ISSUES PAPER TWO

FURTHER PROCESSING OF MINERALS AND MANUFACTURE OF MATERIALS CONTAINING RADIOACTIVE AND NUCLEAR SUBSTANCES

NUCLEAR FUEL CYCLE ROYAL COMMISSION

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THE NUCLEAR FUEL CYCLE ROYAL COMMISSION IS TASKED BY ITS TERMS OF REFERENCE WITH CONSIDERING 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 REPROCESSING 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.

YOUR SUBMISSION

The Royal Commission is seeking submissions from interested members of the community, both within Australia and overseas, who have evidence, information or views which are relevant to its inquiry.

The purpose of this Issues Paper is to assist those proposing to make a submission to the Royal Commission.

It provides a factual background, from identified sources, relevant to understanding the questions on which the Commission seeks submissions. A submission should be in response to the questions posed in this Issues Paper. Your submission may address all, some or only one of the questions. Your submission is not limited by the factual background set out in this Issues Paper.

If you wish to make a submission on a topic that is not in response to a question in this Issues Paper you may do so, but it must be contained as an Appendix to your main submission which addresses the questions posed.

Before writing your submission you should read the Submissions Guideline (www.nuclearrc.sa.gov.au) issued by the Royal Commission. It may answer questions you have as to the form and content of your submission and how your submission will best assist the Commission.

A. FURTHER PROCESSING

Unlike coal or natural gas, uranium oxide (U_3O_8) is not suitable for use as a fuel for electricity generation without further processing. The processes which are undertaken to transform the uranium oxide into a usable fuel are conversion, enrichment and fuel fabrication.[1] Further, once used to generate electricity, the spent fuel can be reprocessed to extract usable materials which in turn can be recycled into new fuel.

Uranium conversion is a process which involves the chemical change of uranium oxide (U_3O_8) produced from mining and milling activities into a gas, uranium hexafluoride (UF_6).

Uranium enrichment occurs following conversion. The purpose of this process is to increase the concentration of a particular form of uranium isotope necessary for use in most types of nuclear reactors. Natural uranium contains two forms (or isotopes) of uranium (U-238 and U-235) which are naturally found in the ratio of 99.3% and 0.7%. Although some reactors (such as the CANDU reactor design) can operate on the naturally occurring ratio of these two isotopes, most require a higher percentage of U-235 (3 to 4%). The process of enrichment achieves that desired ratio.

Uranium is currently enriched either by use of a centrifuge or by a process of gaseous diffusion, although gaseous diffusion plants are being phased-out due to their higher energy demands and costs of operation. New enrichment technologies are also being developed including an Australian innovation (SILEX) which separates isotopes using a pulsed laser. In this process, finely tuned lasers are used to energise a particular isotope of uranium so it can be separated, collected and concentrated.

Fuel fabrication is carried out after enrichment and is undertaken prior to its use in a nuclear reactor. The process typically involves the transformation of the enriched uranium (UF_6) into uranium oxide (UO_2), which is produced in the form of a pressed pellet. The pressed pellets are then inserted into fuel rods (usually tubes made from zirconium alloy) which are the components of the fuel assembly that are used in the reactor. Because there are many different nuclear reactor designs, fuel assemblies are manufactured specific to the reactor.

Reprocessing can occur following the use of uranium fuel in a reactor. Over time, the processes that occur during reactor operation make the fuel less efficient. That is, the ratio of the uranium isotopes in the fuel changes as a result of the fission process, creating new elements such as caesium and strontium which ultimately prevent the reactor from producing further energy using that fuel. While that is the case, much of the uranium in the fuel remains usable. In order to separate out the usable fuel it must be reprocessed. Usually, this process requires the spent fuel from nuclear reactors to be dissolved, allowing for the extraction and separation of plutonium produced during the fission process and residual uranium. The uranium and plutonium that is separated from spent fuel during aqueous chemical reprocessing can be made into new fuel and re-used. It is called mixed oxide (MOX) fuel due to this combination of uranium and plutonium. Additionally, recovered uranium oxide can be enriched further to produce re-enriched uranium oxide (REU) fuel which does not contain plutonium.

