power plant. This plant can contain up to 12 x 50 MWe modules providing an output of 600 MWe on an 18 hectare site.

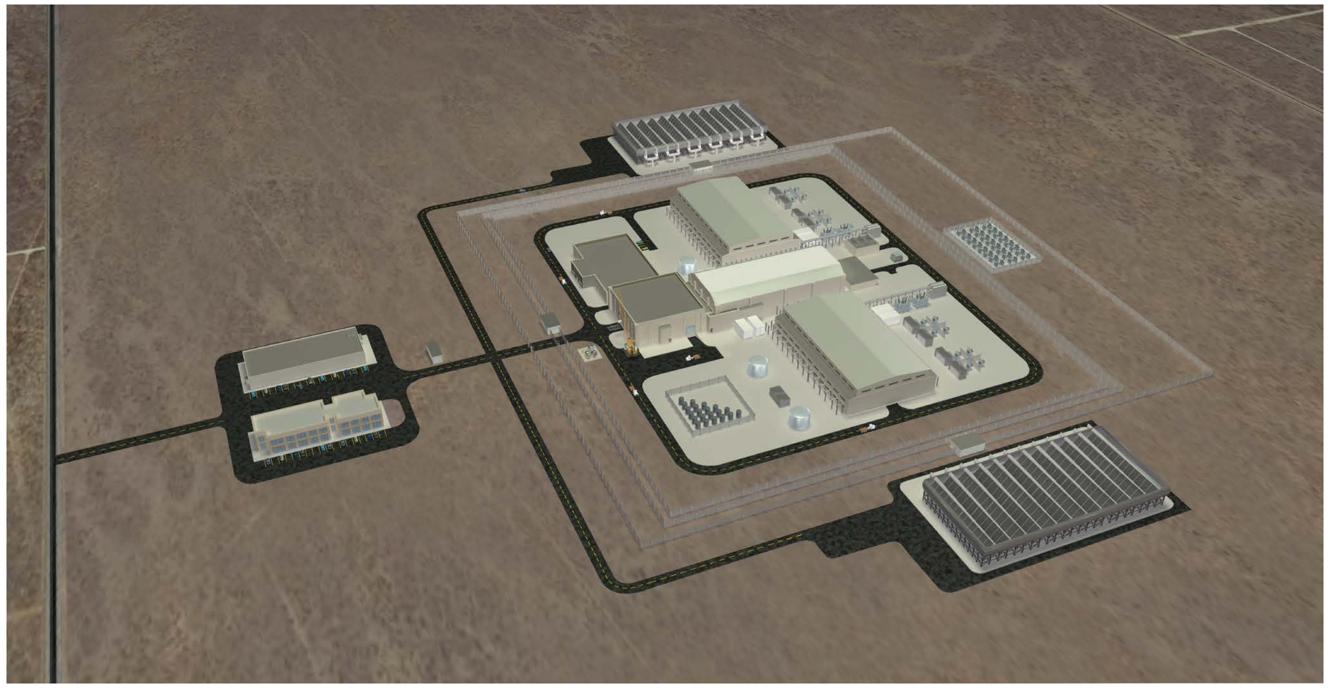

Fig 1: NuScale (USA) 12 modules site 600 MWe (12 x 50MWe modules) - 18 hectares

2. Nuclear plants require minimal local infrastructure for the supply of fuel. Hence, they can in principle be located close to load centres where the power is needed – rather than, for example, at the pit head (as for coal fired plants) or requiring reticulation of gas or electricity over long distances. To supply electricity to coastal cities, nuclear plants could therefore be located on coastal sites (with appropriate protection against flooding, e.g. by a tsunami) and would use sea water for cooling. For SMRs at inland sites, air cooling towers are used, as in the above NuScale illustration.

3. Nuclear plants contain substantial inventories of radioactive materials. Although, as explained in the answer to Q3.13, nuclear power would be one of the safest forms of electricity generation in South Australia (as well as being one of the most environmentally friendly) there is understandable public concern about safety. This will support pressure for remote siting, as was the practice in the early days of nuclear power generation, while siting close to urban load centres may be politically unacceptable.

An attractive first nuclear power plant for South Australia would be a small modular reactor, e.g. the NuScale SMR illustrated above requiring about 18 hectares for up to 600 MWe electrical output. The reactor complex would be below ground with a conventional turbine hall and support facilities above ground. Current assessments by NuScale, which are being examined by the US NRC, demonstrate that the emergency planning zone (EPZ) normally provided for nuclear power plants could be reduced to the site boundary. This relatively small footprint area gives great flexibility for location in South Australia. Studies in other countries, particularly in the USA, indicate that small modular reactor plants can be located on sites of retired coal-fired power stations to take advantage of existing infrastructure such as cooling water supply and grid connection. With the closure announced of some coal fired power plants in South Australia, this may be an option to consider.

Final site selection after feasibility studies options have been evaluated should be by expression of interest from local communities. Overseas experience has indicated that the expression of interest process ensures a full understanding of all ramifications of the construction and operation of nuclear facilities for that community. Generally the financial advantages of construction and operation and the payment of local rates and charges guaranteed for 50 years or more have been the deciding factor after all of the technical and environmental implications are understood by the community, after full consultation and education programs. A successful example of a voluntary site selection has been the Okiluoto nuclear waste storage and disposal facilities for Finland's nuclear power program.

Extensive international guidance and experience is available on the siting of nuclear power plants. The hierarchy of IAEA Safety Standards involves three levels.

Firstly the *IAEA Fundamental Safety Principles* (IAEA 2006) sets out the fundamental safety objective to protect people and the environment from the harmful effects of ionising radiation.

Supporting the *Safety Fundamentals* are *Safety Requirements*. The requirements for siting are listed in *Site Evaluation for Nuclear Installations* (NS-R-3, IAEA 2003).

Criteria for assessment and selection of suitable sites include:

- Health, safety and security factors
- Size of the site and vulnerability to extreme natural or man-made disturbance events
- Engineering and cost factors, including availability of cooling water, electrical infrastructure and distance to load centres
- Socio-economic factors
- Environmental considerations

Lastly *Safety Guides* provide assistance on how to comply with Safety Requirements. Several Safety Guides are associated with siting, e.g. *Seismic Hazards in Site Evaluation for Nuclear Power Plants* (IAEA 2010).

For nuclear facilities in Australia, ARPANSA has recently (Aug 2014) published its Regulatory Guide *Siting of Controlled Facilities*, based on the IAEA documents. Section 5 provides guidance on site selection and characterisation, including the evaluation of potential sites.

Siting criteria include:

- Site and regional characteristics that could obviously compromise safety
- Current and anticipated land use
- Cultural significance
- Economic significance; and
- Demographic considerations.

Conclusion

There is extensive international guidance and experience available for the siting of nuclear power plants and there are many suitable locations in South Australia.

Final selection of a site, after a range of feasibility study options have been considered and evaluated, should be by expression of interest from local communities.

Question 3.2

Are there commercial reactor technologies (or emerging technologies which may be commercially available in the next two decades) that can be installed and connected to the NEM? If so, what are those technologies, and what are the characteristics that make them technically suitable? What are the characteristics of the NEM that determine the suitability of a reactor for connection?

Response

There are several proven commercial reactor technologies and emerging nuclear technologies suitable for connection to the NEM. The characteristics of the NEM that would enable nuclear power to make a useful contribution are:

- **Insufficient lack of diversity in electricity generation technologies registered in the NEM.**
  - Historically the mix of generation was driven by the relatively low cost of fossil fuel generation and the limited opportunities for large hydro schemes. Coal generally and to this day has a cost advantage relative to other fuel sources. Reliance on fossil fuels has thus been very successful in providing cheap, reliable electricity supply in the past, but international moves towards low emission electricity generation technologies places Australia in an uncomfortable position. Nuclear power would provide diversity.
- **Proportion of baseload demand across the NEM.**
  - The optimal plant mix in the NEM is a function of the load demand curve. (AEMO SA load duration curves). Typically plant run as baseload has a 70% load factor in the NEM. Nuclear power is a baseload technology, high capacity factor (90%) generation technology which over time could replace fossil fuel baseload generation.
- **Current high greenhouse gas emissions**
  - The NEM has one of the highest kg CO_2-e/MWh emissions in the world, due mainly to the reliance on fossil fuels. Operating emission rates are published on a daily basis by the AEMO. The kg CO_2-e/MWH figures for a typical day in May 2015 were[1]:

NEM	917
VIC	1,213
NSW	911
QLD	873
SA	622
TAS	0

Although typically lower than Victoria, Queensland and NSW, the South Australian figure is still relatively high, in spite of the States 1,477 MW registered wind capacity. This is because of the intermittency of wind generation and the need for fossil fuel plant backup.

For the financial year 2013-14, AEMO reported that the electricity generation by fuel type in SA was 61% fossil, 33% wind and 6% solar.

There are no CO_2 emissions from the operation of nuclear power plants. This characteristic of nuclear power and good load following characteristics would make a significant contribution to the reduction of CO_2 emissions from electricity generation.

- **Increasing proportion of non-dispatchable generation**
  - The proportion of non-dispatchable generation in the NEM is increasing due to the increasing number of both wind turbines and solar PV generation. This leads to problems with system stability and the need for standby plant. A minimum amount of conventional synchronous generation is needed for stable system operation (300-400 MW). Nuclear power is reliable and dispatchable and could reduce this problem.
- **Increasing proportion of generation that is affected by the weather conditions**
  - Wind turbines are weather dependent. Although output can now be accurately forecast, there are recorded periods exceeding one day when the output is below 10% of rated capacity (Wind Energy in Australia daily wind energy production). For example there were two days in early June 2015 when the total wind energy production in the whole of Australia was less than 10% of rated capacity. Also the solar PV output varies rapidly with cloud cover. Nuclear power is unaffected by weather conditions.

Suitable nuclear power plants for the NEM

The large nuclear reactors that are being built for example in South Korea, China, USA and UAE are probably too large for the NEM and particularly for the small SA grid.

Country	Reactor	MW output gross	MW output net
South Korea UAE	KEPCO APR-1400	1,455	1,400
China USA	Westinghouse AP-1000	1,200	1,117

Nuclear power plants would run as baseload including overnight when demand is minimum, typically 1100 – 1500 MW in SA. The loss of a single large 1,000 MW nuclear unit could however cause loss of the SA grid stability. In some countries (e.g. Finland) the loss of a large nuclear unit is accommodated by an automatic load shedding scheme, but this might not be an acceptable approach for the small SA grid system.

Small Modular Reactor (SMR) are well suited to the SA system. “Small” by IAEA definition is less than 300 MWe but typically SMRs are ~ 100 MWe. “Modular” means assembled at a factory off site with the economy and high QA of factory mass production of a simple standard design. The complete reactor vessel is transported as one unit to the site, reducing site construction time and costs and reducing the probability of project delays. Initial investment is much less than that of a big reactor and modules can be easily added as extra capacity is required, thus deferring capital investment whilst operating units generate cash flow to support the additional modules when justified by load growth.

Many SMRs are designed to be multipurpose – in addition to electricity generation they can also be used for desalination or to supply process heat. An advantage of SMRs is their natural (passive) safety. No electrical supplies or pumps are required to cool the reactor, this is achieved by natural convection and gravity coolant feed. This feature ensures the reactor remains safe, even under the most severe accident conditions. SMRs are simpler to operate and maintenance costs are reduced. The reactor containment can be installed below ground providing protection against external hazards and unauthorised interference.

There is extensive experience of much of the technology employed by SMRs. For many years they have been the power supply for submarines and icebreakers where totally reliable power is essential. SMRs based on proven PWR technology include:

Country	Reactor	Module size	2015 Status
USA	Generation mPower	180 MWe	Basic design completed
USA	NuScale	45 MWe	Design certification application scheduled for 2016
South Korea	KAERI SMART	100 MWe	Design approval 2012, first construction expected soon
Argentina	CNEA/INVAP CAREM	27 MWe	Under construction, operation scheduled for 2017
Russia	KLT-40S	35 MWe	Floating plant under construction, deployment 2016
China	CNNC/NPIC ACP-100	100 MWe	Design completed, start of construction expected 2015

Also under development are SMRs using Gen IV technology which will be available by 2020-2025.

Fast Neutron SMRs are very compact due to the high conductivity liquid metal coolant and they operate at higher efficiencies due to their higher operating temperatures. An example is the Toshiba 4S, a 10 MWe SMR designed for remote locations that currently rely on expensive diesel generators. The 4S can operate for 30 years before refuelling is required.

Very High Temperature Gas Reactors use helium as coolant with outlet temperatures up to 900oC and TRISO fuel. Following the experience of operating the 10 MWTh experimental VHTR at the Institute of Nuclear and New Energy Technology (INET) in China since 2000, two 105 MWe demonstration units are now under construction in Shandong Province.

Another emerging technology is the Integral Fast Reactor (IFR). This recycles the spent fuel from the current Generation II light water reactors in a Sodium Cooled Fast (SFR) reactor to produce electricity and reduce the current stocks of spent fuel. An example is the GE-Hitachi PRISM being considered for burning the UK plutonium stocks and producing 311 MWe [2]. The resultant waste from a fast reactor is significantly reduced, much shorter lived and easier to manage.

Conclusion

A nuclear power plant consisting of one or more SMRs could make a valuable contribution to baseload low emissions electricity generation in the NEM. Although a baseload plant, the output can be adjusted up and down at typically 10%/min (NuScale) to respond to changing grid demand or variations in renewables supply. If necessary, the turbine condenser can be air-cooled so that the plant does not have to be located where there are large cooling water supplies. This allows a wide range of plant locations to suit the NEM requirements.

Reference

[1] AEMO 2015 CO^2 EII summary results http://www.aemo.com.au/Electricity/Settlements/Carbon-Dioxide-Equivalent-Intensity-Index

[2] http://gehitachiprism.com/

Question 3.3

Are there commercial reactor technologies (or emerging technologies which may be commercially available in the next two decades) that can be installed and connected in an off-grid setting? If so, what are those technologies, and what are the characteristics that make them technically suitable? What are the characteristics of any particular off-grid setting that determine the suitability of a reactor for connection?

Response

There are a number of examples worldwide where off grid nuclear power is a viable option compared with diesel. However most of these have special requirements, for example the Arctic regions of Russia and Canada. The current low price of diesel fuel and the potential introduction of low-cost refined coal/water fuel for large diesel power generation plant militates against the introduction of nuclear power in Australian off grid situations without a price on carbon. Any concept for off grid in South Australia would need a detailed feasibility study for the specific location.

Nonetheless, under development are SMRs using Gen IV technology, which will be available by 2020 - 2025 and would be more suitable for remote locations.

Fast Neutron SMRs are very compact due to the high conductivity liquid metal coolant. They operate at higher efficiencies due to their higher operating temperatures. An example is the Toshiba 4S which is a 10 MWe SMR designed for remote locations that currently rely on expensive diesel generators. The 4S can operate for 30 years before refuelling is required.

Very High Temperature Gas Reactors use helium as coolant with outlet temperatures up to 900oC and TRISO fuel. Following the experience of operating the 10 MWTh experimental VHTR at the Institute of Nuclear and New Energy Technology (INET) in China since 2000, two 105 MWe demonstration units are now under construction in Shandong Province.

In an off-grid application, most nuclear power plants would still require a small diesel generator to supply start up power for the reactor.

There could be other advantages of using nuclear power off-grid. Nuclear fuel costs and volumes are low compared to coal, gas and diesel. With a mine site SMR there is an incentive to convert as much mine machinery as possible to electric drive and automated operations to save costs on fossil fuels.

Question 3.4

What factors affect the assessment of viability for installing any facility to generate electricity in the NEM? How might those factors be quantified and assessed? What are the factors in an off-grid setting exclusively?

How might they be quantified and assessed?

Response

Factors affecting the viability of generating facilities are economic and physical.

Economic factors

In current NEM economic conditions no baseload investment is warranted due to oversupply and the low wholesale price of electricity. NEM problems are well covered by an Energy Australia submission (21 Feb 2014) to the Energy White Paper issues paper - quote "The National Electricity Market (NEM) recently celebrated fifteen years since its creation. While recognised by some as a successful microeconomic reform, experience has demonstrated that it is a market subject to serious government intervention that struggles to deliver long-term marginal cost to investors over time. While customers have benefited in the short term from unsustainably low wholesale prices, there are likely to be longer term consequences. Unlike the generation sector, the return of long run marginal costs to networks is enshrined in legislation".

The current NEM average commercial return barely covers operating costs with no allowance for capital investment return. In fact the above paper notes that 50% of Australian generators actually lost money in 2013. New investment is thus unlikely without additional payments in some form or another.

Based on a NEM wholesale market price of $60/MWh and the AETA 2013 LCOE for the various technologies in 2020 [1], estimated additional payments required are as follows;

Low emissions technology	Mean AETA 2013 LCOE $/MWh	Additional payment $/MWh
Solar photovoltaic non-tracking non-dispatchable	$120	$60
Wind onshore non-dispatchable	$80	$20
Solar thermal with storage dispatchable	$160	$100
Nuclear dispatchable	$130	$70

Thus an additional payment of around $70/MWh is required to warrant nuclear investment under current NEM rules and regulations, subject to a feasibility study.

For comparison, one of the contracts following the 2015 ACT Government reverse auction for wind power was awarded to Hornsdale wind power [2]. The ACT will pay a Feed-in Tariff of $92/MWh for 100 MW, which using the $60/MWh NEM wholesale market price would imply an additional payment of $32/MWh for non-dispatchable wind power.

It is useful to look at the impact of renewables, operating at zero marginal cost, on electricity markets worldwide. Wind transfers the weather risk and costs to the rest of the system. The paper by Darwell [3] examines the situation in the UK where market wholesale prices have been driven down and the cost of new investment cannot be recovered.

