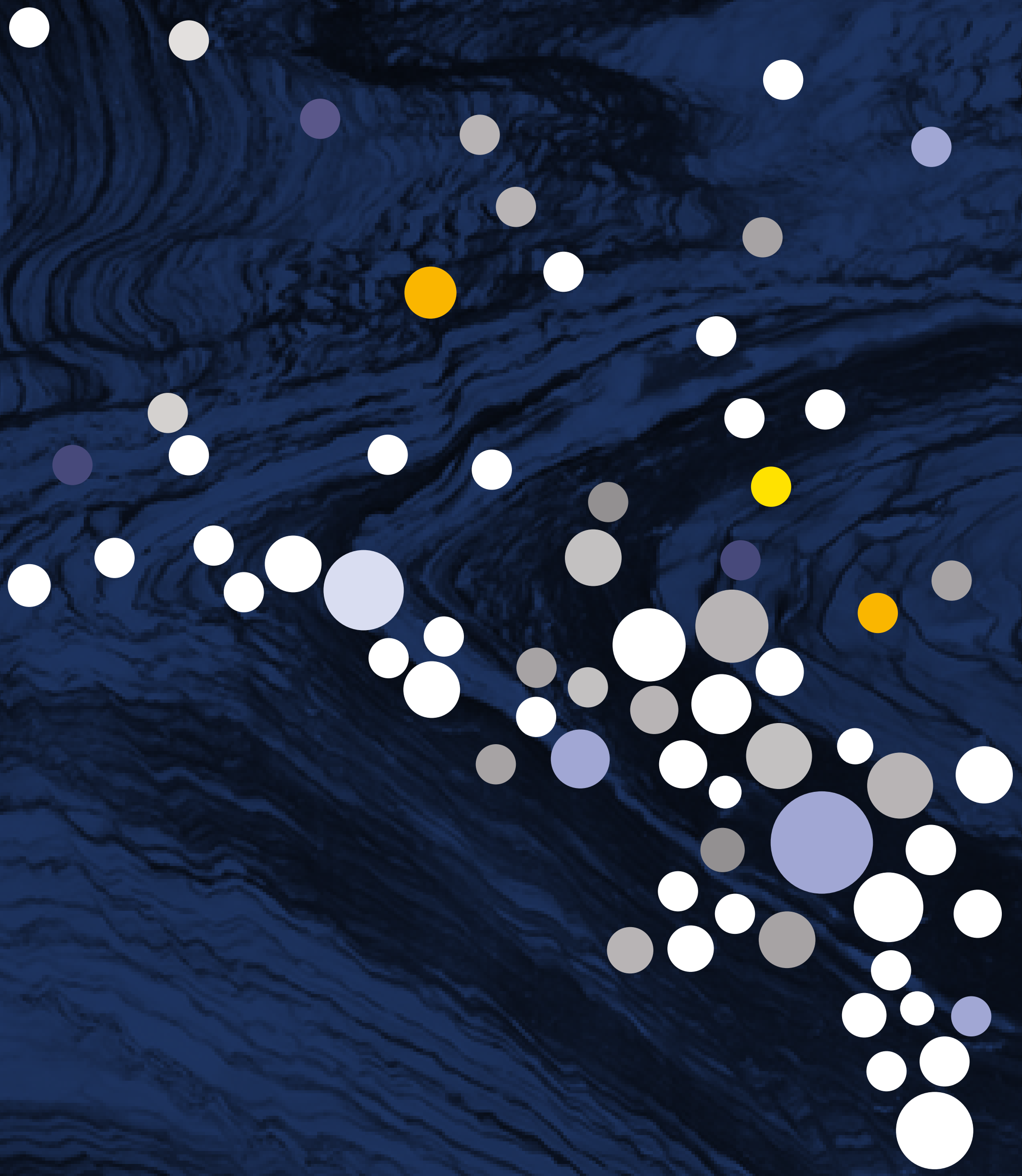
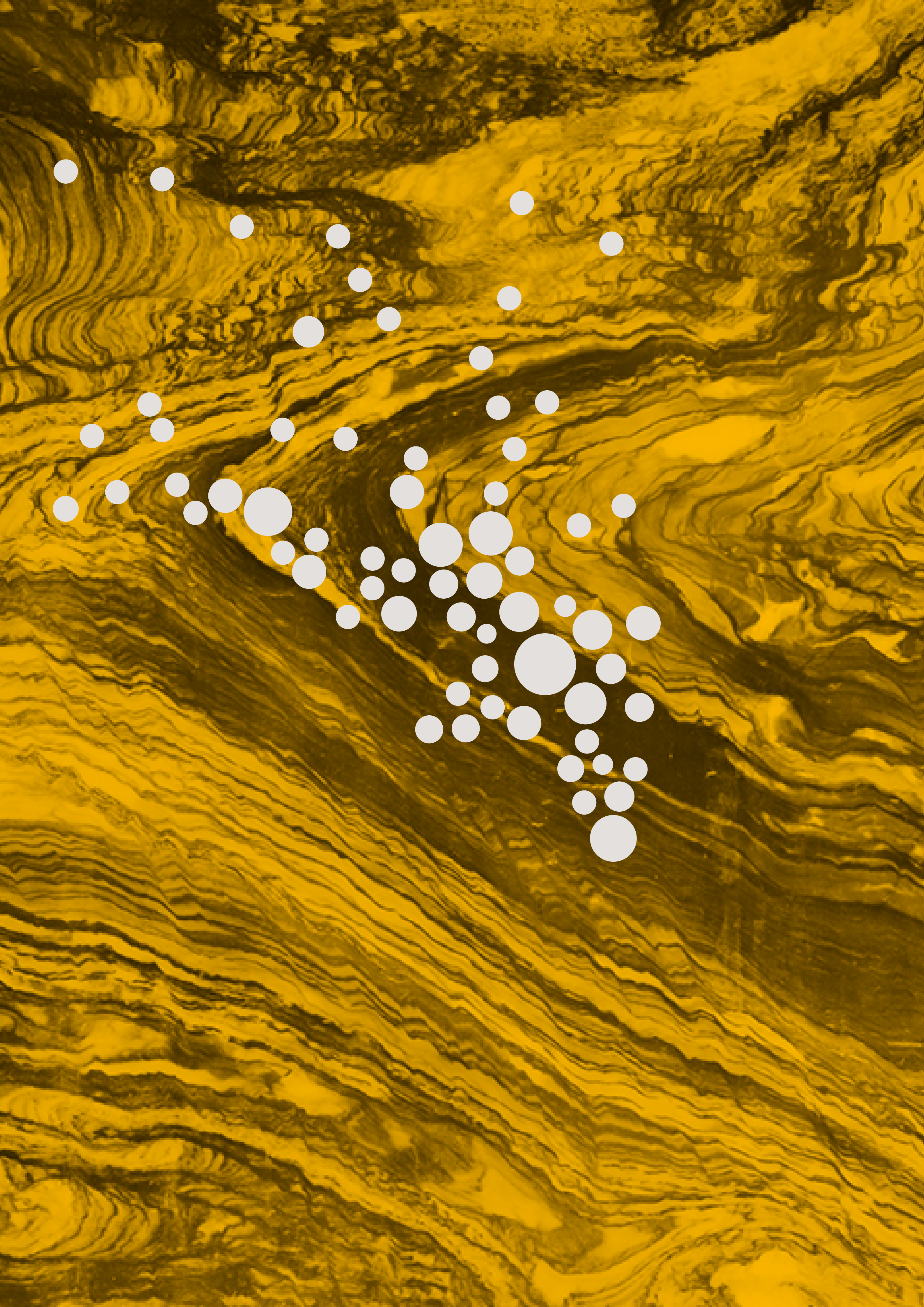


NUCLEAR FUEL CYCLE ROYAL COMMISSION REPORT

MAY 2016



NUCLEAR FUEL CYCLE ROYAL COMMISSION REPORT

Rear Admiral the Honourable Kevin Scarce AC CSC RAN (Rtd) – Commissioner

May 2016

NUCLEAR
FUEL CYCLE
ROYAL
COMMISSION

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6 May 2016

His Excellency the Honourable Hieu Van Le AO
Governor of South Australia
Government House
ADELAIDE SA 5000

Your Excellency

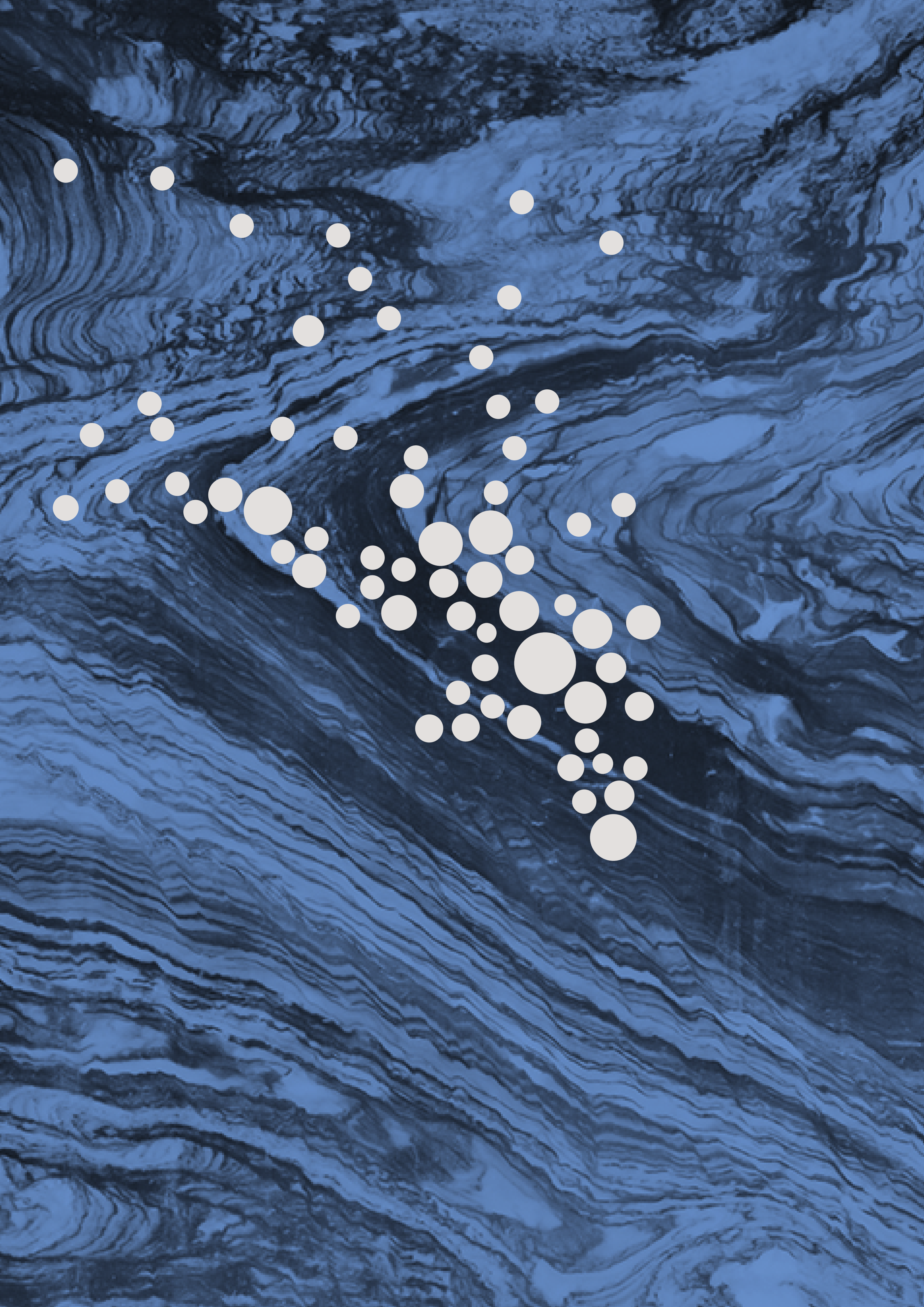
On 19 March 2015 you issued to me a Commission to inquire into and report on the potential to participate in four areas of activity in South Australia that comprise the nuclear fuel cycle.

I hereby present you with my Report pursuant to the Commission addressing the Terms of Reference.

Yours sincerely

Kevin J Scarce AC CSC
Royal Commissioner
Nuclear Fuel Cycle Royal Commission

investigating opportunities and risks for south australia



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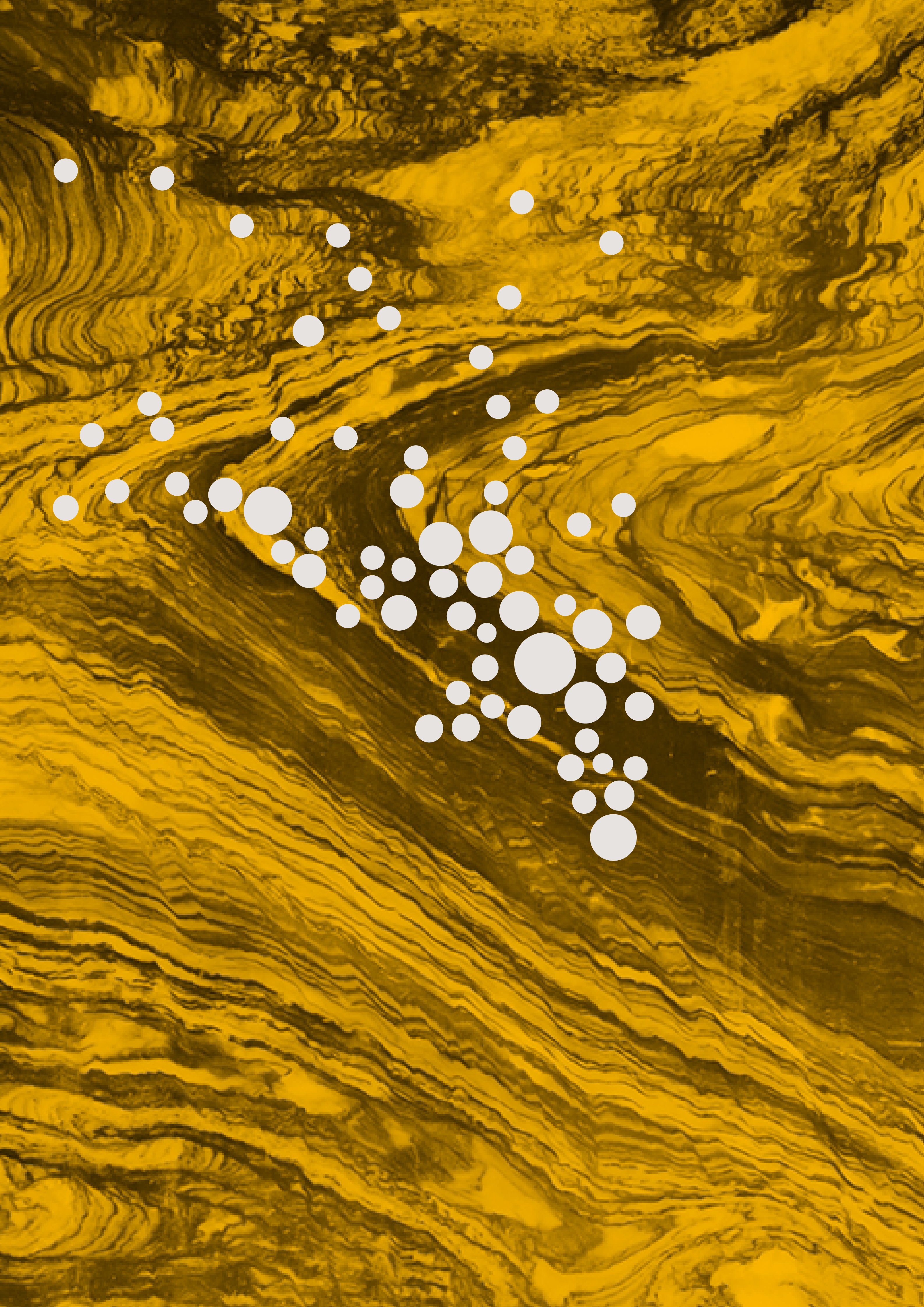


PREFACE

The Nuclear Fuel Cycle Royal Commission was established by the South Australian Government on 19 March 2015 to undertake an independent and comprehensive investigation into the potential for increasing South Australia's participation in the nuclear fuel cycle, specifically in four areas of activity:

- expanded exploration, extraction and milling of minerals containing radioactive materials
- the further processing of minerals and the processing and manufacture of materials containing radioactive and nuclear substances
- the use of nuclear fuels for electricity generation
- the establishment of facilities for the storage and disposal of radioactive and nuclear waste.

In each of these areas, the Commission was required to examine and report by 6 May 2016 on the feasibility, viability, risks and opportunities associated with a potential expansion of the nuclear fuel cycle from the perspectives of the environment, the economy and the community, including regional, remote and Aboriginal communities.

The Commission committed to conducting an independent, evidence-based process that was open and transparent. From the outset, its focus was on understanding facts and not accepting perceptions.

The Commission's process was independent of government, industry and lobby groups. It was conducted by a dedicated group supported by external expertise engaged by the Commission.

At the outset, the Commission produced Issues Papers inviting submissions on the associated risks and opportunities of each of the activities in the cycle.

In response to the Issues Papers, the Commission received as evidence more than 250 submissions from a wide range of individuals and organisations in the private, public and not-for profit sectors.

In its public sessions conducted from September 2015, the Commission heard oral evidence from 132 expert witnesses from Australia and overseas, which was streamed live on the internet.

It also conducted its own research, in Australia and overseas. As part of considering the commercial viability and economic impacts of potential nuclear activities specific to South Australia, the Commission engaged organisations with the expertise and experience to undertake detailed assessments.

Internationally, the Commission held meetings and site inspections at nuclear fuel cycle facilities and with experts in Asia, Canada, Europe, the United Arab Emirates, United Kingdom, and United States of America.

The major elements of this evidence were drawn together in the Commission's Tentative Findings, which were published on 15 February 2016, with an invitation for responses to better inform this report. About 170 responses that directly addressed the contents of the Tentative Findings were received.

In conducting an open and transparent process, and to encourage participation in its activities as the inquiry proceeded, the Commission engaged widely with the South Australian community, including five rounds of community information sessions in regional, remote and Aboriginal communities.

The Commission's approach has produced a large volume of information, which supports the reasoning and findings in this report. The submissions, public session videos and transcripts, financial assessment reports and Tentative Findings responses are published on the Commission's website, www.nuclearrc.sa.gov.au

This report represents both an end and a beginning: the culmination of the Commission's work, but the start of consideration by South Australians as to whether they want to increase the state's participation in the nuclear fuel cycle.

SUMMARY

South Australia can safely increase its participation in nuclear activities. Such participation brings social, environmental, safety and financial risks. The state is already managing some of these risks, and the remainder are manageable.

Some new nuclear fuel cycle activities (see Figure S.1) are viable. One in particular, the disposal of international used fuel and intermediate level waste, could provide significant and enduring economic benefits to the South Australian community.

Viability analysis undertaken for the Commission determined that a waste disposal facility could generate more than $100 billion income in excess of expenditure (including a $32 billion reserve fund for facility closure and ongoing monitoring) over the 120-year life of the project (or $51 billion discounted at 4 per cent). Given the significance of the potential revenue and the extended project timeframes, the Commission has found that were such a project to proceed, it must be owned and controlled by the state government, and that the wealth generated should be preserved and equitably shared for current and future generations of South Australians. This presents an opportunity that should be pursued.

Social consent is fundamental to undertaking any new nuclear project. Social consent requires sufficient public support in South Australia to proceed with legislating, planning and implementing a project. Local community consent is required to host a facility. In the event that this involves regional, remote and Aboriginal communities, consent processes must account for their particular values and concerns.

Political bipartisanship and stable government policy are also essential. This is particularly important given the long-term operation of facilities and the need for certainty for potential client nations.

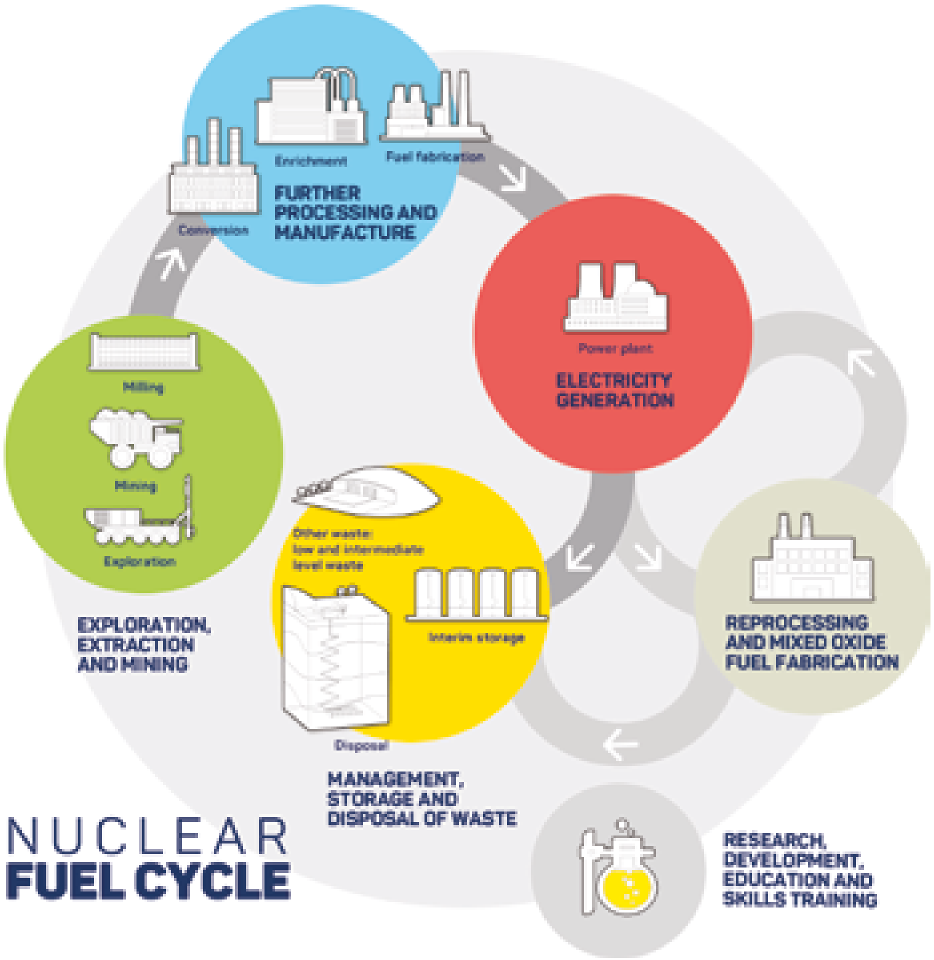


Figure S.1: The nuclear fuel cycle

EXPLORATION AND MINING OF RADIOACTIVE ORES

The Commission found that the administrative and regulatory processes that manage current exploration and mining operations are sufficient to support a safe expansion of activity. However, the existing regulatory approvals processes for new uranium mines are unnecessarily duplicative at the state and federal levels. The Commission therefore recommends that the South Australian Government **pursue the simplification of state and federal mining approval requirements for radioactive ores, to deliver a single assessment and approvals process.**

There is good geological reason to believe new commercial deposits of uranium could be found in South Australia, but the challenge is that vast areas in the state remain unexplored. There are a number of barriers to industry investment in further exploration while commodity prices are relatively low.

Expanded uranium exploration and mining would provide additional benefits to the state. To realise this potential, the Commission recommends that the state government **further enhance the integration and public availability of pre-competitive geophysical data in South Australia.** It should **undertake further geophysical surveys in priority areas, where mineral prospectivity is high and available data is limited.** It should also **commit to increased, long-term and counter-cyclical investment in programs such as the Plan for Accelerating Exploration (PACE) to encourage and support industry investment in the exploration of greenfield locations.**

While lessons learned from legacy sites in Port Pirie and Radium Hill are now incorporated in contemporary regulatory standards for new operations, the Commission recommends that for future developments the South Australian Government **ensure the full costs of decommissioning and remediation with respect to radioactive ore mining projects are secured in advance from miners through associated guarantees**.

FURTHER PROCESSING AND MANUFACTURE FROM RADIOACTIVE ORES

The Commission found the most significant environmental and safety risks associated with further processing of uranium for use in nuclear reactors are posed by chemicals rather than radioactivity. Many of these materials are already used and safely managed in Australia. Some risks would require new regulatory frameworks.

South Australia is technically capable of providing these services; however, there are significant barriers to entering these commercial markets. Further, these markets are currently over-supplied. The Commission considers that the provision of these services would not, either singularly or in combination, be commercially viable in the next decade.

There could be a potential competitive advantage if further processing services were linked with a guarantee to take back used fuel for permanent disposal. This concept of fuel leasing could in turn provide additional employment and technology-transfer opportunities. The Commission recommends that the South Australian Government **remove at the state level, and pursue removal of at the federal level, existing prohibitions on the licensing of further processing activities, to enable commercial development of multilateral facilities as part of nuclear fuel leasing arrangements.**

In relation to the production of medical isotopes, there are potential opportunities to expand existing facilities in the state. The Commission recommends that the South Australian Government **promote and actively support commercialisation strategies for the increased and more efficient use of the cyclotron at the South Australian Health and Medical Research Institute (SAHMRI).**

ELECTRICITY GENERATION FROM NUCLEAR FUELS

The Commission looked closely at reactor safety and the major accidents associated with nuclear power plants. While acknowledging the severe consequences of such accidents, the Commission has found sufficient evidence of safe operation and improvements such that nuclear power should not be discounted as an energy option on the basis of safety.

Taking into account the South Australian energy market characteristics and the cost of building and operating a range of nuclear power plants, the Commission has found it would not be commercially viable to develop a nuclear power plant in South Australia beyond 2030 under current market rules.

However, there will in coming decades be a need to significantly reduce carbon emissions and as a result to decarbonise Australia's electricity sector. Nuclear power, as a low-carbon energy source comparable with other renewable technologies, may be required as part of a lower-carbon electricity system. While the development of other low-carbon technologies will influence whether nuclear power would be required to meet Australia's future energy needs, it would not be able to play a role unless action is taken now to plan for its potential implementation. The Commission recommends that the South Australian Government **pursue removal at the federal level of existing prohibitions on nuclear power generation to allow it to contribute to a low-carbon electricity system, if required.**

In developing Australia's future electricity system there is a need to analyse the elements and operation of that system as a whole, and not any single element in isolation. This will be significant in determining the role that nuclear and any other technologies should play. The Commission recommends that the South Australian Government **promote and collaborate on the development of a comprehensive national energy policy that enables all technologies, including nuclear, to contribute to a reliable, low-carbon electricity network at the lowest possible system cost.**

Given the prospect that new reactor designs, and in particular smaller reactors, might be viably integrated in the Australian electricity network, the Commission recommends that the South Australian Government also **collaborate with the Australian Government to commission expert monitoring and reporting on the commercialisation of new nuclear reactor designs that may offer economic value for nuclear power generation.**

MANAGEMENT, STORAGE AND DISPOSAL OF RADIOACTIVE WASTE

There are large inventories of used nuclear fuel and intermediate level waste in safe but temporary storage around the world. Used nuclear fuel, a solid ceramic in metal cladding, generates heat, is highly radioactive and hazardous. The level of hazard reduces over time with radiation levels decreasing rapidly during the first 30 to 50 years of storage, with the most radioactive elements decaying within the first 500 years. However, the less radioactive but longer-lived elements of used nuclear fuel require containment and isolation for at least 100 000 years. The most serious accident involving used nuclear fuel involves potential exposure to radiation. Used fuel in storage or disposal cannot cause an explosion similar to that associated with a severe accident at a nuclear reactor.

There is international consensus that deep geological disposal is the best available approach to long-term disposal of used fuel. The Commission has found that there are now advanced programs in a number of countries that have developed systems and technologies to isolate and contain used nuclear fuel in a geological disposal facility for up to one million years. The most advanced of these will commence operation in the 2020s.

The safety of deep geological disposal is assured through the combined operation of geology and engineered barriers, and a detailed understanding of the radiological risks associated with used nuclear fuel. The evolution of geological conditions during the past hundreds of millions of years is well understood, and therefore future behaviour over hundreds of thousands of years can be predicted with confidence following detailed study. Engineered barriers are designed and constructed to complement the surrounding geology, and thereby provide a passively safe system of isolation and containment. The predicted future interactions between the used fuel, the engineered barriers and the surrounding geology are complex, but can be modelled and tested with a high degree of precision. The Commission has therefore found that South Australia has the necessary attributes and capabilities to develop a world-class waste disposal facility, and to do so safely.

To determine its viability, the Commission deliberately took a cautious and conservative approach to assessing used fuel inventories and potential global interest in international used fuel disposal. Based on those inputs, the Commission determined that a waste disposal facility could generate $51 billion during its operation (discounted at the rate of 4 per cent). Further analysis indicated that by accumulating all operating profits in a State Wealth Fund, and annually reinvesting half the interest generated, a fund of $445 billion could be generated over 70 years (in current dollar terms).

There is a range of complex and important steps that would need to be taken to progress such a proposal. The Commission has therefore recommended that the South Australian Government **pursue the opportunity to establish used nuclear fuel and intermediate level waste storage and disposal facilities in South Australia consistent with the process and principles outlined in Chapter 10 of this report.** This includes suggested immediate steps, and those that may arise in the future. The immediate steps are for the government to:

a. make public the Commission's report in full

b. define a concept, in broad terms, for the storage and disposal of international used fuel and intermediate level waste in South Australia, on which the views of the South Australian community be sought

c. establish a dedicated agency to undertake community engagement to assess whether there is social consent to proceed

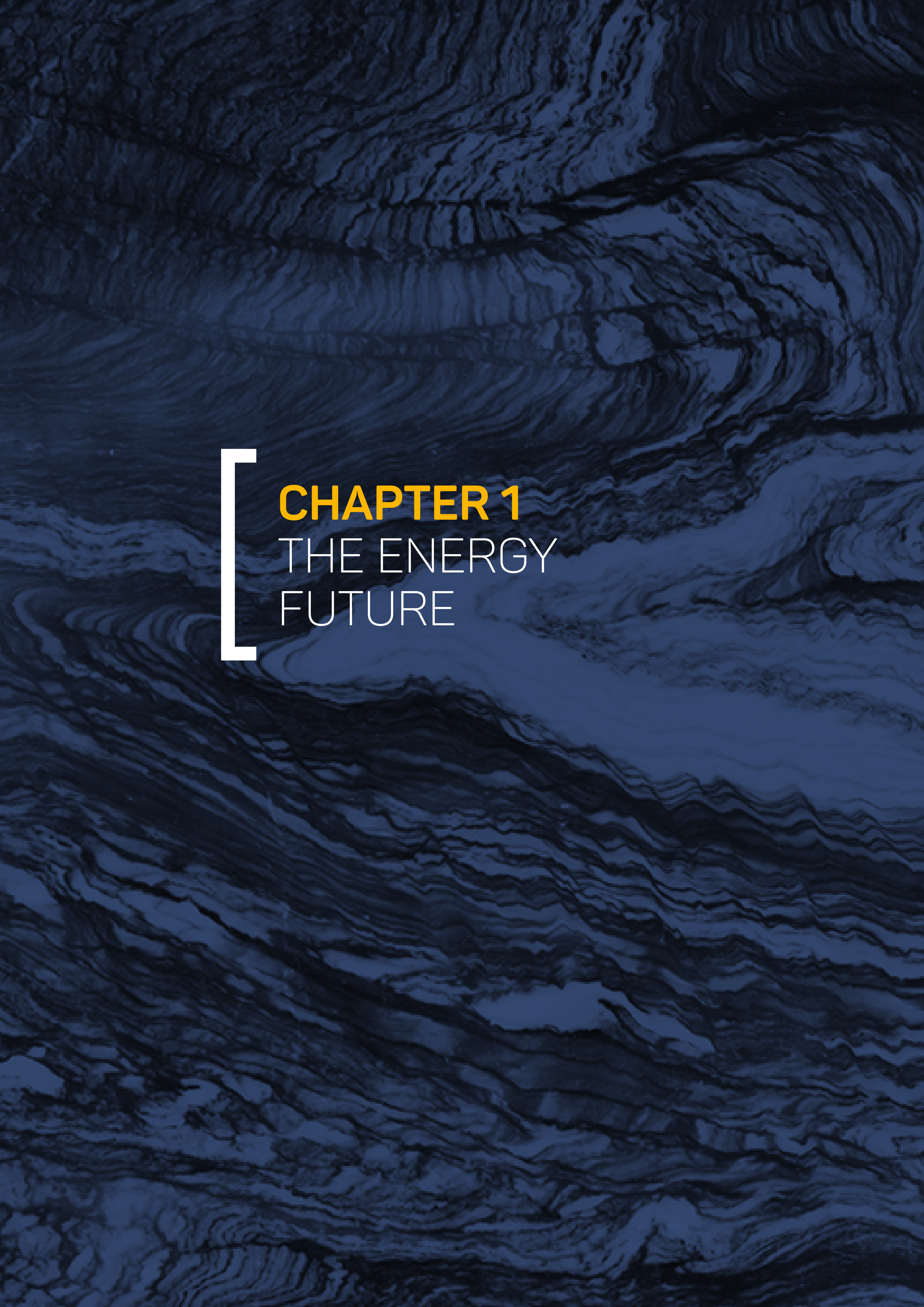
d. in addition, task that agency to:

  i. prepare a draft framework for the further development of the concept, including initial siting criteria

  ii. seek the support and cooperation of the Australian Government

  iii. determine whether and on what basis potential client nations would be willing to commit to participate.

The immediate next steps should be undertaken free from any debate about whether expenditure of public money in pursuing this opportunity is contrary to law. The government may quite properly want to seek further information or greater detail on matters considered by the Commission. It may also seek information in anticipation of a community request. Therefore, the Commission recommends that the South Australian Government **remove the legislative constraint in section 13 of the *Nuclear Waste Storage Facility (Prohibition) Act 2000* that would preclude an orderly, detailed and thorough analysis and discussion of the opportunity to establish such facilities in South Australia.**



CHAPTER 1
THE ENERGY FUTURE

CHAPTER 1: THE ENERGY FUTURE

1. The energy sector in Australia is undergoing transformation. This transformation needs to be guided by stable medium- to long-term government policies to encourage investment. Such policies should be based on evidence, not opinion or emotion.

There can be no doubt that the energy sector in Australia and elsewhere is changing dramatically. Although the major trends of this transformation are increasingly apparent, the extent and pace of change are not.[1] The trends include a decentralisation of electricity generation, the retirement of ageing coal plants, the development of new generation technologies, a focus on and preference for low-carbon energy sources, and changes in networks and the way in which the costs of these networks will be met.[2]

It remains unclear which energy options Australia will embrace.[3] The CSIRO's comprehensive Future Grid Forum Research Program, in analysis undertaken in 2013 and 2015, indicates that any of a range of possible scenarios for Australia's future electricity system remains plausible.[4] Any claim that there is certainty about future outcomes should be treated with caution.

The evidence suggests that the pace of changes to the energy sector will depend upon government policy, and will not be driven by technology and cost alone.[5] The transition pathway to low-carbon sources will be influenced by their relative costs and policy choices such as the incentives provided for new capacity to be installed.[6] The changes in transmission and distribution networks will be influenced by the extent of decentralised generation, ongoing reliance on networks to provide reliability of supply, and a desire for decentralised generators to sell surplus electricity.[7] It will also be influenced by the development of new pricing models to equitably fund networks among their users. All these matters will also be influenced by consumer behaviour in adopting new technologies for generation, storage and demand management.

Energy transformation will require substantial capital investment in both generation and networks.[8] Investment in generation has been affected by uncertainty about future policy,[9] recently demonstrated by the effect on investment from changes in 2012 to legislated subsidies in favour of renewables.[10] This is not to express a view about the desirability of those changes but to illustrate that investment is highly sensitive to policy uncertainty.

Given the complexity of the issues and cost of transformation, planning must be based on evidence.[11] That evidence should focus on a combination of cost, reliability and carbon intensity. This is discussed in greater detail in Chapter 4 Electricity generation. It is critical that long-term decision making should not rely solely on what is presently popular.

2. The opportunities for future South Australian participation in the global markets for uranium ore and other nuclear fuel cycle services are highly dependent on the policies and decisions of all nations to address climate change.

The Paris Agreement negotiated at the 2015 United Nations (UN) Climate Change Conference agrees to overall global reductions aimed at limiting any rise of the global average temperature to well below 2 degrees Celsius (°C) above pre-industrial levels. The Paris Agreement allows signatories to develop their own measures for reducing emissions and does not identify mechanisms for determining a country's share of reductions.[12]

This flexibility makes medium and long-term predictions about the actions needed to be taken to transition to low-carbon systems challenging. While the goal and general trends are known, neither the pace of change nor the transition pathway for any country can be identified with certainty.[13]

This is significant to the development of future energy generation technology, including nuclear energy and the industries that supply it.[14] The suitability of nuclear power for any country depends on the other power generation options available, as well as its political, economic and social circumstances. Many countries have already pursued nuclear power, some have committed to pursuing it, some are considering it, and others have decided against it or decided to abandon it.[15]

For this reason considerable caution must be exercised in making predictions about the future growth of nuclear power. There are firm global commitments to growth in installed nuclear capacity from current levels of about 380 gigawatts (GWe) to about 450 GWe by 2030.[16] However, firm predictions beyond 2030 are much more problematic.

Estimates by the International Energy Agency (IEA) based on emissions targets consistent with the Paris Agreement's 'well below 2 °C' target, show very substantial growth in nuclear generation.[17] That scenario is possible, as are scenarios with little or no growth. Ambitious projections of long-term nuclear industry growth have a history of not being realised. It is for that reason the Commission has not relied on such projections in its reasoning.

3. Significant additional global action will be required to achieve the 'well below 2 °C' target. The slower the abatement action taken now, the greater the action that will need to be taken later, and the greater its costs and impact on the economy.

Before the Paris conference, countries informed the UN of their stated intentions to reduce carbon emissions.[18] The intended nationally determined contributions reflected a range of commitments to reduce emissions of greenhouse gases, the most significant of which is carbon dioxide.[19]

Even if implemeted, modelling suggests that these commitments will only limit the increase in global temperature to about 2.7 °C.[20] That central estimate is within a fairly wide range of an increase up to 4 °C. Even assuming countries meet their commitments, the 'well below 2 °C' target will require significant further action.[21]

If one takes the approach of a total carbon budget reflecting the total permissible emissions into the atmosphere, it can be seen that the slower the abatement actions taken now, the faster the need for abatement in the future.[22] Modelling of emissions mitigation schemes to reduce global warming demonstrates that delaying emissions reductions from 2020 to 2032 would require more than a doubling of reduction rates to meet the same target.[23]

Moreover, analysis suggests that the speed of abatement will affect its ultimate cost.[24] Delayed abatement will, in the interim, increase risks of temperature increase, entrench a more emissions-intensive economy and defer cost reductions in low-emissions technology.[25] This will lead to higher eventual costs of abatement. Further, costs have been projected to increase at a rate disproportionate to the delay.[26]

4. It will be necessary to significantly transform Australia's energy sector to both reduce emissions and support pathways to decarbonise other economic sectors such as transport.

Australia has many options in reducing emissions from electricity generation. They include measures to improve efficiency and new technologies that manage demand.[27]

Given that electricity generation in Australia accounts for about one-third of national carbon emissions,[28] there is a need to transform the electricity generation sector to meet future carbon emission targets.

There is a widely held view, although it is not current policy in Australia, that to achieve the 'well below 2 °C' target it will be necessary to have an energy sector with zero net emissions by 2050.[29] Modelling suggests that it is unlikely that Australia could fully decarbonise its electricity sector by 2050 by relying on renewables alone. Combined cycle gas turbines will be required for system stability in the absence of other dispatchable generation. The importance of this timeframe is that such a transition is necessary to facilitate transformations in other sectors. For example, to switch fuel from carbon-intensive energy sources in industry and transport it is necessary to support a transition from carbon-based fuels to either electric- or hydrogen-fuelled vehicles, which is now incentivised in some countries.[30]

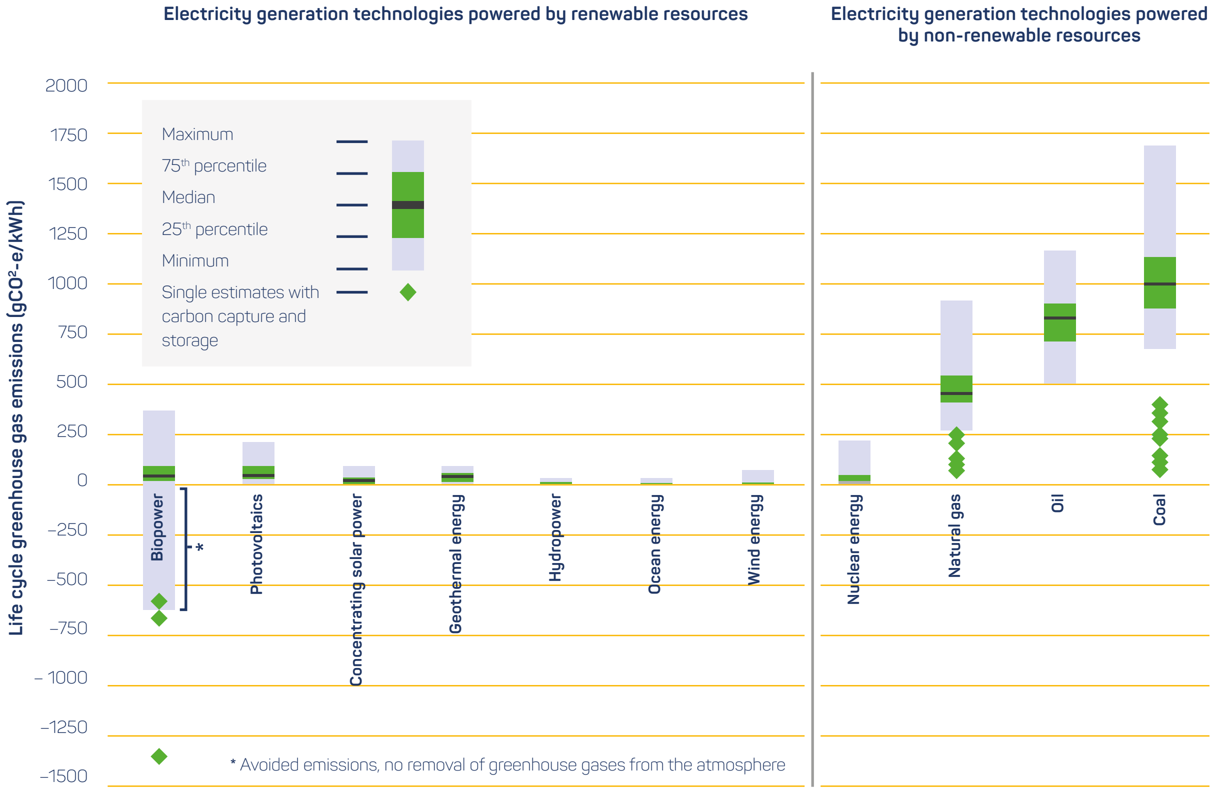
5. Nuclear power is presently, and will remain in the foreseeable future, a low-carbon energy generation technology.

Some energy generation technologies, particularly those that burn fossil fuels, generate substantial carbon emissions during their operation, while others such as solar photovoltaic (PV), concentrated solar thermal, wind and nuclear do not.[31] However, all energy generation technologies create emissions over their life cycle. These emissions are generated during plant construction (including in the extraction, manufacture and use of building materials such as steel, concrete and silicon), operation, maintenance and decommissioning.[32]

A large number of studies of life cycle emissions from electricity generation have been undertaken over several decades, with divergent results.

The National Renewable Energy Laboratory (NREL), the primary laboratory for renewable energy and energy efficiency research and development in the United States, undertook a peer-reviewed analysis and harmonisation of all earlier studies on carbon emissions from various electricity generation technologies. The significance of the harmonisation was that the assumptions and parameters of the various studies were assessed, allowing for their direct comparison.[33] The output of the analysis has been adopted by the Intergovernmental Panel on Climate Change (IPCC).

As shown in Figure 1.1, the median estimates under the NREL analysis ranked the emissions of nuclear (12 grams carbon dioxide equivalent per kilowatt hour (gCO_2-e/kWh) within the range of solar PV (18–50 gCO_2-e/kWh, depending on technology choice) and wind (12 gCO_2-e/kWh).



* Avoided emissions, no removal of greenhouse gases from the atmosphere

Figure 1.1: Life cycle greenhouse gas emissions for electricity generation technologies

Data sourced from National Renewable Energy Laboratory, 'Life cycle assessment harmonization results and findings', NREL.gov, last modified 21 July 2014, www.nrel.gov/analysis/sustain_lca_results.html

Note: gCO_2-e/kWh=grams carbon dioxide equivalent per kilowatt hour

That nuclear has emissions in the range of solar PV, wind, concentrated solar thermal and other renewables is supported by other significant contemporary studies.[34] In each case, those technologies are substantially less carbon-intensive than gas and significantly less again than coal. Across earlier studies the estimated emissions range for nuclear has varied considerably.[35] This variation arises from different methods for performing harmonisation over a large range of studies—some may be less complicated to perform, but result in less precision.[36] The NREL study is significant because of its comprehensive and detailed analysis.

The breakdown of carbon emissions for nuclear energy has been estimated to be approximately one-third for activities and services associated with manufacturing nuclear fuel, one-third for construction and decommissioning, and one-third for operation, storage and disposal of waste.[37] The life cycle carbon emissions for nuclear power have decreased marginally in recent years. This is due to increased energy efficiency, particularly the shift to centrifuge enrichment techniques from the more energy-intensive gaseous diffusion, and the higher proportion of low-carbon electricity used in nuclear conversion, enrichment and fuel fabrication.[38]

Nuclear will continue to be a low-carbon option for the foreseeable future. Studies have shown that even a substantial decline of ore grades to levels far lower than those currently mined in Canada or Australia (from either uranium-specific or polymetallic deposits) would have a minor effect on carbon emissions from nuclear power.[39] In any event, if uranium demand were to increase there is significant potential for the discovery of new deposits with economic grades. Were that to occur, the emissions intensity of mining uranium would not increase.[40]

6. In Australia, nuclear power cannot contribute to emissions reductions before 2030 because of the long lead time to make new capacity operational. It could contribute after that time, which may be important if more rapid action is required to be taken to reach a net zero emissions target from energy generation by 2050.

Following a lengthy period in which new reactors were not constructed in Europe and the United States, recent experience in those countries indicates that new nuclear capacity has taken substantially longer to construct than planned.[41] Construction of new reactors has at best, in countries outside Europe and the United States, been completed in about six years.[42] The fastest development of a new global nuclear program is in the United Arab Emirates; it took 10 years from the initial policy decision in 2008 to the planned start of operations in 2017. This program had the advantage of replicating nuclear plant designs already constructed and licensed in their country of origin.

When construction times are combined with the time it would take to develop a regulatory structure and implement policy,[43] the earliest likely date at which nuclear power could come into operation in Australia would be from 2030.[44] The Commission does not accept views that a nuclear power capability would take longer on the basis that a decade-long period of decision making and planning would be required.[45] Those timeframes reflect a business-as-usual approach and do not account for a targeted focus on achieving an outcome to address a recognised need.

In the event that fast and rapid action is required by Australia after 2030, nuclear power might play a useful role. This becomes particularly significant if the nation makes only modest progress in reducing emissions before 2030 and is required to commit to eliminating carbon emissions from electricity generation by 2050. In pursuing a policy of rapid decarbonisation, nuclear power might be a useful and significant contributor.

7. It would be wise to plan now for a contingency in which external pressure is applied to Australia to more rapidly decarbonise. Action taken now to settle policy for the delivery and operation of nuclear power would enable it to potentially contribute to reducing carbon emissions.

Australia's current emissions reduction targets, and any further contributions, both national and international, were the subject of discussion before the UN 2015 Climate Change Conference. In the period leading up to the first progress review of the Paris Agreement in 2020, Australia's future commitments could again be the subject of discussion. That will occur in the context of other countries forming views about their fair share of abatement and the respective contribution of other nations to achieving the overall goal.

In that time, Australia may come under pressure to decarbonise more rapidly than it had planned. It is apparent from the Paris Agreement, with its associated national commitments, that the politics of climate change abatement remain fluid.

Australia's current commitments require it to reduce emissions to five per cent below 2000 levels by 2020, giving a target of 530 megatonnes carbon dioxide equivalent ($MtCO_2$-e).[46] Australia's emissions are projected to be 656 $MtCO_2$-e in 2019–20, requiring a further reduction of 126 $MtCO_2$-e to meet the target.[47] Firm commitments to further reductions have not yet been made.

Previous policy measures aimed at addressing carbon emissions have proven politically contentious. This has led to limited discussion and consideration of potential policy options. As scientific evidence on the impact of climate change mounts, perhaps it is time for a change in approach to facilitate a scientifically led debate. Long-term policy options need to be considered now if the nation is to avoid the disproportionate consequences of attempting to quickly reduce carbon emissions from electricity generation.

The Australian Government will formally review its current and future carbon abatement commitments in 2017.[48] This would be an ideal time for scientific rather than politically led discussions about future options.

The scope of the review has not been defined. In view of what is said elsewhere in this report, it will be important for such a review to contemplate not only Australia's current and short-term commitments, but also to prepare a strategy to meet longer-term goals, with sufficient flexibility to accommodate future developments.

8. While it is not clear whether nuclear power would be the best choice for Australia beyond 2030, it would be prudent for it not to be precluded as an option.

Australia should position itself to be able to take advantage of all the potential options in the event of a requirement for rapid emissions reduction.[49] It would be wise to facilitate a technology neutral policy for Australia's future electricity generation mix.

To make a range of technologies available, action is required now.

In the case of nuclear power, those actions include the:

- amendment of existing legislation
- setting of key policies that would send relevant signals for private sector investment
- development of an electricity market structure
- development of a new regulatory framework that addresses key principles of non-proliferation, safety and security in the use of nuclear energy.[50]

If such preparatory steps are deferred, nuclear power would continue to be precluded as an option—meaning that it would always be an option over the horizon.

Making nuclear power available as an option does not mean it would be the best choice for Australia in 2030. Other developments may well lessen the need for it. However, that should not be assumed. The present considerable optimism about the future cost of renewable generation and storage does not ensure certainty about these outcomes.[51] Nor should the development of nuclear be regarded as static. As nuclear projects are implemented in other countries, and as new systems are developed, particularly small modular reactors, the costs of nuclear may demonstrate that it should be part of a low-cost, low-carbon energy system in Australia.

NOTES

1 Transcripts: Baldwin, p. 1586–1587; Swift & Falcon, pp. 49–52, 62; Graham, p. 410; Skarbek, pp. 36–37. Submissions: Australian Industry Group, pp. 2–5.

2 Transcripts: Makhijani, pp. 428–429; Swift, pp. 140–141.

3 Transcript: Makhijani, pp. 428–429. Submission: Australian Industry Group, pp. 2–5.

4 CSIRO, *Change and choice: The future grid forum's analysis of Australia's potential electricity pathways to 2050*, 2013; *CSIRO, Electricity network transformation roadmap: Future grid forum: 2015 refresh – Technical report*, 2015, p. 100.

5 Transcript: Diesendorf, pp. 67–72.

6 Transcripts: Constable & Cook, pp. 463–464; Garnaut, p. 21. ClimateWorks Australia, *Pathways to deep decarbonisation in 2050*, ClimateWorks Australia, 2014, p. 5.

7 Transcript: Makhijani, pp. 428–429.

8 ClimateWorks Australia, *Pathways to deep decarbonisation in 2050*, ClimateWorks Australia, 2014, p. 5.

9 Transcript: Garnaut, pp. 16–17. Submission: Australian Industry Group, p. 4.

10 Transcript: Garnaut, p. 15–17.

11 Submission: Energy Policy Institute of Australia, pp. 3–4.

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Transcripts and submissions can be found at the Nuclear Fuel Cycle Royal Commission's website:www.nuclearrc.sa.gov.au/transcripts and www.nuclearrc.sa.gov.au/submissions

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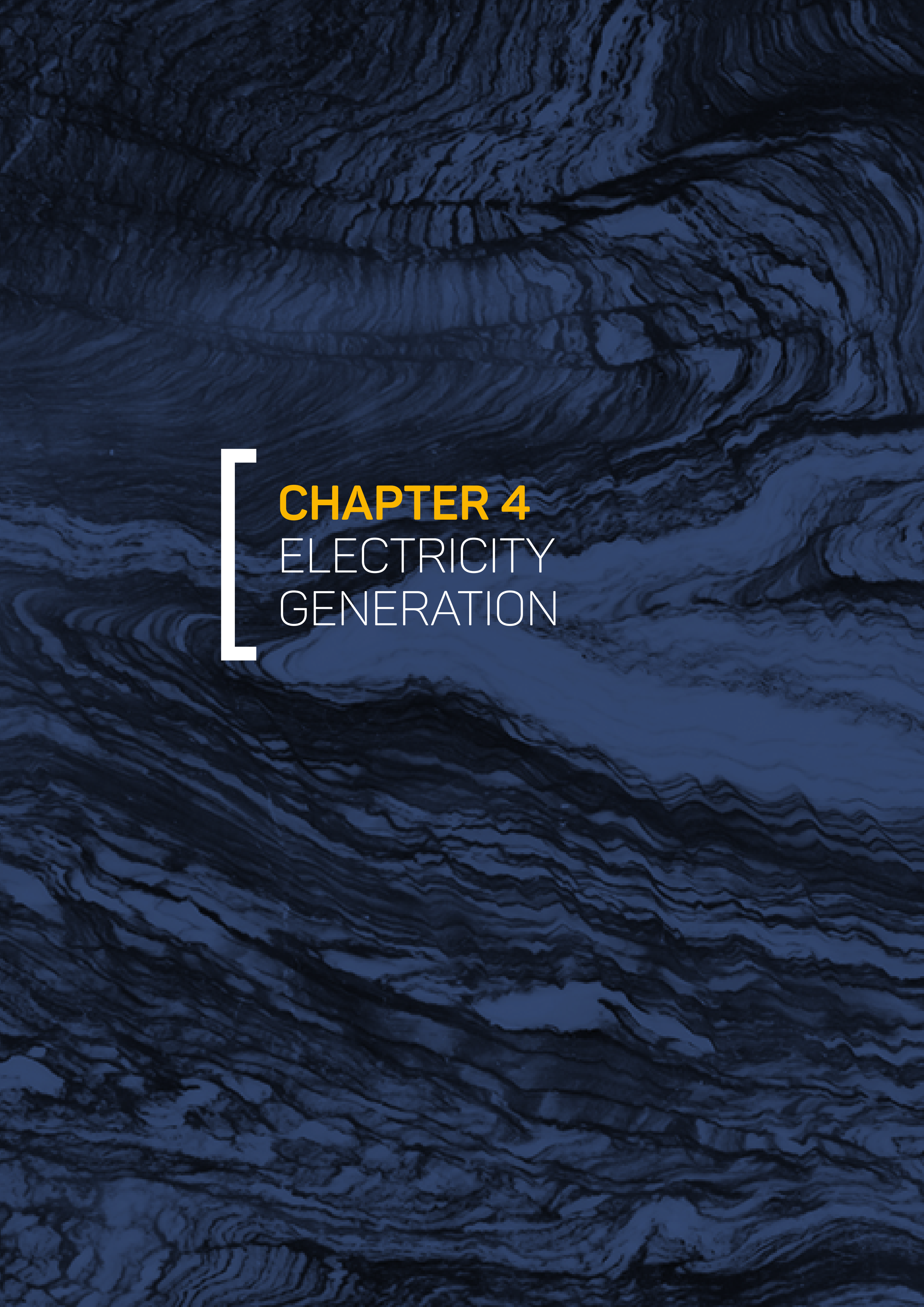

CHAPTER 4

ELECTRICITY GENERATION

CHAPTER 4: ELECTRICITY GENERATION

The activity under consideration is the establishment and operation of facilities to generate electricity from nuclear fuels in South Australia.

WHAT ARE THE RISKS?

34. Nuclear power plants are very complex systems, capable of producing large amounts of energy. They are designed and operated by humans, who can make mistakes.

Nuclear power reactors are carefully engineered vessels that enable the heat energy produced from the fission of uranium nuclei to be captured, through boiling water and creating steam, and transferred to a steam turbine electricity generating system. The electric power output of new light water reactors being deployed today is up to 1600 megawatts electric (MWe).[1] Modern reactor designs are described further in Appendix E: Nuclear energy – present and future.

The risks associated with generating nuclear power are fundamentally related to the large amount of energy produced in the relatively small volume of a reactor core. Hazards that must be managed and controlled in a reactor include the rate of fission heat produced and, in certain circumstances associated with the failure of equipment or control systems, the potential release of radioactive materials.[2] During normal operation, excess heat in a reactor is removed by a coolant, which in most modern reactors is water. When a reactor is shut down, whether for routine reasons or due to an accident, the fission chain reaction immediately stops; however, thermal energy remains in the fuel and the radioactive decay of fission products produces new heat.[3] This can cause damage to, and even melting of, fuel material if the heat is not removed by a coolant.[4]

Fuel cooling in all scenarios is of paramount importance as coolant loss can quickly develop into a serious loss-of-coolant-accident (LOCA). Nuclear engineers and safety analysts focus extensively on ways to avoid fuel damage in all credible and simultaneous LOCA pathways, including coolant pipe breaks and loss of power to coolant pumps.

While reactor design plays a significant role in overall safety, human operation is equally important: human error in management, control, maintenance and accident response can have severe consequences. Human error and reactor design flaws have been shown to be critical contributing factors to operating inadequacies, equipment damage and technical failures that can lead to major accidents.[5]

Modern reactor designs incorporate many safety mechanisms to protect against operator error, as discussed in Appendix E.

35. There have been three major accidents in nuclear power plants involving the release of radioactive material into the environment: Three Mile Island in 1979, Chernobyl in 1986 and Fukushima Daiichi in 2011. Each accident has been thoroughly and credibly investigated to determine both the causes and lessons to be learned.

The three major reactor accidents have been carefully analysed and better understood through root-cause investigations, resulting in numerous principles that could be applied to improve safety. Credible studies include those by the International Atomic Energy Agency (IAEA), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the United States Nuclear Regulatory Commission (NRC).[6]

The broader health impacts are addressed in Chapter 7: Radiation risks.

THREE MILE ISLAND

In March 1979, one of the two Three Mile Island nuclear reactors in Pennsylvania, USA, suffered a serious loss of coolant. The combination of equipment failures and inadequate operator safety training and response led to a loss of water to remove heat from the reactor's core.[7] This caused the partial melting of fuel assemblies.[8] Primary water flow to the damaged core was eventually restored many hours later.[9] No deaths or injuries resulted. The vast majority of radiation released from the core was contained within the reactor containment building, with only insignificant amounts being released to the environment.[10] The reactor has remained out of operation since the accident.[11]

An initial inquiry[12] and subsequent analyses of the accident have led to many improvements in plant design and operation, as well as increased scrutiny and more stringent safety requirements from the regulator in the USA.[13]

CHERNOBYL

The Chernobyl reactor in Ukraine was a Russian RBMK design, unique to the former Soviet Union. Such a reactor used natural uranium for fuel, water as a coolant, and graphite as a moderator. This kind of reactor could be unstable in certain operating conditions. If an RBMK reactor lost its coolant its nuclear reaction proceeded faster, due to the greater moderating effects of graphite in the absence of water, rather than the reaction stopping itself as in the case of light water reactors. Also, RMBK reactors lack the level of containment that light water reactors have.

The accident at the Chernobyl reactor in April 1986 was due to this instability, combined with serious deficiencies in safety culture, operator experience and management capability.[14] Through bypassing safety systems during an unauthorised experimental test of the reactor control system, the core became unstable, leading to an increase rather than a decrease in fission heat production as the core temperature rose.[15] This induced two chemical explosions and a consequent fire that ultimately caused the death of two workers and the release of a significant amount of radioactive material into the environment over 10 days.[16]

FUKUSHIMA DAIICHI

In March 2011 the Great East Japan earthquake and tsunami triggered a nuclear accident at the Fukushima Daiichi nuclear power plant. The circumstances are explained in greater detail in Appendix F: The Fukushima Daiichi accident. In summary, the reactors at the Fukushima Daiichi plant were early-model boiling water reactors. Flooding caused a loss of both on-site and off-site electrical power and led to the loss of reactor core cooling capability in three reactors.[17] This ultimately resulted in a LOCA that caused fuel melting and fission product release.[18] The parallel generation of hydrogen gas resulted in chemical explosions, causing significant structural damage to plant buildings.[19] Thorough examinations of the incident identified various deficiencies including:

1. critical weaknesses in plant design and in emergency preparedness in the event of severe flooding.[20] These included an insufficiently high flood wall, emergency power supplies that were vulnerable to flooding, and a more limited form of primary containment compared to modern reactors
2. weaknesses in Japan's regulatory framework in both a lack of regulatory independence and multiple decision makers, which obscured lines of responsibility[21]
3. the absence of an appropriate safety culture within the reactor operator, the nuclear regulator and the government[22], resulting in a number of unchallenged assumptions[23], including that the plant was so safe that an accident of this magnitude was simply unthinkable, and that electrical power could never be lost at a plant for more than a short time
4. lower preparedness among plant operators for the conditions and stresses that could arise in the event of a severe accident.

Table 4.1: Environmental releases for specific radionuclides from the Three Mile Island, Chernobyl and Fukushima Daiichi accidents

Accident	Iodine-131 (PBq)	Caesium-137 (PBq)
Three Mile Island[a]	0.00055	–
Chernobyl[b]	1760	85
Fukushima Daiichi[c]	100–500	6–20

a. L Battist & HT Peterson Jr, 'Radiological consequences of the Three Mile Island accident', Office of the Standards Development, US Nuclear Regulatory Commission, Washington D.C., 1980, p. 264.
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c. UNSCEAR, *Sources, effects and risks of ionizing radiation*, vol. I, scientific annex A, 2013, p. 40.
Note: The becquerel (Bq) is the SI unit of radioactivity equal to one decay event per second. One petabecquerel (PBq) is equal to 10^{15} Bq.

RELEASES OF RADIATION

The major radioactive substances released into the environment during these accidents are summarised in Table 4.1. Two radionuclides, the short-lived iodine-131 (^{131}I), with a half-life of eight days, and the long-lived caesium-137 (^{137}Cs), with a half-life of 30 years, were particularly significant for the radiation doses they delivered to the environment. Strontium was also released, but the additional radioactivity associated with its release was negligible when compared with natural background levels.[24]

At Three Mile Island, although fission products were released from the damaged core into the containment vessel, only very small amounts of radioactive substances were released into the environment.[25] At Fukushima, considerable amounts of radioactive substances, predominantly caesium and iodine, were released into the environment.[26] The effective dose of radiation to the Japanese public was about 10–15 per cent of the comparable dose to the European populations affected by radiation from Chernobyl.[27]

36. The lessons learned from the design, siting and cultural factors that contributed to these accidents have been applied to new developments.