The commonly used commercial technique of reprocessing is known as PUREX (Plutonium URanium EXtraction). An alternative process not presently used commercially, pyroprocessing, is being investigated for use with fuels used in next generation reactor designs. Use of this technique may allow a reduction of the radioactive life of the waste products. Furthermore, it is not proposed that this process would separate plutonium from the other elements.

FURTHER PROCESSING CONTINUED

While current commercial nuclear reactor designs generate electricity from uranium fuels, technologies are under development which use thorium. The naturally occurring isotope of thorium (Th-232) does not require the same process of conversion and enrichment as uranium. Instead, thorium requires irradiation in a reactor together with uranium (or exposure to neutrons in an accelerator-driven system) to produce U-233. Energy is produced in the thorium fuel cycle through the fission of the isotope U-233. Development of thorium reactor concepts is ongoing, with possible fuel designs including pebbles, fuel assemblies or liquid metal fuel. Currently, there are no thorium-based reactor designs being actively promoted for broad commercial use.

The *Environment Protection and Biodiversity Conservation Act 1999 (Cth)* prohibits approval being given under that Act for the construction or operation of either an enrichment plant, a fuel fabrication plant or a reprocessing facility in Australia. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) regulates the establishment and operation of nuclear installations by Commonwealth entities through the issuing of licences. Pursuant to the *Australian Radiation Protection and Nuclear Safety Act 1998 (Cth)*, ARPANSA is prohibited from authorising a Commonwealth entity to construct or operate those facilities.

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

[1] Some reactors use fuel containing uranium which has not been enriched.

B. MANUFACTURE

Medical and scientific radioisotopes are developed from stable elements such as strontium, molybdenum, americium, technetium, and radioactive isotopes of hydrogen (H-2 and H-3) and iodine (I-131). They are generally manufactured close to the locations at which they are required (for example, hospitals) because they decay rapidly. There is increasing demand for the use of radioactive materials in scientific aparatus and medical instruments and fluids. Australia produces most of these isotopes at the Open Pool Australian Lightwater (OPAL) research reactor at Lucas Heights near Sydney.

Science and industry use radioactive elements in quality control and in instrumentation. Some specific examples include: the use of gauges to measure the levels of liquids in containers; gamma radiography to show flaws in welded joints; the analysis of the age of substances and materials (such as an isotope of carbon for carbon rich materials, an isotope of hydrogen (H-3) for groundwater and an isotope of lead (Pb-210) for sand and soil). There are many other uses.

Radioactive and nuclear materials are also used in the manufacture of other items including smoke detectors, scintillometers (gamma counters), geophysical tools, portable chemistry detectors (X-Ray Diffraction, X-Ray Fluorescence) and medical investigative machinery (electromagnetics and Geiger counters). There is very limited manufacture of these products in Australia as the radioactive components are sourced from international suppliers.

The manufacture of radioactive materials for these purposes will utilise either a reactor (which splits apart an element to produce the desired element) or a cyclotron (which builds an element from another element by adding particles). The process used depends on the elements required. Traditionally, many reactors overseas which are used to create isotopes for medical use are fuelled by uranium enriched to higher levels. However, approaches are currently being developed that do not require uranium at higher levels of enrichment.

Currently in South Australia, the cyclotron at the South Australian Health and Medical Research Institute (SAHMRI) is used to produce radioisotopes for medical use and scientific research. These products are not exported.

Considering these issues,

2.2. Would it be feasible for South Australia to assume a greater role in manufacturing materials containing radioactive and nuclear substances? What factors need to be taken into account in making that determination? Which factors are most important and why?

2.3. What legislative and regulatory arrangements would need to be in place to facilitate further processing and further manufacturing activities, including the transport of the products which they generate? How could these arrangements be developed so that they are most effective?

C. VIABILITY

In Australia, minerals containing radioactive materials such as uranium, thorium and rare earth elements are located, mined, milled and then exported overseas. However, there are no facilities at which uranium is further processed for use in nuclear reactors to generate electricity.

Globally, total annual conversion capacity is approximately 76,000 t, although demand for conversion services ranges from 60,000 to 64,000 t annually.[2] According to the International Atomic Energy Agency's (IAEA) Nuclear Technology Review 2014, six countries (United States, United Kingdom, Russia, France, China and Canada) operate commercial scale plants for the conversion to UF_6.[3] Smaller conversion facilities are also in operation in Argentina, Brazil, Iran and Japan.