An overall oversupply situation has been evident for the 15 year history of the NEM. As the balance moves toward undersupply due to either generation retirements and/or load increases, prices in the pool will rise very quickly. Supply imbalance produces short term elevated prices. In future years these may become more common place. With the existing structure of the NEM, it is difficult for any potential power station investor to predict, with any accuracy, long term prices beyond a few years.

The NEM structure has been encouraging investment in low capital cost/low fuel efficiency Open Cycle Gas Turbines (OCGTs) to counteract the volatility of the non-dispatchable wind and solar PV. The NEM structure will not encourage more investment in base load generation (nuclear or otherwise) until non-dispatchable intermittent generators are required to fund or provide firm capacity.

As the NEM is an energy-only market, it does not differentiate between the dollar value of MWhs produced from dispatchable and non-dispatchable generation. Dispatchable MWhs are of very enhanced value because of the reduced backup requirements. While additional payments for nuclear generation would speed up implementation, better overall economic outcomes would be achieved for customers if the NEM was modified to reflect the different values of dispatchable and non-dispatchable generation.

Physical factors

The physical constraints for nuclear power generation relate principally to the maximum unit size that can be effectively installed in any part of the grid and the realistic exclusion zones that may be required for those particular installations. In general a move towards the use of SMRs with unit sizes up to 300 MWe allows flexibility in meeting these requirements particularly in South Australia, subject to appropriate geotechnical conditions and transport logistics.

There are a number of examples from around the world where off grid supply of electricity using nuclear power is a viable option compared with the use of diesel engine power generation, but most of these installations have special requirements (for example the Arctic regions of Russia and Canada). The current low price of diesel fuel and the potential introduction of low-cost coal/ water fuel for use in large diesel power generation plant militates against the introduction of nuclear power in off grid situations in Australia. Any concept for off grid nuclear power generation in South Australia would need to be the subject of a detailed feasibility study for the specific location under consideration.

Conclusion

Investment in any new generation in the NEM is subject to acceptable long-term market pricing.

References

[1] Australian Energy Technology Assessment 2013 update http://www.industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/aeta/AETA-Update-Dec-13.doc

[2] http://www.environment.act.gov.au/energy/wind_power

[3] Central Planning with Market Features, Centre for Policy Studies (UK), Rupert Darwell, March 2015

Question 3.5

What are the conditions that would be necessary for new nuclear generation capacity to be viable in the NEM? Would there be a need, for example, for new infrastructure such as transmission lines to be constructed, or changes to how the generator is scheduled or paid? How do those conditions differ between the NEM and an off-grid setting, and why?

Response

The major conditions necessary for a nuclear power installation include an off-take agreement, Feed-in Tariff, or market price, or market price and additional payments at least matching the levels noted under question 3.4 above.

With a wide range of potential sites available, only minor costs for HV grid connection are required. In the United States, some coal-fired power stations are considering installing SMRs on their sites to replace old capacity and take advantage of the available skilled workforce and infrastructure. This could be a sound strategy for South Australia.

There is no doubt that remote nuclear power will become a viable Australian proposition. However a development period is needed to achieve reliable automatic or remote operation. This level of sophistication will probably be achieved at an acceptable cost within the next 20 years.

Conclusion

A small modular reactor could be sited close to existing transmission lines minimising the cost of new infrastructure.

The viability of new nuclear generation would depend on an economic off-take agreement or long-term NEM wholesale market price at a level to at least cover the plant LCOE.

Question 3.6

What are the specific models and case studies that demonstrate the best practice for the establishment and operation of new facilities for the generation of electricity from nuclear fuels? What are the less successful examples? Where have they been implemented in practice? What relevant lessons can be drawn from them if such facilities were established in South Australia?

Response

Many excellent management and engineering practice examples can be drawn from nuclear power installations worldwide, but most of the overseas examples relate to very large installations which are inappropriate for South Australia. The most relevant study example is the establishment, commissioning, and operation of the OPAL research reactor at Lucas Heights, New South Wales, in which Australian engineering and management skills were partnered with international capabilities.

The reason for this relevance is many faceted:

- The first SA nuclear power station would most likely use SMR technology and be built underground. OPAL is of similar physical size and partially underground.
- Overall, OPAL is more technically complex than any current SMR design, although it would have some physically larger components requiring carefully planned transport logistics. The OPAL reactor is a complex multipurpose facility providing neutron beams for scientific research, silicon irradiation facilities for the semiconductor industry and molybdenum irradiation for

the production of radiopharmaceuticals. The integration of these facilities in one reactor installation was a significant engineering feat.

- The OPAL and SMR approval and installation program timeframe would be similar
- OPAL was supplied from Argentina and installed under a design/construction partnership contract using local construction companies. The first reactor modules for a South Australian nuclear power station would also be sourced from overseas and installed by the vendor with assistance from the local workforce.
- OPAL was approved and built under an Australian regulatory regime as would a new nuclear power station constructed in South Australia.
- Over 50% of the value of OPAL utilised Australian construction and manufacturing capability. A similar proportion should be achieved for a SMR in South Australia.
- The OPAL project was fully managed by an Australian client team comprising experienced project managers supported by ANSTO technical staff.

Many lessons arose from this very successful local example and the key outcomes and recommendations can be summarised as follows:

- The development of a nuclear power program in South Australia is a straightforward engineering application similar to other complex process plants of similar value.
- An experienced client project management team overseeing all aspects of the project is vital. That experience should extend to long experience in adapting overseas technology to conform to local Australian conditions and regulations. High level project and contract management skills are the key requirement with specialist nuclear expertise supplied by supporting staff. This is no different from any other technically complex project using imported technology.
- A two-stage specification development process is required covering initial expressions of interest leading to preliminary selection of the power reactor and steam plant supplier followed by final detailed specification , contracting and pricing agreements. While initial cost is important life-cycle costing is the ultimate selection criteria. Many factors require analysis to achieve accurate life-cycle costing.
- The client team must control directly the management of balance of plant and civil engineering design in conjunction with the reactor supplier. Australia has a wealth of consulting engineering groups to support detail design. These are best managed by the client and not under a design/construct model by construction contract groups with other core skills.
- Management of balance of plant contracting plan and construction implementation must be carried out by the client team.
- Management of local regulatory approval is best managed by a combined client and reactor supplier team.
- Commissioning and initial operator training in conjunction with the reactor supplier must be managed by the client team and the new operations group management.
- The only committee associated with the project should be a risk management group with a range of participants with diverse but relevant practical experience.

The OPAL client management team operated under the constraints of a single design/construct contract for the balance of plant components and civil, mechanical, and electrical construction. Unfortunately the Australian contractor was not sufficiently experienced with work of this nature which led to a range of less than satisfactory outcomes. While these outcomes did not directly impact safe operation of the reactor itself they led to avoidable complexities with long-term operation of the facility as a whole. A less than optimal balance of initial capital cost and long-term operating cost has been the outcome with a range of potentially difficult maintenance issues for the future. The client management team spent an unnecessary proportion of its time on specification conformance and contract resolution issues with the Australian construction contractor.

There are many examples where forcing project risk down to contractors or parties not competent or sufficiently skilled to manage such risk leads to poor project outcomes. In complex engineering projects there is a need for the client to accept responsibility for major decisions at the highest level after careful evaluation of all the factors involved other than simply lowest possible cost.

IAEA Milestones Program

The IAEA provides excellent guidance for the establishment of a nuclear power program.

The Milestones Program [1] identifies the key infrastructure issues to be considered, for examples the regulatory framework, safeguards, human resources development and environmental protection etc. An important first step for South Australia would be the establishment of a Nuclear Energy Program Implementing Organisation (NEIPO) to examine all these issues. Fortunately for South Australia much of the program infrastructure is already in place, for example the safeguards system.

Conclusion

The OPAL development at Lucas Heights provides an excellent management example for an SMR nuclear power station in South Australia. Extensive international guidance is available from the IAEA to assist in establishing a nuclear power program in South Australia.

References

[1] IAEA Nuclear Energy Series NG-G-3.1 Milestones in the Development of a National Infrastructure for Nuclear Power

Question 3.7

What place is there in the generation market, if any, for electricity generated from nuclear fuels to play in the medium or long term?

Why? What is the basis for that prediction including the relevant demand scenarios?

Response

Nuclear power generation must play an important role based on the key factors of security, electricity cost, baseload capability and system emissions.

Environmental factors

Clearly the world needs to progressively move away from fossil fuels towards low emissions electricity. Fifty years ago key drivers were the extent of particulate and sulphur dioxide pollution from coal fired power stations and the need to conserve natural gas for petrochemical and plastics feedstock production. While engineering developments to minimise coal-fired power station pollution and petroleum exploration have lessened these concerns, a more fundamental understanding of the role of carbon dioxide in the earth's environment has strengthened resolve to move away from fossil fuels when economically feasible to do so.

Countries understanding the need for low-cost electricity for economic growth and population benefits, with minimum environmental impact, have already moved to nuclear power.

A standout example is South Korea moving over the last few decades to strong economic growth based on nuclear energy and low-cost electricity for its industry and people.

Energy Security

Australia defines energy security too narrowly on economic harm which is risk managed through the market, and gives insufficient attention to the fact that energy security is a multi-dimensional concept intertwined across the social, political, economic and environmental spectrum. In 2014 Engineers Australia released a policy report on energy security titled; "Energy Security for Australia: Crafting a comprehensive energy security policy" which called for all energy stakeholders to move beyond the commodity view of energy to a systems view. Specifically the report identified the inadequacy of the current definition of energy security and recommended the following definition:

"Energy security is the adequate, reliable and competitive supply of sustainable, low-carbon energy and energy services at global, national and local scales; across short, medium and long-term timeframes; and in the context of minimising consumption and demand, maximising energy intensity, and balancing the trade-offs and complementarities between energy and other security referents of value, notably the four key domains of 1) national economic and national security, 2) food and water security, 3) sustainable development and environmental security, and 4) social stability and energy stress." [1]

Uncertainty in the Australian energy futures is one of the many reasons why Australia needs to ensure that resilience and security are core components of our national energy and infrastructure strategy. This is a policy consideration that must involve coordination across sector, portfolio and jurisdictional lines ensuring that there are no unintended consequences which unnecessarily increase vulnerabilities, threats and risks to Australia's energy security. Energy security comes from diverse portfolio management of energy sectors and does not seek a 'silver bullet' by preferential investment in an industry to the exclusion of other sources of energy. Therefore, consideration of nuclear energy as a new competitor in energy generation and a low carbon form of energy will enhance economic and environmental security. The nuclear energy supply chain could be contained within Australia through it's life cycle therefore avoiding future geopolitical issues affecting global supply chains.

Australian governments and energy security stakeholders must consider nuclear energy in a framework of comprehensive energy security. While Australia has reaped significant benefits from the ready availability of cheap and abundant fossil fuel, it has given a competitive advantage to energy-intensive industries as well as to other sectors of the economy and society. The reliance on fossil fuel based energy because of its availability introduces a major economic vulnerability in the economy. If significant global action on greenhouse gas reductions occurs, the consequences for Australian energy exports and even Australian goods and services due to their high carbon footprints may be severe. Australia may not have a sustainable future if the nation remains tied to a fossil fuel based energy system which can rapidly become marginalised by global society and undermines the environmental health of future generations. Embracing nuclear generation of electricity will avoid these potential security failures.

Comparison

The role nuclear power must play needs to be based on key factors including security, electricity cost, baseload capability, and systems emissions. An analysis of these factors for South Korea [2] is as follows:

	Nuclear	Coal	Wind	Hydro	Gas	Oil	Solar
Cost $/MWh	30	39	97	103	110	148	498
Availability (energy security)	High 90%	High 90%	Low 30-40%	Low Water dependent	High 90%	High 90%	Low 20%
Baseload	Yes	Yes	No	Yes	Yes	Yes	No
System CO_2 emissions	Low	High	Low/ Medium	Low	Medium	High	Low/ Medium

Note – Wind and solar system emissions are listed as low/medium since the back-up generation could be hydro (low) or gas (medium).

Conclusion

Nuclear power would provide the most cost-effective base load, low emissions electricity generation for South Australia based on current overseas experience. Australian governments and energy security stakeholders must consider nuclear energy in a framework of comprehensive energy security.

References

[1] Greet N and Yates, A, Energy Security for Australia: Crafting a comprehensive energy security policy, Engineers Australia Policy Report 4 Dec 14 p31.

[2] Present and Future of Nuclear power in Korea, Jong-Shin Kim, President and CEO Korea Hydro & Nuclear power Co. October 2009.

Question 3.8

What issues should be considered in a comparative analysis of the advantages and disadvantages of the generation of electricity from nuclear fuels as opposed to other sources? What are the most important issues? Why? How should they be analysed?

Response

Advantages

Diverse energy security

The utilisation of a mix of all low emissions electricity generation technologies will be essential to achieve long-term greenhouse gas emissions targets. A problem with one technology (as is now demonstrated with the reliance on coal and the emergence of climate change as a major issue) can be a major disruption for an industry that relies on long-term planning and capital investment. The Energy White Paper supports a technology neutrality approach to future electricity supply, enabling all technologies to be considered. This position is strongly endorsed.

As referred to in the response to Question 3.7 Australian governments and energy security stakeholders must consider nuclear energy in a framework of comprehensive energy security.

Baseload, high capacity factor

The types of plant in the NEM that provide the baseload, dispatchable power are coal, gas and hydro. Only hydro is a low emissions technology and any increase in hydro generation is limited due to the scarcity of available sites given the exploitation of the Snowy Mountains and Tasmania. Nuclear power is a baseload, high capacity factor technology. Baseload power is essential for major industrial and commercial loads.

Low greenhouse gas emissions

On a lifecycle basis, including mining, enrichment, construction and operation, greenhouse gas emissions for nuclear power is comparable to other low emissions technologies, particularly solar and wind. This has been extensively studied by the IPCC [1], NEI [2], OECD [3] and UMPNR [4]. (see response to Question 3.11 for further details). If system factors are taken into account, then emissions from weather dependent technologies like wind and solar can be much higher, depending on the backup technology. For South Australia this is currently coal and gas. This would change with nuclear backup.

Up to 2009, nuclear generation worldwide has saved 64,000 million tonnes of CO_2-e emissions, equivalent to 320 years of Australia's current generation emissions [5].

Climate change scientists at the University Adelaide, NASA, Massachusetts Institute of Technology and Carnegie Institution have put on record their assessment that the only way to avoid a significant rise in world temperature is to develop nuclear power generation [7].

Compact site

Nuclear is a very dense source of power in terms of fuel requirements and real estate needs. A nuclear power plant requires a relatively small area per unit output. The 600 MWe NuScale SMR occupies 18 hectares (see illustration in response to Question 3.1). This reduces site costs and offers flexibility in location.

Not weather dependent

Nuclear power operates day and night, regardless of the weather.

Multipurpose

New generation reactors can be multipurpose, supplying not only electricity but also process heat and desalination. For example the China National Nuclear Corporation/Nuclear Power Institute of China ACP-100 SMR has been designed to supply 100 MWe and 12 million litres/day desalination and 420t/h steam at 3.5 MPa and 250oC.

Sodium Fast Reactors (SFR) operate at temperatures of 550oC enable the production of heat for industrial processes such as petroleum refining, oil shale and oil sand processing.

High Temperature Gas Reactors (HTGR) operate at up to 900oC providing heat for higher temperature processes such as hydrogen production, coal gasification and steam reforming of natural gas. The 110 MWe HTR-PM High Temperature Gas Reactor under construction at Shandong, China is scheduled to begin operating in 2016.

Remote locations

Nuclear power plants can be located in remote locations where fossil fuel transport is expensive or where it is uneconomic to construct a new gas pipeline. The turbine condenser can be air cooled where adequate cooling water is not available.

Low fuel costs and fuel security

Fuel costs are typically only 25%-30% of nuclear power production costs, compared to 70%-80% for coal and gas plants, making nuclear less sensitive to fuel cost variations.

The energy density of nuclear fuel (Uranium 235) is far greater than that of fossil fuels. Approximately 27 tonnes of uranium fuel is required each year by a 1000MWe nuclear reactor; in contrast a coal fired power station burns over two and a half million tonnes of coal for the same electrical output [6]. Nuclear power plants keep at least two years' supply of fuel assemblies on site, providing security against supply interruptions.

Long plant lifetime

Modern nuclear power reactors are designed with a sixty year life.

Proven technology

There is over sixty years' experience of nuclear power reactor operations, particularly light water reactors (LWRs) which make up 82% of the 439 power reactors operable worldwide (ENS Jan 2015). The majority of these (63%) are Pressurised Water Reactors (PWRs).

Sustainability

World proven uranium resources are adequate for over 100 years in LWRs [8]. In addition there are uranium and plutonium sources from reprocessing spent fuel and uranium from nuclear weapons programs, particularly Russia, downblended for commercial power reactors.

The Integral fast Reactor (IFR) recycles spent fuel enabling 150 times more energy to be extracted from the original uranium. Large stores of spent fuel are available worldwide for this process.

Thorium is four times more abundant in the earth's crust than uranium. The technology has been demonstrated in the UK, Germany and the USA but was discontinued due to the abundance of uranium. Thorium is now being revisited, particularly in China. Australia (ANSTO) is assisting with this work.

Finally, progress is being made towards commercial fusion through the International Thermonuclear Experimental Reactor (ITER) being built in France. A one GW fusion plant would require only 125 kg/year of deuterium and 125 kg/year of tritium for fuel.