The three major nuclear accidents have shown that the numerous complex interdependencies at nuclear power plants need to be understood, monitored and controlled so that reactor cooling is maintained at all times. Many analyses of the accidents have advanced the industry's understanding of how accidents comprise a progression of events from an initiating incident.[28] This has helped to reduce the probability of LOCAs in modern reactors through improvements in physical engineering and design measures, sophisticated instrumentation, automated operational controls and interlocks, and strengthening safety cultures.[29] The establishment and subsequent updates of international nuclear safety reporting mechanisms through the Convention on Nuclear Safety (1994) have also fostered international cooperation and information sharing on lessons learned among nuclear power plant operators.[30]

In the year that followed the Fukushima accident, many countries cooperated in a comprehensive assessment of nuclear risk and safety (so-called 'stress tests') to review the design of nuclear power plants against site-specific extreme external hazards.[31] These tests have led to useful recommendations, including the installation of additional backup electrical power and cooling water sources.[32] To mitigate the potential release of radioactive materials, measures have been developed and implemented in many countries. These measures include improved emergency response planning, reactor operator training, human-factors engineering, and radiation protection strategies, including administering iodine tablets to potentially affected individuals.[33] Following the Fukushima accident, all of Japan's remaining nuclear reactors were shut down for a review of their safety. Reactors are permitted to restart only after these reviews and are subject to a new regulatory framework. The restarts are progressive and are proceeding slowly,[34] due primarily to community resistance. Three of 46 reactors have been restarted to date.

In September 2012, the IAEA Director General initiated an inquiry into the Fukushima Daiichi accident. The resultant report, *The Fukushima Daiichi accident: Report by the Director General*, and its associated technical volumes, released in 2015, identified a number of lessons for the global nuclear industry that built on those learned from the stress tests, previous nuclear accidents and other studies of the Fukushima accident.[35] Lessons presented in the report focused on:

1. the design of nuclear power plants and their safety systems
2. radiation containment
3. the need to properly prepare for multiple severe external hazards that simultaneously or in sequence affect operations at nuclear power plants
4. the need to strengthen regulatory oversight and assessment of plants
5. the need to create safety cultures in which stakeholders question basic assumptions and continually improve operational safety.[36]

While there can be no guarantee that severe accidents will not occur again, they are rare, given there have been 16 000 cumulative years of nuclear power plant operation in 33 countries. The risk of a nuclear accident should not of itself preclude the consideration of nuclear power as a future electricity generation option.[37]

If nuclear power were to be contemplated in South Australia, the responsible operator would be able to benefit from the accumulated safety knowledge of the global nuclear industry, including the lessons learned from prior accidents. As well, relevant local reactor safety expertise from the Australian Nuclear Science and Technology Organisation (ANSTO) and the Australian Radiation Protection and Nuclear Safety Authority (ARPANSA) is available.

IS THE ACTIVITY FEASIBLE?

37. Nuclear power is a mature, low-carbon electricity generation technology. Its deployment is characterised by large upfront capital costs and long periods of construction and operation. It offers high capacity and reliability, but does not efficiently follow the peaks and troughs of a highly variable demand profile.

The use of nuclear fission to commercially generate electricity was first achieved over 60 years ago.[38] Today the world's fleet of commercial nuclear power plants is predominantly made up of a small number of established water-cooled designs.[39]

Since the 1950s, reactor designs have continued to evolve to deliver increased efficiency and improved safety.[40] Large, modern designs incorporate independent safety systems that are both 'active', which include electrically powered pumps and valves, and 'passive', which take advantage of fundamental physical forces and mechanisms such as gravity and natural convection to maintain cooling to the reactor core.[41] 'Defence in depth' is another key safety feature of modern reactors; it ensures multiple barriers are in place to provide protection should a single barrier fail.[42]

Nuclear power plants are essentially baseload generators that run continuously. Their ability to operate flexibly to meet variations in demand depends on the reactor type and the refuelling cycle. The typical features of modern nuclear reactor designs are addressed in Appendix E.

In recent years, the complexity of some larger-capacity reactor designs and more stringent reliability and safety requirements have increased the difficulties of plant construction.[43] These have been key drivers of the cost and schedule overruns that have characterised recent construction programs[44], including several plants in Europe and the USA. Further, contemporary construction experience has declined given the lapse of time between current building programs and those undertaken decades ago.[45] Recent estimates of the cost of construction excluding finance (the overnight construction cost) in Europe and the USA range from A$9.25 billion for a Westinghouse AP1000 plant to A$14.8bn for an AREVA-designed EPR plant, with estimated construction schedules ranging from six to fifteen years, including cost and schedule over-runs.[46] The quoted contract price of the United Arab Emirates' current build program is slightly lower, at A$7.1bn for each of the four APR1400 reactors under construction. However, it is not known whether the vendor has been able to deliver the project within its contracted projection.[47]

Some evidence suggests that, for the current generation of large reactors, integrated construction programs involving multiple reactors of standardised design may have greater success in adhering to planned costs and achieving shorter build schedules.[48] The Commission's approach to estimating the capital construction cost of a nuclear power plant for the purpose of analysing its viability for Australia is explained in Finding 45 and in Appendix G: Nuclear power in South Australia—analysis of viability and economic impacts.

38. The technology to develop a nuclear power plant could be transferred readily from experienced commercial vendors. Careful consideration would need to be given to appropriate siting to ensure that water requirements for reactor operation could be met sustainably.

A number of commercial reactor vendors are capable of partnering with a South Australian entity for the construction and operation of a nuclear power plant. In nations new to nuclear power, partnerships for the development of a plant typically include arrangements to allow for knowledge transfer and local workforce training.[49] The lack of experience with nuclear power generation in South Australia would not preclude the development of a nuclear power plant at an appropriate site.[50]

The geophysical characteristics necessary for safe and efficient plant operation include low seismicity and ready access to adequate amounts of water for the current generation of large light water reactors.[51] While most parts of South Australia are geologically stable, sustainable access to water resources would need to be carefully assessed, given the reliance on water for cooling in most modern nuclear power plants.

In relation to the location for any potential large nuclear power plant in South Australia, a coastal site would be necessary to meet the significant water requirements for cooling using saltwater.[52] These requirements are addressed in detail in Appendix E.

Coastal siting might be a lesser consideration for future small modular reactor (SMR) designs, which have not yet been commercially developed.[53] Importantly, freshwater requirements for plant operation also need to be considered.[54]

39. If nuclear power were to be considered in South Australia, analysis should focus on a proven design that has been constructed with active and passive safety features. For commercial electricity generation in the foreseeable future this would include analysis of potential small modular reactors based on light water designs because of their suitability for integration in smaller markets, but not advanced fast reactors or other innovative reactor designs.

Any consideration of nuclear power in South Australia would need to focus on a reactor design with the following characteristics:

1. A proven design licensed by a reputable nuclear safety regulator. This would avoid project, technical and commercial risks and costs associated with construction of first-of-a-kind technology.[55] It also would increase confidence that the design would be able to be licensed in Australia, as it would need to comply with the relevant Australian licensing and regulatory framework. It may also reduce the level, and associated costs and timeframes, of the design assessment required.
2. A design previously constructed, ideally multiple times, would allow cost and schedule to be determined with greater certainty.[56] As nuclear power plant construction projects proceed overseas, reported construction costs should be monitored closely and independently verified.

3. A reactor design should be based on recent construction, with an experienced team and specialist workforce.[57]
4. The design should incorporate proven active and passive safety features for nuclear power plants (see Appendix E for a detailed explanation) that capture lessons learned from ongoing operations and fault scenarios.

Several proven designs incorporate the required and preferred design features identified above, and it is likely that more will become available in the next decade.[58] In particular, given the current maturity of the technology, it is likely that light water SMR designs will be available.[59] The smaller capacity of SMRs makes them attractive for integration in smaller electricity markets such as the National Electricity Market (NEM) in South Australia.[60] For this reason, it will be important to follow the development of such reactors.

Although there are no commercially operational examples of light water SMRs[61], several are in advanced stages of development and the early phase of licensing.[62] A study commissioned by the British government to address the potential availability of identified light water SMR designs confirmed the need for further detailed technical analysis. The study found SMRs would require A$1bn–2bn of development funding over five to seven years to be commercialised. Commercial deployment of a design would provide credible evidence of capability and cost.

In comparison, advanced fast reactors and other innovative reactor designs are unlikely to be feasible or viable in the foreseeable future (see Appendix E).[63] The development of such a first-of-a-kind project in South Australia would have high commercial and technical risk.[64] Although prototype and demonstration reactors are operating, there is no licensed, commercially proven design. Development to that point would require substantial capital investment.[65] Moreover, electricity generated from such reactors has not been demonstrated to be cost competitive with current light water reactor designs.[66]

The recent conclusion of the Generation IV International Forum (GIF)[67], which issued updated projections for fast reactor and innovative systems in January 2014[68], suggests the most advanced system will start a demonstration phase (which involves completing the detailed design of a prototype system and undertaking its licensing, construction and operation) in about 2021.[69] The demonstration phase is expected to last at least 10 years and each system demonstrated will require funding of several billion US dollars.[70] As a result, the earliest possible date for the commercial operation of fast reactor and other innovative reactor designs is 2031.[71] This timeframe is subject to significant project, technical and funding risk. It extends by six years a similar assessment undertaken by GIF in 2002.[72] This means that such designs could not realistically be ready for commercial deployment in South Australia or elsewhere before the late 2030s, and possibly later.[73]

40. The future viability of nuclear power, as for any generation source, can only be analysed as part of the electricity supply system in which it would be integrated.

The potential viability of a new nuclear power plant in South Australia cannot be determined by simply comparing its associated costs with those of other electricity generating technologies.[74] Commercial profitability would be determined by the more complex issues of how, when, and at what price the electricity produced by any new generating plant would be made available to customers.[75] This requires an understanding of the established market structure, its rules of operation and its likely evolution.[76]

South Australia is part of the NEM, which is one of the longest continuous electricity transmission systems in the world. The NEM supplies electricity to about 10 million customers across the Australian Capital Territory, New South Wales, Queensland, South Australia, Tasmania and Victoria.[77] The main network is a legacy system—designed in the 1980s—comprising more than 300 generators that supply electricity via the transmission network.[78] Six cross-border interconnectors connect the transmission networks of the participating regions, with the amount of electricity imported or exported at any given time limited by the capacity of the transmission line.[79] Figure 4.1 shows the physical generating and transmission assets in the South Australian subregion of the NEM. The coal-fired power plant located at Port Augusta has been omitted as it will cease operation in 2016.

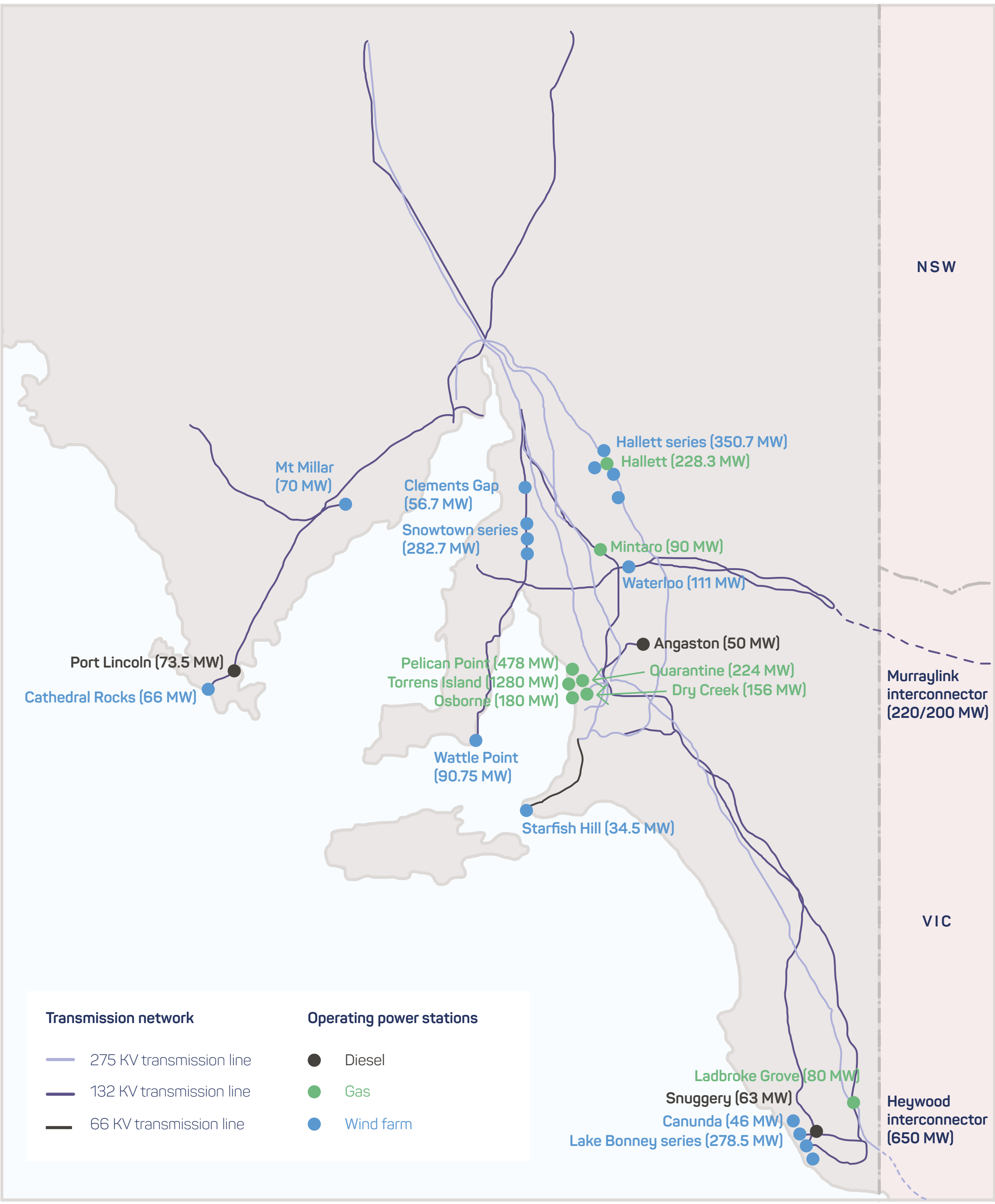

Figure 4.1: The South Australian region of the National Electricity Market (NEM), detailing power stations, transmission networks and interconnectors

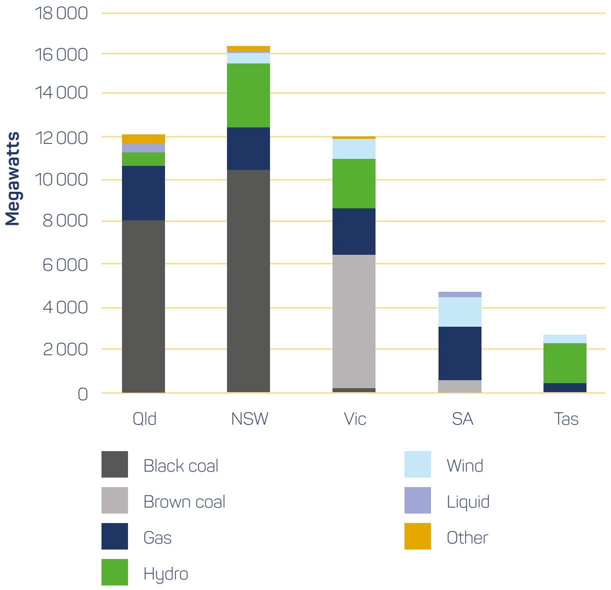

Figure 4.2: NEM generation capacity by region and fuel source, 2015

Data sourced from the Australian Energy Regulator (AER), *State of the energy market report,* 30 June 2015, p. 29

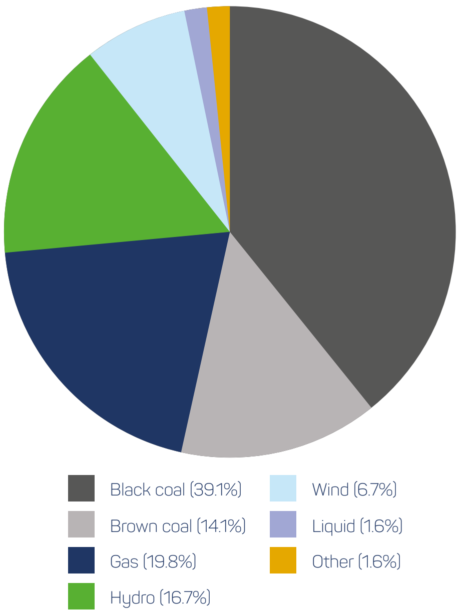

Figure 4.3: NEM generation capacity by fuel source, 2014/15

Data sourced from AER and Australian Energy Market Operator (AEMO)

41. The NEM is carbon-emissions intensive, does not require electricity generation sources to bear the full costs of their carbon emissions, and is subject to government interventions directed at lowering carbon emissions, which are not technology neutral and have not been demonstrated to achieve a low-carbon system with the lowest overall cost.

Black and brown coal-fired generators represented 53 per cent of installed generation capacity in the NEM in 2014/15 (see Figure 4.2 and Figure 4.3), but supplied 76 per cent of output.[80] This high share of coal-fired generation contributes more than one-third of national carbon emissions, and means the Australian electricity sector is one of the most carbon-intensive in the world (see Figure 4.4).[81]

The retirement of a significant percentage of that capacity is already planned over the next two decades.

There is currently no mechanism to impose the cost of emissions on generators, although this was enacted by carbon pricing from 1 July 2012 to 30 June 2014. During this time coal-fired generation output declined by 12 per cent, but it quickly recovered when carbon pricing was abolished. The Large-scale Renewable Energy Target (LRET) scheme, which was launched in 2001, aimed to decrease the carbon emissions intensity of the NEM by providing a financial incentive for renewable energy generation technologies to enter the market. The LRET is not a technology–neutral scheme: it offers incentives to develop a group of renewable technologies—most significantly wind and solar PV. Different policies are likely to have differing economic impacts and costs in reducing CO_2 emissions. They also have different effects in different NEM regions (see Box: South Australia's electricity price competitiveness to 2030 and beyond). A review of policies, their effectiveness and economic impacts will be released by the Climate Change Authority in 2016.[82]

42. While the NEM predominantly comprises ageing centralised generators, low average wholesale prices and relatively flat average demand forecasts present challenges to the viability of any new electricity generation infrastructure suited to baseload supply.

Approximately 58 per cent of coal-fired and 24 per cent of gas-fired generation in the NEM was first commissioned more than 30 years ago, as shown in Figure 4.5, although this does not account for capacity expansions and upgrades after commissioning. Consequently, a significant number of generators have fully amortised capital costs, allowing them to operate at low short-run marginal costs and therefore offer low wholesale prices for the energy they generate. Any new capacity would be more expensive because capital costs would need to be recovered. At some stage, as the existing generators require replacement, incentives for investment in new generation capacity may need to be contemplated.

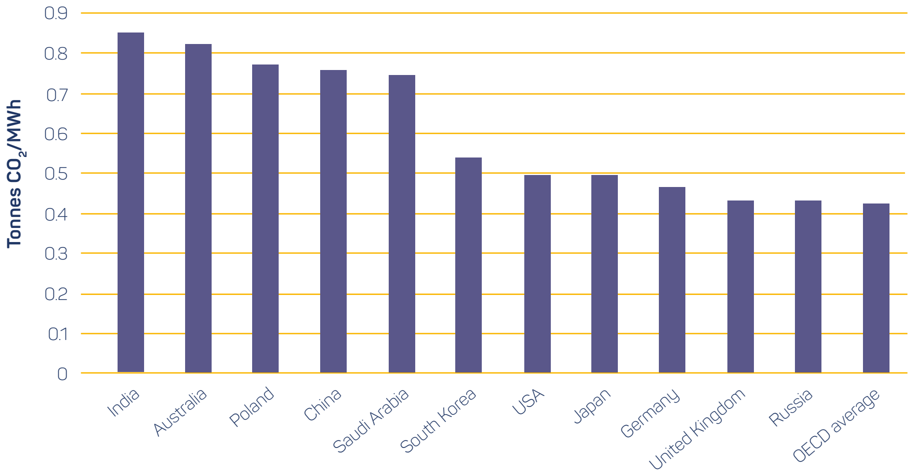

Figure 4.4: Electricity sector emissions for various OECD countries in 2011

Data sourced from A Stock, *Australia's electricity sector: Ageing, inefficient and unprepared*, Climate Council of Australia, 2014, p. 8

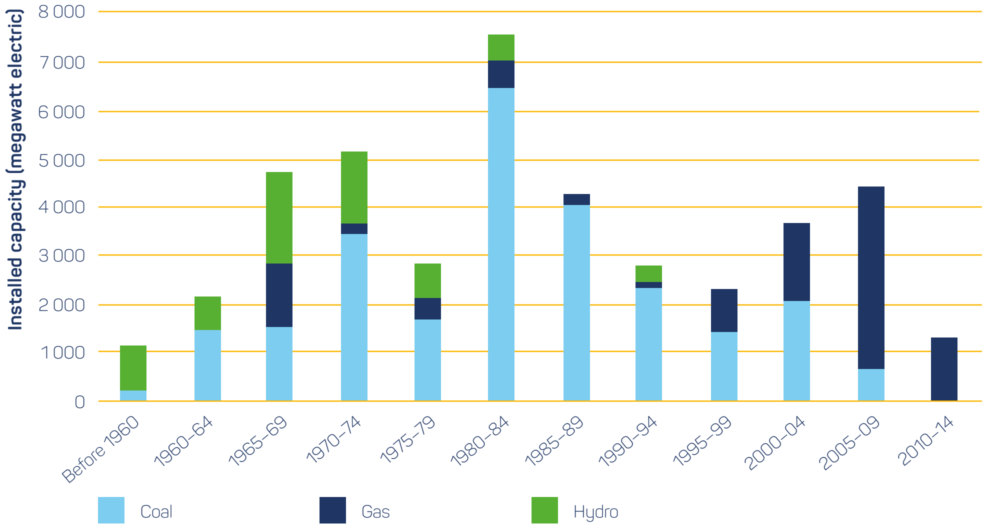

Figure 4.5: First commissioning date of operational baseload capacity in the NEM

Data sourced from the Chamber of Minerals and Energy of Western Australia, submission to the Nuclear Fuel Cycle Royal Commission, p. 22

A significant amount of generating capacity will be withdrawn from South Australia during the next few years due to the closure and mothballing of coal and gas-fired generators. This will place more reliance on importing electricity from Victoria through the interconnectors, unless generation capacity is replaced locally.[83]

Generators in the NEM sell electricity through a wholesale spot market. As an energy market, generators are paid based on the energy they supply, and the cheapest offers of electricity at any time are dispatched to meet demand.[84] Generators need to be able to offer their electricity at a sufficiently competitive price to ensure selection for dispatch and are only able to sell electricity at very high prices when demand exceeds available supply.[85]

As shown in Figure 4.6, electricity demand in the NEM has declined during the past five years due to several factors including high electricity prices, penetration of roof-top solar photovoltaics (PV), increased energy efficiency and the closure of aluminium smelting and manufacturing facilities, for example, automotive factory closures in Victoria

BASELOAD VERSUS PEAKING GENERATORS

Generation technologies differ in terms of their flexibility of operation and consequently their ability to take advantage of fluctuations in the market.

Baseload generators such as coal and nuclear are typically operated to maintain a constant level of generation, and are therefore most profitable when required to meet a steady and predictable level of demand.

Peaking generators such as gas are able to start up quickly compared with other generation technologies, and therefore have the flexibility to react to sharp increases in demand. Peaking generators can still be profitable even though they may only operate for several days a year. Because they are the only source of supply at such times, they are able to charge large wholesale prices, enabling them to meet their costs despite their infrequent operation.

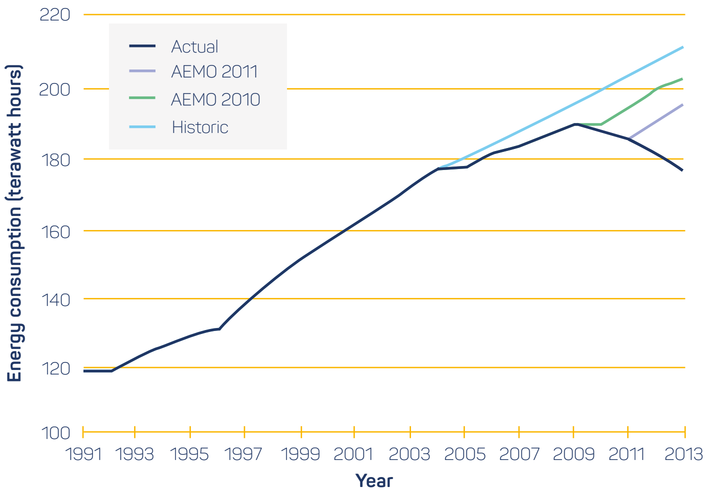

Figure 4.6: Energy consumption in the NEM—actual and predicted

and South Australia.[86] This decline, which was not predicted by the industry, has resulted in the temporary and permanent removal of some capacity from the NEM.[87]

The flat demand for electricity has negated the need for further generation investment in the near future, with the vast majority of new generation being LRET-incentivised wind energy.[88] However, the intermittent nature of wind generation can lead to it supplying a large amount of energy during low demand periods, resulting in low and even negative wholesale prices at these times. This presents a challenge for baseload generation technologies to compete financially.[89]

43. The following characteristics of the South Australian region of the NEM affect the viability of current or potential new baseload generators, such as a nuclear power plant:

a. The annual demand profile is characterised by peaks that substantially exceed average daily demand, which results in one-third of South Australia's generation mix being used less than 200 hours annually.

The South Australian region of the NEM is characterised by significant peaks in its demand profile on both short and long time scales. This is predicted to continue, with the maximum demand forecast to reach 2.2 times the average demand by 2024–25, easily the largest ratio of any region in the NEM, as shown in Figure 4.7 and discussed in Box: South Australia's electricity price competitiveness to 2030 and beyond.[90] This poses a significant challenge for the commercial viability of large-scale plant because although a large amount of capacity is needed to meet maximum demand, the amount of time this maximum capacity is used is limited.

b. The daily minimum demand for electricity has been falling as a result of increased penetration of solar PV. Yet solar PV has had little effect on peak demand requirements.

The minimum operational demand typically occurs in the middle of the day, and, given this coincides with the maximum operation of solar PV, has caused a steady decrease in operational minimum demand in South Australia during the past several years. By 2023–24, it is expected that solar PV will completely meet demand between 12:30 and 14:30 on particular minimum demand days.[91] Conversely, the uptake of solar PV has had little impact on operational maximum demand, particularly as peak demand typically occurs between 16:00 and 21:00 on hot summer days, when solar PV is past peak operation.[92]

c. Total demand is small, with low expected short- and medium-term growth, such that a very large generator would supply a large portion of demand.

As discussed, total demand in South Australia is relatively small compared with other regions in the NEM, with maximum demand between 2900 megawatts (MWe) and 3400 MWe.[93] Large-scale generators typically have capacity of about 1000 MWe, approximately one-third of current maximum demand in South Australia.

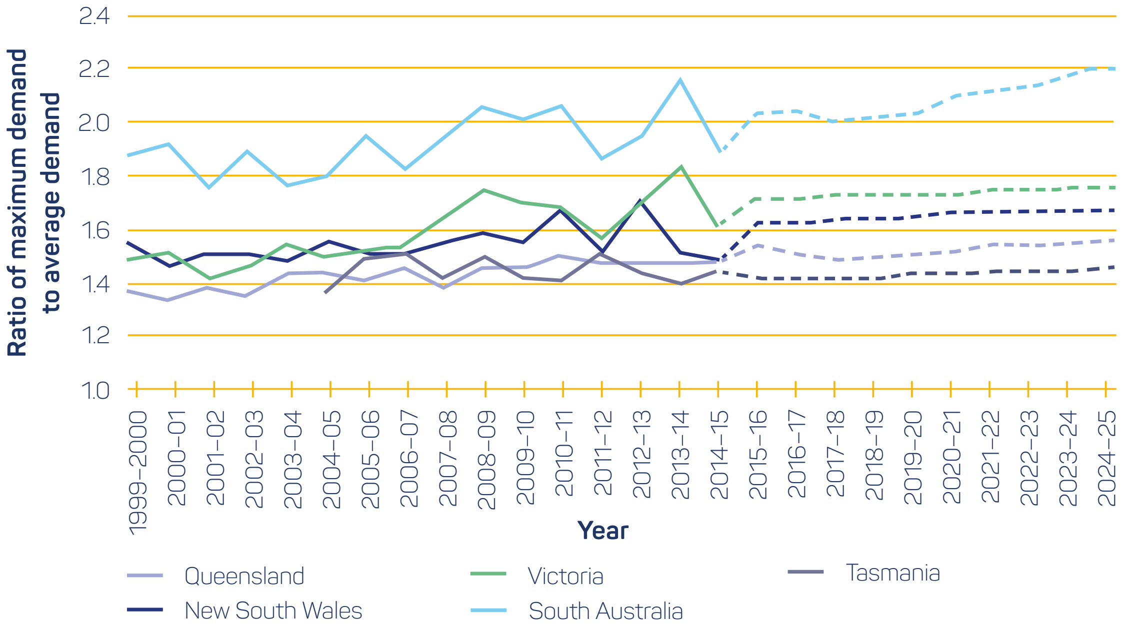

Figure 4.7: Ratio of maximum demand to average demand for each region in the NEM

Data sourced from AER, *State of the energy market report*, 30 June 2015, p. 26

d. There is substantial, and growing, intermittent generating capacity, which relies on interstate coal generation and peaking gas generation to continuously balance supply and demand.

In 2014/15, wind and solar PV made up 34 per cent and 7 per cent respectively of South Australia's total generation capacity. This high penetration of intermittent generation necessitates having a large amount of capacity that is ready to meet demand in periods of low wind and sunlight. Demand cannot always be met by local generation, requiring South Australia to import electricity from Victoria via the Heywood and Murraylink interconnectors.[94] This is typically sourced from coal-fired generation due to its low cost.[95]

e. The penetration of wind has altered the operational characteristics of existing gas and coal generation from baseload to load following.

Because wind farms typically have very low short-run marginal costs, they can place particularly low-cost bids in the NEM, which consequently sees all wind energy dispatched in South Australia when it is available.[96] As a result, fossil fuel plants that were historically operating as baseload generation are now operating as peaking generation, that is, periodically dispatched to meet peak demand rather than constantly supplying the minimum demand.

f. South Australia's relative isolation from the wider NEM due to limited transmission interconnection inhibits the import and export of electricity.

The import and export of electricity across state borders is limited by the physical constraints of the interconnectors—200/220 MWe for Murraylink and 460 MWe (currently being upgraded to 650 MWe) for Heywood.[97]

g. Relative to other regions of the NEM, South Australia has one of the highest average wholesale prices and some of the greatest price volatility.

South Australia has had either the highest or second-highest average annual electricity wholesale price in the NEM for each of the past nine financial years.[98] This has negatively affected the competitiveness of energy-intensive industries in the state. Additionally, South Australia has experienced significant price volatility (both highs and lows) in the past few years compared to other NEM regions. Price volatility in South Australia has been driven by coal and gas plant withdrawals, concentrated generator ownership (lack of competition), and limited capacity to import electricity via the interconnectors (see Box: South Australia's electricity price competitiveness to 2030 and beyond).[99]

SA'S ELECTRICITY PRICE COMPETITIVENESS TO 2030 AND BEYOND—POLICY IMPACTS

The Commission's modelling considered the effect on wholesale electricity prices in a scenario where there was no nuclear, but increasing renewable generation to 2030 and beyond. This assessment was necessary to both form a baseline against which the introduction of nuclear generation could be contrasted and identify any supply shortfall that a nuclear generator could fill.

This analysis offers some insights into the policy effects of reducing carbon emissions to South Australia's future electricity competitiveness relative to other regions of the NEM to 2030 and beyond.

Over recent years, the South Australian subregion of the NEM has had some of the highest average wholesale electricity prices in the nation. These prices make up part of the retail electricity price paid by businesses and households. The other parts are the cost of the transmission and distribution network, taxes, and subsidies paid to generators. Figure 4.8 compares South Australian wholesale prices with those of other NEM subregions since 2006/07.

The volatility in South Australia's wholesale electricity prices (the extent to which prices range from highs to lows) relative to the other NEM states is shown in Figure 4.9. South Australia experiences a much higher frequency of both negative and very high regional reference prices relative to the other NEM states. The very low price events are attributable to significant electricity supply from intermittent renewables during periods of low demand, whereas the very high price events are attributable to a combination of factors, including on occasion the need to rely on open cycle gas turbines when there is little or no supply from intermittent renewables.

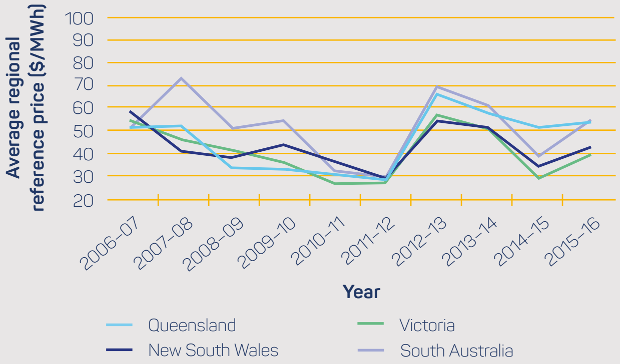

Figure 4.8: Annual average regional wholesale price across mainland NEM states from 2006/07 to 2014/15

Data sourced from Australian Energy Market Operator (AEMO), Average price tables

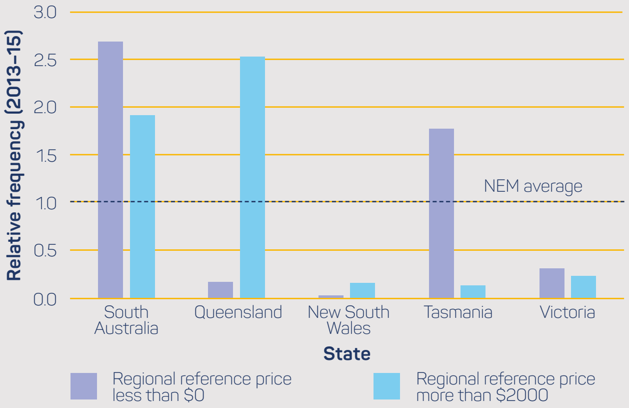

Figure 4.9: The frequency of negative and very high regional wholesale prices in NEM regions relative to the average, 2013–15

Data sourced from AEMO, Pricing event reports

The modelling undertaken for the Commission distinguished between two means of delivering low-carbon energy generation to meet abatement targets between 2017 and 2030:

1. continuing policies, such as the LRET scheme and emissions reduction fund, which is not technology neutral (a Current Policies scenario).
2. introducing market mechanisms, such as a carbon price, which is technology neutral (the New Carbon Price scenario).[1]

After 2030, the model assumed that a carbon price would apply. The scenarios and corresponding assumptions are explained in greater detail in Table G.2 and Figure G.2 in Appendix G: Nuclear power in South Australia—analysis of viability and economic impacts. The wholesale price was derived from the lowest-cost mix of technologies that was determined based on the current Australian estimates of the costs of renewables and storage shown in Figure G.3 of Appendix G. These assume subtantial cost reductions for both renewables and storage technologies.

Under both scenarios the average wholesale electricity price is higher in South Australia than it is now. However, the two policies had significantly different effects on electricity price competitiveness for South Australia.

SA'S ELECTRICITY PRICE COMPETITIVENESS TO 2030 AND BEYOND—POLICY IMPACTS (CONT'D)

Current policy mechanisms (not technology neutral)

A continuation of current policy interventions was shown to lead to continuing growth and relatively higher concentration of renewable generation in South Australia, compared to other regions (see Figure 4.10). The difference arises in the analysis as a result of better wind resources in South Australia; the presence of existing low-cost generation in some other regions, which diminishes the attractiveness of installing new capacity; and differences in state-based policies supporting new renewable capacity.

This policy has clear implications for wholesale price competitiveness in South Australia, as shown in Figure 4.11. In the period between 2017 and 2030, it leads to wholesale electricity prices in the state being 20 per cent higher than the NEM average. The comparatively higher price in the model arises from a combination of effects that includes the predicted high penetration of renewables in South Australia, the lack of diversity in the local generation mix to meet the balance of demand, and the lower shares of renewable generation in other regions of the mainland NEM.

Carbon price policy mechanism (technology neutral)

If a technology-neutral policy such as a carbon price were introduced to drive emissions reductions, there would be more uniform growth in the share of renewable generation across the mainland NEM states, as shown in Figure 4.10. This is because all generators must meet the full costs of their carbon emissions, including low-cost generators in other regions. Under this policy South Australia was still estimated to have the greatest share of renewable generation; however average wholesale prices in the state became similar to other regions as a carbon price leads to a rapid increase in renewable capacity from 2017, as shown in Figure 4.11.

Prices converge under both scenarios beyond 2030, as a carbon price is assumed to apply under both scenarios modelled.

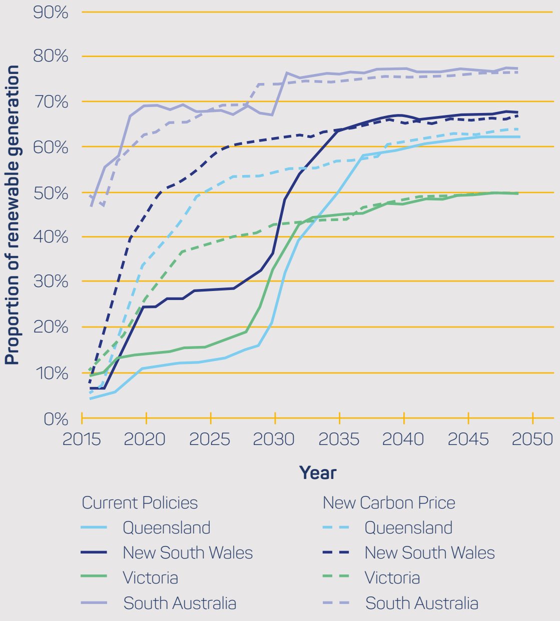

Figure 4.10: Renewable generation as a proportion of total generation by 2050 in the mainland NEM states under the Current Policies or New Carbon Price scenarios

Data sourced from Ernst & Young, *CGE modelling assessment*, underlying market model data

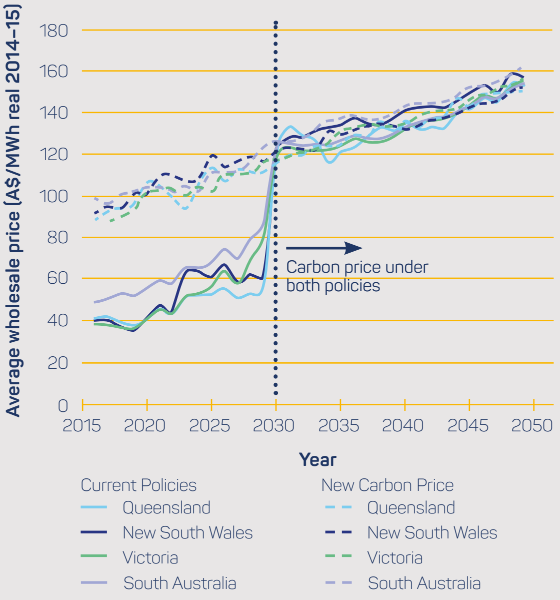

Figure 4.11: Annual average wholesale price of electricity to 2050 for all mainland NEM states under Current Policies and New Carbon Price scenarios

Source: Ernst & Young, *CGE modelling assessment*, underlying market model data

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[1] Ernst & Young, *Computational general equilibrium modelling assessment*, report prepared for the Nuclear Fuel Cycle Royal Commission, Adelaide, February 2016, section 3.2, pp. 26-27.

IN WHAT CIRCUMSTANCES IS THE ACTIVITY VIABLE?

44. An assessment of the viability of establishing a nuclear power plant in the South Australian NEM would require a full systems investigation.

Whether any additional electricity generator, including a nuclear power plant, would be able to deliver a sufficient return on investment in the South Australian NEM depends on whether it would be dispatched to supply electricity at a price that generates profits. This would require a full systems analysis of:

- the costs of establishing and operating a new nuclear power plant in South Australia[100]
- the levels of future demand in the South Australian NEM at the time that such a plant might be operating, which in turn would require an analysis of the earliest reasonable date of operation[101]
- the costs and outputs of the generators that would be competing to meet that demand—both existing generators and those likely to be integrated into the grid over the same time—which would inform analysis of the wholesale prices with which a new nuclear power plant might need to compete[102]
- the impact of carbon abatement policy measures on the electricity market[103]
- wholesale prices in the South Australian subregion following the introduction of any new generating capacity.[104]

45. Based on analyses addressing these issues, it can be concluded that, on the present estimate of costs and under current market arrangements, nuclear power would not be commercially viable to supply baseload electricity to the South Australian subregion of the NEM from 2030 (being the earliest date for its possible introduction).

The Commission did not find that nuclear power is 'too expensive' to be viable or that it is 'yesterday's technology'. Rather, it found that a nuclear power plant of currently available size at current costs of construction would not be viable in the South Australian market under current market rules.[105] The outcome of this analysis is consistent with a wide range of realistic scenarios. It does not necessarily apply to other jurisdictions in Australia. In fact, some of the modelling suggests that nuclear might well be viable elsewhere, as the challenges facing baseload generation in South Australia are not shared with other regions of the NEM. This is explained in more detail below, and in Appendix G: Nuclear power in South Australia—analysis of viability and economic impacts.

CAPITAL COST OF NUCLEAR

The development of a nuclear power plant involves a substantial upfront capital investment before operating revenues are earned. The amount of this investment is therefore critical to an analysis of viability. To have confidence in its estimated costs, the Commission applied the following criteria:

1. The reactor technology had to have been successfully constructed and commissioned elsewhere at least twice by 2022.
2. All cost estimates were to be based on realised-cost benchmarks or, if they were not available, independently verified estimates.

In terms of attempting to establish the likely capital costs of a new nuclear power plant, the Commission assessed that the most reliable data is recent, realised benchmarks in project development and construction timeframes. In the case of new technologies that have not been constructed, such as SMRs, the Commission considered that it was necessary to take a conservative approach to projected costs until they could be demonstrated. It did not consider the costs of advanced reactors that are not commercially proven and hence have no reliable bases for estimating costs.

The estimate of total costs used by the Commission for construction of a large pressurised water reactor (PWR) is set out in Table 4.2. The estimate is derived from known costs of the Westinghouse AP1000 PWR (1125 MWe) based on available realised costs for the four units (two each at Vogtle and VC Summer) under construction in the USA.[106] The known costs were adjusted as they relate to the construction of reactors in pairs, whereas the costs estimated in Table 4.2 are for a single reactor. The analysis sought to apply costs to local conditions by estimating additional expenditure associated with establishing supporting infrastructure such as electrical connection, reserve capacity, roads and wharf facilities, and water supplies. Separate estimates were made for greenfield and brownfield sites, which took account of the proximity of existing infrastructure.

Table 4.2: Capital and supporting infrastructure costs for a large nuclear reactor (PWR) at a brownfield and greenfield site

Site	PWR (1125 MWe) (A$ 2014[a])
Brownfield site	$8962m ($7966/kW)
Greenfield site	$9323m ($8287/kW)

a. Includes pre-construction, licensing, supporting infrastructure and connection costs.
Note: Megawatt electric (MWe); per kilowatt (/kW).
Data sourced from WSP/Parsons Brinckerhoff, *Final report: Quantitative analysis and initial business case – establishing a nuclear power plant and systems in South Australia*, report prepared for the Nuclear Fuel Cycle Royal Commission, Adelaide, February 2016, section 6.

Because of the potential for plants with smaller capacity to successfully integrate with the South Australian NEM, the Commission considered the viability of light water SMRs of less than 400 MWe. Because even the most advanced designs for such SMRs have not been commercially licensed, there are no available benchmarks.

The Commission undertook the analysis based on two of the more advanced SMR designs, which are in the process of licensing and appear to have prospects for commercial deployment.[107] In the absence of a demonstration of the SMR's actual costs, the Commission was not prepared to accept the projections of costs made by nuclear power plant vendors. These projections ranged from A$7000 to A$8000 per kilowatt, which is substantially lower than the Commission's analysis.[108] While the Commission accepts that the projections represent the target for vendors, and are in some cases their best estimate of costs, it could not confidently proceed on that basis.

Given this, the capital costs of SMR systems for the purposes of the Commission's study was estimated to be 5 per cent higher than that of the large-scale PWR costs presented in Table 4.2, on the basis that a small plant has not been demonstrated to achieve the economies of scale of a large plant.[109] The costs of licensing and project development were added to that. The cost estimates used by the Commission for constructing two types of SMR, including supporting infrastructure, on either a brownfield or greenfield site are set out in Table 4.3.

Table 4.3: SMR capital and supporting infrastructure for two designs

Site	SMR (285 MWe) (A$ 2014[a])	SMR (360 MWe) (A$ 2014[a])
Brownfield site	$2942m ($10 323/kW)	$3302m ($9173/kW)
Greenfield site	$3331m ($11 689/kW)	$3692m ($10 256/kW)

a. Includes pre-construction, licensing, supporting infrastructure and connection costs.
Note: Megawatt electric (MWe); per kilowatt (/kW).
Data sourced from WSP/Parsons Brinckerhoff, *Establishing a nuclear power plant*, tables ES1–8.

The cost estimates used by the Commission are, in the case of a large nuclear reactor (PWR), substantially higher than those used in the Australian Energy Technology Assessment 2013 Model Update (AETA 2013), but similar to those used in the Australian Power Generation Technology Report in 2015, set out in Table 4.4.[110] Internationally, the IAEA and the International Energy Agency (IEA) have published costs in the same order as the AETA 2013 costs. The Commission's higher costs are substantially explained by its use of a lower exchange rate (the long-term average), inclusion of pre-construction and project development costs (excluded in the AETA analysis), and supporting infrastructure such as port facilities.

Table 4.4: PWR and SMR capital and supporting infrastructure costs for a brownfield site

	PWR	SMR
Australian Energy Technology Assessment 2013 Model Update **(first-of-a-kind costs)[a]**	$6392/kW	$11 778/kW
EPRI/CO_2CRC Australian Power Generation Technology Report **(2015)[b]**	$9000/kW	N/A

a. Bureau of Resources and Energy Economics, Australian Government, Canberra, 2013.
b. Electric Power Research Institute, 2015, p. 127.
Note: Per kilowatt (/kW).

TIMEFRAME FOR INTRODUCTION AND LIKELY DEMAND AT THAT TIME

The Commission considers 2030 to be the earliest that a nuclear power plant could reasonably be expected to start operation in South Australia. This allows 14 years for establishing regulatory systems and expertise, undertaking a detailed assessment of the nuclear supply chain before pre-licensing activities, licensing, project development and construction for a large plant. This is an ambitious timeframe, but the Commission considers it reasonable if there were an imperative for development.[111]

Total network demand at that time will depend on the extent to which some renewable generation, energy storage and electric vehicle technologies are deployed. While increased roof-top solar PV would reduce demand, electric vehicles would both increase total consumption and change the demand profile. The extent to which these technologies may be deployed will be substantially driven by cost reductions that may be realised up to 2030.

To account for this uncertainty, the Commission's analysis of future demand in the NEM is based on separate projections for the residential, business and industrial sectors (incorporating network losses), including reducing demand to take account of solar PV generation and storage 'behind the meter', that is, local storage within businesses and residences. Different projections were made, taking account of growth in demand for electric vehicles, other economic activities (including population growth) and the effect on demand caused by consumers' response to increasing prices.

COMPETING GENERATION TECHNOLOGIES

To determine which technologies would be able to offer the lowest overall wholesale electricity prices to meet expected demand in 2030, the Commission used the most recent Australian estimates of costs published in the *Australian Power Generation Technology Report* (2015).[112] It also took account of expected reductions in cost previously published as part of the AETA 2013 update[113], as shown in Figure G.3 in Appendix G.

The cost of nuclear power plants is assumed to remain stable to 2050. Responses to the Tentative Findings have criticised that position, suggesting that cost reductions should have been assumed in response to rising global deployment. In the Commission's view there is significant uncertainty in relation to realising such cost reductions, given the lack of demonstrated evidence to date in Western democracies.

IMPACT OF CARBON ABATEMENT POLICIES

The mix of generation technologies likely to be competing with a nuclear power plant and their wholesale costs would also be affected by the scope and timing of policy measures to reduce the CO_2 emissions intensity of the energy sector. Such measures could affect the wholesale price of electricity and, if they are targeted, advantage particular technologies. The modelling undertaken for the Commission took this into account.

Significant uncertainty remains in relation to the policy measures that are likely to be implemented. To reasonably account for the likely impact of such measures, the Commission developed what it considers are plausible scenarios. These scenarios are based on existing measures (for example, the emissions reduction fund and LRET), recent policies (for example, a carbon price and emissions trading scheme), and the Australian Government's emissions reduction goals for 2030.[114]

Based on each of the above inputs, market modelling was undertaken to determine the lowest-cost mix of generation in the wholesale market that would make up the NEM to 2050. The model also determined the price of electricity that would correspond to this mix. This is discussed in further detail in Appendix G.

Nuclear power, on current costs, was not part of the lowest-cost mix.[115] Instead, significant growth in intermittent renewable generation was estimated to be supported by a combination of 900 MWe of combined cycle gas turbine capacity, the current level of peaking gas generation of 950 MWe and behind-the-meter energy storage. The mix of installed gas generation was found to comprise about 25 per cent of South Australia's total generation in 2030 and 22 per cent in 2050.[116]

46. The conclusion that nuclear power is not viable in South Australia remains the case:

a. on a range of predicted wholesale electricity prices incorporating a range of possible carbon prices

The Commission undertook analysis to determine whether the implementation of various carbon abatement policy measures could improve the viability of a nuclear power plant in South Australia. The analysis included hypothetical scenarios ranging from less stringent measures to more. They were:

- a continuation of the emissions reduction fund to meet abatement objectives of 26–28 per cent of 2005 levels by 2030 and implementation of a carbon price beyond 2030 to meet an emissions reduction of 80 per cent of 2000 levels by 2050 (Current Policies scenario)[117]
- the implementation of a carbon price in 2017 to meet the same emissions reduction objectives as those achieved under current policies (New Carbon Price scenario)[118]
- the implementation of a carbon price in 2017 to meet an emissions reduction objective of 65 per cent of 2005 levels by 2030 and complete decarbonisation by 2050 (Strong Carbon Price scenario).[119]

Only the Strong Carbon Price scenario would achieve emissions abatement consistent with the 'well below 2 °C' target affirmed at the 2015 United Nations Climate Change Conference in Paris.[120] Such a scenario significantly increased the wholesale price of electricity under current market rules (see Figure 4.12).

As would be expected, the potential viability of a nuclear power plant in South Australia improved under more stringent carbon policies, but remained unviable even under the Strong Carbon Price scenario.

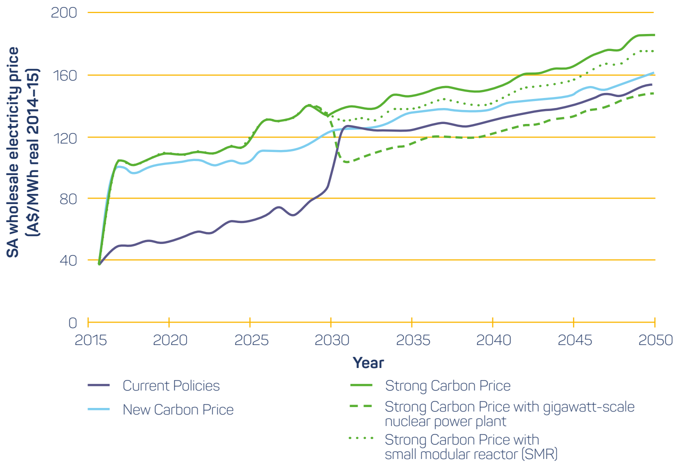

Figure 4.12: Annual average real wholesale electricity price in South Australia, 2014/15 prices

Data sourced from Ernst & Young, *CGE modelling assessment*, section 5.9, figure 47

Further, the construction and operation of a nuclear power plant were found not to have a positive rate of return at a commercial cost of capital of 10 per cent under any of the carbon abatement scenarios. The estimations of viability presented in Table 4.5 represent the best-case scenario for nuclear, operating as a baseload plant in South Australia with an expanded interconnection of up to 2 gigawatt electrical (GWe), if it were commissioned in either 2030 or 2050.

Table 4.5: Profitability at a commercial rate of return (10 per cent) of large and small nuclear power plants commissioned in 2030 or 2050 under the New Carbon Price and Strong Carbon Price scenarios

	Net Carbon Price Net present value (A$ billion 2015)		Strong Carbon Price Net present value (A$ billion 2015)	
Year of commission	**2030**	**2050**	**2030**	**2050**
Small modular reactor (285 MWe)	−2.2	−1.9	−1.8	−1.4
Large nuclear power plant (1125 MWe)	−7.4	−6.4	−6.3	−4.7

Data sourced from DGA Consulting/Carisway, *Final report for the quantitative viability analysis of electricity generation from nuclear fuels*, report prepared for the Nuclear Fuel Cycle Royal Commission, Adelaide, February 2016, section 6, tables 35–36].

b. for both large or proposed new small reactor designs

The establishment of a large nuclear power plant in the South Australian NEM was assessed to lead to an almost one-quarter decline in average wholesale prices (see Figure 4.12). While positive for South Australian consumers, this would dramatically affect the revenue earned and thus the viability of such a plant in this market.

This effect on wholesale prices is due to the relatively small size of the South Australian market. The introduction of a large nuclear power plant would be likely to have a much smaller impact on wholesale prices in Victoria and New South Wales because its output would form a much smaller portion of total demand. The modelling undertaken for the Commission indicated that a large nuclear generator in South Australia selling half its electricity in Victoria (through transmission) would only decrease wholesale prices in Victoria by 3 per cent.

A small nuclear power plant was not viable. This is not due to its effect on reducing wholesale prices, which fell by only 6 per cent (see Figure 4.12). Rather, its viability was mainly affected by its anticipated 15–30 per cent higher construction cost per kilowatt when compared with a large plant. This underscores the need to carefully follow the actual costs in small nuclear plant developments globally and any potential relevance to South Australia.

c. under current and potentially substantially expanded interconnection capacity to Victoria and NSW

Modelling showed that under current levels of interconnection, up to half of all nuclear generation from either a small or large nuclear power plant in South Australia would not be used (generation shedding). This would have a significant effect on the viability of a nuclear power plant, doubling the levelised cost of energy generation. It would also lead to the less efficient operation of the installed level of renewable generation, as about 40 per cent of output would be unused over a year unless grid storage systems were developed.[121]

However, as the penetration of intermittent generation in South Australia increases, so too will the viability of additional interconnection capacity between the state and the rest of the NEM.[122] This is to facilitate both the export of renewable electricity and the reduction of peak electricity prices in South Australia when there is reduced supply from intermittent sources. A joint AEMO/ElectraNet study in 2011 that assessed the viability of transmission upgrades found that only a relatively small upgrade to the Heywood interconnector was justifiable at that time. However, it anticipated that under some carbon abatement scenarios, consistent with the strong policies analysed by the Commission, an expansion of capacity to 2000 MWe would be viable in 2025.[123]

For those reasons the modelling undertaken for the Commission analysed the effects on viability of a South Australian nuclear power plant if transmission were substantially expanded to 2000 MWe, enabling the plant to export substantial additional electricity into the eastern regions of the NEM. Even with such exports, the analysis showed that a large nuclear plant was not viable.[124]

d. under a range of predictions of demand in 2030, including with significant uptake of electric vehicles.

Nuclear was not viable even on more optimistic views of future demand. The Commission analysed demand on a number of bases, including those with the largest forecast uptake of electric vehicles. Electric vehicles would be expected to add to grid demand through fuel switching from oil and to alter demand profiles depending on the time of charging, but also to contribute to storage in the network. Even in more optimistic scenarios of uptake, equal to 20 per cent of the light vehicle fleet in South Australia, neither a large nor small nuclear power plant in South Australia was assessed to generate a positive rate of return.

47. Off-grid nuclear power is also unlikely to be viable in South Australia in the foreseeable future because of low demand, even assuming optimistic growth of mining activities, and the likely location of that demand.

An off-grid electricity market, not connected to the NEM, supplies mining and remote communities in South Australia.[125] There is currently 77 MWe of installed off-grid generating capacity, dominated by diesel and natural gas generators, to meet 236 GWh of demand.[126] More than 80 per cent of the electricity consumed meets the requirements of industrial customers, predominantly mine operators.[127] However, the off-grid industrial sector is a small subset of the total electricity requirements of the mining industry in South Australia.

In 2014, studies undertaken at the request of the South Australian Government estimated that total electricity demand from the mining sector was 1.7 terawatt hours (TWh) and was estimated to rise to up to 6 TWh by 2023–32, under ambitious scenarios.[128] Even if those outcomes were realised, it is unlikely that new nuclear power plants would be the economic option to supply the required electricity, for three main reasons:

1. Mining operators require flexible energy systems that are able to scale up and down in response to fluctuations in operational requirements.[129] This affects the capacity utilisation of a generator. A nuclear power plant, because of its high capital costs, requires high levels of utilisation to be viable.
2. The construction and operation of a new nuclear plant in a remote location is likely to increase capital costs, making it less attractive than established alternatives.[130]
3. Even if a mining region were likely to generate the large and stable demand necessary to support a nuclear power plant, it may nevertheless be more cost effective to connect that mining region to the NEM for its power needs, the cost of which could be estimated with greater certainty than a nuclear power plant.[131]

48. While nuclear generation is not currently viable, it is possible that this assessment may change. Its commercial viability as part of the NEM in South Australia under current market rules would be improved if:

a. a national requirement for near-zero CO_2 emissions from the electricity sector made it impossible to rely on gas generation (open cycle gas turbine and combined cycle gas turbine) to balance intermittency from renewable sources

Gas-fired generation plays a significant role in providing reliable supply under all future low-carbon scenarios for the electricity sector. Under the Commission's model of a Strong Carbon Price scenario, gas was estimated to deliver more than 30 per cent of generation across the NEM by 2050.[132] Combined cycle gas turbine generation, even under a Strong Carbon Price scenario, was estimated to be profitable despite greater emissions intensity than nuclear.

However, implicit in the Commission's and other models of a future low-carbon electricity sector is that international carbon permits could be acquired to offset gas-fired generation emissions. The viability of gas-fired generation would be affected if either the cost or the credibility of emissions permits did not meet expectations.[133] Either outcome would result in a higher domestic carbon price that would improve the relative viability of nuclear power generation as part of the lowest-cost, low-carbon mix of energy generation.

SOUTH AUSTRALIA'S FUTURE ENERGY GENERATION MIX

There is considerable optimism about the potential of renewable technologies to meet South Australia's electricity needs. However, even with anticipated substantial reductions in costs, wind, solar PV and energy storage alone will not provide the lowest-cost mix of electricity generation.

Developments in renewable electricity generation technologies, particularly wind and solar, are of considerable interest and importance to the community. Reductions in the costs of such technologies during the past decade have been faster than anticipated, and further reductions are forecast. Modelling undertaken for the Commission and others suggests that intermittent renewable generation and storage technologies will make up a substantial share of the future lowest-cost mix of supply.[1]

However, the output of those models shows that even with expected cost reductions and favourable carbon emission abatement policies, the lowest-cost generation mix does not consist of wind, solar and storage alone.[2] In most cases, it also incorporates a significant level of firm, dispatchable fossil fuel-based generation capacity to constantly match demand with supply.[3] That is the case even under strong climate action scenarios.

This is due to a combination of our electricity demand profile, the intermittent nature of wind and solar generation, and the cost of installing new capacity. Given the demand peaks experienced in South Australia, the amount of wind, solar and storage capacity that would be required to reliably meet those peaks is substantial. However, as each additional wind, solar or storage unit is installed, it is likely to be required only to supply electricity to meet an increasingly smaller portion of demand.[4] Based on such limited utilisation, the revenue able to be achieved will eventually be insufficient to recover the costs of the unit's installation.

It is cheaper overall for gas-fired generation to be deployed to meet the highest peaks of demand, as gas plants are generally profitable as long as they can supply a sufficient level of demand at a higher price than the cost of fuel. This may have adverse implications for the cost of decarbonisation of the electricity sector if expected price reductions in renewable energy technologies are not realised.[5]

This is the reason future scenarios for an electricity system comprising only renewable energy sources often include a substantial share of geothermal and/or pumped hydro generation. The question remains as to whether either of these technologies is commercially feasible and cost effective at the required scale, as compared to gas-fired and/or nuclear, as discussed at Findings 51–54.

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[1] Ernst & Young, *CGE modelling assessment*, section 6.

[2] DGA Consulting/Carisway, *Final report for the quantitative viability analysis of electricity generation from nuclear fuels*, report prepared for the Nuclear Fuel Cycle Royal Commission, Adelaide, February 2016, sections 4.6–4.7.

[3] Ernst & Young, *CGE modelling assessment*, section 5.5.8.

[4] Khalipour & Vasallo, 'Leaving the grid: an ambition or a real choice', *Energy Policy* 82, July 2015.

[5] DGA Consulting/Carisway, *Final report*, section 5.2.2; Ernst & Young, *CGE modelling assessment*, section 5.5.8.

b. the intermittency of renewables could not be supported adequately by cost-effective storage at scale or by new demand sources such as 'power to fuel', which converts surplus power into a transport fuel source

Residential and grid-scale energy storage offers the potential to store surplus energy from intermittent wind and solar generation when supply exceeds demand, and to later release that energy when demand exceeds supply.[134] Although residential storage is not yet commercially viable[135], all current modelling assessments, including those undertaken for the Commission, see storage playing a significantly larger role in supporting the establishment and integration of additional intermittent renewable generation capacity.[136]

Similarly, other emerging technologies such as power-to-fuel arrangements may offer the potential to convert surplus electricity to a transport fuel in the form of hydrogen.[137] However, these technologies are yet to be demonstrated at scale in Australia.

Storage and power-to-fuel technologies also offer the potential to displace capital expenditure on the transmission and distribution networks. However, if the expected reductions in the cost of these technologies are not realised, the potential for nuclear power to provide reliable generation capacity to balance the intermittency of wind and solar would be improved.

c. system augmentations required to support substantially greater wind generation and commercial solar PV were more expensive than anticipated

Intermittent generation capacity requires electricity network support, therefore potentially increasing costs in several ways.