It is estimated that the total global capacity for enrichment is 65 million separative work units (SWUs, being a measure of effort required to separate isotopes of uranium), although current international demand for enrichment is estimated to be about 49 million SWUs.[4] Major commercial enrichment services are carried out by CNNC (China), AREVA (France), ROSATOM (Russia), USEC and URENCO (both United States).[5]

Total global fuel fabrication capacity is presently around 13,000 t (fuel assemblies containing enriched uranium) for use in light water reactors and 4,000 t (fuel assemblies containing natural uranium) for pressurised heavy-water reactors.[6]

The viability of undertaking these activities at facilities in South Australia would depend on views about future demand and supply in the medium and long term given the time it would take to establish those operations. In a report published in 2013, the World Nuclear Association estimated future supply and demand for conversion, enrichment and fuel fabrication services.[7] Its estimates suggest that there is sufficient capacity to meet demand in all areas in the short term. However, in the medium term (see Figures 1 and 2) there may be a need for increased capacity for conversion and enrichment. Overall, there remains some uncertainty about nuclear fuel demand. In the 'high' case, there will be unmet demand for conversion and enrichment by 2030, although on the 'low' case existing capacity will meet future demand.

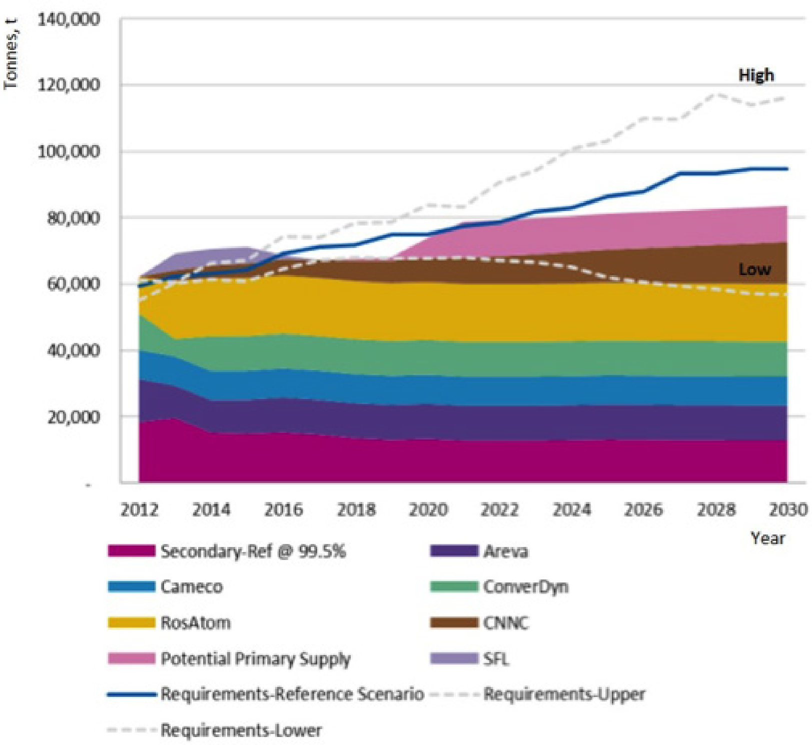

Figure 1 Projected world uranium enrichment supply-demand balance to 2030

(Source: World Nuclear Association, 2013, *The Global Nuclear Fuel Market: Supply and Demand 2013-2030*)

VIABILITY CONTINUED

Aside from issues of international demand and supply, whether new facilities would be established in South Australia would depend on any comparative advantage that it had over other locations where that investment might occur, including at existing facilities. For example, in the case of enrichment facilities, a factor which may influence the existence of any comparative advantage is the availability of competitively priced electricity to enable the efficient operation of those facilities. South Australia's decision to establish facilities for the conversion, enrichment, fuel fabrication or reprocessing of uranium could also be influenced by developments in prospective technologies, such as pyroprocessing and the development and production of high-performance materials for the thorium fuel cycle or other new reactor technologies.

