Government of **Western Australia**
Department of **Mines and Petroleum**

Guide to Uranium in Western Australia

May 2013

Contents

1. Introduction

The Department of Mines and Petroleum is the primary State Government agency responsible for regulating the uranium mining industry in Western Australia.

In 2009 the Western Australian Liberal-National coalition government lifted a ban on uranium mining in Western Australia, with the following commitments:

- The industry will meet all international safeguards in relation to the safe and peaceful use of uranium resources.
- All necessary environmental approvals will be obtained in relation to the mining of uranium and the transport of uranium oxide.
- A safe workplace for all employees involved in the mining and the transport of uranium oxide will be ensured[1].

This guide provides an overview of the uranium industry, as well as information regarding the health, safety and environmental management of uranium mining and transport of uranium oxide in Western Australia.

Figure 1: Uranium ore

Figure 2: Uranium oxide (yellowcake)

1.1 What is uranium?

Uranium (chemical symbol U) is a naturally occurring radioactive element. Uranium is found in trace amounts in rocks, soil, water and air. In its natural state uranium is weakly radioactive and needs to be enriched before it can be used as nuclear fuel.

The ore (Figure 1) extracted at the mine is refined into uranium oxide before it is exported. When refined it is a silver coloured heavy metal similar to lead. It is about 70 per cent more dense than lead – a small 10 centimetre cube of pure uranium would weigh 20 kilograms[2].

Processing mined ore into uranium oxide (sometimes called yellowcake) (Figure 2) is done at the mine site. It involves crushing the ore and separating the waste rock. Chemical processes are then used to extract the uranium.

See Figure 3: Steps in processing uranium ore.

U FACTS

The main use of uranium is as a fuel in nuclear reactors to generate electricity, in the manufacture of radioisotopes for medical purposes and in nuclear science research.

[1]Colin Barnett, Premier; Minister for State Development, *Mon 17 November, 2008*
[2]International Atomic Energy Agency, *Feature Story: Depleted Uranium*

Figure 3: Steps in processing uranium ore

Uranium oxide cannot directly be used as fuel for a nuclear reactor. After being packaged carefully for transport it is exported for further processing.

The main stages in the uranium fuel for power generation cycle are:

- mining and milling
- conversion and enrichment
- fuel fabrication
- fission in reactor for generation of nuclear power or production of radioisotopes
- reprocessing and recycling
- disposal and storage of waste.

For more information on the uranium fuel cycle, please see: Section 7.1 The nuclear fuel cycle.

1.2 Global uranium mining

Australia is the world's third largest producer of uranium after Kazakhstan and Canada. South Australia's Olympic Dam is the world's largest known uranium deposit, currently producing around six per cent of the world's uranium.

The top three exporting countries account for almost 65 per cent of uranium production worldwide. There are currently 19 uranium producing countries, including Namibia, Niger, the Russian Federation, the United States, China and the Ukraine. There are about 45 operating uranium mines worldwide, with over 120 prospective new mines across the globe, many of which are in Canada, Australia and Argentina[3].

1.3 Uranium industry in Australia

In 2011-12, Australia exported just under 7000 tonnes of uranium oxide, for a value of $607 million, to be used in nuclear reactors in North America, Europe and Asia.[4]

Australia has been a part of the world uranium industry almost since its inception. In the 1930s ores were mined at Radium Hill and Mount Painter in South Australia.

In the late 1940s, the Australian government offered tax free incentives to promote the discovery of uranium deposits.

Uranium was mined and treated in Australia from the 1950s until 1971 at Radium Hill in South Australia, Rum Jungle in the Northern Territory, and Mary Kathleen in Queensland. Production ceased when ore reserves were exhausted or contracts of sales to the USA and UK were filled.

The development of civil nuclear power stimulated a second wave of exploration activity in the late 1960s. A total of some 60 uranium deposits were identified from the 1950s through to the late 1970s. Since then only two significant new deposits have been found: Kintyre and Beverley Four Mile.

Mary Kathleen's second production phase was from 1976 to the end of 1982. Narbalek mine in the Northern Territory was opened in 1979. The orebody was mined out in one dry season in 1980 and the ore stockpiled for treatment. The mine site is now rehabilitated. Ranger Mine in the Northern Territory was opened in 1981 and continues to this day.

Olympic Dam in South Australia is the world's largest known uranium orebody and has been operating since 1988. The small Beverley mine in South Australia started operation late in 2000 and Honeymoon mine, also in South Australia opened in 2011.

[3]International Atomic Energy Agency (2011) *Uranium Resources, Production and Demand*
[4]World Nuclear Association (2012) *World Uranium Mining*

Decade	NUCLEAR POWER DEVELOPMENTS WORLDWIDE	URANIUM MINING IN AUSTRALIA
1780s	**1789** – Martin Klaproth discovers uranium	
1890s	**1895** – Henri Bequerel discovers alpha and beta radiation **1895** – Wilhelm Rontgen discovers ionising radiation **1896** – Pierre and Marie Curie names gamma radiation	Uranium deposits identified in South Australia
1930s	**1938** – Otto Hahn and Fritz Strassman demonstrate atomic fission	Uranium ores mined at Radium Hill and Mount Painter (South Australia) for medical purposes
1940s	**1942** – Enrico Ferni and team conduct first successful nuclear reaction **1945, 16 July** – First successful testing of atomic device at Alamagordo in New Mexico **1945, 6 August** – Hiroshima bombing	Uranium exploration encouraged by Federal government
1950s	**1951** – First nuclear reactor produces electricity, Idaho USA **1954** – USSR's Obninsk Nuclear Power Plant becomes world first power plant to generate electricity for a power grid **1956** – First commercial nuclear power station opens in England	**1954** – Uranium mining commences Rum Jungle in NT and Radium Hill in SA reopened
1960s	Installed nuclear capacity rises from less than 1 gigawatt in 1960 to 100 gigawatts in 1970	Development of nuclear energy worldwide stimulates exploration — about 60 deposits discovered (including the world's largest, Olympic Dam)
1970s	Anti-nuclear activism increases worldwide fuelled by concern over proliferation of weapons, reactor safety and waste disposal **1979** – Three Mile Island incident	**1973** – Australia becomes signatory to nuclear nonproliferation treaty **1976** – Refusal of railway workers to transport uranium ore from Mary Kathleen in QLD leads to national rail strike **1977** – ALP commits to no Australian involvement in nuclear energy
1980s	**1970s and 80s** – Rising economic costs of nuclear generation and falling fossil fuel prices lead to slow down in nuclear power industry **1986** – Chernobyl disaster	**1984** – ALP articulates "Three Mine Policy" allowing uranium mining at Narbalek, Ranger and Olympic Dam mines **1988** – Olympic Dam commences production
1990s	Growth in number of nuclear power plants due to technological and managerial improvements, deregulation and safety improvements	
2000s	**2011** – Fukushima incident. Japan, Germany, Sweden announce phase out of nuclear power	**2007** – Federal ALP's "Three Mines Policy" overturned **2008** – WA State Government overturns uranium mining ban in WA
2012	436 nuclear reactors operating, 62 under construction, 167 on order or planned worldwide. Growth in China, South Korea, Russia	NSW State Government allows uranium exploration QLD State overturns ban on uranium mining WA government approves first uranium mine

Figure 4: History of nuclear technology and uranium mining

1.4 Uranium in Western Australia

As of June 2012, Western Australia's (WA) has known deposits of about 211,000 tonnes of uranium. Figure 5 shows a list of uranium deposits in western Australia and Figure 6 is a map of deposits.

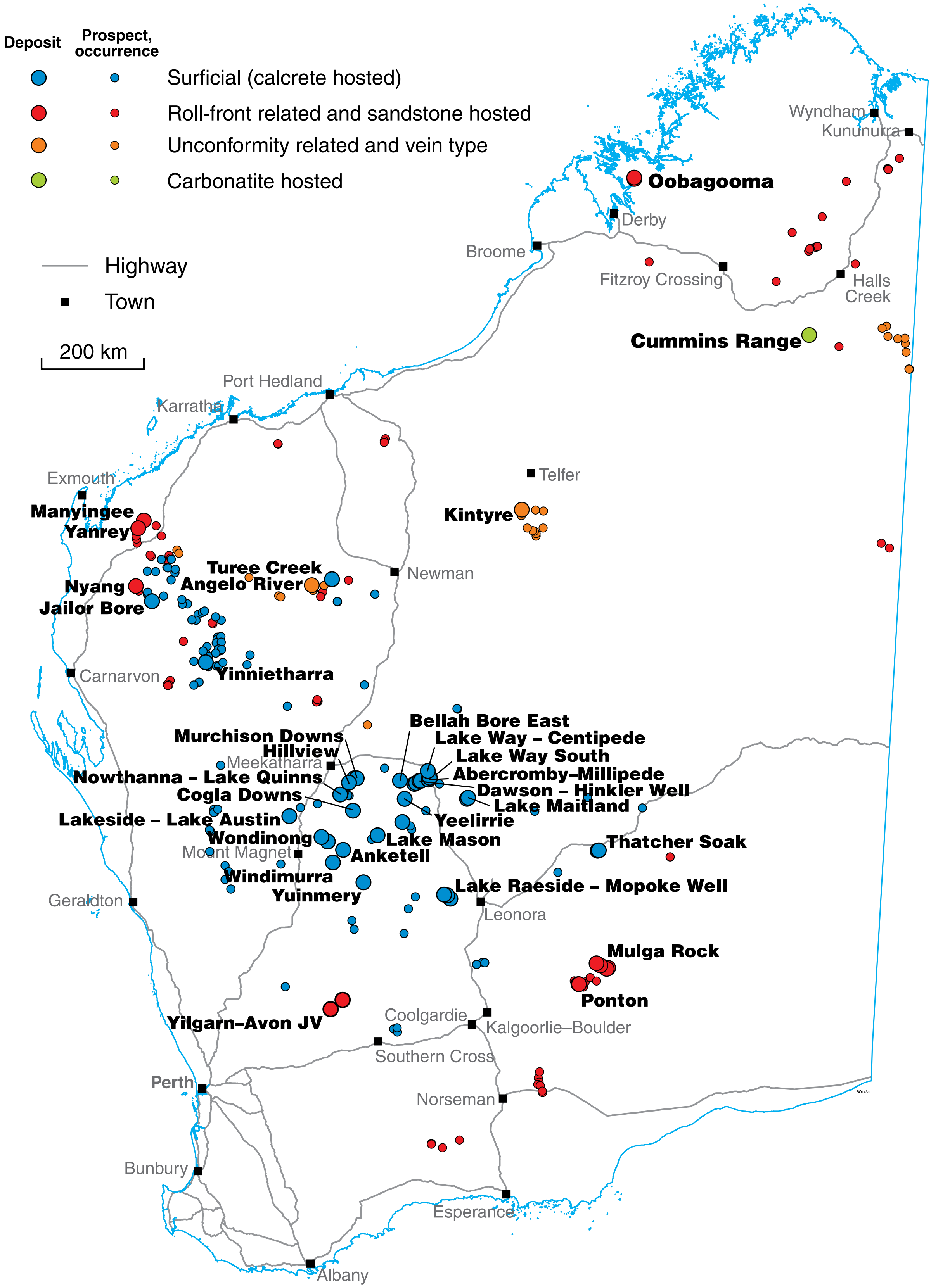
Project name	Project owner	Resources (Mt)	Resources (ppm)	Contained U_3O_8 (Kt)	Contained U_3O_8 (Mlbs)
Yeelirrie	Cameco	36.6	1562	57.24	127.1
Mulga Rock	Vimy Resources	59.7	554	33.08	73.4
Kintyre	Cameco, Mitsubishi	5.3	5583	29.40	65.3
Lake Way – Centipede	Toro Energy	27.1	539	14.61	32.4
Manyingee	Paladin Energy	13.8	850	11.71	26.0
Lake Maitland	Toro Energy	20.8	486	10.10	22.4
Oobagooma	Paladin Energy	8.3	1200	9.96	22.1
Yanrey	Cauldron Energy	36.1	270	9.76	21.5
Ponton	Manhattan Corp.	26.0	300	7.80	17.3
Thatcher Soak	Magnis Res., Gold Road Res.	27.7	203	7.73	17.2
Nyang – Carley Bore	Paladin Energy	22.8	313	7.14	15.9
Nowthanna – Lake Quinns	Toro Energy, Yellow Rock	15.0	405	6.02	13.4
Hillview	Encounter Resources	27.6	174	4.80	10.7
Dawson – Hinkler Well	Toro Energy	13.1	312	4.08	9.1
Windimurra	P R Gianni	19.0	180	3.42	7.6
Theseus	Toro Energy	6.3	493	3.11	6.9
Anketell	Energy Metals	16.3	167	2.72	6.0
Lake Raeside – Mopoke Well	Energy Metals	10.1	175	1.77	3.9
Lake Mason	Energy Metals	9.1	185	1.68	3.7
Yilgarn – Avon JV	Mindax Ltd, Quasar Resources	6.2	237	1.47	3.3
Wondinong	Zeedam Ent., Montezuma Mining	6.6	190	1.25	2.8
Lakeside – Lake Austin	Energy Metals	2.7	350	0.96	2.1
Angelo River	S A Macdonald	0.6	1240	0.80	1.8
Jailor Bore	R C Cooper	1.4	500	0.72	1.6
Cummins Range	Navigator Resources	4.9	145	0.71	1.6
Yuinmery	B R Legendre	1.6	370	0.59	1.3
Yinnietharra – Minindi Creek	South Coast Minerals	3.5	123	0.43	1.0
Turee Creek	Aldershot Resources	1.1	350	0.37	0.8
Murchison Downs	Faurex Pty Ltd	0.3	633	0.19	0.4
Yarrabubba – Cogla Downs	Mithril Resources	0.2	630	0.10	0.2
Bellah Bore East	Encounter Resources	0.4	210	0.07	0.2
Lake Way South	Encounter Resources, Metals X	0.2	244	0.05	0.1
		430.4		**233.84**	**519.1**