For example, it requires additional capacity to be installed that substantially exceeds the demand for energy from the network. That overcapacity is required to manage the intermittency of supply and allow for the storage of sufficient energy in the system so that it may be released during periods of low supply.[138]

Further, new wind and commercial solar PV generation plants need to be connected to the NEM. As the optimal locations for such plants within reasonable proximity to the existing transmission network reach capacity, extensions to the transmission network would be required to connect increasingly more remote locations.[139] The increasing costs of that network augmentation have not been studied in detail.[140]

Integrating more intermittent generation in the NEM would also require augmentation of the transmission and distribution networks to reduce congestion during periods of peak supply from roof-top PV and wind generators when instantaneous generation exceeds transmission capacity. A 2013 AEMO study estimated that without such augmentation in South Australia, up to 15 per cent of the installed total energy output of wind generators may be curtailed by 2020–21 due to transmission constraints.[141]

If system augmentations are more expensive than current estimates, the cost of deploying additional wind and solar PV generation would increase. This would improve the relative viability of a large or small nuclear power plant because it is likely to be able to be integrated into existing networks without significant augmentation.

d. the costs and risks associated with demonstrating and integrating carbon capture and storage with fossil fuel generation at scale are greater than presently anticipated

Carbon capture and storage integrated with combined cycle gas turbine generation was estimated by both the Future Grid Forum's and ClimateWorks Australia's analyses of future low-carbon energy systems to meet a significant share of generation by 2050.[142] In the modelling undertaken for the Commission, the technology was also shown to be viable under current estimates.

However, as discussed at Appendix G, those outcomes are premised on cost projections assuming technical solutions that are yet to be realised. If these solutions do not eventuate, or their costs are more expensive than currently anticipated, the potential role of a nuclear power plant as a low-carbon source of reliable electricity generation would be greater.

e. current capital and operating costs of nuclear plants were substantially reduced, which would require overcoming complexities and inexperience in project construction. Some reductions in costs have been partially demonstrated for recent plants constructed in China, but not yet in Europe or the USA

The viability of a large or small nuclear power plant is highly sensitive to the cost of its construction. Capital expenditure including the cost of project development, licensing, construction, connection, ancillary infrastructure and accrued debt interest contributes to about three quarters

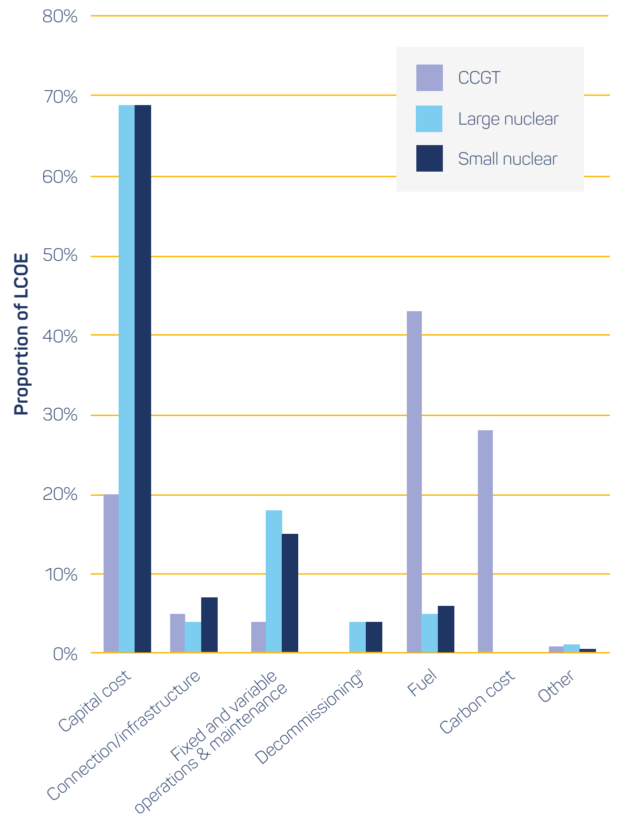

Figure 4.13: The contribution of cost components to the levelised cost of electricity (LCOE) from small and large nuclear power plants and combined cycle gas turbine (CCGT) generation[143]

[a] Decommissioning costs not included for CCGT

of the levelised cost of electricity (LCOE) generated by a nuclear power plant, as shown in Figure 4.13. The contribution of these elements to the LCOE is slightly larger for the small plant because of its lower energy output. Figure 4.13 also shows that more than 70 per cent of the LCOE of a combined cycle gas turbine generator is due to the cost of fuel (43 per cent) and carbon emissions (28 per cent), assuming a carbon price of about $120 per tonne (/t) in 2030 and $255/t in 2050.

Based on the Commission's analysis, for a nuclear power plant to achieve an LCOE competitive with a combined cycle gas turbine plant, capital and infrastructure costs for the nuclear power plant would need to decrease by about 25 per cent.[144]

Reductions in costs have been partially demonstrated for plants constructed in China, but this is not apparent in Europe or the USA. The feasibility of achieving such cost reductions for a nuclear power plant project in Australia is highly uncertain. It will be significant for South Australia to follow developments in international build programs that will show whether or not the nuclear energy industry is capable of applying lessons learned to reduce construction costs. Importantly, the conditions to make such reductions possible in the build country would also need to apply in South Australia.[145]

f. changes to government policy resulted in a combination of:

i. a price on carbon emissions in the economy (including from electricity generation)

The Commission's modelling suggested that a nuclear power plant would not be viable in South Australia even under carbon pricing policies consistent with achieving the 'well below 2 °C' target agreed in Paris in December because other low-carbon generation would be taken up before nuclear.[146] However, more stringent emissions abatement policies have the potential to improve the viability of nuclear power in combination with other measures.

ii. finance at lower cost than available on the commercial market (that is, a form of loan guarantee)

The Commission's analysis showed that the viability of a new nuclear power plant would be highly sensitive to the cost of capital. While not viable at a commercial weighted average cost of capital equal to 10 per cent, a large or small plant would offer a marginally positive return on investment assuming a cost of capital of 6 per cent, and the strongest emissions abatement scenario consistent with achieving the 'well below 2 °C' target.[147]

This is significant given that such a cost of capital is typical for the financing of public projects by government.[148] It can be obtained for the private sector in circumstances where a government guarantee is available. Such arrangements were used to secure the guarantee of the loan provided to develop the Vogtle 4 and 5 nuclear power plants in the USA.[149]

This observation is not a comment on the suitability of taking such a course. It would be a decision to be taken in the context of the commercial and public circumstances faced by a government were it seeking to secure particular types of electricity generation in the public interest.[150]

iii. long-term revenue certainty for investors.

For capital-intensive projects, in the absence of public funding, revenue certainty is important to secure investment.[151] In a market-based electricity system such as the NEM, revenue certainty could only be secured if a long-term power purchase agreement could be established.[152]

Such arrangements are in place in Australia for renewables (including most recently by the Australian Capital Territory Government in an auction for 200 MWe of wind generation capacity)[153] and internationally by other mechanisms such as the Contract for Difference model that was established in the United Kingdom to fund a range of technologies, including both renewables and the Hinkley Point C nuclear power project.[154]

49. The challenges to the viability of nuclear power generation under current market conditions in South Australia should not preclude its consideration as part of a future energy generation portfolio for the NEM. There is value in having nuclear as an option that could be implemented readily.

To achieve deep emission reductions, there is a need for substantial investment in low-carbon generation capacity between now and 2030.[155] The only low-carbon technologies that have been commercially deployed in Australia are wind and solar PV. With increasing reliance on such intermittent generation technologies, there will be a need for substantial investment in reliable generation supply to meet the balance of demand when sufficient wind or sunlight is not available.

Gas-fired technologies will continue to play a significant role in this respect.[156] However, an electricity system that relies only on intermittent renewables and gas risks depending on a single source of supply (gas) at an acceptable price. Gas-fired technologies are not, however, low carbon.

Other renewable technologies including enhanced geothermal systems, grid-scale energy storage, and carbon capture and storage could also play a significant role in helping to balance the intermittency of wind and solar, but their deployment would face significant technical and commercial challenges.

Nuclear power is a mature and deployable low-carbon option that provides reliable electricity supply at almost all times. It is therefore a credible alternative or complement to gas-fired generation in terms of assuring security of supply.[157] Although currently more expensive than combined cycle gas turbine generation, nuclear technologies may achieve cost reductions if expectations of increased global deployment were realised.[158]

50. A future national electricity supply system must be designed to be low carbon and highly reliable at the lowest possible system cost. Resolving this 'trilemma' will be difficult and will require carefully considered government policies.

To meet carbon abatement targets, the electricity sector will need to be one of the first sectors to be decarbonised. A low-carbon electricity system would also need to maintain current levels of reliability. It should be an objective of policy-makers to ensure that those outcomes are delivered at lowest possible cost.[159]

There is a substantial challenge in meeting the three requirements of low carbon, high reliability and low cost.[160] No single option for electricity generation currently commercially available in Australia meets all three criteria because of the intermittency of renewables, the emissions intensity of fossil fuel generation, and the high capital costs of developing nuclear power.

Policy interventions to deliver a transition from the current system to a future system would need to be planned carefully. There is a range of available options to achieve those outcomes, and lessons to be learned from past experience.[161]

The Australian Government has already intervened in the NEM to achieve emissions reductions by offering incentives to install new renewable capacity.[162] The LRET scheme provides an incentive to install new capacity by requiring retailers to purchase electricity from renewable generators[163], and has been successful in driving the installation of significant wind generation capacity. Substantial amounts of roof-top solar PV have resulted from feed-in tariff schemes and direct subsidies to households on the purchase costs of those systems.

While those interventions have reduced the emissions intensity of the electricity sector, they also have had significant effects on the market in the following ways:

1. Intermittent renewable generation capacity has contributed to increased price volatility in the NEM and risks to power system stability. The integration of significant intermittent generation affects the capability of the network to automatically and continuously match supply and demand.[164]

2. The profitability of gas generation has improved, given its ability to respond rapidly to meet shortfalls in supply.
3. The profitability of baseload forms of generation has decreased, thereby discouraging new entry for baseload capacity.[165]
4. The installation of roof-top solar PV has reduced operational demand from the network and required augmentation to the distribution network, as well as encouraged the installation of storage technologies.[166]

The likely impacts of any future energy policy options on the electricity market as a whole must be fully understood before implementation.

51. There are many combinations of generation technologies for a future low-carbon electricity system: it is not a simple choice between nuclear or renewables.

There are many possible combinations of technologies that could form a future low-carbon energy system.[167]

The view put to the Commission that 'we should develop our wind and solar power instead of nuclear' ignores the unique attributes of different generation technologies and their combinations in an electricity network.[168] While wind and roof-top solar PV will continue to play a significant role, their intermittency means they need to be combined with other technologies.[169] There is a wide range of choices of generating technologies to meet the balance of demand, including combinations of lower emission gas technologies, nuclear, geothermal, concentrated solar thermal and energy storage.[170]

Arguments that the choice is between renewables and nuclear fail to address the cost of each system, and the reality of which combination of particular technologies would meet reliability requirements in terms of being capable of deployment when needed.

The need for a combination of technologies is due to the characteristics of electricity demand.[171] The components of that demand (its minimum, average and peaks) dictate the necessary mix of generators. The suitability of generators depends on their operating characteristics and cost. Specifically, the viability of generators with high capital costs and low operating costs is driven by continuous operation or, in the cases of wind and solar PV, when the resource is available.[172] In comparison, the cost structure of gas generation is such that electricity is only produced when prices exceed their variable operating costs (based predominantly on the cost of fuel).

Based on a number of studies undertaken in Australia, including for the Commission, the mix of technologies that will make up the future electricity sector is diverse.[173] While the future market share of generating technologies modelled shows there are several options for achieving emissions abatement, it is equally important for decision-makers to contemplate how those technologies could be made available at scale, and the cost of doing so.

52. Identifying whether a particular generation portfolio would deliver electricity at the lowest possible cost requires an analysis of the future cost of the system as a whole.

Identifying which combination of technologies would be the lowest cost, including whether that mix included nuclear, would require an analysis of the future cost of the whole electricity system, that is, the total costs of electricity generation, transmission and distribution.

This would require a more sophisticated analysis than that advanced in numerous submissions by proponents of particular technologies based solely on the cost per unit of energy generated (LCOE). A variation on that argument was that, because a technology was expected in future to have a lower cost per unit generated, it would outcompete a rival. Such arguments were made both against and in favour of nuclear.[174]

These arguments fail to take account of the system costs of a technology, and also the varying value of electricity produced at different times depending on demand (and therefore customer willingness to pay). LCOE does not, therefore, reflect the revenues that a generator would receive, which is relevant to whether an investor would be willing to build new capacity. LCOE has limits as a tool for making decisions about the relative viability of different generators.[175]

LCOE does provide a baseline measure for comparing the competitiveness of different generating technologies.[176] It captures the cost of building, operating and decommissioning a generating plant over its financial life and its availability over that time (net of scheduled and unscheduled shutdowns).[177] However, LCOE does not take account of the costs of integrating that generation as part of the system, specifically the cost of:

- reserve generation capacity that may be required to meet total demand when the variable renewable energy technology is not available[178]
- additional inter- and intra-regional transmission, distribution and storage infrastructure to ensure generation from geographically disparate locations is transmitted to demand centres.[179]

For those planning a future electricity system (and the market in which it will operate), the relevant issue is the total systems cost, accounting for the cost of generation, connection, inter- and intra-regional expansion of transmission and distribution networks, and grid support costs.

AEMO's 2013 *100% renewables study* gave an indication of the potential total system costs of a hypothetical generation system comprising only renewable energy sources.[180] It was found that the total cost of developing such a system would be $250 billion, which is 200 times the annual value of electricity sold.[181] This assessment took into account anticipated reductions in the cost of renewables, and therefore their expected cost competitiveness with other generation options. How such a system could be funded, and whether it could be developed through private investment alone, is questionable.

53. At present, there is no analysis of a future NEM that examines total system costs based on a range of credible low-carbon energy generation options. Such an analysis would be required before it could be asserted that any option would deliver reliable, low-carbon electricity at the lowest overall cost—with or without nuclear power.

There have been few analyses of the total cost of developing a low-carbon future energy system in Australia, other than AEMO's *100% renewables study*. Other studies undertaken through the Future Grid Forum (FGF) in 2013 and 2015 and ClimateWorks Australia in 2015 have added significantly to discussion and understanding in this area.[182] However, none of these analyses was designed to provide the type of comprehensive investigation required. For policy-makers to consider the implications of different scenarios and avoid unintended consequences of policy interventions, assessments need to be undertaken on the basis of realistic expectations of technology deployment, taking into account the current level of investment and development.

Further study is needed into whether there will be sufficient returns in the electricity market to drive the commercial deployment of desirable, low-carbon energy generation technologies by the private sector. Many of the desirable types of generation technology have substantial upfront capital costs, making viability highly susceptible to the cost of finance.[183]

Further, the studies mentioned indicate that currently commercially unproven generation technologies will assume significant roles as part of a future energy system. In the case of the FGF and ClimateWorks studies, geothermal and/or carbon capture and storage paired with fossil-fuel technologies occupy more than one-fifth of generation by 2050.[184] The FGF and AEMO models assume a significant role for geothermal. Additional investigation is required into the impact of including and excluding those technologies to take account of the fact that they might not be available.[185]

The assessments to date also do not take account of the uncertainty surrounding assumed cost reductions in some technologies. While the costs of nuclear, solar PV and wind are based on established benchmarks, the same is not true for other technologies. Further analysis should be undertaken that includes the true cost of demonstrating technical feasibility, and thus enables 'like-for-like' cost comparisons with mature technologies. Such an approach would also enable certain classes of technologies to be excluded from system studies on the basis of expected costs of demonstration and the likely timeframe for availability.[186]

TIDAL AND GEOTHERMAL RESOURCES

Australia has no commercial-scale ocean energy projects at an advanced stage of development. Pilot-scale projects of less than 1 MWe, developed with substantial government support, are at an early stage of development and are yet to be demonstrated as commercially viable. Prospective reductions in cost depend on outcomes from research, development and demonstration. The deployment of tidal and geothermal technologies also is challenged by the remoteness of resources from grids and siting.[187]

There has been no commercial demonstration of enhanced geothermal systems in Australia. Following initial optimism, there has been substantial disinvestment given the failure to demonstrate permeability at depths suitable for electricity generation, high drill costs and the need to better understand the potential for induced seismicity. Direct-use geothermal, while it has cost advantages in specific settings, has to date had limited ability to contribute to electricity generation and supply in the NEM.[188]

BIOMASS

Existing commercial bio-energy applications are focused on the localised use of sugarcane residues and wood waste and the capture of gas from landfills and sewage plants. The expansion of the use of this resource is limited by a combination of economic factors: its seasonality, the value of biomass or the land on which it is cultivated for other uses, the energy consumed in its cultivation and transport, and its low-energy density.[189]

CARBON CAPTURE AND STORAGE

Carbon capture and storage (CCS) remains commercially unproven at scale in Australia and internationally. The retrofitting of capture systems with existing natural gas- or coal-fired power stations is not currently commercially viable and there are technical challenges in demonstrating the long-term stability of CO_2 in underground formations.[190] Optimism in the last decade about cost reductions in these systems has not been realised, despite the demonstration of the technical feasibility of injecting carbon dioxide into underground formations in the Boundary Dam (Canada) and the Gorgon Basin (Western Australia) oil recovery projects.[191]

While it is proposed that substantial investment in research and development may prove the feasibility of CCS in Australia[192], options modelling undertaken for the Commission suggested that a substantial portion of that investment would need to be publicly funded. A private investor would have insufficient revenue certainty from future generation plants integrating CCS to recover the capital and interest costs of research and development. In any event, the wide deployment of CCS also will be significantly affected by economic factors associated with the price of oil and gas, the efficiency of carbon dioxide separation, and constraints associated with siting and delivering community consent.[193]

ENERGY STORAGE

While battery storage technologies for a range of South Australian commercial and residential consumers are likely to be viable in the near future (particularly for those with time-of-use or capacity-based tariffs and who can integrate photovoltaic systems), the same is not true for on-grid storage. Battery, thermal or pumped hydro storage may have a future role by displacing additional transmission capacity and/or peaking generation capacity. A recent CSIRO analysis, based on expected declines in battery prices, concluded that the levelised cost of energy from lithium-ion batteries could be competitive with gas peaking power plants by 2035, but only in parts of the network such as South Australia and Queensland where there is a significant requirement for peaking capacity.[194]

54. A critical issue to be determined in a total systems cost analysis of a future NEM is whether nuclear could lower the total costs of electricity generation and supply.

Some of the additional systems costs required to support low-carbon electricity systems incorporating substantial market shares of wind and solar PV paired with storage capacity have been discussed previously. Other combinations of low-carbon generation may not impose the same costs.

Nuclear power may offer the potential to reduce total system costs by reducing the need for the measures discussed in Finding 52 and their associated costs. While nuclear power requires some reserve capacity to address outages during refuelling, it does not require measures to address intermittency and could if appropriately sited be integrated with the existing transmission network.[195]

In addition, nuclear power generation facilities have an expected operational life of at least 60 years, with possible extensions beyond that, whereas wind and other conventional renewable generation systems have asset lives of less than 25 years.[196] The extent to which the installation of nuclear may, over its lifetime, obviate the need for capacity that would otherwise have to be installed is an important consideration in an assessment of its value in a network.[197]

Whether nuclear would, in light of its current higher costs, result in lower total system costs is unknown. That would require further study including an analysis of a realistic timeframe of deployment in Australia in substitution for other technologies and system upgrades.

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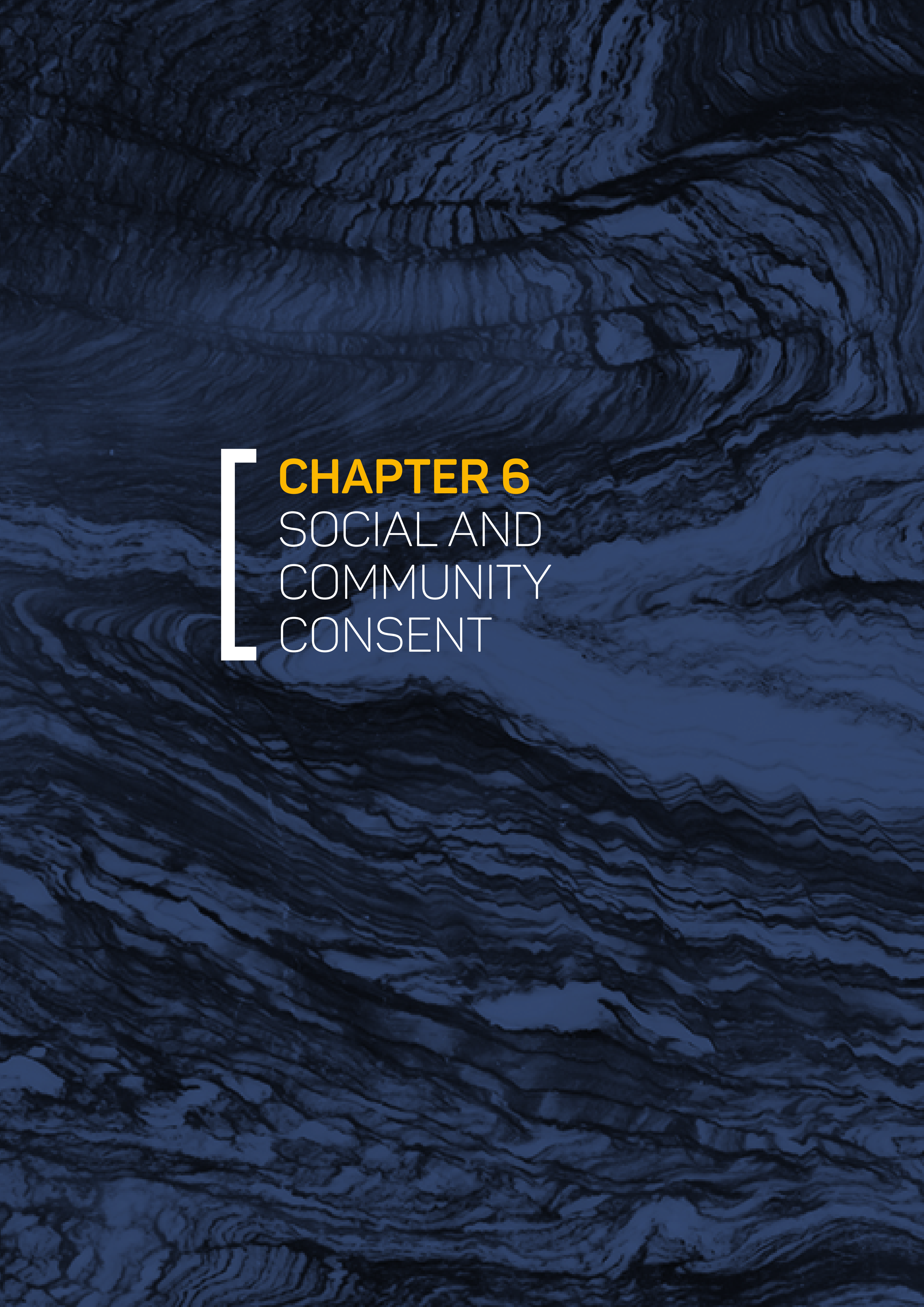

CHAPTER 6

SOCIAL AND COMMUNITY CONSENT

CHAPTER 6: SOCIAL AND COMMUNITY CONSENT

CONSENT

95. Both broad social consent and specific community consent must be obtained for any new nuclear activity to commence in South Australia.

96. Social consent means obtaining broad public support culminating in legislative endorsement of an activity by the relevant parliament, and maintaining that support for the life of the project.

Social consent is the ongoing public support that is necessary for an activity to be undertaken in a society. It is contingent on confidence that the activity is, or will be, performed consistent with the community's expectations, standards and values.

Social consent is something that is commonly taken into account as part of a political process. It is not given once for the life of an activity. In the past, social consent has been held and later lost for activities across many industries, whether because community attitudes, standards and expectations have shifted or confidence in the activity has weakened. Settled community opinions against an activity also can be reversed with technological advances, as in fields such as genetic medicine.

Because of these shifts, a public vote on a proposal is not a reliable indicator of ongoing social consent: A vote for or against a proposal one day may not result in the same level of social consent one month later.

Social consent is fundamental to the feasibility of a new or expanded nuclear development in South Australia. In such cases, which often involve decades of project development and significant capital expenditure, all stakeholders would need to be confident that social consent was not only gained, but also could reasonably be expected to be sustained through both the development and life of the project.

To facilitate nuclear activities, it will be necessary to amend existing laws that prohibit the establishment of types of nuclear facilities and pass laws to regulate their conduct. This approval would hinge on a political judgement as to whether there is sustainable public confidence that the activity can be safely and securely undertaken. Further, major projects are, by nature, transgenerational, and require bipartisan and continuing political support that does not fall prey to the caprice of election cycles.

Chapter 10: Recommendations and next steps, identifies aspects of this process (respecting that it is in part political) that would be necessary to determine whether there is social consent for an activity.

97. Community consent, being informed agreement from an affected community, would be required for a specific proposal.

For any nuclear project to proceed successfully and sustainably, it must have the informed consent of the community in the project's location, in addition to that of rights holders who may be affected, including landowners or leaseholders, and native title holders or claimants. Community consent, as distinct from the broader concept of social consent, must be measured on a more localised basis.

To achieve this, the membership of the community would need to be defined.[1] This would require consideration of the potential impacts of the proposal and its associated infrastructure on, for example, the geographical area, proximity to residents and land users, other local industries, and the expected project life. The more far-reaching the proposal, the broader the extent of the community whose collective consent must be measured.[2]

There is no universally applicable definition of 'community' for the purpose of identifying whose consent would be required before a nuclear development could proceed. This is reflected in the various approaches taken by countries in siting nuclear facilities (see Appendix H: Siting significant facilities—case studies).[3] Some communities have been well defined and organised, with existing decision-making structures. This was the case in Belgium, Finland and France, where governments and proponents embarking on nuclear developments proceeded on the basis that the existing municipal boundaries determined the scope of the relevant community.[4] Where such clear definitions and structures do not exist, it may be necessary to create new structures that develop community capacity.

The threshold for consent will differ for each community according to its concerns, rights and values. It does not require unanimity. There is no universally accepted understanding of how consent for nuclear projects may be gained and measured.[5] Because of this, any project proponent should adopt a consultative approach to defining 'community' and 'consent' and encourage early community agreement on how decisions are to be made and who has the right to make and communicate decisions (including consent) in relation to a proposed development.[6] This might involve the proponent developing, in close consultation with the community, a 'consent plan' that is flexible and inclusive rather than prescriptive.[7]

98. With respect to new uranium mining projects, no measures to further regulate community consent or community engagement appear required.

Historically the subject of extensive public and political debate[8], today uranium mining in South Australia is a lawful activity that has bipartisan political support. Although a proposal for a new uranium mine would be opposed by some, uranium mining now has broad public acceptance.[9]

The uranium mining industry in Australia well understands the importance of having community support.[10] Genuine community engagement on a proposed development followed by obtaining the community's consent are widely accepted as critical to project success and sustainability.[11] Any project proponent should be able to provide evidence of engagement in accordance with the principles set out at Finding 100.[12]

99. Efforts over recent decades internationally to develop nuclear projects by focusing on technical considerations without an equal or even greater emphasis on systematic engagement with the community have commonly failed.

South Australia can learn valuable lessons on the importance of obtaining community consent from the numerous international attempts, both failed and successful, to site new nuclear facilities. In a number of cases from the 1970s to the 1990s, the process considered only site technical characteristics, including geology, seismology and safety. Communities were not consulted, nor did they provide consent. Where proponents and governments pushed ahead without community consent, developments failed.[13]

Since the mid-1990s, most governments and proponents have adopted a new approach that involved communities in siting decisions. For example, by volunteering to be involved in a phased and adaptive learning and decision-making process, communities' receptiveness to hosting a nuclear facility have improved.[14] South Australia can learn from these more recent experiences, particularly in Belgium, Canada (which shares many political and physical characteristics with South Australia), France, Germany and South Korea. Appendix H: Siting significant facilities—case studies provides details on some of these experiences.

100. Successful processes for engaging with a community to seek consent for a new type of nuclear facility have a range of key characteristics, such as:

a. transparency of the decision-making framework and requirements for licensing and approval, and a willingness to adapt that framework as necessary to meet new or unforeseen developments

Transparency requires that factual and timely information on a proposal is made available to the affected community.[15] Proponents, local governments, regulators and parliaments play significant roles in ensuring that communities understand what is being proposed and the requirements for licensing and approval.[16] Transparency among and from these agents helps to build trust in the regulatory oversight and safety of any activity.

Adaptability and flexibility have been key features of successful engagement processes in a number of countries including Canada and the United Kingdom. This has enabled participating communities to slow or accelerate their engagement based on their particular needs. The engagement processes have been flexible enough to evolve based on experience.[17]

b. willingness to accept longer community engagement timeframes than usual for typical developments and avoid fixing arbitrary interim deadlines

The technical and complex nature of nuclear activities and the timeframes required to effectively build community understanding about a proposal, means that the community engagement process would take longer than for other industrial developments. Deadlines set primarily for commercial and technical reasons, without considering the community's need to consider and digest information, can undermine community confidence and its willingness to ultimately provide consent. Setting arbitrary timeframes at the start of a process can undermine public confidence in the community engagement approach.

c. early and deep engagement with local communities to build their knowledge and understanding using a partnership model between the proponent and the community

International experience in siting nuclear facilities shows that involving communities in early decisionmaking can improve project outcomes.[18] Building community capacity to participate in or engage with developments can improve, for example, facility design or environmental monitoring by harnessing local knowledge.[19] At the same time, the community gains greater knowledge and understanding of the project.

Successful means of engagement and knowledge building used by nuclear project proponents include: site tours of similar developments or facilities, community meetings, visitor centres, newsletters, websites, and community shopfronts or reading rooms.[20] A partnership model for engagement, used successfully overseas, creates a forum in which stakeholders work together to develop conceptual designs for nuclear facilities, build knowledge and share information.[21] Such a model could also be the vehicle through which the threshold for community consent is defined and consent provided.[22] Members of partnerships may include the project proponent, affected communities, experts, the regulator and local government. The partnership model developed in Belgium for a nuclear waste management facility was particularly successful and could be adapted to suit the South Australian context. The precise model and membership structure would need to be developed in close consultation with any affected communities.

d. an ability for local communities to engage in a learning process about hosting a facility without being required to commit to the facility

Any siting process would need to allow interested volunteer communities to learn about a proposal and what would be involved in hosting a facility.[23] It would need to be clearly and broadly communicated that volunteering to participate in this learning process would not amount to consent for a siting decision. The process would need to enable communities to decide for themselves whether they wanted to progress to more detailed discussions regarding a proposal.[24] It is critical, drawing from the United Kingdom experience, that there is no threshold for decision-points to participating in the learning process. For local communities and their leadership bodies there are no small decisions on nuclear matters.

THE BELGIAN PARTNERSHIP MODEL

Figure 6.1: A site visit held as part of the Belgian partnership model. Image courtesy of ONDRAF/NIRAS.

The partnership model developed in Belgium successfully facilitated engagement between the country's nuclear waste management agency, ONDRAF/NIRAS, and three potential host communities that expressed willingness to receive information about a proposal for a low and intermediate level radioactive waste disposal facility.[1]

Partnerships were established to address both the technical and socioeconomic aspects of the proposal, including facility design, safety and health, research and information dissemination, and community development.[2] The partnerships were provided with resources to fund their own research into the proposal. They were conduits of information to and from the wider community.[3] The successful partnership in the municipality of Dessel worked with ONDRAF/NIRAS to modify the proposal design to incorporate additional monitoring mechanisms and to develop a benefits package that was important to the community.[4] See Appendix H for more details.

[1] IPPA Project, *Case study: Site selection of final disposal of LLW and ILW Belgium (local partnership)*, Implementing Public Participation Approaches in Radioactive Waste Disposal, Seventh Euratom Research and Training Framework Programme on Nuclear Energy, European Commission, 2013, p. 1, http://toolbox.ippaproject.eu/files/LocalPartnership_CaseStudy_Site-selection-LILW-Belgium_20130312.pdf.

[2] ibid., p. 2.

[3] STOLA-Dessel, *Belgian low-level and short-lived waste: Does it belong in Dessel?*, STOLA-Dessel, Dessel, 2004, p. 8.

[4] IPPA Project, Case study: Site selection, p. 2; ONDRAF/NIRAS, The cAt project in Dessel: A long-term solution for Belgian category A waste, Brussels, 2010, http://www.niras-cat.be/downloads/cAt_brochureENG.pdf.

It would become apparent at particular points in the learning process when a community needs the resources to engage more fully and deeply on a proposal. In this respect, the learning process is two-way: the proponent in turn should be able and willing to learn about the community and its needs, concerns and interests, and be prepared to respond accordingly. Such a continuous loop has been adopted and used successfully in Belgium, Canada and, in a revised process, the United Kingdom.

e. resourcing of a community organisation to:

i. deliberate and meet in relation to the proposal

ii. engage independent scientific advisors to assist it in relation to issues of importance and to review scientific information

Resources might include funds for communities to employ independent expert advisers, hold meetings and employ staff to manage the engagement and learning process; or to otherwise allow them to participate on equal terms in proposal deliberations without incurring expenses.[25] Examples of community resourcing include the funding of the Belgian partnerships by the proponent, ONDRAF/NIRAS, and of the Maralinga Tjarutja people in South Australia, where independent scientific advice on the land clean-up was funded by the Australian Government.[26] The level and purpose of community resourcing, including funding, would depend on the community's needs, the degree to which the community engaged with the proposal, and the aspects of the proposal being considered.

f. the presence of a regulator that is:

i. trusted and experienced

ii. accessible to the community and willing to provide information on both the regulatory process and its decision making, the proposal and its views on that proposal

A regulator that is trusted by and accountable and accessible to the community is fundamental to confidence in the proposed activity and, ultimately, to community consent and project success.[27] Public confidence is assisted by an independent and capable regulator that is able to independently verify assessments made by a proponent and willing to communicate its views and assessments to the community.

A function of the Australian Government's nuclear safety regulator, the Australian Radiation Protection and Nuclear Safety Agency, is to engage and provide information to the public.[28] Were a new nuclear activity proposed for South Australia, it would be important to have a regulator that performed that general role in addition to providing specific information and assessments and analysis of a proposal.

g. the availability of scientific evidence and, where necessary, multiple, corroborating bodies of evidence to demonstrate the effectiveness of steps taken to address risks

For communities to have trust in the environmental and public safety of nuclear activities or developments, scientific evidence needs to demonstrate that the risks of any proposal are adequately addressed. Accordingly, community members must have confidence in the accuracy of proponent data and modelling, and the measures proposed to address risks. Data collection processes must be transparent and made available to the public. Scientific evidence needs to be assessed and verified by independent experts and trusted regulators. At all times, steps should be taken to ensure that the information provided to communities is objective and intelligible.[29] Communities may want to engage independent expert advisers to satisfy themselves they clearly understand the risks and how they are to be managed.[30]

h. provision of a range of benefits, identified as important by the community, for the service it provides to the wider society for hosting that facility

South Australians can take advantage of opportunities and wisely manage any associated risks to create a positive sustainable legacy for the state, as well as for the local, affected communities. Should a nuclear development proposal receive social consent, the state government would need to lead community discussion to identify principles that would underpin decisions about the investment and distribution of benefits. Rarely have projects succeeded unless they have significant community benefits, and those benefits have been determined in conjunction with the community.

Care should be taken to ensure that any benefits would be sustainable and align with the particular community's goals. There should also be specific regard and planning for the long-term social and economic development of the community.[31] It would be important that benefits are applied broadly across local communities, and specified in advance where possible, to avoid the perception of bribes.[32] Benefits would need to be tangible, significant and negotiated, as with other elements of the proposal.[33] Money should not be paid to communities upfront. Instead, it should be received based on the phased development of the project.

Internationally, public support for siting radioactive waste management facilities has been shown to increase when the benefits are broadened, for example, by collocating such facilities with research institutions that are tasked with investigating disposal techniques, radiation safety and potential future uses of spent fuel.[34] This experience could be considered in South Australia. Research and development into new technologies, and health, social and cultural innovation, could also be supported.

i. consistency of individuals involved in the development and delivery of those projects.

The successful development and delivery of a nuclear project requires a long-term personal commitment from stakeholders to see that project through to fruition. Maintaining continuity of stakeholders over time allows relationships to be built and, accordingly, trust and understanding to develop. This is especially important for Aboriginal communities.[35] Engagement with Aboriginal South Australians requires relationships to be built on trust and integrity, viewed as a sustained relationship in which stakeholders work together to achieve shared goals.[36]

Stakeholders will change, and these transitions require planning and management. Efforts should be made to record and effectively transfer knowledge about the processes used to build relationships and any agreements that have been reached.[37]

101. Any engagement process with a potentially affected community needs to be designed with an understanding of and respect for the way in which that community has formed its views in the past.

South Australians' attitudes toward nuclear activities have been shaped by historical events in our lifetimes both in and outside the state. These include the British nuclear weapons testing at Maralinga in South Australia in the 1950s and 1960s, and nuclear reactor accidents at Three Mile Island in 1979, Chernobyl in 1986 and Fukushima in 2011.[38] Attitudes also have been influenced by broader cultural and political factors, the media, international influences and education.[39]

A project proponent would have to be able to demonstrate to the South Australian public and all affected or interested communities, how and why the proposed activity would be different to these significant historical events that have contributed to the formation of their attitudes. This reinforces the need for community engagement processes to be flexible and allow access to comprehensive information about a nuclear proposal, as well as to provide sufficient time to absorb and debate the proposal.

Site tours can be useful to show communities exactly what a proposed development would entail.[40] Site tours in this context should be differentiated from those used by industries or organisations as an element of public relations. Their focus must be on supporting informed consent through an opportunity to consider and relate a similar development to the particular circumstances of the interested community. Participants should include respected and trusted opinion leaders in their communities who are able to effectively report what they have seen.[41] Opinion leaders shape debates, and aid community understanding and acceptance of matters of public policy.[42] Therefore, engagement with such leaders would be central to general public and local community understanding of any proposal for a new nuclear development in South Australia.

102. Applied to the South Australian context, the impact of atomic weapons testing at Maralinga in the 1950s and 1960s remains very significant to Aboriginal people. Those tests, and subsequent actions, have left many Aboriginal people with a deep scepticism about the ability of government to ensure that any new nuclear activities would be undertaken safely.

The damage caused by the atomic tests carried out by the British Government is still felt profoundly by many Aboriginal South Australians, particularly those from communities that were directly affected. In these communities, nuclear activities in general are often associated with the detrimental effects of the events at Maralinga.[43] This sentiment was reflected in many submissions from Aboriginal individuals and groups received by the Commission.[44] In its submission, the Alinytjara Wilurara Natural Resources Management Board stated:

> *It must be remembered that the people of our region suffered significant personal, cultural and social harm as a result of the testing of nuclear weapons. The living memory of this phase of our shared history casts a long shadow over any contemporary conversation regarding the nuclear fuel cycle.*[45]

The 1985 report of the Royal Commission into British Nuclear Tests in Australia (the McClelland Royal Commission) recognised the harm that the testing caused Aboriginal people. It found that Aboriginal people in the Wallatinna area experienced radioactive fallout in the form of a mist or cloud, and that they suffered vomiting or temporary illness as a result of either radiation exposure or a 'psychogenic reaction', or both. On the evidence available, the McClelland Royal Commission could not reach conclusions on whether other illnesses suffered by Aboriginal individuals were caused by fallout from the tests.[46]

While the Nuclear Fuel Cycle Royal Commission is not tasked with examining the many far-reaching impacts of the atomic tests nor the acts of previous governments on this matter, aspects of the Maralinga legacy are relevant to the consideration of any future nuclear activity in the state. It would be important for any government and project proponent to understand the way historical events have shaped the attitudes of South Australians, particularly Aboriginal South Australians, towards nuclear activities.[47] Acknowledging the impacts of the past and enduring concerns would be fundamental to respectful communication and engagement with Aboriginal communities on nuclear issues.[48]

For a specific proposal on land in which there are Aboriginal rights and interests, it would be necessary to demonstrate to Aboriginal communities' satisfaction how the development would be different to the atomic testing and how lessons had been learned from the past.[49] A fundamental lesson, which should be applied from now, is that any new nuclear activity should not proceed unless and until the health and environmental risks are fully understood by the affected community.[50] To this end, a sustained, respectful and inclusive process for educating communities about health and environmental risks, adhering to the principles discussed at Findings 100 and 104, would be essential. Depending on the location and nature of the activity, this may need to address whether any particular risks arise for Aboriginal traditional and contemporary lifestyles.[51]

Another theme that has emerged throughout the Commission's inquiry is scepticism among some Aboriginal South Australians about the ability of government and industry to deliver on future commitments. This concern is founded on past failures.[52] For any engagement process to achieve a fair result, the government and project proponent must ensure that any discussions regarding risks and opportunities are realistic and that commitments made are kept, through, for example, binding agreements with appropriate mechanisms to address ongoing compliance and deal with disputes.[53]

103. As part of a community engagement process, there are established and sophisticated frameworks that have supported deliberation on complex issues in the past, through which Aboriginal communities in South Australia should be approached.

South Australia has 20 years' experience with the native title framework, which has been used successfully by communities and proponents to facilitate negotiation and decision-making processes about developments.[54] Structures in this framework include native title representative organisations, prescribed bodies corporate, Indigenous land use agreements and native title management committees. These structures have processes through which information is presented to and discussed and debated in Aboriginal communities.

Regional authorities are an emerging representative structure for Aboriginal nations[55] and South Australia's natural resources management boards are an additional mechanism through which Aboriginal communities could be engaged. The Alinytjara Wilurara Natural Resources Management Board, for example, has developed successful engagement programs and partnerships between development proponents and communities that have recognised, respected and enhanced the interests and values of all parties to an agreement within the native title framework.[56]

Numerous organisations represent South Australia's Aboriginal communities across a range of functions and interests. A project proponent should take care that, if an organisation has been given responsibility for making a decision in a community, it is the one that the community views as legitimate to make such a decision relevant to that particular issue. Depending on the location, an appropriate combination of mechanisms for engagement with land- and rights-holding structures may be required.

104. Principles for engagement with Aboriginal communities in many cases apply equally to the urban, regional and remote communities of which they are an integral part. In addition to principles for community engagement set out at Finding 100, the Commission recommends, based on feedback from Aboriginal communities, that the following principles apply:

a. any progress towards an activity is based on a principle of negotiation in good faith and on equal terms

It is essential that the process of engagement with Aboriginal communities empowers people to participate on equal terms in discussions about a proposal.[57] This would require appropriate resourcing of communities, including providing information, expert advice, translation services and staff to manage the learning and engagement process, as discussed at Finding 100.[58] The process would need to allow sufficient time to ensure that Aboriginal people understand the full extent of any potential impacts that may result from the proposed activity and reach informed decisions according to their own processes.[59]

b. there is a common and realistic understanding as to both the risks and opportunities of the proposed activity—it is essential that benefits are not oversold and risks are not underestimated

Aboriginal communities would need to be provided with transparent and objective information about the risks and opportunities that may arise from an activity over time.[60] This may include providing some information in graphics[61], using appropriately trained translators[62], providing funding for independent expert advisors[63], or taking community representatives on tours of similar sites.[64] The communities would also need to understand and agree to the distribution and future use of any benefits arising from the project. It should also be acknowledged that for Aboriginal communities, cultural values will underpin the balancing and weighting of risk against benefit and guide decisions on 'acceptable risk'.

c. there is early engagement with representative organisations and the local community about a proposed activity, including preparing a framework for further engagement

Taking time to establish relationships with community members and their representatives at the outset of a proposal can deliver better outcomes in the later phase of the process.[65] Early and sustained engagement with Aboriginal communities should start with developing an agreed approach to consultation, with the nature of the engagement process to be determined by the participating communities.[66] Given community willingness to recognise and respect traditional knowledge in South Australia[67], a project proponent should be open to using such local knowledge to inform facility designs and make siting decisions, as has occurred overseas.[68] A genuine recognition of cultural knowledge and an opportunity for knowledge sharing with other aspects of project planning and design have the potential to enhance overall project outcomes.

d. the proposals place particular emphasis on long-term risks and opportunities

Many community groups and individuals have expressed concerns about long-terms risks of nuclear development and their potential effect on future generations.[69] If specific nuclear facilities were to be proposed for South Australia, the long-term social, environmental, cultural and economic risks and opportunities and how they would be managed would need to be clearly addressed.[70] It would be important for the project proponent to be able to demonstrate there would be a net positive impact arising from the proposed activity.[71]

e. the communication process is practical, genuine and agreed by the community

Communication between stakeholders should be face-to-face where possible[72], conducted in accordance with a process devised by the community[73], and continuous.[74] Resources should be allocated so that stakeholders can meet face-to-face.[75] This will be understood by a community to be genuine if the proponent and other stakeholders do what they say they will do. That process is assisted if outcomes are agreed and can then be seen to be implemented.

f. realistic, and potentially longer than usual, timeframes are set for the community engagement process and decision making

Engagement and decision-making processes will need to proceed at a pace that is acceptable to the affected community so that it can receive, learn about, assess and act on information according to its own needs, values and interests.[76] Accordingly, longer timeframes may be required for free and informed decisions to be reached collectively by communities.[77] Any requirement to build additional community capacity so that it could participate in the learning and decision-making processes on equal terms would need to be factored into the timeframe.[78]

g. the community is supported to make its own decision, whether yes or no, free from the influence or pressure of the proponent or lobby groups with their own agendas

Communities participating in discussions about a proposal must be able to learn, deliberate and make decisions free from external pressure, influence, coercion, intimidation or manipulation.[79] Care should be taken to ensure that any misinformation is quickly corrected and that information provided is objective and independently verified.[80]

Aboriginal communities in particular can be vulnerable to criticism from external sources if they engage in a process to learn about a nuclear activity. This has occurred in the Northern Territory and Western Australia.[81] Communities that volunteer to partake in a process would need to be supported to cope with such criticism.[82] It would also be important that those communities and individuals who do not support a particular proposal are treated with respect.[83]

Success should not be measured in terms of a community providing consent to a particular activity or development.[84] Instead, it should be measured by a community making a free and informed decision—regardless of whether that is yes or no. Communicating this at the outset of a proposal would increase the legitimacy of the community engagement processes.[85]

LAND, HERITAGE AND RESPECTING RIGHTS

105. To the extent that any project would be proposed on land in which there are Aboriginal rights and interests, including native title rights and interests, they must be respected.

While suggesting suitable sites for any new facility is beyond the scope of the Commission's inquiry, it also must be acknowledged that the range of Aboriginal rights and interests in South Australian land is widespread and diverse. These include those recognised and protected under the *Native Title Act 1993* (Cth) and the *Aboriginal Heritage Act 1988* (SA), through mechanisms such as the right to negotiate and Indigenous land use agreements[86], as well as rights and interests in Aboriginal freehold land established under specific legislation.[87] A proponent of a nuclear development would need to understand and adhere to the frameworks that protect Aboriginal rights and interests.

While existing legal and regulatory regimes provide some protection and guidance, more than bare observance of legal requirements would be required. Early and meaningful engagement by a proponent would be fundamental to demonstrating genuine respect for rights and interest holders.[88]

106. The deep connection that Aboriginal people have with the land and their responsibility for its care must be understood and respected by any nuclear project proponent.

For many Aboriginal people, identities are defined in terms of their relationship to their lands, as the following quotation attests:

> *Native title rights and interests are integrally linked to the health of country, with rights and interests including the right to hunt, gather, camp, conduct ceremonies, teach younger generations and conduct cultural activities. These depend on a healthy environment, and without a healthy environment, cultural practices are put at risk.*[89]

As evidenced by submissions to the Commission, many Aboriginal people view nuclear activities as dangerous acts that bring harm to the land and, therefore, harm to themselves, their ancestors and their descendants.[90] This extends to a belief in the need to proactively protect land and heritage. These views reinforce the need for a project proponent to exercise great care and consideration in the way it engages with and seeks to inform a community about any proposal to avoid social harm. In demonstrating understanding of and respect for Aboriginal people's connection to the land and their desire to continue to practise their living tradition, proponents would need to engage with Aboriginal communities according to the principles outlined at Finding 100, ensuring that cultural and land rights and interests are respected and protected.

107. There are existing regulatory mechanisms for the protection and preservation of Aboriginal heritage, which would, with some qualifications, apply to any future nuclear developments in South Australia.

The Aboriginal Heritage Act establishes the key framework for protecting Aboriginal heritage in South Australia. Under this Act, it would be an offence for a proponent embarking on a new nuclear development to damage, disturb or interfere with Aboriginal sites, objects and remains.[91] Under this framework, proponents should gather as much information as possible about heritage sites by working closely with local Aboriginal groups.[92] Proponents may apply to the Minister for Aboriginal Affairs and Reconciliation for authorisation to undertake an activity that would disturb a heritage site.[93] In determining whether to authorise such an activity, the Minister is required by the Aboriginal Heritage Act to consult with interested Aboriginal organisations and individuals, and traditional owners.[94] Aboriginal heritage can also be protected through binding agreements and Aboriginal cultural heritage management plans.[95]

The exception to this framework is the Olympic Dam mine. In the event of expanded operations as a result of the *Roxby Downs (Indenture Ratification) Act 1982* (SA), the predecessor to the Aboriginal Heritage Act, the *Aboriginal Heritage Act 1979* (SA) applies with some qualification.[96] However, heritage issues are addressed under the Olympic Dam Agreement between the mine owner BHP Billiton and the Barngarla, Kokatha and Kuyani Aboriginal groups. This agreement contains a Heritage Management Protocol that places further obligations on BHP Billiton for Aboriginal heritage protection and management.[97]

Although a systematic analysis was beyond the scope of the Commission, it has heard criticisms of the heritage protection framework, particularly the consultative provisions.[98] It has also heard of both positive and negative experiences concerning respect for the views of Aboriginal communities. A consistent theme is that it is critical to the satisfaction of a community that a project proponent does not seek to aggressively pursue a minimum legal compliance approach to Aboriginal heritage management.

Additional mechanisms for protecting Aboriginal heritage exist within the native title framework. Aboriginal heritage is among the wide range of matters that can be addressed in binding Indigenous land use agreements and in agreements made under the *Mining Act 1971* (SA).[99]

In relation to exploration and mining, specific regulatory requirements including programs for environment protection and rehabilitation (PEPRs) and conditions imposed on mining licences are to ensure that the protection and management of Aboriginal heritage is addressed before the start and during operation of a mine.[100]

The Aboriginal Heritage Act has recently been amended to clarify and preserve the rights and interests of a 'Recognised Aboriginal Representative Body', which may correspond with the registered native title body corporate in respect of any area.[101] The amendments recognise that it is desirable for a project proponent to negotiate a local heritage agreement with such a representative body before seeking the Minister's authorisation. Assuming these amendments will enter into effect, a proponent should ensure that it plans and implements any project by working closely and genuinely with the relevant Aboriginal communities and in accordance with the practical guidance set out in this chapter.

108. From a practical standpoint, bearing in mind the concerns expressed in many submissions about potential risks to heritage and culture posed by developments, there are important principles that any nuclear proponent should observe.

While compliance with regulatory frameworks is essential for any proponent wanting to progress a proposal, it is equally critical that a proponent ensures that:

a. those with knowledge and responsibility for heritage in a community clearly understand the nature and extent of a proposal

b. processes are established that exhaustively identify what must be protected

c. negotiations about proposals accommodate concerns about heritage

d. what is agreed as a result of negotiation is legally binding

e. mechanisms exist to monitor ongoing compliance with agreed commitments and address disputes arising between parties.

Early engagement with a community about these protections would be essential to building the type of trusting and sustainable relationship required for any project to progress.

NOTES

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9 ibid., p. 141.

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22 Jenkins-Smith et al., *Summary of approaches*, p. 16; Derveaux, Radioactive waste management essentials.

23 Transcripts: Ellis, p. 1457; Jenkins-Smith, p. 1082, Watts, p. 1157.

24 NWMO, *Implementing adaptive phased management*; Jenkins-Smith et al., *Summary of approaches*, p. 16.

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28 Transcript: Davoren, p. 1342.

29 Submission: Maralinga Tjarutja & Yalata Community Incorporated p. 28.

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31 Submission: Alinytjara Wilurara Natural Resources Management (AWNRM) Board pp. 3, 6.

32 Jenkins-Smith et al., *Summary of approaches*, p. 6.

33 STOLA-Dessel, *Belgian low-level and short-lived waste*; ONDRAF/NIRAS, *The cAt project in Dessel*; OECD-NEA, Partnering for long-term management; OECD-NEA, *Radioactive waste repositories*.

34 Jenkins-Smith et al., *Summary of approaches*, p. 5.

35 Transcripts: Guthrie, p. 1120; Larkin, p. 1233; Agius, p. 1184. Submission: Maralinga Tjarutja & Yalata Community Incorporated pp. 29, 31.

36 Submission: Golder Associates, p. 6.

Transcripts and submissions can be found at the Nuclear Fuel Cycle Royal Commission's website:www.nuclearrc.sa.gov.au/transcripts and www.nuclearrc.sa.gov.au/submissions

37 Transcript: Guthrie, p. 1120.

38 Submission: Anggumathanha Camp Law Mob, p. 9; D Stehlik, *Understanding the formation of attitudes to nuclear power in Australia*, National Academies Forum, Melbourne, 2010, pp. 29–32.

39 Transcripts: Stehlik, pp. 1057–66; Davoren, p. 1341; Stehlik, *Understanding the formation*, pp. 32–37.

40 Transcripts: Davoren, pp. 1341–1342; Guthrie, p. 1119; G Gracie, 'Who are the Martu?', *Opportunity North Magazine*, August 2011, https://www.cameco.com/australia/kintyre/community_information/who_are_martu/; STOLA-Dessel, *Belgian low-level and short-lived waste*, p. 15.

41 Transcript: Guthrie, p. 1119.

42 Stehlik, *Understanding the formation*, p. 9.

43 Submission: Campbell Law, p. 3. G Graetz, 'Uranium mining and first peoples', p. 342; Stehlik, *Understanding the formation*, p. 30.

44 Transcript: Thomas, p. 1208. Submissions: AWNRM Board p. 5; Anggumathanha Camp Law Mob, p. 10; Anderson p. 2; Australian Nuclear Free Alliance p. 1; Yami Lester; Maralinga Tjarutja & Yalata Community Incorporated pp. 13–16, 28; Representatives of Native Title Parties p. 2; South Australian Native Title Services p. 3; West Mallee Protection pp. 5–6; Yankunytjatjara Native Title Aboriginal Corporation pp. 1–2; Young.

45 Submission: AWNRM Board, p. 1; JR McClelland, J Fitch & WJA Jonas, *The report of the Royal Commission into British nuclear tests in Australia 1985*, Australian Government Publishing Service, Canberra, 1985, p. 17.

46 McClelland et al., *Report of the Royal Commission*, p. 17.

47 Submissions: South Australian Native Title Services p. 4; AWNRM Board p. 5. Stehlik, *Understanding the formation*, pp. ii, 30.

48 Submission: Maralinga Tjarutja & Yalata Community Incorporated, p. 28.

49 McClelland et al., *Report of the Royal Commission*.

50 Submission: Maralinga Tjarutja & Yalata Community Incorporated p. 30.

51 Submissions: Maralinga Tjarutja & Yalata Community Incorporated pp. 30–32; South Australian Native Title Services pp. 2–3.

52 Submissions: South Australian Native Title Services, p. 3; Anggumathanha Camp Law Mob, pp. 2–6; Marsh p. 3.

53 Transcripts: Thomas, p. 1204; Collett, Larkin, Brown, Cane, Preece & Davoren, p. 1224.

54 Transcripts: Agius, pp. 1180–1181; Thomas, pp. 1192–1194, 1201.

55 DSD: *Aboriginal Regional Authority Policy*.

56 Transcript: Agius, pp. 1175–1176.

57 Transcripts: Agius, p. 1190; Preece, p. 1220. Submission: Maralinga Tjarutja & Yalata Community Incorporated, pp. 28–29.

58 Submission: Anggumathanha Camp Law Mob, p. 10.

59 Submissions: The University of Adelaide, p. 5; Maralinga Tjarutja & Yalata Community Incorporated, p. 29; Golder Associates, p. 6; Maralinga Tjarutja & Yalata Community Incorporated, p. 29; AWNRM Board, p. 5.

60 Submission: Maralinga Tjarutja & Yalata Community Incorporated, p. 29.

61 Transcript: Agius, p. 1174.

62 Transcript: Agius, p. 1173. Submission: Yankunytjatjara Native Title Aboriginal Corporation, p. 3.

63 Transcripts: Mallants, p. 1347; Guthrie, p. 1116; Davoren, p. 1337.

64 Transcripts: Davoren, pp. 1341–1342; Guthrie, p. 1119. STOLA-Dessel, *Belgian low-level and short-lived waste*, p. 15; Gracie, 'Who are the Martu?'.

65 Transcripts: Agius, pp. 1185–1187; Guthrie, p. 1115; Thomas, p. 1200. Submission: Golder Associates, p. 6.

66 Submission: Golder Associates, p. 6.

67 Submission: Anggumathanha Camp Law Mob, p. 5.

68 STOLA-Dessel, *Belgian low-level and short-lived waste*, p. 31.

69 Submissions: Anggumathanha Camp Law Mob; Anderson; Campbell Law; Josephite Reconciliation Circle; Kaurna; Kokatha Aboriginal Corporation; Lester; Mahomed; Marsh; Ngoppon Together; Representatives of Native Title Parties; South Australian Native Title Services; West Mallee Protection; Yankunytjatjara Native Title Aboriginal Corporation.

70 Submissions: Maralinga Tjarutja & Yalata Community Incorporated, pp. 25–27, 29; Toro Energy, pp. 18, 27.

71 Transcript: Agius, p. 1187. Submissions: AWNRM Board, p. 4; Uranium Council, p. 12.

72 Transcripts: Agius, p. 1190; Cane, p. 1223; Submission: Maralinga Tjarutja & Yalata Community Incorporated, p. 28.

73 Submission: Maralinga Tjarutja & Yalata Community Incorporated, p. 28.

74 Submissions: Maralinga Tjarutja & Yalata Community Incorporated, p. 20; Golder Associates, p. 6.

75 Transcript: Cane, p. 1223.

76 Transcipt: Thomas, p. 1198. Submissions: Maralinga Tjarutja & Yalata Community Incorporated, p. 29; Golder Associates, p. 6.

77 Submission: Maralinga Tjarutja & Yalata Community Incorporated, p. 29.

78 Transcripts: Thomas, p. 1199; Guthrie, p. 1118; Watts, p. 1164.

79 Transcript: Preece, p. 1220. Submissions: Maralinga Tjarutja & Yalata Community Incorporated, p. 29; The University of Adelaide, p. 13.

80 Transcript: Cane, pp. 1230–1231. Submission: Maralinga Tjarutja & Yalata Community Incorporated, p. 33.

81 Transcript: Davoren, p. 1340. Central Desert Native Title Services, *Media statement*, media release, Perth, 28 May 2012.

82 Submission: Maralinga Tjarutja & Yalata Community Incorporated, p. 33.

83 Submission: Marsh, pp. 4–5.

84 Pescatore & Jenkins-Smith, *Reflections on siting approaches*, p. 5.

85 ibid.

86 *Native Title Act 1993* (Cth) Part 2, Div 3.

87 *Anangu Pitjantjatjara Yankunytjatjara Land Rights Act 1981; Maralinga Tjarutja Land Rights Act 1984; Aboriginal Lands Trust Act 2013* (SA).

88 Transcripts: Agius, p. 1185–1187; Guthrie, p. 1115; Thomas, p. 1100.

89 Submission: South Australian Native Title Services, pp. 2–3.

90 Submissions: Representatives of Native Title Parties; Lester; Anggumathanha Camp Law Mob; Kokatha Aboriginal Corporation; Marsh; South Australian Native Title Services.

91 *Aboriginal Heritage Act 1988* (SA) s 23.

92 *Aboriginal Heritage Act 1988* (SA); DSD, *DSD-AAR Aboriginal heritage guideline 10: risk management*, DSD, Government of South Australia, 2015, http://www.statedevelopment.sa.gov.au/upload/aard/publications/10-risk-management.pdf.

93 *Aboriginal Heritage Act 1988* (SA) s 23.

94 ibid., s 13.

95 DSD, *Aboriginal heritage guideline 10*, pp. 3–4.

96 *Roxby Downs (Indenture Ratification) Act 1982* (SA) s 9.

97 BHP Billiton, 'Aboriginal Cultural Heritage', in *Olympic Dam Expansion: Draft environmental impact statement 2009*, BHP Billiton, Australia, 2009, p. 546, http://www.bhpbilliton.com/society/regulatory.

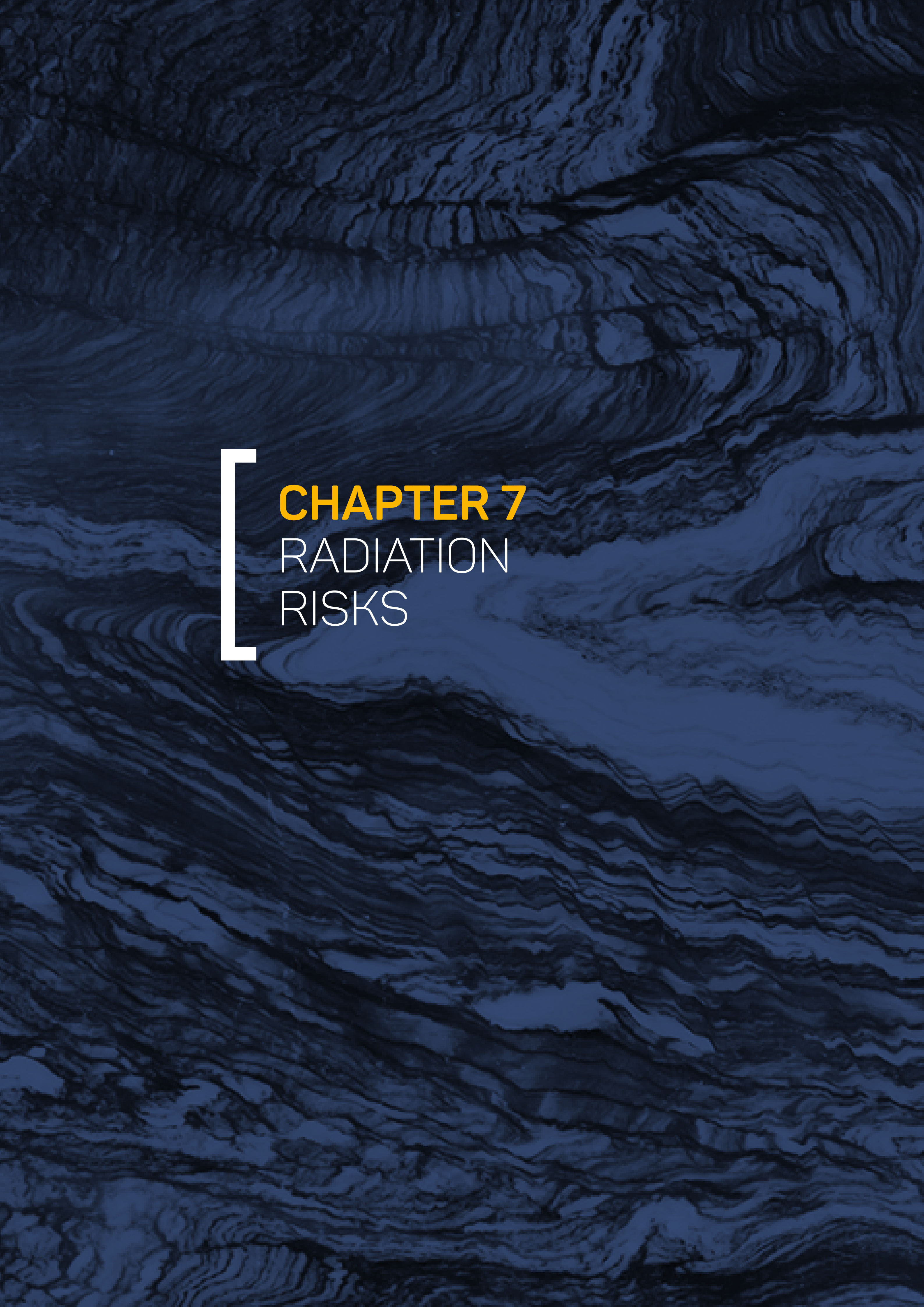
98 Submission: Department of Premier and Cabinet (DPC), *Review of the Aboriginal Heritage Act 1988: Scoping paper*, Government of South Australia, Adelaide, December 2008, p. 9.