Regulation

The International Atomic Energy Agency (IAEA) establishes the standards and international best practices for the nuclear industry worldwide. Australia has a permanent seat on the IAEA Board of Governors and plays an important role in establishing and maintaining these standards.

There is extensive international experience of nuclear regulation and already competent, well established Australian nuclear regulators (see responses to Questions 3.10 and 3.14).

Advantages of Small Modular Reactors (SMR):

- Suitable for small grid systems and remote locations
- Smaller reactors can be easily cooled by natural (passive) systems using gravity and natural convection
- The reactor vessel can be installed below ground level providing protection against external hazards (including aircraft) and unauthorised interference
- The reactor module is factory built, with the economy and high QA of factory mass production and standardised design
- Factory build of the reactor module minimises on-site construction and reduces project delays
- Simple design to operate and maintain, with low maintenance costs for passive cooling systems
- Smaller initial capital costs compared to a large reactor
- Modules can be added as demand increases so limiting the need for unduly early capital investment while cashflow returns from the first modules provide for additional modules as required by load growth
- There is extensive experience of the most common technology (PWR) employed by SMRs. For many years SMRs have been used for submarines and icebreakers where totally reliable power is essential

The Commonwealth of Australia 2006 Uranium Mining Processing and Nuclear Energy Report examined nuclear power and concluded that it should be considered as an option [7].

Disadvantages

Nuclear Liability

Adequate funds have to be available to satisfy liability claims for personal injury and property damage in the event of a nuclear accident. Because of the potential for cross border consequences, an international nuclear liability convention is required. There are a number of international instruments (e.g. Paris Convention, Vienna Convention) but at present no Convention to which all countries are contracted. The best possibility is the Convention on Supplementary Compensation for Nuclear Damage which came into force on 15 April 2015. Australia has signed (but not ratified) this Convention.

Nuclear power plant owners pay for insurance, typically up to a set level, while the State is responsible for higher levels. For example the Price-Anderson Act in the USA requires owners of power plants to take out a first tier insurance for $375m. There is also a second tier available where every reactor owner would pay a prorated share of the excess up to $127.3m each. The second tier would currently provide $13.2 billion. The average annual premium is $830,000 for a single reactor unit, with a discount for more than one reactor on a site. These are for very large USA reactors and it is likely that the premium for a Small Modular Reactor with passive safety would be lower, but still a significant cost.

In Australia there is an unlimited Commonwealth Government nuclear liability covering the ANSTO activities in particular.

However the nuclear liability system also has an advantage for anyone affected by a nuclear accident in that there is absolute operator liability regardless of fault. The claimant only has to prove a causal link between the incident and damage.

Legislation

The major legal obstacle to the deployment of nuclear power in Australia lies in the two pieces of Commonwealth legislation that prohibit the licensing of a nuclear power reactor in Australia.

The Acts are:

- Environmental Protection and Biodiversity Conservation (EPBC) Act 1999 section 140A
- Australian Radiation Protection and Nuclear Safety (ARPANS) Act 1998 section 10

There are also specific prohibitions in three States (NSW, QLD, VIC) but not in South Australia.

Engineering Disadvantages

There are no intractable engineering disadvantages associated with the introduction of a nuclear power program in South Australia as demonstrated by numerous examples around the world.

For example even though South Australia is in a mild seismic activity area, all nuclear reactors (including the OPAL reactor at Lucas Heights) are designed to international seismic standards. Even at Fukushima, all reactor seismic protections worked correctly and no reactors were damaged by the seismic event itself. They were damaged by the following tsunami. Nuclear power plants in Japan that were also affected by the tsunami (eg Onagawa) survived because, unlike Fukushima, they had an adequately engineered seawall to protect against a tsunami.

Radiation

Radiation is part of our everyday environment, in the atmosphere, ground, food and radon, plus additional radiation from flying, medical diagnosis and treatment etc. This is explained further in the response to Question 3.13

Safety

Two steps have to be taken to make a reactor safe in an emergency situation:

1. Stop the nuclear fission (chain reaction) by inserting neutron absorbing control rods into the reactor. This operates on a failsafe basis and even in the case of Fukushima all control rods inserted and the nuclear reaction stopped.
2. The reactor continues to produce some heat after shutdown and this residual heat has to be removed. Old reactors like the type at Fukushima, typically rely on pumped water and back up diesel electrical supplies to ensure reactor safety. Modern reactors employ natural (passive) water cooling by gravity feed and natural convection and conduction. These systems are within the reactor containment, protected from external hazards, and do not depend on external electrical supplies. Similar to the OPAL reactor at Lucas Heights, the NuScale SMR illustrated in the response to Question 1 sits in a large pool of water which removes the heat in an incident. There is no operator action required and no external electrical supplies required.

Even when considering old technology, historically, nuclear power is one of the safest technologies for the generation of electricity [9]. The relative safety is reflected in a study commissioned by Friends of the Earth in the UK [10] which concluded that:

“overall the safety risks associated with nuclear power appear to be more in line with lifecycle impacts from renewable energy technologies, and significantly lower than for coal and natural gas per MWh of supplied energy”.

Proliferation

Some people are concerned that a nuclear power program would be a route to a nuclear weapon. There are two routes to a nuclear weapon:

1. Highly enriched uranium, requiring >80% enriched U-235. Natural uranium contains 0.7% u-235 and it is enriched to <5% for commercial nuclear reactor fuel. It would be useless to divert commercial nuclear reactor fuel for use in a nuclear weapon.
2. Plutonium, requiring quite pure plutonium-239. The majority of reactors worldwide are light water reactors, refuelled off-load, every 12 – 18 months or more. After radiation in the reactor, commercial spent fuel contains Pu-239, Pu-240, Pu-241 and other higher actinides rendering it unfit for a nuclear weapon.

The IAEA Non-Proliferation Treaty safeguards system, to which Australia already reports, tracks all nuclear material – see response to Question 3.14

Economics

The Australian Government Bureau of Resources and Energy Economics (BREE) Australian Energy Technology Assessment 2013 LCOE figures [11] for Australian conditions show that nuclear is one of the lowest cost baseload low emissions technologies for the generation of electricity.

The initial capital cost in particular is perceived to be high, but comparisons often do not take into account the effects of capacity factor on true capital costs.

The table below compares the NuScale SMR with the latest renewable energy projects:

Plant	Output MWe net	Capital cost A$m	Cost/MWe A$m	Capacity Factor	Comparative cost/MWe for 90% CF A$m
NuScale SMR (6 modules) [14]	285	1425	5*	90%	5*
Hornsdale wind [15]	270	900	3.33	44%	6.8
Boco Rock wind [16]	113	361	3.2	35%	8.3
Royolla solar [17]	20	60	3	21%	12.8
Broken Hill/Nyngan solar [18]	155	440	$2.8	25.7%	9.8

On a realistic comparison of capital costs/MWe, nuclear is seen to be competitive. A NuScale plant has not yet been constructed, therefore the estimated cost (*shown here in USD) still has to be proven, although NuScale has carried out detailed cost studies.

True comparisons of capital cost have implications for the cost of CO_2 abatement. To achieve an abatement of say 15,000 GWh/year (the probable requirement to reach current emissions targets) would cost less for nuclear than for non-dispatchable wind, assuming that enough very high capacity factor wind sites can be found like Hornsdale.

In carrying out true economic assessments, the matter of intermittency of renewable energy supplies needs to be factored into comparisons. Supply from intermittent sources needs to be balanced with fast-responding generation, such as hydro where it is available, or alternatively with open-loop gas turbines. Accordingly, where intermittent supplies are relied on, the capital cost of a firm supply needs to be included in the comparison. As described in response to Question 3.2, SMRs have the capacity to respond quickly and thus provide the fast responding generation required.

Radioactive waste

Solid radioactive waste produced directly from operating a nuclear power reactor is low level waste (LLW) and intermediate level waste (ILW). See IAEA Classification of Radioactive Waste GSG-1. Typically, the waste for a 1 GWe nuclear power plant is $150m^3$/yr LLW and $8.6m^3$/yr ILW [13]. LLW is produced during day to day operations and consists of paper, cleaning papers, non-reusable clothing, filters and resins. This waste is sorted, compacted and packaged on site into drums. The ILW is mainly resins from radioactive water treatment systems and metallic waste from maintenance. It has higher levels of radioactivity and is stored in shielded containers. Solid radioactive waste is normally stored on site until a central repository is available.

Gaseous and liquid wastes are produced during routine operation and are treated to limits specified by the nuclear regulator before discharge.

Typical gaseous radionuclides are tritium, noble gases, iodine and turbine off-gases. Gaseous wastes are collected, retained for 45-60 days to allow short lived emitters to decay, then filtered and monitored to be within discharge limits before release to the atmosphere via a vent stack. Gaseous waste discharges are well within annual authorised limits. As an example, for a twin French 1300 MWe PWR the gaseous release is < 50 TBq/yr with an annual authorised limit of 1650 TBq/yr.

Liquid waste is produced by activation of chemicals (eg lithium) in the primary cooling circuit, activated corrosion products from reactor materials and non-aqueous liquid waste, e.g oil. Liquid waste is collected, monitored, filtered and treated by ion-exchange resin/evaporation/reverse osmosis. Liquid waste is converted to solid whenever possible. The final liquid is monitored and discharged within limits. Average liquid annual discharge for a twin 1300

MWe PWR is <24 TBq tritium (annual limit 80 TBq/yr) and < 3 GBq all other liquids (annual limit 1.1 TBq/yr)

There is over fifty years' experience of routine nuclear power plant low level gaseous and liquid discharges with no effects to the local communities or the environment. All nuclear power plants conduct routine environmental monitoring in the vicinity of the plant and the results are published.

There is no high level waste (HLW) produced from the day to day operation of a nuclear reactor. HLW is highly radioactive and is also defined as having a heat output of >2 kW/m^3.

Reactors have to be routinely refuelled and the discharged fuel, referred to as spent fuel, is highly radioactive. If spent fuel is not reprocessed it is stored as high level waste (HLW). If reprocessed, the separated and vitrified fission products and actinides are stored as HLW.

Decommissioning

Up to 2015, about 110 commercial power reactors, 46 experimental reactors and 250 research reactors have been retired from operation and some have been fully dismantled [12]. Twelve large power reactors have been completely dismantled in the USA. The cost of decommissioning is typically covered by building up a fund during the operation of the plant. For example, in the USA utilities collect 0.1 -0.2cents/kWh to fund decommissioning [12].

The advantage for a new reactor build in South Australia is that modern reactors take account of decommissioning in their initial design. For example ANSTO's OPAL reactor has design features to simplify decommissioning and this was part of the safety case submitted to the regulator (ARPANSA) for the construction licence.

There is a fully costed example of decommissioning in Australia. ANSTO's MOATA research reactor operated 1961 - 1995. The reactor fuel was removed immediately following shutdown, to remove the major source of radioactivity. This has now been returned to the USA, without return of any waste, in accordance with the USA research reactor agreement. In 2009/2010 the reactor was completely dismantled and the site is now being reused. The cost was $4.15m. The IAEA are using this ANSTO project as an example of good international practice for decommissioning.

Conclusions

Nuclear power has advantages and disadvantages. The advantages, particularly the supply of baseload low emissions electricity, would provide a useful option for Australia.

The disadvantages can be managed.

Ultimately the analysis and quantifying of the advantages and disadvantages of the introduction of nuclear power in South Australia will come down to a careful evaluation of all of the key factors noted throughout this submission as part of a feasibility study before any final decision can be made. Many of the factors require substantial technical experience in the nuclear engineering field to evaluate. The outcomes will require careful communication to a wider audience.

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Question 3.9

What are the lessons to be learned from accidents, such as that at Fukushima, in relation to the possible establishment of any proposed nuclear facility to generate electricity in South Australia? Have those demonstrated risks and other known safety risks associated with the operation of nuclear plants been addressed? How and by what means? What are the processes that would need to be undertaken to build confidence in the community generally, or specific communities, in the design, establishment and operation of such facilities?

Response

The nuclear power sector is rated as one of the safest industrial activities in the world today basically because of the very high safety standards and safety culture.

There have been three major reactor accidents in the history of civil nuclear power - Three Mile Island, Chernobyl and Fukushima. The Three Mile Island accident, rated on the IAEA International Nuclear Events Scale (INES) scale at 4, was contained without harm to anyone, the Chernobyl accident rated 7 on the INES scale, involved an intense fire without provision for containment, and the third at Fukushima also rated 7 on the INES scale severely tested the containment, allowing some release of radioactivity. These are the only major accidents to have occurred in over 15,000 cumulative reactor-years of commercial nuclear power operation in 33 countries. The evidence over six decades shows that nuclear power is a safe means of generating electricity. The risk of accidents in nuclear power plants is low and declining. The consequences of an accident or terrorist attack are minimal compared with other commonly accepted risks. Radiological effects on people of any radioactive releases can be avoided. [1]

The Chernobyl and Fukushima accidents were predicted by the nuclear engineering community not specifically but through an understanding of the design concepts and the cultural/management regimes under which they were operated. The engineering lessons arising from these accidents and others have been incorporated in the evolving design development and existing plant review modification programs of all nuclear power stations. The management and regulatory lessons have been incorporated in international standards for the safe operation of all nuclear power plant.

It is not appropriate to link these accidents beyond the lessons learned to all current or future nuclear power plants assuming that any new plants will have exactly the same problems. An analysis of the history of any ongoing technological development indicates that this is not a logical proposition or observed outcome.

With this in mind it is clear that the introduction of nuclear power in South Australia should follow well proven design concepts which have been developed over many years and are now shown to be wholly reliable.

Nuclear activities are underpinned by a regime of internationally recognised and policed system of national regulation under the supervision and guidance of the International Atomic Energy Agency (IAEA). There needs to be strong national legislation underpinning the national nuclear regulatory systems for the control of nuclear related activities which pose a risk of death or injury due to work accidents, and in particular exposure to nuclear generated radiation for workers and the public. In Australia the relevant body is the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) established in 1999. In the case of the Chernobyl plant a nuclear regulator did not exist and in the case of the Fukushima plant the regulator was ineffective.

The single most important activity is to ensure the creation of a nuclear safety culture in all levels of activity within the industry. This means that everyone from company boards and managers down to operations and maintenance workers have a clear awareness of nuclear safety and understanding of their place in achieving this appropriate to their activities. The culture needs to be supported by a system of technical and management training and where necessary authorised qualifications.

Review of Nuclear Accidents

Chernobyl

A review of the Russian nuclear power program by a British delegation in 1966 led to the conclusion that that sector was an accident waiting to happen. The British delegation identified low quality design, rushed construction driven by the Russian weapons program, and an unsatisfactory operating culture. The Chernobyl accident was initiated by a poorly planned 'scientific' experiment testing the ability of the reactor to supply steam and consequently electrical power beyond the point of emergency shutdown. The experiment bypassed or overrode a number of the basic safety systems that were incorporated in the reactor control system and the general operating procedures.

The RBMK design used at Chernobyl would never again be considered for use because of its unstable characteristics and lack of a containment.

A major lesson has been that nuclear power stations require intelligent and careful design based on risk assessment and Defence in Depth [2] design principles. Any testing requires to be very carefully considered and planned including independent reviews. There was no independent nuclear regulator for the Chernobyl power plant at that time. [3].

Three Mile Island

The root cause of the accident was an inadequately designed alarm and control system which finally overwhelmed the operators. At a detailed level, operating procedures were inadequate, plant identification was inadequate, the operators undertook incorrect actions reacting to over 52 standing alarms, and lessons from other nuclear power stations had not been incorporated into operating procedures [4]. An eventual accident was predicted many years previously by Admiral H G Rickover USN [5,6].

The basic design integrity of the reactor safety containment system was not compromised even though the fuel load was severely damaged. The PWR design used at TMI has since been modified to ensure that a similar accident could not happen again.

Many lessons on operator psychology, control system interfaces and experienced engineer backup have emerged as a result of this accident and similar accidents particularly in the petroleum industry. An Australian accident with many parallels, but unfortunately with more severe consequences, occurred at the Esso gas processing plant at Longford in Victoria in 1997. The accident and its subsequent outcomes were examined by Hopkins [7]. This reference book is profoundly important as a guide and provides recommendations for the safe management of any future nuclear plant in South Australia. The review of the cultural and sociological aspects of the Longford accident goes well beyond the normal engineering focus of such accident investigations. It requires the whole operation of high reliability industrial organisations to be examined.

The current designs of small modular reactors incorporating inherent passive shutdown capability have been a major outcome of this accident.

Fukushima

The root cause of this accident has been traced back to the culture of the operating organisation and its national regulator, particularly at a senior off-site level [8]. Insufficient off-site management focus was given to recommendations for safety improvement because additional safety improvement investment was not thought to be warranted for a plant about to be shut down.

The response to question 3.10 addresses the recommendations arising from the Fukushima incident and a number of others where long-term management deficiencies ultimately cause serious safety problems.

The Fukushima event did confirm the adequacy of seismic design practice. Although the Boiling Water Reactor (BWR) plants were of outdated design, they shut down safely following the fourth largest earthquake ever recorded. The key initiating reason for the reactor accident was the tsunami – one of the largest tsunamis in recorded history and more than twice the size of the tsunami assumed for the design of the power station. This was the common initiating cause of terminal damage to four of the six reactors.

There were simple engineering measures such as an adequate seawall and locating diesel generators and other essential equipment at elevated levels or in water tight compartments that could have been taken to protect the emergency power supplies of the Fukushima Daiichi nuclear power station from flooding. These measures have now been, or are being, applied to existing nuclear plants where the risk of flooding exists.