Note: Some resource estimates are historic and predate JORC

As of February 2013 **Mt** = millions of tonnes **ppm** = parts per million **Kt** = kilo tonnes **Mlbs** = millions of pounds

Figure 5: List of known uranium deposits in Western Australia

Uranium sites by mineralisation style



2. Uranium deposit types, mining and production methods

2.1 Deposit types

There are 14 types of uranium deposits found around the world. In igneous (volcanic), sedimentary and hydrothermal (formed by a combination of heat and water deep within the Earth's crust) environments. In Western Australia, uranium has so far been discovered in four main deposit types:

Surficial (calcrete) – the majority of Western Australia's known uranium deposits are surficial. They are typically near the surface, in sediments or soils. The Yeelirrie deposit in WA is the world's largest surficial deposit with other deposits including Lake Way, Centipede, Thatcher Soak and Lake Maitland.

Sandstone hosted (roll front) – these deposits occur in sandstone, in crescent shaped ore bodies. The Mulga Rock deposit is an example of a roll front deposit.

Vein type (unconformity related) – in places where two types of rock meet and one is much older than the other (which is called an unconformity). Vein type deposits comprise about nine per cent of the world's uranium sources. In WA the only known deposits of this type are at Kintyre and Turee Creek.

Intrusive carbonatite – when magma (molten rock from deep within the Earth) is forced upwards into existing rock within the Earth's crust and cools and solidifies into igneous rock, this is known as intrusive rock. In WA, intrusive carbonatite and pegmatite formations in the Kimberley region are known to host uranium, at Cummins Range, and also near Halls Creek.

2.2 Uranium mining methods

The way in which uranium is mined depends on the surrounding geology, the size of the orebody, its position and the surrounding environment.

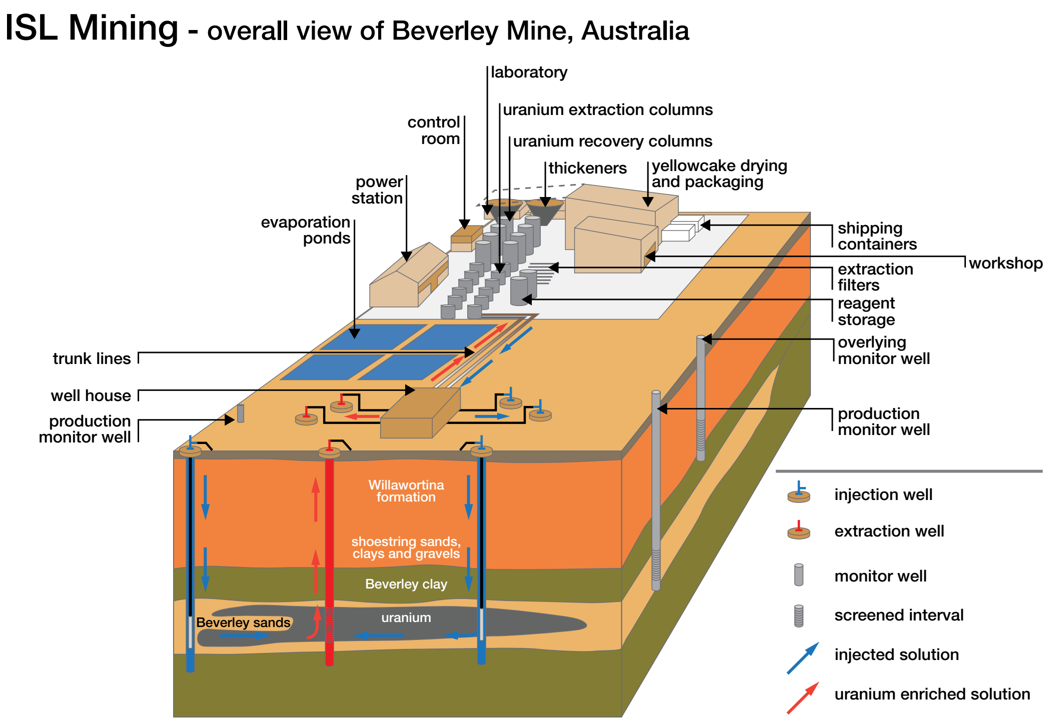


Figure 7: In Situ Leaching at Beverly mine in South Australia. Source Heathgate Resources.

Uranium is mined in one of three ways:

Openpit (or opencut) – in places where the orebody is close to the surface, the simplest method of accessing it is an opencut mine, in which the overburden (rock covering the orebody) is removed to allow mining of the underlying uranium orebody. In 2011, approximately 17 per cent of uranium was produced this way[5]. Opencut mining, although very cost-effective, creates the highest level of land disturbance (Figure 8).

Underground – suitable for rich orebodies that are deeper in the earth, underground mining is more difficult and complex. It requires precise tunnelling, ventilation, ground support, and specialised equipment designed to operate in confined spaces. In 2011, approximately 30 per cent of world uranium was mined this way.

In Situ Recovery (or In Situ Leaching) – uranium that is found in permeable materials such as sand or gravel can be most effectively mined through in situ recovery. This process involves pumping weakly acidic or alkaline water into the orebody where it dissolves the uranium. The resulting uranium-rich solution is then pumped to the surface, the uranium is extracted and leaching solution is reused. In 2011, approximately 45 per cent of world uranium was mined this way. Figure 7 is a diagram of In Situ Leaching at Beverly mine in South Australia.

Figure 8 © AREVA, TAILLAT JEAN–MARIE, Somaïr open pit mine. Arlit. NIGER

For more information about In Situ Recovery see:
Australia's In Situ Recovery best practice guide
www.ret.gov.au/resources/Documents/Mining/uranium/In-situ-uranium.pdf

U FACTS

Like all mining in Australia, uranium mining is subject to royalty payments that compensate the people of Western Australia for taking the resource. At the current rate, five per cent of the money earned on the sale of uranium is payable as a State royalty.

[5]International Atomic Energy Agency (2011) *Uranium Resources, Production and Demand*

3. Uranium and radiation

Radiation is energy travelling as waves (such as light and heat, microwaves, radiowaves, ultraviolet, x-rays and gamma rays) or particles (such as alpha, beta and neutrons). Radiation is all around us – cosmic rays from outer space, and gamma rays from the naturally occurring radioactive minerals in the earth (see Figure 9).

Uranium is radioactive because its atom is unstable and, in simple terms, to become stable must lose excess energy by moving through a series of thirteen radioactive "daughter" elements to become a stable element, lead.

The energy emitted during this 'radioactive decay' is known as ionizing radiation. Ionizing radiation is radiation energetic enough to detach electrons from atoms or molecules.

Although there are other types of ionising radiation, the uranium mining industry generally concerns itself with three (Figure 9):

Alpha Radiation – at the moment of decay, when an atom stabilises by emitting extra mass, it ejects the nucleus of a helium atom at very high speed. These are relatively heavy and will penetrate matter for only a short range. An alpha particle will slow down (i.e. lose most of its energy) in about 30 millimetres in the air and can be stopped by a piece of paper. Alpha particles can't penetrate the outer layers of skin, but can cause damage if inhaled or ingested.

Beta Radiation – atoms that carry too many neutrons to be stable produce electrons, formed by the conversion of a neutron into a proton. These electrons are ejected at about ten times the speed of alpha particles – almost the speed of light – and can penetrate down to the deepest layer of skin. However because they are so much smaller than alpha particles, beta particles are generally much less ionising. Prolonged exposure of the skin to beta-emitting contaminants can cause damage, and inhaling or ingesting beta particles can also be harmful.

Gamma Radiation – electromagnetic waves at the highest frequency (and therefore energy) level of the electromagnetic spectrum, gamma rays travel at the speed of light, and are able to penetrate deeply into human tissue and travel relatively long distances in air. Similar to x-rays in their energy and effect, gamma rays are weakly ionising and require dense layers of material, such as lead shielding, for protection. As gamma radiation passes through material such as wood or metal, it will lose some of its intensity and become less damaging.

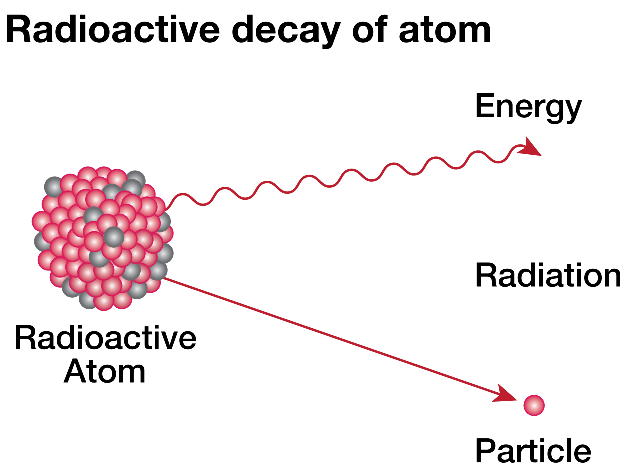


Figure 9: Radiation is energy travelling as waves or particles

U FACTS

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) website offers detailed information regarding radiation and its effects. To learn more visit:

www.arpansa.gov.au/RadiationProtection/basics/index.cfm

more information can also be found at the International Atomic Energy Agency:

www.iaea.org

The World Health Organisation:

www.who.int/ionizing_radiation/about/what_is_ir/en/index.html, www.who.int/entity/ionizing_radiation/a_e/Basic%20Info%20leaflet-E%20march%202005.pdf

or the US Environmental Protection Authority:

www.epa.gov/rpdweb00/understand/atom.html

U FACTS

Decay Products:
When a radioactive atom decays, it may not immediately change from radioactive to inert in one move. Instead, it can undergo several changes, becoming a new radionuclide, or decay product, at each step. For example, radon gas is a radionuclide produced by the decay of naturally occurring uranium. In places where there are large concentrations of granite that hold considerable amounts of natural uranium, radon gas can be present.

Decay products are also released due to radioactive decay of uranium and these decay products must be accounted for in all safety measures for mining projects.