99 Department of the Premier and Cabinet, *Review of the Aboriginal Heritage Act 1988*, p. 4; *Mining Act 1971* (SA) Part 9B; *Native Title Act 1993* (Cth) Part 2, Div 3.

100 *Mining Act 1971* (SA); DSD, *Minerals regulatory guidelines*, pp. 11–12.

101 *Aboriginal Heritage (Miscellaneous) Amendment Bill 2016* (SA).

Transcripts and submissions can be found at the Nuclear Fuel Cycle Royal Commission's website:www.nuclearrc.sa.gov.au/transcripts and www.nuclearrc.sa.gov.au/submissions



CHAPTER 7

RADIATION RISKS

CHAPTER 7: RADIATION RISKS

109. Australia's annual limits on the amount of ionising radiation (in 'doses') that can be absorbed for the public, workers and the environment are set on a precautionary basis. As people and the environment are constantly exposed to natural background radiation, the limits seek to minimise exposure to additional radiation from artificial sources.

All people are continuously exposed to ionising radiation from natural sources, or 'natural background radiation', throughout their lives.[1] Natural background radiation arises from a variety of sources, including rocks and soil (terrestrial radiation) and matter in outer space (cosmic radiation). People are exposed to the natural radiation present in their bodies, in the food they eat and in the radon gas they inhale, which comes from the ground.[2]

The level of natural background radiation that people will be exposed to depends on their location and the combination of radioactive sources present at that location.[3] On a worldwide basis, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has estimated that an individual's average annual exposure from natural background radiation is 2.4 millisieverts (mSv).[4] In Australia, the public is exposed to between 1.69 mSv and 3.79 mSv of natural background radiation per year.[5]

Figure 7.1 compares the additional doses that the public receives from artificial sources of radiation from medicine with the range of expected doses that the public in Australia and the United Kingdom receive from natural background radiation, and from nuclear facilities in the United Kingdom and Spain. In all cases, the additional doses to the public from nuclear fuel cycle facilities are many times lower than the annual regulatory limit fixed for those doses. It is also evident that doses from these facilities are much lower than natural background radiation and medical procedures.

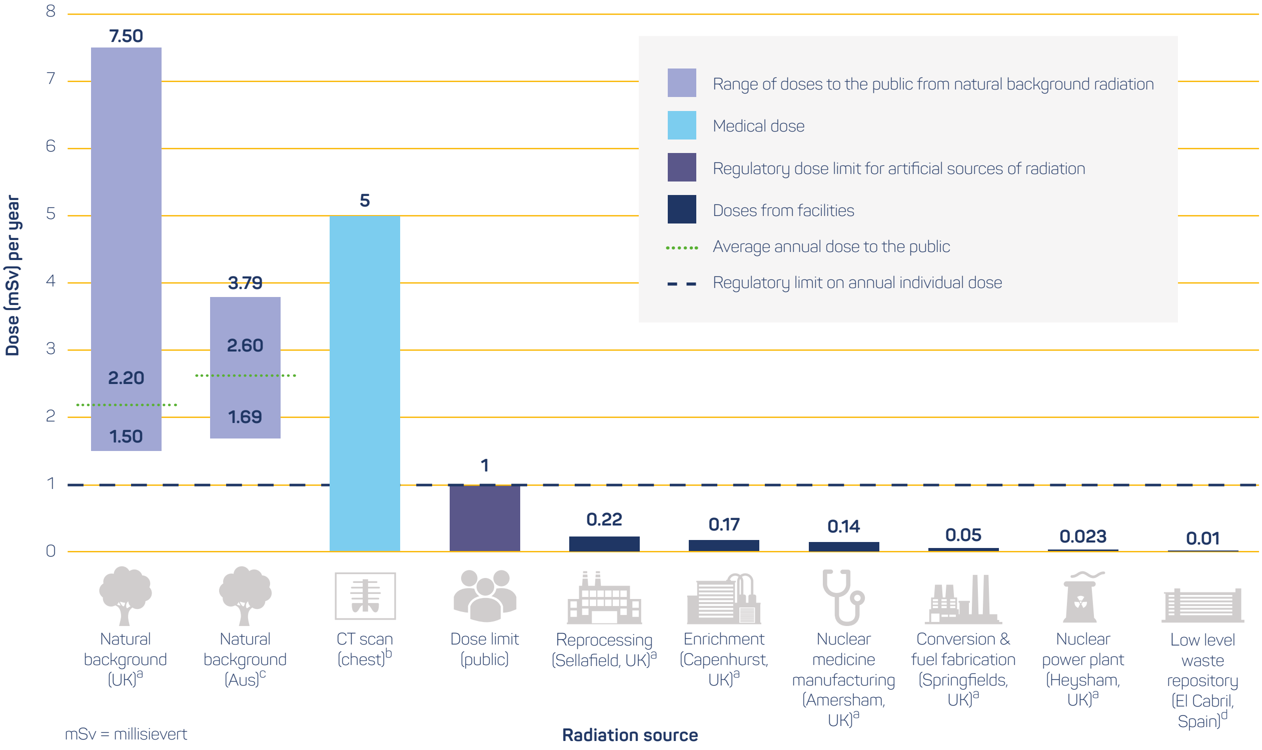


Figure 7.1: Expected radiation doses to the public from natural background radiation, medical sources and international nuclear fuel cycle facilities, and regulatory limit for doses of radiation to the public additional to natural background sources and medical procedures

a. Centre for Environment, Fisheries and Aquaculture Science (Cefas), on behalf of the Environment Agency, Food Standards Agency, Food Standards Scotland, Natural Resources Wales, Northern Ireland Environment Agency & Scottish Environment Protection Agency, *Radioactivity in food and the environment*, 2014 (RIFE – 20), Cefas, United Kingdom, October 2015, pp. 10, 12, 18–19

b. Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), *Ionising radiation and health*, fact sheet, ARPANSA, September 2015, http://www.arpansa.gov.au/RadiationProtection/Factsheets/is_ionising.cfm

c. SD Muston, 'Spatial variability of background radiation in Australia', master's dissertation, RMIT University, Melbourne, 2014, p. 38

d. E Neri (ENRESA), letter to the Nuclear Fuel Cycle Royal Commission, 21 December 2015

Radiation exposure often takes place for diagnostic or therapeutic purposes in medicine. For example, a computed tomography (CT) scan of the chest would give the recipient a radiation dose of 5 mSv, although CT scans can result in higher doses of up to about 10 mSv.[6]

In Australia, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) develops national standards for protecting the public, workers and the environment from the harmful effects of radiation based on international requirements.[7] These standards are uniformly applied in the states and territories. ARPANSA develops these standards in accordance with the principles of[8]:

- justification, which requires that the individual or society more generally receives a sufficient net benefit to offset the possible radiation harm caused by an exposure
- optimisation, which requires that all reasonable measures are taken to minimise the likelihood of exposures taking place, the number of people who are exposed and the magnitude of any exposures, including in accidents
- limitation, which requires that no individual is exposed to excessive radiation by reason of any radiation safety measures implemented to address risks to the broader community, unless the individual is receiving medical treatment.

In its application of these principles, ARPANSA sets limits on the permissible doses of radiation which the public and workers can receive from manmade sources, which are additional to natural background radiation.

For the public, the limits are significantly lower than what an average Australian might expect to receive from natural sources in any year. ARPANSA has specified that the effective dose limit for members of the public is 1 mSv a year.[9] This limit does not apply to radiation exposure in occupational or medical settings, where doses may exceed 1 mSv a year.

Although the limits are higher for workers, the principles that apply to public exposure also apply to minimise occupational exposure. For radiation workers, the limit is generally 20 mSv a year, averaged over five consecutive years, and no more than 50 mSv in any one year.[10] Radiation doses to workers are discussed in more detail later in this chapter.

In the case of the environment, operators of facilities that release radiation are required to optimise environmental radiation exposure. This involves determining an appropriate 'environmental reference level' (ERL) at which releases of radiation (above natural background radiation) would create little risk to the environment. Unlike dose limits for the public and workers, ERLs are calculated for specific projects to account for the diversity of flora and fauna present in nature.[11]

110. At very high levels of radiation exposure, adverse health impacts can be directly observed or inferred from statistical analysis; however, at low levels (in the range of ordinary exposures from natural background sources) there is ongoing scientific debate on the extent of any health risk. Despite this uncertainty, it is appropriate to apply a precautionary approach to radiation safety, even at low levels of exposure.

Over the past century, there has been extensive research into the effects of radiation on the human body. (See Appendix K: Radiation concepts, for more detailed information about the different types of ionising radiation and their biological effects on humans.)

While there is scientific consensus that human exposure to high doses of radiation will cause adverse health effects[12], there is disagreement about the health effects of radiation at low doses. It has been argued that any dose of radiation is unsafe and adverse health effects can result from natural background radiation alone[13], although no evidence was presented to the Commission that definitively supported these claims. Conversely, some studies have suggested that low doses of radiation could have positive health effects.[14]

This debate cannot be readily resolved. The health impacts of low levels of radiation are obscured as people are continuously exposed to natural background radiation and make other lifestyle choices that have adverse health effects. This makes it difficult to isolate the causes of those impacts with any certainty using current scientific methodologies.[15] Further, although it is known that radiation exposure can potentially cause cancer and other diseases, it is impossible to unequivocally attribute this to radiation or any other possible cause in an individual.[16]

Given these issues, the most conservative approach to managing radiation risks is to assume that any increase in radiation exposure will lead to a corresponding increase in risk to human health. That approach is known as the linear non-threshold (LNT) assumption and, in light of the ongoing debate, is the most prudent way to manage health risks from radiation exposure.[17] This is consistent with statements made by UNSCEAR and guidance by the International Commission on Radiological Protection.[18]

111. Any new nuclear facilities in South Australia would need to be designed and operated to ensure regulatory limits are not exceeded. The greater the radiation risk, the greater the level of engineered barriers, automation of processes and protective work practices required.

Australia's radiation safety regime adopts an approach in accordance with the LNT assumption.[19] Consequently, all facilities where radioactive substances are handled or produced must implement appropriate controls to ensure that doses of radiation are as low as reasonably achievable.[20] To that end, engineered control measures are designed and built into modern facilities before they begin operations. These measures include shielding to ensure there are low radiation areas and additional barriers to separate people from processes involving the greatest potential for radiation exposure.[21]

When planning a project to mine or mill uranium in South Australia, proponents are required to formulate a radiation management plan (RMP) and a radioactive waste management plan (RWMP), which outline the measures that would be in place to protect the public, workers and the environment from radiation during project operation and in managing wastes that are produced. Assessments must be undertaken of the potential pathways for radiation exposure, the controls that would apply to each pathway and how the effectiveness of those controls would be monitored.[22] The South Australian Environment Protection Authority (EPA) reviews and approves RMPs and RWMPs before any mining or milling operations start and, during operations, carries out quarterly inspections to ensure the plans are properly implemented.[23] It would be appropriate to undertake similar assessments in relation to any new nuclear facilities in South Australia.

112. Data from modern nuclear fuel cycle facilities demonstrates they operate well within the applicable regulatory limits for workers, the public and the environment. Doses of radiation to the local community from any new nuclear facilities in South Australia could be expected to be in the range of those estimated from the international nuclear facilities set out in Figure 7.1.

Internationally, operators and regulators of nuclear facilities undertake studies on radiation exposure to the public. For example, in the United Kingdom the various environmental and food safety regulators monitor radiation levels in food, and in land and marine environments near nuclear facilities. Radiation is released into the environment from nuclear facilities in the form of gaseous, liquid or particulate discharges. Some gamma radiation may also be released directly from the facility.[24] To assess the dose of radiation that the public might receive from a facility, regulators develop a 'representative person', who performs activities that could result in exposure to radiation from the facility, such as eating locally produced food and attending the local area for work or other purposes. These habits are determined on the basis of local survey data, with the representative person performing the activities that could cause exposure more frequently than the average person.[25] The estimated doses in Figure 7.1 relate to a representative person who carries out all the activities that have been identified as leading to radiation exposure.[26]

As Figure 7.1 indicates, the levels of radiation exposure to the public from international nuclear fuel cycle facilities are lower than what might be expected from natural background radiation. Keeping in mind the regulatory framework already in place, it is reasonable to envisage that any new nuclear facilities constructed in South Australia would be expected to give rise to doses in the range of those assessed at international facilities. Indeed, at the Open Pool Australian Lightwater (OPAL) research reactor operated by the Australian Nuclear Science and Technology Organisation (ANSTO) in New South Wales, the maximum potential dose to nearby residents from the facility's airborne emissions in 2014–15 was 0.0026 mSv, or less than 0.3 per cent of the 1 mSv annual dose limit for the public.[27]

113. The likely dose of radiation that members of the public would receive from a deep geological disposal facility has been estimated in assessments by overseas regulators. Even for the most conservative assumptions about future site conditions, radiation doses to the public are well below applicable regulatory limits.

The potential doses of radiation to the public from deep geological disposal facilities are estimated in 'safety cases' which are assessed by regulatory authorities. Estimates are made for both operations and after closure. Safety cases are discussed in more detail in Chapter 5 at Finding 69, with particular reference to long term safety.

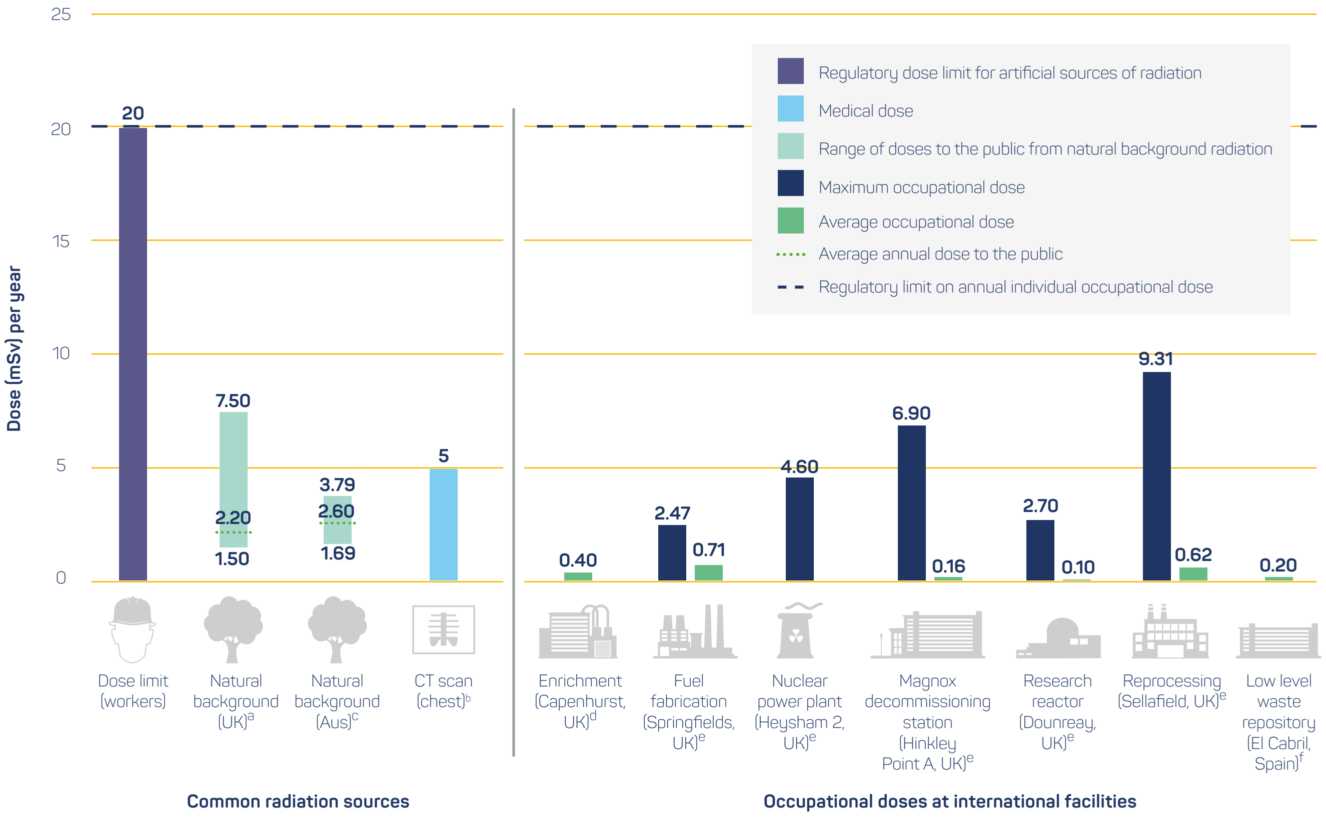
With respect to operational safety at a disposal facility, the risks are similar to those that arise when loading dry casks at reactor sites. However, at the point at which used fuel is ready for disposal, though still highly hazardous, radiation levels are significantly lower than when dry storage of the used fuel began. The principal risk in used fuel storage and disposal operations is a used fuel assembly being physically damaged during on-site handling.

Once containers of used fuel have been placed in the disposal facility, it is closed by backfilling the tunnels to place it in a passively safe state. Assessments in Finland and Sweden are based on known characteristics of the materials throughout the first 10 000 years after closure. In the reference scenario, the used fuel containers will remain integral.[28] Despite the use of high-quality welding techniques, the reference scenario for Finland has conservatively assessed the consequences of a container with a small hole being emplaced.[29] Even in that unlikely scenario, the potential annual dose to the most exposed person will be less than 0.000001 mSv, which is a tiny fraction of the annual dose from natural background radiation.[30]

For other baseline scenarios, additional assessments have been made that take into account changes in groundwater conditions, container corrosion rates and the effects of climate change.[31] For these scenarios, potential annual doses to the most exposed person are still significantly less than 0.001 mSv.[32]

As geological disposal sites have not yet been identified in Belgium and Switzerland, their safety cases are at a more preliminary stage. Nevertheless, their reference scenarios show that annual doses during the first 10 000 years after closure will be significantly less than 0.0001 mSv.[33]

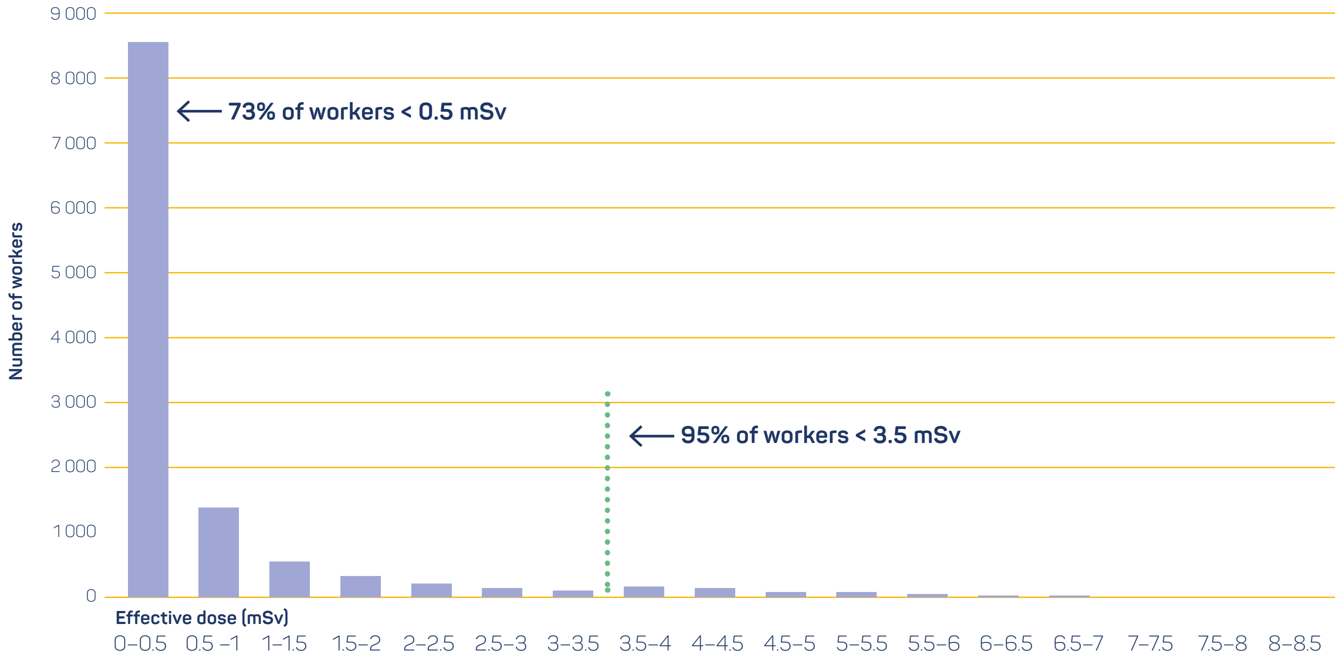
The safety cases also assess the potential doses that could arise from unlikely events, such as inadvertent intrusion after the facility's closure. Siting the facility at an appropriate depth, away from natural resources, and preserving records



mSv = millisievert

Figure 7.2: Expected radiation doses to workers from common sources, measured occupational doses at international nuclear fuel cycle facilities and regulatory occupational limit for doses of radiation additional to natural background sources

a. Cefas, *Radioactivity in food and environment*, p. 19
b. ARPANSA, *Ionising radiation and health*
c. Muston, 'Spatial variability of background radiation', p. 38
d. URENCO, *Sustainability report 2014*, URENCO Ltd, United Kingdom, 2015
e. Transcript: Fisher, p. 1789 and accompanying slides
f. E Neri (ENRESA), letter to the Nuclear Fuel Cycle Royal Commission, 21 December 2015



Effective dose (mSv)	0–0.5	0.5 –1	1–1.5	1.5–2	2–2.5	2.5–3	3–3.5	3.5–4	4–4.5	4.5–5	5–5.5	5.5–6	6–6.5	6.5–7	7–7.5	7.5–8	8–8.5
No. of workers	8 505	1 361	529	324	201	123	111	174	131	97	50	42	32	18	7	2	0

Figure 7.3: Annual dose distribution for all Australian uranium workers in 2014

Data sourced from ARPANSA, 'Analysis of ARPANSA data', *ANRDR in Review*, Issue 2, July 2015, p.5

of the site reduces the likelihood that this could occur while the used fuel presents a safety hazard.[34] The greatest potential doses from these unlikely scenarios would arise from drilling into a container of used fuel.[35] If that occurred soon after closure and parts of the fuel were brought to the surface, the driller would receive a significant radiation dose.[36] In addition, the most exposed member of the public could receive doses of a few tenths of a mSv a year, which is less than typical regulatory limits of 0.1 mSv per year for disposal facilities.[37]

Appendix I: Safety cases for geological disposal facilities provides a more detailed description of assessments of long term safety of geological disposal facilities.

114. For workers at nuclear facilities, the annual dose of radiation received varies depending on the nature of the tasks performed. The range of occupational exposures that might arise in South Australia from nuclear fuel cycle activities could be expected to be in the range of those recorded at the international nuclear facilities set out in Figure 7.2.

Given the implementation of the radiation management practices discussed earlier, exposures to workers at nuclear facilities could be expected to be in the ranges depicted in Figure 7.2. It can be seen that the average occupational dose received by workers is only a fraction of natural background radiation, and the maximum occupational dose received by any worker recently at those facilities is less than half of the annual occupational regulatory limit of 20 mSv.

At uranium mines in South Australia, radiation safety is already regulated by the EPA. It does so in accordance with ARPANSA's Radiation Protection Series, thereby maintaining national uniformity in radiation safety standards.[38] Operators of uranium mines are required to monitor the doses that workers receive to ensure that regulatory limits are not exceeded.[39]

Radiation exposure at uranium mines has not always been addressed in the way it is today. For example, at the Radium Hill mine, which operated from 1952 to 1961 in eastern South Australia, control measures for radiation safety were minimal and, at times, may even have been absent.[40] There is evidence that the lack of priority placed on radiation safety and the consequent exposure of miners to radiation led to an increased risk of developing lung cancer, although it is not known what impact smoking may have had.[41]

Modern uranium mines are required to be operated in accordance with the radiation safety principles outlined earlier, and operators need to demonstrate their ability to do this before receiving approval to proceed. Operators are required to provide information on worker radiation exposure to the Australian National Radiation Dose Register (ANRDR), which is a consolidated source of worker dose data administered by ARPANSA. A central source allows trends in occupational radiation exposure to be monitored, although the actual doses received by workers are likely to be lower than recorded as the data does not take into account the effect of protective equipment.[42] As the ANRDR data in Figure 7.3 shows, 73 per cent of workers in Australian uranium mines during 2014 received an annual dose of radiation of less than 0.5 mSv.[43] This is significantly less than the radiation doses received by miners in the past.[44]

115. The more significant radiation risks are created in the event of an uncontrolled release of nuclear or radioactive material during an accident at a nuclear power plant. The severity of those risks can vary depending on the extent of any such release. Authoritative international organisations have extensively evaluated the independent and peer-reviewed epidemiological data obtained by medical doctors and other scientists into the health effects of each accident. The credibility of these organisations and their findings is not open to doubt.

Other than the survivors of the Nagasaki and Hiroshima atomic bombs, the populations affected by the nuclear power plant accident at Chernobyl in 1986 have been the subject of the most extensive studies into radiation health effects. The most prominent is the study undertaken by the 'Chernobyl Forum', a joint study involving eight United Nations (UN) organisations and the governments of Belarus, the Russian Federation and Ukraine, which released its reports in 2006.[45] The most recent and comprehensive assessment of the available evidence, including the Chernobyl Forum reports, was published by UNSCEAR in 2011. Research into the effects of the Chernobyl accident is ongoing and society's understanding of its impacts will further improve.

The circumstances surrounding the nuclear accident at Fukushima Daiichi in 2011 are markedly different to those at Chernobyl. This difference led to very different levels of radiation release. The Fukushima accident, its causes and the measures taken in response, are discussed in more detail in Appendix F: The Fukushima Daiichi accident.

In its findings into the Fukushima accident, published in 2014, UNSCEAR estimated that the atmospheric release of the radioactive elements iodine-131 and caesium-137 (which contribute most to the radiation exposure to the public and the environment) were respectively about 10 per cent and 20 per cent of the levels released from the Chernobyl accident.[46] Further, the total dose of radiation to the Japanese public was about 10–15 per cent of the comparable dose to the European populations affected by radiation from Chernobyl.[47]

Despite its extensive studies into both accidents, UNSCEAR's standing as an authoritative source has been questioned. Claims were made in oral evidence to the Commission that the experts in UNSCEAR were not appropriately qualified and its investigations used data which was either incomplete or of poor quality, thereby excluding significant radiological impacts from its findings.[48] In addition, it was asserted that the World Health Organization (WHO) was prohibited by the International Atomic Energy Agency (IAEA) from undertaking its investigations appropriately and it did not physically examine the health effects of the Chernobyl or Fukushima accidents.[49]

UNSCEAR comprises 27 member states, including Australia, and its investigations are performed by teams of experts nominated by those states. In the case of the study into the Fukushima accident, a cohort of more than 80 scientific experts (including medical doctors) was assembled from specialists in 18 countries. They were organised into various expert groups which undertook independent investigations and reviewed data collected and provided by Japanese government agencies, UN member states, international organisations such as the Food and Agriculture Organization of the UN, and WHO, and non-governmental organisations.[50]

The WHO is the peak UN authority responsible for assessing current international health issues, including those arising in emergencies, and providing guidance about the appropriate management response. Its guidance, on topics including radiation, is developed independently of the IAEA.[51] Having led the comprehensive Chernobyl Forum studies in the past, it was directly involved in the assessment of health risks resulting from the earthquake, tsunami and nuclear power plant accident at Fukushima. After doing so over the course of two years, it produced a Health Risk Assessment in 2013 which estimated the future health impact of the accident on affected populations based on the available data at the time and using widely accepted methodologies and conservative assumptions.[52]

Both UNSCEAR and WHO draw similar conclusions from their independent investigations. Given their role, composition and the comprehensive nature of the investigations, they should be accepted.

116. The most serious consequences for human health caused by the radiation releases following the Chernobyl and Fukushima Daiichi accidents are well understood, although sometimes misreported. Given the latency of some less serious but potential consequences, ongoing health monitoring of affected areas and populations will continue. This will enhance understanding of health impacts of exposure. The detriment to mental health of persons affected by each accident and evacuation must also be acknowledged, particularly in future emergency response planning.

Despite the depth of research into the Chernobyl accident, there are very different views about the estimated health impacts asserted to be attributable to the radiation released. A paper by Yablokov, Nesterenko and Nesterenko concluded that 'the overall mortality rate for the period from April 1986 to the end of 2004 from the Chernobyl catastrophe was estimated at 985,000 additional deaths'.[53] That conclusion was reached using overly simplistic methodologies to analyse cause and effect, and without considering extraneous factors such as socioeconomic conditions and the impact of increased screening.[54] Such methodologies are known to give rise to erroneous conclusions and, given the additional difficulties in attributing health effects to low levels of radiation exposure, have been recommended against by UNSCEAR.[55] The publication, including its methodologies and conclusions, has been specifically criticised in the scientific literature.[56]

With respect to the presence of radioactive materials in the environment at Chernobyl, it has been claimed that the radioactivity in some places will increase over time.[57] Certain radioactive elements, known as 'hot particles', were released during the accident and the levels of one of those elements—americium-241—are increasing as it is a product of the decay of other radionuclides.[58] However, because these hot particles are 'heavier' than other elements, they do not travel far from the nuclear power plant site in the event of an accident.[59] Although these elements will remain radioactive in the long term, they will only be present in trace quantities.[60] Those quantities will not materially add to radiation from background sources.

UNSCEAR has identified several areas where uncertainties affect its ability to draw conclusions from the available evidence about the health effects of Chernobyl. As cancer and other stochastic effects are difficult to attribute to radiation given they have other potential causes, it is only possible to determine a probability that the effect was wholly or partly caused by radiation exposure. Each effect must be examined on its own merits and in light of other relevant factors. These limitations are even more pronounced in the populations that received low doses of radiation from the Chernobyl accident given the presence of natural background radiation.[61]

Bearing these uncertainties in mind, UNSCEAR made the following conclusions[62]:

- Of the plant staff and emergency workers who received very high doses of radiation, 134 people developed acute radiation syndrome (ARS), which caused the deaths of 28 of those people. Two other workers died in the immediate aftermath of the accident from causes unrelated to radiation exposure.
- Of the ARS survivors, a further 19 had died by 2006 (two decades later), although their deaths were not directly attributable to radiation exposure. The remaining ARS survivors experience skin injuries, cataracts and ulceration as a result of radiation exposure, the severity of which is consistent with the dose of radiation received. No other health conditions experienced by the ARS survivors have been attributable to radiation exposure.
- Among the public, who received much lower doses of radiation than the plant staff and emergency workers, there were no cases of ARS or associated fatalities. A significant increase in thyroid cancers was observed in members of the local population who were children or adolescents at the time of the accident. Doses of radiation to the thyroid were caused by the contamination of milk with radioactive iodine in the immediate days after the accident. Radiation is considered to have contributed to a large proportion of the 6848 cases of thyroid cancer reported between 1991 and 2005. Fifteen of these proved fatal.
- While those who received high doses of radioactive iodine or were exposed as children or adolescents are at increased risk of developing radiation-related conditions, it has not been possible to confirm whether any further health impacts were attributable to radiation. As the public were generally exposed to doses of radiation in the range of those from natural background sources, it is unlikely that any identifiable health impacts will be attributable to radiation released as a result of the accident.

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In its assessment of the health impacts from radiation released at Fukushima, UNSCEAR reached the following conclusions[63]:

- No plant staff, emergency worker or member of the public died or developed acute health effects (such as ARS) as a result of radiation exposure. A small proportion of workers received higher doses during the accident and in the immediate clean-up period; however, these doses are understood to be a long way below the threshold for acute effects.
- In estimating potential health risks, including solid cancers, thyroid cancer, leukaemia, breast cancer and diseases associated with prenatal exposure, UNSCEAR considered the extent to which radiation exposure would affect the natural incidence of these diseases in the exposed populations. In general, it was concluded that it would not be possible to discern an increase in these diseases from that baseline level of risk.
- There may be an increased risk of cancer, particularly of the thyroid, and hypothyroidism in more vulnerable groups, including the 173 workers who received effective doses of 100 mSv or more, and infants and children in the evacuation zone. However, any such increase would be difficult to attribute to the accident, given the understood levels of exposure.

UNSCEAR stated that its findings do not preclude the possibility that health effects attributable to radiation from the Fukushima accident might be identified in future.[64] To that end, it has implemented a process of ongoing review of new information about radiation effects from Fukushima.[65] In the first of these reviews, in 2015, UNSCEAR concluded that its findings on the health implications for workers and the public 'remain valid and are largely unaffected by new information that has been published so far'.[66]

The health of the people exposed to radiation from the Fukushima and Chernobyl accidents will continue to be monitored by local authorities and the international community over the coming decades. Given the increase in thyroid examinations in Fukushima, it is expected that thyroid abnormalities not necessarily attributable to radiation will be identified that would not have been detected otherwise.[67] Further study since UNSCEAR's report has supported this view.[68] In the case of Chernobyl, the Chernobyl Tissue Bank has been established as a central data repository to assist in understanding how radiation induces cancers.[69]

Following the accidents at Chernobyl and Fukushima, evacuations and other response measures reduced the risk that radiation presented to local populations. However, these measures in themselves gave rise to other health implications.[70] Studies have found increased levels of depression and anxiety in populations affected by the Chernobyl accident.[71] In Japan, the comprehensive Mental Health and Lifestyle Survey indicated the presence of severe traumatic problems in adults from the Fukushima evacuation zone.[72] Mental conditions are also likely to lead to negative health effects and will have significant implications for public health.[73]

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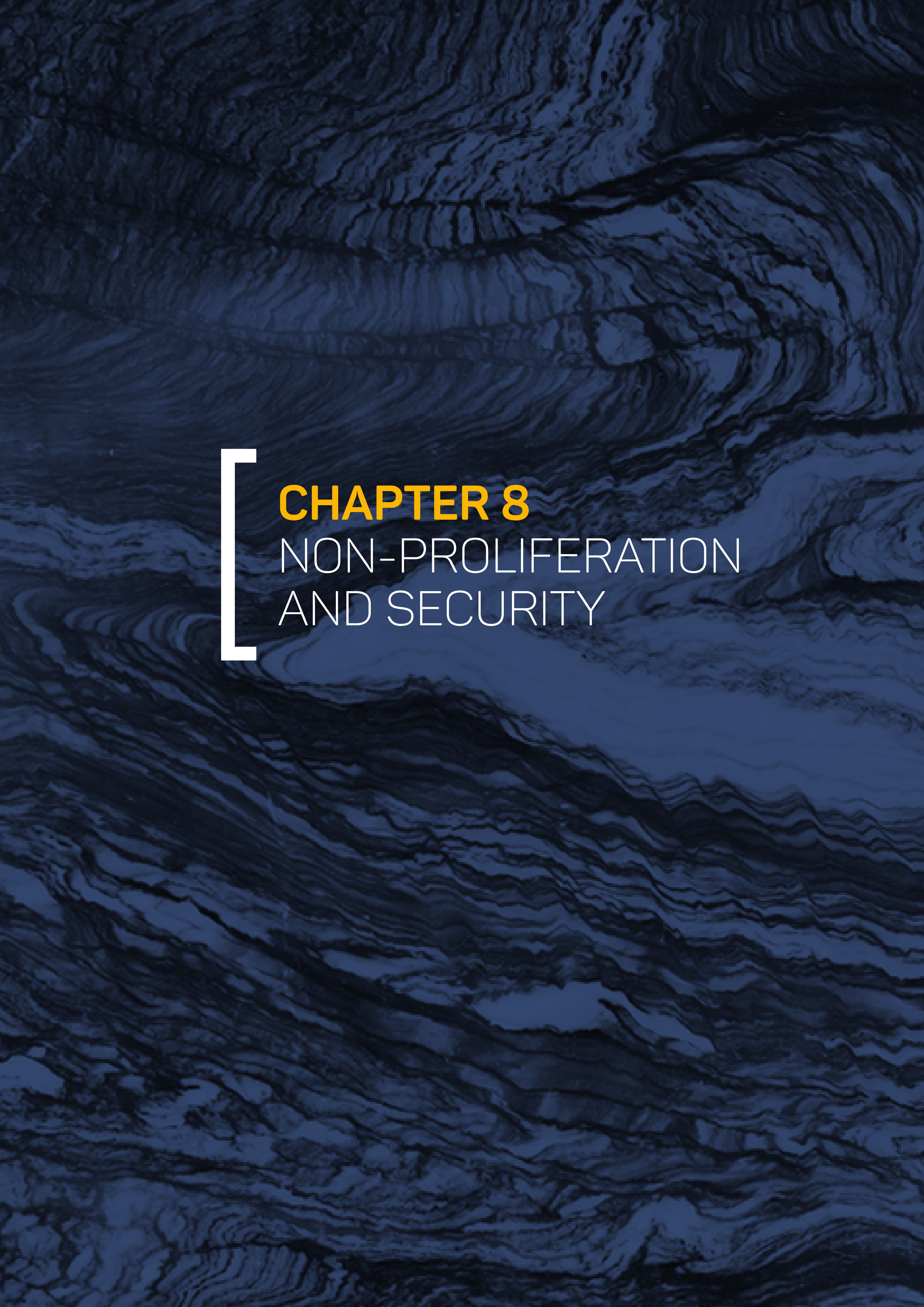

CHAPTER 8

NON-PROLIFERATION AND SECURITY

CHAPTER 8: NON-PROLIFERATION AND SECURITY

117. Australia has sound non-proliferation and nuclear security credentials developed over many decades. Maintaining that reputation would be critical in contemplating participation in new nuclear fuel cycle activities.

In considering the nuclear proliferation and security risks associated with new nuclear activities in South Australia, the focus should be on Australia's policies and international reputation in relation to these issues and the relevant geopolitical environment. Any further nuclear activities in South Australia would be subject to the current international and domestic regulatory regime that is concerned with nuclear proliferation and security. It follows that the proliferation and security risks associated with further nuclear activities must be considered in the South Australian context, rather than circumstances which apply to other countries or which existed in the past.

The Commission's attention has been drawn to Australia's more supportive attitude towards nuclear weapons in the past. It was said there is no guarantee it would not revert to this policy position given the right circumstances.[1] That argument fails to consider the significant changes since the peak of the Cold War era, primarily the establishment and adoption of the international legal regime for non-proliferation. In light of the following, the Commission does not accept that it is credible to suggest Australia has nuclear weapons ambitions.

Underpinning the non-proliferation framework is the Treaty on the Non-proliferation of Nuclear Weapons (NPT), which seeks to constrain the number of countries that possess nuclear weapons by prohibiting their development or acquisition (Article II) and mandating the implementation of measures known as safeguards to verify compliance with that prohibition (Article III). Australia has been a party to the NPT since 1970 and ratified its requirements in 1973, legally committing to the international community not to develop or acquire nuclear weapons.

Since that time, Australia has developed a strong reputation in non-proliferation because of its active involvement in strengthening the international safeguards system and by undertaking measures to facilitate global non-proliferation efforts in addition to the minimum requirements of the NPT.[2] Australia is a party to the South Pacific Nuclear Free Zone Treaty through which it relinquishes any potential decision to acquire or possess nuclear weapons (Article 3) and commits to preventing the stationing (Article 5) or testing (Article 6) of any nuclear weapon in its territory by others. It is also a member of the Nuclear Suppliers Group, a collective of countries that supply nuclear materials and technologies only in accordance with guidelines that are complementary to the NPT arrangements.[3] Australia has a longstanding history of supporting strengthened International Atomic Energy Agency (IAEA) safeguards, including through its chairing of the IAEA's Standing Advisory Group on Safeguards Implementation, facilitating field trials for new safeguards technologies and procedures, and being the first country to conclude an Additional Protocol to its safeguards agreement with the IAEA.[4]

Regarding nuclear security, Australia has demonstrated a successful approach to managing security risks at its existing nuclear fuel cycle facilities. It is involved in several international measures to promote the importance of nuclear security, including as a founding member of the Global Initiative to Combat Nuclear Terrorism, a member of numerous IAEA bodies concerned with nuclear security and a regular contributor to the IAEA Nuclear Security Fund.[5] Recently, the Nuclear Threat Initiative ranked Australia as first in the world based on the security measures in place to protect its nuclear materials and facilities.[6]

Australia's compliance with the NPT is verified through its application of IAEA safeguards to all nuclear activities.

118. Any nuclear fuel cycle facility to be built in South Australia would need to be constructed and operated in accordance with the strengthened international safeguards system, thereby assuring other countries that the facility is used solely for peaceful purposes.

In addressing international non-proliferation objectives, it is important for countries to not only act in accordance with global norms directed towards that end, but also to be seen as doing so by other nations. Concerns have been expressed that, in some circumstances, a nation's entry into or expanded involvement in the nuclear fuel cycle could create an impression in other countries that such actions might be taken for non-peaceful purposes.[7] The issue is said to arise particularly where nuclear fuel cycle activities are undertaken in the absence of any clear economic rationale, potentially creating the impression that national security considerations are driving their development.[8]

Generally, the separation between civil and military uses of nuclear technology and materials is well understood by countries.[9] However, the precise international policy implications associated with the development of new nuclear activities can differ based on the specific activity contemplated. Activities involving uranium mining, uranium conversion and fuel fabrication, power generation using nuclear fuels, and nuclear waste storage and disposal are unlikely to raise international concerns about Australia's intentions.[10]

In the context of uranium mining, different views have been expressed regarding the recently concluded bilateral agreement to export Australian uranium to India. The reservations are largely founded on India's non-membership of the NPT and Comprehensive Nuclear-Test-Ban Treaty (CTBT), and the potential for the supply of uranium to create surplus capacity in a customer's domestic stocks for use in weapons production.[11]

While these are legitimate concerns to hold, it is important for countries such as Australia to engage in diplomacy as a way of expanding the reach of global non-proliferation norms.[12] The Parliament of Australia's Joint Standing Committee on Treaties (JSCOT) recognised this issue in its appraisal of the proposed agreement with India.[13] In its response to that appraisal, the Australian Government indicated that it is already engaged in dialogue with India consistent with JSCOT's recommendations in this regard.[14]

The position would be more complex if uranium enrichment or used fuel reprocessing operations were established in Australia, especially without economic justification.[15] It might be difficult in that case to convince other countries that these capabilities were being developed exclusively for peaceful purposes, even though that would be true in Australia. There is also a risk that doing so might set an international precedent and lead others to consider doing the same for national security reasons.[16] For this reason, if enrichment or reprocessing activities were to be undertaken in the future, they should take place on a multilateral basis as discussed further in Finding 121.

If Australia were to widen its involvement in nuclear activities, it would need to be proactive in assuring other countries that it remains committed to its international and domestic non-proliferation obligations. Several means of doing so are already in train. Australia is active in supporting the development of verification infrastructure to promote the CTBT's entry into force.[17] In addition, Australia was central to establishing the Asia-Pacific Safeguards Network (APSN). Consisting primarily of regional organisations involved in nuclear safeguards, APSN seeks to promote greater quality in safeguards implementation through training and information sharing in collaboration with the IAEA.[18]

119. The potential for proliferation risks from nuclear fuel cycle activities is greatest for enrichment or reprocessing because those facilities can produce highly enriched uranium or separated plutonium capable of use in nuclear weapons.

The extent to which each nuclear fuel cycle activity gives rise to proliferation risks is closely associated with the potential production of weapons-usable material during the activity.

Nuclear weapons require either highly enriched uranium (HEU), which comprises about 90 per cent of the uranium-235 isotope, or plutonium, which, in the context of weapons, should be made up of primarily plutonium-239.[19] Enriched uranium and separated plutonium are produced using technologies for, respectively, uranium enrichment and used fuel reprocessing. Ordinarily, nuclear fuel cycle activities undertaken for the purpose of power generation do not produce HEU or plutonium with the ideal isotopic composition for use in nuclear weapons. However, uranium enrichment and used fuel reprocessing provide at least the basic capability to acquire these materials and are therefore of greatest concern to the non-proliferation regime.[20]

International bodies, national governments and industry recognise that these processing activities are most sensitive to proliferation risks, therefore the technologies' use is subject to a range of measures that seek to limit those risks. International transfers of nuclear material and technologies are performed in accordance with bilateral agreements executed between the governments of the countries involved in the transactions.[21] Australia already has bilateral arrangements with every nation to which it exports UOC. These agreements impose numerous conditions on the recipient nation, including the acceptance of IAEA safeguards on the material and establishment of administrative arrangements to account for the material to the Australian Safeguards and Non-Proliferation Office (ASNO).[22]

The Nuclear Suppliers Group has issued Guidelines which set out detailed conditions for the supply of enrichment technology, such as measures against replication of the technology and alternative arrangements to the establishment of national facilities including supplier involvement and appropriate multinational participation.[23] Consistent with this, the existing enrichment technology providers, namely URENCO and TENEX, do so on a 'black box' basis, whereby critical design information relating to the technology is withheld as a barrier to its replication.[24] Although black box arrangements are not impregnable,[25] they are an additional barrier to improper application of the technology, increasing the number of measures in place to minimise proliferation risks.[26]

Other stages of the nuclear fuel cycle can give rise to proliferation concerns, but to a far lesser degree than uranium enrichment and used fuel reprocessing. They include[27]:

- uranium mining and conversion, the products of which are unusable in a nuclear weapon without enrichment or, if already incorporated into used fuel, reprocessing
- the storage and disposal of low and intermediate level wastes, being either contaminated materials or wastes immobilised in glass, ceramic or concrete. Even if some wastes contain trace amounts of enriched uranium or separated plutonium, they are practically irrecoverable for weapons use
- the storage and disposal of high level wastes, which do not contain materials readily recoverable for use in weapons
- the storage and disposal of used fuel. Although it contains plutonium, used fuel would require the further step of reprocessing before the plutonium could be used in a weapon
- nuclear power plants. Although such plants produce plutonium in uranium fuel, that plutonium is not usable in weapons unless it is separated through reprocessing.

120. Engagement in new nuclear fuel cycle activities would require further regulation in Australia. Models of regulation addressing proliferation from other jurisdictions could be applied to an Australian context for any potential new activity.

The proliferation risks associated with the nuclear fuel cycle are managed through a combination of technical and regulatory means. Where a Comprehensive Safeguards Agreement (CSA) has been concluded with the IAEA, a country is required to accept IAEA safeguards on all nuclear material within the nation's control and used for peaceful purposes.[28]

Safeguards allow nuclear material flows to be tracked such that any diversion for non-peaceful purposes would be detected. The IAEA implements safeguards using the state-level concept: a means by which it is able to allocate safeguards efficiently by considering a country's entire nuclear fuel cycle.[29] In practice, safeguards require the nation state to provide information to the IAEA about nuclear material flows, which is subsequently audited based on the IAEA's own field observations (incorporating various surveillance, containment and process monitoring techniques) and information it receives from other sources.[30]

Claims have been made that the utility of IAEA safeguards is adversely affected by countries providing limited information.[31] However, limits placed on the information provided to the IAEA, whether resulting from commercial confidentiality or national security reasons, are unlikely to be a barrier to nuclear materials accounting. Arrangements can be devised that balance the need for effective verification with the need for maintaining the confidentiality of sensitive technological aspects.[32]

It is also said that material accounting discrepancies (known as material unaccounted for, or MUF) are commonplace.[33] The concept of MUF relates to the variation between the estimated and measured samples of nuclear materials that are being processed during a nuclear fuel cycle activity at a given time. The variance could be positive or negative and does not necessarily indicate that any nuclear material is absent.[34] Further, nuclear materials accounting is complemented by containment and surveillance measures, such as cameras, portal monitors and radiation monitors, to provide assurance that nuclear material has not been removed.[35]

A CSA (including an Additional Protocol) has been implemented in Australia for many years. The arrangements under the agreement are managed by ASNO, which monitors the production and movement of nuclear materials to, from and within all Australian states.[36] An expansion of South Australia's involvement in the nuclear fuel cycle would have implications for both the IAEA's and ASNO's roles in managing the associated proliferation risks, commensurate with the level of risk associated with the specific activity.[37] Other nation states, such as Japan, already manage proliferation risks in the context of a more comprehensive nuclear fuel cycle. Australia would be able to draw on that experience should a decision be made to proceed in that direction.[38]

121. In the event that a fuel leasing arrangement provided the basis to establish enrichment facilities, that activity should be carried out under an appropriate multilateral arrangement with partner countries.

A nation's engagement in domestic enrichment activities can cause other countries to question whether those activities are for exclusively peaceful purposes. In the absence of appropriate assurances, such a scenario is likely to have a negative impact on regional diplomatic relations.[39] If South Australia sought to establish enrichment capabilities in future, the ideal pathway would be through a multilateral approach with partner countries. The participation of other countries in those activities provides an additional level of assurance that enrichment capabilities will not be used for non-peaceful purposes.[40]

Internationally, numerous multilateral approaches have been considered in the past, particularly in the context of enrichment services.[41] There are examples of enrichment service providers currently operating through a multinational model, particularly URENCO (established through treaties between Germany, the Netherlands and the United Kingdom). The International Uranium Enrichment Centre in Angarsk, Siberia also has multilateral participation. The advantages of multilateral approaches generally include[42]:

- minimising the spread of enrichment technology to facilities in multiple countries
- making the potential for any one participating country to withdraw from the NPT more difficult, particularly if that country seeks to do so without arousing suspicion at an early stage
- reducing the potential for HEU to be produced or diverted in secret
- allowing for the efficient application of safeguards to a centralised facility by the IAEA, especially if the multilateral arrangement incorporates IAEA oversight
- reassuring the international community that the development of enrichment capabilities is for exclusively peaceful purposes.

It is argued that the future establishment of multilateral arrangements (short of incorporating all existing domestic facilities into those arrangements) is unlikely to have any positive impact on non-proliferation efforts. As evidenced by the Pakistani nuclear scientist AQ Khan's ability to steal and distribute enrichment technology from URENCO in the past, the concept can present some risks.[43]

The practical implementation of a viable multilateral arrangement would not be simple and would need to address any vulnerabilities that have been exploited in the past. For a proposal of this nature to be attractive to customer countries who would otherwise develop domestic enrichment capabilities, a reliable supply of nuclear fuel would need to be assured without discrimination.[44] However, it is also true that a multilateral arrangement manages proliferation risks much more effectively than domestic arrangements.[45]

122. Nuclear fuel cycle activities give rise to security risks, which are comparatively lower in Australia than in other parts of the world. They are already managed at nuclear fuel cycle facilities in accordance with a mature international framework.

Security at nuclear fuel cycle facilities is broadly concerned with the risks of:

- unauthorised removal of nuclear materials
- the theft of proliferation-sensitive technology
- the sabotage of facilities.

In guarding against unauthorised removal of materials, the primary consideration is the extent to which the material could be used in a nuclear explosive device. This dictates how attractive the material might be to people seeking to construct such a device. Given that Australia possesses minimal quantities of attractive material (HEU or plutonium) and has a small number of nuclear sites, the level of security risk is much lower than in many other countries.[46] The likelihood of the material being removed for radiological dispersal is also a significant consideration.

In the case of technology theft, the concern is directed towards preventing the dissemination of enrichment and reprocessing technologies.[47] For sabotage, the main issue is the radiological consequences that could result from a malicious act directed at the nuclear facility.[48]

The international community places great emphasis on addressing threats to nuclear security, having created standards for that purpose and guidance for their implementation. The Convention on the Physical Protection of Nuclear Material (and its 2005 Amendment) and the International Convention for the Suppression of Acts of Nuclear Terrorism place obligations on nations to have a regulatory structure in place that effectively deters, resists and reprimands attempts to breach security at nuclear fuel cycle facilities and during domestic and international transport of nuclear materials.

The IAEA also has developed principles for assessing the magnitude of security risks and the appropriate response measures that should be implemented.[49] Most recently, the United States held the fourth in a series of Nuclear Security Summits, which was attended by more than 50 nations that reaffirmed their commitment to further strengthen the relevant international architecture and, in doing so, maintain international cooperation.[50]

New nuclear facilities are designed, constructed and operated in a manner that supports the effective management of security risks. For example, current nuclear reactor designs, given they are at higher risk of sabotage due to their inherent driving force for radiation dispersal, are developed to be able to withstand the impact of an aircraft collision.[51] Nuclear power plant operators also have stationed on-site teams that are highly trained in counter-terrorism operations to respond to security threats.[52]

In Australia, security risks are already managed in accordance with international guidance. In consultation with ASNO, the Australian Nuclear Science and Technology Organisation has developed a security plan for its nuclear reactor at Lucas Heights, to address credible hostile scenarios formulated on the basis of advice from national intelligence agencies.[53]

Security plans rely on the concept of defence in depth, which employs multiple layers of security to protect a facility from becoming vulnerable should a single barrier be overcome. The security layers incorporate physical barriers to restrict access, technological means including area surveillance, and measures to prevent cyber attack. Security plans are tested in exercises designed to simulate realistic threats. Current Australian arrangements were peer-reviewed in 2013 by the IAEA-led International Physical Protection Advisory Service, with positive feedback provided and recommendations made as to how they might be further strengthened.[54]

123. The development of a proposal to receive used fuel would require the construction of a new secured port and railway. However, the risk of intentional interference or misuse of used fuel is greatly limited by the characteristics of the fuel and the casks in which it is stored and transported.

There are numerous facilities around the world covering all aspects of the nuclear fuel cycle where security risks are managed in accordance with international standards and guidance. Measures in place at these facilities employ the principles discussed earlier to meet security threats by employing multiple barriers. The practical security arrangements, comprising physical, technological and procedural facets, are tailored to the relative sabotage and other threat risks presented by a specific facility.

In the context of used fuel storage and disposal facilities, used fuel incorporates barriers to potential security risks, particularly its inherent radiological properties and the nature of the casks in which it is transported and stored. The difficulties in physically removing the used fuel, followed by the need for reprocessing capabilities to recover any plutonium for use in a weapon, reduce its potential attractiveness for theft.

Used fuel is highly radioactive and needs to be isolated from people and the environment to ensure that its harmful effects are contained.[55] This is achieved during transport and storage, primarily through the use of purpose-designed casks, which are handled remotely as a further means of radiation safety. Casks containing used fuel are sealed and require specialist equipment to open them.[56] During storage, used fuel is contained in large casks made of steel, concrete or a combination of both.[57] The casks are stored in an area protected by multiple physical barriers and equipped with technological means to detect unauthorised access or intrusion.[58] The analysis undertaken by Jacobs for the Commission included financial provision for security barriers, security systems to complement them and contractors to provide security services.[59]

Attempts could conceivably be made to steal a cask during transport or to sabotage a consignment of used fuel. In an extreme case, sabotage could be attempted using heavy weapons, such as armour-piercing rockets.[60]

The risk of used fuel being stolen during transport is limited by the difficulty associated with moving the casks. The transport package incorporates extensive shielding to contain radiation and its structure is reinforced to withstand a wide range of accident conditions. Each package is about four to five metres long and weighs more than 100 tonnes.[61] Consequently, their transport requires heavy vehicles and their movement from one mode of carriage to another requires specialist equipment.[62]

To plan, resource and execute a breach of security would be extremely challenging. Even if an organisation had the physical capabilities to do so, the breach would need to be planned and performed without attracting the attention and subsequent intervention of international and national security agencies. Further, should an attempt at theft or sabotage be made, a transport plan would be in place that would incorporate appropriate emergency response measures, including the assistance of state and federal law enforcement agencies and even the military. Therefore, even in the unlikely event that one of these potential threats materialised, there would be a comprehensive framework in place to respond to the threat and mitigate any consequences arising as a result.[63]

NOTES

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7 Submissions: CCSA, ACF & FoE, pp. 94–95, 101; ICANW, pp. 9, 12; MAPWA & PHAA, pp. 21–22, 46.

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29 Transcript: Floyd, pp. 1512–1513. IAEA Department of Safeguards, 'IAEA Safeguards: Serving Nuclear Non-Proliferation', IAEA, Vienna, 2015, pp. 11–13.

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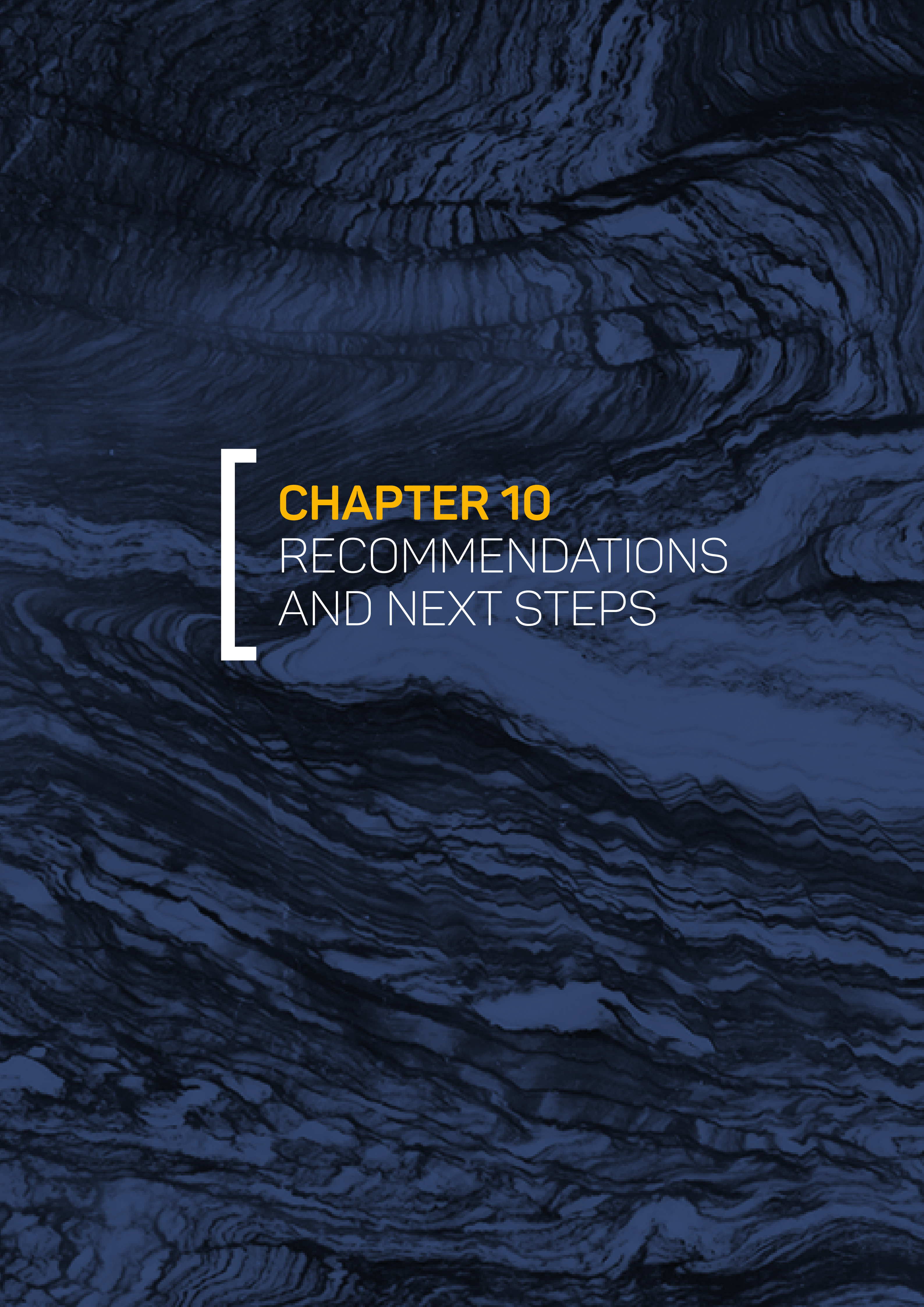
Transcripts and submissions can be found at the Nuclear Fuel Cycle Royal Commission's website:www.nuclearrc.sa.gov.au/transcripts and www.nuclearrc.sa.gov.au/submissions



CHAPTER 10

RECOMMENDATIONS AND NEXT STEPS

CHAPTER 10: RECOMMENDATIONS AND NEXT STEPS

RECOMMENDATIONS

Based on the findings set out in this report, the Commission recommends that the South Australian Government:

1. pursue the simplification of state and federal mining approval requirements for radioactive ores, to deliver a single assessment and approvals process
2. further enhance the integration and public availability of pre-competitive geophysical data in South Australia
3. undertake further geophysical surveys in priority areas, where mineral prospectivity is high and available data is limited
4. commit to increased, long-term and counter-cyclical investment in programs such as the Plan for Accelerating Exploration (PACE) to encourage and support industry investment in the exploration of greenfield locations
5. ensure the full costs of decommissioning and remediation with respect to radioactive ore mining projects are secured in advance from miners through associated guarantees
6. remove at the state level, and pursue removal of at the federal level, existing prohibitions on the licensing of further processing activities, to enable commercial development of multilateral facilities as part of nuclear fuel leasing arrangements
7. promote and actively support commercialisation strategies for the increased and more efficient use of the cyclotron at the South Australian Health and Medical Research Institute (SAHMRI)
8. pursue removal at the federal level of existing prohibitions on nuclear power generation to allow it to contribute to a low-carbon electricity system, if required
9. promote and collaborate on the development of a comprehensive national energy policy that enables all technologies, including nuclear, to contribute to a reliable, low-carbon electricity network at the lowest possible system cost
10. collaborate with the Australian Government to commission expert monitoring and reporting on the commercialisation of new nuclear reactor designs that may offer economic value for nuclear power generation
11. pursue the opportunity to establish used nuclear fuel and intermediate level waste storage and disposal facilities in South Australia consistent with the process and principles outlined in Chapter 10 of this report
12. remove the legislative constraint in section 13 of the *Nuclear Waste Storage Facility (Prohibition) Act 2000* that would preclude an orderly, detailed and thorough analysis and discussion of the opportunity to establish such facilities in South Australia.