At a detailed level the lessons learned can be summarised as follows;

- the severity of external events must be carefully analysed in particular vulnerability of the electrical grid system to external events
- it is essential to maintain instrumentation, lighting and communications under all foreseen conditions
- it is essential to guarantee core cooling post trip with diverse and physically separated cooling systems
- it is essential to protect the containment systems from risk of hydrogen explosion, the possibility of backflow in vent systems, and the possible effects of explosions on adjacent plant
- it is essential to ensure the safety of spent fuel in storage under all foreseen circumstances
- accident management for multiple/prolonged reactor events must be carefully designed and documented in advance particularly the formal hierarchy of leadership and decision making

The last item above is very carefully managed at ANSTO Lucas Heights with randomly initiated mock accidents to test the preparedness of all on-site and off-site emergency services and personnel including local police and ambulance staff.

There was a common major failure of independent nuclear safety regulation linking the Chernobyl and Fukushima accidents, both rated as the highest (level 7) in the IAEA International Nuclear Events Scale (INES) [9].

Radiological safety lessons

Chernobyl

The most comprehensive analysis of the Chernobyl accident is the UN Chernobyl Forum report [10]. The UN Chernobyl Forum was an initiative of the IAEA, in cooperation with the WHO, UNDP, FAO, UNEP, UN-OCHA, UNSCEAR, the World Bank and the governments of Belarus, the Russian Federation and the Ukraine.

The report concluded that:

"The total number of people that could have died or could die in the future due to Chernobyl originated exposure over the lifetime of emergency workers and residents of most contaminated areas is estimated to be around 4,000. This total includes some 50 emergency workers who died of acute radiation syndrome (ARS) in 1986 and other causes in later years; 9 children who died of thyroid cancer; and an estimated 3,940 people that could die from cancer contracted as a result of radiation exposure. The latter number accounts for the 200,000 emergency and recovery operation workers from 1986–1987, 116,000 evacuees, and 270,000 residents of most contaminated areas."

"The average effective doses for the general population of contaminated areas accumulated in 1986–2005 were estimated to be between 10 and 20 mSv in various regions. Some residents received up to some hundred mSv, and others received lower doses. It should be noted that the average doses received by residents of the territories contaminated by Chernobyl fallout are generally lower than those received by people who live in well-known areas of high natural background radiation in India, Iran, Brazil and China. Some residents in these areas receive over 25 mSv per year from the radioactive materials in the soil on which they live without any apparent health effects."

"…. a substantial increase in thyroid cancer among those exposed as children was recorded subsequent to the accident. Between 1992–2000 in Belarus, Russia and Ukraine about 4,000 cases of thyroid cancer were diagnosed …. For the 1,152 thyroid cancer cases diagnosed among children in Belarus during 1986–2002 and treated, the survival rate was 98.8%. …. Taking into account the substantial risk of thyroid cancer in children and adolescents and the high thyroid doses received, we can be reasonably certain that most of the thyroid cancer incidence can be attributed to radiation."

"The vast majority of about five million people residing in contaminated areas of Belarus, Russia and Ukraine currently receive annual effective dose from the Chernobyl fallout of less than 1 mSv (a recommended dose limit for the general public). However, about 100,000 residents of the more contaminated areas still receive more than 1 mSv annually. Although future reduction of exposure levels is expected to be rather slow, i.e. of about 3 to 5% per year, the great majority of dose from the accident has already been accumulated."

"Because of the relatively low dose levels to which the population of the Chernobyl-affected regions was exposed, there is no evidence nor any likelihood of observing decreased fertility among males or females in the general population as a direct result of radiation exposure. These doses are also unlikely to have any effect on the number of stillbirths, adverse pregnancy outcomes, delivery complications or the overall health of children."

"Since the Chernobyl accident, some 350,000 people have been relocated away from the most severely contaminated areas. 116,000 of them were evacuated immediately after the accident …. Although resettlement reduced the population's dose of radiation, it was for many a deeply traumatic experience. Even when resettlers were compensated for their losses, offered free houses and given a choice of resettlement location, many retained a deep sense of injustice about the process. Many are unemployed and believe they are without a place in society and have little control over their own lives. Some older resettlers may never adjust…. Paradoxically, people who remained in their villages (and even more so the "self-settlers," those who were evacuated and then returned to their homes despite restrictions) have coped better psychologically with the accident's aftermath than have those who were resettled to less contaminated areas."

Fukushima

The latest reports on the radiological effects from Fukushima were considered at the sixtieth session of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) held in May 2013 and chaired by Australia (Dr Carl-Magnus Larsson) [11]. The UNSCEAR report found:

"No radiation-related deaths or acute diseases have been observed among the workers and general public exposed to radiation from the accident"

"The doses to the general public, both those incurred during the first year and estimated for their lifetimes, are generally low or very low. No discernible increased incidence of radiation-related health effects are expected among exposed members of the public or their descendants. The most important health effect is on mental and social well-being, related to the enormous impact of the earthquake, tsunami and nuclear accident, and the fear and stigma related to the perceived risk of exposure to ionising radiation."

"As an immediate response, the Government of Japan recommended the evacuation of about 78,000 people living within a 20-km radius of the power plant. Later, in April 2011, the Government recommended the evacuation of about 10,000 more people living further to the north-west of the plant because of the high levels of radioactive material on the ground. The evacuations greatly reduced (by up to a factor of 10) the levels of exposure that would have otherwise have been received by those living in those areas."

Developing Community Confidence

While international knowledge and experience is continually growing and being applied to nuclear power plant design and operation and other complex process plant design, operating risks will continue to be minimised but are unlikely to be wholly eliminated.

Based on overseas experience the processes that need to be undertaken to build confidence in the community generally, or specific communities, for the design, establishment and operation of nuclear power plants cover a range of requirements. Favourable public perception of nuclear energy will continue to be important to ensure the political mandate to take forward a strategy for this technology. This will require an effective public engagement strategy at both national and local level that listens to local issues and addresses these in an open and transparent manner.

The UK Nuclear Industry Council report "In the Public Eye: Nuclear Energy and Society " (Dalton 2014) sets out a high-level strategy for the effective management of engagement of the public on nuclear energy.

This includes a recommendation to follow four best practice principles within a public engagement strategy:

- ensure clarity in communications to enhance an appreciation of energy matters, recognise the social, economic, and environmental benefit of nuclear energy
- build trust in those who communicate to enhance understanding of nuclear matters, recognising the need for respect, openness, and transparency
- enable dialogue with the public to provide opportunities to listen and address those issues which are in the public mind, recognise the value of challenge
- facilitate consultation with local stakeholders and those who may have influenced on nuclear energy matters recognising the need to be a good neighbour.

To help ensure clarity in all public engagement it will be important that particular elements of the key messages associated with the introduction of nuclear power are developed into a clear and concise strategic narrative. Consultation will need to address how nuclear power technology can best be deployed in the manner that provides local benefit to those most affected by the development.

Some thoughts on how this may be achieved in Australia are as follows;

Education

- Publicity to educate the general public about the government regulatory body ARPANSA and its responsibilities in safeguarding public safety and as an unbiased authority on the acceptability of nuclear proposals for industrial activities.
- An immediate and sustained campaign to address misapprehensions about the key safety aspects of previous accidents and their impacts set in the context of the wider consequences for the population. This may be led by an authoritative Government agency, with the intention of improving the public understanding and acceptance of nuclear power as revealed in public opinion surveys. Prior to Fukushima a survey of Australian public opinion in 2011 showed 42% were willing to accept nuclear power. This accords well with a UK public survey in June 2013, which showed UK public support at 46% for nuclear power stations. A subsequent Australian survey post Fukushima in March 2012 showed a marked change in opinion with 40% of the public not willing to accept nuclear power as an option to help tackle climate change.
- A sustained programme of information on the potential benefits of nuclear power generation and the provision of informed information about nuclear safety and radiation to improve the understanding of nuclear related activities for members of the population who may be in the vicinity of proposed nuclear facilities.

Later education, once industrial activities have started:

- Training at all levels with a coordinated system of nuclear training appropriate to the tasks of administrators, professional staff, engineering and radiological protection and health physics of all disciplines. These courses may need to be subject to nuclear regulator supervision to ensure they meet appropriate training needs.
- A sustained programme of public engagement by all nuclear facility operators to educate local members of the public in schools colleges and bodies of influences such as business councils in the details of the activities similar to what is done by major mining companies about their activities to gain public understanding and support.

Conclusion

The key lessons from all the accidents are:

- The Safety Culture of the operating organisation must be of the highest level
- The nuclear regulator must be independent of any industry influences
- Modern nuclear reactors should incorporate natural (passive) cooling systems that do not require external electrical or water supplies in an incident to keep the reactor safe.

The nuclear power industry worldwide has moved on from previous serious accidents and implemented the lessons learned in existing nuclear power stations and new designs. Even though the previous accidents in fact had only minor radiological safety consequences, public confidence needs to be rebuilt to understand the very high safety level that can be achieved with nuclear power plants.

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Question 3.10

If a facility to generate electricity from nuclear fuels was established in South Australia, what regulatory regime to address safety would need to be established? What are the best examples of those regimes? What can be drawn from them?

Response

Australia already has a competent and very well managed Commonwealth nuclear regulatory regime.

A strong competent regulatory authority with effective independence in regulatory decision making is a fundamental requirement of any nuclear safety regulatory framework. It is of utmost importance that the competent regulatory authority has the ability to exercise its powers impartially, transparently, and free from undue influence in its regulatory decision-making to ensure a high level of nuclear safety. Regulatory decisions and enforcement actions in the field of nuclear safety should be based on objective safety related technical considerations and should be established without any undue external influence that might compromise safety such as undue influence associated with changing political, economic, or societal conditions. (EURATOM 2009)[1].

The IAEA Safety Standard Government, Legal and Regulatory Framework for Safety GSR Part 1 establishes the international best practice and lists the key requirements for a nuclear regulator. The objective is to protect the safety of people and the environment from the effects of ionising radiation. The nuclear power plant operator must have the prime responsibility for safety. The public and the operator must have confidence in the nuclear regulator.

"The Government, through the legal system, shall establish and maintain a regulatory body, and shall confer on it the legal authority and provide it with the competence and the resources necessary to fulfil its statutory obligation for the regulatory control of facilities and activities"

GSR Part 1 Requirement 3

Key requirements are:

- The regulatory body must be effectively independent in its safety related decision making and has functional separation from entities having responsibilities or interests that could unduly influence its decision making. For example, the Nuclear Regulator must not be established within a government department that has any responsibilities for industry.
- The regulator must have appropriate competencies. The regulatory body must have a full time staff capable of either performing regulatory reviews and assessments, or evaluating any assessments performed for it by consultants. For the foreseeable future, the number of nuclear facilities in Australia would be too few to require a separate Technical Support Organisation as for example exists in France.

International best practice is for the establishment of a national nuclear regulator. It would not be efficient or effective for each state and territory to establish its own nuclear regulator.

In the USA, UK and UAE, a single national nuclear regulator is responsible for:

- Radiation safety
- Nuclear safety
- Nuclear security
- Safeguards
- Transport of radioactive materials

The area where it is more appropriate for States to be involved is mining. This is particularly appropriate for South Australia where Olympic Dam is principally a copper mine and uranium is a by-product.

International best practice is to keep environmental and WHS regulation separate from nuclear regulation.

The latest country to start a nuclear power program is the United Arab Emirates (UAE). They have established the Federal Authority for Nuclear Regulation (FANR) which has a Director General and a board with nine members. FANR has all the responsibilities listed above.

The UK has one of the most experienced nuclear regulators in the world (established 1959). In 2011, they became the Office for Nuclear Regulation (ONR) and increased the scope to include safeguards, security and transport which were previously the responsibilities of other government departments. They also changed the structure to a CEO and Board of Directors and established a Public Corporation in 2014.

An alternative structure is for regulatory decisions to be made by a panel of commissioners and a chairman as is the structure in the USA (Nuclear Regulatory Commission with five commissioners) and in Canada (Canadian Nuclear Safety Commission which has seven commissioners).

Australia already has a competent and very well managed Commonwealth nuclear regulatory regime with staff with wide international experience.

However under the current regime the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is responsible for radiation safety and nuclear safety and the Australian Safeguards and Non-Proliferation Office (ASNO) is responsible for security and safeguards. There is inevitably some overlap, particularly in the security area.

Many of the ARPANSA staff have extensive experience in operating nuclear power plants both civil and military. There is no fundamental reason why the ARPANS Act 1998 cannot be amended to include the regulation of nuclear power in Australia. There would be a requirement for some additional appropriately qualified and experienced staff.

The issues paper implies that a regulatory regime is required to manage the special risks associated with generating electricity from nuclear fuels however the regulatory function is merely an underpinning structure for overall good management and safety culture.

As a general principle there are really no special risks associated with the generation of nuclear power beyond those found in most existing power stations or similar major chemical or industrial processing plants. The management of radiation risks have many parallels with the management of potentially hazardous chemicals. Ultimately the management of any potential risks or occupational health and safety regime resides with the operators of the plant and the culture of the managing organisation.

Regulatory guidelines for best practice can be developed and legislated but day-to-day high quality operational leadership is the ultimate best practice criteria. Plant operators respect the need for high level of safety awareness when they see company boards with a first principles focus on all aspects of safety.

Conclusions

Australia already has a competent and very well managed Commonwealth nuclear regulatory regime. The legislation requires revision to include the States and Territories.

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Question 3.11

How might a comparison of the emission of greenhouse gases from generating electricity in South Australia from nuclear fuels as opposed to other sources be quantified, assessed or modelled? What information, including that drawn from relevant operational experience should be used in that comparative assessment? What general considerations are relevant in conducting those assessments or developing these models?

Response

The data required for the analysis of greenhouse gas emissions from existing low emission technologies is readily available. For example the World Federation of Engineering Organisations publication Nuclear Power Feasibility notes the following general levels.

Technology	Lifecycle CO_2-e emissions kg/MWh
Lightwater reactors	20
Wind	30
Hydroelectric power	30
Photovoltaics	80
Biomass	100
Carbon capture and sequestration	250
Gas-fired combines cycle	450
Gas-fired open cycle	760
Oil fired	500 – 1200
Black coal	750 – 1250
Brown coal (lignite)	1100 - 1700

Note: lifecycle includes mining, construction, operation and decommissioning

On a lifecycle basis, including mining, enrichment, construction and operation, greenhouse gas emissions for nuclear power is comparable to other low emissions technologies, particularly solar and wind. This has been extensively studied by the IPCC [2], NEI [3], OECD [4] and UMPNR [5]. If system factors are taken into account, then emissions from weather dependent technologies like wind and solar are much higher, due to the need for backup generation which is currently fossil fuelled in South Australia. This situation would change if the backup was provided by nuclear power.

A recent (2014) study by Hatch (Canada) [7] of worldwide Life Cycle Assessments (LCA) standardised under ISO 14040 examined 46 wind and 79 nuclear studies, including wind studies in Australia.

For nuclear these studies included the extraction and production of uranium fuel, operation of nuclear reactors, construction and decommissioning of the power plant, and the management of nuclear waste. Construction of waste management facilities for radioactive waste is also included.

The nuclear studies include the enrichment of uranium from 0.7% to 3%-5% for a typical Gen II/Gen III reactor. Some LCAs consider enrichment by gaseous diffusion which is a more energy intensive process (2,500 kWh/SWU) than the centrifuge process (40 kWh/SWU). All gaseous diffusion plants are now shutdown and replaced by centrifuge plants, so in this regard the studies over-estimate the GHG emissions.

The concentration of uranium in the ore depends on the location of the deposit and varies from 0.03% - 20% worldwide. The GHG emissions depend to some extent on the ore grade, mining technology and whether uranium is the sole product, or a by-product as at Olympic Dam which is mainly a copper mine. Since uranium fuel for a possible nuclear power reactor in South Australia would be supplied by an international fuel fabricator, it is appropriate to consider an average international ore grade, and not particularly any South Australian ore grades.

For wind these studies included extraction, production, transportation and waste management of all consumables for construction, decommissioning and operation of onshore wind farms. Studies which included beneficial impacts of recycling and re-use provided an emissions credit. System emissions due to the requirement for backup for wind were not considered, as this requires consideration of the local power system.

The statistical mean total lifecycle emissions of greenhouse gases are:

Technology	GHG $kgCO_2$-e/MWh
Onshore wind	10.5
Nuclear	18.5
Natural gas combined cycle gas turbine (NCCGT)	478
Mix 20% wind + 80% NCCGT	385

This meta-analysis of worldwide studies confirms that lifecycle emissions from nuclear are comparable to wind and solar.

In the Australian context, the AEMO issue daily emissions [1] for each state in the NEM based on calculations from individual power station data of their operating emissions:

Figures for operating emissions from a typical day in May 2015

	CO_2-e emissions Kg/MWh	Comments
Victoria	1,213	Brown coal generation
NSW	911	Black coal generation
Queensland	873	Black coal
South Australia	622	Wind supported by fossil fuels
Tasmania	0	Hydro and wind
NEM	917	Heavily dependent on fossil fuels

What is missing and would be needed is specific analysis of those technologies as they impact the existing South Australian grid system and its day-to-day operation. This is not a simple proposition and the Commission may consider the need to request a study if the information is not provided in other submissions.

For example it has been noted by Dr Robert Barr Engineers Australia Electrical Engineer of the Year 2012 (Barr 2012) that the introduction of intermittent renewable electricity generation in Australia has caused more carbon dioxide emissions than if those technologies were not there. At that time intermittent renewable source generation required system backup utilising quick start open cycle gas turbines burning natural gas. That gas could have been utilised more efficiently in combined cycle gas turbines operating in a grid without solar or wind power. How that previous example applies to the South Australian grid would require special study.