Against that background,

2.4. What are the projections for future supply and demand for conversion, enrichment, fuel fabrication or reprocessing activities? What is the evidence to support those projections? Might it be viable for one or more of those activities, or an aspect of them, to be established in South Australia in the medium or long term? What is the reason for thinking that would be so? What conditions would be necessary for that to be viable?

While Australia does not participate in commercial activities of conversion, enrichment and fabrication, it does engage in the production and manufacture of reactor based radiopharmaceuticals and nuclear medicines. The Australian Nuclear Science and Technology Organisation (ANSTO) is the principal supplier and exporter of these products from Australia. Approximately 13% of all international sales are to customers in locations such as New Zealand and the South East Asian region.[8]

Radiopharmaceuticals produced using cyclotrons are distributed to a large network of nuclear medicine centres across Australia and New Zealand. These are principally used for the detection, treatment and further imaging of cancer and include isotopes of iodine (I-123 and I-131) and gallium (Ga-67). New radiopharmaceuticals are being developed by ANSTO Health for manufacture and include an isotope of lutetium (Lu-177) for cancer treatment.[9]

2.5. Could South Australia viably increase its participation in manufacturing materials containing radioactive and nuclear substances? Why or why not? What evidence is there about this issue? What new or emerging technologies are being developed which might impact this decision?

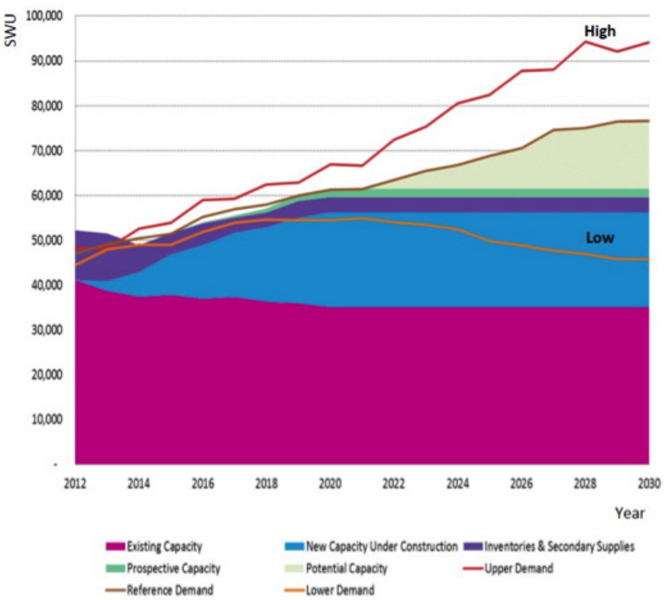

Figure 2 Projected world uranium enrichment supply-demand balance to 2030

(Source: World Nuclear Association, 2013, *The Global Nuclear Fuel Market: Supply and Demand 2013-2030*)

[2] IAEA, Nuclear Technology Review 2014, available at http://www.iaea.org/About/Policy/GC/GC58/GC58InfDocuments/English/gc58inf-4_en.pdf.

[3] As above.

[4] As above.

[5] As above.

[6] WEC, World Energy Resources: Uranium and Nuclear 2013, available at http://www.worldenergy.org/wp-content/uploads/2013/10/WER_2013_4_Uranium_and_Nuclear.pdf.

[7] World Nuclear Association, 2013, The Global Nuclear Fuel Market: Supply and Demand 2013-2030.

[8] ANSTO Annual Report 2013-2014, available at http://www.ansto.gov.au/cs/groups/corporate/documents/document/mdaw/mdi3/~edisp/acs054324.pdf.

[9] ANSTO, available at http://www.ansto.gov.au/BusinessServices/ANSTOHealth/Radiopharmaceuticals/index.htm.

D. RISKS AND OPPORTUNITIES

Each step in the further processing of minerals containing radioactive and nuclear materials produces hazardous substances and wastes which require considered management to protect the environment and to protect workers involved. Conversion and enrichment activities create hazardous liquid wastes, as well as low level and intermediate level radioactive wastes (including tails, in the case of enrichment).[10] Fuel fabrication produces various industrial and combustible wastes including dewatered waste sludge and uranium ash. Spent fuel reprocessing generates radioactive wastes, although if it was not reprocessed, spent fuel in itself would require storage and disposal as high level waste.[11] Further, reprocessing of spent fuel through current processes leaves fission products and other long-lived radioactive materials (including plutonium and waste) which require appropriate treatment, although the extent of these may be reduced through the use of emerging technologies, such as pyroprocessing.