NEXT STEPS

The findings and recommendations in this report represent the beginning of a new series of deliberations that will involve conversations, conclusions and ultimately decisions for the people of South Australia, their institutions and government.

MINING, FURTHER PROCESSING AND ELECTRICITY GENERATION

The expansion of uranium **mining** in South Australia will provide additional benefits to the state. Simplifying the existing regulatory approvals process, and enhancing the further integration and public availability of geophysical data, would help to realise those benefits.

Further processing of radioactive materials would not be viable in South Australia in the next decade. However, fuel leasing based on local used fuel storage and disposal services could create a competitive advantage sufficient to support multilateral entry into some of the global further processing markets in the longer term. Existing prohibitions on the establishment and operation of further processing facilities should be removed, to allow potential fuel leasing opportunities to be explored. This would require action from the Australian Government, which the state government should pursue.

The Commission has found that commercial **electricity generation** from nuclear fuels is not viable in South Australia under current market rules. However, it has found that nuclear energy has the potential to contribute to national emissions abatement after 2030. Given the need for significant decarbonisation of our electricity sector to meet future emissions reduction goals, the Commission has recommended the development of a comprehensive national energy policy, which enables all technologies, including nuclear, to contribute to a reliable, low-carbon electricity network at the lowest possible system cost.

MANAGEMENT, STORAGE AND DISPOSAL OF WASTE

The Commission's findings with respect to radioactive **waste storage and disposal** identify a substantial economic opportunity. If it is to be pursued, it calls for immediate action.

The Commission's key findings are that the disposal of used fuel and intermediate level waste (ILW) could be undertaken safely in a permanent geological disposal facility in South Australia. This would have the potential to deliver significant inter-generational economic benefits to the community. The key recommendation in this regard is that the South Australian Government pursue the opportunity to establish used nuclear fuel and ILW storage and disposal facilities in South Australia consistent with the processes and principles outlined in this chapter.

The Commission appreciates that this is a complex task. It has learned of many failed attempts internationally to progress domestic used fuel disposal projects. The Commission has therefore outlined the steps it considers would need to be taken, both immediately and in the future, should the state government accept its recommendations.

The most important next step would be to engage with the South Australian community to establish whether it wants the government to develop a firm proposal for the storage and disposal of used fuel and ILW. Some South Australians will already have strong opposing or supportive views, which need to be respected. However, many others would require more information before they were able to form a view. This would involve a balanced discussion and debate, based on the understood facts with respect to risks and opportunities.

In setting out the following processes and principles, the Commission recognises, based on experiences overseas, that adaptability of the process is crucial. The importance of allowing the views of the affected community to be heard, to influence and to be reflected in any process cannot be overstated. The next steps are not prescriptions, but principled guidance that the Commission considers would be required at a minimum for progress to be made.

The immediate steps are for the state government to:

1. make public the Commission's report in full as soon as possible
2. define a concept, in broad terms, for the storage and disposal of international used fuel and ILW in South Australia, on which the views of the South Australian community be sought
3. establish a dedicated agency, overseen by an advisory board, to undertake community engagement to assess whether there is social consent to proceed
4. in addition, task that agency to
    a. prepare a draft framework for the further development of the concept, including initial siting criteria
    b. seek the support and cooperation of the Australian Government
    c. determine whether and on what basis potential client nations would be willing to commit to participation.

The future steps, assuming the immediate steps lead the state government to proceed further, are for the government to:

1. pass legislation to facilitate and regulate the development of international used fuel and ILW storage and disposal facilities in South Australia
2. support the community development of a detailed project proposal, including a consent-based process for facility siting.

Each of these steps is discussed in more detail below.

APPLICATION OF THE NUCLEAR WASTE STORAGE FACILITY (PROHIBITION) ACT 2000

The *Nuclear Waste Storage Facility (Prohibition) Act 2000* contains, in section 13, a broadly worded prohibition on the expending of public money 'for the purpose of encouraging or financing any activity associated with the construction or operation of a nuclear waste storage facility' in South Australia.

Amendments recently made to section 13 introduce an exception that allows the use of public money 'for the purpose of encouraging or financing community consultation or debate on the desirability or otherwise of constructing or operating a nuclear waste storage facility' in South Australia.

That exception does not become law unless a recommendation is made by the Commission to conduct public consultation. In recommending the government pursue the opportunity to establish a disposal facility through a process of public consultation, it is anticipated that the exception will apply.

The Commission considers that the immediate steps outlined in this chapter are connected to fostering effective and informed community consultation and debate. In following the Commission's recommendations, the government may at some point be accused of acting beyond the exception. The government quite properly may want to seek further information or greater detail about matters considered by the Commission in order to satisfy itself. It may also want to seek information in anticipation of a community request. It should not have to answer a legal question on each occasion as to whether its activity is 'for the purpose of community consultation or debate' or whether it otherwise falls outside section 13.

It would be preferable for the immediate steps to be undertaken free from any debate about whether expenditure of public money is lawful, through the repeal of section 13.

The prohibitions on the construction or operation of a nuclear waste storage facility (section 8) and on the importation of nuclear waste (section 9) would remain in force while the proposed immediate steps are undertaken.

IMMEDIATE STEPS

1. Make public the Commission's report in full as soon as possible

Many people in the community will be interested in and seeking information on the Commission's findings. There is a vast array of information and misinformation available publicly on matters relevant to its Terms of Reference.

The report of the Commission is intended to make a significant contribution to this body of knowledge from a broad range of reputable and reliable sources, including the integration and analysis of evidence specific to South Australia. It is also important that it be made public in its entirety as part of a continued commitment to transparency in decision-making. Such action would be critical for maintaining respectful community engagement based on the ready exchange of information.

2. Define a concept, in broad terms, for the storage and disposal of international used fuel and ILW in South Australia, on which the views of the South Australian community be sought

Following the submission of this report, it is for the government to decide whether and what further action it would want to take.

If it determines to proceed, the government would need to be clear with the community on what is proposed for any engagement to be meaningful, focused and substantive. It would allow the community to ask and have answered, in broad terms, questions about risks and opportunities.

Defining the concept does not mean there is a need to design or site any facility. Examples of the type of facilities and arrangements to allow the activity to be properly understood would be sufficient. For example, the concept could be based on, or draw elements from, the integrated storage and disposal facility addressed in Chapter 5: Management, storage and disposal of nuclear and radioactive waste.

In releasing the concept for further investigation and discussion, the government must explain its intent in seeking social consent. It should be prepared to provide information about the concept and its plans. It can explain its views of the systems and processes that it would establish in the event it had public support. It should also be prepared to correct misinformation about any of those matters. This does not mean the government would need to commit to developing a storage and disposal facility. The point of the release of a concept is to stimulate and facilitate discussion on that concept, which in turn could be changed by the ensuing deliberations.

3. Establish a dedicated agency overseen by an advisory board to undertake community engagement to assess whether there is social consent to proceed.

As the community engagement process to assess whether such social consent exists would be complex, it would benefit from being led by an independent advisory board, supported by a dedicated, multi-disciplinary agency.

The advisory board would set the strategic direction of the activities to be undertaken. Its independence would be critical if the process and outcomes were to withstand multiple election cycles. The board should be comprised of independent, trusted South Australian community leaders who, given the long-term nature of any development, must be (and be perceived to be) balanced and non-partisan. Its members also should have experience and skill in direct engagement with South Australia's diverse community. The board would need to maintain a culture of transparency and uphold the highest order of careful, measured and ethical conduct.

It would need to be supported by a dedicated agency of experts and administrators from relevant fields of nuclear safety, public health (particularly radiation), engineering, law, environmental science, commerce and economics, and community engagement. Not all of this technical expertise would be required on a full-time basis, and the composition of the agency would need to evolve over time. It would be assisted by the transfer of research information and knowledge from the Commission on technical, social and economic matters. The continuing focus of both the board and agency would be on the public communication of complex issues.

Task and functions

The primary task of the board and agency would be to conduct the process concerned with social consent.

The issue to be considered in the process of community engagement is whether used fuel storage and disposal should be engaged in and, if so, the principles that should govern its future development. The question for consideration is not, as the Commission has sometimes heard, whether the state should instead pursue this or a different economic opportunity. On the basis outlined in this report, used fuel storage and disposal would be economically self-sustaining. It does not present a choice between mutually exclusive options. In fact, the Commission's view is that the proceeds from the activity could support investment in other economic, social and environmental areas.

Assessing social consent should not be viewed in terms of shaping ideas or influencing opinion. The significant challenge exists in establishing the facts in relation to the concept, to the extent that the community and its government are able to make an informed judgement. This challenge arises due to:

- the extent to which people have the time needed to learn about and carefully consider such matters
- the need to build trust and confidence in the provision of information
- the existence of misconceptions, fuelled by misinformation, that influence public understanding and awareness.

Taking the above into account, the dedicated agency should assess the level and sustainability of social consent to proceed by undertaking the following approach.

Task 1: Prepare and publicise a framework that defines the objectives of the assessment process, and how these are proposed to be achieved. This would ensure that the process and purpose of community engagement are understood, and remain consistent.

Task 2: Undertake public engagement by providing information, establishing facts, addressing misinformation and narrowing the scope of discussion to relevant issues. The aim is to facilitate a process of learning for all South Australians, including government, rather than conduct an exercise in advocacy and promotion. This would not prevent it from publicly countering misinformation by challenging those who make unsupported claims.

In later stages, with the facts established, it would be appropriate for representatives of government and other community interests to take more active and public positions either for or against a specific proposition.

Based on the principles discussed in Chapter 6: Social and community consent, public engagement must be:

- face-to-face as far as practicable, with tangible examples or demonstration of concepts
- socially and geographically inclusive. Specific approaches would need to be developed to ensure the engagement of regional, remote and Aboriginal communities. This should occur as early as possible
- transparent, in that each individual's and organisation's involvement or contribution from the start of the engagement process is acknowledged, recorded and, where relevant, responded to
- factual, based on information from appropriately skilled and qualified people

- adaptable. As new and pertinent information is received, it must be incorporated into the community engagement process.

Task 3: Seek feedback from South Australians as to whether, based on the information provided, they would support the government in developing a firm proposal for the storage and disposal of international used fuel and ILW in this state. This step would be likely to evolve from the later stages of Task 2.

As the public engagement process progressed, and the community's and government's understanding and awareness of the risks and opportunities improved (including by incorporation of feedback from the parallel activities contemplated below), issues and principles of importance to South Australians would emerge.

There should be no arbitrary timeframe for the conclusion of the engagement process, although it is feasible that the balance of informed public opinion could start to become clear after six to 18 months of engagement. Given the activity would represent an economic opportunity that South Australia could accept or reject, the process would not need to be unnecessarily prolonged once the balance of opinion appeared clear and likely to be sustained.

4. Further task the dedicated agency to, concurrently:

- **a. prepare a draft framework for the further development of the concept, including initial siting criteria**
- **b. seek the support and cooperation of the Australian Government**
- **c. determine whether and on what basis potential client nations would be willing to commit to participation.**

These activities, further outlined below, would in due course inform the social consent process.

In order to proceed, both the government and the public must understand the nature of the potential infrastructure proposed, the potential scope of operations, and the potential scale of risks and benefits. The government and South Australians would also want to understand how a location for any facilities may be determined, whether the federal government would support and facilitate any proposal, and what may need to occur to obtain greater certainty of commercial viability. This would require further analysis. The activities must be concurrent because their development would be mutually informed. For example, the position of client nations would be informed by the position of the Australian Government; similarly, the position of the Australian Government would likely be informed by the framework for further development and the views of potential client countries. The results of the analysis and other information associated with the three concurrent strands of activity would need to be presented to the community.

a. Prepare a draft framework for the further development of the concept, including initial siting criteria

Social consent needs to be informed by an understanding of the principles and processes that would apply to ensure the safe implementation of a proposal, including initial siting criteria.

Determining the location of any proposed facilities would be a complex and potentially lengthy process, requiring detailed social and technical analysis and community consent. It would not be possible to undertake and conclude that process before broad social consent is achieved. However, it is possible in advance to be clear about the process and principles under which that process would be undertaken.

A draft framework for the further development of the concept, including initial siting criteria, should be prepared and released for comment. It would specify the geoscientific factors that need to be considered to ensure the safety of a geological repository. The initial siting criteria would specify factors in general terms that would be relevant to identifying in a preliminary way a suitable site for a geological disposal facility.

The framework would explain how those factors would be applied as part of a future process for seeking community consent for hosting the facilities contemplated in the proposal, along with a proposed process for undertaking more detailed site investigations.

The preparation of a draft implementation framework for further public discussion needs to be clearly distinguished from a process to seek consent to construct facilities at particular sites.

Such a framework, including initial siting criteria, have been developed in other countries that are seeking to progress domestic geological disposal facilities, including Canada[1], the United Kingdom[2] and the United States.[3] Siting criteria may include a location that:

a. has sufficient land area to accommodate the facilities

b. is outside protected or sensitive environments or places

c. at the depth of the facility, does not contain known groundwater resources suitable for drinking, agriculture or industrial uses

d. does not contain economically exploitable natural resources

e. is not in areas with known seismic, geological and hydrogeological characteristics that would prevent the site from being safe, given the safety factors for a facility

This list is not intended to be exhaustive. The international approaches would provide a useful basis for developing criteria applicable to the South Australian context for consideration and discussion with the community.

b. Seek the support and cooperation of the Australian Government

The continued assistance of the Australian Government in a number of areas would be necessary to further explore the feasibility of international used fuel storage and disposal in South Australia. That assistance would be an extension of the facilitation and assistance the federal government has already provided to the Commission. It would be critical in sustaining an environment in the South Australian community where risks and benefits can be freely and fully discussed.

Given the Australian Government's international responsibilities with respect to non-proliferation, nuclear safety and nuclear security, such support would also be important to both Australian citizens and the international community. Federal assistance and support would be required to facilitate discussions between the South Australian Government and relevant nations and international organisations, including the International Atomic Energy Agency.

In addition, the public engagement process in South Australia would need to include information about the potential nature and form of regulatory arrangements for any proposed facilities. Some preliminary analysis is necessary on potential options for regulatory regime design, including consideration of safety regulation, environmental protection, transport safety and security, customs requirements, non-proliferation assurance and taxation implications. This would traverse both state and federal jurisdiction, and require active participation from and cooperation between authorities at both levels of government.

This support and commitment must be long term and sufficient to endure leadership changes and election cycles.

c. Determine whether and on what basis potential client nations would be willing to commit to participation.

A preliminary indication should be sought from potential client countries as to their interest in further discussions on their potential participation, along with identification of what they would require to be able to make a firm commitment.

The Commission has assessed the potential participation of client nations based on known and future inventories of used fuel and, in the absence of a market, on available proxies of potential willingness to pay. In the absence of either a firm proposal or social consent, the Commission could not expect countries to indicate their commitment. Nonetheless, during its visits the Commission was informed that countries would be interested in further discussions on this issue.

To provide the South Australian community with more detailed information regarding economic viability and potential benefits, it is necessary to determine with more confidence whether potential client nations would be willing to use an international used fuel storage and disposal facility in South Australia. In doing so, it would be necessary to identify what will be important to such client nations before making an initial commitment.

What is needed at this point is an expression of interest in more detailed discussion. No party can or should be asked to make a commitment at this initial stage. The development of trust and openness is critical to the ongoing relationship that must be established with potential client nations. To the greatest extent possible within diplomatic constraints, formal expressions of interest should be able to be made available to the South Australian community, to inform the public engagement process.

FUTURE STEPS

If, following the activities contemplated above, the South Australian Government determines there is sufficient social consent to proceed further, the following future steps are likely to be required.

1. Introduce legislation to facilitate and regulate the development of international used fuel and ILW storage and disposal facilities in South Australia

The ultimate authority for the activity would come in the form of the approval by the South Australian Parliament of facilitative legislation. Such legislation would need to remain in place without substantive amendment beyond electoral cycles in order to provide the necessary certainty and stability for the safe and efficient development of viable international used fuel storage and disposal facilities in this state.

A significant first step would be the establishment of an independent, government-owned statutory authority to initially develop, and potentially implement, a proposal for an international used fuel storage and disposal facility. The powers and functions, constitution, decision-making process and oversight of the authority would need to be made clear. Consideration should be given to the establishment of an expert board to oversee and provide strategic direction to the authority.

Legislation also would be required with provisions that:

- repeal existing prohibitions to the activity being undertaken, or other provisions that inhibit both a proposal being developed
- identify the principles necessary to guide the development of a proposal, which ought reflect the results of the public engagement process undertaken as part of assessing social consent
- establish initial frameworks for regulation of the development and implementation of a proposal, without addressing the detail of regulation necessary for later stages of any project. This would reflect the results of the joint Commonwealth–State cooperative analysis contemplated above
- identify the principles applicable to the protection and future use of any profits received from the operation of those facilities through, for example, a State Wealth Fund. While any profits would not be realised for many years, the establishment of guiding principles within legislation would be likely to assist in maintaining public support for the project.

2. Support the community development of a detailed project proposal, including a consent-based process for facility siting:

a. The authority should seek to identify communities with an interest in learning more about hosting a facility

b. The authority would continue to visit interested communities to provide further information

c. Interested communities should organise their desired decision-making framework

d. The authority and a community may commence negotiations

The development of a proposal would require significant and detailed geological, engineering, commercial, legal, and regulatory analysis, as with any large infrastructure project. However, based on international experience, the area of most complexity is likely to be identifying appropriate sites for the facilities and their associated infrastructure. This aspect differentiates the development of projects related to the storage and disposal of nuclear waste from other infrastructure projects, and is therefore addressed in some detail here.

Interested groups within communities must be able to seek information related to hosting a facility, without any obligation or commitment to proceed, and at an agreed pace. The authority must be suitably resourced and prepared to engage with communities at this pace, including if a community wants to proceed quickly. Given the diversity of South Australian communities and their specific circumstances, the community consent process must evolve over time for each community. Although thresholds for continued investment can be developed, the process should be undertaken without the imposition of arbitrary timeframes or fixed criteria.

An appropriate community consent process would be influenced by the outcome of the proposed immediate steps outlined previously. It is therefore inappropriate to attempt at this point to suggest a precise course of action. However, based on the findings and discussion in Chapter 6: Social and community consent, the following steps might be contemplated and modified in the particular circumstances.

a. The authority should seek to identify communities with an interest in learning more about hosting a facility

The authority should initially provide information (including through public meetings) to all South Australian regions on the siting and community consent process. In doing so, the authority may also meet with local organisations or individuals with an interest in learning more. Consideration should be given to establishing a visitor centre in a central location to allow interested members of the public to access information and ask questions.

Engagement at this early stage should focus on information associated with the process that would be undertaken to determine community consent, and key considerations for the siting of infrastructure (including generic or, if appropriate, host-rock-specific siting criteria), approaches to management of risks and principles for community benefits.

In addition to being provided with information on the community consent process, communities would be invited to consider whether they wanted to learn more about hosting a facility. There should be no criteria for accepting such an invitation: one or more individuals or organisations in a community could ask to learn more. Such a request would not be binding on any community, and would not take the form of any prescriptive registration of interest or nomination.

b. The authority would continue to visit interested communities to provide further information

The authority would commence a longer-term engagement with all those people or organisations interested in learning more about hosting a facility, taking into account the principles discussed in Chapter 6. The way in which this information would be provided could be determined in consultation with the individuals or organisations, which could involve a meeting with one or more individuals or organisations at one time. These may be requested in the context of an existing organisation's business or operations, and as such not be public meetings. This may apply similarly to individuals.

Taking this into account, all materials and information provided during this stage must also be made publicly available on a readily accessible platform (website or similar) to maintain transparency of this process.

At this time, it would be appropriate to undertake a preliminary assessment of site suitability. This would assess the location against the initial siting criteria, and therefore indicate whether it might proceed to be assessed in more detail. Such action should only be undertaken in close consultation with all local community interests engaged in the process.

c. Interested communities should organise their desired decision-making framework

In time, a community may want to start planning how it could organise itself to begin the process of considering consent, and how a proposed project might apply to their specific circumstances. A community would need to consider not only risks and opportunities associated with hosting a nuclear facility, but also how it might make decisions in relation to these. No arbitrary criteria or limitations should be placed on communities in their contemplation of how they might organise themselves to begin a process of discussing consent.

These processes are critically important, involve complex considerations, and must evolve over time. It is also possible that some communities may have trusted and functional pre-existing structures that allow these processes to proceed more quickly. While some elements can only be undertaken by that community, there is a role for the statutory authority to understand the nature and progress of such discussions. It is possible that elements of this process may require resources and other support, for example, assistance with hiring venues to host community discussions or the provision of skilled facilitators to help resolve difficult matters. The authority would be responsible for providing this support, on the basis there was some level of support in that community to take these next steps.

d. The authority and a community may commence negotiations

A community may reach a point where it is sufficiently organised and informed that it wants to commence more formal negotiations regarding the siting of infrastructure and associated matters of risk management and benefit. This would include, as a start, allowing the authority to undertake more detailed technical investigations of a particular site to better understand whether it has the geological, hydrogeological, chemical and mechanical characteristics necessary to ensure safety.

It is important that the authority does not start negotiating until communities are ready to do so. While there are varied and complex matters of risk and potential opportunities associated with a project to consider, there are equally important and complex considerations related to how a particular community is represented, how information is provided and disseminated, who from the community makes decisions, and how decisions are made.

However, neither should the process be unnecessarily prolonged. The establishment of a nuclear waste storage facility is a matter of choice for a community. To this end, it is reasonable for the authority to determine thresholds for continued investment. These thresholds should be explained to the community.

It would be an important first step for both parties (the authority and the community, through their nominated representatives) to agree on principles for the negotiation process. This would include fundamental aspects of how meetings would be conducted and outcomes recorded and disseminated, but would also consider potential options for mediation should negotiations stall, the basis on which the community representatives are authorised to negotiate and make decisions, and how the final agreement, if reached, would be recorded and enacted.

At the appropriate time, a package of benefits would need to be negotiated with a potential host community in exchange for hosting a site. From the outset it should be acknowledged that there would be a substantial package of community benefits. These negotiations must incorporate the ability for a community to influence how the project is developed, to take account of local knowledge, needs, circumstances and aspirations.

A community deciding to undertake such a negotiation would need to be suitably resourced to do so. This support could include coordination and administration, independent scientific advice to assess matters related to siting and associated project risks and management, advice related to developing an appropriate package of benefits, and assistance in disseminating information in the community. Such resourcing is potentially significant. Before providing resources, the authority would need to be satisfied that there is a suitable commitment to consider hosting a facility, and a level of genuine local community support.

It is possible that the authority might, in time, be negotiating with more than one community and be at different stages of negotiations with each as it does so. It is also possible that the negotiation process would not identify a location with appropriate geotechnical characteristics or a local community willing to host the proposed infrastructure. This must be understood and acknowledged by all parties throughout the process.

CONCLUSION

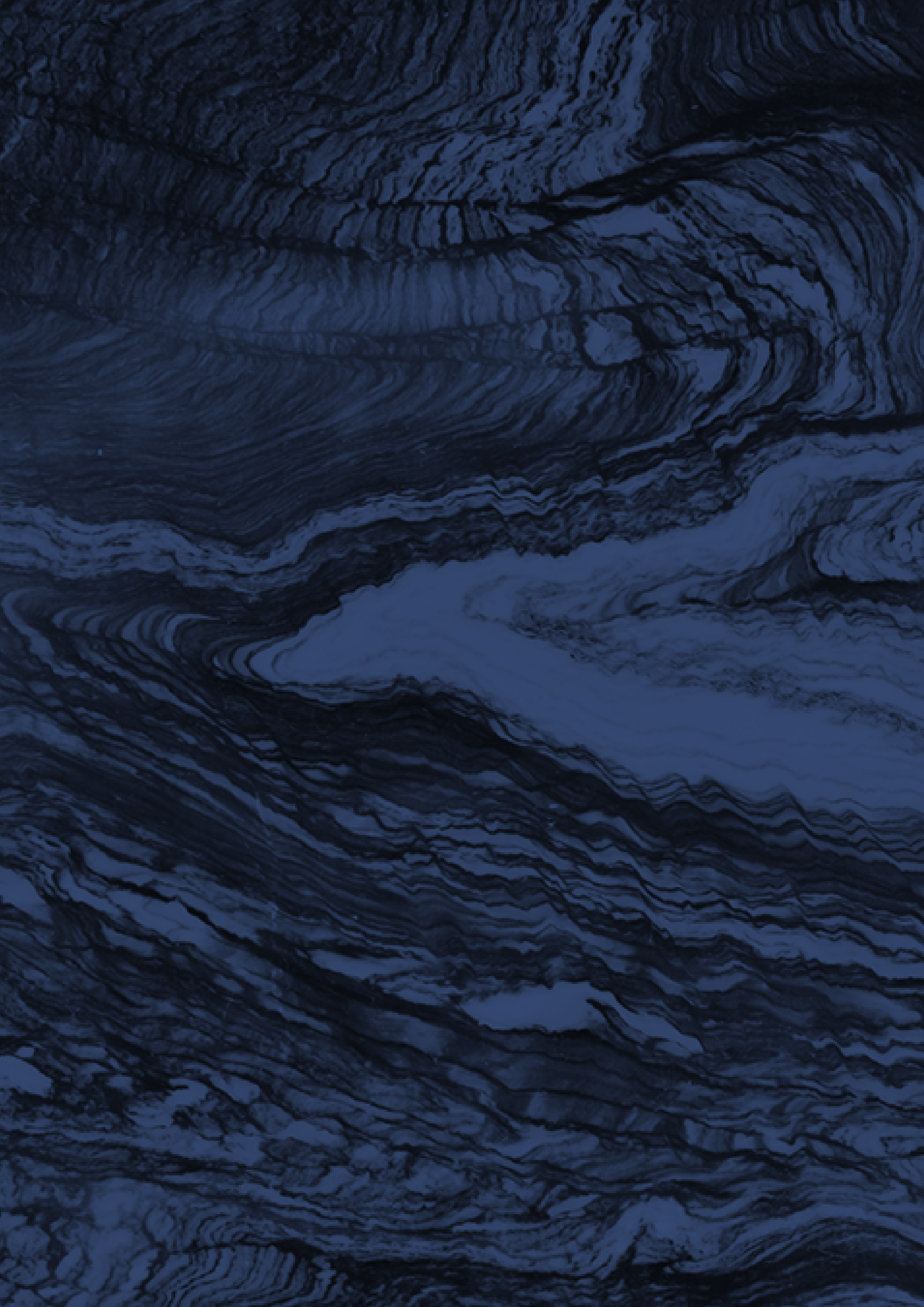
Unlike nations with domestic nuclear power industries, Australia need not find a solution for the safe, long-term management of used nuclear fuel. Australia has no immediate or future domestic requirement for used fuel storage and disposal facilities. The immediate issue facing South Australians is whether, on balance, it considers the potential opportunities to be of sufficient benefit, and the potential risks to be manageable, so as to support the further and more serious investigation of the commercial development of such a project in this state. The Commission's firm conclusion is that this opportunity should be actively pursued, and as soon as possible.

NOTES

1 National Waste Management Organization, *Moving forward together: Process for selecting a site for Canada's deep geological repository for used nuclear fuel*, NWMO, May 2010, https://www.nwmo.ca/

2 Department for Environment, Food and Rural Affairs et al. (Defra), *Managing radioactive waste safely: A framework for implementing geological disposal*, A White Paper by Defra, BERR and the devolved administrators for Wales and Northern Ireland, Defra, June 2008.

3 US Department of Energy (DoE), *General guidelines for the preliminary screening of potential sites for a nuclear waste repository*, 10 Code of Federal Regulations Part 960, 2003.



APPENDICES

APPENDIX A: TERMS OF REFERENCE

The Commission is to inquire into and report upon the following matters:

EXPLORATION, EXTRACTION AND MILLING

1. The feasibility of expanding the current level of exploration, extraction and milling of minerals containing radioactive materials in South Australia, the circumstances necessary for such an increase to occur and to be viable, the risks and opportunities created by expanding the level of exploration, extraction and milling, and the measures that might be required to facilitate and regulate that increase in activity.

FURTHER PROCESSING AND MANUFACTURE

2. The feasibility of further processing minerals, and processing and manufacturing materials containing radioactive and nuclear substances (but not for, or from, military uses), including conversion, enrichment, fabrication or re-processing in South Australia, the circumstances necessary for processing or manufacture to be viable, the risks and opportunities associated with establishing and undertaking that processing or manufacture, and the measures that might be required to facilitate and regulate the establishment and carrying out of processing or manufacture.

ELECTRICITY GENERATION

3. The feasibility of establishing and operating facilities to generate electricity from nuclear fuels in South Australia, the circumstances necessary for that to occur and to be viable, the relative advantages and disadvantages of generating electricity from nuclear fuels as opposed to other sources (including greenhouse gas emissions), the risks and opportunities associated with that activity (including its impact on renewable sources and the electricity market), and the measures that might be required to facilitate and regulate their establishment and operation.

MANAGEMENT, STORAGE AND DISPOSAL OF WASTE

4. The feasibility of establishing facilities in South Australia for the management, storage and disposal of nuclear and radioactive waste from the use of nuclear and radioactive materials in power generation, industry, research and medicine (but not from military uses), the circumstances necessary for those facilities to be established and to be viable, the risks and opportunities associated with establishing and operating those facilities, and the measures that might be required to facilitate and regulate their establishment and operation.

In inquiring into the risks and opportunities associated with the above activities, consideration should be given, as appropriate, to their future impact upon the South Australian:

a. economy (including the potential for the development of related sectors and adverse impact on other sectors);

b. environment (including considering lessons learned from past South Australian extraction, milling and processing practices); and

c. community (incorporating regional, remote and Aboriginal communities) including potential impacts on health and safety.

APPENDIX B: THE COMMISSION

INTRODUCTION

The Nuclear Fuel Cycle Royal Commission was established by the South Australian Government on 19 March 2015 to undertake an independent and comprehensive investigation into the potential for increasing South Australia's participation in the nuclear fuel cycle. It was required to report to the Governor of South Australia by 6 May 2016.

The Commission's task was to prepare a considered report to government to inform future decision making.

The Commission determined that its process would be:

- evidence-based—meaning that it was concerned with facts and identifying the basis for claims made, rather than seeking views
- open and transparent—enabling interested parties to provide evidence, watch evidence being given, consider and comment on the Commission's tentative findings, and scrutinise the basis for its findings
- independent—forming its views independent of government, industry and lobby groups.

EVIDENCE-BASED

The Commission collected evidence from four sources: written submissions, oral evidence in public sessions, its own research including overseas site visits, and commissioned studies. It carefully considered the reliability and credibility of the evidence it received, and was particularly concerned to understand the basis for many claims made in relation to the issues it considered. This report identifies the evidence the Commission considered to be the most cogent from reliable and credible sources.

Although the Commission considered all the evidence it received, it has not addressed in this report every issue raised in the evidence. Nor has it identified where it has expressly accepted or rejected evidence.

WRITTEN SUBMISSIONS ON OATH

In May 2015, the Commission released four issues papers (focused on exploration and mining, further processing, electricity generation, and storage and disposal of waste), which provided background information related to its Terms of Reference, and invited interested persons to respond to questions. People and organisations were given three months to make written submissions on oath as evidence for the Commission to consider.

The Commission received more than 250 submissions from the community, organisations, industry and government.

Anyone who contacted the Commission seeking help to comply with its process was assisted. At the outset the Commission made public that it would, by arrangement, receive submissions by other means. As a result, it took several oral submissions.

ORAL EVIDENCE IN PUBLIC SESSIONS

The Commission held a series of public sessions from September to December 2015, and in April 2016, on topics of interest to it. In those sessions it received oral evidence on oath from persons with relevant experience and expertise.

The public sessions were conducted informally, with a view to encouraging discussion with witnesses on central topics to draw out information of particular relevance. Witnesses gave evidence to the Commissioner on the basis of questions from Counsel Assisting. Most public sessions were conducted in the Commission's session room in Adelaide, and all sessions were streamed live on the Commission's website. Transcripts and videos were later made available to be downloaded from the website.

Over 37 sitting days, the Commission heard from 132 witnesses from Australia and overseas, including from Belgium, Canada, Finland, Germany, South Korea, Spain, Switzerland, the United Kingdom and the United States of America.

COMMISSION RESEARCH, INCLUDING VISITS TO FACILITIES OVERSEAS AND IN AUSTRALIA

The Commission spoke to representatives from governments, regulators, industry proponents and opponents during visits to Austria, Belgium, Canada, Finland, France, Japan, South Korea, Switzerland, Taiwan, the United Arab Emirates, the United Kingdom and the United States (see Figure B.1). A significant part of the visit to Japan was to the Fukushima district and the Fukushima Daiichi plant to witness firsthand the devastation of the 2011 tsunami and nuclear accident.

COMMISSIONED STUDIES

The Commission engaged organisations with expertise to undertake detailed assessments of the potential commercial viability of establishing nuclear facilities in South Australia to undertake further processing, to generate electricity, and to store and dispose of used fuel and nuclear waste. It also sought an analysis that considered the wider economic effects of investments made in developing those facilities.

It commissioned expert assessments in relation to fuel leasing, the risks of transporting used fuel, how safety cases are undertaken for geological disposal facilities, and skills requirements for the development of nuclear facilities.

The views expressed in these reports are the professional views of the organisations and individuals that prepared them. As such, the Commission treated these reports in the same way as evidence—and the extent to which they have been accepted and relied on is identified in the findings and the reasoning in support of those findings.

OPEN AND TRANSPARENT

The Commission conducted its process with the objective of engaging all South Australians, to encourage feedback, scrutiny and informed debate on the facts and the evidence.

Throughout the process, it published on its website the written submissions it received, information about its international visits, the oral evidence and transcripts, and its tentative findings. It provided information about its key staff and advisors, and disclosed any of their relevant interests.

The Commission held two series of metropolitan and regional information sessions around South Australia, first to inform the public about the role and scope of the Commission's inquiry and the submissions process, and subsequently to explain its tentative findings and invite responses. A wide range of community information sessions were held in metropolitan and regional areas throughout the state (see Figure B.2).

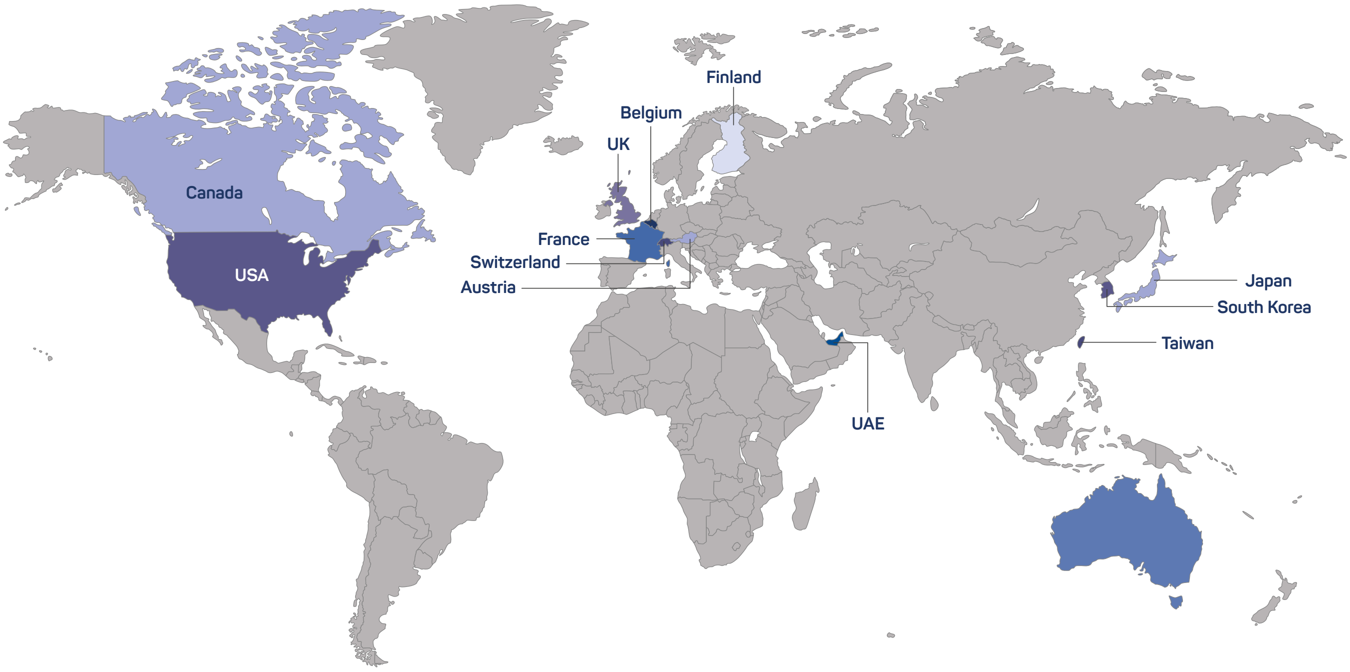


Figure B.1: Countries visited by the Commission

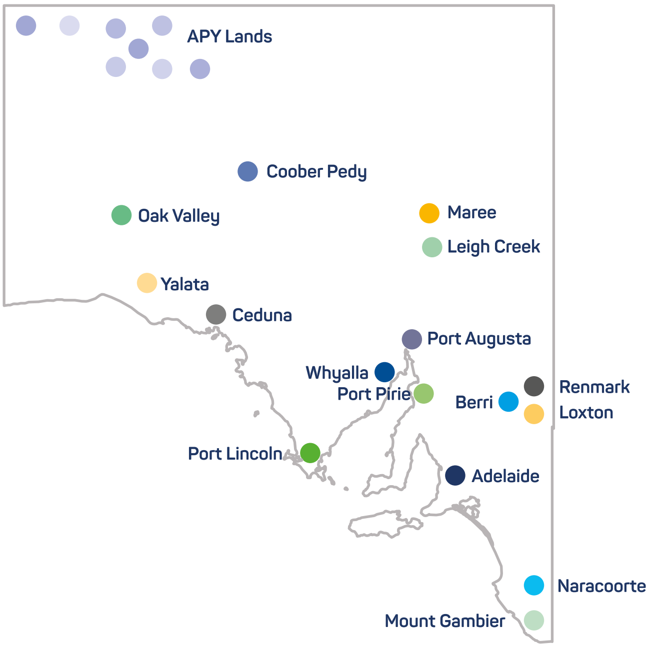


Figure B.2: South Australian locations visited by the Commission

The release of the Tentative Findings on 15 February 2016 shared with the community the Commission's preliminary thinking on issues it considered important, based on evidence. The Commission sought scrutiny by inviting public responses within five weeks. It received more than 170 direct responses. The Commission read all responses and they informed the structure and range of issues addressed in the final report.

The Commission engaged regularly with Aboriginal communities, including through public information sessions. It financially supported the convening of two meetings of the South Australian Native Title Congress (in Port Augusta and Adelaide) to discuss issues relating to the Commission. The Commission also met with the State Aboriginal Heritage Committee and other representative groups and individuals.

During its many visits to Aboriginal communities, the Commission provided an interpreter and written materials in Pitjantjatjara to assist with the communication process.

INDEPENDENT

The Commission had its own staff and engaged its own experts.

COMMISSION STAFF

The Commission had a range of technical, legal support and administrative staff led by Commissioner, Rear Admiral the Honourable Kevin Scarce AC CSC RAN (Rtd).

Chief of Staff

Greg Ward

Legal

Chad Jacobi, Counsel Assisting
Lucinda Byers, Solicitor Assisting
Bonnie Russell, Solicitor
Wesley Taylor, Solicitor

Technical

Dr Julian Kelly, Team Leader

Research Officers

Dr Massey De los Reyes
Ashok Kaniyal
Laura Rollison
Rebecca Stohr

Research Assistants

Meri Dharmarajah
Dr Geordan Graetz
David McGranaghan
Dr Christiaan Ridings
David Scroggs

Administration and communications

Jon Bok, Regional Engagement Manager
Helen O'Brien, Business and Information Manager
Lyn Pobke, Executive Assistant
Jenny Turner, Senior Communications Manager
Brittany Mara, Administration Officer
Jacque Mullen, Records Officer

Editor

Rowena Austin

ADVISORY COMMITTEES

The Commission was supported by advisory committees, which provided valuable technical advice on issues of concern to the Commission.

Expert Advisory Committee

An Expert Advisory Committee was established to advise and guide the Commission on a broad range of topics throughout its inquiry. The committee provided comment on drafts of the issues papers, the tentative findings and this report. Its members were:

- Professor Barry Brook, Chair of Environmental Sustainability, University of Tasmania
- Mr John Carlson AM, former Director-General of the Australian Safeguards and Non-proliferation Office
- Professor Ian Lowe AO, past President of the Australian Conservation Foundation and Emeritus Professor of Science, Technology and Society, Griffith University
- Dr Timothy Stone CBE, Visiting Professor at University College London
- Dr Leanna Read, South Australia's Chief Scientist and expert in biotechnology.

Socioeconomic Modelling Advisory Committee

A Socioeconomic Modelling Advisory Committee was established to advise on the development of the economic assessments and their interpretation. Its members were:

- Professor Ken Baldwin, Director of the Energy Change Institute and Deputy Director of the Research School of Physics and Engineering, Australian National University
- Professor Quentin Grafton, Chairholder of the UNESCO Chair in Water Economics and Transboundary Water Governance, Australian National University
- Professor Paul Kerin, Professor and Head of School of Economics, University of Adelaide
- Professor Sue Richardson, Matthew Flinders Distinguished Professor, Flinders University
- Professor Mike Young, Professor, Faculty of Professions, University of Adelaide.

Radiation Medical Advisory Committee

The Commission also engaged medical experts as a Radiation Medical Advisory Committee to advise on current research and knowledge on the health effects of radiation, and the interpretation of medical evidence received by the Commission. Its members were:

- Professor Roger Allison, Executive Director, Cancer Care Services, Royal Brisbane and Women's Hospital
- Professor Dorothy Keefe, Professor of Cancer Medicine, University of Adelaide; Medical Oncologist, Royal Adelaide Hospital Cancer Centre; and Clinical Ambassador, Transforming Health, SA Health
- Dr Leanna Read, South Australia's Chief Scientist and expert in biotechnology
- Professor Daniel Roos, Professor, School of Medicine, University of Adelaide; Senior Radiation Oncologist, Royal Adelaide Hospital.

ACKNOWLEDGEMENTS

Preparing a relevant, detailed and evidence-based report on a topic that may affect all South Australians, including future generations, was an important task. The Commission's staff understood its magnitude and worked with determination and integrity to meet the report deadline. The Commission acknowledges the valuable contributions of its staff and advisors to allow that to occur.

The Commission acknowledges the contributions of its consultants, contractors and the numerous individuals who provided valuable assistance to the Commission.

The Commission extends its gratitude to the many experts who generously provided their time to assist it to both gather and understand a vast amount of information on a range of complex and technical topics.

WITNESSES AT PUBLIC SESSIONS

TOPIC 1: CLIMATE CHANGE AND ENERGY POLICY

9, 14 and 23 September 2015; 23 October 2015; 2 and 10 December 2015

Professor Ross Garnaut AO
Ms Anna Skarbek
Professor John Quiggin
Mr David Swift and Ms Nicola Falcon
Associate Professor Mark Diesendorf
Professor Graham Nathan and Dr Robert Dickinson
Professor David Karoly
Professor Tom Wigley
Professor Ken Baldwin
Professor John Fletcher

TOPIC 2: THE NATIONAL ELECTRICITY MARKET

18 September 2015

Mr David Swift
Mr Rainer Korte, Mr Hugo Klingenberg and Mr Brad Harrison
Mr Craig Oakeshott
Mr Mark Vincent

TOPIC 3: GEOLOGY AND HYDROGEOLOGY OF SOUTH AUSTRALIA

22 and 23 September 2015

Professor David Giles
Professor Graham Heinson
Dr Steve Hill
Dr Andy Barnicoat and Mr Martin Wehner
Mr Neil Power and Mr Lloyd Sampson

TOPIC 4: LOW-CARBON ENERGY GENERATION OPTIONS

29 September 2015; 1, 7 and 30 October 2015; 5 November 2015

Mr Donald Hoffman
Mr Andrew Stock
Mr Richard Turner
Mr Jonathan Whalley
Mr Paul Graham
Mr Arjun Makhijani
Dr Keung Koo Kim and Dr Kyun S Zee
Ms Tania Constable and Professor Peter Cook
Mr Thomas Marcille
Dr Eric Loewen
Mr Michael McGough
Ms Rita Bowser and Mr Michael Corletti

TOPIC 5: ESTIMATING COSTS AND BENEFITS OF NUCLEAR ACTIVITIES

6 October 2015

Mr Brian Gihm
Mr David Downing and Mr Kenneth Green
Mr Tim Johnson
Mr Robert Riebolge and Mr David Lenton
Mr Craig Mickle and Dr Jyothi Gali

TOPIC 6: ENVIRONMENTAL IMPACTS: LESSONS LEARNED FROM PAST MINING AND MILLING PRACTICES IN SOUTH AUSTRALIA (CASE STUDIES: PORT PIRIE RARE EARTHS TREATMENT FACILITY AND RADIUM HILL)

8 October 2015

Mr Kevin Kakoschke OAM
Mr Greg Marshall and Mr Tony Ward
Mr Keith Baldry, Mr Graham Palmer and Dr Artem Borysenko
Dr Paul Ashley

TOPIC 7: EXPANSION OF EXPLORATION AND MINING

14 October 2015; 10 November 2015

Dr Andrea Marsland-Smith
Mr Keith Baldry, Mr Daniel Bellifemine and Ms Gabrielle Wigley
Ms Jacqui McGill
Dr Vanessa Guthrie
Dr Ted Tyne and Mr Greg Marshall

TOPIC 8: ADDING VALUE TO SOUTH AUSTRALIAN RADIOACTIVE MATERIALS

15 October 2015

Professor Frank von Hippel
Mr James Voss
Dr Michael Goldsworthy
Dr Patrick Upson

TOPIC 9: NUCLEAR REACTOR SAFETY AND REGULATION

21 October 2015

Dr Gordon Edwards
Professor Per Peterson
Mr Hefin Griffiths and Mr Mark Summerfield
Mr Peter Wilkinson

TOPIC 10: NUCLEAR ACCIDENT: FUKUSHIMA DAIICHI

22 October 2015

Dr Stephen Solomon
Mr Gustavo Caruso
Dr Mike Weightman

TOPIC 11: EFFECTS AND THREATS OF RADIATION

27 October 2015; 15 December 2015

Dr Helen Caldicott
Dr Carl-Magnus Larsson
Professor Geraldine Thomas
Mr Steve Fisher

TOPIC 12: INSURING AGAINST NUCLEAR ACCIDENT

5 November 2015

Mr Steven McIntosh
Mr Mark Popplewell

TOPIC 13: COMMUNITY ENGAGEMENT AND NUCLEAR FACILITIES – GENERAL PRINCIPLES

9 November 2015

Professor Daniela Stehlik
Professor Hank Jenkins-Smith
Ms Barbara Campany

TOPIC 13: COMMUNITY ENGAGEMENT AND NUCLEAR FACILITIES–ENGAGEMENT WITH ABORIGINAL COMMUNITIES

12 and 16 November 2015

Mr Bob Watts
Mr Parry Agius
Mr Keith Thomas
Mr Andrew Collett AM, Mr Christopher Larkin,
Mr Dennis Brown, Dr Scott Cane, Mr Richard Preece and
Mr Patrick Davoren

TOPIC 14: TRANSPORTATION OF NUCLEAR MATERIALS

17 November 2015

Dr Edwin Lyman
Mr Frank Boulton
Mr Jack Dillich and Dr Samir Sarkar
Mr Hefin Griffiths
Mr Alastair Brown

TOPIC 15: LOW AND INTERMEDIATE LEVEL WASTE STORAGE AND DISPOSAL

18 November 2015

Mr Patrick Davoren
Dr Dirk Mallants
Dr Sami Hautakangas
Mr Emilio García Neri

TOPIC 16: HIGH LEVEL WASTE STORAGE AND DISPOSAL

23, 24 and 25 November 2015; 4, 5 and 6 April 2016

Dr Thomas Cochran
Mr Timo Äikäs
Dr Sami Hautakangas
Mr Alun Ellis
Dr Mark Nutt and Ms Natalia Saraeva
Dr Charles McCombie
Dr Maarten Van Geet
Dr Felix Altorfer
Professor Rodney Ewing

TOPIC 17: SECURITY AND NON-PROLIFERATION RISKS

25 November 2015; 2 December 2015

Professor Henry Sokolski
Dr Robert Floyd
Professor the Hon Gareth Evans AC QC

TOPIC 18: FINANCING AND INVESTMENT IN NUCLEAR FACILITIES

30 November 2015; 2 and 10 December 2015

Mr Mark Higson
Mr Brendan Lyon and Mr Jonathan Kennedy
Dr Darryl Murphy
Mr David Knox

TOPIC 19: OPPORTUNITIES IN NUCLEAR MEDICINE

3 December 2015

Mr Prab Takhar and Professor Eva Bezak
Mr Marco Baccanti
Mr Shaun Jenkinson

TOPIC 20: NUCLEAR EDUCATION AND SKILLS DEVELOPMENT

3, 4 and 10 December 2015

Professor Jon Billowes and Dr John Roberts
Dr Adrian Paterson
Professor Aidan Byrne
Mr Ross Miller

TOPIC 21: REGULATORY OVERSIGHT

11 December 2015

Mr Donald Hoffman
Dr John Loy
Mr John Carlson AM

PUBLISHED SUBMISSIONS

Abbott, James

Aboriginal Congress of South Australia

Adelaide Hills Climate Action Group

Alchemides Pty Ltd

Alinytjara Wilurara Natural Resources Management Board

Askin, Henry

Association of Mining and Exploration Companies (AMEC)

Anderson, Christine

Anderson, Geraldine

Anggumathanha Camp Law Mob

Australian Nuclear Science and Technology Organisation (ANSTO)

AREVA Resources Australia Pty Ltd

Arius Association

Australian Radiation Protection Society SA

Australian Academy of Technological Sciences and Engineering (ATSE)

Australian Democrats

The Australian Government

The Australian Industry Group

The Australia Institute

Australian ITER Forum

Australian Nuclear Association

Australian Nuclear Free Alliance

Australian Workers Union

Bereznai, George

BHP Billiton

Bluegreen Power Technologies Pty Ltd

Bolton, Peter

Bowman, David

Brooks, Colin

Brown, Bobby

Brown, James

Burke, Robert

Business SA

Caldicott, Helen

Camarsh, Christopher; Carnegie, Georgina; Herring, J. Stephen and Cassidy, Maja

Campbell, Ashley

Campbell Law

Cancer Council, Australia

Catt, Claire

Cauldron Energy Ltd

Cenic, Goran

Centre for Culture Land and Sea Inc.

Centre for Energy Technology, University of Adelaide

Chalmers, Mark

Chamber of Minerals and Energy WA

City of Port Adelaide and Enfield

Clean Bight Alliance Australia

Collett, John

Conservation Council of WA

Construction, Forestry, Mining & Energy Union SA (CFMEU)

Cooper, Mark (Institute for Energy and the Environment)

Cooper, Tim

Cusack, Mary

Dickinson, Robert

Diesendorf, Mark

Dingle, Margaret

District Council of Robe

Doctors for the Environment

Drummond, Michelle

Duncan, Ian

Durbidge, Colin John

East Cliff Consulting

Eastman, Robert

Eckermann, Dayne

Economic Development Board SA

Edwards, Sean

Electrical Trades Union

Emerson, John

Energy Policy Institute of Australia

Energy Supply Association of Australia

Engineers Australia

ENuff

Environmental Defenders Office

Faulkner, Carol

Fiedler, Alexander

Fisher, Bill

Flew, Brian and May, Ivan

Fraser, Colin Malcolm

Frazer Nash Consultancy

Friends of the Earth Adelaide

Friends of the Earth Adelaide, the Australian Conservation Foundation, and the Conservation Council of SA

Friends of the Earth Australia, the Australian Conservation Foundation, and the Conservation Council of SA

Gale, Luke

Gartrell, Grant

GE Hitachi Nuclear Energy

Geiser, Tom

GeoSynthesis Pty Ltd

Giles, Mnemosyne

Gladstone Uniting Church

Glover, Graham

Golder Associates

Grano, Stephen

Gray, Terry

Grenatec

Grundy, Ken

Gun, Richard and Crouch, Philip

Harris, Paul

Heck, Ulrike

Higson, Donald

Hine, Garry

Hudson, Geoff

Hunter, Sally

Illert, Chris

International Campaign to Abolish Nuclear Weapons (ICAN), Australia

Jakobsson, Darren

Jans, Peter

Josephite SA Reconciliation Circle

JRHC Enterprises Pty Ltd

Kaurna Yerta

Keane, Rebecca

Kelly, Tim

Kenyon, Tom

Khurana, Ashok

Kokatha Aboriginal Corporation

Langley, Paul

Law Society of South Australia

Lester, Karina

Lester, Yami

Lerc, Loraine

Ludlam, Scott

Luke, Timothy (Catalyst Energy)

Mace Australia

Mahomed, Irene

Maralinga Tjarutja and Yalata Community Incorporated

Marsh, Enice

Martingale Inc.

McEwin, Kathryn

McGovern, Annie

Medical Association for Prevention of War Australia Inc. and Public Health Association Australia

Medlin, Clare

Minerals Council of Australia

Modistach, Ian

Monceaux, Dan

Murphy, Barry

Murphy, Graeme

Newlands, John

Ngarrindjeri Regional Authority Inc.

Ngoppon Together Inc

Nicholson, Martin and Archer, Oscar

Niven, Robert (School of Engineering and Information Technology, UNSW)

Noonan, David

Nuclear Operations Watch Port Adelaide (NOWPA)

Orszanski, Roman

The Outback Communities Authority

Parkinson, Alan

Pearson, Clive

Penfold-Newton, Margaret

Poetzl, Yuri

Prospect Local Environment Group (PLEG)

Prospect Residents Association

Quail, Ivan

Quiggin, John

Reid, David

Repower Port Augusta

Resource Solutions - Australia

Resources and Engineering Skills Alliance

Reynolds, John

Risk Frontiers Macquarie University

Rowbottom, Gary

Rowland, Phillipa

Russell, Geoff

Scantech

Scott, Andrew

Skinner, Vivienne

South Australian Native Title Service (SANTS)

Suthern, Kerryn

Siemag

Silex Systems Ltd

Smart, Roger

SMR Nuclear Technology Pty Ltd

South Australian Chamber of Mines and Energy (SACOME)

Starcore Nuclear

Steele Environment Solutions

Stewart, James

Studsvik

Sykes, Pamela

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APPENDIX C: FURTHER PROCESSING METHODS

The uranium oxide (U_3O_8) produced through mining and milling operations must undergo a series of additional processing steps in order to be transformed into a fuel that will generate electricity in a nuclear power plant. The required processes are conversion, enrichment and fuel fabrication.[1] Additionally, used nuclear fuel can be reprocessed to provide new fuel.

URANIUM CONVERSION

The conversion process refines the U_3O_8 and chemically converts it into uranium hexafluoride (UF_6) which readily changes from a solid form to a gas, which is necessary for the enrichment process.[2]

There are two well-established chemical methods for conversion, known as the 'wet' and 'dry' processes. The primary difference between the two techniques is in the way impurities, such as molybdenum and vanadium, are removed. In the wet conversion process they are removed in the second stage using a liquid solvent, and only very pure intermediate products are processed through to the later stages. The dry process does not use liquid solvents but instead removes impurities in the final fluorination stage. Both methods use fluidised bed reactors, employed extensively in chemical process industries, to carry out the chemical reactions that transform U_3O_8 into UF_6.

The final product is pure UF_6, which is transferred into specialised cylinders suitable for storage and transport to an enrichment plant.

WET CONVERSION PROCESS

The key feature of the wet conversion route is that U_3O_8 is pretreated using acid digestion and solvent extraction steps to remove impurity metals and other elements. This yields pure uranium trioxide (UO_3) which is then reacted with hydrogen fluoride (HF) to produce uranium tetrafluoride (UF_4). The final step involves reacting UF_4 with fluorine gas (F_2) in a separate vessel to give UF_6 which is liquefied before transfer into cylinders.[3]

For the production of heavy water reactor fuel, UO_3 is reacted with hydrogen gas (H_2) to produce UO_2 which is suitable for the fabrication of ceramic fuel pellets.

DRY FLUORIDE VOLATILITY PROCESS

In the dry conversion process, U_3O_8 is first heated in H_2 gas to produce UO_2. This compound is physically ground into a uniform size, such that it can be fed into a fluidised bed reactor and reacted with HF to produce UF_4. This compound is fluorinated with F_2 to give UF_6 which is further purified using a distillation process that removes impurities.[4]

ENRICHMENT

In order to be used as a fuel in light water reactors, uranium needs to be enriched in the ^{235}U isotope to between 3 per cent and 5 per cent from its natural abundance of 0.71 per cent. The process of uranium enrichment adjusts the ratio of the three natural uranium isotopes (^{234}U, ^{235}U and ^{238}U) to produce one with an increased proportion of ^{235}U. The remaining portion (commonly called the 'tails') is depleted in ^{235}U and is less radioactive. Uranium enrichment effort is measured and supplied in 'separative work' units. Separative work can be described as the amount of enrichment effort required to increase the concentration of ^{235}U in a set amount of uranium, to a given, higher ^{235}U concentration.[5]

CENTRIFUGES

Commercial enrichment is undertaken using large numbers of interconnected gas centrifuges: highly engineered, fast-rotating cylinders in which the UF_6 is subjected to a large centrifugal force. Heavier ^{238}U molecules move closer to the outer wall of the centrifuge than the lighter ^{235}U molecules. To achieve a high separation factor at each stage, modern centrifuges must rotate at speeds beyond that of sound, and therefore operate in a vacuum. The centrifuge process is difficult to master, since the high rate of rotation requires that the centrifuge be very strong and perfectly balanced, and capable of operating in such a state for many years without maintenance.

The stream that is slightly enriched in ^{235}U is then fed into successively higher stages of centrifuge to progressively enrich the ^{235}U. It requires tens of thousands of centrifuge stages to enrich commercial quantities of uranium. The other stream (the 'tails') is depleted uranium and is recycled back into the next lower stage of centrifuges.

LASER ENRICHMENT

Laser enrichment is based on molecular laser separation technology and has shown some promise as a possible commercial uranium enrichment technique. The process uses infrared lasers to selectively excite and ionise ^{235}U atoms in a stream of UF_6 giving high single-stage separation factors.[6] It is currently under development and has not yet been proven commercially, with one company recently discontinuing its efforts.[7]

FUEL FABRICATION

The final process step before uranium can be used as a fuel is fabrication into pellets within fuel 'bundles', either as enriched or natural fuel. Typically this is achieved in two key steps:

- UF_6 gas is chemically converted into a solid uranium dioxide (UO_2) powder
- UO_2 powder is fabricated into pellets which are then assembled into fuel bundles.

The UO_2 powder is pressed, compacted and sintered into dense ceramic pellets which are machined to the exact dimensions required. The pellets are typically loaded into zirconium tubes, which are assembled into the required fuel geometry. Light water reactors use fuel assemblies that are more than 3.5 m long. Heavy water reactors use short 50 cm bundles.

Nuclear fuel assemblies are specifically designed for particular types of reactors and are made to exacting standards. Many thousands of pellets have to go through rigorous quality assurance before being loaded into zirconium tubes. The product quality of the fuel assembly is a key factor for any power plant operation to assure safety and reliability. Fuel manufactured to the appropriate safety and design standards will support the reactor defence-in-depth approach.[8]

USED FUEL REPROCESSING

Used nuclear fuel can be reprocessed to recover fissile and fertile material in order to provide new fuel for existing and future nuclear power plants.

Only recycled uranium and plutonium can be reused in light water reactors as fresh fuel. Fast reactors can use recycled actinide components including uranium, plutonium, neptunium and americium as well as depleted uranium from the enrichment process. The fertile ^{238}U can be transformed into ^{239}Pu which can be burned in a fast reactor.

The reprocessing of used nuclear fuel is difficult. Full remote-handling operations are required, in 'hot cells'—heavily shielded rooms with thick concrete walls and thick lead-glass windows to protect operators. Hot cells have complex manipulator arms that are controlled by operators outside the cell.[9]

AQUEOUS REPROCESSING

Commercial used nuclear fuel reprocessing plants use the proven aqueous PUREX (Plutonium URanium EXtraction) process.[10] Used fuel is chopped into pieces and treated with strong acid. Most of the fuel dissolves and the liquid stream is subjected to multiple solvent extraction and ion exchange stages to partition groups of elements: uranium, plutonium, fission products and 'minor actinides'.

The products from fuel reprocessing can be fabricated into a fuel known as mixed oxide (MOX) fuel in a specialist fabrication facility. MOX fuel is manufactured from plutonium recovered from used reactor fuel, which is mixed with depleted uranium from the uranium enrichment process, at about 7 per cent to 10 per cent plutonium. This mixture is equivalent to approximately 4.5 per cent enriched uranium oxide fuel.[11]

PYROPROCESSING

Used nuclear fuel can also be treated with high temperature 'pyroprocessing' methods to achieve desired chemical separations. One of the main pyroprocessing techniques involves electrochemically treating the used fuel in one or more molten salt baths incorporating electrodes that allow for selectively separating used fuel components through voltage control. This strategy is particularly well suited for treating used metallic fast reactor fuels.

Another strategy is to simply heat used fuel to high temperatures, either alone or with other materials, in order to separate and remove particular components. Pyroprocessing research and development programs have been under way for many years in countries including the US, Japan and Russia. It is being used in the US to treat used fuel from a shut-down pilot fast reactor, but pyroprocessing has not yet been deployed in the commercial nuclear industry.[12]

NOTES

1 Hatch, *Final report: Quantitative analyses and business case for the development of uranium conversion, enrichment and fuel fabrication facilities in South Australia*, report prepared for the Nuclear Fuel Cycle Royal Commission, December 2015, p. 6, http://nuclearrc.sa.gov.au/

2 Tsoulfanidis, *Nuclear energy: selected entries from the encyclopaedia of sustainability science and technology*, Springer Science & Business Media, Berlin, 2012, pp. 233–243.

3 I Crossland (ed.), *Nuclear fuel cycle science and engineering*, Elsevier, 2012, pp. 151–158.

4 CE Johnson & J Fischer, *The fluorination of uranium from dried solids and its application to the fluoride volatility process*, Argonne National Laboratory Report (ANL-6117), 1960.

5 World Nuclear Association (WNA), 'Uranium Enrichment', April 2016, http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment.aspx.