An estimate of carbon dioxide emissions with generous capacity factors for the renewable options requiring quick start backup in an existing grid is as follows;

Wind 30% capacity factor with OCGT backup	540 kg/MWh
Photovoltaic 20% capacity factor with OCGT backup	620 kg/MWh
No renewables 100% combined cycle gas turbine	450 kg/MWh

This outcome or its current perturbation is generally not well understood. How this example applies to the South Australian grid would require special study.

If in fact renewable low capacity and intermittent operation in South Australia is backed up by supply from the interconnection with Victoria or a future nuclear power generator the above specific carbon dioxide emission estimates are likely to be as follows;

wind 30% capacity factor with Victoria interconnector backup	770 kg/MWh
wind 30% capacity factor with nuclear backup	23 kg/MWh

Avoided cost of carbon dioxide

The move to renewable energy and the consideration of the introduction of nuclear power generation has generally been driven by concern for rising greenhouse gas levels. The cost of carbon dioxide reduction options and real community economic outcomes have generally not been considered or identified. We are not aware of any previous study for any section of the Australian grid which clearly defines the cost of avoided greenhouse gas emissions particularly carbon dioxide for any technology option. Recent studies published by the Grattan Institute (Grattan 2015) and the Brookings Institute (Brookings 2015) provide a lead as to the development of more rigorous methods of analysis to cover carbon dioxide cost reduction options.
The Brookings study while USA specific indicates that nuclear power provides far more nett benefits because solar and wind generation facilities suffer from a very high capacity cost per megawatt, very low capacity factors, and low reliability, which result in low avoided emissions and low avoided energy cost per dollar invested.

Financial support incentives in the United States, Europe, and Australia are available for wind, solar, small-scale hydro, biomass and other renewable energy sources. Generally no incentive policies are available for other low or no carbon alternatives such as nuclear, large-scale hydro, or gas combined cycle power stations. Yet the analysis results noted in the Brookings paper demonstrate clearly that these three latter alternatives are far more cost-effective per megawatt of capacity in reducing carbon dioxide emissions than wind or solar. In both the United States and Europe there is political opposition to all three of these alternatives on environmental and safety grounds, despite their superiority in reducing carbon dioxide emissions. This outcome gives some indication of the technical understanding problems and quality of debate in those countries and the need for caution when reviewing their policies as a guide to what may be developed in Australia. Recent media reports indicate that some understanding is growing in Europe with a consequence swing against renewable energy options on the basis of excessive subsidy cost and low carbon dioxide reduction outcomes. (Australian 2013) [6].

The Commission should consider the case for developing a South Australia specific analysis on the net benefits of low carbon electricity technology options including nuclear power for that state. Small modular reactor units in the 180 MW electrical size range are now designed to work in conjunction with existing intermittent units on a grid and are capable of load change at ten percent per minute. This rate of change capability provides a useful backup for existing intermittent non-dispatchable renewable electricity sources with no additional carbon dioxide emission release. Longer term the introduction of nuclear power electricity generation removes any need for additional installation of high cost renewable generation options if their sole rationale for existence is to lower carbon dioxide output from electricity generation.

Conclusion

The Commission should consider the case for developing a South Australia specific analysis on the net benefits of low carbon electricity technology options including nuclear power for that state.

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Question 3.12

What are the wastes (other than greenhouse gases) produced in generating electricity from nuclear and other fuels and technologies? What is the evidence of the impacts of those wastes on the community and the environment? Is there any accepted means by which those impacts can be compared? Have such assessments making those comparisons been undertaken, and if so, what are the results? Can those results be adapted so as to be relevant to an analysis of the generation of electricity in South Australia?

Response

A commercial nuclear power plant produces some radioactive waste which has to be managed.

Radioactive waste management is certainly a sector of nuclear power generation about which the perception of the engineering community, aware of the progress achieved in the last two decades, differs deeply from the perception of the public at large who, in general, may consider that this aspect constitutes an insoluble problem. The document WFEO Nuclear Power Feasibility section 5 provides a comprehensive review of the issues and engineering solutions as they are now understood.

All base load power generation utilising fossil or nuclear fuels produces waste products. The choice is to discharge all of the waste directly into the atmosphere and local environment from fossil fired power stations or control and manage all of the waste products as is the case for nuclear power stations.

Solid radioactive waste produced directly from operating a nuclear power reactor is low level waste (LLW) and intermediate level waste (ILW). See IAEA Classification of Radioactive Waste GSG-1. Typical figures for a 1 GWe nuclear power plant are 150m^3/yr LLW and 8.6m^3/yr ILW [1]. LLW is produced during day to day operations and consists of paper, cleaning papers, non-reusable clothing, filters and resins. This waste is sorted, compacted and packaged on site into drums. The ILW is mainly resins from treatment of radioactive water and metallic waste from maintenance. It has higher levels of radioactivity and is stored in shielded containers. Solid radioactive waste is normally stored on site until a central repository is available.

Gaseous and liquid wastes are also produced during routine operation and are treated before discharge within limits specified by the nuclear regulator.

Typical gaseous radionuclides are tritium, noble gases, iodine and turbine off-gases. Gaseous wastes are collected, retained for 45-60 days to allow short lived emitters to decay, then filtered and monitored to be within discharge limits before release to the atmosphere via a vent stack. Gaseous waste discharges are well within annual authorised limits, as an example for a twin French 1300 MWe PWR the gaseous release is < 50 TBq/yr with an annual authorised limit of 1650 TBq/yr.

Liquid waste is produced by activation of chemicals (eg lithium) in the primary cooling circuit, activated corrosion products from reactor materials and non-aqueous liquid waste, e.g oil. Liquid waste is collected, monitored, filtered and treated by ion-exchange resin/evaporation/reverse osmosis. Liquid waste is converted to solid whenever possible. The final liquid is monitored and discharged within limits. Average liquid annual discharge for a twin 1300 MWe PWR is <24 TBq tritium (annual limit 80 TBq/yr) and < 3 GBq all other liquids (annual limit 1.1 TBq/yr)

There is over fifty years' experience of routine nuclear power plant low level gaseous and liquid discharges with no effects to the local communities or the environment. All nuclear power plants conduct routine environmental monitoring in the vicinity of the plant and the results are published.

There is no high level waste (HLW) produced from the day to day operation of a nuclear reactor. HLW is highly radioactive and is also defined as having a heat output of >2 kW/m^3.

Most reactors have to be routinely refuelled and the discharged fuel usually referred to as spent fuel is highly radioactive. If spent fuel is not to be reprocessed it is stored as high level waste (HLW). If reprocessed, the separated and typically vitrified fission products and actinides are stored as HLW.

Spent fuel contains unburnt uranium and plutonium as well as highly radioactive fission products. Non-fissile uranium-238 in nuclear fuel absorbs neutrons in thermal neutron reactors (PWRs and BWRs), initially generating weapons grade plutonium-239 (much of which is actually burnt in the reactor). Longer term irradiation generates plutonium-240, which is highly unsuitable for weapons, then plutonium-241 and heavier elements (called "minor actinides"). The plutonium and unburnt uranium are potentially recyclable as fuel, after extraction by chemical reprocessing from the spent fuel, and may therefore legitimately be regarded as resources – not waste.

In the 1970's, the Carter Administration in the US decreed that spent fuel should be treated as a waste product and not reprocessed, because of fears that the plutonium that it contained might otherwise be diverted into the illicit production of nuclear weapons. Plutonium and the minor actinides are also highly toxic. Plutonium-239 has a half-life of 24,100 years and some of the minor actinides are even longer lived, leading to the postulation that the isolation of this waste must be totally guaranteed for hundreds of thousands of years.

An alternative policy, adopted in Europe, has been that spent fuel should be chemically reprocessed to extract plutonium and unburnt uranium as valuable fuels for recycling back into the nuclear fuel cycle. Plutonium may be a particularly valuable fuel for fast neutron reactors and for thorium breeder reactors, if this technology becomes commercially viable. All plutonium isotopes can be utilised in this way.

Since the 1970's, there have been two major developments influencing this situation:

1. The much higher burn-up of fuel achieved in modern commercial reactors has significantly increased the concentration of the 240-isotope in plutonium so that it is not suitable for making weapons[1] .
2. It is recognised that – if spent fuel is chemically reprocessed to remove all the plutonium (for recycle) and all the minor actinides (which can be burnt eventually in fast neutron reactors) – the most significant hazards in the remaining waste are fission products with half-lives of only about 30 years. After a few hundred years, this fission product waste would be less radioactive than the ore body from which the uranium was originally mined. And once it has been solidified, encapsulated and buried deep in a stable geological repository, it will be better isolated from the environment than the original ore body[2] . In particular, solid waste – even if it contains traces of uranium and plutonium – does not generate the radon gas which is generated from the decay chain of uranium that has been free in the earth's crust for billions of years. Radon constitutes about half of our exposure to natural radiation.

Many sites in South Australia would be very suitable technically for the safe, permanent disposal of the high level waste from the reprocessing of spent fuel, whether our own or from overseas. At present, there is no high level waste in Australia and the importation of foreign waste and spent fuel is prohibited.

Chemical reprocessing of spent fuel from reactors to recycle plutonium as fuel for nuclear power generation would be consistent with our obligations as a signatory of the Nuclear Non-Proliferation Treaty (NPT). In fact, the more that the nuclear industry is domestically based, the easier it would be for the Australian Safeguards and Non-proliferation Office (ASNO) to ensure that those obligations are met. However, all nuclear fuel cycle activities apart from uranium mining are currently illegal in Australia.

Chemical reprocessing of radioactive materials to extract medical radioisotopes has been carried out safely at Lucas Heights for over 50 years.

Recent studies have been carried out in the United States on the impact of coal-fired power station ash disposal regimes (Concerned Scientists 2014) The health impacts of coal-fired generation ash disposal regimes on local communities are outlined in the above reports and are many orders of magnitude more severe than any recorded adverse impacts of nuclear power plants even including direct accidents.

Those detailed studies have led to legislation covering the use and management of ash ponds in a number of US states and can be expected to extend to other jurisdictions worldwide in the long-term. The engineering requirements to meet those new legislated standards are expected to be so expensive as to shut down many coal-fired power stations in the United States.

As noted above power station waste issues have as been well understood for many decades by the engineering and scientific sectors if not the wider community. In the case of South Australia a specific study would be required based on the principles noted in the studies referenced above.

Conclusion

International experience shows that radioactive waste can be managed without risk to the community.

[1] This does not obviate the need for safeguards to ensure that plutonium is not diverted into illicit uses, e.g. by terrorists to make "dirty bombs" or promote fear in other ways.

[2] If plutonium needs to be stored for any length of time, pending recycle, it could be left as a mixture with fission products, so as to deter any thoughts that anyone might have of diverting it, e.g. for purposes of terrorism.

References

[1] Westinghouse AP-1000 UK Safety Report

Question 3.13

What risks for health and safety would be created by establishing facilities for the generation of electricity from nuclear fuels? What needs to be done to ensure that risks do not exceed safe levels?

Response

The generation of electrical energy is now the major use of the nuclear fuel cycle. All industrial activities involve some risk to human health and safety and no means of generating electricity is risk free. Nuclear power has proved to be one of the safest industries in which to work and one of the safest ways to generate most of the electricity the world needs. Radiological risks from modern nuclear power plants are very low.

Nuclear power plant safety and radiation protection are examined in Section 7 of reference [1].

The choice of any technology or mixture of technologies will inevitably be a matter of balancing the different costs, benefits and risks. While considerable technical and management progress has been achieved on this balance over the last few decades, and with the safety of nuclear power installations, little advance has been achieved in the area of social acceptability.

Risks potentially impacting on the health and safety of a nuclear power plant workforce are mitigated by appropriate design and subsequent operation of the plant. More broadly, the safety of any local community is ensured by:

1. Appropriate siting
2. Good design
3. Quality assurance
4. Competent operation
5. Learning from experience
6. Analysis and assessment of safety in relation to all the above matters
7. Proper regulatory oversight.

Siting

For nuclear facilities in Australia, ARPANSA has recently (Aug 2014) published their Regulatory Guide Siting of Controlled Facilities, based on the IAEA documents.

Section 5 provides guidance on site selection and characterisation, including the evaluation of potential sites.

Siting criteria for nuclear power plants in Australia would certainly need to include the exclusion of the public and of activities unrelated to plant operations from the area immediately surrounding the plant (the plant site). There would also need to be assurance of a zone in which urgent procedures such as temporary evacuation would be feasible to protect the public from potential exposure to radiation in the event of an accident (the emergency planning zone or EPZ). One of the lessons learned from the accidents at Chernobyl and Fukushima (see the Response to Question 3.9) is that the criteria for implementation of emergency procedures need careful consideration.

Design

Nuclear plants must be designed to ensure that radiation levels in normal operation are sufficiently far below limits that are prescribed as safe to allow for uncertainties, both for workers who are occupationally exposed and for others including members of the general public who are outside the site boundary. Designs must incorporate shielding and control and monitoring systems for these purposes. The dose limits recommended by the International Commission on Radiological Protection (ICRP) [2] are:

- 100 mSv[3] over any 5-year period for occupational exposure;
- 1 mSv/y for members of the public;
- Doses should be as far as is reasonably achievable below these levels, taking economic and social factors into account ("as low as is reasonably achievable" or ALARA).

By good design, safe operation and applying the ALARA principle, the typical dose to nuclear workers is kept far below these limits. For example, a typical annual dose to a nuclear worker is 1 mSv/yr [UNSCEAR 3].

In Australia, these same (conservative) ICRP dose limits are applied by the National Directory for Radiation Protection, Schedule 1 – dose limits [4] and the ARPANS Regulations [5].

The possibility of accidents is also taken into account in design. All foreseeable failures of plant and operation and possible external threats are taken into account. Unforeseen faults and events do occur – designs must therefore incorporate the following multiple layers of defence in depth against plant failures:

- Diverse and redundant protection systems to shut down the plant in the event of significant equipment malfunctions or when otherwise required, and maintain the plant in a safe condition;
- A system for emergency cooling of the reactor's fuel core in case normal cooling is lost;
- Facilities for rejection of heat from the plant under normal and accident conditions, to prevent overheating generally;
- A leak tight containment building, with its own heat removal system, as a last line of protection against the release of radioactive material in a core-melt accident.

Quality assurance

Nuclear plants are engineered and constructed to the highest quality standards, which are rigorously monitored during manufacture and checked during construction and commissioning. Quality assurance is incumbent upon all parties but the overall responsibility for safety rests with the owner and operator of the plant.

Operation

The staff that operate nuclear plants must have the highest levels of specialised expertise. Nuclear plants cannot be allowed to operate without such staff. For managers, this generally requires university qualifications at least to graduate level. All staff who are directly involved with operation must be aware of the principles of radiation protection. All operations must be supervised – and all operational staff must be monitored for radiation exposure – by professional health physicists.

But ultimately, all aspects of health and safety management come back to appropriate leadership of the organisation through to leadership of each work group and the acceptance of personal and collective responsibility by each group member (safety culture).

The training and recruitment of suitably qualified and experienced staff is a significant challenge facing the renaissance of the nuclear industry worldwide. As a consequence of the three major reactor accidents that have occurred (at Three Mile Island, Chernobyl and Fukushima) there was, in each case, a decline in education and training in this field because of reduced interest in the use of nuclear power (a prohibition in Australia) and reduced interest in working in this industry (no job opportunities in Australia). For many years, there was no nuclear engineering course in any Australian university. This situation has started to change but it takes time and there is a long way to go.

Nevertheless, this impediment need only be temporary if governments are prepared to take action to stimulate the required education and training. Clearly, nuclear plants can be and are operated safely overseas. Australia is already a notable and respected contributor to the management of safety in the nuclear industry worldwide, through the operations of the Australian Nuclear Science and Technology Organisation (ANSTO) and the participation of ANSTO staff in international activities such as the work of the International Atomic Energy Agency (IAEA).

Experience

Issues Paper Three states: "A nuclear accident has the potential to cause significant and wide-ranging damage to people, property and the environment due to the harmful effects of exposure to radiation."

During the 60-year history of nuclear power generation throughout the world, in nearly 500 nuclear power plants of various types, the only time that this potential has been fully realised was at Chernobyl in 1986 [6]. The Chernobyl accident was uniquely a failure of soviet technology: a badly designed and badly operated reactor, of a type (water cooled and graphite moderated) that will never be built again. It was an accident that simply could not occur in any of the reactor types that are being built today anywhere in the world.

[3] The sievert (Sv) is the unit of dose that is generally used in the field of radiation protection. As explained in reference [2], the dose in Sv is the absorbed dose in joules of energy per kilogram of tissue, multiplied by factors that depend on the type of radiation (for equivalent dose) and the relevant tissue (for effective dose). One Sv is a large dose; low doses are usually expressed in mSv

Accidents do occur, even in well designed and well operated power stations, but engineers learn from experience and take such failures into account for the future. There are simple engineering measures that could have been taken to protect the emergency power supplies of the Fukushima Daiichi nuclear power station from flooding by one of the largest tsunamis in recorded history – more than twice the size of the tsunami assumed for the design of the power station. These measures have now been, or are being, applied to existing nuclear plants where the risk of flooding exists. However, the Fukushima event did confirm the adequacy of seismic design practice.

In the light of the Fukushima experience, the design of many future plants, particularly small modular reactors (SMRs), will incorporate passive safety features such as cooling by natural circulation when shut down, thus obviating the need for emergency power supplies which failed due to flooding by the tsunami at Fukushima.

Safety assessment

There are two main approaches to nuclear safety assessment: one called "deterministic" and the other "probabilistic". Both have their strengths and their weaknesses but the probabilistic approach is the more realistic.