UF_6 is itself a hazardous chemical and, if combined with water vapour during conversion activities, can form hydrofluoric acid (HF) which can create health implications if inhaled or ingested.[12] However, this risk is generally well understood and techniques exist to manage it appropriately, including, for example, mechanisms which neutralise the toxicity of the HF (HF scrubbers).

Further risks potentially arise from radiation. They may arise directly during operations to produce uranium products and through the handling, transport, storage and disposal of wastes produced by those activities, or indirectly through potential contamination of the environment and further exposure to humans and other biological organisms from those sources. Though humans and other biological organisms are exposed throughout their lives to radiation from natural sources (such as cosmic radiation, the Earth and the environment), exposure to radiation from nuclear and radioactive materials presents more substantial risks. The extent of those risks depends upon the radioactive substances, types of radiation emitted, their extent and their physical and chemical forms.[13] Those risks need to be analysed comprehensively, bearing in mind the facilities at which further processing or manufacturing activities take place.

Regulations exist to control the exposure of workers and the wider community to radiation. Radiation dose limits and requirements for radiation protection are developed in accordance with Australian and international standards by the IAEA. The *Radiation Protection and Control Act 1982 (SA)* and its regulations specify maximum safe limits of exposure. Radiation exposure is also taken into account in the design, operations and procedures at facilities where radioactive materials are managed. The public is generally excluded from entering facilities at which concentrated radioactive materials are present, although circumstances may exist in which a member of the public will need to attend a facility where a radiation source is present, such as a nuclear medicine department in a hospital for the purpose of diagnosis and treatment.

In South Australia, the manufacturing of products containing radioactive substances is also regulated. Facilities which manufacture these products must be licenced by the Environment Protection Agency (EPA) under the *Radiation Protection and Control Act 1982* (SA). It is a condition of those licences that a Radioactive Management Plan (RMP) is in place which details how the products are handled, transported and used. Distributors must also hold licences (which incorporate RMPs) for the possession and sale of such products.

In the absence of any prohibition, the establishment of facilities for the conversion, enrichment, fuel fabrication or reprocessing of minerals containing radioactive substances would require approvals and licences to be obtained under State and Commonwealth planning, environmental and radiation protection legislation. Assessments of predicted environmental impacts arising from those activities and plans for the management of those impacts would need to be formulated to obtain approvals under those laws. Those processes require public notification and consultation before approvals and licences are issued. Licences would be the subject of conditions concerning the handling management and treatment of wastes as well as conditions for managing environmental impacts.

Where they have a relevant bearing on understanding the impacts of establishing these activities, the Commission will consider whether there are lessons to be learned from past South Australian processing practices.

Due to the presence of uranium and plutonium in spent fuel, there are security and safeguards implications associated with its management, possession and transportation. As a result, permits to possess and transport this material must be obtained under the *Nuclear Non-Proliferation (Safeguards) Act 1987 (Cth)*. Furthermore, separate authorisation is required under Customs regulations in order to import or export spent fuel. The IAEA has also published standards for the safe international transport of radioactive materials.

In addition to those matters, a technical capability in Australia to enrich uranium and reprocess spent fuel gives rise to non-proliferation policy issues given the potential for those technologies to be applied for non-peaceful purposes. Such a capability would raise policy and strategic issues for Australia to consider as part of its diplomatic and international relations. Careful consideration would need to be given to how the international community could be assured that such technologies would only be used consistently with Australia's obligations under the Treaty on the Non-proliferation of Nuclear Weapons (NPT).

RISKS & OPPORTUNITIES CONTINUED

Bearing these issues in mind,

2.6. What are the specific models and case studies that demonstrate the best practice for the establishment, operation and regulation of facilities for the conversion, enrichment, fuel fabrication or reprocessing of, or the manufacture of materials containing, radioactive and nuclear substances? What are the less successful examples? Where have they been implemented? What lessons can be drawn from them?

2.7. What are the processes that would need to be undertaken to build confidence in the community generally, or specific communities, in the design, establishment and operation of such facilities?