6 ASX ComNews, *Silex Systems Limited: Annual report to shareholders*, October 2014.

7 World Nuclear News, 'GE-Hitachi to exit laser enrichment JV', *World Nuclear News*, 19 April 2016, http://www.world-nuclear-news.org/UF-GE-Hitachi-to-exit-laser-enrichment-JV-1904168.html

8 WNA, 'Nuclear fuel fabrication', April 2016, http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Conversion-Enrichment-and-Fabrication/Fuel-Fabrication/.

9 WNA, 'Processing of used nuclear fuel', November 2014, http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/processing-of-used-nuclear-fuel.aspx.

10 ibid.

11 ibid.

12 ibid.

Transcripts and submissions can be found at the Nuclear Fuel Cycle Royal Commission's website: www.nuclearrc.sa.gov.au/transcripts and www.nuclearrc.sa.gov.au/submissions

APPENDIX D: FURTHER PROCESSING–ANALYSIS OF VIABILITY AND ECONOMIC IMPACTS

1. ANALYSIS OF VIABILITY—COMMISSIONED STUDY

This study, undertaken by Hatch Pty Ltd, assessed the business case and provides quantitative analyses for establishing facilities in South Australia that provide further processing services—uranium conversion, enrichment and fuel fabrication. These services have been suggested as having potential to add value to the state's exports of uranium oxide concentrates.

The study assessed the potential returns on investment of establishing the facilities in South Australia. It estimated the revenues and lifecycle costs of a range of uranium processing facilities with the capacity to process volumes equal to Australia's uranium production.

ASSUMPTIONS AND INPUTS

Further processing services

The study analysed several different types of uranium conversion, enrichment and fuel fabrication services, either on a standalone basis or in various combinations, including as vertically integrated activities, as shown in Figure D.1.

Facility capacity

As a baseline the analysis used a capacity based upon Australia's current share in the market for uranium oxide concentrate, comprising both its average output and growth to 2030 consistent with an expansion in global nuclear capacity. That growth in capacity is consistent with the commitments made by countries prior to the 2015 Paris Climate Change Conference in their intended nationally determined contributions (INDCs).[1]

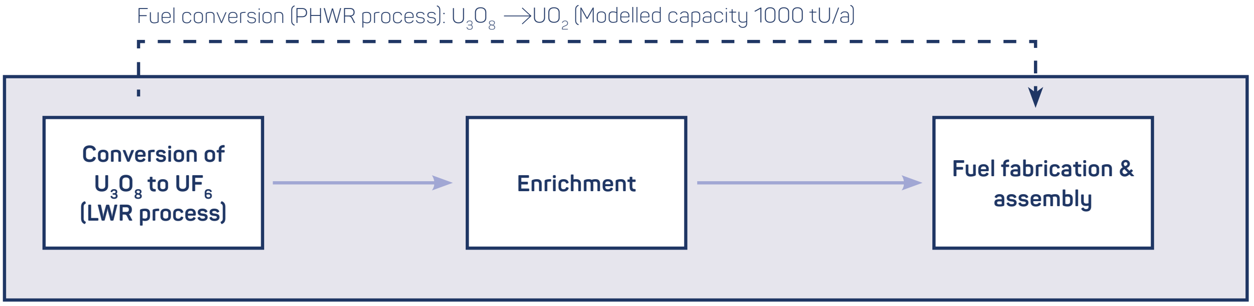
Table D.1 compares the capacity of the facilities addressed in the assessment to current global installed capacity and to relevant currently operating facilities. It shows that while the increment to current global capacity would be between 8 per cent and 17 per cent for the light water reactor (LWR) fuel, the increment to the heavy water reactor (HWR) fuel production capacity would be 23 per cent.

Capital and operating costs

Lifecycle costs were estimated for the development of further processing facilities in South Australia, including each of the five project phases—design, construction, commissioning, operation and decommissioning—as well as waste management.[2]

To estimate capital costs for each of the facilities and the combination of facilities, major equipment and material inventories were developed using process flowcharts for each facility type. These components and materials costs were then individually priced using standard chemical engineering plant cost evaluation methods and commercially available material cost databases.[3]

For each of these facilities, detailed cost estimates were also developed for supporting transport infrastructure (access to roads and port facilities) and for accessing electricity and gas distribution networks. These estimates were made for a hypothetical brownfield location that was assumed to be



Conversion technology options
1. Dry fluoride volatility process
2. Wet conversion

Modelled capacity: 10 000 tU/a

Enrichment technology options
1. Gas centrifuge
2. Laser enrichment

Modelled capacity: 7.1 million SWU/a

Process options
1. LWR fuel alone
2. LWR and PHWR fuel in 90:10 ratio

Modelled capacity
LWR fabricated fuel: 1095 tU/a.
PHWR fabricated fuel: 990 tU/a.

tU/a = tonnes of uranium per annum
LWR = light water reactor
PHWR = pressurised heavy water reactor
SWU = separative work unit

Figure D.1: Conversion, enrichment and fuel fabrication processes and technology assessed

Table D.1: Comparison of modelled facility capacities to current global installed capacity and to capacity of commercially established facilities

Facility	Global installed capacity (2015)	Modelled facility capacity	Increment to current global capacity (%)	Comparable commercially established facilities
Light water reactor process				
Conversion to UF_6	59 100 tU/a	10 000 tU/a	17	Canada: Port Hope, Cameco wet conversion facility (12 500 tU/a) USA: Metropolis, Illinois Converdyn dry conversion facility (17 600 tU/a)
Enrichment	57 million SWU	7.1 million SWU	12	France: Georges Besse II gas centrifuge enrichment facility (7–7.5 million SWU)
Fuel fabrication	13 600 tU/a	1095 tHM/a	8	USA (several): Columbia, Westinghouse facility (1150 tU/a)
Pressurised heavy reactor process (no enrichment)				
Conversion to UO_2	4320 tU/a[a]	1000 tHM/a	23	Canada: Port Hope, Cameco (2800 tU/a)
Fuel fabrication	4320 tU/a	990 tHM/a	23	France: Georges Besse II gas centrifuge enrichment facility (7–7.5 million SWU)

[a] Based on World Nuclear Association 2015 figures
Notes: tHM/a = tonnes of heavy metal per annum, SWU = separative work unit, tU/a = tonnes of uranium per annum
Source: World Nuclear Association

near existing supporting infrastructure and a hypothetical greenfield location that was assumed to be 30–50 km from these facilities. Potential cost synergies from the collocation of further processing facilities were not included, which suggests that further reductions in costs could be achieved.[4]

For operating and other project lifecycle costs, estimates were drawn from technical literature, historical projects, calculations based on process requirement analyses, and financial, environmental and regulatory compliance reports of commercially established facilities.[5]

Estimated capital costs for further processing facilities (base case) are presented in Table D.2. Capital and operating cost estimates were able to be made with greater certainty for the commercially proven wet conversion, gas centrifuge and fuel fabrication processes. The dry conversion technology (with only one operational facility) and laser enrichment technology (not yet commercially proven),[6] have substantial cost uncertainties even though they are estimated to require significantly smaller capital investments than the wet conversion and gas centrifuge processes respectively.

Table D.2: Lifecycle capital and operating costs for LWR processing facilities (2015 A$)

	Wet conversion	Dry conversion	Gas centrifuge enrichment	Laser enrichment	LWR fuel fabrication
Capital costs	$437.4m	$247.2m	$7623.0m	$2616.0m	$977.7m
Operating costs (per year)	$98.0m	$66.0m	$82.0m	$83.0m	$243.0m
Plant design capacity (per year)	10 000 tU	10 000 tU	7.1m SWU	7.1m SWU	1095 tU

Notes: tU = tonnes of uranium, m = million, LWR = light water reactor, SWU = separative work unit
Source: Hatch

Table D.3: Spot and long-term average prices for uranium conversion and enrichment services, 2015

Service	Spot price (A$)	Long-term average price (A$)
Conversion (A$/kgU)	8.4	20.8[a]
Enrichment (A$/SWU)	77.9	182[b]
LWR fuel fabrication (A$/kgHM)	N/A	409
PHWR fuel fabrication (A$/kgHM)	N/A	136

[a] Long-term average price
[b] Over the period 2005–11
Notes: US$1 = A$0.77, kgU = kilograms of uranium, kgHM = kilograms of heavy metal, LWR = light water reactor, PHWR = pressurised heavy water reactor, SWU = separative work unit
Source: Hatch

Revenues

Assessments of viability required determining a range of prices that could be used to estimate revenues that a prospective facility developed in South Australia might secure.

Uranium conversion, enrichment and fuel fabrication services are not traded in meaningful quantities on a commodity exchange.[7] However, prices of actual transactions are available and from them a long-term average price can be determined. Both spot and long-term average prices for conversion and enrichment are presented in Table D.3.

An assessment of viability undertaken on the basis of the long-term average price assumes that either new supply would meet new demand or displace an existing supplier.

In comparison with prices for conversion and enrichment, estimates for fuel fabrication services are more difficult to establish, given that they are based on negotiated long-term contracts and there is no spot market. The analyses undertaken used financial and purchasing reports published by utilities KEPCO (South Korea) and Ontario Power Generation (Canada) to estimate an average price.[8]
The long-term average prices used are set out in Table D.3.

RESULTS OF VIABILITY ANALYSIS

Overall, viewed on a standalone basis, the financial assessments suggested that most further processing facilities were not viable. Those based on currently used and proven technologies were at best marginal investments, and in many cases had negative returns.[9] Positive returns were indicated for facilities that used proprietary or unproven technologies, although that assumed significant investments were made to demonstrate and commercialise those technologies, but no estimate of these investments were made or included as part of the analyses.

Those outcomes are reflected in Figure D.2, which shows facilities assessed to be viable in the upper-right quadrant. They were assessed to be viable if they were profitable with an internal rate of return of 10 per cent—the amount a private investor would expect to receive on an investment.

The relative viability of each of the processing technologies for LWR fuel as standalone facilities is presented in Figure D.2.[10]

Figure D.2: Commercial viability of standalone facilities

Conversion

While the wet conversion process is marginal but negative, the dry conversion process is very profitable, as shown in Table D.4.

This outcome is in large part a result of the dry conversion process being simpler and requiring fewer processing steps than the wet process—which means that, in the assessments, it has lower capital and operating costs.[11] However, it is important to note that the dry conversion facility carries far greater technical risks.

Table D.4: Project net present value (NPV) for standalone conversion facilities (A$ millions 2015)

Facility	NPV at A$21 per kgU
Wet conversion	-1
Dry conversion	383

Note: kgU = kilograms of uranium
Source: Hatch

Enrichment

Gas centrifuge enrichment is not viable under most realistic future scenarios.[12] In comparison, laser enrichment, if it could be commercially demonstrated at scale, could be highly viable as a disruptive technology. The assessment did not take into account the potentially substantial costs associated with proving commercial feasibility.[13] If it could be, the analysis suggests it would have a substantial competitive advantage over existing producers.[14]

The comparison of the viability of enrichment by gas centrifuge and laser enrichment can be seen in Table D.5.

Table D.5: Project net present value (NPV) for standalone enrichment facilities (A$ millions 2015)

Facility	NPV at A$182 per SWU	NPV at A$78 per SWU
Gas centrifuge enrichment	-709	-5013
Laser enrichment	3114	-1191

Note: SWU = separative work unit
Source: Based on data supplied by Hatch

Fabrication

A fuel fabrication facility manufacturing light water fuel would be viable if contracts could be secured at or above the current estimated prices (approximately US$315 per kilogram of heavy metal (HM)[15]). However, the fabrication of both light and heavy water reactor fuel in a 90:10 ratio in a hybrid facility was found to be less profitable.[16]

SENSITIVITY–VERTICAL INTEGRATION OF TWO OR MORE SERVICES

The analysis was also undertaken on the basis that two or more services might be integrated. That was undertaken for the following reasons:

- Because of the distances involved to export large quantities of uranium concentrate from South Australia to existing uranium conversion suppliers, it is considered uneconomic for the converted product to be returned to the state for enrichment and/or fuel fabrication.
- Standalone fuel fabrication facilities would not be expected to be developed without there being a supplier to a domestic nuclear power plant market, and would therefore—if located in South Australia—need to be associated with conversion and enrichment facilities.[17]

Table D.6 presents a summary of the estimated project returns from investment in various combinations of vertically integrated facilities grouped on the basis of whether they rely on proven technologies (wet conversion and gas centrifuge enrichment) or unproven/niche technologies (dry conversion and laser enrichment). A profitable outcome is shown by a rate of return greater than 10 per cent. A sensitivity analysis was also undertaken to address the risks respectively of significant cost overruns or an adverse market, where the price is significantly lower than the long-term average.

Integrated facilities based on proven technologies that also included fuel fabrication yielded a higher rate of return, than when conversion and enrichment were considered on a standalone basis; however, they were still not viable. Integrated facilities based on unproven or niche technologies, with the qualifications stated above, were viable. It can also be seen that they were less sensitive to adverse market conditions or cost overruns.

Table D.6: Internal rates of return for vertically integrated facilities

Facilities internal rate of return (after tax, real basis)	Conversion, enrichment and fuel fabrication		Conversion and enrichment	
	Proven technologies	Unproven/niche technologies	Proven technologies	Unproven/niche technologies
Baseline scenario: Reference capex estimate, market recovers	9.4%	19.3%	7.8%	20.3%
No market recovery	4.2%	11.3%	1.9%	10.0%
Cost overrun	6.5%	12.0%	5.1%	12.0%
Worst case scenario: Cost overrun, no market recovery	2.2%	6.2%	<1.0%	4.8%

Source: Hatch

2. ANALYSIS OF ECONOMIC IMPACTS —COMMISSIONED STUDY

Economic modelling using a general equilibrium model was undertaken by Ernst and Young to assess the potential effect on the wider South Australian economy of investments being made in further processing facilities. It estimated changes in key measures of economic activity such as gross state income, gross state product, wages and employment.

The modelling undertaken used the transparent, peer-reviewed model maintained by the Victoria University Centre of Policy Studies known as the Victoria University Regional Model (VURM).[18] *This model has been used widely in Australia to assess the effects of investments made in one part of the economy on economic activity more broadly.*

ASSUMPTIONS AND INPUTS

The potential macroeconomic impacts of providing further processing services were assessed by assuming private investment in conversion and enrichment facilities in 2024 for operational commencement in 2030.[19]

It was assumed that a combined investment was made in conversion and enrichment facilities based on proven technologies. Investment in fuel fabrication facilities was not assessed as it was considered that, in the timeframe to 2030, it would not be feasible to establish a sufficiently broad technical skills base to capture market share.

The investment in further processing facilities was assumed to be made in an international market where Australia had implemented a carbon price to meet the abatement targets agreed at the Paris Climate Change Conference.[20]

RESULTS OF ANALYSIS OF ECONOMIC IMPACTS

The combination of conversion and enrichment facilities was estimated to generate annual export revenues for South Australia of A$657m in current terms.

Investment in further processing facilities in South Australia was also estimated to deliver modest but positive outcomes of an additional 0.5 per cent in 2030 for the South Australian economy, as shown in Table D.7.

In the two years prior to commencement of operations, the construction work force would peak at approximately 4000 persons employed on a full time equivalent basis, but this would decline to 1000 persons over the operational phase.[21]

Table D.7: Impact of investment in conversion and enrichment facilities on South Australian economy

	2029–30	2049–50
Gross state income	A$898m (0.65%)	A$794m (0.39%)
Gross state product	A$671m (0.47%)	A$914m (0.45%)
Wages	0.09%	0.02%
Total employment	1013	1000
Direct employment	210	324

Source: Ernst & Young

NOTES

1 Hatch, *Final report: Quantitative analyses and business case for the development of uranium conversion, enrichment and fuel fabrication*, report prepared for the Nuclear Fuel Cycle Royal Commission, Adelaide, 2015, section 3.6.1, table 3.4, http://nuclearrc.sa.gov.au/

2 ibid., section 5, http://nuclearrc.sa.gov.au/

3 ibid., pp. vi, section 5, pp. 42–63.

4 ibid., section 7.3, p. 71.

5 ibid., p. vi.

6 ibid., p. vii

7 ibid., section 9.1.2, p. 106.

8 ibid., section 9.1.7, p. 108.

9 ibid., section 9.2, pp. 110–128, section 9.3, pp. 128–131.

10 Nuclear Fuel Cycle Royal Commission internal analysis using Hatch financial model.

11 Hatch, *Final report: Quantitative analyses and business case*, section 4.2.3, pp.34–5.

12 ibid., pp. 111, 115, figure 9.4.

13 ibid., section 4.3.2.1, p.38.

14 ibid., section 9.2.4, p. 115.

15 ibid., section 9.1.7, p. 108.

16 ibid., section 9.2.5, p. 115.

17 ibid., section 2.3.3, p. 11.

18 Ernst & Young, *Computational general equilibrium modelling assessment*, report prepared for the Nuclear Fuel Cycle Royal Commission, Adelaide, February 2015, sections 2.3, 2.4, http://nuclearrc.sa.gov.au/

19 ibid., section 4.2.1.

20 ibid., section 3.2, table 7.

21 ibid., section 6.2.2, figure 57.

Transcripts and submissions can be found at the Nuclear Fuel Cycle Royal Commission's website: www.nuclearrc.sa.gov.au/transcripts and www.nuclearrc.sa.gov.au/submissions

APPENDIX E: NUCLEAR ENERGY—PRESENT AND FUTURE

NUCLEAR POWER PLANT FEATURES

A nuclear power plant produces electricity using heat energy, as do coal and gas fired power plants. The difference for a nuclear power plant lies in the way the heat is created.

Nuclear reactors rely on a controlled process of nuclear fission to produce heat. Nuclear fission is the term applied to an atomic nucleus splitting into smaller elements, releasing neutrons and a large amount of energy.

Nuclear fission produces much more energy than chemical combustion—in the range of 10 000 to 20 000 times more in mass terms. Nuclear fuel is very energy dense: one tonne of uranium fuel yields the same amount of electric power as 20 000 tonnes of black coal or 8.5 million cubic metres of gas. The same nuclear fuel is used in a reactor for up to five years.[1]

In order to safely harness this heat energy and convert it into electricity, special highly engineered pressure vessels, called nuclear reactors, are required.

The key elements of a nuclear reactor are illustrated in Figure E.1.

FUEL ZONE

All nuclear reactors are fuelled by a material that is capable of sustaining nuclear fission. Most commonly this is an isotope of uranium, ^{235}U. The fuel needs to be put into a robust form, such as a ceramic or metal alloy, or encased in graphite, due to the high temperatures of the fuel. Nuclear fuel assemblies are specifically designed for particular types of reactors and are made to exacting standards (refer to Appendix C: Further processing methods).

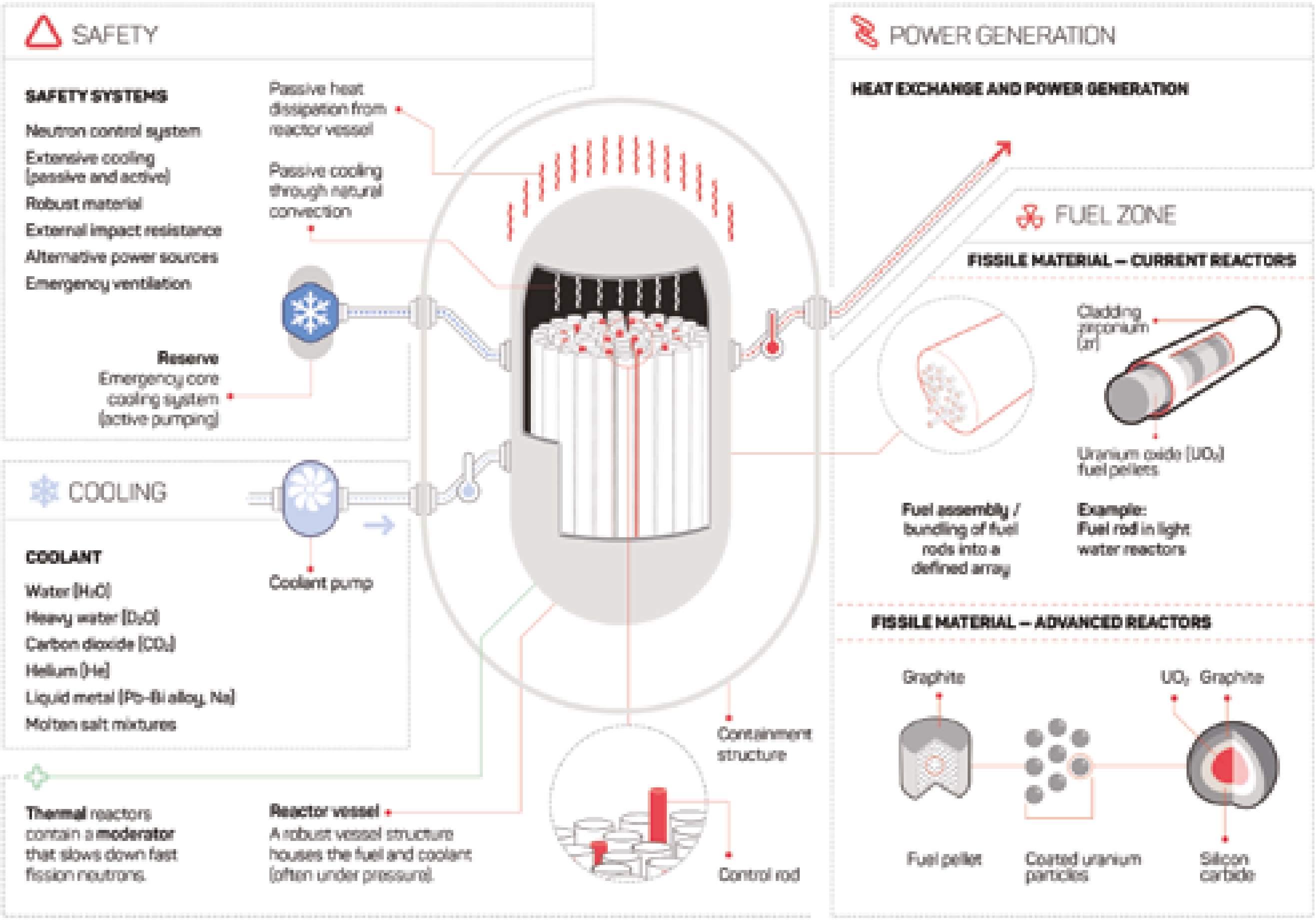


Figure E.1: Key elements of a nuclear reactor

The three main fuel assembly types currently produced are for pressurised water reactors (PWR), boiling water reactors (BWR) and CANDU pressurised heavy water reactors (PHWR). The key elements in a nuclear fuel system and the physical differences in fuel assembly designs are shown in Figure E.2.

COOLANT

Coolants are necessary in a reactor to absorb the heat from the fuel and to transfer that energy to the turbines. Most reactors have multiple cooling circuits and use water, either light or heavy, as the coolant. Some reactors use a gas, such as helium or carbon dioxide. Some advanced reactors use other kinds of coolants, such as liquid metals.[2]

HEAT EXCHANGE AND POWER GENERATION

The heat generated from the fission process in the reactor core is converted into high pressure steam, either directly or in a steam generator, which is fed through conventional steam turbines, similar to those used in coal power plants. The steam expands and causes the turbines to rotate, which in turn drives a generator that produces electricity. Commercial power plants are connected to a high voltage grid to distribute the electricity across a wide geographical area.

LOAD FOLLOWING

Nuclear power plants are typically operated as baseload generators that run continuously at full power. 'Load following' is an operational mode where the electricity output of a power plant is adjusted to reflect the changing electricity demand. Some of the currently operating nuclear plants are configured to have some load following capability; however, it is more economical to run them at full power. Furthermore, operating at full power is less demanding on both the plant equipment and the fuel.[3]

COOLING WATER REQUIREMENTS

Water requirements vary according to features of the particular reactor design, including the operating temperature and the type of cooling system employed.[4] A 'once-through' cooling system involves withdrawing water from a nearby sea, river or major inland water body and circulating large volumes through a condenser(s) in a single pass. The water is then discharged back into the original water source a few degrees warmer without much loss (through evaporation) from the amount initially withdrawn.

Alternatively, cooling may be carried out by 'recirculation': that is, water initially withdrawn from the sea, a river, etc., is recirculated from the condenser to a cooling tower and back to the condenser. A cooling pond works in much the same way.[5] Recirculation is much more efficient in its use of water, compared with the once-through system.

At present, cooling water requirements of nuclear power plants exceed those of fossil fuel power stations by 20–25 per cent on average per m^3/MW hour (Table E.1). This is due to the lower thermal efficiency in most of the existing nuclear power plants, as they operate with lower steam pressures and temperatures. A number of newer nuclear technologies aim to minimise the use of water by, for example, maximising cooling tower concentrations.[6]

COMMON REACTOR TYPES

The two main types of reactor in operation today are the pressurised water reactor (PWR) and the boiling water reactor (BWR) which account for approximately 64 per cent and 18 per cent respectively of operating nuclear power reactors.[8] The key differences between these two types of reactor are:

- The PWR primary coolant is kept under high pressure, which stops it from boiling. A separate secondary circuit, with secondary coolant where steam is generated, is used to drive the turbine.
- In BWRs there is a single circuit in which the water is at lower pressure than in a PWR so that it boils in the core to create steam. This is then used to directly drive the turbines in the absence of a secondary coolant. Since the water in the core becomes contaminated with traces of radionuclides, the turbine is part of the reactor circuit and must be shielded.[9]

Table E.1: Water use for different cooling systems (m^3/MW/hour)

Cooling system	Once-through (withdrawal)	Cooling pond (consumption)	Cooling towers (consumption)
Nuclear	95–230	2–4	3–4
Fossil-fuelled	76–190	1-2	2
Natural gas/oil	29–76	–	1

Source: International Atomic Energy Agency (IAEA)[7]

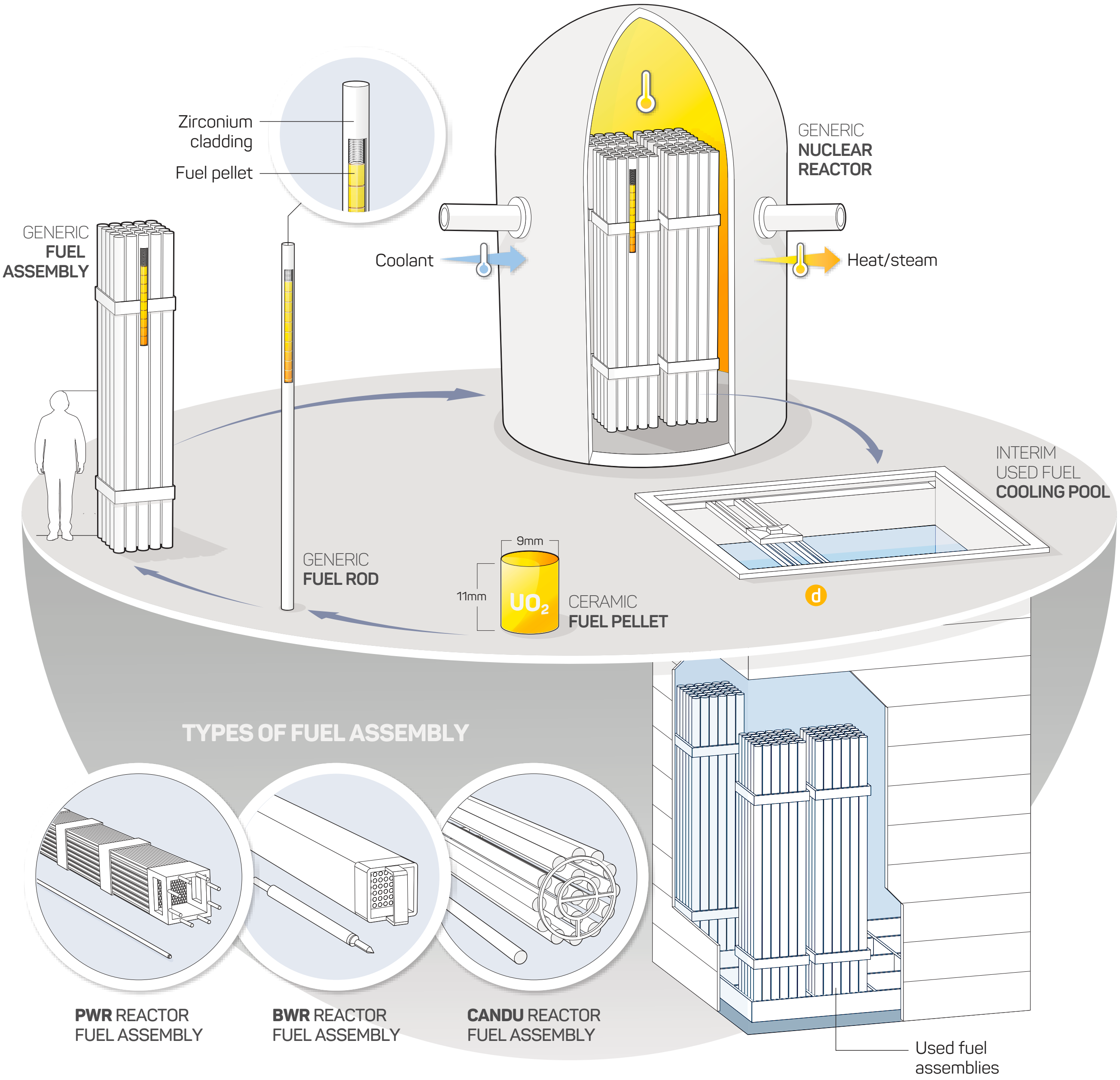


Figure E.2: A nuclear fuel system

NUCLEAR POWER PLANT SAFETY

SHUTTING DOWN A REACTOR AND DISSIPATING HEAT

Shutting down a reactor as part of normal operating procedures or in a fault or emergency situation involves inserting neutron-absorbing material into the core. This rapidly absorbs neutrons and stops the chain reaction and the production of heat from nuclear fission. In all commercial reactors this process is designed to occur automatically and without the need for human intervention.[10]

When the reactor has been shut down and the fission process stopped, it is still necesary to remove residual heat from the core and heat produced from the radioactive decay of the fission products in the fuel. Ongoing cooling is required to effectively remove the heat from the reactor core until the fuel is removed from the reactor.

Most commercial power reactors use water as the primary fuel coolant in closed cycles—those in which the water is recirculated to the reactor core after delivering heat to the turbine/generator system. Given the importance of maintaining adequate cooling for the fuel, reactors are also designed to supply additional coolant in the event of primary coolant loss.

In addition to the systems used for normal operations, all operating reactors are equipped with an emergency *active cooling system*, which makes available large amounts of supplementary water and multiple pumps with independent power supplies.

An emphasis in newer reactor designs is to provide additional fuel cooling using *passive cooling measures*. These rely exclusively on the fundamental physical effects of thermal expansion, gravity and the flow of heat to cooler zones. This can provide core cooling through natural circulation for extended periods without manual or mechanical intervention.[11]

Both active and passive safety systems can provide ongoing fuel and core cooling. However, passive systems to remove heat from the core reduce the dependence on active equipment (e.g. pumps and valves) and operator action in an emergency, and so are an increasingly important design feature for future reactors.

DEFENCE IN DEPTH AND REDUNDANT SYSTEMS

Modern nuclear power plants are designed to incorporate the 'defence in depth' concept. This means that no single human error or equipment failure at one level of defence, nor even a combination of failures at more than one level of defence, can escalate to jeopardise or lead to harm to the public or the environment.[12]

Defence in depth is based on having multiple barriers between radioactive materials and the workforce, the public and the environment, as well as redundancy and diversity of systems. The concept includes measures to protect the barriers themselves and ensures a high level of safety is reliably achieved through:

- high-quality design and construction of nuclear power plant systems
- equipment designed to prevent operational issues or human failures and errors developing into problems
- comprehensive monitoring and regular testing to detect equipment or operator failures
- redundant and diverse systems to control damage to the fuel and prevent significant radioactive releases
- provisions and countermeasures to reduce the effect of severe fuel damage
- improved human performance and a strong safety culture.

IMPACT RESISTANCE OF NUCLEAR REACTORS

Designers of nuclear power plants and the regulators that license plants have considered the potential for impact hazards that could challenge the safety and security of a nuclear power plant, such as terrorist attack and deliberate or accidental aircraft impact.[13]

In 2009 the US Nuclear Regulatory Commission amended its regulations to require applicants for new nuclear power reactors to perform a design-specific assessment of the effects on the facility of the impact of a large commercial aircraft.[14] In Europe, similar regulations are in place to ensure design standards take account of the hazards from impacts.[15]

While differences in detail exist among nuclear reactor types, the fundamental levels of external protection from an impact are:

- the external reinforcement of the outer containment structure
- thick steel construction of the reactor pressure vessel
- fuel and cladding designed to contain radioactive material in the core.

Detailed analysis and modelling has been undertaken on impact events to predict potential damage to the reactor containment.[16] In a postulated aircraft crash, analyses confirmed that concrete walls in the external power plant structure (typically more than one metre thick) are strong enough to protect the fuel from impacts of large commercial aircraft.[17]

Figure E.3, a photo of the Flamanville PWR under construction in France, shows the inner steel containment structure prior to being covered in a thick concrete outer containment. This is typical of a modern light water reactor that is designed to resist and survive large aircraft impacts.

Figure E.4 shows the external containment structure of an existing PWR power plant.

In some newer designs the reactors are recessed into the ground to provide improved protection from impact hazards, as illustrated in Figure E.5. The reactors which are below ground level can be seen on the lower right.

EMERGENCY VENTILATION

In severe accident scenarios hazardous gases may be produced, most notably hydrogen which is potentially explosive. As a result, nuclear power plants also have chemical recombiners to control hydrogen build-up and also, if required, the ability to vent gas into the external reactor building.[18]

Figure E.3: Flamanville PWR plant under construction

Image courtesy of EDF

Figure E.4: External containment of an operating PWR plant

Image courtesy of EDF

Figure E.5: NuScale small modular reactor

Image courtesy of NuScale Inc.

SMALL LIGHT WATER MODULAR REACTORS

Most commercial nuclear plants operating have a generating capacity of about 1 GWe.[19]

A number of firms (see Table E.2) have sought to develop small reactors based on light water designs with generating capacities in the range of 300 MWe or less.[20]

It is thought that such reactors might have the potential to be integrated into a wider range of networks than large plants. Developers of these reactors are aiming to lower the typical construction costs associated with nuclear plants through serial fabrication at an off-site facility, with components brought together at the operational site for final assembly.

This modularisation of components leads such designs to be referred to as small modular reactors (SMRs).[21]

Light water SMR designs using proven light water reactor technology are in various stages of development, with the most advanced being in the licensing process.[22]

There are numerous light water SMR designs being developed, with the most common design features including:

- modular design and small size, lending itself to multiple units on the same site
- smaller output, reducing the level of radioactive inventory in the reactor
- less reliance on active safety systems and pumps to remove heat from the reactor, including during fault or accident conditions
- less cooling water required, so SMRs are more suitable for operating in remote regions and for specific applications such as mining or desalination
- compact design enabling off-site fabrication, if manufactured at a sufficient scale, which can facilitate implementation of higher quality standards and lead to lower construction costs
- below-ground siting of the reactor unit to provide improved protection from natural or external hazards such as aircraft impact
- reduced size of safety exclusion zones
- ability to remove the reactor modules for dismantling and decommissioning at the end of the operational lifetime.

Table E.2: Selected SMR designs under development

SMR type	Vendor/Developer	Country	Description
NuScale	NuScale Power LLC	USA	50 MWe Integral PWR module Deployed with up to 12 modules per plant.
SMART	Korean Atomic Energy Research Institute (KAERI)	South Korea	90 MWe Integral PWR unit Deployed with up to 2 units per plant
mPower	BWX Technologies Inc.	USA	180 MWe Integral PWR unit Deployed with up to 2 units per plant
Westinghouse	Westinghouse Electric Company	USA	225Mwe Integral PWR
ACP100	China National Nuclear Corporation (CNNC)	China	100 MWe PWR
Holtec	SMR LLC (subsidiary of Holtec International)	USA	160 MWe PWR

Source: World Nuclear Association[25]

On the current cost estimates, SMRs require less capital investment prior to producing returns compared with larger scale reactor designs.[23] However, there are no commercially operating examples of light water SMRs that can validate whether the design features listed above can be achieved collectively in a commercial context. In addition, those analysing SMR developments have identified hurdles and uncertainties facing development and commercial deployment including the following[24]:

- SMRs have a relatively small electrical output, yet some costs including staffing may not decrease in proportion to the decreased output.
- SMRs have lower thermal efficiency than large reactors, which generally translates to higher fuel consumption and spent fuel volumes over the life of a reactor.
- SMR-specific safety analyses need to be undertaken to demonstrate their robustness, for example during seismic events.
- It is claimed that much of the SMR plant can be fabricated in a factory environment and transported to site for construction. However, it would be expensive to set up this facility and it would require multiple customers to commit to purchasing SMR plants to justify the investment.
- Reduced safety exclusion zones for small reactors have yet to be confirmed by regulators.
- Timescales and costs associated with the licensing process are still to be established.
- SMR designers need to raise the necessary funds to complete the development before a commercial trial of the developing designs can take place.
- Customers who are willing to take on first-of-a-kind technology risks must be secured.

FAST REACTORS AND REACTORS WITH OTHER INNOVATIVE DESIGNS

Notwithstanding the commercial dominance of LWR designs, work has been undertaken for many decades to improve the sustainability and efficiency of nuclear fuel use in reactors for power production, since current designs utilise less than 1 per cent of the mined uranium. There is also interest in using different nuclear fuel sources such as 'burning' heavy radionuclides and depleted uranium, which are created as byproducts from used fuel reprocessing and fuel enrichment respectively.

For those reasons, different reactor designs have been developed that include:

- fuel forms that can operate at higher temperatures than the current zirconium-clad oxide fuels used in light water reactors
- fuel zones that use higher energy neutrons, the so-called 'fast spectrum'
- coolants that can operate at higher temperatures than water.

Reactors with these design features have operated since the 1960s, but principally as experimental, prototype or demonstration nuclear reactors.[26]

In recognition of the long period and costs involved in their further development, consensus was reached internationally in 2001 that no single country could overcome, in a timely manner, the technical and engineering challenges associated with advanced reactor developments and technologies. Nor could a single country commit the long term resources needed and afford the cost and risks associated with building the next generation of nuclear energy systems.[27]

That consensus led to the establishment of the Generation IV International Forum (Gen IV Forum) to support and manage international cooperation and collaboration on advanced reactor development.[28] Notwithstanding that consensus, some development continues to occur on a national basis.

The Gen IV Forum selected a grouping of six advanced reactor designs updated in January 2014 that are referred to as 'Generation IV' (Gen IV) set out below in Table E.3. The Gen IV Forum has agreed on a common set of high level goals or objectives:

- *Sustainability:* Meets clean air objectives and promotes long term availability of systems and effective fuel, minimising waste volumes and intergenerational burden
- *Economics:* Lifecycle cost advantages over other energy sources, with a comparable level of financial risk
- *Safety and reliability:* Excellence in safety and reliability through a very low likelihood of reactor core damage and removal of the need for an off-site emergency response
- *Proliferation resistance and physical protection:* Least attractive and desirable route for the diversion or theft of weapons-usable materials, and increased physical protection against acts of terrorism.

FAST REACTORS

Many of the Gen IV designs are fast reactors, which utilise fast neutrons rather than the slow or thermal neutrons used by commercial nuclear reactors in operation today. Fast reactors can fission ^{238}U as well as the ^{235}U and this means that more than 60 times more energy can be extracted from the original uranium compared to current reactors. They are also able to use some materials from high level waste as fuel.[30]

Most of the six selected systems employ a closed fuel cycle to increase fuel utilisation and reduce the amount of high-level waste that needs to be sent to a repository for final disposal. High operating temperatures for four of the selected Gen IV Forum systems enable thermochemical hydrogen production, which could prove to be important for future transport fuels.[31]

VERY HIGH TEMPERATURE GAS REACTOR

The very high temperature gas reactor (VHTR), which is one of the systems selected by the Gen IV Forum, is a graphite-moderated, helium-cooled thermal reactor. High outlet temperatures allow thermochemical hydrogen production.[32]

The VHTR has some flexibility in fuel configuration, but no fuel recycling initially. Fuel is in particle form less than a millimetre in diameter, which may be incorporated into billiard ball sized pebbles or prismatic graphite blocks. The VHTR has potential for high fuel burn-up—around three to four times the level of current reactors. VHTR is planned to offer improved passive safety, low operation and maintenance costs, and modular construction features.[33] VHTR can also 'burn' waste actinides if fuel is specially adapted and fabricated for this purpose.[34]

OUTLOOK FOR THE DEPLOYMENT OF FAST REACTORS AND OTHER INNOVATIVE DESIGNS

Presently there are no operational fast reactors or other innovative designs that can be used to validate their potential for commercial deployment.[35] Several countries have research and development programs for improved fast reactors, with some being in place since the 1950s, with significant challenges still to be overcome before commercial operation is achieved.[36]

Today India and Russia regard fast reactors as a priority in their nuclear programs. They also feature in the nuclear energy programs for Japan, China and France. Experimental prototype and demonstration reactor designs are currently in operation in several countries including Russia, China and India.[37]

Prototype and demonstration VHTR designs have previously operated in various countries, although all have been shut down.[38] A twin 105 MWe gas-cooled HTR-PM ('high temperature gas cooled – pebble bed modular') demonstration unit at Shidaowan in China commenced construction in December 2012 and is expected to start operation in late 2017.[39]

Based on the updated technology roadmaps published by the Gen IV Forum in 2014 for Generation IV designs, a reactor demonstration phase is expected to begin in approximately 2021 for the most advanced system.[40] This phase is expected to last at least 10 years and will require funding of several billion US dollars for each system. As a result, based on the published Generation IV planning basis, the earliest timescales for commercial deployment of fast reactors and other innovative designs is reported as 2031.[41]

The proposed Russian BN-1200 design, which is planned as the commercial design developed from the existing BN-800 demonstration sodium cooled fast reactor, may be in operation before then.[42]

In addition, the proposed Chinese twin 600 MWe HTR-PM reactor (which is made up of 6 x 105 MWe modules) at Ruijin city in China's Jiangxi province passed a preliminary feasibility review in early 2015. This design is based on the demonstration HTR-PM reactor, with construction expected to start in 2017 and grid connection expected in 2021.[43]

All the timescales described above are, however, subject to significant project, technical and funding risk, as with any complex technology development.

Table E.3: Reactor designs selected by the Generation IV International Forum

	Neutron spectrum (fast/ thermal)	Coolant	Temperature (°C)	Pressure[a]	Fuel	Fuel cycle	Size(s) (MWe)	Uses
Gas-cooled fast reactors	fast	helium	850	high	^{238}U[b]	closed, on site	1200	electricity & hydrogen
Lead-cooled fast reactors	fast	lead or Pb-B	480–570	low	^{238}U[b]	closed, regional	20–180[c] 300–1200 600–1000	electricity & hydrogen
Molten salt fast reactors	fast	fluoride salts	700–800	low	UF in salt	closed	1000	electricity & hydrogen
Molten salt reactor - Advanced high-temperature reactors	thermal	fluoride salts	750–1000	low	UO^2 particles in prism	open	1000–1500	hydrogen
Sodium-cooled fast reactors	fast	sodium	500–550	low	^{238}U & MOX	closed	50–150 600–1500	electricity
Supercritical water-cooled reactors	thermal or fast	water	510–625	very high	UO^2	open (thermal) closed (fast)	300–700 1000–1500	electricity
Very high temperature gas reactors	thermal	helium	900–1000	high	UO^2 prism or pebbles	open	250–300[3]	electricity & hydrogen

[a] high = 7–15 MPa

[b] = with some ^{235}U or ^{239}Pu

[c] 'battery' model with long cassette core life (15–20 years) or replaceable reactor module

Source: World Nuclear Association[29]

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Transcripts and submissions can be found at the Nuclear Fuel Cycle Royal Commission's website: www.nuclearrc.sa.gov.au/transcripts and www.nuclearrc.sa.gov.au/submissions

APPENDIX F: THE FUKUSHIMA DAIICHI ACCIDENT

At 2.46pm Japan Standard Time (JST) on Friday 11 March 2011, a magnitude 9.0 earthquake struck 130 km off the north-east coast of Japan's main island of Honshu. The Great East Japan earthquake was caused by 'a sudden release of energy at the interface where the Pacific tectonic plate forces its way under the North American tectonic plate'.[1] The earthquake lasted for more than two minutes and caused significant damage to infrastructure and property along the east coast of Japan.[2] It also resulted in a 10–20 m horizontal shift of the sea floor and local coastal subsidence of about half a metre.[3]

When the earthquake struck, three of the six reactor units at Tokyo Electric Power Company's (TEPCO) Fukushima Daiichi nuclear power plant were operating at full power. Units 1–3 shut down automatically according to design when plant sensors detected ground vibrations and triggered the reactor protection systems, thereby controlling the reactivity of the nuclear fuel, which is a fundamental safety function.[4] Units 4–6 were in planned shutdown for maintenance and refuelling at the time.[5] Although the earthquake caused no significant damage to the reactor units, it did cut off external AC power supply to the plant.[6] Emergency cooling was maintained as per design by diesel generators located in the basements of the turbine buildings of each reactor unit.[7]

The earthquake caused two tsunamis. Several warnings were issued by the government.[8] The first small tsunami was measured by a wave height meter located 1.5 km off the coast of the Fukushima Daiichi plant at 3.27pm JST.[9] The main tsunami, measuring 14–15 m in run-up height[10], struck the Fukushima Daiichi site at 3.36–3.37pm JST, and ultimately flooded over 500 square kilometres of land.[11] More than 15 000 people were killed and over 6000 injured as a result of the earthquake and tsunami, and around 2500 people were reported to still be missing as of March 2015.[12]

THE IMPACTS OF THE TSUNAMI ON FUKUSHIMA DAIICHI

Units 1–4 of the Fukushima Daiichi plant were built 10 m above sea level, while Units 5 and 6 had elevations of 13 m (see Figure F.1 and Figure F.2).[13] A 4-metre-high sea wall, with a breakwater height of 5.5 m, had been constructed to shield the plant from potential tsunami waves.[14] The sea wall and breakwater protected the site against the small wave, which had a run-up height of 4–5 m.[15] However, the main tsunami wave inundated the Fukushima Daiichi site, flooding and disabling 12 of the plant's 13 emergency diesel AC power generators, located at an elevation of 2 m.[16] This affected the cooling systems of the reactors and spent fuel pools.[17] In addition to disabling the emergency generators, the tsunami flooded the 125 volt DC batteries that supplied power to the instruments for Units 1, 2 and 4, which resulted in the loss of the instruments, controls and lighting for these units.[18]

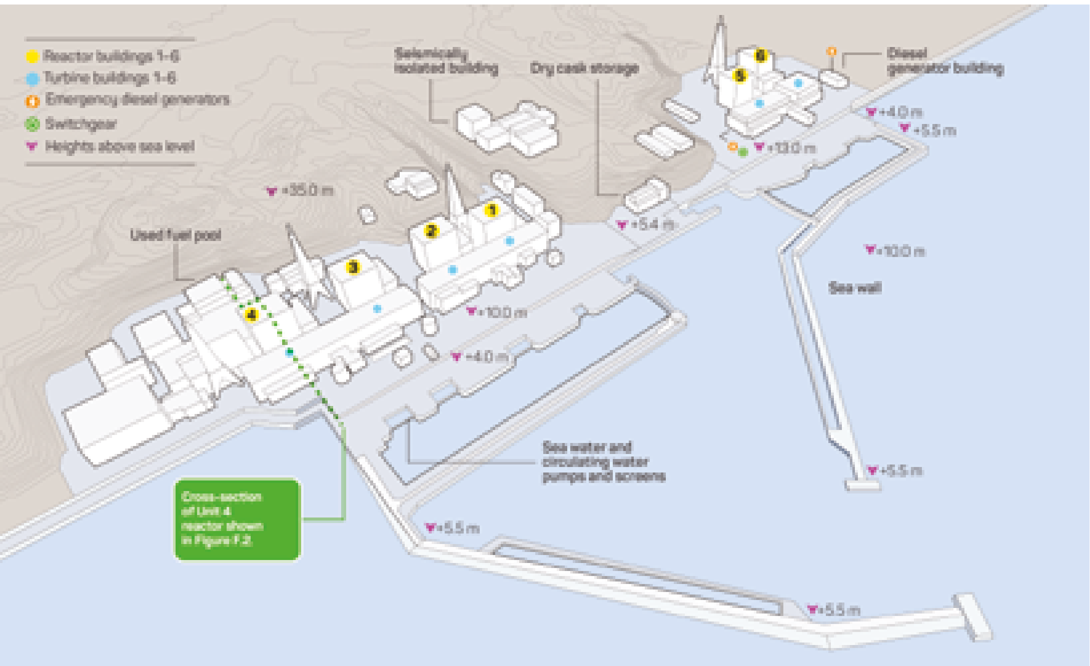

Figure F:1: The elevations and locations of structures and components at the Fukushima Daiichi nuclear power plant

Image adapted from TEPCO data

The widespread destruction caused by the tsunami made it impossible for external electricity supplies to be restored in time to avert melting of the fuel.

Without cooling and water injection, the heat generated by radioactive decay in the fuel caused the water levels in Units 1–3 to drop.[19] The loss of cooling for an extended period of time meant that the nuclear fuel overheated. The high temperatures also caused the exposed zirconium fuel cladding to react with the water vapour in the units resulting in the formation of large quantities of hydrogen gas.[20]

The hydrogen gas leaked from the primary containment vessels, resulting in explosions inside the reactor buildings of Units 1, 3 and 4. In addition, for Units 1, 2 and 3, the extended periods without cooling led to core melting and subsequent damage to the floors of the reactor vessels.[21] Hydrogen gas in Units 1 and 3 migrated from the primary containment vessels and caused explosions on the service floors, which injured workers and damaged the reactor buildings (see Figure F.3).[22] An explosion in the Unit 4 reactor building was caused by the migration of hydrogen gas produced in Unit 3 via a common ventilation system.[23] This destroyed the structure above the service floor and also injured workers.[24] It is thought that there was a containment vessel failure and uncontrolled releases of radioactive materials from Unit 2, though this has not yet been confirmed.[25]

Approximately nine days after the initial loss of power to the plant, AC power was restored to Units 1 and 2.[26] Units 3 and 4 were connected to off-site power approximately one week after Units 1 and 2.[27] Power was restored to Unit 5 through a power line connection to the diesel generators located at Unit 6.[28] On 20 March 2011, Units 5 and 6 were the first to reach a 'cold shutdown state' after the reactor temperatures were brought below 100 °C.[29]

During their response to the nuclear accident, emergency workers attempted to control the escalation of events to limit their impacts. They focused on maintaining cooling in the reactors using the reactor cooling systems[30], but also improvised methods, such as using fire engines to directly inject cooling water into the reactors, and attempted to re-establish temporary AC power.[31] Where damage from the tsunami or hydrogen explosions made this impossible[32], operators tried to prevent or limit the release of radioactive material from the reactor units. Activities included manual venting to depressurise the reactor or containment vessels.[33]

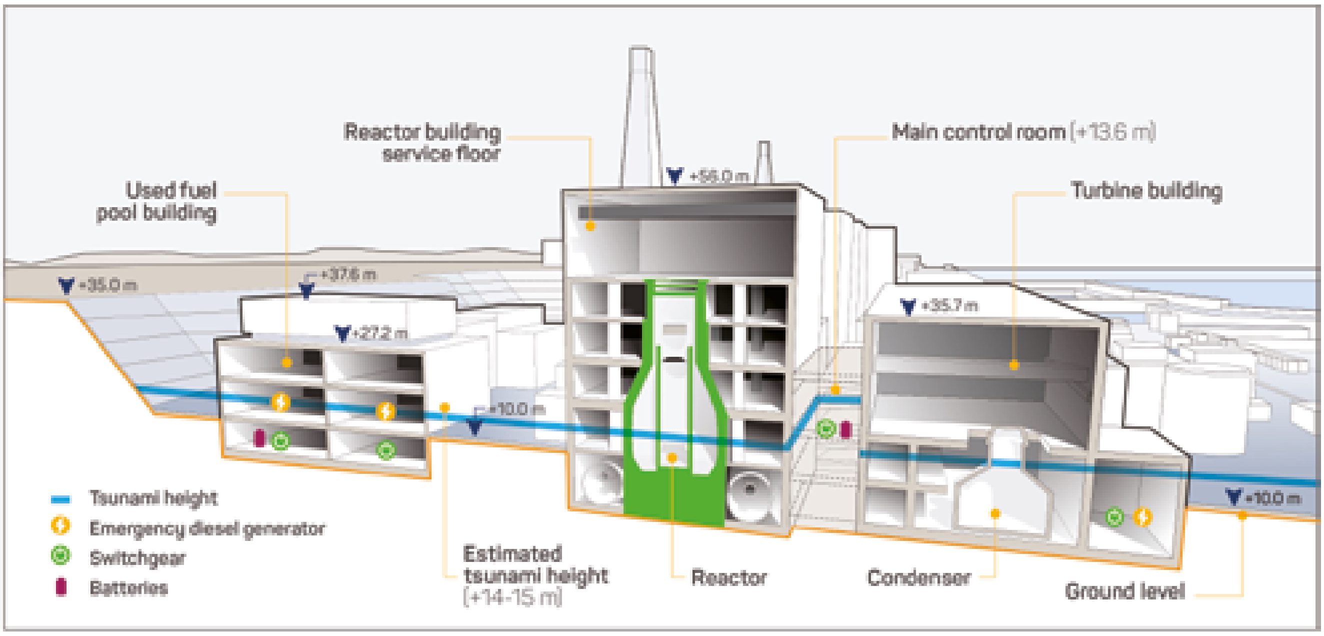

Figure F.2: Cross-section of Unit 4 showing elevations of the plant and the equipment, and the tsunami height

Image adapted from TEPCO data

Figure F.3: Fukushima Daiichi Unit 3 as it appeared on 15 March 2011

Image courtesy of TEPCO

In response to the accident and the potential radiological hazard posed to the surrounding population, the Fukushima Prefecture and, subsequently, the Japanese Government made successive evacuation declarations of increasing radius from the evening of 11 March to 12 March. The Japanese Government also ordered residents within a 20–30 km radial zone to shelter until 25 March.[34] On 16 December 2011, the Japanese Government and TEPCO announced the close of the 'accident phase' of the events at the Fukushima Daiichi plant (see Figure F.4).[35]

There have been no deaths or cases of radiation sickness (of workers, emergency responders and members of the public) attributable to the nuclear accident.[36] However, three workers at the Fukushima Daiichi plant were killed by the earthquake and tsunami.[37] The psychological stress experienced by evacuees as a consequence of the accident and tsunami and the dislocation of evacuees from their communities and livelihoods has had significant health and social impacts.[38]

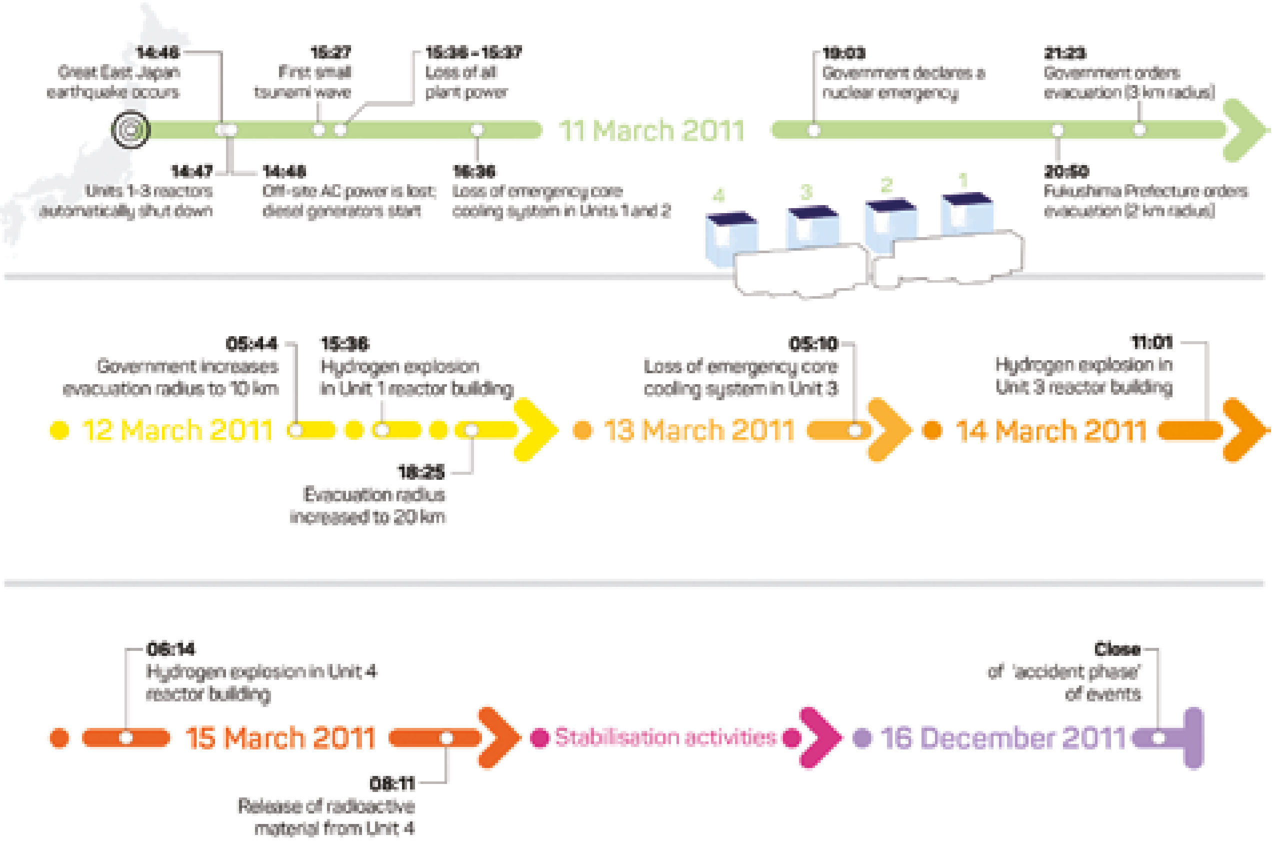

Figure F.4: Timeline of events for 11–15 March 2011, and up to 16 December 2011

Fukushima is an agricultural prefecture, and the economic impacts of the nuclear accident on agricultural production and food consumption, given the radioactive contamination, have been significant. There has also been a wider economic impact in Japan as a consequence of the nuclear accident, as forced reactor shutdowns resulted in a rise in energy imports at significant cost.[39]

The broader impacts of the earthquake and tsunami included damage to or destruction of at least 332 395 buildings, 2126 roads, 56 bridges and 26 railways along the east coast of Honshu. Electricity, gas and water supplies, telecommunications and railway services were also disrupted.[40] The estimated total loss for the Japanese economy caused by the earthquake and tsunami is in the order of US$309 billion.[41]

CAUSES OF THE ACCIDENT

There were a number of deficiencies in the plant design, emergency preparedness, regulatory framework and safety culture in Japan that contributed to the accident and the severity of its impacts.

The Fukushima Daiichi plant was only designed to withstand earthquakes up to magnitude 8.0 and tsunamis up to 5.5 m in height. This design was based on historical seismic records and was not updated to reflect new learning or studies of more recent seismic and tsunami events, nor the experiences of other countries that had faced emergencies at nuclear power plants.[42] Given the magnitude 9.0 earthquake and the 14–15 m tsunami, the events went 'beyond design basis'.[43]

The consequence of the earthquake and tsunami was the simultaneous loss of power to multiple reactor units for an extended period. This revealed several unchallenged design assumptions that:

- nuclear technologies and, particularly, the Fukushima Daiichi plant, were so safe that an accident of the kind experienced was thought to be impossible[44]
- there would never be a loss of power to all units at the same time and any power outage would only be for a short time[45]
- there would not be more than one event to which operators would simultaneously have to respond.[46]

In addition to the design flaws and unchallenged assumptions, workers lacked appropriate training for emergency management, and emergency operational guidelines were inadequate at both the regulatory and corporate levels.[47]

Owing to the nature of the emergency, workers were required to improvise solutions, often without appropriate equipment.[48]

Japan's regulatory framework for nuclear power plants was deficient at the time of the accident.[49] The framework was complex, with a number of agencies having overlapping responsibilities.[50] Additionally, regulators were not sufficiently independent of nuclear power companies[51], including TEPCO.[52] The safety culture at the Fukushima Daiichi plant was characterised by complacency, in which operators and stakeholders did not challenge the assumptions.[53] Accordingly, there was no innovation in the safety culture or the regulatory framework.[54]

Tsunami countermeasures plus normal and emergency operating procedures were not aligned with International Atomic Energy Agency (IAEA) guidelines, and periodic safety inspections did not comply with international standards.[55] Despite this, Japan's Nuclear and Industrial Safety Agency permitted the Fukushima Daiichi plant to operate, and did not require improvements to safety and design, including implementing countermeasures for extreme natural events and emergency preparedness.[56]

As reported in Chapter 4, Electricity generation, a number of lessons learned from the Fukushima Daiichi nuclear accident are being applied to existing nuclear power plants and new nuclear developments. The report by the Director General of the IAEA identifies 45 lessons to improve nuclear safety and emergency preparedness in the wake of the Fukushima Daiichi nuclear accident.[57] Other lessons have been reported by TEPCO[58], the United States National Academy of Sciences[59], the United States Nuclear Regulatory Commission[60], the Institute of Nuclear Power Operations[61], and Greenpeace International.[62]

THE STATUS OF DECOMMISSIONING AND REMEDIATION WORKS

Since the Fukushima Daiichi accident, TEPCO and relevant Japanese Government agencies have developed a plan to decommission Units 1–4 and a strategy to remediate the site and surrounding environment.[63] The first phase of the decommissioning plan—removal of fuel from the spent fuel pools—is ongoing.[64] The second phase—removal of fuel debris from the site—is expected to take ten years.[65] Full decommissioning of Units 1–4 is expected to take 30 to 40 years.[66] The remediation strategy aims to reduce the radiation exposure from contaminated land areas by taking direct action on the contaminated areas and limiting exposure pathways to humans.[67] The costs of decommissioning have been estimated at ¥976 billion (A$10.74 billion), while compensation costs are estimated to be ¥6441.2 billion (A$70.88 billion). Combined, the costs amount to approximately ¥7417.2 billion (A$81.62 billion).[68] The true costs will only become known once decommissioning works are complete.