The deterministic approach is based on the concept of a "maximum credible accident" (MCA), or a maximum credible event such as an earthquake, tsunami, aircraft crash or act of sabotage. The MCA for a PWR or BWR is a loss of coolant accident causing core meltdown, with an intact containment. Maximum credible external events are generally determined on the basis of expert judgement. (The numerical probabilities of relevant events are often highly uncertain.) The assessment criteria are acceptable radiation doses to a person who is permanently located downwind from the nuclear plant following the accident and a child who drinks milk from a cow that grazes continuously at a similar location (that being the relevant exposure route for radioactive iodine). This gives a sense of confidence that may be misleading because a worse accident or event is often physically possible; such an event has sometimes been called an "Act of God".

One of the most famous "Acts of God" in history was the destruction of the city of Sodom during the third millennium BC. Recent research suggests that this event was the consequence of an earthquake and tsunami. We now know that earthquakes and tsunamis do occur with disastrous consequences well in excess of anticipated levels.

In probabilistic risk analysis (PRA), it is accepted that anything that is physically possible has a finite probability of occurring. Unfortunately, this opens the possibility (after the event) that a newspaper journalist could write – or a lawyer could stand up in court and say – "they knew it was going to happen". In truth, "they" did recognise that it could happen.

In PRA, the probabilities and consequences of physically possible combinations of plant failures (fault-trees) and events (event-trees) are evaluated. This helps to identify potential weaknesses in design and provides an objective, quantitative measure of the overall risk.

The probabilistic safety criteria (PSC) used for probabilistic safety assessment (PSA) are in the following forms:

- the estimated frequency of core-melt accidents must be less than 10^4 per year (a likelihood of once in 10,000 years for each reactor);
- the estimated fatality risk to individual members of the public must be less than 10^6 per year (a risk equivalent to one death per year per million people).

PSC have been proposed for societal (collective) risk, distinguishing between urban and remote sites, but are generally not used.

According to the World Nuclear Association (WNA), there is now 16,000 reactor-years of experience with civil nuclear power plants. Most of this experience is with PWRs and BWRs, the designs of which have now been updated to obviate the risks inherent in the TMI and Fukushima designs. This record is reassuring but not yet sufficient by itself to demonstrate that the core melt frequency is less than once in 10,000 years. PSA supplements hard experience to provide this extra reassurance.

The US Nuclear Regulatory Commission relies on PRA in requiring the estimated core-melt frequency for existing nuclear power plants to be less than once in 10,000 years, and US utilities in requiring it to be less than once in 100,000 years for new plants. The estimated core melt frequency for the Westinghouse PWRs that are being built today is less than once in a million years for each reactor, and it is once in 100 million years for two designs of small modular reactor (SMR) that are being developed.

Estimates less than once in 100,000 years might be regarded as somewhat speculative because of limitations on PRA imposed by very unlikely common causes and common modes of failure, and by the uncertainties in all data at very low levels of probability. However, they are not needed for the demonstration of an adequate level of human safety. Given that:

- the core melt frequency is less than once in 10,000 years; and
- there is effective and reliable containment; and
- with effective health physics controls on the reactor site, the maximum risk (delayed cancer fatality) to nuclear plant workers would be around 0.02 in the unlikely event of containment failure (see the Response to Question 3.9); and
- the risks to the public from radiation exposure under the same circumstances would be much lower than the risks to emergency workers on the site;

then the risk to members of the public at highest risk (and even to nuclear plant workers) is well below once in a million per person-year, which is itself about 100 times less than the average risk of being killed in a motor vehicle traffic accident and about 2000 times less than the normal incidence of death due to cancer from all causes [Australian Bureau of Statistics].

Regulation

Safety in every nuclear installation is subject to the oversight of independent regulatory authorities at all stages: siting, design, manufacture of components, construction and operation. The regulatory authority sets the siting criteria, codes and standards. In Australia, this authority is the Australian Radiation Protection Nuclear Safety Agency (ARPANSA). The ARPANSA Act would need to be amended before the appropriate regulatory infrastructure could be developed for nuclear power generation of electricity in Australia.

Australia already has many excellent examples of occupational health & safety leadership based on safety principles that go well beyond regulatory requirements, e.g. those that have been implemented at ANSTO with outstanding results [7].

Unfortunately, although the overall responsibility for safety always rests with the owner and operator of the plant, regulatory failures have contributed to the two most serious nuclear plant accidents – at Chernobyl and Fukushima – due to the special socio/political situations in the former USSR and in Japan.

Conclusions

Nuclear power would be one of the safest ways to contribute to low emissions electricity generation in South Australia. Radiological risks to the public from nuclear power generation would be very low.

References

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Question 3.14

What safeguards issues are created by the establishment of a facility for the generation of electricity from nuclear fuels? Can those implications be addressed adequately? If so, by what means?

Response

"Safeguards' is the total system for accounting for nuclear materials. Safeguards are measures applied by the International Atomic Energy Agency (IAEA) to verify that non-proliferation commitments made by States under Safeguards Agreements with the IAEA are fulfilled. This system is already working well in Australia.

Nuclear material (ref ASNO) is:

Nuclear material means any source or any special fissionable material as defined below (see the Nuclear Non-Proliferation (Safeguards) Act 1987, and Article XX of the Statute of the International Atomic Energy Agency):

a. The term "special fissionable material" means plutonium-239; uranium- 233; uranium enriched in the isotopes 235 or 233; any material containing one or more of the foregoing; but the term "special fissionable material" does not include source material.

b. The term "uranium enriched in the isotopes 235 or 233" means uranium containing the isotopes 235 or 233 or both in an amount such that the abundance ratio of the sum of these isotopes to the isotope 238 is greater than the ratio of the isotope 235 to the isotope 238 occurring in nature.

c. The term "source material" means uranium containing the mixture of isotopes occurring in nature; uranium depleted in the isotope 235; thorium; any of the foregoing in the form of metal, alloy, chemical compound, or concentrate.

For a nuclear power plant (NPP) this starts with the delivery of new fuel assemblies. There is a formal transfer of the nuclear material in the new fuel assemblies, typically low enriched uranium with <5% U-235, from the fuel manufacturer to the NPP operator. Often the fuel manufacturer and the NPP are located in different countries so this involves a transfer of nuclear material between countries. The fuel assemblies are stored in a dedicated fuel store on the reactor site until required for refuelling the reactor.

After loading into the reactor and irradiation, the fuel composition changes due to fission and absorption processes. Typical light water reactor irradiated spent fuel consists of:

- Mainly U-238
- Reduced quantity of U-235, typically ~ 1% enriched
- Isotopes of plutonium, including Pu-239, Pu-240, Pu-241, Pu-242
- Other minor actinides, e.g. americium, neptunium, curium
- Fission products, e.g. cesium, strontium, iodine, xenon

The quantities of nuclear material in the fuel discharged from the reactor (spent fuel) cannot be easily measured. The reactor operator uses an approved code to estimate the quantities of uranium and plutonium in the spent fuel for safeguards purposes.

The safeguards issues created by the establishment of a nuclear power plant relate to both the new fuel and spent fuel. There are well established internationally agreed practices.

In practice in Australia, safeguards are applied at three levels:

1. The NPP organisation will have its own safeguards department which should be independent of the operating organisation. This safeguards department maintains records of all nuclear material on site. For example, the Australian Nuclear Science and Technology Organisation (ANSTO) has a safeguards department which accounts for all nuclear material on site. They have 58 years' experience of safeguards for ANSTO's nuclear reactors.
2. The Australian Safeguards and Non-Proliferation Office (ASNO), in the Department of Foreign Affairs and Trade, is responsible for ensuring Australia's obligations for safeguards. The Nuclear Non-Proliferation (Safeguards) Act 1987 gives effect to Australia's obligations under the NPT including the Safeguards Agreements and Additional Protocol with the IAEA. In the case of ANSTO, ASNO will independently check the quantities of nuclear materials held for example in connection with the OPAL reactor.
3. The IAEA is the verifying authority for the Nuclear Non-Proliferation Treaty (NPT) and the world's inspectorate for nuclear materials control. Australia signed the Safeguards Agreement as required by the NPT in 1974. In practice, a team of IAEA inspectors will regularly visit the ANSTO site and verify the quantities of nuclear materials.

Conclusion

For the establishment of a new facility for the generation of electricity by nuclear fuels in South Australia, there is a well-established safeguards system already in place in Australia. The new facility will require their own independent safeguards department and ASNO may require more human resources to cope with the additional work, but the full safeguards system is already in existence (see also response to question 3.10).

Question 3.15

What impact might the establishment of a facility to generate electricity from nuclear fuels have on the electricity market and existing generation sources? What is the evidence from other existing markets internationally in which nuclear energy is generated? Would it complement other sources and in what circumstances? What sources might it be a substitute for, and in what circumstances?

Response

As noted in sections 3.4 above there is no place in the current NEM for nuclear power generation without similar levels of financial support or change of concept for the cost-effective reduction of carbon dioxide emissions.

The long-term strategic view must be founded on the following facts;

- Burning low-cost coal to produce low-cost electricity to support value adding resources or manufacturing is no longer accepted by the Australian community.
- The Australian community does support cost-effective methods of reducing carbon dioxide emissions from all sources.
- The generation of electricity using nuclear power has always been one of the most cost-effective options for community scale base load power. Section 3.16 notes the high system cost for other low emission technologies.
- Overseas studies have indicated that the generation of electricity using nuclear power provides one of the most cost-effective options for the reduction of carbon dioxide emissions.

Under the circumstances noted above, the strategic directions, while not exactly the same, have parallels with those undertaken by France in the 1970s and currently by China and South Korea.

Conclusion

If the longer term interests of the community as a whole are taken into account, nuclear power could play an important role in electricity generation.

Question 3.16

How might a comparison of the unit costs in generating electricity in South Australia from nuclear fuels as opposed to other sources be quantified, assessed or modelled? What information, including that drawn from relevant operational experience, should be used in that comparative assessment? What general considerations should be borne in mind in conducting those assessments or models?

Response

While unit cost is certainly an important consideration it is notoriously difficult to ensure that the cost implications of all factors can be quantified or even fully assessed without a site-specific assessment.

The development of a project inevitably requires the investigation of a large range of issues across most engineering disciplines and the environmental impacts. As a general principle no two projects and consequently no two development projects are the same so these technical and environmental issues have to be addressed to a greater or lesser extent in evaluating any project development potential. In particular energy project concepts that might be seen to be working well in Europe or the USA can never be assumed to work well in Australia.

Not surprisingly, technical issues tend to predominate when assessing the development potential of the project in the feasibility study process. But the principal purpose of a feasibility study is to determine whether a development opportunity makes good sense not just whether it is technically possible. Resolution of technical issues is often seen as the primary focus of a feasibility study, whereas in reality, these technical issues are the basis upon which an asset delivery and business plan is built. This is not to say that technical issues are unimportant – they are a prerequisite to the demonstration of a project's viability.

The feasibility study process must therefore demonstrate that not only have the technical issues been satisfactorily addressed but also the broader commercial, economic and social issues have been considered in the development of a comprehensive business plan, which includes an assessment of the risk – reward profile of the proposed development and other viable options. (McKenzie, Cusworth 2007)[1].

The range of submissions and references supplied to the commission may be sufficient to underpin a bankable feasibility study based on the specific requirements of South Australia. First of a kind assessments need to be clearly differentiated from longer term multiple installations.

There are a wide range of previous power generation cost comparison reports available but very few cover the real impact of each technology in a grid system and in particular the actual cost of avoided greenhouse gas emissions, an important factor in the public perception.

The simplistic figure of levelised cost of electricity (LCOE) unit cost is a useful comparison but in reality cannot be used to compare intermittent low capacity with base load electricity generation. For example the work carried out by the Australian Government Bureau of Resources and Energy Economics (BREE) is only step one of a two-step unit cost evaluation process for decision-makers. BREE notes that "LCOE provides a generalised cost estimate and does not account for site specific factors that would be encountered when constructing an actual power plant. As a result the costs associated with integrating a particular technology in a specific location to a specific electricity network are not considered".

Without a full feasibility study for a South Australia site specific assessment for investment in intermittent renewable generation costs it is estimated that LCOE values should be approximately doubled or even tripled from the figures published by BREE. Recent work by the Grattan Institute noted above and the Brookings Institute noted above have moved beyond simplistic levelised cost of electricity concepts to more accurate assessment of the real cost taking into account actual system factors.

Some groups advocate that Australia should move to the generation of electricity by 100% renewable sources. This is obviously a technical possibility and in fact Australia has the best potential resource and space in the world for the generation of electricity from solar energy. The fact that energy provided by the sun, from wind, and wave sources is free tends to blind some advocates to the fact that there is a cost to collect that energy. What seems to be missing is rigorous engineering and financial analysis to support this advocacy to the level of consideration for potential financial investment or even preliminary discussion on what the real cost would be.

In fact wind and solar power collection and distribution are very costly from a social perspective because of their very high capacity cost, their very low capacity factors, and their lack of reliability. Even the most rudimentary engineering analysis indicates that to overcome these factors a large complex interconnected grid would be needed to link up to four times the required spatially separated nameplate capacity and even then 100% reliability could not be guaranteed. The financial ramifications of this engineering requirement indicate levelised cost of electricity values up to six times those currently assumed for wind or solar power if a network costs are also considered. Of course none of this is an issue if the basic public policy aim is to simply stimulate the economy through infrastructure development using electricity consumer funds at the expense of consumers and industry economic viability.

The European outcome of policies of this nature makes sobering reading (Australian 2013). Not only have escalating electricity costs to the consumer become a major political issue but more fossil fuel power stations are now being constructed militating against reduction in CO_2 by programs that were the basis of the original (misguided) investments. Some might argue that these were unintended consequences arising from the massive renewable energy investment programmes but the fundamental issues have been well understood by the European engineering community for many years. It is very difficult to rationalise the closure of German nuclear power plants given the world renowned quality of German engineering in general but the consequences of those policies are now becoming clear with the need for Germany to build more coal-fired power plants.

All the general information currently available indicates that a rigorous study of the nuclear power option for South Australia would lead to a beneficial lowest cost outcome compared with all other options. There are a number of engineering consulting groups in Australia capable of carrying out this task to the standards required for investment decision.

A range of BREE and other LCOE estimated values for base load and intermittent power generation for 2020 technologies and are noted as follows (AETA 2013);

Base Load Installations	LCOE $/MWh
Nuclear gigawatt scale reactor	90 to120
Nuclear SMRs	110 to 190
Combined cycle gas turbines	75 to 120
Direct injection refined coal-fired engine	100
Supercritical pulverised black coal	60 to 110
Solar thermal with storage	95 to 280
Open cycle gas turbines	155 to 260

Intermittent Low Capacity Generation	LCOE $/MWh
Wind onshore	55 to 120
Solar photovoltaic	60 to 190
Wind offshore	120 to 230

The very wide range of values noted above reflects a wide range of particular sites and cost models. These values can only be refined for installations in South Australia by a rigorous feasibility study.

Conclusions

Only a rigorous feasibility study of the nuclear power option for South Australia would lead to credible unit cost scenario from this source of power generation.

References

[1] Cusworth McKenzie 2007-The Use and Abuse of Feasibility Studies. Project Evaluation Conference Melbourne 2007

Question 3.17

Would the establishment of such facilities give rise to impacts on other sectors of the economy? How should they be estimated and using what information? Have such impacts been demonstrated in other economies similar to Australia?

Response

There would be several benefits from the establishment of a nuclear power plant in South Australia. These include the development of new industries, innovation and jobs.

Flow on benefits to other sectors of the economy from the establishment of a nuclear power program in South Australia would be twofold - generalised economic multiplier effects from local supply work and an upgrading of the manufacturing skill base.

General economic impact assessment studies from many mining/processing projects across Australia indicate that the local and extended community see a two to three times economic multiplier effect directly attributed to major project expenditure. Expenditure includes capital equipment purchase and construction labour expenditure. While yearly operating expenditure tends to be much lower similar multiplier effects are found but for a much longer period. A similar but unfortunately reverse impact can already be perceived for the eventual closedown of Australia's motor vehicle industry and possible shipbuilding facility closures.

It is very important to support and develop facilities to ensure the highest possible proportion of local supply within technical/economic reason. Much of a nuclear power plant balance of supply and manufacture is well within local capabilities given the OPAL research reactor development experience and the following two criteria – first, the implementation proven quality management systems and second, management commitment to adhere to them without compromise.

The impacts of a nuclear power program would also flow into an outcome of more advanced technology manufacturing capability. It can be difficult to quantify the benefits but as a small significant example an extensive staff retraining program at ANSTO for the engineering management and workshop personnel can be referenced [1].

The introduction of a staff learning skills program in that division together with a quality management and certification program commencing in 2002 led to a significant competitive improvement of highly specialised fabrication and manufacturing capability for equipment not available anywhere else in Australia. Overall cost went down driven by the following key changes:

- The workforce became more involved.
- The workforce assumed responsibility for all of their work including all capital equipment purchases.
- Lost time accidents and incidents fell to 5 times lower than previous levels.

The outcomes lead to decisions to manufacture highly specialised scientific instrumentation for the OPAL reactor development program rather than purchase overseas.

A nuclear power and associated support industries program in South Australia could easily replicate this experience to the point where a much larger supply proportion of plant could be locally sourced for future installations across Australia and potentially Southeast Asia. There are a number of other countries which have achieved this outcome starting from a much lower education and skills base but with more focused aspirations and leadership.

Attractive employment opportunities for the local labour force will be generated. Additional benefits will be realised through capacity building and skills development in the local labour force through apprenticeships, traineeships and skills training, as well as ongoing skills transfer between imported and local labour and the permanent migration of some overseas sourced skilled labour. These factors are difficult to fully quantify but have been demonstrated on the OPAL reactor development project and many major mining and processing plant developments throughout Australia.