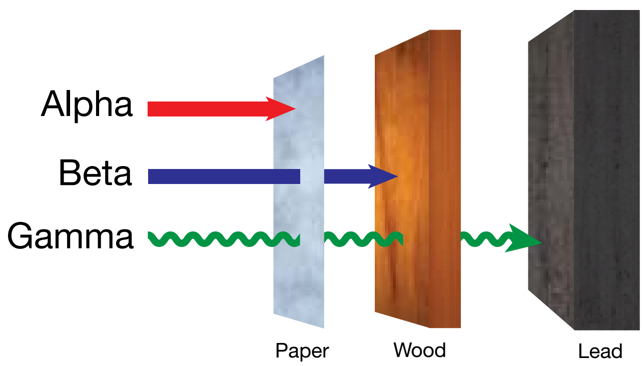


Figure 10: Types of radiation

3.1 Half-life

The concept of a half-life is crucial to the understanding of radiation. The term refers to the time it takes for half of the radioactive nuclei in any given quantity to decay into other products, which themselves may in turn be either radioactive or stable.

3.2 Exposure to radiation

Everyone in the world is exposed to some kind of ionising radiation all the time. Each year most Australians are subject to an annual dose of about 1.5 milliSieverts of radiation from natural and medical sources[6]. Natural background radiation comes from a range of sources including cosmic rays; naturally occurring radioactive materials (NORM) that occur in minerals such as granite, radon gas in the air we breathe; and radioactive materials in our food and drink.

Exposure to radiation when working with uranium commonly occurs in three ways – inhaling, ingesting, or external exposure to gamma rays.

Protection against these forms of exposure can be simple. To avoid inhaling some alpha and beta emitting particles, dust masks should be worn when working with these kinds of radiation sources.

Avoiding ingesting particles can be as simple as maintaining proper hygiene – washing hands after working near radiation sources and before meals to remove particles or dust on the skin.

Protection from gamma exposure is achieved by reducing the time spent with radiation sources, moving away from radiation sources or shielding yourself from radiation sources. This is known simply as time, distance and shielding.

Such protective measures are a mandatory part of Occupational Safety and Health policies.

For more information please see:
Section 4 of this guide
Uranium mining safety in Western Australia

[6] ARPANSA (2011) *Fact Sheet 17: Ionising Radiation and Health*

U FACTS

In Western Australia, the Department of Mines and Petroleum enforces strict exposure limits as prescribed by the Radiological Council; companies must not allow the public to be exposed to more than one milliSievert per year.

Data from Australia's longest operating uranium mines, Ranger and Olympic Dam, shows that people living in the nearby communities of Jabiru and Roxby Downs typically receive about 0.01 or 0.02 milliSieverts of mining-originated radiation per annum – a tiny fraction of the allowable limit.

(Source: Radiation Control in the Mining & Mineral Processing Industry: Radiation Workers' Handbook)

3.3 Measuring radiation exposure

There are a number of ways to measure radiation emission and exposure. These range from measuring the radioactivity of a particular substance *(Becquerel)*, to determining the amount of energy each type of radiation deposits in a material *(Gray)*, to the hazard presented by exposure *(Sievert)*.

Measures of the actual radiation dose received are expressed in Sieverts, although because this is a relatively large unit the usual form is milliSievert (mSv) – equal to one thousandth of a Sievert.

3.4 Effects of radiation exposure to humans

The risks associated with radiation exposure depends on a number of factors including dose received. The most hazardous kind of exposure is an acute dose, a high dose of radiation delivered over a short period, from a few hours to a few days.

The effects of an acute dose can include rapid development of radiation sickness. Some symptons can be gastrointestinal disorders, bacterial infections, haemorrhaging, anaemia, loss of body fluids, and electrolyte imbalance. Delayed biological effects can include cataracts, temporary sterility, cancer, and genetic effects. Extremely high levels of acute radiation exposure can result in death within a few hours, days or weeks.

As a precaution, the 'As Low As Reasonably Practicable' (ALARP) approach is typically adopted for radiation safety.

Please see figures 11 and 12 for more information.

Indicative dose range (mSv)	Effects on human health (including unborn child)
Up to 10	No direct evidence of human health effects
10 – 1000	No early effects; increased incidence of certain cancers in exposed populations at higher doses
1000 – 10,000	Radiation sickness (risk of death); increased incidence of certain cancers in exposed populations
Above 10,000	Fatal always

Figure 11: Effects of Radiation on Human Health[8]

Source or mode	Typical dose (mSv)
10 hour aeroplane flight	0.03
Chest x-ray	0.05
CT scan	10
Annual dose from natural background	2.4
Annual dose to nuclear worker	1
Annual cosmic radiation at sea level	0.4
Annual cosmic radiation Mexico City (2,300m)	0.8
Chernobyl recovery workers in 1986	150

Figure 12: Sources of radiation exposure[9]

[8]United Nations Scientific Committee on the Effects of Atomic Radiation (2011) *Answers to Frequently Asked Questions*
[9]United Nations Scientific Committee on the Effects of Atomic Radiation (2011) *Answers to Frequently Asked Questions*

For more information about radiation, health and the environment, please refer to the International Atomic Energy Agency:

Australian Radiation Protection and Nuclear Safety Agency:
www.arpansa.gov.au/radiationprotection/basics/health_ion.cfm

www.iaea.org/Publications/Booklets/RadPeopleEnv/pdf/radiation_low.pdf

United Nations Scientific Committee on the Effects of Atomic Radiation:
www.unscear.org/unscear/en/faq.html?print

The World Health Organisation:
www.who.int/ionizing_radiation/about/what_is_ir/en/index.html

© AREVA, TAILLAT JEAN–MARIE, Somaïr ore processing plant. Niger

4. Uranium mining safety in WA

The Department of Mines and Petroleum (DMP) and the Radiological Council in Western Australia regulate at the highest international levels to ensure that risk to workers, communities and the environment from uranium mining is minimised. Please refer to the international nuclear power industry section of this guide for more information.

4.1 Community safety

DMPs primary objective is to ensure that the community and workers are safe and that any mining meets all safety, health and environmental standards, consistent with relevant State and Federal legislation, regulations and policies.

Measures implemented to ensure radiation safety for workers and the communities living near mine sites and transport routes include:

- approval of a Radiation Management Plan prior to any operation covering the mine, processing plant and transport arrangements

For more information about transport, please see: Section 5. Uranium transport safety in Western Australia.

- employment of a permanent specialist Radiation Safety Officer whose job it is to ensure that all regulations and conditions are adhered to and that best practice is employed at every step
- employee induction and training in matters regarding radioactivity and radiation
- comprehensive emergency planning and preparedness
- comprehensive personnel and environmental monitoring
- strict regulation of the mining, processing and transportation of radioactive materials, with oversight by the Resources Safety Division of DMP and the Radiological Council to ensure compliance.

4.2 Worker safety

Uranium exploration and mine workers are subject to a broad range of safety regulations, protocols and practices, and a more rigorous health monitoring regime than most other mine workers.

The International Commission on Radiological Protection (ICRP) recommendation on dose limitations state that any radiation dose arising from human activity must be:

- justified: the activity must do more human good than harm
- optimised: the dose must be ALARP
- limited: dose limits are to ensure an adequate standard of protection even to the most highly exposed person

Mine workers employed in the uranium industry undergo radiation management training, including:

- learning about radiation types, their potential effects, and how they are monitored and measured
- radiation protection standards and regulations
- the use and maintenance of radiation monitoring and personal protection equipment (PPE)
- emergency procedures
- personal hygiene and radiation (simple hand washing can prevent ingestion of alpha and beta particles)
- reporting of breaches, problems, potential safety issues and health issues.

U FACTS

Australian miners working with radioactive ores usually receive an average of 2-5 milliSieverts per year. This is well within the maximum annual dose of 20 milliSieverts per year recommended by the guidelines of the Australian Radiation Protection and Nuclear Safety Agency, Radiological Council WA, International Commission on Radiological Protection and the International Atomic Energy Agency, which form the basis of Australian legislation covering mine worker radiation safety.

Companies collect and monitor radiation dose data and report to DMP and the Radiological Council on a regular basis. For uranium mine sites, this information is also shared with the Australian National Radiation Dose Register (ANRDR).

The ANRDR is operated by the Australian Radiation Protection and Nuclear Safety Agency and collects, stores, manages and disseminates records of radiation doses received by workers in the course of their employment. The centralised database provides for audits of dose records to verify that uranium workers are in compliance with radiological dose limits throughout their whole career, regardless of the jurisdiction or mine.

The ANRDR has been open to receive dose records from companies since 1 July 2010, and workers are able to request a personal dosage history.

It is also a requirement (Regulation 11 of Radiation Safety General Regulations) that employers keep records and tell employees of their monitoring results.

4.3 Radiation management plans

Uranium exploration and mining companies must prepare a Radiation Management Plan. The plan must include *"measures that can be taken to control the exposure of employees and members of the public to radiation at or from the mine"*. This is achieved by strict measures implemented at the mine site (for example, controls regarding public access to site and strict controls on dust), and regulations governing the packaging and transport of the ore.

Radiation management plans cover a range of environmental issues such as dust management to reduce the possibility of airborne radioactive materials escaping into the environment, the safe storage and transport of radioactive materials, and environmental monitoring to ensure that radiation levels in the air, water, flora, fauna and personnel monitoring do not exceed allowable levels. The Radioactive Waste Management Plan (which can be part of the Radiation Management Plan) deals with the storage, transport and disposal of radioactive waste (refer to the Waste Management section in uranium mining and the environment.

The Department of Mines and Petroleum (DMP) has prepared guidelines "Managing naturally occurring radioactive materials (NORM)" to help companies prepare and implement Radiation Management Plans. These guidelines can be accessed through DMP's website. www.dmp.wa.gov.au/6745.aspx See Figure 12.

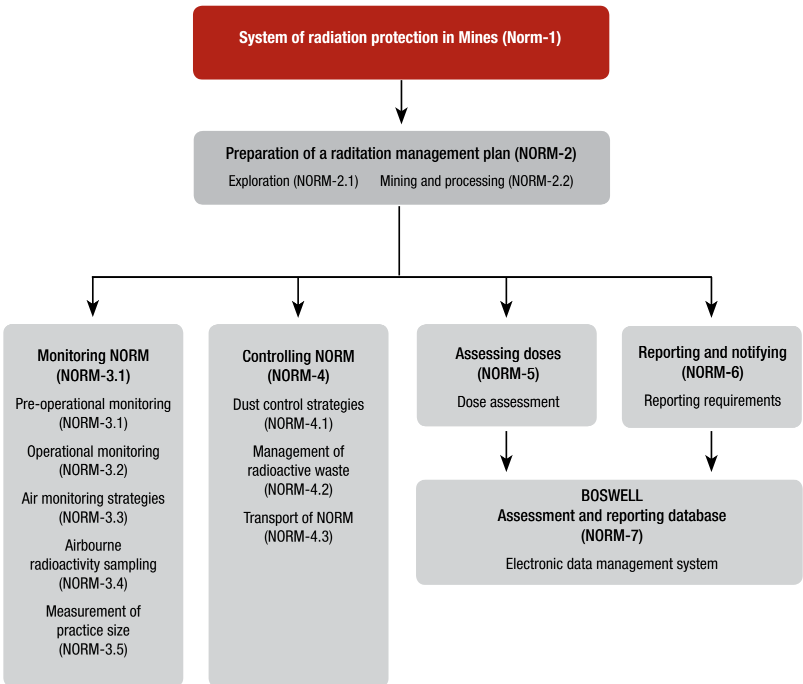


Figure 13: Managing naturally occuring radiation material. Source DMP

Compliance with the provisions of the Radiation Management Plan are subject to inspection by officers of DMP. Companies can be inspected at any time. DMP inspectors are empowered, under the *Mine Safety and Inspection Act 1994* to enter a mine at any time and undertake whatever actions they deem necessary to complete their inspection covering all aspects of the mines operation.