According to one estimate, approximately 135 000 people remain evacuated.[69] This figure includes 75 000 residents evacuated due to the nuclear accident and a further 60 000 evacuated due to the tsunami and earthquake.[70] Some evacuees have now been able to return to their homes.[71] Consistent with the international nuclear liability system, compensation is being paid to evacuees, homeowners and businesses for pain and suffering, loss of property, expenses incurred from evacuation and loss of income or revenue.[72] In September 2011, the Japanese Government established the Nuclear Damage Compensation Facilitation Corporation (renamed the Nuclear Damage Compensation and Decommissioning Facilitation Corporation in August 2014) to oversee decommissioning and remediation works and the compensation scheme.[73]

A significant amount of contaminated water has accumulated on the Fukushima Daiichi site.[74] This water is treated to remove all radionuclides except for tritium, which restricts the ability to release treated water to the sea. Accordingly, the treated water is stored on the site in tanks.[75] Some contaminated water has been released to the sea due to equipment failure and heavy rainfall. More extensive monitoring and mitigation measures have been introduced, but a sustainable solution is yet to be developed.[76]

Research into demonstration-scale technology to remove tritium with a view to full-scale operation is ongoing.[77]

NOTES

1 International Atomic Energy Agency (IAEA), *The Fukushima Daiichi accident: Report by the Director General*, GC(59)/14, IAEA, Vienna, 2015, p. 23.

2 IAEA, *The Fukushima Daiichi accident*, pp. 1, 23.

3 World Nuclear Association (WNA), 'Fukushima accident', March 2016, http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-accident.aspx

4 The safety systems for controlling the reactivity of nuclear fuel in the reactor core are the reactor protection and control rod drive systems. Before the earthquake, Fukushima Daiichi Units 1–3 were operating, while Units 4–6 were shut down for maintenance and refuelling. The reactors in Units 1–3 were automatically shut down by their reactor protection systems, which were activated by the plant's seismic event monitoring equipment. The insertion of control rods by the control rod drive systems stopped the nuclear chain reaction in the nuclear fuel and shutdown the reactors. IAEA, *The Fukushima Daiichi accident*, pp. 5, 24.

5 Eleven reactors at four nuclear power plants were operating in the region when the earthquake occurred and were shut down automatically. In addition to Fukushima Daiichi Units 1–3, TEPCO's Fukushima Daini Units 1–4, Tohoku's Onagawa Units 1–3, and Japco's Tokai reactor were operating. WNA, 'Fukushima accident'; IAEA, *The Fukushima Daiichi accident*, p. 1.

6 WNA, 'Fukushima accident'.

7 IAEA, *The Fukushima Daiichi accident*, p. 24.

8 The first tsunami warning was issued three minutes after the earthquake (2.49pm) and predicted a 3 m wave height. The second tsunami warning was issued at 3.15pm, 29 minutes after the earthquake, and predicted a 6 m wave. A third warning was issued at 3.30pm, 44 minutes after the earthquake, and predicted a wave height greater than 10 m. Committee on Lessons Learned from the Fukushima Nuclear Accident for Improving Safety and Security of U.S. Nuclear Plants, Nuclear and Radiation Studies Board, Division on Earth and Life Studies; National Research Council (Committee on Lessons Learned), *Lessons learned from the Fukushima nuclear accident for improving safety and security of U.S. nuclear plants*, National Academy of Sciences, The National Academies Press (NAP), Washington, D.C., 2014, p. 103.

9 Committee on Lessons Learned, *Lessons learned*, pp. 90–91.

10 Higher run-up (maximum 39 m) and inundation (maximum 33 m) heights were experienced at other locations along the Japanese coast. IAEA, *The Fukushima Daiichi Accident*, p. 30.

11 United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), *Sources, effects and risks of ionizing radiation*, UNSCEAR 2013 Report to the General Assembly with scientific annexes, vol. 1, Scientific Annex A: Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami, UNSCEAR, UN, New York, 2014, p. 6.

12 IAEA, *The Fukushima Daiichi accident*, p. 1.

13 Elevations are relative to the Onahama Peil (Onahama Port Construction Standard Surface) (OP). Elevations have not been corrected for the ground subsidence that occurred as a result of the earthquake. Committee on Lessons Learned, *Lessons learned*, p. 84.

14 Committee on Lessons Learned, *Lessons learned*, p. 84.

15 IAEA, *The Fukushima Daiichi accident*, pp. 30–31.

16 Committee on Lessons Learned, *Lessons learned*, p. 84.

17 Tokyo Electric Power Company (TEPCO), *The development of lessons from the Fukushima Daiichi nuclear accident*, TEPCO, March 2013, p. 12.

18 IAEA, *The Fukushima Daiichi accident*, p. 32.

19 ibid., pp. 35, 42–43.

20 ibid., p. 57.

21 ibid.

22 ibid., p. 38.

23 ibid., p. 58.

24 ibid., p. 42.

25 ibid., p. 43.

Transcripts and submissions can be found at the Nuclear Fuel Cycle Royal Commission's website: www.nuclearrc.sa.gov.au/transcripts and www.nuclearrc.sa.gov.au/submissions

26 ibid., pp. 44–47.

27 ibid., p. 47.

28 ibid.

29 The term 'cold shutdown state' was defined by the Japanese Government specifically for the Fukushima Daiichi reactors. Its definition differs from the terminology used by the IAEA. IAEA, *The Fukushima Daiichi accident*, pp. 47–48.

30 IAEA, *The Fukushima Daiichi accident*, p. 26.

31 ibid., pp. 34–44.

32 ibid., pp. 37, 39, 42.

33 ibid., pp. 35–43.

34 ibid., p. 84.

35 ibid., p. 48.

36 UNSCEAR, *Sources, effects and risks*, p. 10.

37 WNA, 'Fukushima accident'.

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39 Transcript: Weightman, p. 831. V Vivoda & G Graetz, 'Nuclear policy and regulation in Japan after Fukushima: Navigating the crisis', *Journal of Contemporary Asia* 45, no. 3, p. 493.

40 United States Geological Survey (USGS), Earthquake summary, 23 March 2015, http://earthquake.usgs.gov/earthquakes/eqinthenews/2011/usc0001xgp/#summary

41 USGS, Earthquake summary.

42 Earthquakes in Chile in 1960 and 2010 registered magnitudes of 9.5 and 8.8 respectively, while earthquakes in Alaska (1964) and Sumatra (2004) recorded magnitudes of 9.2; IAEA, *The Fukushima Daiichi accident*, pp. 3–4, 23.

43 Transcript: Caruso, p. 821.

44 Transcript: Caruso, p. 825. IAEA, *The Fukushima Daiichi accident*, foreword.

45 IAEA, *The Fukushima Daiichi accident*, pp. 6, 59.

46 ibid., p. 5.

47 ibid., pp. 4, 59.

48 Transcript: Caruso, p. 822; IAEA, *The Fukushima Daiichi accident*, foreword.

49 Transcript: Weightman, p. 833.

50 ibid., p. 837.

51 ibid., p. 839.

52 Transcript: Caruso, p. 824. Vivoda & Graetz, 'Nuclear policy and regulation', pp. 497–500.

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62 Greenpeace International, *Lessons from Fukushima*, Greenpeace International, Amsterdam, February 2012.

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65 TEPCO, *The development of lessons*, p. 37.

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67 ibid., p. 15.

68 T Holloway (Australian Embassy), letter to Nuclear Fuel Cycle Royal Commission on Fukushima Daiichi NPP accident costs, 25 April 2016. Currencies have been converted based on the average 2015 conversion rate – ¥1 = A$0.011.

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72 S Matsuura, 'The current progress of relief of victims of nuclear damage caused by the Fukushima Daiichi nuclear power plant accident', in Organisation of Economic Co-operation and Development (OECD) – Nuclear Energy Agency (NEA), *Japan's compensation system for nuclear damage: as related to the TEPCO Fukushima Daiichi nuclear accident*, OECD–NEA, 2012, p. 34.

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74 IAEA, *The Fukushima Daiichi accident*, p. 149.

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APPENDIX G: NUCLEAR POWER IN SOUTH AUSTRALIA—ANALYSIS OF VIABILITY AND ECONOMIC IMPACTS

NUCLEAR POWER IN SOUTH AUSTRALIA—ANALYSIS OF VIABILITY AND ECONOMIC IMPACTS

A combination of analyses was undertaken to determine whether nuclear energy would be viable in South Australia in the future.

A study undertaken by WSP/Parsons Brinckerhoff assessed the business case and provides quantitative analyses for developing a nuclear power plant and supporting infrastructure in South Australia.[1]

A separate study undertaken by Ernst & Young evaluated the impact of possible emissions abatement policies consistent with government policy to determine both the future energy generation mix in Australia and associated wholesale electricity prices across the National Electricity Market (NEM). Those outputs were needed to determine the market in which a nuclear power plant would operate.[2]

The outputs of both studies were used in a complementary study undertaken by DGA/Carisway which used the studies' inputs and projections of future electricity demand in South Australia in order to assess the commercial viability of both a large and small nuclear power plant operating in South Australia in 2030 or 2050.[3]

1. ANALYSIS OF VIABILITY—COMMISSIONED STUDY

ASSUMPTIONS AND INPUTS

Nuclear technology options assessed

The financial analysis initially evaluated reactor designs in the Generation III and III+ categories with a generation capacity between 700 MWe and 1600 MWe as well as small modular reactors with a generation capacity less than 300 MWe.[4]

To be further assessed, the reactor technology was required to have:

- been successfully constructed and commissioned elsewhere at least twice by 2022
- cost estimates that were able to be based on realised costs benchmarks or, if they were not available, estimates that could be independently verified.

The analysis considered the most reliable data to be recent, realised benchmarks in project development and construction time frames.

Designs from the following vendors were initially considered[5]:

- light water reactors: Westinghouse AP1000 pressurised water reactor and GE Hitachi economic simplified boiling water reactor
- pressurised heavy water reactors: Atomic Energy of Canada Limited EC6 and ACR-1000
- small modular reactors: NuScale and B&W Bechtel mPower.

The Westinghouse AP1000 reactor was assessed as being the only advanced pressurised water reactor that met the criteria of having been constructed and commissioned elsewhere at least twice before 2022.[6] This assessment was made on the basis that two units are currently under construction in the USA (Vogtle and VC Summer) and China.[7] Public reporting requirements for the costs of developing these reactors in the USA offered a robust basis for estimating the cost of such a facility in South Australia.[8]

Two boiling water reactor designs were considered. While the advanced boiling water reactor has been constructed in Japan and Taiwan, the economic simplified boiling water reactor that incorporates more passive safety features has received only design certification in the USA but is not being constructed.[9] These reactor designs were not further considered.

The EC6 pressurised heavy water reactor is a new design that has not yet been deployed anywhere in the world; the realistic potential for its deployment before 2030 is not known. The status of the advanced ACR-1000 design based on the CANDU 6 model is also not presently known. These reactor designs were not further considered.[10]

A number of small modular reactor designs are currently at various stages of design, component testing, licensing and commercial development. The two designs included for analysis of viability—NuScale and B&W Bechtel mPower—have received substantial funding from the US Department of Energy and are close to having design submissions that are ready to be reviewed by the US Nuclear Regulatory Commission.[11]

While sufficient design and test work has shown that the design of these reactors is likely to be technically feasible, the extent to which efficiency in factory assembly-line type fabrication will overcome the economies of scale offered by a large nuclear power plant is uncertain.[12]

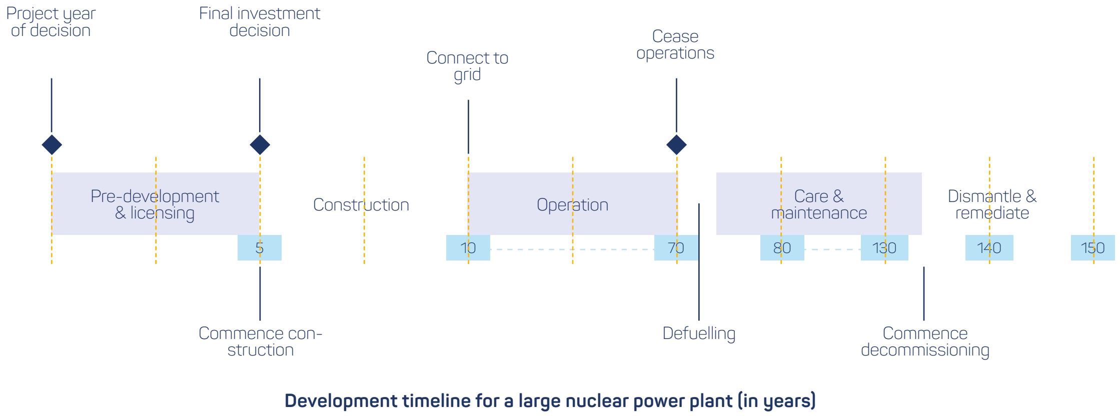


Figure G.1: Development timeline for a large nuclear power plant

Source: WSP/Parsons Brinckerhoff

NON-NUCLEAR OPTIONS ASSESSED

The study also analysed separately two non-nuclear energy generation options that could be operated as part of a low-carbon energy generation system with intermittent renewable technologies. It assessed the viability of installing a commercially proven combined cycle gas turbine system. As an alternative, the gas turbine system was modelled with the unproven carbon capture and storage technology. That analysis provided a baseline against which the viability of nuclear could be measured.

TIMELINE FOR CONSTRUCTION AND OPERATION IN AUSTRALIA

Using the development time frame for a large nuclear power plant in the USA as a basis, an approximate timeline for the development of a large nuclear power plant is presented in Figure G.1.[13] It shows a projected total time frame of approximately 10 years for pre-construction activities including project development, regulatory approval, and licensing and facility construction.

The analysis assumed that project development and licensing time frames for a small modular reactor would be the same as that for a pressurised water reactor. It assumed a short construction time frame of three years on the basis of the pre-fabricated design of small modular reactors.

SITING

Due to costs associated with construction being affected by the presence of existing infrastructure, the viability analysis was undertaken siting the plants on both greenfield or brownfield sites.

A brownfield site was assumed to be very close to or adjacent to established road and electricity transmission infrastructure. A greenfield site, on the other hand, was assumed to be located 50 km from existing supporting infrastructure. For both siting scenarios, a wharf facility was assumed to be developed to support the construction of these facilities and to enable fuel to be transported to and from the nuclear power plant.[14]

CAPITAL AND OPERATING COSTS

Capital cost estimates for the large nuclear power plant were based on realised costs for the Westinghouse AP1000 projects in the USA.[15]

For small modular reactors, cost estimates were based on those of a large scale PWR, with an additional 5 per cent to take account of the absence of benchmark costs.[16]

For both large and small nuclear plants, supporting infrastructure cost estimates were based on realised costs for roads, electrical network infrastructure and wharf facilities in South Australia.[17]

The capital operating and used fuel management costs estimated for the Commission are presented in Table G.1.

For the non-nuclear generating technologies used as a comparison, the capital and operating cost estimates for a combined cycle gas turbine system were drawn from studies published by the Australian Energy Technology Assessment and the Electric Power Research Institute study for the Carbon Dioxide Cooperative Research Centre (CDCRC).

The analysis used the gas price forecast produced for the Australian Energy Market Operator by Acil Allen in December 2014. On this basis, it was assumed that gas prices would vary marginally in the range $9.20–$10.20 per gigajoule between 2030 and 2050.[18]

Table G.1: Life cycle capital and operating costs for two types of small modular reactor and a large nuclear reactor at brownfield and greenfield sites

A$ 2014	Small modular reactor (360 MWe capacity)	Small modular reactor (285 MWe capacity)	Large nuclear reactor (pressurised water reactor – 1125 MWe capacity)
Brownfield site	$3302m ($9173/kW)	$2942m ($10 323/kW)	$8962m ($7966/kW)
Greenfield site	$3692m ($10 256/kW)	$3331m ($11 689/kW)	$9323m ($8287/kW)
Non-fuel operating costs	$61m	$48m	$190m
Fuel costs	$11.80/MWh	$11.80/MWh	$9.90/MWh
Used fuel disposal cost	$5.80/MWh	$5.80/MWh	$4.90/MWh

Source: WSP/Parsons Brinckerhoff

Notes: m = million, MWe = megawatt electrical, MWh = megawatt hour

Table G.2: Assumed level of CO_2-e emissions reduction and corresponding policy mechanisms

Scenario	Current policies	New carbon price	Strong carbon price
Assumed level of emissions reduction	2030: 26–28% reduction in CO_2-e emissions relative to 2005 levels 2050: 80% reduction in CO_2-e emissions relative to 2005 levels		2030: 65% reduction in CO_2-e emissions relative to 2005 levels 2050: complete decarbonisation
Economic policy	Expansion of emissions reduction fund to 2030 Carbon price implemented beyond 2030	Carbon price policy implemented over the period 2017–2050	Carbon price policy implemented over the period 2017–2050

Source: Ernst & Young

FUTURE TECHNOLOGY MIX

An assessment was undertaken to determine the likely future combination of energy generation technologies comprising solar photovoltaic (PV) and wind generation (both with and without energy storage), battery vehicle to grid with electrical vehicle storage, and open cycle gas turbines.[19] This was analysed as being affected by both abatement policies and the costs of those technologies.

EMISSIONS ABATEMENT POLICY

Three scenarios were developed to reflect a range of realistic and possible emissions abatement targets and policies: see Table G.2. The future carbon price to which each of those policies correspond can be seen in Figure G.2.

FUTURE ENERGY GENERATION COSTS

This analysis required an assessment of the impact of the future costs for renewable energy generation and storage technologies, as well as fossil-fuelled generation and carbon capture and storage.

The analysis relied on the estimates of costs from the Australian power generation technology report (2015)[20], to determine which technologies would be able to offer the lowest overall wholesale electricity prices to meet expected demand in 2030. It took account of expected reductions in cost previously published as part of the Australian Energy Technology Assessment 2013 update, as shown in Figure G.3. The cost reductions in those assessments favour new technologies over mature ones, and assume significant reductions in the cost of wind, solar PV, and carbon capture and storage compared to nuclear and fossil fuel generators.

The costs for nuclear were based on the analysis developed above, but excluding project development and licensing costs. This ensured a consistent comparison with the other technologies in the market model. The costs for nuclear are shown with the costs for other technologies in Figure G.3.[21]

The analysis of profitability, however, included project development and licensing costs.

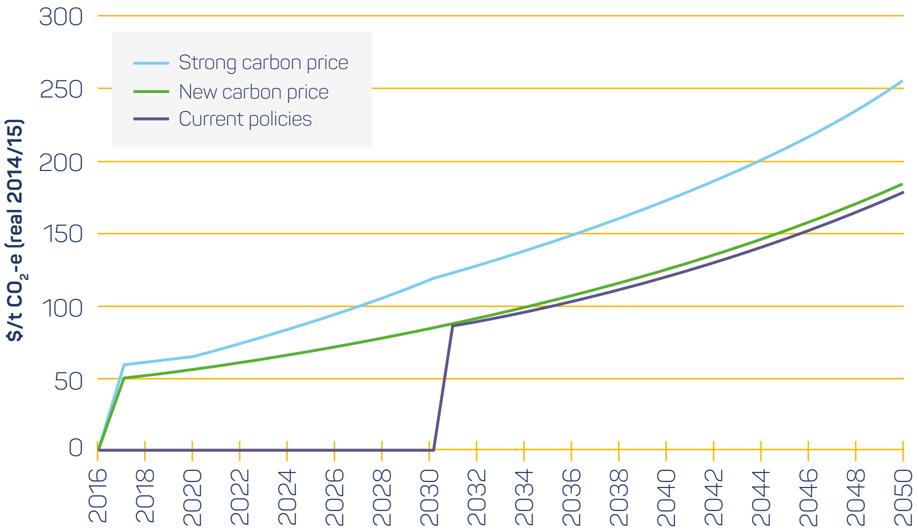
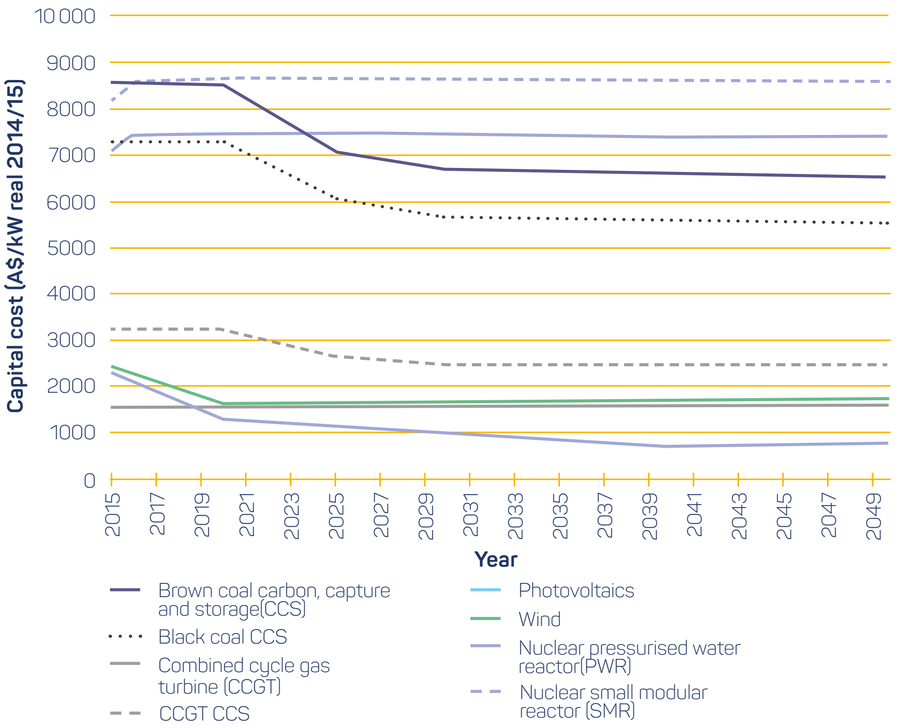


Figure G.2: Assumed carbon prices under the Current Policies, New Carbon Price and Strong Carbon Price scenarios

Source: Ernst & Young



kW = Kilowatt

Figure G.3: Estimated capital costs of key technologies to 2050

Source: Ernst & Young

DEMAND

The analysis of demand required views to be reached about the extent to which residential customers would deploy rooftop solar PV and storage technologies and adopt electric vehicles in the future, as each of these affects network demand. However, no independent assessment was made on the returns to the households making those investments. The analysis assumed:

- that saturation capacity for solar PV (75 per cent of suitable dwellings would have installed capacities of 3.5 kW each) would be reached in South Australia by 2028.[22]
- the substantial uptake of storage technologies by half of all households with solar PV systems would lead to battery storage totalling 1.75 GWh by 2030. This is consistent with the assessments of the CSIRO's Future Grid Forum report[23] and a separate 2015 CSIRO assessment of future energy storage trends for the Australian Energy Market Commission[24] on the basis that the costs of these systems would halve by 2030.[25]
- a higher rate of uptake of electric vehicles under the strong carbon price scenario and a lower rate of uptake under the new carbon price scenario that were consistent with those made by ClimateWorks and Future Grid Forum analyses respectively.[26]

A sensitivity study presented in Figure G.4 outlines the effect of these assumptions being different.

The potential for meeting demand from other regions of the NEM was addressed. For the scenarios that included nuclear generation, an interconnector capacity of 2000 MWe was assumed. However, these analyses did not assess the potential viability of undertaking upgrades to the capacity of connection between South Australia and the eastern regions of the NEM because that would require a detailed regulatory investment test to assess net benefits to electricity consumers in different regions of the NEM.[27]

Electricity demand across Australia was estimated using the general equilibrium modelling analysis for the entire Australian economy, which takes into account the wider economic impacts of implementing emissions abatement policies.

The outcomes of these analyses on demand are shown in Figure G.4.

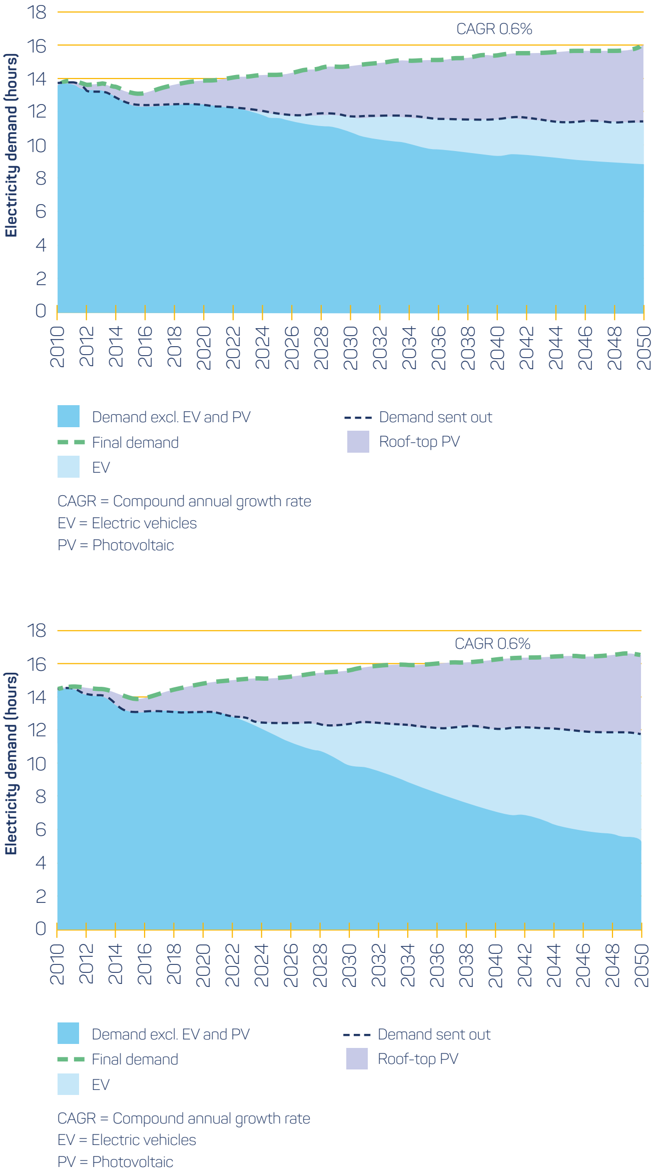


Figure G.4: Electricity demand to 2050 under the New Carbon Price (top) and Strong Carbon Price (bottom) scenarios

Source: Ernst & Young

Notwithstanding projections of a slight increase in total electricity consumption over the next decade in South Australia, the proportion of electricity that would need to be supplied from centralised generation is likely to fall. This is the outcome under either the new carbon price or the strong carbon price scenario.

The electricity demand profile in South Australia was estimated in 2030 and 2050 from data showing network demand at 30-minute intervals in each consumer category: household, business and industry for a full year.[28]

The demand that a nuclear power plant operating as a baseload facility in South Australia could meet was determined on the basis that energy from a nuclear plant would be dispatched after residential solar PV and wind generation.

EXTENT OF DEMAND FOR A NUCLEAR PLANT TO SUPPLY ELECTRICITY IN SOUTH AUSTRALIA

An average operational capacity factor for a large nuclear power plant was estimated to be 92 per cent and for a small modular reactor of 93–95 per cent.[29] That was based upon the capacity factors of modern plants operating in the USA.

Assuming the lowest cost mix of generation and a strong carbon price, the analysis showed:

- half of the annual electricity output of a large nuclear power plant
- 63 per cent of annual electricity output of a small modular reactor[30] would be dispatched within the South Australian region of the NEM.

When there was an excess of supply it was assumed that the balance would be exported to the eastern regions of the NEM through an expanded interconnector of 2000 MW capacity.

RESULTS OF ANALYSIS OF VIABILITY

The introduction of a large nuclear power plant into the South Australian region of the NEM in 2030 as a baseload plant would have an immediate impact by reducing the wholesale regional reference price of electricity in South Australia: see Figure G.5. It would be reduced by about 24 per cent, or $33/MWh, under the strong carbon price scenario.

In comparison, the introduction of a small modular reactor into the South Australian region of the NEM in 2030 would be expected to reduce wholesale prices by approximately 6 per cent, or $8/MWh.

In contrast, the integration of combined cycle gas turbine, or gas turbine with carbon capture and storage, does not have any impact on wholesale prices.

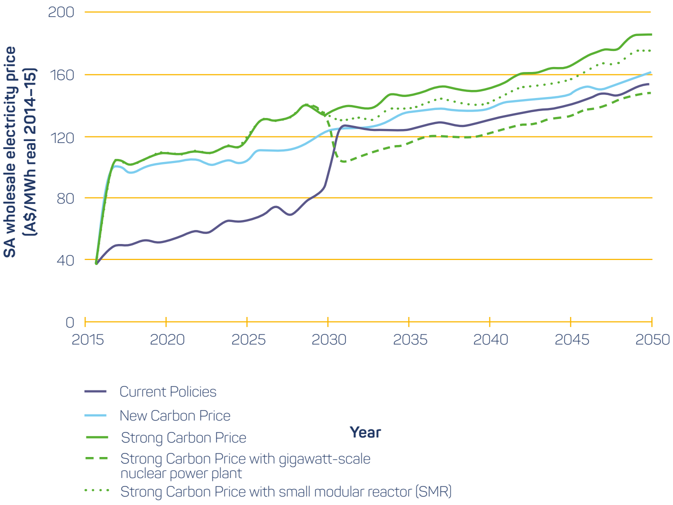


Figure G.5: Annual average real wholesale electricity price in South Australia, 2014/15 prices

Source: Ernst & Young

That is because these generators do not operate in periods of increased supply from renewables or low demand, but only operate when the wholesale price of electricity is greater than their cost of operation.[31]

Based on the annual generation output of both a large and small nuclear plant and the prevailing wholesale price, the revenues of a large and small nuclear plant were estimated. From those revenues and based on the costs discussed earlier, an analysis of profitability showed that both the small modular reactor and large nuclear power plant options consistently deliver strongly negative outcomes under either carbon price scenario on a commercial rate of return of 10 per cent: see Table G.3.[32]

An investment in a combined cycle gas turbine (CCGT) system was found to be viable under all emissions abatement scenarios irrespective of when the facility is commissioned.[33] The viability of installing CCGT with carbon capture and storage was, in comparison, assessed using a different approach that accounted for both the cost and inherent uncertainty associated with proving its feasibility. It was found that it would not be commercially viable due to the significant costs associated with proving the stability of CO_2 in underground geological formations.[34] This is discussed in more detail in Box G.1.

Table G.3: Profitability at a commercial rate of return (10%) for large and small nuclear power plants and combined cycle gas turbine plants commissioned in 2030 or 2050 under the new carbon price and strong carbon price scenarios (internal rates of return provided in parentheses for all scenarios)

Net present value (A$ billion 2015)	New carbon price		Strong carbon price	
Year commissioned for operation	**2030**	**2050**	**2030**	**2050**
Small modular reactor (285 MWe)	–2.2 (4.8%)	–1.9 (5.1%)	–1.8 (5.9%)	–1.4 (6.6%)
Large nuclear reactor (1125 MWe)	–7.4 (4.5%)	–6.4 (4.8%)	–6.3 (5.6%)	–4.7 (6.4%)
Combined cycle gas turbine (374 MWe)	0.22 (13%)	0.37 (14%)	0.32 (14%)	0.57 (16%)

Source: DGA Consulting/Carisway

Table G.3 also shows in brackets the internal rate of return that would correspond to the net present value of the investment being equal to zero. These internal rates of return show that a nuclear power plant would be profitable if it received finance at a cost of capital of between 4.5 per cent and 6.6 per cent. While commercial finance is not typically available at this interest rate, if a nuclear power plant were developed as a public project or received a guarantee on debt from a public institution, it might be profitable.

SENSITIVITY ANALYSIS

A sensitivity analysis reflecting a higher cost of meeting abatement goals and a lower consumer uptake of storage was undertaken based upon a higher carbon price (25 per cent higher than the base case) and a lower uptake of residential storage technologies (40 per cent lower than the base case).

This led to a wholesale electricity price (shown in Figure G.6) estimated to be 49 per cent higher in 2050 than under the base strong carbon price scenario.[35]

To assess the potential viability of nuclear power under this scenario, a comparison was made between the levelised cost of electricity of the large nuclear reactor and small reactor options and the levelised price of electricity they would receive over their lifetimes. It was assessed that if the levelised cost of electricity was lower than the levelised price of electricity, a nuclear power plant could be commercially viable in South Australia.

Even with the higher wholesale prices of that scenario, investment in a large nuclear plant would not be viable at present costs. However, as shown in Figure G.7, it might be viable if it were able to be delivered for a cost that is 8 per cent less than the current estimates set out in Table G.1.[36] The same result would prevail, at current costs, if finance could be obtained at 7 per cent: see Figure G.8.

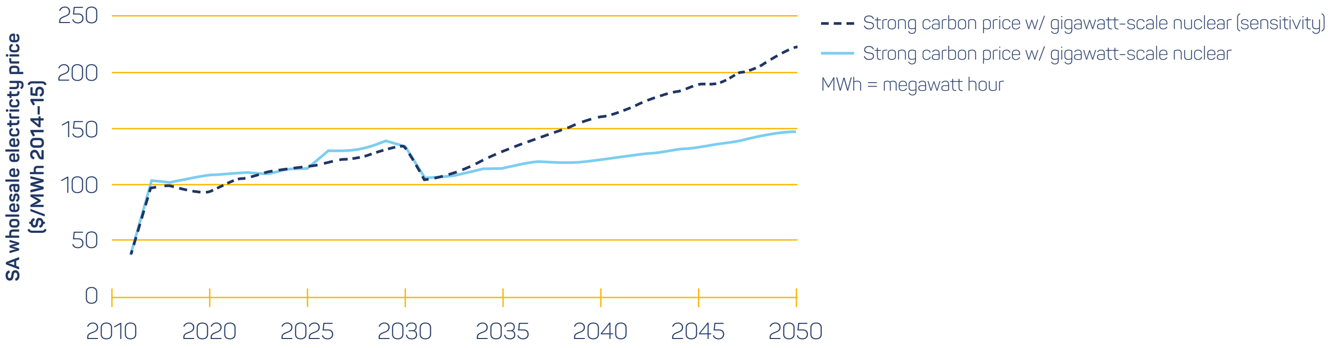


Figure G.6: Annual average real wholesale electricity price in South Australia, 2014/15 prices, Strong Carbon Price sensitivity

Source: WSP/Parsons Brinckerhoff

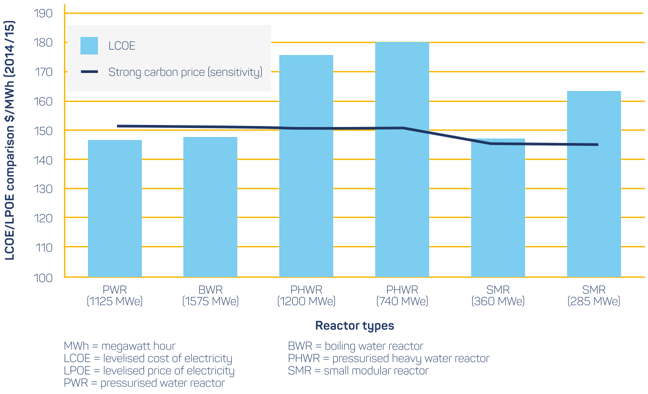


Figure G.7: Low capital cost

Source: WSP/Parsons Brinckerhoff

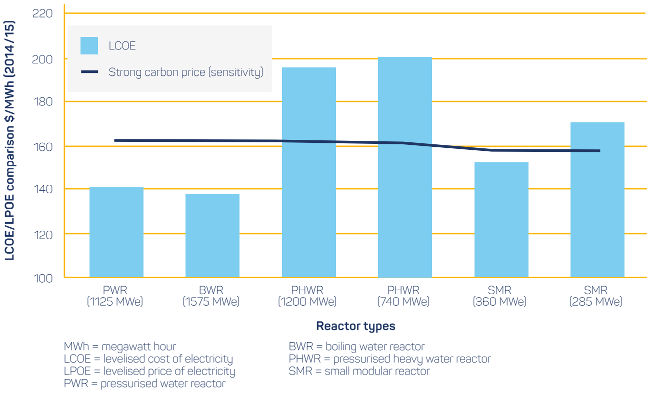


Figure G.8: Low finance cost (7 per cent)

Source: WSP/Parsons Brinckerhoff

2. ANALYSIS OF ECONOMIC IMPACTS —COMMISSIONED STUDY

Economic modelling using a general equilibrium model was undertaken by Ernst & Young to assess the potential effect on the wider South Australian economy of investments being made in either a small or large nuclear power plant. It estimated changes in key measures of economic activity such as gross state income, gross state product, wages and employment.

The modelling undertaken used the transparent, peer-reviewed model maintained by the Victoria University Centre of Policy Studies known as the Victoria University Regional Model (VURM).[41] *This model has been used widely in Australia to assess the effects of investments made in one part of the economy on economic activity more broadly.*

ASSUMPTIONS AND INPUTS

The potential macroeconomic impacts of investing in either a large nuclear power plant or a SMR (285 MWe) were assessed. Given that the business case assessments showed that investment in a nuclear power plant would not deliver a rate of return greater than the commercial benchmark of 10 per cent, for the purposes of the model it was necessary to assume that a substantial subsidy was made to fund its development.[42] It was assumed that this subsidy would only be provided for an investment in either a small or large nuclear power plant under the strong carbon price scenario in response to a government policy decision to meet aggressive emissions reduction targets by 2050.

RESULTS

The modelling analysis showed that investment in either the small or large nuclear power plant would have negative impacts on the South Australian economy between 2030 and 2050, even though there are some positive effects over the construction phase.

This negative economic impact arises because nuclear power does not offer a source of electricity generation that can deliver a commercial rate of return through private investment alone. This outcome is indeed consistent with the business case analyses, which showed that while a nuclear power plant investment does not yield a commercial rate of return under any circumstances, an investment in combined cycle gas turbine does, even under the strong carbon price scenario.[43]

The scale of the impact depends upon the extent to which funds used to develop the nuclear plant impact expenditure on other activities which themselves generate state income.

If an investment in either a large or small plant were funded such that it does not lead to reduced state government expenditure in other areas, it leads to a modest improvement to gross state product and a modest reduction in gross state income in 2049–2050: see Table G.4 and Table G.5.

This outcome arises because a significant decrease in wholesale electricity prices in the SA region of the NEM could lead to significant electricity exports through an expanded interconnector to the eastern region of the NEM: that is, SA could become a net exporter of electricity.

The effect of investment in a large plant if it did lead to reduced state government expenditure in other areas, was estimated to be a substantial decrease in gross state income (–3.6 per cent) and gross state product of (–3 per cent) in 2049–50: see Table G.4.

TECHNOLOGICAL UNCERTAINTY IN PROVING THE VIABILITY OF CARBON CAPTURE AND STORAGE

Carbon capture and storage technologies have been put forward to the Commission as having the potential to reduce the emissions intensity of fossil fuel electricity generation technologies such as combined cycle gas turbine systems. However, while the technologies to capture CO_2 from exhaust gas streams are commercially available, there are substantial uncertainties associated with the capacity of geological reservoirs to store CO_2 and the operational integrity of these reservoirs at high CO_2 injection rates. Substantial investments in research, development and demonstration activities will need to be made to resolve these challenges.[37]

To provide a consistent basis for comparing the viability of energy systems that incorporate carbon capture and storage against technologically mature technologies such as nuclear, the cost associated with demonstrating the feasibility of the technologies must be included. Not only does this assessment need to incorporate the cost of research, development and demonstration (RD&D) activities but also a risk that, even after these investments are made, the technologies remain unproven and the entire investment is lost. To date, most research and development activities in carbon capture and storage have been based on numerical modelling analyses. To validate these numerical modelling analyses there is a need for an investment of $1bn–$2bn in site characterisation, exploration and appraisal activities.[38]

If the costs and uncertainties associated with RD&D activities are incorporated into the model, a combined cycle gas turbine system that incorporates carbon capture and storage is unlikely to yield a commercial rate of return under any scenario. This is because private investors are unlikely to make the substantial investments in RD&D activities that would be necessary to prove the feasibility of this technology. This outcome arose even if a strong carbon price was imposed across the economy.[39]

This means that substantial public investment in RD&D activities would be necessary to support the development of technologies to prove carbon capture and storage for commercial deployment with fossil fuel fired power stations. An assessment of nuclear technologies has to be considered alongside the cost of proving the feasibility of unproven technologies such as carbon capture and storage.

This method of analysis is also applicable to other immature technologies such as energy storage and geothermal energy that will require substantial investment in RD&D to realise expected cost reductions.[40] If these cost reductions are not realised, there is a substantial risk that the cost of achieving emissions reduction outcomes would be higher than has been projected.

Table G.4: Impact of investment in a large nuclear power plant on the South Australian economy in 2030 and 2050 under the Strong Carbon Price scenario

Large nuclear power plant	2029–30	2049–50	2049–50 [a]
Gross state income	$486m (0.36%)	–$7178m (–3.6%)	–$594m (–0.30%)
Gross state product	$524m (0.37%)	–$6000m (–3.0%)	$201m (0.10%)
Wages	0.11%	0.50%	
Total employment	575	620	
Direct employment	330	258	

[a] Economic impact assuming expenditure on developing nuclear power plant does not impact other government expenditure.

Note: m = million

Source: Ernst & Young

Table G.5: Impact of investment in a small nuclear plant on the South Australian economy in 2030 and 2050 under the Strong Carbon Price scenario

Small nuclear power plant	2029–30	2049–50 [a]
Gross state income	$370m (0.27%)	–$68m (–0.03%)
Gross state product	$344m (0.24%)	$107m (0.05%)
Wages	–0.02%	0.14%
Total employment	540	473
Direct employment	167	120

[a] Economic impact assuming expenditure on developing nuclear power plant costs does not impact other government expenditure.

Note: m = million

Source: Ernst & Young

NOTES

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6 ibid., section 2.4.1.2.

7 ibid., section 6.2.1.1.

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9 ibid., section 2.4.2.

10 ibid., section 2.4.3.

11 ibid., section 2.5.

12 ibid.

13 ibid., figure 3.1, section 3.2.2, section 6.4.

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26 ibid., section 5.1.

27 WSP/Parsons Brinckerhoff, *Establishing a nuclear power plant*, section 7.1.5.

28 DGA Consulting/Carisway, *Electricity generation*, executive summary, p. 9.

29 WSP/Parsons Brinckerhoff, *Establishing a nuclear power plant*, executive summary p. xvii, section 6.8.

30 DGA Consulting/Carisway, *Electricity generation*, section 4.6.

31 Ernst & Young, *CGE modelling assessment*, section 5.9; DGA Consulting/Carisway, *Electricity generation*, sections 5.2.2, 5.7 .

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42 ibid., section 6.5

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Transcripts and submissions can be found at the Nuclear Fuel Cycle Royal Commission's website: www.nuclearrc.sa.gov.au/transcripts and www.nuclearrc.sa.gov.au/submissions

APPENDIX H: SITING SIGNIFICANT FACILITIES—CASE STUDIES

This appendix presents the findings of six case studies. Five of the studies provide details of the processes used internationally to site new radioactive waste disposal facilities and the relevant aspects of community engagement of each case. The cases are:

- the ONKALO deep geological repository in Finland
- the Konrad deep geological repository in Germany
- the cAt Project surface repository in Belgium
- the CIGEO deep geological repository in France
- the Wolsong surface and geological repository in South Korea.

The final study provides details of the approach used by Energy Resources of Australia in its engagement with Mirarr traditional owners regarding the Ranger uranium mine in Australia's Northern Territory.

Together, these case studies provide valuable lessons on community engagement when siting any future nuclear development in South Australia. The cases show that proponents made mistakes in their early engagement with the affected communities, principally addressing technical issues and paying little attention to community concerns. These initial approaches resulted in either a failure to gain consent or, where the development proceeded, as in the case of the Konrad facility, a rejection of the siting process as illegitimate or unfair by the local community.

In most of the cases, siting approaches were revised to take into consideration the concerns, rights and interests of the affected communities. These changed approaches have resulted in successful facility siting in the Finnish, Belgian, French and South Korean cases.

The case studies support discussion in Chapter 5 and Chapter 6.

CASE STUDY 1

ONKALO DEEP GEOLOGICAL REPOSITORY AT OLKILUOTO, EURAJOKI, FINLAND

ONKALO (see Figure H.1) is expected to be the world's first permanent deep geological repository for spent nuclear fuel. It is being developed in the municipality of Eurajoki, Finland. The proponent company, Posiva, was established in 1995 as the joint initiative of two Finnish electrical energy firms: Teollisuuden Voima Oyj (TVO) (60 per cent) and Fortum Power & Heat Oy (40 per cent). ONKALO is estimated to become operational in 2022–23 and will be closed (permanently sealed) in 2120.[1] Eurajoki, which is an existing nuclear community—home to the Olkiluoto nuclear power plant—provided its consent to locate the facility in the municipality. In December 2000, the Finnish Government issued a 'Decision-in-Principle' in favour of the project.[2] The closest village is 8 km from the facility area.[3] The local economy is supported by industries including agriculture, forestry and tourism.[4] Eurajoki is a popular holiday destination.[5]

Figure H.1: The ONKALO facility (foreground) with the Olkiluoto nuclear power plant above

Image courtesy of Posiva Oy[6]

Development of the project

Construction of the repository will commence in 2016 following receipt of the necessary licence in 2015.[7] The entire project timeline is shown in Figure H.2.

The Nuclear Energy Act 1987 and the Nuclear Energy Decree 1988 govern nuclear developments in Finland, and are set by parliament; other relevant regulatory decrees are set by government. Regulatory oversight is provided by the Radiation and Nuclear Safety Authority (STUK). The licensing procedure is as follows:

1. Application for Decision(s)-in-Principle, both for development approval and final disposal plan; subsequent ratification by parliament
   - environmental impact assessment (EIA) to be conducted in accordance with the Act on the Environmental Impact Assessment Procedure 1994 and the Nuclear Energy Act
   - local municipality vote (veto right)—established in the constitution and the Nuclear Energy Act
   - safety appraisal by STUK (veto right)
2. Application for construction licence—issued by government, Preliminary Safety Analysis Report
3. Application for operating licence—issued by government, Final Safety Analysis Report.[8]

Specific aspects of community engagement

Steps in the community engagement process are shown in Table H.1. Initial consultations with potential host communities commenced in 1987 following a self-selection process, which was preceded by a geological assessment by TVO. Posiva used an environmental impact assessment (EIA) process (1997–99) as a means of ascertaining community sentiment in four volunteer municipalities (Eurajoki, Loviisa, Äänekoski and Kuhmo).[9]

Posiva established proactive stakeholder engagement strategies aimed at promoting the benefits of the project to the municipalities in the knowledge that municipalities had a veto right. Posiva faced opposition from residents, councils and civil society organisations in three municipalities: Loviisa, Äänekoski and Kuhmo. There was no organised opposition in Eurajoki.[10]

Posiva sought to narrow the knowledge gap between nuclear experts and Eurajoki residents. The company linked the development of the repository to the local institutions and culture, in particular the restoration of a local mansion, and to the delivery of employment opportunities, increased tax revenues, and positive health and education impacts.[11]

Posiva was thoughtful in the way it engaged with the community and built trust in the ONKALO project.[12] Several municipal politicians played a role in overturning an earlier ban on the disposal of used fuel in Eurajoki.[13]

The role of STUK was influential in engaging with residents and other citizens, and addressing concerns about risks. 'STUK has been involved in the process from the very beginning and has been at the disposal of the citizens as an independent organisation giving information and being present when required. That has also created some confidence to citizens'.[14]

The 1999 and 2008 EIAs utilised a number of community engagement initiatives (e.g. meetings, a visitor centre, and a travelling exhibition) aimed at generating interaction with the community, soliciting resident input into project design, communicating expert knowledge and reducing misunderstandings about project risks.[16]

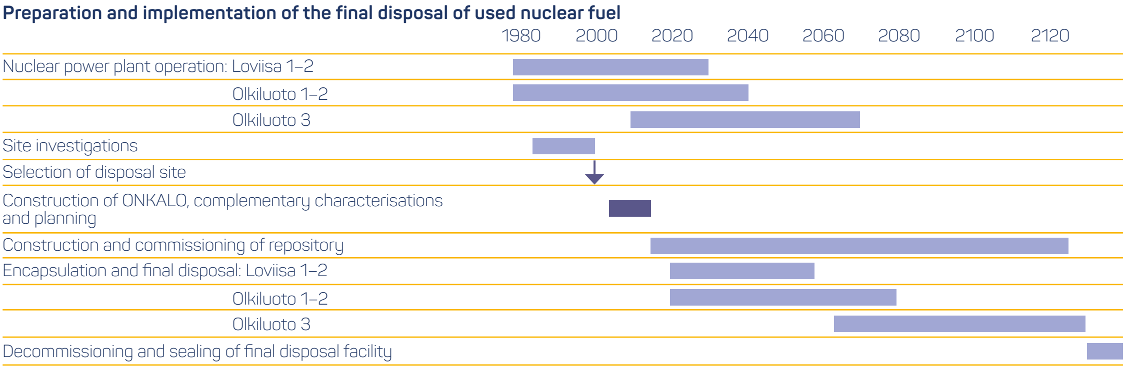

Figure H.2: ONKALO project timeline

Data supplied by Posiva Oy

Table H.1: Points at which community engagement occurred

Date	Event
Late 1980s	Liaison group established by TVO and Eurajoki
1993	Following Eurajoki council elections in 1992, National Coalition Party councillors propose engagement with TVO about hosting a spent nuclear fuel repository
1994-12	Eurajoki overturns previous ban on hosting repository
1996-02	Eurajoki opinion on the repository formed (favourable)
1997–1999	Environmental Impact Assessment process; report delivered 1999
1997-04	Posiva announces that municipal visions will be considered as part of the EIA process
1998-01-22	Vuojoki Working Party established by Eurajoki and TVO/Posiva to negotiate compensation agreement for hosting repository; 21 meetings held between 22 January 1998 and 24 January 2000
1998-12	Eurajoki's Olkiluoto Vision approved by municipal council (20 votes in favour of the repository, 7 against)
1999-05-03	Vuojoki Agreement (compensation agreement) approved by Eurajoki municipal council
1999-05-26	Vuojoki Agreement signed by Posiva and Eurajoki municipal council
Community consent: 2000-01-24	Eurajoki municipal council approves a favourable statement on the Decision-in-Principle (veto right)
2000-12-21	Government approves the Decision-in-Principle
2001-05-18	Parliament ratifies the Decision-in-Principle
2008-03 / 05	Environmental Impact Assessment process (expansion)

Sources: Kojo, Litmanen. [15]

Newsletters were the main medium through which Posiva informed the public on the development of ONKALO.[17]

Perceptions of the Eurajoki municipal council and residents about hosting a repository changed following sustained engagement between TVO (later Posiva) and the community from 1985 to 2000. The project came to be seen as part of, and emerging from within, the community.[18] Working and liaison groups between the companies and municipality contributed to changed perceptions, as did the engagement and communication tools—including language—used by Posiva to describe the development and its associated risks and opportunities.[19] For example, Posiva used the term 'final disposal' instead of 'nuclear waste' or 'spent fuel' in its communication with Eurajoki residents.[20]

Key lessons

Several key lessons emerge for community engagement practice from this case study:

- There is a need to create a sense of shared ownership in order for community consent to be obtained and maintained. Accordingly, a development has to be seen to be built from within the community.
- Public trust in the credibility of the regulatory system was crucial to residents' acceptance of ONKALO.
- Concerns about tourism, other local industries and the natural environment were not impediments to siting ONKALO.
- Due to the set timeframe for project delivery, the community (Eurajoki) was able to exercise its right to veto the development within two years of stating its favourable disposition toward the project. This meant that the community was not left with uncertainty.

Risks were discussed only in the context of assuring residents that the technical experts were competent. Posiva created a 'collective cocoon of safety' around the project.[21]

CASE STUDY 2

KONRAD DEEP GEOLOGICAL REPOSITORY IN SALZGITTER, LOWER SAXONY, GERMANY

Konrad (Figure H.3) is an abandoned iron ore mine in Salzgitter, Lower Saxony, Germany, which is being converted into a low and intermediate level waste (LILW) repository.[22] Disposal will occur in hard rock (coral oolith) at depth below –800 m, under a naturally occurring 400-metre-thick clay barrier.[23] The repository will hold 303 000 cubic metres of radioactive waste at a planned disposal rate of 10 000 cubic metres per year of operation.[24] Konrad was granted a 'plan-approval decision' (licence) in 2002, after many years of legal hurdles and community opposition.[25] In 1984, the German Government awarded German company DBE responsibility for the construction and operation of Konrad.[26] Regulatory oversight is provided by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), while the Federal Office for Radiation Protection (BfS) is the implementing agency for radioactive waste management. The economy of Salzgitter is based on industrial activity, services, culture and history.[27]

Development of the project

The licensing procedure was conducted in several stages (see Table H.2). It required consultation with the public and involvement of local authorities.[28] Technical bodies also were involved at the national and *Länd* (state) level. The licensing procedure in the Konrad case proceeded according to the processes established in a plan-approval application.[29] The German Bundestag passed a new Repository Site Selection Act in 2013, which does not apply to Konrad.[30]

Specific aspects of community engagement

The Konrad mine was first proposed by the local community as a potential site for a disposal facility following a favourable statement on its suitability by the then responsible agency, the Physikalisch-Technische Bundesanstalt.[32] However, for most of the 1970s, '80s and '90s, there was limited engagement with the host community regarding the siting of Konrad.[33]

There has been community opposition to Konrad since the site was first selected.[34] Environmental groups mobilised against Konrad due to concerns about its safety and the site selection process.[35] According to AG Schacht Konrad, a group established to oppose the repository development,

Figure H.3: The Konrad facility in Salzgitter

Image courtesy of the Federal Office for Radiation Protection

Table H.2: Konrad project timeline and points at which community engagement occurred

Date	Event
1976–1982	Konrad is examined for its suitability as a repository for low and intermediate level waste
1982-08-31	Application filed to initiate a plan-approval procedure for disposal by Physikalisch-Technische Bundesanstalt, predecessor of the Federal Office for Radiation Protection; repository plan submitted to 70 authorities and nature conservation organisations for their opinions
1983-05	Information Centre for Nuclear Waste Management opens in Salzgitter
1989	Repository plan submitted to the Lower Saxony Environment Ministry for approval
1991	Germany's Federal Administrative Court issues a directive to force the public display of the plan documents. Application documents are open for public inspection for two months; across Germany, 289,387 objections to the project are submitted
1992-09-25 – 1993-03-06	75-day public hearing on the repository proposal; objections raised by affected residents in their submissions and the statements of civil society organisations are discussed during the hearing
2000-06-14	German Government announces that the plan-approval process is complete
2002-05-22	Lower Saxony Environment Ministry grants approval for Konrad
2002–2006	Eight legal actions lodged against Konrad by communities, rural districts, churches and private individuals
2006-03-08	Lüneburg Higher Administrative Court dismisses actions and does not permit a revision; one claimant appeals to the Federal Administrative Court
2007-03-26	Federal Administrative Court upholds the Lüneburg Court's decision; the plan-approval for Konrad is effective and enforceable
2007-04-03	Federal Administrative Court rejects non-admission complaint; City of Salzgitter begins proceedings against Konrad in Germany's Constitutional Court
2007-05-30	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) commissions BfS to begin construction of the repository; opening date of 2013 announced
2008-02-21	Constitutional Court rejects legal action brought against Konrad by City of Salzgitter
2008	Approval of operating plan
2011-05-27	Announcement of Konrad Repository Foundation: €100 million (A$147.8 million) will be paid to City of Salzgitter over 35 years
2013-05-15	BMUB announces new opening date (2021), with delay due to need for mine site shaft remediation
2013-10	Construction firm DBE announces new estimated costs for Konrad. The new year for completion is announced as 2022. DBE is required to re-engineer the project to correct assumptions that were made about the project in the 1980s and '90s, and to account for scientific and technological advances, as well as amended legislative requirements

Sources: BfS, AG Schacht Konrad[31]

the project still does not have the support of the host community or the City of Salzgitter.[36]

In 2011, the German Government announced that the City of Salzgitter would receive €100 million (A$147.8 million) over 35 years (majority of funds paid by electric utilities) in return for hosting the repository.[37]

Key lessons

Several key lessons emerge from this case study for community engagement practice:

- Local confidence in the agents responsible for the site selection process was diminished following the 'top-down' siting process, which was viewed by the community as being 'unfair'.[38]
- There is a need for a formal site selection procedure, which engages with prospective host communities. Such a procedure has now been developed by Germany for the selection of a future repository site for disposal of high level waste (HLW).
- The community's perceived lack of engagement from project proponents and concerns about the repository's development resulted in legal actions being brought against the project. These actions have caused significant delays in project delivery.

CASE STUDY 3

THE CAT PROJECT SURFACE REPOSITORY IN DESSEL, ANTWERP, BELGIUM

The Belgian program for the disposal of low level radioactive waste (the cAt Project) is an integrated project for surface disposal of Category A waste (low and intermediate level short-lived waste) in Dessel, Belgium (see Figure H.4). The facility is designed to hold 70 500 m^3 of waste, and is expected to be operational in 2022.[39] Disposal will occur over an indicative duration of 50 years, with a nuclear regulatory control phase involving monitoring and surveillance to continue for 250 years after repository closure. The project integrates technical considerations with socioeconomic aspects, and is a consequence of a unique local partnership process involving the proponent, ONDRAF/NIRAS, and the host community of Dessel, which was established by the Belgian Government. Dessel has a long history with nuclear research and industry, including nuclear fuel production (all activities stopped in 2012) and storage facilities for high level, intermediate level and low level waste. Site selection was driven by community support.[40]

Development of the project

ONDRAF/NIRAS is the independent national agency (answerable to the Ministers for Economic Affairs and Energy) responsible for the management of radioactive waste and enriched fissile materials in Belgium.[41] The Federal Agency for Nuclear Control (FANC) is responsible for licensing, control and surveillance of nuclear activities, including waste management and disposal. The licensing procedure for radioactive waste management and disposal facilities is as follows:

1. licence application submitted to FANC. FANC reviews application and seeks advice of the Scientific Council for Ionizing Radiation (a body of 22 experts in nuclear safety, radiological protection and environmental protection)
2. licence application and preliminary safety advice forwarded to municipal authorities for public enquiry and advice
3. application forwarded to provincial authority for advice. International treaty consultations occur at this time

Figure H.4: Artist's impression of the proposed surface repository in Dessel after closure

Image courtesy of ONDRAF/NIRAS

4. Scientific Council for Ionizing Radiation provides final advice to FANC (veto)
5. licence granted by royal decree, countersigned by Minister for Home Affairs.[42]

Table H.3 shows the project timeline and points of community engagement.

Specific aspects of community engagement

Following the failure of site surveys in the 1980s and early 1990s to identify a repository site that had community support[44], the Belgian Government announced in 1998 that it would concentrate its site selection process for a repository on existing nuclear and volunteer communities, and involve these communities in the process.[45]

Local partnerships were established in three volunteer communities (Dessel, Mol and Fleurus-Farciennes); each partnership signed an agreement with ONDRAF/NIRAS.[46] The partnerships were required to develop technical conceptual proposals for final disposal facilities that also addressed socioeconomic considerations. Municipal councils were required to approve or reject the proposals. The Belgian Government decided final site selection based on an assessment of community consent following community council deliberation. The process resulted in the selection of the municipality of Dessel in June 2006, based on the concept developed by STOLA-Dessel.[47]

Partnerships were tasked with:

- evaluating concepts for disposal facilities integrating technical considerations (design, safety, environmental

Table H.3: The cAt Project timeline and points at which community engagement occurred

Date	Event
1998-01-16	Belgian Government announces start of process to identify location for a repository for Category A waste; Minister of the Economy tasks ONDRAF/NIRAS with overseeing this process
1999-09	Municipality of Dessel and ONDRAF/NIRAS establish the local partnership, STOLA-Dessel
2004-11	STOLA-Dessel publicly states support for siting of repository in Dessel and presents concept proposal
Community consent: 2005-01-27	Dessel municipal council unanimously endorses STOLA-Dessel proposal to develop repository
2005-04	STORA, successor organisation to STOLA-Dessel, founded
2006-06-23	Belgian Government selects Dessel, an existing nuclear community, as the location of the surface repository
2007–2011	Detailed site studies conducted
2010-03	cAt Project master plan released
2011–2012	The Organisation for Economic Co-operation and Development - Nuclear Energy Agency (OECD–NEA) reviews key aspects of the safety case at the request of the Belgian Government
2012	Safety case adapted in response to OECD–NEA's peer review questions/comments; these have been addressed by ONDRAF/NIRAS and its technical support organisations
2013-01-31	ONDRAF/NIRAS submits the adapted safety case to the Federal Agency for Nuclear Control (FANC) as part of the request for a licence to build and operate the surface repository
2013–2016	ONDRAF/NIRAS and its technical support organisations carry out additional safety calculations based on FANC's review comments
2017	*Expected date to submit safety case to the Scientific Council for Ionizing Radiation*
2018	*Expected date to obtain nuclear licence for surface disposal*
2022	*Expected date when repository is operational*

Sources: ONDRAF/NIRAS, NIRAS, OECD–NEA, STORA[43] and health) and social aspects (socioeconomic added value and ecological preconditions)

- facilitating radioactive waste management research complementary to ONDRAF/NIRAS' research
- being forums for structured project negotiation and local consultation
- communicating with local residents.[48]

The key features of the partnership process were:

- the partnership methodology was developed by researchers at two universities in consultation with ONDRAF/NIRAS[49]
- each partnership received an annual budget of ~€250 000 (A$370 000) from ONDRAF/NIRAS to cover operational, staffing and logistical costs. A one-off payment of ~€150 000 (A$222 000) was provided to develop the conceptual proposal and to conduct a socioeconomic assessment[50]
- membership of the partnerships was open to any resident, and was voluntary; neighbouring communities could observe the process[51]
- partnerships had two full-time paid staff (drawn from the ~€250 000); they had general assemblies of the membership and boards of directors, and established working groups on topics of importance to partnership members[52]
- ONDRAF/NIRAS staff were members of both the partnerships proper and the individual working groups; the agency had a veto over project safety[53]
- external experts were invited to explain and discuss many different aspects of radioactive waste management (waste characteristics, repository safety, construction, properties of engineered barriers, transport etc.)
- members of the communities could approach the partnerships with questions and they were answered[54]
- the timeframe for partnerships to develop concepts was extended by several years to allow for communities to become sufficiently aware of the proposal
- there were ongoing community engagement programs developed by the successful partnership[55]

Outcomes include:

- a successful social learning process involving knowledge transfer from experts to residents and vice-versa; because of local partnership involvement, the project became technically better and received broad support across the community[56]
- changes to the ONDRAF/NIRAS preliminary technical design proposal to include a stronger engineered control system and ongoing monitoring systems[57]
- voting of the general assembly of the local partnership and the municipal council indicated receipt of community consent. In Dessel, the general assembly of the local partnership and the municipal council expressed unanimous support for the STOLA-Dessel proposal.