South Australia has an opportunity to lead the country in the nuclear generation technology. With the centre of demand of the NEM on the east coast of Australia, investment in South Australia requires some competitive advantage. For this reason there may be advantages in the SA government moving early in the direction of nuclear generation ahead of the other states.

Contrary to the issues paper comment on this subject Australia is already sufficiently serviced with sufficient numbers of highly experienced nuclear engineering staff to implement the first stages of a nuclear power plant program albeit with a majority currently working in other industry sectors. Initially the numbers of nuclear trained project managers and experienced specialised nuclear engineers required would be no more than twenty, and these could easily direct all of the other design and construction disciplines with local engineering consultants and construction contractors as required.

Our experience is that it takes about 1 to 2 years to train appropriately qualified mechanical and electrical engineering graduates with about five to ten years' experience to move into nuclear engineering areas. The extent of documentation supporting nuclear science, engineering principles, that practice is extensive and freely available and well supported by local and overseas universities operating in Australia.

Experience around the world is that many nuclear power stations become tourist attractions and educational resources in themselves. For example ANSTO's Discovery Centre at Lucas Heights attracted over 15,000 visitors in 2014. Heysham AGR nuclear power plant on the northwest coast of the UK is one of the top tourist attractions in the area.

Conclusion

A timely start to a South Australian nuclear power program will have widespread economic effects including new industries, innovation and new jobs, whilst also having the potential to provide high-quality manufacturing skills and outputs support for similar programs in other States and south-east Asian countries.

References

[1] Hill 2003 -Teaching Smart People To Think the Learning Skills Program at Australia's Nuclear Research Facility. 11th International Conference on Thinking. Phoenix Arizona 2003

Issues Paper 4 – Management, storage and disposal of nuclear and radioactive waste

Question 4.5

What are the specific models and case studies that demonstrate the best practice for the establishment, operation and regulation of facilities for the storage or disposal of nuclear or radioactive waste? What are the less successful examples? Where have they been implemented in practice? What new methods have been proposed? What lessons can be drawn from them?

Response

No industrial activity can be carried out without some risk to health and safety. Risks associated with processing and storage of nuclear and radioactive waste are no greater, and are less in some cases, than risks associated with many other industries that are accepted by society, including the manufacture and storage of potentially hazardous chemicals at sites close to many major cities (e.g. at Botany, a suburb of Sydney). They are managed in much the same way as risks from the chemical industry – a significant difference being the need to shield against radiation.

Radiological risks are better understood than many conventional risks. Experience overseas has shown that they can be managed safely, with less risk to health and safety than accepted risks from the chemical industry. Storage of radioactive materials and chemical processing to extract medical radioisotopes have been carried out safely at Lucas Heights, near Sydney, for over 50 years.

Risks to health and safety associated with disposal of nuclear and radioactive waste would be even lower than risks from processing and storage. Management practices in general are subject to greater care and surveillance than management of chemical wastes – and chemical wastes, unlike radioactive waste, do not decay. Within about 120,000 years, the radioactive content of spent nuclear fuel (containing plutonium and other trans-uranium "minor actinides") decays to be less than the radioactive content of the ore body from which the uranium was originally mined. If spent fuel is chemically reprocessed to remove all the plutonium (for recycle) and all the minor actinides (which can be burnt eventually in fast neutron reactors), the most significant hazards in the remaining waste are fission products with half-lives of about 30 years. The time taken for this fission product waste to be less radioactive than that original ore body would be a few hundred years.

Whether or not spent nuclear fuel is reprocessed (or is itself treated as waste), once the waste has been buried deep in a stable geological repository, it will be better isolated from the environment than the original ore body. In particular, nuclear waste does not generate the radon gas which is generated from the decay chain of uranium that has been free in the earth's crust for billions of years. Radon on average constitutes about half of our exposure to natural radiation but rarely reaches levels that cause a health risk.

Radiation has two useful characteristics:

- It is easy to detect at levels far below the detection threshold of any noxious substance (one can detect a single disintegration whereas one cannot detect a given chemical unless billions of molecules are present)
- When detected, distance, time of exposure and shielding provide protection

Classification of radioactive waste in Australia

Radioactive waste in Australia is classified in accordance with the ARPANSA Safety Guide for Classification of Radioactive Waste RPS20, 2010. To ensure compliance with international practice, this safety guide is based on the IAEA Safety Guide Classification of Radioactive Waste GSG-1, 2009.

For any radioactive waste facility, the applicant has to develop a safety case that includes the organisational and technical arrangements; waste characteristics; design of the facility including engineered barriers, and the arrangements for its construction, operation, closure and post-closure stages.

Low level Waste (LLW)

The majority by quantity of radioactive waste in Australia is solid Low Level Waste (LLW).

The current total Commonwealth inventory is 4,048.28 m^3, with a current annual production of <40m^3/year [2]. Of this, 1,936m^3 is held at Lucas Heights by ANSTO, and 2,100 m^3 is held at Woomera by CSIRO. The CSIRO waste consists of lightly contaminated soil from research into processing radioactive ores in the 1950/60s'.

Other LLW consists of solid waste from the routine day-to-day operations of the OPAL research reactor and other facilities at Lucas Heights; hospitals and industry (some hospitals may also be storing redundant radium sources which could be LLW or ILW). Typical waste is paper, cleaning materials, resins, filters and lightly contaminated scrap metal. The waste is sorted, and compacted into 220 litre drums and stored on site. No shielding is required as the radiation level on the outside of the drum is low. The drum provides containment. Radionuclides with half-lives of less than about thirty years are considered to be short lived. The time for LLW to decay to background levels is normally assumed to be within 300 years.

The IAEA guidance for this waste is in a Near Surface Repository [1]. This has engineered features to contain the waste for 300 years, i.e. a number of barriers to restrict release of the radionuclides to the environment.

Protection is achieved through the use of natural and engineered barriers and institutional controls. Operation of these barriers and controls is required until radiation levels decay to a level that cannot give rise to health or environmental concerns or appreciable security risk. International and Australian codes consider that institutional controls can reasonably be assured for a period of 300 years.

There are many good examples of Near Surface Repositories worldwide, e.g.:

- UK - Drigg, Dounreay
- France - Centre de la Manche, Centre de L'Aube
- Japan - Rokkasho-Mura
- USA - Barnwell (South Carolina), Richland (Washington), Clive (Utah), Texas Compact Facility

An example of international best practice is El Cabril in Spain (Fig 1),

Fig 1: El Cabril Disposal Facility, Cordoba, Andalusia, Spain (ENRESA)

El Cabril stores low level waste from Spain's nuclear facilities, hospitals and industry. The facility has been authorised for its full capacity of 28,200 m^3 since 2001. 84% of the LLW comes from nuclear facilities, 7% from hospitals and 9% from others.

El Cabril is an engineered disposal facility with several layers of containment (fig2).

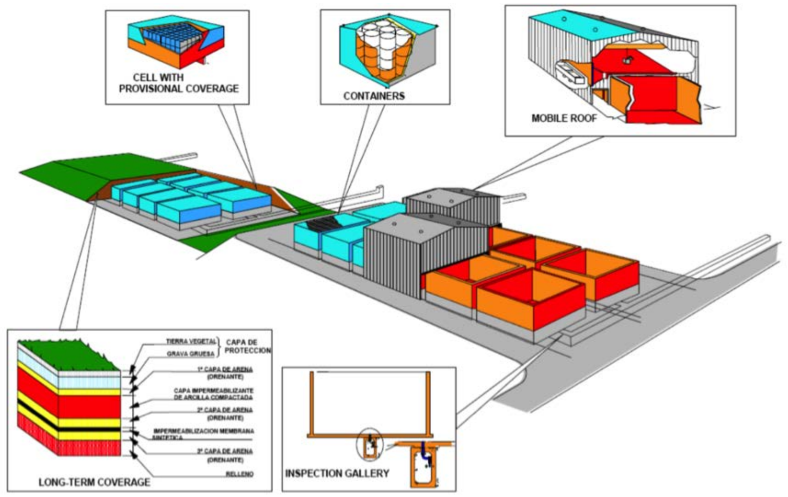

Fig 2: El Cabril engineering design (ENRESA)

Packages (usually drums) of LLW are received on site and loaded into concrete containers which are then filled with grout. 320 containers are loaded into each concrete cell. A moveable roof over an operating cell protects it from the weather during this period. When a cell is full, it is backfilled with grout for stability and covered with a reinforced concrete top slab. When a complete platform of cells have been filled, the platform is covered with layers of clay, impermeable membrane, gravel and soil for additional isolation of the waste from the environment and visual appearance.

There would be no incentive for overseas countries to send their LLW to Australia for disposal because:

- Countries with nuclear facilities have constructed their own LLW repositories. There is extensive international experience of a simple engineered solution for this relatively short lived waste.
- The cost of transport of large quantities of LLW would be uneconomic.

However there could be an economic incentive for South Australia to build a LLW facility for Australian LLW. The Federal Government has for many years been trying to establish a Near Surface Repository and this would be a good opportunity for South Australia to derive regular income from storing LLW, in particular Commonwealth LLW.

South Australia would be an ideal location. Between 1992 and 2004, an exhaustive scientific investigation based on nationally agreed scope, procedure and criteria, identified eight regions in Australia that would be suitable for this purpose. An area of 67,000 square km in central-north South Australia was identified as the most promising region.

South Australia would also be a particularly appropriate location since the largest quantity of LLW (CSIRO contaminated soil) is already held on a temporary basis at Woomera.

It would be certainly an improvement in safety and security if all the hospital radioactive waste was moved to a central secure location. At present, Commonwealth, State and Territory LLW is stored at more than 100 sites across Australia [2].

This could also establish South Australia's Near Surface Repository as a model for other countries in our region.

El Cabril has 180 staff on site. Spain has 8 operational nuclear power plants so the annual quantity of LLW from nuclear facilities is more than currently in Australia, but this will increase when Australia commences its nuclear power program. A 1,000 MWe light water reactor produces around 150m^3/year of LLW [3].

For Low Level Waste

Security implications - low

Community acceptance - many examples worldwide of repositories

Environmental and safety risks - low, engineered barriers and institutional controls

Transport risks - low

Intermediate Level Waste (ILW)

The current total Commonwealth inventory of ILW is 551.5 m^3, with a current annual production of <5m^3/year [1]. The majority of the ILW (451m^3) is held at ANSTO. It consists of higher activity operational waste including irradiation cans, ion exchange resins, aluminium end pieces of fuel rods, control arms and general waste from radiopharmaceutical production.

This type of waste requires shielding and is stored in underground vaults. It is handled in shielded metal casks. It does not require cooling.

If Australia started a nuclear power program, the typical quantity of ILW produced would be around 8.6m^3/year for a 1,000 MWe reactor [3]. This is mainly resins from radioactive water treatment systems. The quantity would be smaller for a Small Modular Reactor.

If South Australia does proceed with a Near Surface Repository for LLW, then it could consider co-locating an ILW store. This would be a building which would house shielded metal casks containing the ILW on an interim basis. There is extensive international experience with these types of casks.

ILW from reprocessing spent fuel from ANSTO's research reactors will be returned to Australia in 2015 in a TN-81 combined transport/storage container, weighing 115 tonnes. This will be held in an interim store at Lucas heights, but could be transferred to a central ILW store.

Also ANSTO is building a new plant to process waste from radiopharmaceutical production in Synroc as ILW. This could also be stored in the ILW store.

In the longer term, ILW could be co-located in a deep underground facility with High Level Waste.

High Level Waste (HLW)

HLW has higher activity than ILW and produces significant heat. The normally accepted definition of the heat load is > 2kW/m^3. HLW is not produced during routine day to day reactor operations and is only associated with spent fuel.

When a power reactor is refuelled, the spent fuel that is removed is highly radioactive and still producing heat. Normal practice is to store the spent fuel in a cooling pond close to the reactor for several years to allow the radioactivity and heat load to decay. There are then four potential stages of spent fuel management:

- interim dry storage;
- reprocessing if unburnt fissile materials are to be recycled and/or transuranic waste materials are to be removed;
- burning of recycled materials and transuranic waste in a fast neutron reactor;
- final disposal of complete spent fuel assemblies or other HLW

Interim dry store

The spent fuel is transferred to dry storage which can be a metal cask; a metal lined concrete cask; a silo or a vault. This is only an interim solution, pending final disposal, but it is current practice in many countries, particularly the USA. The casks are passively cooled by natural convection. The casks are massive, typically weighing 100 tonnes. There is extensive experience of dry storage. Security, environmental and safety risks are low.

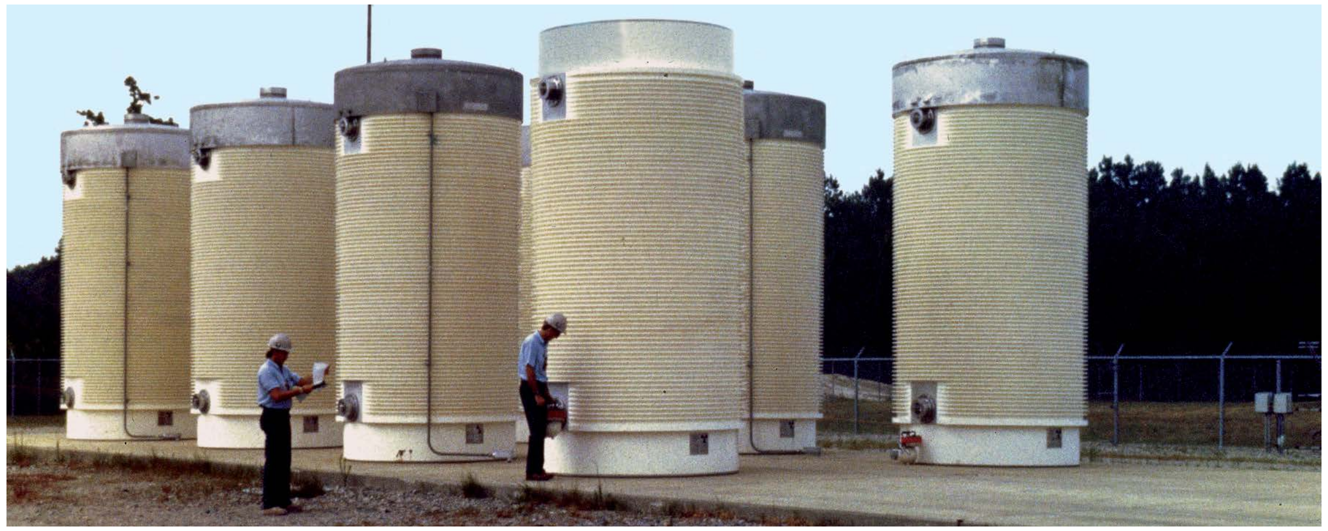

Fig 3: Spent fuel in dry store casks (USA)Spent fuel reprocessing

The spent fuel can be reprocessed to recover the uranium and plutonium for reuse. The dominant technology is the aqueous PUREX (plutonium and uranium extraction) and there are plants operating in France, UK, Russia and India.

Reprocessing advantages:

- recovered plutonium can be used in thermal reactors as MOX fuel or in fast reactors
- waste volume is reduced to 1/5th
- reduction of short and long-term radiotoxicity
- waste form suitable for long-term storage (vitrified)
- waste does not contain any fissile materials so there are no safeguards issues
- PUREX is a mature technology

However there are also disadvantages:

- Complex expensive plant requiring careful control of contamination, radiation and criticality
- Some proliferation concerns as plutonium is separated (although reprocessed plutonium from a light water power reactor is unsuitable for weapons manufacture)
- The final product is usually still HLW, although the quantity and activity are both lower

Reprocessing technology has been available since the 1950's, but not universally adopted for political and commercial reasons. To date, 90,000t of 290,000t of the commercial spent fuel that has been discharged from nuclear power plants has been reprocessed.

An alternative technology is pyrometallurgical processing. This has been used particularly for the Integral Fast Reactor system. This is a non-aqueous process and does not separate plutonium making it more proliferation resistant than PUREX. See further details below in the fast reactor section.

Final Disposal

If spent fuel is to be sent for direct disposal, it is then classified as HLW. The IAEA Specific Safety Requirements for Disposal of Radioactive Waste [1] specify deep geological disposal.

IAEA Safety Standard SSG-14 [4] provides guidance for the site characterisation and the safety approach to containment and isolation.

The fuel cladding, the disposal container, back filling material and the bedrock provide multiple barriers to the release of radioactive materials. The depth provides a long pathway to release, protects against aboveground climate changes and deters intrusion.

The effectiveness of a geological repository can be seen at the OKLO site in Gabon, Central Africa [5]. 2,000 million year ago, the proportion of fissile U-235 in uranium was 3% (compared to 0.7% today) and together with water as a moderator this enabled natural nuclear reactors to operate intermittently over a period of 1 million years. The fission products have decayed to stable products and it can be seen that most of the "radioactive waste" is retained close to the reactor in iron and clay, even in a highly porous environment.

Many radioactive products are not very mobile.

After many years of research, several countries are making progress towards a deep geological repository.

Sweden

In Sweden, utilities pay a 0.04 kr (US$0.52c) per kWh fee to cover the cost of waste disposal.

Sweden made a decision not to reprocess spent fuel and a central storage facility (CLAB) has been in operation since 1985 at Oskarshamn. Following a site volunteer process, Forsmark, Osthammar municipality, Uppsala was chosen as the site for the repository.