The Radiation Management Plan must also detail how the uranium oxide will be packed and stored before transit. DMP and the Radiological Council assess the plan to ensure it is consistent with the Radiation Safety (Transport of Radioactive Substances) Regulations 2002, which adopts the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) Code of Practice for the Safe Transport of Radioactive Material. This forms the Australian standard for transporting, packing and storing radioactive material, and adopts the International Regulations published by the International Atomic Energy Agency (IAEA).

The standards have been developed by the ARPANSA, based on international protocols developed by the IAEA and the International Commission on Radiological Protection (ICRP). These standards are listed in the ARPANSA Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005).

U FACTS

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) has maintained an Australian Radiation Incident Register since 1971. The Register provides a national focus for incidents and accidents involving ionising radiation, and produces an annual summary report detailing all reported incidents across 31 categories. It also provides feedback and guidance to users of radiation, aimed at preventing or limiting the consequences of radiation accidents.

The annual summary reports are available at: *www.arpansa.gov.au/radiationprotection/arir/index.cfm*

4.4 Radiation monitoring devices

Radiation monitoring devices are instruments that can measure radiation in the environment, on the surface of objects and the doses of radiation received by people. The following is a list of devices that are used on mine sites in Australia.

Thermoluminescent dosimeter: Measures the cumulative radiation dose received over the period it is worn (usually 4 to 12 weeks) (Figure 13).

Figure 14: Thermoluminescent dosimeter – worn by workers to measure cumulative radiation dose. Source ARPANSA

Personal air sampler: Where alpha radiation (particles) may be present in the worker's breathing zone due to dust, a personal air sampler can be worn to sample the air to provide airborne dust levels.

Alpha frisker: A surface contamination monitor, the frisker allows workers to check their hands before breaks, following hand-washing. The frisker should also be used after showering at shift end and to check equipment for contamination before it leaves the site.

4.5 Safety in operations

Legislation and regulation dictate that every aspect of a mining operation is designed to ensure safety for the workers and the broader community. Operations are designed to be as low-risk as possible and also to ensure that in the event of an emergency problematic materials and substances can be quickly and effectively indentified and contained.

In designing uranium mines and processing facilities, the overriding principle is ALARP – keeping radiation exposure As Low As Reasonably Practicable.

Some of the measures include (but are not limited to):

- building bunds around holding tanks and vessels that handle radioactive material, and providing hose down facilities and sumps
- vacuum systems for use in dry process areas where hosing cannot be done
- extensive dust control and suppression systems, for example including damping down stockpiles through the crushing and screening processes, and providing cover and ventilation/dust extraction to all material transfer points
- controlled access to and around the site
- vehicle washing systems at exit points
- decontamination areas equipped with high pressure hoses and sumps that do not allow the contaminated material to enter the environment
- ensuring that all workers shower and change before leaving the site
- leak detection systems in processing plants
- systems that ensure all equipment and materials are tested before leaving site.

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5. Uranium transport safety in Western Australia

Uranium oxide will be transported by road from the producing mine sites in WA to existing container port facilities in South Australia or the Northern Territory, for shipment to international customers. Australia has been shipping uranium oxide out of these ports for more than 30 years. During this period, there have been no reported incidents involving the transport of uranium.

In Western Australia the transportation of uranium oxide is regulated by the Radiological Council, under the Radiation Safety (Transport of Radioactive Substances) Regulations. This is done through two mechanisms – the assessment of a Radiation Protection Programme (commonly referred to as a Transport Management Plan) prepared by the company, and the provision of a licence to transport. To obtain a licence, the transport contractor must undergo a recognised training course or have qualifications or experience that is acceptable to the Radiological Council.

The Transport Management Plan will be assessed by the Radiological Council and the Australian Safeguards and Non-Proliferation Office (ASNO) to ensure the transport of uranium oxide is consistent with international and national regulations. ASNO requires the company to identify the route it will take. The Transport Management Plan includes the following information:

- types of packaging
- details of containers and mode of transport
- number of employees involved in transport and their estimated exposure times and doses
- amounts and radioactivity level of transported materials, frequency of transport movements
- estimates of potential exposure to members of the general public and the environment in the course of normal operations and in case of transport accidents (including specific emergency response procedures)
- summary of operational procedures, particularly illustrating measures taken to ensure strict compliance with transport safety regulations (including the Western Australian Radiation Safety *(Transport of Radioactive Substances) Regulations 2002)*.

Other required safety measures include ensuring vehicles have appropriate equipment to enable communication at all times with the company, transporter, local police, emergency services and company security staff.

5.1 Packaging uranium oxide for transport

Uranium oxide is sealed in 200-litre steel drums in accordance with IAEA requirements. Each drum has a tight fitting lid that is secured to the drum by means of a steel locking ring and then clamped by a locking ring bolt.

The drums normally contain between 370 kilograms and 400 kilograms of uranium oxide depending on product density and delivery location. The drums are stowed securely into 20 foot International Organisation for Standardisation (ISO) shipping containers for road, rail and sea transportation. The uranium oxide is double encapsulated or 'wrap' protected – an inner sealed container (drum) within an outer shipping container. This minimises the likelihood of uranium oxide spilling as a result of an incident.

Drums are secured inside the shipping containers to international standards using a webbed Kevlar-based strapping system designed to withstand the G-forces expected during road, rail and sea transportation and associated handling operations (see Figure 14). This arrangement for securing the drums is approved and audited annually by the Australian Maritime Safety Authority (AMSA) for sea transport. Uranium oxide that is stored before or during shipment must be placed in a secure area with restricted access. Specialised drum lifting equipment must be used when loading shipping containers.

Figure 14: Packing of uranium oxide before transport

© ERA, Transporting uranium at Ranger Mine.

The drums are tightly sealed and monitored prior to container loading. Accidental dispersal of radioactive material via dust or mud on equipment leaving the site is prevented because anything leaving the mine site is washed and checked. Only after passing a contamination clearance process, and formally recorded as clean, may it leave the mine site.

There is little radiation risk when uranium oxide is packed for transport and it is safe for personnel to work near the containers during packing and loading. ASNO grants permits for transporters of uranium oxide to depart the mine site and for shipment overseas.

5.2 Protecting communities along the transport route from radiation

Uranium oxide is classified as a 'Low Specific Activity' LSA-1 material because of the low level of radiation per unit mass. The strict packaging requirements mean that any radiation exposure from the transport of processed uranium oxide is very low. The risk to the public of radiation exposure through the transport of uranium oxide is negligible.

In the unlikely event of a spill, management of the clean up is covered by the Emergency Response Plan prepared by the mining company and the Western Australian Hazardous Materials Energy Management Plan administered by FESA. This plan includes limiting public exposure and monitoring of the area after the spill.

As uranium oxide is only weakly radioactive, radioactivity would not be the highest priority item in an accident resulting in a spill. Emergency authorities deal with all problems created by an accident in the same way they would with any accident involving a hazardous material. As for all dangerous goods, hazards are communicated by marking, labelling, placarding and documentation. This assists in the identification of possible hazards if there is an accident, and assists authorities in ensuring appropriate precautions are used (eg gloves, dust masks, thorough washing after clean-up etc).

Even in a severe accident, uranium oxide does not pose a fire or explosion hazard.

The company transporting the uranium oxide submits an Emergency Response Plan to the Radiological Council for assessment (usually as part of the transport plan) outlining the procedures in place for dealing with foreseeable accidents. This includes providing appropriate driver training for uranium oxide transport and a requirement to carry a response kit to immediately contain any spill of uranium oxide.

Driver training will include management and clean-up of uranium oxide and also how to limit the public's exposure from the material.

If the spill is a result of a road accident, the driver will contain and isolate the material. If the driver(s) is incapacitated, the first response is likely to be both the Police and the Fire and Emergency Services (FESA). FESA administers *the Western Australian Hazardous Materials Emergency Management Plan (Westplan – Hazmat)*. This plan outlines the emergency procedures that FESA and the police will follow in the event of a spill. The plan is designed to cover radioactive materials and is suitable for the management of a uranium oxide spill.

In the event of an emergency, the Department of Health's Radiation Health Unit provides an advisory role to FESA and the police. This may include monitoring clean up and post clean up radiation levels.

This planned response is consistent with procedures in South Australia, where the transport of uranium oxide has occurred without major incident for more than 20 years.

Guidance on emergency procedures are provided in the *ARPANSA Code of Practice for the Safe Transport of Radioactive Material*.

5.3 Keeping uranium oxide secure during transportation

ASNO is Australia's national safeguards and nuclear security authority, responsible for ensuring Australia meets its safeguards, non-proliferation and nuclear security obligations, and for facilitating IAEA safeguards inspection activities in Australia.

ASNO issues conditional permits to companies for the production, transportation, handling and storage of uranium oxide. The permits cover a comprehensive range of responsibilities and requirements, which include appropriate security, the maintenance of documentary evidence, records of production, material transfers and export shipments.

A strict requirement is placed on companies to notify ASNO of any changes in conditions or incidents during transport of uranium oxide. This also applies during production and storage.

Through ASNO, Australia takes a robust approach to ensuring effective control of radioactive material. The security measures put in place cover three areas:

1. Prevention – protects the uranium oxide being transported from malicious acts
2. Detection and response – to malicious acts involving uranium oxide
3. Information coordination and analysis – providing information on export quantities, movements, arrivals at destinations etc.

In the event of a deliberate attack on the transportation of uranium oxide, the Chemical, Biological, Radiological, and Nuclear (CBRN) State Emergency Plan applies. This is implemented if the Commissioner of Police believes that there was a terrorist action involved. In this case, the Office of State Security and Emergency Coordination, Department of Premier and Cabinet coordinate the response.

© ERA, Transporting uranium at Ranger Mine.

© ERA, Transporting uranium at Ranger Mine.

5.4 General transport safety

Given that the drivers of the transport vehicles are likely to receive the highest doses of radiation, monitoring the drivers' radiation doses through the use of personal radiation monitoring devices is the best indicator of radiation exposure. The monitoring is continuous and cumulative.

The operation of heavy vehicles is strictly regulated and the normal rules for heavy vehicle transportation apply to transporting uranium oxide. The WA Department of Transport is responsible for administering heavy vehicle legislation and manages vehicle and driver licensing. The Department of Transport provides standards and guidance material for heavy vehicles in Western Australia, including safe load restraints, speed limits, compliance inspections and National Driver Work Diaries. The Department of Main Roads is responsible for managing heavy vehicle access to the State's road network.

For more information:
Safe Guide to Uranium Transport by the Department of Resources, Energy and Tourism:
www.ret.gov.au/resources/documents/mining/uranium/guide-to-safe-transport-of-uoc.pdf

Code of Practice for the Safe Transport of Radioactive Material (2008 Edition), Australian Radiation Protection and Nuclear Safety Agency:
www.arpansa.gov.au/Publications/codes/rps2.cfm

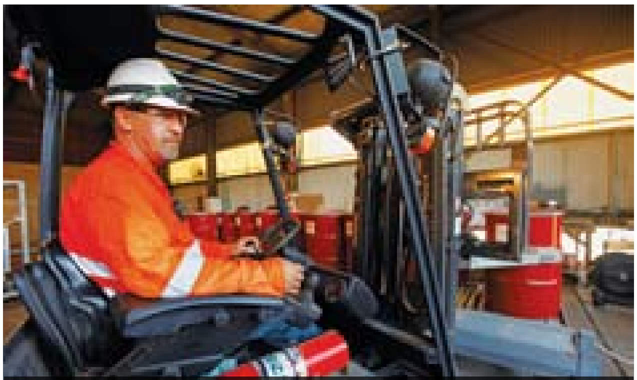
U FACTS

The Federal *Nuclear Non-proliferation (Safeguards) Act 1987* is used to enforce Australia's treaty obligations, and is administered by ASNO. Australian exports of uranium oxide are subject to Australia's safeguards requirements, underpinned by IAEA safeguards, designed to ensure that Australian uranium is used strictly for peaceful purposes (i.e. electricity generation in nuclear power reactors).