2.8. What additional risks for health and safety would be created by the establishment and operation of such facilities in South Australia? What needs to be done to ensure that risks would not exceed safe levels? Can anything be done to better understand those risks?

2.9. What additional environmental risks would be created by the establishment and operation of such facilities in South Australia? Are there strategies for managing those risks? If not, what strategies would need to be developed? How would any current approach to management need to be changed or adapted?

2.10. Given current techniques for further processing of radioactive and nuclear substances, what are the relevant lessons for the contemporary management of environmental impacts which should be learned from past South Australian processing practices?

2.11. What security implications are created by the activities of conversion, enrichment, fabrication or reprocessing of nuclear fuel, or by further manufacturing activities, in South Australia? What is the evidence which suggests that such risks might materialise? Can they be addressed and by what means?

2.12. What safeguards issues are created by the further participation in South Australia in activities (such as the production of uranium oxide, conversion, enrichment, fuel fabrication or reprocessing) necessary for uranium to be used as a fuel in electricity generation? Can those implications be addressed? If so, by what means? Further, would the possession of those technical capabilities give rise to strategic and policy issues for Australia? If so, what are those issues and how could they be addressed?

Existing technologies for the processing and manufacture of products containing radioactive or nuclear materials are covered by country-specific and international intellectual property law protections. Any adaption or acquisition of existing technologies would have to be through agreement with the owner of the intellectual property. Compensation in the form of fees and royalties may also be payable to the owner. In addition, restrictions may be placed on the freedom of local and international trade as a condition of being permitted to use the technology for processing or manufacture.

South Australia has a history of invention, innovation and manufacturing. It may be possible to adapt current or past manufacturing centres to a future processing or manufacturing industry for radioactive or nuclear materials. The utility in doing so would be dependent on local and international demand for the products.

As Australia does not operate any conversion, enrichment, fuel fabrication or reprocessing facilities, there is no direct experience from which to estimate the economic value of those activities. However, in 2006, a Commonwealth Government taskforce estimated that Australia's annual export revenue could be increased by $1.8 billion at that time if the then estimated 12,000 tonnes of uranium oxide was transformed domestically into nuclear fuel.[14]

The manufacturing volumes and values for radioactive or nuclear materials in products is difficult to quantify due to the diverse range of products involved. This will be a complex sector to assess as some manufacturers create the radioactive or nuclear sources required for their products, whilst others will utilise components from other manufacturers. Accounting for the trade involved in the manufacturing of products with radioactive or nuclear components would require further detailed investigation.

If facilities were to be established and operated in South Australia at which further processing or further manufacturing activities were carried out, specialist training by tertiary and technical providers would need to cater for this. Skills required to operate and maintain such facilities would include, for example, nuclear and health physicists, engineers, scientists, managers and transport workers, as well as those with trade related skills.

Given these matters,

2.13. What financial or economic model or method ought be used to estimate the economic benefits from South Australia's establishment and operation of facilities for the conversion, enrichment, fuel fabrication or reprocessing of, or the manufacture of materials containing, radioactive and nuclear substances? What information or data (including that drawn from actual experience elsewhere) should be used in that model or method?

2.14. Would South Australia's establishment and operation of such facilities give rise to impacts on other sectors of the economy? What would those impacts be? How should they be estimated and what information should be used? Have such impacts been demonstrated in other economies similar to South Australia?

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[10] IAEA, Minimization of waste from uranium purification, enrichment and fuel fabrication 1999, available at http://www-pub.iaea.org/MTCD/publications/PDF/te_1115_prn.pdf.

[11] IPFM, Spent Nuclear Fuel Reprocessing in France 2008, available at http://fissilematerials.org/library/rr04.pdf.

[12] GEA, 2012, Global Energy Assessment – Towards a Sustainable Future (Cambridge University Press and IIASA).

[13] ARPANSA, 1985, RHS No. 13, Code of practice for the disposal of radioactive wastes by the user.

[14] Commonwealth of Australia 2006, Uranium Mining, Processing and Nuclear Energy – Opportunities for Australia? Report to the Prime Minister by the Uranium Mining, Processing and Nuclear Energy Review Taskforce.

APRIL 2015
Adelaide, Australia

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