Complete fuel assemblies will be encapsulated in copper canisters and deposited in holes in crystalline bedrock. The void between the bedrock and the canister is filled with bentonite clay to absorb any leakage. This is known as the KBS-3 nuclear waste disposal technology and provides a multi-barrier system consisting of fuel cladding + canister + clay + bedrock.

The repository is 500m deep in 1.9 billion year old granite.

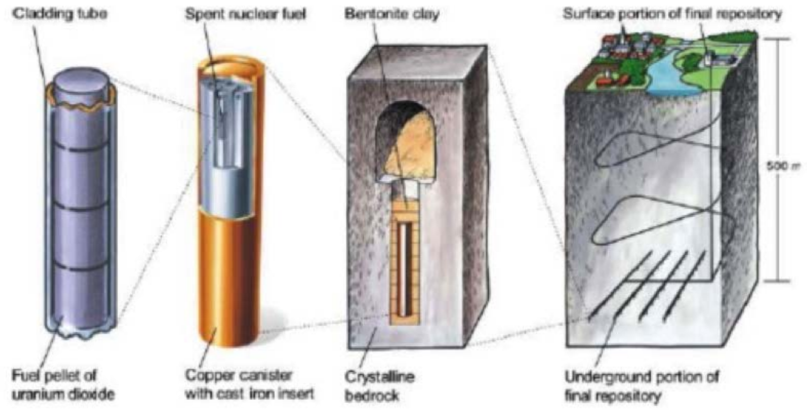

Fig 4: Deep geological repository at Forsmark, Sweden

The construction licence application was lodged by the radioactive waste authority, SKB, in March 2011. The repository is expected to start disposals in 2020.

Finland

Finland also took the decision not to reprocess spent fuel. They have been researching and characterising sites for 30 years. After the Governments decision-in-principle in 2001 to proceed with a deep underground repository, the radioactive waste authority Posiva Oy constructed an underground rock characterisation facility (Onkalo). In December 2012 the construction licence application was lodged by Posivsa for the volunteer Okiluoto site using the same KBS-3 technology as Sweden. The site was chosen as it is seismically stable and has no natural resources that would cause an interest in ore-prospecting or mining activities. The groundwater is saline and not used for drinking water.

The licence application was reviewed by the Finland Radiation and Nuclear Safety authority STUK. In February 2015, STUK published their safety assessment of the construction application [6] stating that the repository can be built to be safe. Following construction, Posiva expect to apply for an operating licence in 2020. According to the law, final disposal may cause an annual radiation dose of no more than 0.1 millisiverts to an exposed individual after the facility is closed. Based on the analysis of release pathways, STUK found that the radiation exposure would be one 10,000th of the specified 0.1 millisiverts limit. The average annual radiation exposure in Finland from natural background is 3.2 millisiverts.

After all the spent nuclear fuel has been disposed of, the operating period will end with the decommissioning of the encapsulation plant located above ground and backfilling as well as sealing the rooms in the disposal facility underground. Close to the surface, the underground rooms will be filled with structures that make intrusion into the repositories difficult.

The spent fuel is held in interim storage for at least 20 years before final disposal. This ensures that the heat load is reduced to a level where no active cooling is required in the underground repository. Any heat is dissipated by natural conduction.

The disposal depth of 400m was chosen taking into account:

- Frequency of fractures in the rock decrease with depth
- Flow rate of groundwater decreases with depth
- Change of above ground conditions due to an ice age – the permafrost is estimated to penetrate to a depth of 60-240m during a dry, cold period lasting 10,000 years

Analysis of long-term scenarios presented in the safety case demonstrated that any long-term radiation doses to people or the environment are many orders of magnitude below the 0.1 mSv limit.

Several other countries, including France and Switzerland are at an advanced stage in deep geological disposal projects.

The conclusion is that deep geological disposal is now a possible technique for final disposal of HLW.

Australian Potential

In 1998-1999, *Pangea Resources Australia Pty Ltd* identified specific areas, including areas in South Australia that would be suitable for disposal of HLW. At that time, however, disposal of radioactive waste was politically unacceptable in Australia.

Burn in a Fast Neutron Reactor

The majority of nuclear power reactors are thermal neutron reactors. The fast neutrons from fission are slowed down by a moderator to thermal energies. This increases the probability of fission in U-235, but decreases the probability of fission in other elements, particularly the higher actinides that are produced by neutron absorption in U-238. Some of the actinide isotopes form the very long-lived constituents of radioactive waste from thermal reactors.

However, if the fast neutrons from fission are not moderated, the actinides will fission and the resulting fission products generally have much shorter half-lives. Spent fuel from the current generation of thermal reactors can be chemically reprocessed to provide fuel for use in a fast neutron reactor and the resulting radioactive waste is much easier to manage.

This reduces the timescale for spent fuel radioactive waste to decay down to the level of the original uranium ore from 120,000 years to < 400 years (see fig 5).

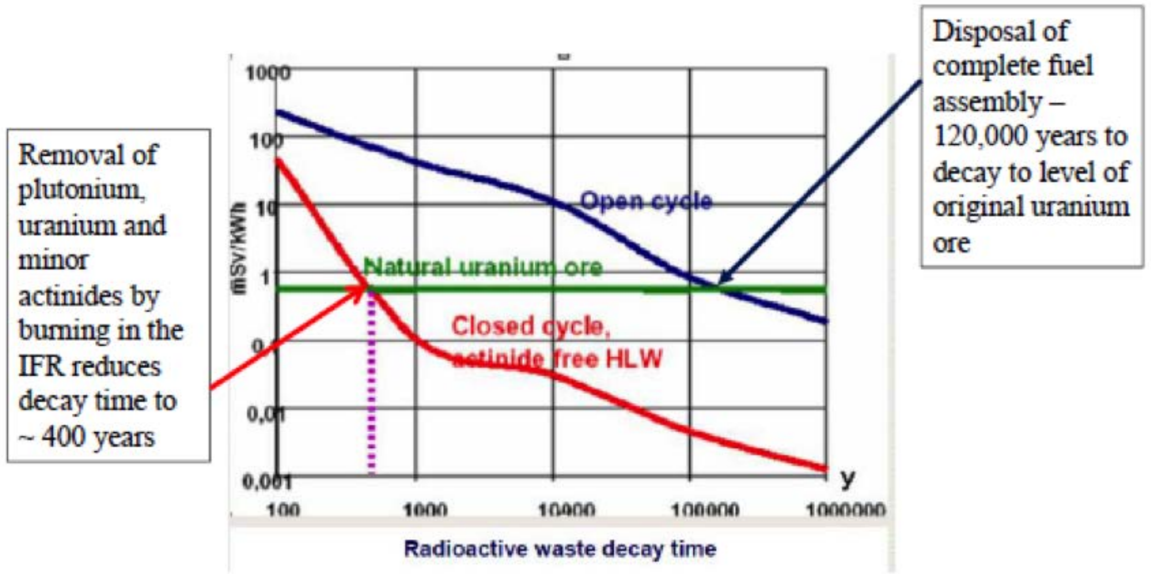

Fig 5: Effect of removing actinides from radioactive material in spent fuel

The complete process of converting thermal reactor spent fuel to fuel for a fast reactor, burning in a fast reactor, and reprocessing the fast reactor spent fuel all on one site was demonstrated at the EBR II Integral Fast Reactor (IFR) project in the USA from 1984-1994 [7].

The IFR has excellent fuel efficiency, safety, waste and non-proliferation characteristics.

Fuel supplies are extended more than one hundred-fold enabled a sustainable future for nuclear energy. The fast reactor has inherently safe properties. The final waste has a much shorter life-time as seen above. The electrorefining process used for fuel processing, unlike the PUREX process, does not separate plutonium so it is more proliferation resistant.

GE-Hitachi is offering its PRISM (Power Reactor Innovative Small Module) [8], a sodium cooled fast reactor with an output of 311 MWe which has been developed from EBR II. This would be a suitable fast neutron reactor for an IFR site. Spent fuel from countries abroad could be imported and processed to make fuel for Prism which would generate electricity.

PRISM is a suitable size (300 MWe) for the South Australian grid. There could be a financial incentive for countries that are not considering a deep geological repository to send their spent fuel to Australia for processing.

The UK is considering PRISM to burn the UK plutonium stocks.

Conclusions

There could be a financial incentive for South Australia to establish a Low Level Waste Repository within the State. The technology of a near surface repository is well understood and the risks to people and the environment are very low.

If a LLW repository was established, a co-located ILW waste store should also be considered. The risks are again low.

A deep geological repository for HLW would not be needed until at least 50 years after the start of a nuclear power program in Australia.

The possibility of an IFR project using PRISM or a similar type of reactor could be investigated by a feasibility study. If spent fuel was imported from abroad for an IFR project, interim storage in dry storage casks is well understood and low risk.

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[7] Plentiful Energy (The Story of the Integral Fast Reactor), Till and Chang, 2011

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Question 4.8

Bearing in mind the measures that would need to be taken in design and siting, what risks for health and safety would be created by establishing facilities to manage, store and dispose of nuclear or radioactive waste?

What needs to be done to ensure that risks do not exceed safe levels?

Can anything be done to better understand those risks?

Response

As described in Issues paper 4, radioactive waste is classified in accordance with the IAEA Safety Guide Classification of Radioactive waste GSG-1.

Low level Waste (LLW) is low activity and relatively short lived. Radionuclides with half-lives of less than about thirty years are considered to be short lived. The time for LLW to decay to background levels is normally assumed to be within 300 years.

The IAEA guidance for this waste is in a Near Surface Repository [1]. This has engineered features to contain the waste for 300 years, i.e. a number of barriers to restrict release of the radionuclides to the environment.

Protection is achieved through the use of natural and engineered barriers and institutional controls. Operation of these barriers and controls is required until radiation levels decay to a level that cannot give rise to health or environmental concerns or appreciable security risk. International and Australian codes consider that institutional controls can reasonably be assured for a period of 300 years.

There is over 50 years of experience of managing low level waste and there are many good examples of Near Surface Repositories worldwide, e.g.:

UK – Drigg, Dounreay

France – Centre de la Manche, Centre de L'Aube

Japan – Rokkasho-Mura

USA – Barnwell (South Carolina), Richland (Washington), Clive (Utah), Texas Compact Facility

An example of international best practice is El Cabril in Spain (see response to Q4.5)

Intermediate Level Waste (ILW) and High Level Waste (HLW) require shielding protection from the higher radiation emitted from this waste. They also typically have longer lifetimes.

In the case of the disposal of a complete spent fuel assembly containing plutonium, uranium and other actinides, the activity would decay to the level of the original uranium ore in ~120,000 years.

The spent fuel is held in interim storage for at least 20 years before final disposal. This ensures that the heat load is reduced to a level where no active cooling is required in the underground repository. Any heat is dissipated by natural conduction. There is more than 30 years' experience of interim storage in dry store casks and the risks are low.

The IAEA Specific Safety Requirements for Disposal of Radioactive Waste [1] specifies deep geological disposal. IAEA Safety Standard SSG-14 [2] provides guidance for the site characterisation and the safety approach to containment and isolation.

Sweden, Finland, France and Switzerland in particular have been researching and characterising sites for more than 30 years. The complete deep disposal system has to include a multi-barrier system to ensure safety for over 100,000 years.

In the Swedish system, also adopted by Finland, complete fuel assemblies will be encapsulated in copper canisters and deposited in holes in crystalline bedrock. The void between the bedrock and the canister is filled with bentonite clay to absorb any leakage. This is known as the KBS-3 nuclear waste disposal technology and provides a multi-barrier system consisting of fuel cladding + canister + clay + bedrock.

The repository is 500m deep in 1.9 billion year old granite.

In Finland the radioactive waste authority Posiva Oy constructed an underground rock characterisation facility (Onkalo). In December 2012 the construction licence application was lodged by Posivsa for the volunteer Okiluoto site using the same KBS-3 technology as Sweden. The site was chosen as it is seismically stable and has no natural resources that would cause an interest in ore-prospecting or mining activities. The groundwater is saline and not used for drinking water.

The copper canisters will have nodular cast iron inserts. They are five metres long and weigh 25 tons when filled with spent fuel. The outer casing consists of 5cm thick copper. The canisters have been constructed to withstand corrosion and the mechanical forces that can result from movements in the rock surrounding the Spent Fuel Repository.

The copper canisters will be embedded in Bentonite clay. The clay acts as a buffer and protects the canister from corrosion and minor movements in the bedrock. The clay buffer will gradually absorb water and swell to fill the space around it and any cracks in the rocks. The clay prevents the escape of any radioactive substances into the rock. The rock isolates the waste, provides a stable chemical environment and protection from events at ground level.

The licence application was reviewed by the Finland Radiation and Nuclear Safety authority STUK. This has provided the opportunity for an assessment of the risks from the final disposal of HLW.

In February 2015, STUK published their safety assessment of the construction application [3] stating that the repository can be built to be safe. Following construction, Posiva expect to apply for an operating licence in 2020. According to the law, final disposal may cause an annual radiation dose of no more than 0.1 millisiverts to an exposed individual after the facility is closed. Based on the analysis of release pathways, STUK found that the radiation exposure would be one 10,000th of the specified 0.1 millisiverts limit. The average annual radiation exposure in Finland from natural background is 3.2 millisiverts.

After all the spent nuclear fuel has been disposed of, the operating period will end with the decommissioning of the encapsulation plant located above ground and backfilling as well as sealing the rooms in the disposal facility underground. Close to the surface, the underground rooms will be filled with structures that make intrusion into the repositories difficult.

The disposal depth of 400m was chosen taking into account:

- Frequency of fractures in the rock decrease with depth
- Flow rate of groundwater decreases with depth
- Change of above ground conditions due to an ice age – the permafrost is estimated to penetrate to a depth of 60-240m during a dry, cold period lasting 10,000 years

Analysis of long-term scenarios presented in the safety case demonstrated that any long-term radiation doses to people or the environment are many orders of magnitude below the 0.1 mSv limit.

This detailed assessment by an experienced nuclear regulator of a proposed deep underground repository provides an understanding of the risks of long-term management of radioactive waste.

References

[1] IAEA Safety Standard Specific Safety Requirements for Disposal of Radioactive Waste SSR-5, 2011

[2] IAEA Safety Standard Specific Safety Guide Geological Disposal Facilities for Radioactive Waste SSG-14

[3] Safety Assessment by the Radiation and Nuclear Safety Authority of Posiva's construction licence application, STUK, 11 February 2015 http://www.stuk.fi/en_GB/

Question 4.10

What are the risks associated with transportation of nuclear or radioactive wastes for storage or disposal in South Australia? Could existing arrangements for the transportation of such wastes be applied for this purpose? What additional measures might be necessary?

Response

Transport of radioactive materials is one area where there is very good international agreement and standards, because the whole of the nuclear fuel cycle, from ore to waste involves transport, in many cases between countries.

There are many classes of Dangerous Goods transported worldwide. Radioactive materials are Class 7 Dangerous Goods and make up ~2% of all dangerous goods. There are many goods that are more dangerous than nuclear materials to transport, e.g. class 1 explosives and class 3 flammable liquids.

The IAEA Safety Standard TS-R-1 [1] provides the detailed safety standards and guidance. For Australia, ARPANSA has recently (December 2014) issued the Code for Safe Transport of Radioactive Materials [2] based on the IAEA Specific Safety Requirements SSR-6. Compliance with this code is mandatory.

Safe Transport is ensured by:

- Containment of radioactive materials
- Control of external radiation levels
- Prevention of criticality
- Prevention of damage caused by heat

There is a graded approach to packages and contents. *The Competent Authority* [1] certifies packages and shipments. In Australia the competent authorities are [2]:

Jurisdiction	Competent Authority
Commonwealth	ARPANSA
South Australia	Environmental Protection Authority
Transport by air	Civil Aviation Safety Authority (CASA)
Transport by sea	Australian Maritime Safety Authority (AMSA)

There are five types of packages:

Package type	Contents
Excepted	Radioactive contents restricted to such low levels that hazards are insignificant
Industrial packages IP -1, IP-2, IP-3	Low activity, e.g. uranium ore in type IP-1 200 litre steel drum
Type A	Limited radioactivity, e.g. new fuel assemblies for a nuclear power reactor
Type B	Highly radioactive materials e.g. spent fuel and HLW
Type C	Transport of radioactive material by air

Type B packages must be capable of withstanding accident conditions without breach of containment or an increase in radiation to a level which would endanger the general public or those involved in rescue operations.

The package has to withstand a series of sequential tests including a drop from 9m high, followed by a drop from 1m onto a punch bar, followed by a fire at 800oC. There is also a water immersion test.

Type B packages are routinely used to transport spent fuel from reactor sites to reprocessing plants or storage. They are also used to transport HLW from reprocessing plants back to the country of origin. A typical spent fuel package weighs 110 tonnes and is 6m long and 2.5m diameter. There has never been an accident with a type B package that has caused any significant radiological release.

In Australia, type B packages are routinely used to transport spent fuel from the research reactors at Lucas Heights to a port for shipment abroad for reprocessing [3].

ILW from reprocessing of spent fuel elements from ANSTO's HIFAR research reactor will be returned to Australia in a type B TN-81 package.

ANSTO has an engineering team that specialise in designing and testing packages for radioactive materials to international standards.

Conclusions

Radioactive materials are transported worldwide to international standards. South Australia has extensive experience of the safe transport of uranium ores.

Transport of LLW and ILW to a site in South Australia would be low risk.

Australia has experience of transport of spent fuel.

References

[1] IAEA Safety Standard Regulations for the Safe Transport of Radioactive Material TS-R-1, 2009

[2] ARPANSA Code Safe Transport of Radioactive Materials, RPS C-2, Dec 2014

[3] ANSTO Management of Radioactive Waste in Australia, January 2011

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