5.5 Export controls

Under Australia's current Uranium Export Policy, uranium oxide exports are strictly for peaceful purposes. Exports are only permitted to countries that: provide an assurance that Australian uranium will not be diverted for non-peaceful or explosive uses; have in place the IAEA additional protocol on strengthened safeguards; and have a bilateral nuclear cooperation agreement with Australia that specifies a range of conditions of supply, including safeguards and physical security conditions.

The export of Australian uranium oxide is subject to the Customs (Prohibited Exports) Regulations 1958. This requires the Federal Resources Minister to issue export permissions to allow exports. These regulations control the secure transport and export of uranium, as well as ongoing tracking of Australian Obligated Nuclear Material overseas, and ensure Australian uranium is only used for peaceful purposes.



© ERA, Transporting uranium at Ranger Mine.

© ERA, Transporting uranium at Ranger Mine.

6. Uranium mining and the environment

There is a range of legislation and associated regulations applicable to uranium projects administered by State and Federal Government agencies specifically designed to protect the environment.

6.1 Exploration

Before uranium exploration can occur in Western Australia, companies must first obtain an exploration licence under the *Mining Act 1978*. They must also have agreements with relevant Native Title holders and landowner/occupiers before an exploration licence can be granted.

© TORO, Lake Mackay Aerial Survey

© TORO, aircore drilling

The company must apply on-line for a Programe of Work exploration.

This document details the proposed exploration activities, and covers specific environmental factors including:

- a description of proposed activities
- a description of the underlying tenure (eg pastoral lease, freehold, conservation reserve, vacant crown land, etc)
- details of the environmental impact, including the area of disturbed ground (for example drill pads, tracks) and total tonnage to be disturbed (e.g. from test pits or cut and fill drill pads/tracks)
- whether or not the proposal will impact on an 'Environmentally Sensitive Area'[10] or registered heritage site[11]. If it does, further approvals are required
- details of environmental management and rehabilitation practices
- depending on the level of disturbance, detailed environmental surveys may be required

At this stage, a Radiation Management Plan is also required by DMP, addressing:

- the procedures for identification and monitoring of radioactive material
- strategies to minimise potential radioactive contamination
- processes to minimise human exposure to radioactive material.

In all cases, the Radiological Council must also assess the Radiation Management Plan and provide separate approval.

[10] As defined under the *Environmental Protection (Clearing of Native Vegetation) Regulations 2005*
[11] As defined under the *Aboriginal Heritage Act 1972*.

6.2 Mining

State Government assessment

Securing approvals to operate a uranium mine in Western Australia begins with obtaining a Mining Lease from DMP under the *Mining Act 1978*.

Following application for the Mining Lease, where companies may be required to demonstrate they have formal agreement under the *Native Title Act 1993* with relevant Native Title holders and access agreements with landowner/occupiers, a range of further approvals are required before activity can begin.

A uranium project has the potential to have a significant impact on the environment. Therefore, a uranium project will be referred to the Environmental Protection Authority (EPA) for assessment. Other approvals in relation to the project cannot be granted until the Western Australian Minister for the Environment approves the proposal.

© AREVA, Processing plant, Tortkuduk South, KATCO, Kazakhstan.

This rigorous process involves determining the level of assessment and what should be included in an environmental impact assessment, the preparation of an environmental impact assessment by the company, a public consultation period, an assessment and report by the Office of the EPA and an appeals period.

The assessment process is usually based on comprehensive scientific studies of the environment and modelling of likely impacts. For example, surveys of flora and fauna (sometimes including bush tucker and subterranean fauna), studies on air quality, surface water and groundwater. For every potential impact that is identified, an applicable management action must be proposed. The assessment document is released for public consultation for at least 10 weeks and then assessed by the Office of the EPA.

Approval is usually granted subject to adherence to environmental and rehabilitation conditions. These may include the preservation of certain habitats, no-go areas, and post-closure works and monitoring.

Federal Government assessment

Uranium mining and milling is classified as a 'nuclear action' under the Federal Government's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and requires environmental assessment and approval if it is likely to have a significant impact on the environment. Uranium mining proposals may also trigger the EPBC Act if they are likely to have a significant impact on other matters of national environmental significance. These include:

- wetlands of international importance
- nationally threatened plants, animals or ecological communities
- listed migratory species
- world or national heritage places.

Proposals that require EPBC Act approval will generally be assessed by the EPA under a bilateral agreement between the Federal and Western Australian governments. Both governments will still need to make separate approval decisions. The Federal Environment Minister must, however, consider any relevant conditions imposed by the Western Australian Government.

Mining Proposal

Following approval by the Western Australian and Federal Ministers' for Environment, the company must submit a comprehensive Mining Proposal to the Department of Mines and Petroleum.

The Mining Proposal details every aspect of the operation including land clearing activities and methods, mining methods, waste management and closure and rehabilitation.

Companies are expected to avoid environmental impacts wherever possible, but where this is not practicable, the company is required to demonstrate how they will monitor and minimise the impact, and rehabilitate the disturbance.

Mining Proposals include plans about how a company will manage impacts to the environment including dust, vegetation clearing and soils, weeds, water, vegetation, fauna, noise and waste (including radioactive waste). A Mining Proposal must also be accompanied by a Mine Closure Plan that demonstrates how appropriate closure and rehabilitation of the site will be achieved.

If approved, the environmental management commitments within the Mining Proposal become conditions of approval. Additional conditions are often imposed to protect the environment. These conditions are legally binding obligations, and the mine operation must be conducted as per the Mining Proposal and tenement conditions. Should the company surrender their tenement or allow it to expire for any reason, or have the tenure forfeited, the legally binding environmental obligations remain in place.

In order to ensure that compliance issues are all met as per the Mining Proposal, the company is required to submit an Annual Environmental Report detailing the activities undertaken in the previous 12 months, and those planned for the coming 12 months.

In conjunction with the Mining Proposal approval, the company must also secure permits and approvals covering a range of activities, which may include:

- native vegetation clearing permit under the *Environmental Protection Act (1986)*
- a works approval and/or licence to construct and operate a plant, tailings storage facility or other ‘prescribed premises’ under Part V of the *Environmental Protection Act (1986)*
- a Groundwater Abstraction Licence under the *Rights in Water and Irrigation Act 1914* required before removing water from a pit or bore
- any activities on reserved land requiring approval from the vested authority of that reserve
- approval under the *Wildlife Conservation Act 1950* for disturbance to declared rare flora
- approval for the project management plan covering the general occupational health and safety aspects of the proposed mining operation, granted by DMP
- a licence for the storage, handling and transportation of bulk dangerous goods (such as chemicals) as required by DMP
- approval under the *Aboriginal Heritage Act 1972* for disturbance to heritage sites.

6.3 Environmental protection measures

Every exploration and mine site presents a unique set of environmental issues to be documented and addressed. There are a number of constants that every company is required to address:

Dust – although dust generated by mining activities must be controlled, uranium mining must also manage any dust which has the potential to carry radioactive materials into the surrounding environment. Some of the ways that dust is managed includes:

- using water or other agents as a dust suppressant
- locating stockpiles as close as possible to mining operations and reducing their size (to reduce wind erosion)
- minimising dump distances
- engineering roads to minimise dust generation and implementing strict speed limits
- progressive rehabilitation.

© AREVA, TAILLAT JEAN–MARIE, Somaïr open pit mine. Arlit. Niger

Water – water use and management is covered in the Mining Proposal. This will describe the hydrogeology of the area under consideration, the potential impacts on surface and groundwater, environmental indicators, water usage for mining purposes and its sources, and water management strategies and actions.

The issues to be addressed include changes in surface water and groundwater levels and quality, and prevention of pollution or contamination. Details are required for water use including proposed extraction from surface and groundwater sources, showing the volumes required and the effect on local water sources.

Efforts are made to reduce the amount of water to be used in the project's operation, but like all mining processes, uranium mining will require water.

Local water sources must be protected from potential contamination arising from uranium activities. Actions that may be undertaken to reduce or eliminate the risk of radioactive materials entering surface or groundwater sources are site specific but can include:

- capturing all wash down water and spillages via bunds, slopes and liners and sequestering it in sumps or ponds
- ensuring that seepage from tailings and waste rock is minimised
- cleaning solid wastes, and storing those that cannot be cleaned of contaminants in rainfall-safe areas or in suitable containers
- reusing or recycling water where practical
- regular surface and groundwater testing.

6.4 Waste management

Waste is generated at most stages of mining and mineral processing and typically includes mineral processing tailings, waste rock, scales, sludges, scrap material and process water, including leaching solutions. Rainfall runoff and seepage from stockpiles and areas of processing plants is also managed.

The hazards posed by mining and mineral processing of uranium are not limited to its radioactivity. Often measures taken to protect the environment from other contaminants are sufficient for radiation protection as well.

© AMANKULOV JANARBEK AMAN, Operator above the elution and resin–loading lines, processing plant, Tortkuduk South, KATCO, Kazakhstan

ARPANSA's "Code of Practice and Safety Guide: Radiation Protection and Radioactive Waste Management in Mining and Minerals Processing" requires that in conjunction with the Radiation Management Plan a specific Radioactive Waste Management Plan (RWMP) should be developed, and this must be approved by DMP and the Radiological Council.

In developing the RWMP, all relevant pathways for dispersion of radionuclides and for radiation exposure of both employees and members of the general public should be considered.

The essential elements of the RWMP are:

- an outline of the processes generating waste
- a description of waste including nature of material (chemical, physical and radiological), contaminants, and quantities and rate of production
- a description of the environment into which the waste will be discharged or disposed, including the baseline radiological characteristics
- heritage (social and cultural) and land use (present and potential).
- a description of the proposed system for waste management including the facilities and procedures involved in the handling, treatment, storage and disposal of radioactive waste
- predictions of environmental concentrations of radionuclides and radiation doses to the public from the proposed waste management practice, including

demonstration that the statutory radiation protection requirements will be met both now and in the future

- a program for monitoring the concentration of radionuclides in the environment and assessment of radiation doses to members of the public arising from waste management practices
- contingency plans for dealing with accidental releases and the circumstances which might lead to uncontrolled releases of radioactive waste in the environment
- contingency plan to cover cases of early shutdown or temporary suspension of operations
- a schedule for reporting on the waste disposal operation and results of monitoring and assessments
- a plan for the decommissioning of the operation and associated waste management facilities, and for the rehabilitation of the site
- a system of periodic assessment and review of the adequacy and effectiveness of the RWMP to take account of potential improvements consistent with best practicable technology.

6.5 Ongoing review and monitoring

All mining operations and exploration projects are required to submit regular reports to DMP to facilitate compliance monitoring. In most cases, it is a condition of the licence that the company provides an Annual Environmental Report to DMP. This Annual Environmental Report must be structured according to guidelines provided by the department, covering:

- a project summary
- site plan
- description of the mining activities including all relevant quantities (for example ore mined, waste moved, etc)
- demonstration of compliance with all environmental conditions issued under the *Mining Act 1978*, including any non-compliance issues
- environmental management, including all environment monitoring results, corrective actions taken, etc
- rehabilitation and closure planning
- future work programme.

Environmental monitoring for any mine site may include continuous airborne dust sampling, passive dust deposition collection and monitoring, and regular surface and groundwater testing. Uranium mining companies also conduct continuous monitoring of radon, radon daughter product concentrations and gamma radiation. The results of ongoing monitoring and management programs are included in the Annual Environmental Report and assessed by DMP. Non-compliance is treated very seriously and can result in fines for individuals and/or companies, and even forfeiture of the mining tenure.

Enforcement action may also be taken by the relevant State or Federal government agencies should the proposal breach any statutory conditions or legislation.

© TORO, Lake Mackay

6.6 Mine Closure

Planning for mine closure is a critical component of environmental management in the mining industry. Nationally and internationally, industry leading practice (see www.ret.gov.au/sdmining) requires that planning for mine closure should start before mining commences and should continue throughout the life of the mine until final closure and relinquishment. A Mine Closure Plan is an essential part of the Mining Proposal.