The successful municipality, Dessel, established the STOLA-Dessel partnership, which comprised 76 representative members from more than 20 local organisations and ONDRAF/NIRAS. Dessel has 9250 residents, of whom 1600 are employed in the nuclear industry (including waste processing and storage, and nuclear fuel fabrication until 2012) and research (Belgian Nuclear Research Centre SCK·CEN).[58]

STOLA-Dessel's remit expired early in 2005. Recognising the need for ongoing community engagement, in April 2005 a new community–ONDRAF/NIRAS partnership, STORA (Study and Consultation Radioactive Waste Dessel), was established to oversee nuclear issues in Dessel.[59] STORA has a general assembly composed of 20 local social, economic, cultural and political organisations. There is a board of directors and three working groups ('follow-up of the disposal site', 'radioactive waste' and 'communication'). STORA receives its budget from ONDRAF/NIRAS.

In 2010, STORA and ONDRAF/NIRAS released the cAt Project master plan. Key features include:

- continuing partnership between the Dessel community and ONDRAF/NIRAS
- a multifunction community centre and theme park aimed at showcasing Dessel as a nuclear town through interactive exhibitions
- a sustainable development fund (private foundation overseen by a board of directors) with an initial capital value of between €90 million (A$132.9 million) and €110 million (A$162.5 million) to provide finance for community projects
- change to the town's zone classification to allow for housing and employment growth
- the development and long-term maintenance of nuclear knowledge within the community
- continuous environmental, safety and health monitoring, including free annual health check-ups for residents.[60]

Key lessons

This case study demonstrates the following lessons for community engagement practice:

- Local stakeholders can provide knowledge regarding socioeconomic circumstances, interests and community priorities, as well as physical and technical characteristics (e.g. local hydrogeology, monitoring and control systems), as the STOLA-Dessel partnership did when amending the initial conceptual design.[61]
  - » The regulator, FANC, was included in the learning process from the outset of the partnerships, and engaged in an active dialogue with the community. This improved the overall scientific rigour of the safety case, promoted trust among parties involved in developing and reviewing the safety case, and enhanced the effectiveness of the regulatory review process.
  - » To build knowledge and gain confidence in the long-term safety of the proposed repository requires time (from the project start in 1998 until the expected date of receiving the licence to build and operate in 2018).[62]
- The partnership process took an expansive view of the term 'stakeholder', such that neighbouring communities were able to receive information and participate as observers.
- Despite the initial challenges associated with radioactive waste management, local residents can develop highly creative and innovative solutions if a framework has been put in place that allows genuine engagement in the project design and management process.[63]
  - » The repository is being viewed by the community as an opportunity to advance community development for many generations to come.[64]
  - » Substantiating the safety case is central to community consent.[65]
- Partnerships will continue to provide input to some aspects of the broader disposal project, such as the multifunctional community centre and oversight of the sustainable development fund.

CASE STUDY 4

CIGEO DEEP GEOLOGICAL REPOSITORY IN BURE, MEUSE/HAUTE-MARNE, FRANCE

CIGEO (Industrial Centre for Geological Disposal) will be a deep geological repository for the disposal of high level waste (HLW) and intermediate level (ILW) long-lived waste in the vicinity of the village of Bure, eastern France (see Figure H.5). Once operated and closed, the repository will hold 11 000 m^3 of vitrified HLW and 110 000 m^3 of long-lived ILW waste.[66] Disposal will occur at a depth of –500 m in clay. A key feature of the repository design (specified in law) is the ability to reverse the disposal to retrieve waste packages for up to 100 years.[67] The progressive approach to reversibility was published in a position paper in 2016.[68] The site was selected by the French Government following community consultation on the basis of its geological conditions.[69] Andra, the French National Radioactive Waste Management Agency, is responsible for developing and managing the repository in conjunction with its prime contractor,

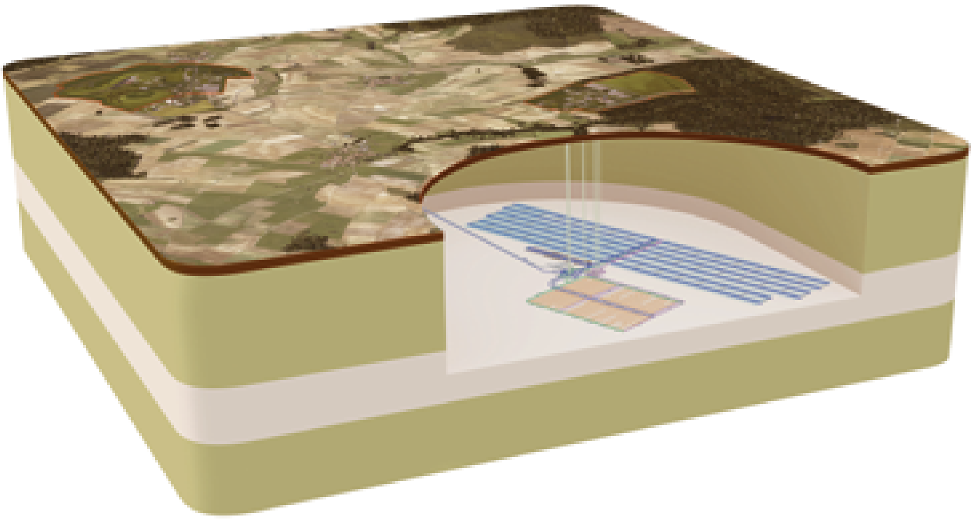

Figure H.5: Model of the CIGEO deep geological repository for disposal of high level and intermediate level long-lived waste at a depth of 500 m

Image courtesy of Andra

Gaiya—a joint venture formed by Technip and Ingerop.[70] The region hosting the facility produces cheese, among which is the world-famous 'Brie de Meaux' cheese.[71]

Development of the project

Licensing of CIGEO is an iterative process involving the regulator, the proponent, the local community and various levels of government. Table H.4 shows the CIGEO project timeline and community engagement points. Stages proceed on the basis of the results of public inquiries and the enactment of specific laws and decrees, which authorise each phase of the development.

The repository will be licensed as a basic nuclear installation (INB).[72] Licensing of INBs is granted within the framework of the decree of 2 November 2007 in application of the Transparency and Security in the Nuclear Field Act 2006 (France). The licensing procedure is as follows:

1. construction licence (authorisation decree)
2. operation licence (commissioning licence)
3. shut-down and decommissioning licences
4. end licences.[73]

Table H.4: CIGEO project timeline and points at which community engagement occurred

Date	Event
1991-12-30	Waste Act 1991 passed by the French parliament, which establishes three fields of research for the management of radioactive waste
1993-01	Siting process starts in 30 volunteer territorial administrative units
1994–1996	Andra carries out geological investigations at four volunteer sites (validated by the French Government) to identify suitable conditions for repository siting
1996-05-10	Decree 96-388 passed requiring public consultation prior to siting of nuclear installations
1997-01-05	Public inquiry into the underground research laboratory (URL) licence application filed by Andra in conjunction with three volunteer host communities
1998-12-09	French Government authorises construction of URL on the Meuse/Haute-Marne site; retrievability of waste is mandated
1999-08-03	Decree of 3 August 1999 authorises Andra to build and operate the URL in the village of Bure
1999	Local Information and Oversight Committee (CLIS) established (structure modified by the 2006 Planning Act)
2001-12	Andra submits safety file to the regulator, the Nuclear Safety Authority (ASN), for review. It was also peer reviewed under the aegis of the Organisation for Economic Co-operation and Development – Nuclear Energy Agency
2005	'Dossier 2005' released. Andra demonstrates to the satisfaction of the ASN that it is feasible and safe to construct a deep geological disposal facility on the Meuse/Haute-Marne site (1 km^2 zone)
2005-09 – 2006-01	Public debate on the management of high level waste, administered by the National Commission on Public Debate (CNDP); 13 public meetings held
2006-06-13	Transparency and Security in the Nuclear Field Act 2006 passed by French parliament
2006-06-28	Planning Act on the Sustainable Management of Radioactive Materials and Waste 2006 passed, which adopts reversible deep geological disposal for the management of HLW and long-lived ILW
2006-12-23	Decree of 23 December 2006 extends Bure URL licence until 31 December 2011
2007	Perennial Observatory of the Environment established on the Meuse/Haute-Marne site to undertake environmental monitoring for at least 100 years
2009-06	Technological Exhibition Facility (in addition to the existing visitor centre) on the Meuse/Haute-Marne site opens to public

Date	Event
2009–2010	French Government approves the 30 km^2 zone of interest proposed by Andra for studying the installation of CIGEO's underground facilities. Site location determined in consultation with community
2011	Industrial design phase for CIGEO starts
2011-12-22	Decree of 22 December 2011 extends Bure URL licence until 31 December 2030
2013-05-15 / 12-15	Second public debate on CIGEO, also administered by the CNDP
2013	Environmental baseline databank established
2013	Industrial design reviewed by ASN and the National Review Board
2015	Preliminary safety file, together with the draft master plan, filed by Andra
2015–2018	*Preliminary safety file to be reviewed by the ASN and an Act passed (before licence is granted) establishing reversibility conditions for CIGEO*
2018	*Licence application for the CIGEO project; third public inquiry to be held prior to delivery of construction licence*
2020–2021	*Construction licence of the INB delivered by the French Government; start of construction*
2025	*CIGEO is expected to be commissioned, subject to approval by the ASN*
2025-2030	*Pilot phase to prove repository design and operation*
2030	*CIGEO to start industrial operation*
2140	*Expected closure*

Sources: Andra, CIGEO, Lebon & Ouzounian, OECD–NEA[74]

Specific aspects of community engagement

Following the failure of an earlier process to identify a repository site, the French parliament in 1991 passed the Waste Act, which specified that there would be no decision on site selection for 15 years.[75] The Act also required that communities be consulted prior to any site investigations.[76]

There is no community right of veto in France. Instead, a public inquiry and debate process results in government decrees, which direct Andra to undertake specified work as agreed by the community during the inquiry process.[77] Two mandated public debates have been held (2005—national level; 2013—district and national level). Following the 2013 public debate, four requirements were added to the project concept:

- development of a pilot plant to prove disposal concept before receipt of an operation licence
- development and regular revision during the operation of the facility of an operational master plan
- schedule changes to allow for the submission of the construction licence in three stages—initial licence application (licence to create) in 2018, then the licence to operate the pilot phase in 2025 and the full licence to operate in 2030
- additional community engagement in the decision-making process[78]

In addition to these changes, the community engagement process has resulted in:

- the requirement that disposal be reversible for up to 100 years, to be clarified via the scheduled 2016 law on the subject
- Andra's plan to connect CIGEO to the national rail network to enable waste packages to be delivered by rail.[79]

A local information and oversight committee (CLIS) to facilitate community engagement was established in the village of Bure in 1999 in accordance with the 1991 Waste Act. However, CLIS is sometimes confused with the proponent, Andra, in community engagement processes.[80]

The nuclear industry in France contributes to the economic development of the Meuse/Haute-Marne districts through two community development funds: Objectif Meuse and GIP (Public Interest Group) Haute-Marne.[81] These two districts with more than 300 townships representing 380 000 residents (2006 figures) are designated as affected and are entitled to receive benefits. However, the operation of the funds is not well understood in the community (including by town mayors) and awareness of nuclear industry-funded projects is low, which has resulted in expressions of concern about the project's value to the community.[82]

Other important aspects of community engagement:

- The strict timeline for project delivery and the associated community engagement process has been criticised by the Meuse General Counsellor (also a CLIS member) for compromising residents' right to information as required by the Aarhus Convention.[83]
- As proposed following the 2013 public debate, Andra proposes to hold periodic reviews and ongoing stakeholder engagement meetings during the operational phase of the repository, according to a master plan for operations.[84]

Key lessons

The following lessons emerged from this case study:

- Proponents need to provide details of what benefits (positive socioeconomic impacts) are funded or facilitated as a result of the development.[85] CLIS and the GIPs have no formal links with each other, which means that benefits arising from the project are not communicated to affected communities.[86]
- A sustained information program is necessary to communicate benefits in order to maintain community consent for the project.[87]
- Reversibility of disposal was not a technical requirement: it emerged as a social requirement through the community engagement process.[88]
- While a strict timetable for project delivery provides for stakeholder certainty, it can also result in lower community confidence if community members believe that the process is rushed and that their voices are not being heard.
- There is a need for clear allocation of responsibilities among the involved parties and various stakeholders.
- Committed involvement of political representatives and decision-makers is required at both the local and national level.
- There is a need for a continuous assessment process for the performance of the system, based on available knowledge (for example, on waste forms and geology), engineering works and safety approaches and assessment.

CASE STUDY 5

WOLSONG LOW AND INTERMEDIATE LEVEL WASTE DISPOSAL CENTER SURFACE AND GEOLOGICAL REPOSITORY IN GYEONGJU CITY, NORTH GYEONGSANG PROVINCE, SOUTH KOREA

The Wolsong Low and Intermediate Level Waste (LILW) Disposal Center (WLDC) is a surface and geological repository located in Gyeongju City, south-east South Korea (see Figure H.6). Construction is occurring in stages: stage one (underground disposal silos at a depth of –80 m to –130 m) started operation in 2014[89]; construction of stage two (near-surface and rock cavern disposal) is ongoing.[90] The repository, which is adjacent to the Wolsong nuclear power plant, is licensed to hold 800 000 barrels (200 L each) or 214 000 m^3.[91] The Korea Radioactive Waste Agency (KORAD) is responsible for developing and managing the WLDC (answerable to the Ministry of Trade, Industry and Energy); the regulator is the Nuclear Safety and Security Commission (NSSC). Gyeongju City is a popular tourism and resort destination, and hosts sites on the World Heritage List.[92] Agriculture, manufacturing and the services industry also contribute significantly to the local economy.[93]

Development of the project

The Minister of Trade, Industry and Energy issues licences for nuclear facilities. The licensing process is as follows:

1. site selection process
2. application for construction permit
   - Korean Institute for Nuclear Safety (KINS) reviews technical files
   - NSSC approves KINS report
3. Minister of Trade, Industry and Energy issues construction permit
4. application for operating licence, which follows above procedure.[94]

Figure H.6: Conceptual model of the Wolsong LILW Disposal Center

Image courtesy of KORAD

Between 1986 and 2004, there was a single site selection process for a repository for high level waste (HLW) and LILW, which resulted in nine failed siting attempts: eight due to community opposition, one due to the discovery of an active fault.[95] However, in 2004, the process was split between the search for a site for disposal of LILW waste and the search for a site for disposal of HLW (the latter process is ongoing and is subject to the Public Engagement Commission on Spent Nuclear Fuel Management).[96]

The Special Act on Support for Areas Hosting the Low and Intermediate Level Radioactive Waste (LILW) Disposal Facility 2005 (South Korea) states that a HLW repository cannot be built in the locality that hosts the LILW repository.[97] The South Korean Government selected Gyeongju City for the WLDC based on the results of a referendum held in four volunteer cities.[98] Table H.5 shows the project timeline and community engagement.

Specific aspects of community engagement

Earlier attempts to site a repository (particularly because of the inclusion of HLW) failed due to inadequate community engagement about the risks and opportunities of the proposed facility.[100] The nine failed siting attempts were 'top-down approaches that did not involve substantial public input and explanation of relative risks and benefits'.[101]

In contrast, in 2005, the South Korean Government changed its site selection strategy. The government 'provided veto power to local residents by introducing a local referendum for the final site selection [LILW] and accepted all local communities that applied for the project as possible candidates'.[102] This raised local residents' perceptions of process fairness and strengthened perceptions about the voluntary nature of the siting procedure.[103]

The South Korean Government additionally offered a package of benefits to the successful host city in order to increase community support for the repository project. The package comprised:

- a special support fund: ₩300 billion (A$352.8 million)
- a local support fee: ₩637 500 (A$749.7) per 200 L drum disposed. A total of 800 000 drums is valued at approximately A$600 million
- community project support: ₩3.2 trillion (A$3.76 billion) to fund 55 local projects
- relocation of the head office of Korean Hydro and Nuclear Power (electric power utility) to Gyeongju City
- a proton accelerator project.[104]

Four cities (comprising the local governments and assemblies, as well as citizen/resident groups) actively campaigned against each other in order to raise resident support to host the repository and to receive the benefits package.[105]

Table H.5: Wolsong project timeline and points at which community engagement occurred

Date	Event
1986–2004	Nine failed attempts at site selection (LILW and HLW)
2004-12	Amendment of the Radioactive Waste Management Policy to separate repository site selection process for disposal of LILW and HLW
2004-12 – 2006-01	Tenth attempt at site selection (LILW); four sites identified through bid solicitation (volunteering)
2005-03	Enactment of the Special Act on Support for Areas Hosting the Low and Intermediate Level Radioactive Waste (LILW) Disposal Facility 2005, which details the package of benefits
2005-03	Organisation of site selection committee (LILW)
2005-06-16	Public notice of new site selection procedure (solicitation application; local referendums; implementation of referendum result; final candidate site selection)
Community consent: 2005-11-02	Referendums held in four cities (Gyeongju City – 89.5%; Gunsan City – 84.4%; Youngdok County – 79.3%; Pohang City – 67.5%)
2006-01-02	South Korean Government selects Gyeongju City as the repository site (LILW) on the basis of the results of the four local referendums
2008-03	South Korean Government enacts Radioactive Waste Management Act 2008
2008-08	Stage one construction and operation licence (LILW); start of construction
2009-01-01	Korea Radioactive Waste Agency (KORAD) established
2012–2019	Stage two construction (LILW)
2014-07	Stage one construction complete
2014-12	Stage one start of operation

Sources: Lee, Leem, Park[99]

Factors leading to the successful site selection and factors leading to failure in the previous attempts are elaborated below.[106]

Success factors:

- separation of LILW and HLW
- enactment of a special law for community benefits package
- free decision of the community as a result of the local referendums
- introduction of a competitive siting process
- trust in the government and regulator.

Failure factors:

- disquiet about long-term safety (risk perception)
- lack of community confidence in the proposed benefits
- lack of community participation in the decision-making process
- lack of transparency in decision making
- lack of trust in the regulator.

Key lessons

Two key lessons emerge from this case study:

- Where the community perceives the benefit from hosting a nuclear development to be greater than its perception of the risks arising from a development, it may provide community consent.[107]
  - » The South Korean Government developed a benefits package to incentivise volunteer communities.

  - The package was developed prior to the site selection process without community consultation and therefore was not viewed as a 'bribe' by volunteer cities.[108]
- The change of site selection strategy (separating LILW from HLW; establishing a community engagement and bid solicitation process) resulted in successful site selection.[109]

CASE STUDY 6

RANGER MINE AT JABIRU, ALLIGATOR RIVERS REGION, NORTHERN TERRITORY

Ranger uranium mine (Figure H.7) is located 260 km south-east of Darwin in the Alligator Rivers Region of the Northern Territory, and started operations in 1980.[110] To date, more than 120 000 tonnes of uranium oxide has been produced from processing ore from Pits 1 and 3.[111] In 2011, Ranger's operator, Energy Resources of Australia (ERA)—a member of the Rio Tinto Group—proposed investigations into the redevelopment of the open cut mine to extract the Ranger 3 Deeps resource (approximately 44 000 tonnes contained uranium oxide) via underground methods.[112] Ranger is surrounded by the World Heritage listed Kakadu National Park. The mine and the previously proposed development of the adjacent Jabiluka uranium deposit have been the focus of anti-nuclear, environmental and Aboriginal land rights campaigns since the 1970s.[113]

Development of the project

The history of Ranger and the associated proposal to mine Jabiluka is important background context to the proposed Ranger 3 Deeps underground mine.[114] Development of Ranger was recommended by the Ranger Uranium Environmental Inquiry ('the Fox report') in 1977. While the Fox report found traditional owners opposed developing Ranger, it also determined the project was in the national interest and, therefore, Aboriginal opposition 'should not be allowed to prevail'.[115] The Mirarr traditional owners were denied the right to veto Ranger under subsection 40(6) of the *Aboriginal Land Rights (Northern Territory) Act 1976*; this right exists for all other Northern Territory traditional owners whose land is subject to the Aboriginal Land Rights Act.[116]

Table H.6 shows the Ranger mine timeline.

Aware that open cut mining at Ranger would finish in 2012, ERA proposed investigations to determine the feasibility of mining Ranger 3 Deeps via underground methods in 2011.[118] ERA approved an exploration decline—a tunnel to aid characterisation of the ore body—in June 2012; this was completed in 2014.[119] ERA conducted a pre-feasibility study during this period.[120] Mirarr did not object to constructing the decline.

Figure H.7: An aerial view of the Ranger uranium mine in the Northern Territory

Image courtesy of Glenn Campbell/Fairfax Syndication

Table H.6: Ranger mine timeline and points at which community engagement occurred

Date	Event
1977	Ranger Uranium Environmental Inquiry recommends construction of the Ranger uranium mine
1978-11-03	Ranger Agreement signed enabling development of Ranger
2000-08	ERA and its owner, North Limited, are acquired by the Rio Tinto Group
2011-08-25	ERA approves $120 million to construct an exploration decline to examine the Ranger 3 Deeps resource
2012-06-14	ERA commits $57 million for a pre-feasibility study of Ranger 3 Deeps
2013-01	ERA submits 'Notice of Intent' and 'Referral' to the Northern Territory Environment Protection Authority and the former Australian Government Department of Sustainability, Environment, Water, Population and Communities
2013-03-13	Australian Government announces that Ranger 3 Deeps is a controlled action and requires assessment under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth)
2013-08	Environmental Impact Statement (EIS) guidelines finalised and issued
2013-12-07	Leach tank failure at the Ranger mine; operations suspended pending regulatory and ERA review
2014-06-05	Regulators approve restart of operations
2014-10-03	ERA submits Draft EIS for public and regulatory review
2014-12-13	Review period on Draft EIS closes
2015-06-11	ERA announces that it will not proceed to a final feasibility study of Ranger 3 Deeps
2015-06-11	Rio Tinto releases media statement withdrawing support for Ranger 3 Deeps
2015-06-12	ERA Board responds to Rio Tinto's media release, reaffirming its commitment to its approach to Ranger 3 Deeps
2015-06-12	GAC announces that Mirarr do not support any extended term of mining at Ranger beyond 2021
2015-06-22	Three independent members of ERA Board resign
2015-10-15	GAC announces that it cannot consider an extension to the Ranger Authority without the support of Rio Tinto
2015-10	ERA commissions strategic review of operations

Note: GAC = Gundjeihmi Aboriginal Corporation

Sources: ERA; Mudd, Kyle, Smith; GAC; Rio Tinto[117]

Regulatory approval for Ranger 3 Deeps was pursued according to the *Environmental Assessment Act* (NT) and the *Environment Protection and Biodiversity Conservation Act* (Cth). This process required ERA to submit an environmental impact statement with a social impact assessment component.[121]

Unlike other mines in Australia, Ranger is not subject to a mineral lease. Instead, it has an Authority to Mine under the *Atomic Energy Act 1953* (Cth). This Authority expires in January 2021, with rehabilitation required to be completed by January 2026.[122] While the initial objective was to execute the proposed Ranger 3 Deeps project within the existing Authority, ERA later commenced a process to seek an extension to the Authority in order to optimise the economics of the project.[123] This would require an amendment to the Atomic Energy Act.[124]

In June 2015, ERA announced that the Ranger 3 Deeps project would not proceed to final feasibility study in the then current operating environment and the infrastructure was placed on care and maintenance.[125] The decision was based on two principal factors: uncertain market conditions and the economics of the project requiring operations beyond the current Ranger Authority.[126] The company stated that it would revisit its economics over time.[127] The June 2015 announcement also advised ERA had commenced discussions with representatives of the traditional owners and the Australian Government regarding a possible extension to the Ranger Authority.

On the same day, Rio Tinto announced that it agreed with the decision not to progress studies on Ranger 3 Deeps and that it did not support any further study or the future development of Ranger 3 Deeps due to the project's economic challenges.[128] Following Rio Tinto's decision to withdraw its support for the Ranger 3 Deeps project, three independent ERA board members (including the chair) resigned due to disagreement with Rio Tinto about the future of the project and the difficulty for ERA to pursue its stated approach without the support of its major shareholder.[129]

In October 2015, the representative body of the Mirarr Aboriginal people—the Gundjeihmi Aboriginal Corporation (GAC)—announced that Mirarr traditional owners would not 'consider any possible extension to the Authority to mine on the Ranger Project area in the absence of support from' Rio Tinto.[130] ERA initiated a strategic review of its operations following communication from the traditional owners; this is due to finish in the March quarter 2016.[131]

Specific aspects of community engagement

The focus of the following discussion is engagement between ERA and Mirarr traditional owners.

The Mirarr traditional owners opposed operations at Ranger when the mine was first proposed in the 1970s.[132] The Aboriginal Land Rights Act specifically excluded the Ranger site from the 'right of veto' provisions contained in that Act. The Australian Government determined that Ranger should proceed as it was in the national interest. The Mirarr felt they had little choice but to agree to the Ranger Agreement, signed in 1978 between the Australian Government and the Northern Land Council[133], which sets out certain terms and conditions for the mine's operations. As a result, for at least the first two decades of Ranger's operational life, relationships between all parties were often characterised by 'acrimony', 'distrust', and 'mutual disengagement'.[134]

Following its acquisition of ERA's owner, North Limited, in 2000, Rio Tinto assumed a majority shareholding in ERA. Rio Tinto applied its community engagement framework to ERA, which has resulted in closer relationships between ERA and traditional owners and their representatives over the last 15 years[135], particularly 2008 to 2013.[136] In this period, ERA and the GAC established new dialogue channels and participated in joint initiatives on environmental and cultural heritage management.[137] ERA entered into a cultural heritage protocol with the GAC in 2006.[138] Such initiatives built trust between traditional owners and ERA, and led to cultural solutions to problems that are also technically sound.[139] ERA continues to provide cultural awareness training for all employees.[140]

Building on the improved relationship, in January 2013 ERA and the GAC signed a new Ranger Agreement. While the terms of the agreement were confidential, it established a 'Relationship Committee' to facilitate dialogue between ERA personnel and traditional owners, and granted more rights and control to the Mirarr over operations at Ranger.[141] The agreement also established the West Arnhem Social Trust, into which ERA undertook to deposit funds to improve Aboriginal social development across the Alligator Rivers Region.[142]

Over the years, ERA has developed an indigenous employment strategy, which includes flexible work arrangements, a mentoring program, workplace literacy and numeracy training, and work experience and school-based apprenticeship support for local students.[143] At 31 December 2015 approximately 13 per cent of ERA's workforce were Aboriginal employees.[144]

The Mirarr have historically refused to participate in periodic social impact assessments (SIAs) due to their belief that to do so would confer legitimacy on ERA's operations.[145] ERA has used its own social assessments (outside regulatory requirements) to identify better ways in which to engage with the community.[146] In 2013, ERA contracted social consultancy Banarra to undertake an SIA (a regulatory requirement) for the proposed Ranger 3 Deeps underground mine. The SIA determined the potential positive social impacts outweighed the negative impacts.[147] GAC Board members were consulted as part of the Ranger 3 Deeps SIA.[148]

A leach tank failure in December 2013 at Ranger set back relationships between ERA and Mirarr. In ERA's 2013 Annual Report, the then chair, Peter McMahon, acknowledged 'the incident re-awakened latent opposition to uranium mining at Ranger, and it has at least interrupted the developing trust between ERA and its community stakeholders, including representatives of the Mirarr people'.[149]

Historically, there have been conflicts within the Alligator Rivers Aboriginal communities (between Mirarr and other groups) regarding the distribution and use of Ranger benefits/royalties and claims about the definition of 'area affected'—those who are entitled to have a say in Ranger's operations and to receive benefits.[150] In 2015, ERA paid $17.9 million in royalties.[151] Despite the economic benefit associated with the Ranger operation, Aboriginal disadvantage is still prevalent in the region.[152]

Key lessons

This case study provides the following lessons:

- There is a need to enshrine community consent provisions at the start of development proposals to avoid ongoing community opposition and potential project failure.
  - » Ranger was constructed without the consent of Mirarr traditional owners.
  - » Engagement with traditional owners throughout the life of a project is essential.
  - » The personal relationships between ERA and GAC personnel, strengthened following Rio Tinto's acquisition of ERA, were crucial to improved project outcomes.
  - » ERA's experience post-2000 shows that community engagement is not a cost, but rather an opportunity.
- Mirarr traditional owners have chosen to engage with ERA through the agency of the GAC. This is not considered 'text book' community engagement practice.[153] However, Mirarr view direct engagement with the company as an unwanted social impact. This again shows that there is no one-size-fits-all approach to community engagement.
  - » Corporate community engagement frameworks do not necessarily align with Aboriginal world views. Proponents need to work with host communities and their representatives to establish culturally appropriate engagement methods.
  - » Engagement with particular community representative groups can precipitate or perpetuate cultural conflicts and disputes about the distribution of benefits.
  - » Determining the community affected and who speaks for that community is difficult and time consuming.
- ERA has found it difficult to effectively communicate the risks and benefits of its operations to traditional owners, such that their sentiment towards Ranger has not substantially changed since the 1970s.
  - » Participation in joint initiatives and adopting cultural solutions to technical problems raised Mirarr traditional owners' trust in ERA.
- There is a need for ongoing social risk and impact monitoring in the same way that environmental and safety risks and impacts are overseen and monitored.

NOTES

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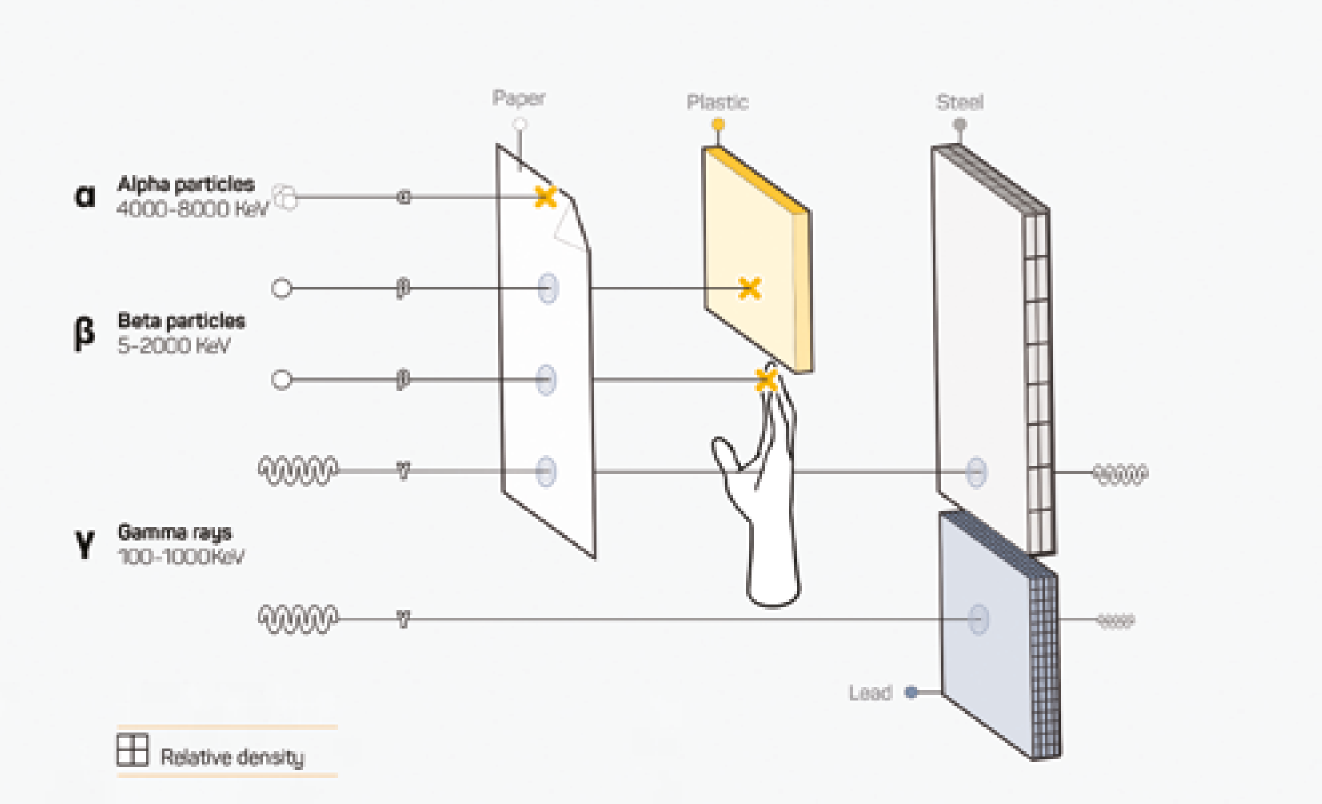
APPENDIX K: RADIATION CONCEPTS

WHAT IS RADIATION?

Radiation comprises particles and electromagnetic waves that have sufficient energy to change the composition of matter, including cells in living creatures.[1] Radiation cannot be seen or heard, and can only be detected and measured accurately and in real time using specialist equipment.

Radiation arises from the radioactive decay of elements on Earth, although it also originates from sources in space.[2] There are three different types of radiation that vary in their physical properties, as seen in Figure K.1. Those types are[3]:

- Alpha radiation: Alpha radiation consists of highly energetic, charged particles that interact with any matter with which they come into contact. As a result, they will not pass through barriers, including human skin, so they are easy to shield against and contain.
- Beta radiation: Beta radiation also consists of highly energetic, charged particles; however, they have a lower charge than alpha particles, do not interact with matter as readily and therefore penetrate further. This makes them more difficult to contain and they require increased shielding.
- Gamma radiation and x-rays: Gamma radiation is naturally occurring but is similar to manufactured x-rays and consists of highly energetic electromagnetic waves. Their high energy enables them to pass through many kinds of materials, including human tissue. Therefore, they are highly penetrative and require a significant amount of shielding.



Source: ARPANSA

Figure K.1: The penetrative ability of different forms of radiation

Neutrons are another common product of radioactive decay.[4] They have a high range of energies and can indirectly damage cells. Neutrons have a similar penetrative ability to gamma radiation.

Radioactive elements that decay can produce one or more types of radiation.[5] This has an impact on the measures that need to be in place to protect people and the environment when radioactive materials are being handled. The duration of the hazard is also affected by the speed of decay. The amount of time it takes for half of the atoms of an isotope to decay is described as a 'half-life'.[6] Some radioactive elements decay quickly—in seconds or fractions of seconds—while others can last for hundreds of thousands of years.[7]

RADIATION DOSE

The concept of a 'dose' is used to quantify the effects of radiation on living things and is the starting point when calculating the effect of radiation on humans. The 'absorbed dose' is a measure of the amount of energy that radiation delivers to a kilogram of material. Doses are measured in units known as gray (Gy).[8]

As previously described, there are a number of different types of radiation, and the impact each type has on living tissue varies. 'Weighting factors' account for the effects of radiation on living tissue when multiplied by the absorbed dose. This is known as the 'equivalent dose' and is measured in sieverts (Sv). To measure low doses, sieverts can be further broken down into millisieverts and microsieverts. One millisievert (mSv) is 0.001 Sv and one microsievert (μSv) is 0.000001 Sv.[9] Low and very low doses of radiation are understood to be below 100 mSv and 10 mSv, respectively.[10]

A weighting factor is used to define the damage caused by radiation exposure to different organs and tissues. Multiplying the tissue weighting factor by the equivalent dose to organs and tissue in humans gives the 'effective dose' to that area, also measured in Sieverts. A total effective dose to a person is the sum of the individual effective doses, which takes into account sensitivities associated with different organs.[11]

RADIOTOXICITY

'Radiotoxicity' describes the toxicity of a particular radionuclide, or combinations of radionuclides, in the event of either ingestion or inhalation. It takes into account both the biochemical (elemental) nature of the nuclide, as well as the type and energy of radiation it emits.[12] Therefore, it addresses how all the individual characteristics (rather than just radioactivity) could harm the human body in postulated scenarios that lead to ingestion or inhalation. For a single radionuclide, the radiotoxicity is obtained by multiplying the amount of the nuclide (measured in Becquerels, or Bq) by established 'dose conversion factors'.[13] For any collection or combination of radionuclides—such as those in used nuclear fuel—the radiotoxicity of the material is the sum of the radiotoxicity of all constituent nuclides. The radiotoxicity, expressed as a dose and measured in millisieverts (mSv), describes the health impact in the event of ingestion or inhalation.

HEALTH EFFECTS OF RADIATION

Exposure to radiation can have a harmful effect on human health. Radiation can damage or cause the death of human cells. Radiation also has the potential to affect the environment and other living organisms through similar mechanisms to human tissue. The effects on fauna can include increased disease, death, or reduced fertility and reproductive success.[14] The types of damage can be defined by two main categories, 'deterministic' and 'stochastic'.

DETERMINISTIC EFFECTS

Deterministic effects occur in cases of very high exposure to radiation, once a certain threshold dose has been exceeded. The severity of the effects increases as the radiation dose increases. Deterministic effects are caused by significant damage to cells or the death of a large population of cells that impact the function of human organs or tissue.[15] These effects develop soon after exposure and may occur within days or weeks of receiving a large dose of radiation. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) defines a high dose of radiation, where acute effects of short term exposures will occur, as more than 1 Sv.[16] The most common effects are associated with bone marrow and its ability to produce blood cells. Other symptoms, such as nausea and vomiting, relate to the gastrointestinal tract.[17] Large doses can cause the central nervous system to fail and, in extreme cases, result in death. A high penetrating dose of radiation in a short period of time can cause acute radiation syndrome.[18] Depending on the dose, this syndrome is characterised by several stages of symptoms including nausea, fever, infection, diarrhoea, bleeding, cardiovascular collapse and respiratory distress, followed by either a period of recovery or death.[18] Delayed deterministic effects can also occur, such as cataracts, which take longer to develop and may not appear for many years following exposure.

STOCHASTIC EFFECTS

Stochastic effects occur as a result of damage to DNA in human cells. Due to this DNA damage, there is the possibility of long-lived mutations in cells, increasing the likelihood of cancerous growths in the future. The higher the dose of radiation received, the greater the likelihood of an effect occurring.[19] There are natural mechanisms that can repair DNA damage, although these are not always effective. Stochastic effects tend to have a longer latency period, from a few years up to tens of years. If reproductive cells are damaged, there is potential to cause hereditary effects, or gene mutations, that can affect the offspring of the exposed person.[20] This effect has been observed in experiments on mammals but no direct evidence has been shown in human populations.[21]

DOSE–RESPONSE RELATIONSHIP

The effects of radiation on biological systems are studied in two ways:

- epidemiological studies, which identify trends and patterns in health effects across a population
- biological studies, which directly observe the effects of radiation on living organisms.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) concludes that it is not presently possible to explicitly attribute a stochastic effect in an individual to radiation exposure. This is because stochastic effects are not distinguishable from other health effects that may arise from different causes.[23] Stochastic effects are not only caused by radiation, but by other lifestyle choices, such as smoking or eating habits, which may bring about the same adverse health effects. Further, the effects may show up in some people and not in others despite their exposure to the same radiation dose. It is only possible to attribute stochastic effects to radiation through epidemiological studies that compare their incidence in an exposed population with a similar one that was not exposed.[24] This is based on the probability that radiation was responsible for an observed increase in the stochastic effects.

These difficulties are even more prominent when studying low radiation doses over long time periods. UNSCEAR recognises that when the dose of radiation decreases to low and very low amounts, the uncertainties in attributing health effects to radiation increase, and the ability to draw conclusions from epidemiological studies is significantly reduced.[25] ARPANSA considers a low dose of radiation to be from 10 to 100 mSv. A very low dose is generally below 10 mSv, which is the range of exposure any member of the public may experience annually.[26] The natural variance in human health, combined with the constant exposure people receive from natural background radiation, means that it has not been possible to establish any significant relationship between health risks and radiation exposure at low doses.

Figure K.2 illustrates the plausible dose–response relationships for health effects (such as cancer) at very low, low, and moderate doses of radiation.

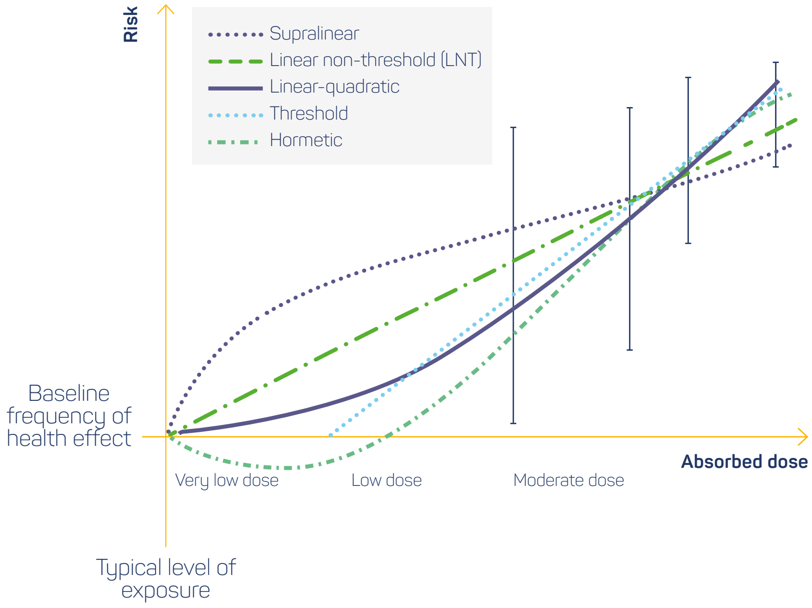


Figure K.2: Schematic plot of possible dose–response relationships (in addition to background exposure) for the risk of health effects in the ranges of very low, low, and moderate doses

Source: UNSCEAR

Given that there are five plausible relationships, there is a large degree of uncertainty in attributing health effects to moderate radiation doses or lower.

At high doses of radiation, the dose–response relationship is far more certain and stochastic effects are much more likely to arise.[27] Very high doses will lead to deterministic effects in addition to an increased risk of cancer.

NOTES

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Transcripts and submissions can be found at the Nuclear Fuel Cycle Royal Commission's website: www.nuclearrc.sa.gov.au/transcripts and www.nuclearrc.sa.gov.au/submissions

GLOSSARY

This glossary defines key terms used in this report.

actinides: a series of 15 elements with an atomic number (i.e. the number of protons in the nucleus) between 89 and 103. The actinides include uranium (92), plutonium (94) and americium (95).

activity (nuclear): the number of decays per unit time taking place in a radioactive material. The unit of activity is the becquerel (Bq), equal to one decay per second.

adsorption: the adhesion of atoms or molecules from a gas or liquid as a thin film to a solid or liquid surface.

advanced reactors: reactor designs in which nuclear fission energy is captured and converted more efficiently than in standard water-cooled reactors. They operate at higher temperatures and employ heat-tolerant coolants such as liquid metal or molten salt, and robust fuel materials including graphite.

alpha particle: an energetic positively charged particle emitted from the nucleus of an atom during alpha radioactive decay and consisting of two protons and two neutrons (a helium nucleus).

amortised capital cost: represents the amount of principal (the original amount borrowed) and interest that would need to be paid in each period over a given repayment schedule, such that at the end of the repayment schedule all interest and principal would have been repaid.

aquifer: a body of permeable rock such as sand or gravel through which groundwater moves, and that can store considerable quantities of water, which is underlain by impermeable material.

atom: a particle of matter that cannot be broken up by a chemical process. Atoms have a nucleus containing positively charged protons and uncharged neutrons, and surrounding the nucleus, a cloud of negatively charged electrons.

atomic number: the number of protons in the nucleus of an atom. See also *mass number*.

beta particle: an energetic particle emitted from the nucleus of an atom during beta radioactive decay. Beta particles are electrons with a negative charge or positrons with a positive electric charge.

borehole: a hole drilled into rock to enable an assessment to be made of the characteristics of the rock itself and of the fluids it contains, e.g. groundwater, petroleum, or natural gas.

brownfield: vacant or unused former industrial land with potential for redevelopment.

burn up: the amount of energy generated from a fixed quantity of nuclear fuel, expressed typically as megawatt days per tonne (MWd/tonne).

carbon dioxide equivalent (CO_2-e): a standard measure that allows different greenhouse gases to be compared in terms of their potential contribution to global warming. See *greenhouse gas*.

capacity factor: the percentage of time that a generator is producing electricity.

carbon capture and storage: technologies involving capturing carbon dioxide from exhaust gases produced by power plants and other industrial facilities and injecting it (sequestration) into a sealed underground storage site.

centrifuge enrichment: a uranium enrichment technology comprising cylinders rotating at high speed to physically separate gas molecules of slightly different masses i.e. uranium hexafluoride with ^{238}U and ^{235}U atoms.

combined cycle gas turbine: a gas fired power plant in which the gas turbine cycle is combined with a steam turbine cycle. The hot exhaust gases from the gas turbine are re-circulated and used to boil water (instead of being vented) and generate steam to spin a steam turbine.

carbon price: the cost—imposed by means of a tax, levy, permit or credit—of emitting carbon dioxide into the atmosphere.

containment: a gastight structure around a nuclear reactor made of reinforced concrete designed to prevent the escape of radioactive materials into the environment in the event of an incident.

control rods: moveable rods, plates or tubes containing boron, cadmium or some other strong absorber of neutrons that suppress the rate of the nuclear reaction in a reactor.

craton: a large, coherent domain of Earth's continental crust that has attained and maintained long-term stability, having undergone little internal deformation, except near its margins.

cyclotron: a device which accelerates charged particles to high energies by the application of electromagnetic forces. The accelerated particles may be used to bombard suitable target materials to produce radioisotopes.

decay (radioactive): the spontaneous disintegration of an atomic nucleus resulting in the release of energy in the form of particles (for example, alpha or beta), or gamma radiation, or a combination of these.

depleted uranium: uranium which has less than the natural percentage (0.7%) of the isotope ^{235}U.

discount rate: a rate that is used to convert future costs or revenues to their present value.

dosimeter: a device used to measure the radiation dose a person receives over a period of time.

dose, absorbed: a measure of the amount of energy deposited in a material by ionising radiation. The unit of measure is the gray (Gy).

dose, effective: a measure of the biological effect of radiation on the whole body. It takes into account the equivalent dose and the differing radiosensitivities of body tissues. The unit of measure is the sievert (Sv), but doses are usually measured in millisieverts (mSv) or microsieverts (μSv).

dose, equivalent: a measure of the biological effect of radiation on a tissue or organ that takes into account the type of radiation. The unit is the sievert (Sv), but doses are usually measured in millisieverts (mSv) or microsieverts (μSv).

dose limit: the maximum radiation dose, defined by regulation, that a person may receive over a stated period of time. It excludes doses from natural background radiation and medical sources.

element: a substance that cannot be divided into simpler substances by chemical means.

electron: a light, negatively charged subatomic particle found in all atoms.

Emissions Reduction Fund (ERF): a scheme established by the Australian Government which provides incentives for carbon emissions reduction activities in the Australian economy.

enhanced geothermal system (EGS): a geothermal energy technology that exploits thermal reservoirs found at depths of at least 3–5 km below the surface of the earth, whose permeability is increased (or enhanced) through a process of hydraulic fracturing to capture heat by creating a closed loop circuit of water.

fast reactor: a type of nuclear reactor in which the fission chain reaction is sustained by fast neutrons, in contrast to the slow, moderated neutrons in most thermal reactors. Fast reactors can burn a wider range of nuclides than thermal reactors, including transuranic elements regarded as wastes. They can be configured to produce or 'breed' more fissile material than they consume. Fast reactors generally use liquid metal coolants, such as sodium.

fissile material: any material containing fissile radionuclides capable of undergoing fission by thermal (or slow) neutrons. For example, ^{235}U and ^{239}Pu are fissile radionuclides.

fission (nuclear): the splitting of a heavy atom into smaller fragments, resulting in the release of neutrons, gamma radiation, and a large amount of energy.

fission products: isotopes of lighter elements created through the fission of fissile material. They are most often unstable and undergo radioactive decay, and include ^{134}Cs, ^{137}Cs and ^{129}I and ^{131}I and ^{90}Sr.

fuel assembly: an engineered array of fuel rods (long, sealed metal tubes) that contain pellets of fissionable material that is used in a nuclear reactor to generate thermal power.

gamma radiation: energetic short wavelength electromagnetic radiation of the same physical nature as light, x-rays, radio waves etc.

gigawatt (GW): one gigawatt is equal to one billion (10^9) watts. See *Watt*.

gigawatt hour (GWh): a gigawatt hour (GWh) is a unit of electrical energy equal to one billion (10^9) watt hours. See *Watt hours*.

gray (Gy): a measure of absorbed ionising radiation dose per unit of mass. 1 gray is equal to one joule absorbed into I kilogram of matter.

greenfield: land that has not previously been developed.

greenhouse gas: a gas that traps heat in the Earth's atmosphere by absorbing reflected solar infrared radiation from the earth, thereby causing the greenhouse effect. The main greenhouse gas is carbon dioxide, others include nitrous oxide, methane, fluorinated gases and water vapour.

half-life, radioactive: the period required for half of the atoms in a population of a particular radionuclide to decay. Half-lives vary, according to the isotope, from less than a millionth of a second to more than a billion years.

heavy metal (HM): commonly used in units such as tonnes Heavy Metal (tHM) and refers to the weight of the uranium and plutonium (if present) in nuclear fuel.

heavy by products: actinides produced in the fission of nuclear fuel.

heavy water: water in which both hydrogen atoms have been replaced with deuterium, the isotope of hydrogen containing one proton and one neutron.

heavy water reactor: a type of nuclear reactor which uses heavy water as a both a moderator and coolant.

highly enriched uranium: uranium enriched to at least 20 per cent ^{235}U.

high level waste (HLW): waste containing large concentrations of short- and long-lived radionuclides that generate significant quantities of heat and requires shielding and cooling.

hot particles: particles of nuclear fuel which are dispersed in a nuclear accident. They include radionuclides of strontium, plutonium and americium.

Intergovernmental Panel on Climate Change (IPCC): the international body for assessing the science related to climate change.

intermediate level waste (ILW): radioactive waste that contains some long-lived radionuclides and has higher levels of radioactivity than low-level waste. It requires shielding and does not generate significant quantities of heat.

internal rate of return: the interest rate that makes the net present value of an investment zero when applied to the projected cash flow from an asset, liability, or financial decision. It is used to assess the profitability of potential investments.

Intended Nationally Determined Contributions (INDC): the intended national efforts towards greenhouse gas emission reductions and climate change mitigation that were outlined by the parties to the United Nations Framework Convention on Climate Change (UNFCCC) in the lead up to the Paris Conference (COP21) in 2015.

ion: an atom that has become electrically charged having gained or lost an electron.

ionising radiation: radiation capable of causing ionisation of the matter through which it passes.

ionisation: process by which an atom or molecule gains or loses electrons.

isotope: Nuclides that have the same atomic number (same number of protons) but different mass numbers (different number of neutrons). Different isotopes of the same element have the same chemical properties but different physical properties.

Large Scale Renewable Energy Target (LRET): An Australian Government scheme which creates a financial incentive for the establishment of large scale renewable energy power stations, such as wind and solar farms. It forms part of the broader Renewable Energy Target (RET).

lifecycle analysis: a systematic procedure for compiling and examining the inputs and outputs of materials and energy consumed over the lifetime of an activity.

light water reactor (LWR): reactors that are moderated and cooled by natural water as opposed to heavy water. Types of light water reactors include pressurised water reactors (PWRs) and boiling water reactors (BWRs).

low level waste (LLW): radioactive waste that emits small amounts of gamma radiation, up to regulatory limits, and that can be handled by workers without shielding due to its small associated dose rates. LLW can contain a range of radionuclides, including small amounts of uranium and thorium, and does not produce heat.

mass number: the total number of protons and neutrons in the nucleus of an atom. Different isotopes of the same element will have different numbers of neutrons and therefore different mass numbers e.g. ^{235}U and ^{238}U.

megawatt: a unit of power equal to one million watts. See *watt*.

mixed oxide fuel (MOX): a reactor fuel comprising both uranium and plutonium oxides.

moderator: a material used in a reactor to slow down high speed neutrons, thus increasing the likelihood of further fission. Examples of moderators include normal water, heavy water, beryllium and graphite.

natural uranium: uranium that has not been enriched.

net present value (NPV): the current value of a security or an investment project, arrived at by discounting all present and future receipts and outgoings at an appropriate rate of discount.

neutron: an uncharged subatomic particle found in the nucleus of all atoms, except ordinary hydrogen. Neutrons are the links in a chain reaction in a nuclear reactor.

nuclear reactor: a structure in which a fission chain reaction can be maintained and controlled.

nucleus: the positively charged core of an atom. It contains nearly all of an atom's mass and contains both the protons and neutrons.

open cycle gas turbine: a gas fired power plant that uses a gas turbine engine to create electricity.

ore grade: the concentration of an element of interest in an ore deposit.

plutonium (Pu): a heavy, radioactive, man-made metallic element with an atomic number of 94. It has a number of isotopes produced by neutron irradiation of ^{238}U in a reactor core.

polymetallic deposit: deposit containing economic grades of several metals such as iron, copper, gold and uranium.

positron emission tomography (PET): a nuclear medical three-dimensional imaging technique, based on injected short-lived radionuclides, able to identify diseased tissue with high resolution.

Precambrian: an expression which describes the Hadean, Archaean, and Proterozoic eons, which together comprise the longest period of geologic time beginning with the consolidation of the Earth's crust and ending approximately 4000 million years later with the beginning of the Cambrian Period around 542 million years ago.

proliferation (nuclear): the spread of nuclear weapons, and more generally, the spread of nuclear technology and knowledge that might be put to military use.

proton: a positively charged subatomic particle found in the nucleus of all atoms.

proton therapy: a type of radiotherapy that uses a beam of protons produced by an accelerator, which are capable of penetrating a defined distance into the body.

radioactive waste: material for which no further use is foreseen that contains or is contaminated with radionuclides above regulated limits.

radioactivity: the inherent property of certain nuclides to emit particles or gamma rays during their spontaneous decay into other stable nuclei.

radioisotope: an isotope of an element that is radioactive.

radionuclide: see *radioisotope*.

radiopharmaceutical: a medicine comprising a radioisotope attached to a molecule that targets diseased tissue or physiological function. Radiopharmaceuticals can be used both for diagnostic purposes (imaging) and for therapy (in certain cancer treatments).

radon: a naturally occurring radioactive element with an atomic number of 86, which is the heaviest known gas. It is produced by the radioactive decay of naturally occurring uranium and thorium.

reactor core: the innermost part of a nuclear reactor that contains the fuel, the moderator (in a thermal reactor), and a coolant; where the fission reaction takes place and the level of radiation is highest.

safeguards, nuclear: political and legal mechanisms, including accounting, surveillance and physical inspections, intended to deter the spread of nuclear weapons by early detection of misuse of nuclear material or technology.

separative work unit (SWU): the amount of enrichment effort required to increase the concentration of ^{235}U in a given amount of uranium to a higher concentration.

short-run marginal cost: the additional cost from a unit increase in an activity.

sievert (Sv): a unit of measurement of *equivalent dose* and *effective dose* equivalent to one joule per kilogram of tissue exposed.

spot market: a market for transactions with settlement at a spot date, usually being the normal, earliest date for delivery. The market price for delivery on the spot date is the spot price or spot rate.

stope: a step-like part of a mine where ore is being extracted.

sulphide: a group of minerals in which the element sulphur (S) is in combination with one or more metallic elements.

tails: the depleted uranium stream produced during the enrichment process.

tailings: the ground rock remaining after particular ore minerals (e.g. uranium oxides) are extracted

tectonic plate: one of the large sections or blocks of the Earth's crust. There are seven major plates (the North American, South American, African, Eurasian, Indo-Australian, Pacific, and Antarctic plates) and at least twelve minor plates.

thorium: a naturally occurring radioactive element with atomic number of 90.

tracer: a radioactive isotope used to follow a chemical or biochemical reaction.

transuranic: any elements with an atomic number greater than uranium. They include plutonium and americium.

United Nations Framework Convention on Climate Change (UNFCCC): An international treaty that aims to address climate change through international cooperation. It entered into force in 1994, and has a Secretariat to assist in making the UNFCCC operational.

used fuel: reactor fuel in its assembly following its discharge from a reactor.

uranium: a radioactive element with atomic number 92 with a number of important isotopes, such as naturally occurring ^{235}U and ^{238}U. Uranium is the basic raw material for nuclear energy.

uranium, enriched: uranium in which the content of the fissile isotope ^{235}U has been increased above the ~0.71% natural content. Uranium must be enriched to be used as fuel for light water reactors. Material with 20 per cent or greater enrichment is called high enriched uranium; below 20 per cent is called low enriched uranium.

uranium oxide concentrate (UOC): a commercial product of a uranium mill, usually containing a high proportion (greater than 90%) of uranium oxide (U_3O_8).

watt (W): a unit of power equal to the amount of energy (one joule) that is consumed in a second (J/s). A subscript that is used alongside references to gigawatt (GW) or megawatt (MW) refers to the generation of either electrical (e) or thermal (th) energy. When it is used in association with a power plant, typically in hundreds of MWe, it describes the capacity of that power plant to generate electricity.

watt hour (Wh): a unit of energy equal to a watt of power (thermal or electric) consumed continuously for one hour. A kilowatt hour (kWh) is a unit of electricity that is typically expressed on retail bills to denote the amount of electrical energy that has been consumed.

venturi scrubber: an air pollution control device that uses water or gas flows to remove fine particles from volatile, hazardous, or corrosive gas streams, or from gas streams containing solid materials that are difficult to handle.

vitrification: a technique for the incorporation of radionuclides into glass for storage and disposal.

yellowcake: see *uranium oxide concentrate.*

SHORTENED FORMS

ABWR: advanced boiling water reactor

AEMO: Australian Energy Market Operator

ANRDR: Australian National Radiation Dose Register

ANSTO: Australian Nuclear Science and Technology Organisation

APSN: Asia-Pacific Safeguards Network

ARPANSA: Australian Radiation Protection and Nuclear Safety Agency

ARS: acute radiation syndrome

ASN: Nuclear Safety Authority (France)

ASNO: Australian Safeguards and Non-proliferation Office

AUD or A$: Australian dollar

BMUB: Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (Germany)

BWR: boiling water reactor

capex: capital expenditure

CCGT: combined cycle gas turbine

CCS: carbon capture and storage

CNNC: China National Nuclear Corporation

CSA: Comprehensive Safeguards Agreement

CSIRO: Commonwealth Scientific and Industrial Research Organisation

CT: computed tomography

CTBT: Comprehensive Nuclear-Test-Ban Treaty

DEWNR: Department of Environment, Water and Natural Resources (South Australia)

DSD: Department of State Development (South Australia)

DU: depleted uranium

EIA: environmental impact assessment

ENSI: Swiss Federal Nuclear Safety Inspectorate

EPA: Environment Protection Authority (South Australia)

EPBC Act: *Environment Protection and Biodiversity Conservation Act 1999* (Cth)

EPRI: Electric Power Research Institute

EPRI/CO_2CRC: Electric Power Research Institute and Carbon Dioxide Cooperative Research Centre

ESBWR: economically simplified boiling water reactor

EUR or €: Euro (currency)

FANC: Federal Agency for Nuclear Control

FAO: Food and Agriculture Organization (United Nations)

FGF: Future Grid Forum

FTE: full-time equivalent

gCO_2-e/kWh: grams carbon dioxide equivalent per kilowatt hour

GDF: geological disposal facility

GJ: gigajoule

GST: goods and services tax (Australian Government)

GWe: gigawatt electrical

Gy: gray, the unit in which a dose of radiation is measured

HEU: highly enriched uranium

HLW: high level waste

HM: heavy metal

HTR-PM: high temperature gas cooled pebble bed modular

HWR: heavy water reactor

IAEA: International Atomic Energy Agency

IDR: intermediate depth repository

IEA: International Energy Agency

ILW: intermediate level waste

INDC: intended nationally determined contribution

INF Code: International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High Level Radioactive Wastes on Board Ships

INLEX: International Expert Group on Nuclear Liability

IPCC: Intergovernmental Panel on Climate Change

ISF: interim storage facility

ISL: in-situ leaching

JSCOT: Joint Standing Committee on Treaties (Parliament of Australia)

KAERI: Korean Atomic Energy Research Institute

kg: kilogram

KINS: Korean Institute for Nuclear Safety

km: kilometre

KORAD: Korea Radioactive Waste Management Corporation

kt: kilotonne

L: litre

LCOE: levelised cost of electricity

LILW: low and intermediate level waste

LLW: low level waste

LNT: linear non-threshold assumption

LOCA: loss-of-coolant accident

LRET: Large-scale Renewable Energy Target (Australian Government)

LWR: light water reactor

m: million

m^3: cubic metre

ML: megalitre

MOX: mixed oxide fuels

mSv: millisievert (0.001 Sv)

mSv/a: millisieverts per year

MtCO$_2$-e: megatonne carbon dioxide equivalent

MUF: material unaccounted for

MWe: megawatts electric

NEA: Nuclear Energy Agency

NEM: National Electricity Market (Australia)

NICNAS: National Industrial Chemicals Notification and Assessment Scheme

NPT: non-proliferation treaty

NPV: net present value

NRC: Nuclear Regulatory Commission (United States)

NSSC: Nuclear Safety and Security Commission (Korea)

OCGT: open cycle gas turbines

OECD: Organisation for Economic Cooperation and Development

OECD–NEA: Organisation for Economic Cooperation and Development–Nuclear Energy Agency

ONDRAF/NIRAS: Agency for Radioactive Waste and Enriched Fissile Materials (Belgium)

OPAL: Open Pool Australian Lightwater

PACE: Plan for Accelerating Exploration (South Australia)

PEPR: Program for Environmental Protection and Rehabilitation (Australia)

PET: positron emission tomography

PHWR: pressurised heavy water reactor

PUREX: plutonium uranium extraction

PV: photovoltaic

PWR: pressurised water reactor

RD&D: research, development and demonstration

RMP: Radiation Management Plan

Rosatom: Rosatom Overseas Inc.

RWMP: Radioactive Waste Management Plan (South Australia)

SAHMRI: South Australian Health and Medical Research Institute

SCK-CEN: Nuclear Research Centre (Belgium)

SKB: Nuclear Fuel and Waste Management Co (Sweden)

SMR: small modular reactor

SPNFZT: South Pacific Nuclear Free Zone Treaty

STEM: science, technology, engineering and maths (based)

STORA: Study and Consultation Radioactive Waste Dessel (Belgium)

STUK: Radiation and Nuclear Safety Authority (Finland)

t: tonnes

TEPCO: Tokyo Electric Power Company

tHM: tonne of heavy metal

THORP: Thermal Oxide Reprocessing Plant

TLD: thermoluminescent dosimeter

tU: metric tonne of uranium

TVO: Teollisuuden Voima Oyj (Finland)

UAE: United Arab Emirates

UN: United Nations

UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation

URL: underground research laboratory

USD or US$: United States dollar

VHTR: very high temperature gas reactor

VURM: Victoria University Regional Model

WHO: World Health Organization

WIPP: Waste Isolation Pilot Plant (United States)

WLDC: Wolsong LILW Disposal Center (Korea)

WNA: World Nuclear Association

WNN: World Nuclear News

°C: degrees Celsius

µSv: microsievert (0.000001 Sv)

₩: Won (currency)