Planning for mine closure incorporates a range of rehabilitation issues, including defining the subsequent land use of the closed mine. In most cases, the mine will be returned to the pre-existing land use as far as reasonable. This usually includes storing and replacing soil, re-establishing the native vegetation, and monitoring and measuring the success of rehabilitation (e.g. vegetation monitoring, fauna monitoring, erosion monitoring, water quality, ecosystem function).

Mine closure plans must be reviewed every three years (or at a frequency determined by DMP and EPA) and submitted to DMP and/or the EPA for approval.

See www.dmp.wa.gov.au/documents/Mine_Closure(2).pdf for Western Australia's mine closure guidelines.

The Radiation Management Plan and Radioactive Waste Management Plan must also cover the decommissioning and rehabilitation of the mine, encompassing:

- sources of radiation from the closed mine
- control measures
- monitoring and demonstration of compliance.

6.7 Mine Rehabilitation Fund (MRF)

The principal objective of a mining securities system is to ensure that sufficient funds are available to government to rehabilitate mine sites in the event that companies do not fulfil their mine rehabilitation and closure obligations. Mining security bonds, otherwise known as environmental bonds or unconditional performance bonds, were originally introduced in the late 1980s as added assurance against companies failing to adequately rehabilitate mine sites.

The Mining Rehabilitation Fund (MRF) is a special purpose account under the *Financial Management Act 2006*. Most holders of mining tenements, including uranium projects, under the *Mining Act 1978* will be required to pay a levy into the MRF. State Agreement projects will be able to apply to join the MRF.

The MRF minimises the Government's unfunded liability in respect of abandoned mine sites, and enhances the State's ongoing capacity to manage and rehabilitate abandoned mines, leading to better environmental and community safety outcomes.

The levy will consist of annual MRF contributions, calculated as a percentage – likely initially to be one per cent – of each tenement's estimated rehabilitation and closure cost/liability calculated annually. The rehabilitation and closure liability amount for a tenement will be assessed in accordance with a per-hectare cost calculator tool developed by DMP.

For more information on the MRF please see:
www.dmp.wa.gov.au/15822.aspx

© TORO, Lake Mackay soil sampling

© TORO, Lake Mackay gravity survey

7. International nuclear power industry

As of July 2012, there were some 435 nuclear reactors operating in 29 countries, generating about 14 per cent of the world's electricity consumption and providing radioisotopes for medical and industrial use. This equates to a demand of approximately 80,000 tonnes of uranium oxide in 2012.

While there have been some commitments by countries to close their nuclear capacity, at July 2012 there were a further 61 reactors under construction, 162 planned and 329 proposed worldwide.[12]

The World Nuclear Association provides comprehensive information about the world nuclear industry: *www.world-nuclear.org*

7.1 The nuclear fuel cycle

Uranium oxide is not usually used directly in nuclear power reactors – it must first go through a conversion and enrichment process. This process occurs outside of Australia in specially designed and licenced facilities (see Figure 15).

7.2 Waste management

All parts of the nuclear power industry produce some radioactive waste. At each stage of the process there are proven technologies to dispose of the radioactive wastes safely.

Exempt Waste – contains such a low concentration of radionuclides that it can be excluded from nuclear regulatory control.

Very Short Lived Waste – can be stored for decay for a limited period (a few years) and then disposed of as regular waste.

Very Low Level Waste – does not need a high level of containment and therefore is suitable for disposal in near surface landfill type facilities with limited regulatory control.

Low Level Waste – covers waste that has limited amounts of long lived radionuclides. Such waste requires robust isolation and containment for periods up to a few hundred years and is suitable for disposal in engineered near surface facilities.

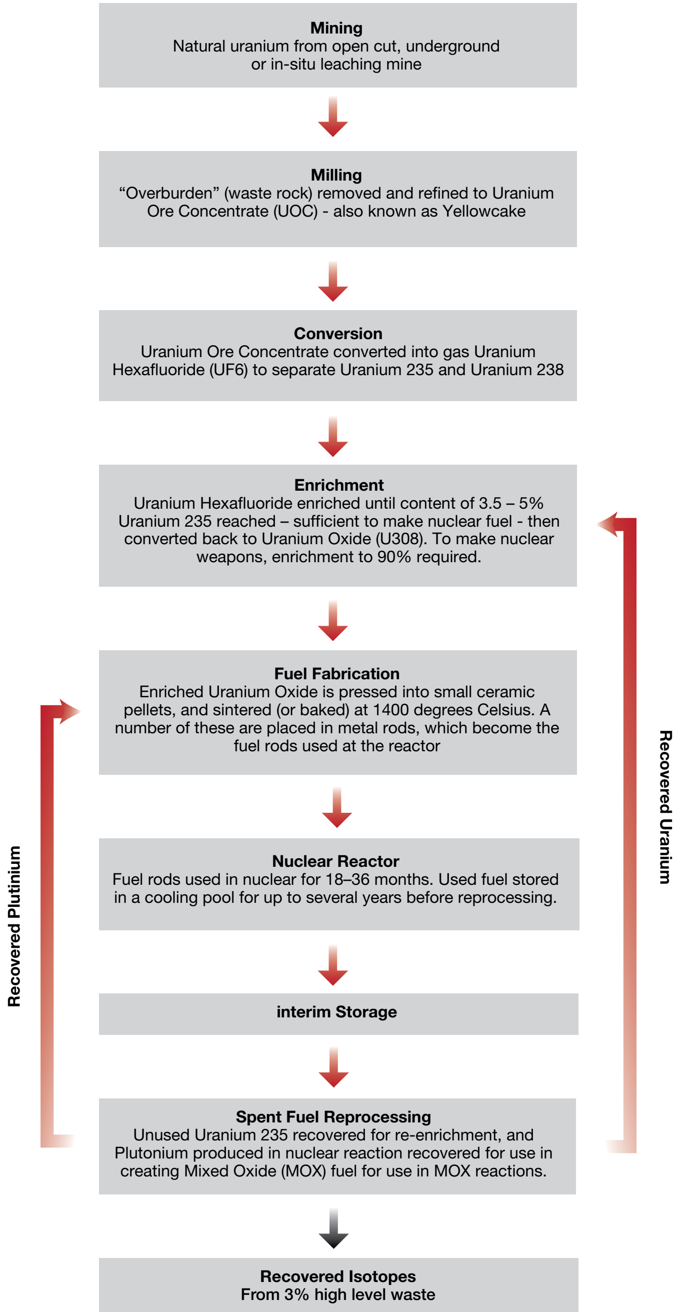


Figure 15: Nuclear fuel cycle. Source: World Nuclear Association

[12] World Nuclear Association

Intermediate Level Waste – contains increased quantities of long lived radionuclides and needs an increase in containment and isolation barriers compared to low level waste. Intermediate Level Waste requires disposal at greater depths of tens to hundreds of metres.

High Level Waste – has high levels of activity that generate significant quantities of heat by the radioactive decay process or waste with large amounts of long lived radionuclides. Disposal in deep, stable geological formations usually 700 metres below the surface is the generally recognised option of disposal of High Level Waste.[13]

7.3 Industry responsibility and risk management

Sustainable development of the uranium mining industry worldwide is based on the principle of stewardship. That is the commitment of all sectors of the industry to work together to ensure that uranium and its by-products are managed in a safe, environmentally, economically and socially responsible manner.

As a supplier of nuclear fuel, Australia is committed to these principles, and to ensuring "the careful selection of countries which are eligible to receive Australian uranium exports. In the case of non-nuclear-weapon states, they must be subject to IAEA full scope safeguards (i.e. IAEA safeguards apply to all existing and future nuclear activities). In the case of nuclear-weapon states, there must be a treaty level assurance that Australian Obligated Nuclear Materials (AONM) will only be used for peaceful purposes, and that AONM will be covered by IAEA safeguards."[14]

Australia's Bilateral Nuclear Cooperation Agreements, administered by the Australian Safeguards and Non-proliferation Office (ASNO), ensure that at any given time, all AONM can be accounted for and tracked across the world. These agreements cover issues such as prior consent for retransfers, reprocessing and enrichment to 20 per cent or more, notifications and reporting, and Annual Inventory Reporting. All AONM is subject to transit matching and report auditing to ensure that the total of Australian nuclear material worldwide are known, and adequately accounted for.

U FACTS

"Megatons to Megawatts" is an innovative program that aims to convert weapons grade uranium (High Enriched Uranium or HEU) into Low Enriched Uranium (LEU) for use in civil nuclear power generation. By August 2011, the program had effectively eliminated 17,000 nuclear warheads from the world's arsenal.

The Megatons to Megawatts program is scheduled to end in 2013 so other sources of uranium supply will be necessary to meet current and future demand for nuclear power.

7.4 Additional protocols

Beyond the terms of the safeguards agreement with the IAEA, Australia has also committed to additional IAEA protocols and strengthened safeguards designed to enhance access to a state's nuclear activities. The IAEA Additional Protocol provides for:

- information about, and access to, all aspects of a state's nuclear fuel cycle, from uranium mines to nuclear waste and any locations where nuclear material intended for non-nuclear uses is present
- inspections at short notice to all buildings on a nuclear site
- information on the manufacture and export of sensitive nuclear technologies and inspection mechanisms for manufacturing and import locations
- access to other nuclear-related locations
- collection of environmental samples outside of declared locations as required.[15]

These protocols, and the bilateral agreements put in place with countries buying Australian uranium, provide Australia with assurances that uranium originating in Australia is only used for peaceful purposes.

[13] International Atomic Energy Agency, Classification of Radioactive Waste, IAEA Safety Standard Series No GSGI, 2009.
[14] www.dfat.gov.au/security/nuclear_safeguards.html
[15] "AEA Safeguards: Stemming the Spread of Nuclear Weapons"

7.5 Bilateral agreements

It should be noted that the NPT does not generally concern itself with the origins of the material, but Australia – as a uranium supplier – assumes an obligation to ensure that material originating here is used only for peaceful purposes.

In order to ensure that this is the case and to facilitate tracking of Australian Obligated Nuclear Material (AONM), Australia is selective of countries which may purchase our uranium, and only begins exports once a nuclear cooperation agreement is in place. These agreements address issues such as physical security, retransfer, permissible enrichment levels and reprocessing.

7.6 Comprehensive test ban treaty

The Comprehensive Nuclear-Test-Ban Treaty was adopted by the United Nations General Assembly in 1996. Australia signed the Treaty on 24 September 1996 and ratified the Treaty on 9 July 1998. The Comprehensive Nuclear-Test-Ban Treaty makes a key contribution to both non-proliferation and disarmament. It serves as a practical step toward nuclear disarmament and as an effective non-proliferation measure by limiting the technological development of nuclear weapons. This treaty will enter into force when China, the Democratic Peoples Republic of Korea, Egypt, India, Iran, Israel, Pakistan and the United States have also ratified it.

© AREVA, Exploration drilling, Dulaan Uul, Mongolia

7.7 International organisations

Figure 16: Flow of radiation protection standards from international to national and State regulations and guidelines.

At an international, national and state level, standards and safeguards are applied to ensure that the industry meets its obligations of security, safety and non-proliferation, and monitoring of these standards occurs at all levels (see Figure 15).

U FACTS

In addition to the provisions of the Non-Proliferation Treaty, which does not generally deal with the origin of nuclear materials, Australia has a network of bilateral safeguard agreements that establish treaty-level conditions on the use of nuclear material exported from Australia. These 22 agreements covering 39 countries encompass issues such as retransfers, high-enrichment and reprocessing.

As far as is practical, the industry's design, construction, commissioning, operations and waste management practices are standardised and regulated uniformly across all nuclear sectors.

UNSCEAR – the United Nations Scientific Committee on the Effects of Atomic Radiation is acknowledged as the world's leading authority on the levels and effects of ionising radiation. UNSCEAR was established in 1955 with a committee comprising scientists from 15 designated UN member states including Australia.

Publications produced UNSCEAR are used as principal sources of information by member states and inform the policies of IAEA and ICRP. UNSCEAR reports annually to the United Nations General Assembly.

IAEA – The peak world advisory body is the **International Atomic Energy Agency**. Reporting to the United Nations General Assembly and Security Council, the IAEA devises, maintains and monitors nuclear safety standards for every aspect of the industry, and ensures that all member states abide by them. The agency verifies compliance via an inspection and reporting regime.

The IAEA also encourages and facilitates technological cooperation, and administers the Nuclear Non-Proliferation Treaty (NPT) – an international agreement that seeks to promote the peaceful use of nuclear technology and to inhibit its use for any military purposes. This includes verifying that member states are abiding by their commitments via inspections.

Australia was a founding member of the IAEA, and has been a signatory to the NPT since 1970, ratifying the treaty in 1973. Australia applies robust measures to ensure Australian uranium is used for peaceful purposes, "including the requirement for an IAEA Additional Protocol, which strengthens the safeguards regime".

Australia is a signatory to all five of the following IAEA Conventions covering the areas of nuclear safety, radiation, physical protection (security), transport and waste ratified by the Agency since 1986:

- Convention on the Physical Protection of Nuclear Material (CPPNM)

- Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management
- Convention on the Early Notification of a Nuclear Accident
- Convention on Assistance in the case of a Nuclear Accident or Radiological Emergency
- Convention on Nuclear Safety
- Further, Australia adheres to additional conventions such as the Convention for the Protection of the Natural Resources and Environment of the South Pacific Region and the Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter, which promote a separate set of protocols by which our uranium industry abides.

ICRP – The **International Commission on Radiological Protection** is an independent, international organisation with an international membership drawn from the scientific and policy-making communities. Its goal is to "prevent cancer and other diseases and effects associated with exposure to ionising radiation, and to protect the environment".[16]

ICRP recommendations form the basis of radiological protection standards, legislation, programmes, and practice worldwide, and Australia's ARPANSA adopts these recommendations as part of its own standards.

NPT – The **Non-Proliferation Treat**y is one of the nuclear world's most well-known and highly regarded instruments. It has been in force for over 40 years and Australia has been a member since 1973.

The purpose of the Treaty is to ensure that the pursuit of development of nuclear industry is undertaken for peaceful purposes, to prevent the spread of nuclear weaponry and to ultimately work towards total nuclear disarmament.

The IAEA administers the NPT, including verifying that member states are abiding by their commitments via inspections.

Australia is also a member of the Nuclear Suppliers Group, which aims to provide guidelines for the export of nuclear materials and related equipment in such a way that the trade does not contribute to the proliferation of nuclear weaponry or other nuclear explosive devices.

© AREVA, TAILLAT JEAN–MARIE, Wellhead, Tortkuduk, Kazakhstan

[16] ICRP Strategic Plan 2011-2017

7.8 National organisations

ARPANSA – the **Australian Radiation Protection and Nuclear Safety Agency** is the peak radiation advisory body in Australia.

ARPANSA leads the development of standards, codes of practice, guidelines and other materials, often in collaboration with international bodies such as IAEA and ICRP. These standards and codes are applied to regulatory guides and forms, as well as forming the basis upon which licenses are issued for various actions such as importing and exporting radioactive materials, and maintaining the security of radioactive materials.

The Federal legislation instruments administered by ARPANSA include:

- *Australian Radiation Protection and Nuclear Safety Act No,133 (1998)*
- *Australian Radiation Protection and Nuclear Safety (Licence Charges) Act No. 134 (1998)*
- *Australian Radiation Protection and Nuclear Safety (Consequential Amendments) Act No. 135 (1998)*
- Australian Radiation Protection and Nuclear Safety Regulations (1999)
- Australian Radiation Protection and Nuclear Safety Regulations (Licence Charges) (1999)

ASNO – the **Australian Safeguards and Non-proliferation Office** has four main areas of responsibility in the nuclear arena:

ASNO has four main areas of responsibility in the nuclear arena:

- the application of safeguards in Australia
- the physical protection and security of nuclear items in Australia including tracking of all Foreign Obligated Nuclear Material – FONM (nuclear material from outside of Australia) and Australian Obligated Nuclear Material – AONM (Australian uranium and nuclear material derived from it)
- the operation of Australia's bilateral nuclear cooperation agreements, including tracking of all FONM and AONM)

© AREVA, Construction of the underground mine, Cigar Lake, Canada.

- contribution to the operation and development of IAEA safeguards and the strengthening of the international nuclear non-proliferation regime.

The Federal legislation instruments administered by ASNO include:

- *Nuclear Non-Proliferation (Safeguards) Act 1987*
- Nuclear Non-Proliferation (Safeguards) Regulations 1987

As part of its work with the NPT, ASNO manages Australia's Network of Nuclear Safeguards Agreements – a matrix of 22 nuclear cooperation agreements covering 39 countries and Taiwan.

RET – the Federal **Department of Resources, Energy and Tourism** issues export permissions for uranium and other controlled ores (includes minerals, ores and concentrates containing more than 500 parts per million (ppm) of uranium and thorium combined. The need to control these exports reflects Australia's stringent nuclear safeguards requirements, including the need to ensure that Australia's non-proliferation requirements are met.

ANSTO – the **Australian Nuclear Science and Technology Organisation** is a research organisation that provides specialist and technical advice, scientific services and products to the public and private sectors, and academia.

7.9 State organisations

The Western Australian uranium mining industry has in place a stringent regulatory system, primarily administered by the Department of Mines and Petroleum (DMP), verified by a complex system of permits and licences, reporting and verification by inspection. Although uranium mining has only been permissible since 2008, Western Australian regulators have over four decades of experience in regulating radioactive materials as a result of mineral sands and tantalum mining, including the management and transport of these radioactive products.

At a Federal level, the Department of Sustainability, Environment, Water, Population and Communities administers the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), that deals with environmental matters of national and international significance. Proposals involving "nuclear actions" require approval under the Act if they are likely to have a significant impact on the environment. The Federal Department has a bilateral assessment agreement with the WA Environmental Protection Authority (EPA), which allows for concurrent environmental assessment with the EPA. A decision by the Federal Minister for Environment under the EPBC Act follows the decision by the Western Australian Minister for the Environment. The Federal Minister may impose additional conditions on the project. Refer to Section 6. Uranium mining and the environment of this guide for more information about Federal government environmental approvals.

The key Western Australian legislative Acts covering the uranium industry include:

- *Environmental Protection Act (1986)*
- *Mining Act (1978)*
- *Radiation Safety Act (1975)*
- *Mines Safety and Inspection Act (1994)*
- *Conservation and Land Management Act 1984*
- *Wildlife Conservation Act 1950*
- *Rights in Water and Irrigation Act 1914*

Within these Acts there are various subsidiary regulations covering environmental protection, radiation safety, transport, mine safety, customs and the Non-Proliferation Treaty (NPT). There are also a number of Western Australian Acts that affect the exploration and mining of uranium, including the *Aboriginal Heritage Act (1972)*, the *Native Title Act (1993)* and the *Contaminated Sites Act (2003)*.

In order for a uranium mining company to commence exploring an area for potential uranium mining, there are 11 separate approvals covering environmental, Indigenous Heritage and Native Title, radiation safety and administration that must be gained. The applications for these matters are assessed by the Department of Mines and Petroleum, the Department of Environment and Conservation, and the Department of Indigenous Affairs.

In order to then proceed to the mining stage, a further 27 approvals are required from the above agencies as well as the Department of Water, the Office of the EPA, and Federal Departments of Sustainability, Environment, Water, Population and Communities.

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The ongoing operations of mining, processing, conversion to uranium oxide and transport are also covered by a range of regulations, verifiable by inspection and reporting.

The principle authorities involved in regulating the industry in Western Australia are detailed below:

Department of Mines and Petroleum (DMP) – DMP assesses, and where appropriate, issues leases, licences or permits for:

- land access for exploration, mining and associated infrastructure
- approval to disturb native vegetation
- the construction and operation of mines and ore processing plants
- radiation management
- storage, packaging and stowing for transport
- management of radiation and radioactive waste (including disposal)
- safety and health issues including those related to radioactive substances, including storage and transport of non-radioactive dangerous goods
- mine rehabilitation and closure.

The Resources Safety Division of DMP – a division dedicated to worker safety and health issues, which issues permits and licences in relation to these issues. The division administers several Western Australian State Government Acts, including:

- *Mines Safety Inspection Act (1994)*
- Mines Safety and Inspection Regulations (1995)
- Mines Safety and Inspection Levy regulations (2010)

The Department of Environment and Conservation (DEC) – responsible for the implementation of the State Government's environmental legislation and regulations.

Within the uranium mining industry, the DEC administers several aspects of the regulatory regime, specifically:

- *Environmental Act (1986)* – Part V Division 3, works approval and licence of prescribed premises
- *Wildlife Conservation Act (1950)*
- *Contaminated Sites Act (2003)*

The Environmental Protection Authority (EPA) – the primary advisor to government on the environmental acceptability of State significant proposals such as uranium mining proposals.

The EPA is an independent authority which consists of a five member board, including the chairperson. Significant proposals will typically undergo an environmental impact assessment, including an assessment of key environmental factors relating to the proposal. The environmental impact assessment includes a public review period which provides an opportunity for the public to comment on the proposal in the form of submissions to the EPA. In preparing its report and recommendations to the Minister for Environment on the acceptability of a proposal, the EPA would consider the issues raised in submissions and the comments provided by Government agencies. The EPA is supported at a technical and scientific level by the Office of the EPA.

The Radiological Council – is the primary regulatory body for radiation in Western Australia. It is an independent authority reporting to the Minister for Health. The Council administers several items of Western Australian State Government legislation:

- *Radiation Safety Act 1975*
- Radiation Safety (General) Regulations 1983
- Radiation Safety (Qualifications) Regulations 1980
- Radiation Safety (Transport of Radioactive Substances) Regulations 2002

The Council prescribes the monitoring requirements for all people exposed to ionising radiation in Western Australia. A focus for the Council includes the handling of radioactive materials, irradiating apparatus such as x-ray machines, and certain electronic products such as lasers The Council, through the Radiation Health Branch personnel who undertake the day to day work of administering the Act, this is achieved through qualification, examinations, prescribed personal radiation monitoring and waste management.

8. Nuclear incidents and accidents

Every industry using complex materials, machinery and processes is subject to incidents and accidents that may result in injury and death. There have been three major incidents at civil nuclear plants – Three Mile Island, Chernobyl and Fukushima.

8.1 Three Mile Island, United States

What went wrong: In March 1979, when Three Mile Island reactor number two was operating at 97 per cent capacity, a secondary cooling circuit malfunction led to a rise in coolant temperature, which triggered an automatic shutdown. A relief valve failed to close, and much of the primary coolant was drained off the core. As a result, its temperature rose, causing severe damage to the core.

This damage resulted in the rupturing of the cladding used in the fuel rods, and some of the fission products contained within them were released into the coolant as it continued to drain through the malfunctioning valve. This contaminated water leaked into a building beyond the containment area, releasing radioactive gases into the atmosphere and setting off alarms.

Although there were other issues that arose during the incident and in the following days, this was the only confirmed release of radioactive materials, most of which were the gases xenon and krypton, and some iodine.

Short-term effects: Uncertainty regarding the nature and extent of the incident caused widespread concern in the region surrounding Three Mile Island. Evacuations of children and pregnant women took place, and state and federal regulatory authorities comprehensively monitored the area. However no person died or contracted radiation-related illnesses immediately following the incident.

The radiation dosage received by the two million people living in the areas surrounding the site was about 0.014 millisieverts. The United States Nuclear Regulatory Commission reports that, "in the months following the accident, although questions were raised about possible adverse effects from radiation on human, animal, and plant life in the Three Mile Island area, none could be directly correlated to the accident. Thousands of environmental samples of air, water, milk, vegetation, soil, and foodstuffs were collected by various groups monitoring the area. Very low levels of radionuclides could be attributed to releases from the accident. However, comprehensive investigations and assessments by several well respected organisations have concluded that in spite of serious damage to the reactor, most of the radiation was contained and that the actual release had negligible effects on the physical health of individuals or the environment."[18]

Long-term effects: In health terms, there have been no observable long-term health effects on the population living near Three Mile Island. A 1991 report in the American Journal of Public Health noted that; "a post-accident increase in cancer rates near the Three Mile Island plant was notable in 1982, persisted for another year, and then declined. Radiation emissions, as modelled mathematically, did not account for the observed increase." The authors postulated that; "an alternative mechanism for the cancer increase near the plant is through changes in care-seeking and diagnostic practice arising from post-accident concern."[19]

Lessons learned: Following the Three Mile Island incident there were major improvements to reactor design and operator training, and in expansion of the Nuclear Regulatory Commission's role, including increased inspections. In addition, the incident led directly to the "establishment of the Institute of Nuclear Power Operations (INPO), the industry's own 'policing' group, and formation of what is now the Nuclear Energy Institute to provide a unified industry approach to generic nuclear regulatory issues."[20]

8.2 Chernobyl, Ukraine[21]

What went wrong: The Chernobyl disaster of 26 April 1986 can be attributed to poor design, inadequate instruction and operator error. The technicians involved were conducting a test of an emergency procedure to ensure that in the event of a general power grid failure, cooling water could still be pumped into reactor number four. A delay of about 75 seconds in the start-up of emergency diesel generators had been identified, and the experiment was to see how long the turbines connected to the reactor would keep spinning in the event of grid failure, and whether the resulting power would be sufficient to keep the coolant pumps working.

The crucial error was in allowing the power output of the reactor to drop below 700Mw during the test. In spite of the operator's moves to increase the power output, it kept falling.

[18] United States Regulatory Commission (2009) *Backgrounder on the Three Mile Island Incident*
[19] M C Hatch, S Wallenstein, J Beyea, J W Nieves, and M Susser (1991) *Cancer rates after the Three Mile Island nuclear accident and proximity of residence to the plant*, American Journal of Public Health
[20] United States Regulatory Commission (2009) *Backgrounder on the Three Mile Island Incident*
[21] United Nations Scientific Committee on the Effects of Atomic Radiation (2012) *The Chernobyl Accident*

Attempts to correct the problem resulted in the violation of the minimum Operating Reactivity Margin, which dictates whether the reactor will slow to a stop, or keep accelerating the fission process. At the same time, the winding down of the turbines reduced the flow of coolant into the reactor. The result was that the coolant boiled and steam began to bubble in the core. To counteract this, the operators started placing control rods back into the core, however in a design of the kind used at Chernobyl, this momentarily increases reactivity. This combined with the instability of the system at the time, exacerbated by higher temperatures in the coolant itself, to produce the initial explosion, followed seconds later by a much more powerful blast. One operator was killed immediately and a second died in hospital shortly after.

A significant portion of the core material was ejected in this second explosion and the atomic fuel and graphite, by now incandescent, started a number of fires. It was at this time that the majority of the radioactive material escaped into the atmosphere. About 50 per cent of the radioactive material ejected was biologically inert noble gases such as xenon and krypton, along with more dangerous elements such as short-lived iodine-131 and long-lived cesium-137 and strontium-90.

Short-term effects: The intensity and extent of the radioactive material release meant that large areas of Europe and Scandinavia experienced varying degrees of fallout. However the short-term death toll was restricted to those employed to battle the blaze and contain the remaining radioactive material.

The World Health Organisation report "Health Effects of the Chernobyl Accident and Special Health Care Programs", released in 2006, states that: "ARS (Acute Radiation Sickness) had originally been diagnosed in 237 emergency workers and later confirmed with detailed clinical analysis in 134 persons. Among these 134 emergency workers, 28 people died in 1986 due to ARS, and 19 more died in 1987-2004 for different reasons (not necessarily related to radiation). Among the general population affected by the Chernobyl radioactive fallout, the doses were very much lower than could have caused acute radiation sickness. There were thus no acute or sub-acute deaths caused by radiation in this group."

The accident caused significant social and economic disruption, as an exclusion zone with a radius of 30 kilometres, which was later extended, necessitated the relocation of a total of 236,000 people. As the World Nuclear Association says, the extension of the exclusion zone was due to the "application of a criterion of 350 milliSieverts projected lifetime radiation dose, though in fact radiation in most of the affected area (apart from half a square kilometre) fell rapidly so that average doses were less than 50 per cent above normal background of 2.5 milliSieverts/year" in the years immediately following the event.

Long-term effects: Over 25 years after the Chernobyl accident, it remains difficult to accurately quantify the long-term health effects. This is compounded by falling health levels and corresponding rises in mortality rates (which are unrelated to the Chernobyl incident) in the three most affected countries.

A 1992 – 2000 spike in the number of reported cases of thyroid cancer among children and adolescents in Belarus, Ukraine and the Russian Federation exposed to ionising radiation as a consequence of the event can be largely attributed to their exposure[22]. However, monitoring of health issues increased following the accident, and may be partially responsible for higher diagnosis levels. In addition, identifying the disease early leads to a 98.8 per cent survival rate. The total number of thyroid cancer deaths attributable to radiation exposure following the accident is nine.

UNSCEAR concludes that, *"although those exposed as children and the emergency and recovery workers are at increased risk of radiation-induced effects, the vast majority of the population need not live in fear of serious health consequences due to the radiation from the Chernobyl accident. For the most part, they were exposed to radiation levels comparable to or a few times higher than annual levels of natural background, and future exposures continue to slowly diminish as the radionuclides decay. Lives have been seriously disrupted by the Chernobyl accident, but from the radiological point of view, generally positive prospects for the future health of most individuals should prevail."*

U FACTS

The most concerning issue from the Chernobyl accident is about the ongoing health of the local population is the continued presence of Caesium-137 within the environment of the 30km exclusion zone. This makes agriculture in that area impossible for the present. However, by 1990, the amount of Caesium-137 in the diet of European Union citizens was approaching pre-accident levels.

[22] United Nations Scientific Committee on the Effects of Atomic Radiation (2012) *The Chernobyl Accident*

The relocation of hundreds of thousands of people, the loss of towns, villages and farmlands, the need to change food sources in the early days after the event, and the ongoing costs of cleaning up the site, monitoring and managing the health of the people, have all contributed to the cost of this terrible event.

The environmental impact of the Chernobyl nuclear power plant accident has been extensively investigated by scientists in the countries affected and by international organisations. Irradiation from radionuclides released from the accident caused numerous acute adverse effects on the plants and animals living in the higher exposure areas within 30 kilometres from the release point. Acute impacts include the increased mortality of coniferous plants, soil invertebrates and mammals and reproductive losses in plants and animals.

Outside of this area, no acute radiation-induced effects in plants and animals have been reported.

By the next growing season following the accident, population viability of plants and animals had substantially recovered as a result of the combined effects of reproduction and immigration from less affected areas. A few years were needed for recovery from major radiation-induced adverse effects in plants and animals.

The recovery of affected biota in the exclusion zone has been facilitated by a decrease in agricultural and industrial activities in the area. As a result, populations of many plants and animals have eventually expanded, and the present environmental conditions have had a positive impact on the biota in the 30 kilometre Exclusion Zone around Chernobyl. Indeed, the Exclusion Zone has paradoxically become a unique sanctuary for biodiversity[23].

Lessons learned In terms of nuclear safety, the Chernobyl explosion led to a wide array of design and operational changes to the type of reactors still being used in Russia (there are currently 11 of that type reactors in use in that country, all of which have been upgraded to much more rigorous safety standards). According to the Nuclear Energy Agency's document "Chernobyl. Assessment of Radiological and Health Impacts", released in 2002, many improvements in radiation protection and emergency preparedness have been introduced as a result of the Chernobyl disaster.

There is no doubt that Chernobyl was a large and catastrophic accident, and the health and social impacts of those living in proximity to the site was and remains substantial. The incident also caused a major re-examination of the nuclear industry and slowed the industry's development. The type of reactor used was only ever installed in the former Soviet Union, and of those still in operation all have been significantly modified to ensure that such an accident will not happen again.

8.3 Fukushima, Japan

What went wrong: At 2.46pm on Friday 11 March 2011, there was an undersea earthquake of moment magnitude 9.0 off the north-east coast of Japan. Following the earthquake the operating units at Fukushima Daiichi Nuclear Power Plant went into emergency shutdown, and the cooling for all units switched to offsite power. When this power source failed due to the loss of power lines in the earthquake, emergency diesel generators on site at Fukushima successfully started up and supplied power to the cooling systems of all units.

Fifty-four minutes after the earthquake, a tsunami, larger than any predicted, smashed into the coast, inundating large sections of the north-east coastline, including the Fukushima Plant. This tsunami, which caused a death toll of over 20,000 people, swamped the emergency diesel generators in all units except one, and precipitated a series of emergencies within the plants.

U FACTS

For more information regarding the Chernobyl incident, please go to the IAEA website: *www.iaea.org/newscenter/features/chernobyl-15/cherno-faq.shtml*

Or to UNSCEAR's website:

www.unscear.org/unscear/en/chernobyl.html#Health

[23]The Chernobyl Forum: 2003-2005 (2006) *Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts,* International Atomic Energy Agency

Battery powered back-up maintained cooling systems in operation for some 24 hours, but soon these were depleted and cooling for units 1, 2 and 3 was degraded or non-existent. In the four days following the earthquake and tsunami, all three of the units operating at the time – units 1, 2 and 3 – suffered further damage from hydrogen explosions generated within their reactor chambers, resulting in varying levels of destruction. At each of these explosions, radioactive material was released into the atmosphere even though the containment of the core in all three units remained intact.

In the ensuing weeks and months, workers battled to keep the nuclear fuel in units 1, 2 and 3 from overheating and releasing further radioactive material, and minimise the spread of contamination. On 16 December 2011 the Japanese Prime Minister announced that all three units had attained a state of cold shutdown and were stable.

The Fukushima incident was rated 7 on the INES International Nuclear Accident Scale. It has resulted in the loss of the three reactors that experienced melt-down, and the writing off of another. However no deaths from radiation or other causes can be attributed to the destruction of the plants at Fukushima.

Short-term effects: The three hydrogen explosions that occurred at the Fukushima Plant were responsible for the majority of radioactive material being ejected. The primary radioactive materials found in the area following the explosions were Iodine 131, which has a half-life of 8 days, Caesium 134, which has a half-life of 2 years, and Caesium 137, which has a half-life of 30 years.

U FACTS

The long term effects of radiation stemming from the incidents at Three Mile Island, Chernobyl and Fukushima continue to be studied. For more information, please visit the websites of the World Health Organization (WHO), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the International Agency for Atomic Energy (IAEA).

The Japanese government ordered an exclusion zone of 20 km around the Fukushima site, and eventually over 160,000 people were evacuated from the area. People living 20 – 30km from the plant who would be exposed to an accumulated dose of over 20 milliSieverts per annum were advised to evacuate.

Japanese authorities protected children in Fukushima prefecture from iodine-131 by evacuating them before radiation was released, issuing stable iodine pills to block iodine-131, and preventing food and water containing the radioactive isotope from being consumed.

In order to minimise the risk of contaminated dust being mobilised by wind or rain, the operators of the nuclear plant sprayed dust-suppressing polymer resins around the plant, and removed much of the debris. This had the effect of further reducing radiation levels around the plant.

There was also some drainage of contaminated water into the ocean near Fukushima. According to the IAEA, “some seafood in the direct vicinity of Tokyo Electric Power Company’s Fukushima has been found to be contaminated at levels above the regulatory limits set by the Japanese Government, and control measures are in place to prevent its consumption”.

A preliminary report from the World Health Organisation (WHO) has estimated the radiation doses that residents of Japan have received in the year following the accident at Fukushima. The report concludes that most people in Fukushima prefecture would have received a radiation dose of between 1 and 10 mSv during the first year after the accident. This compares to levels of about 2.4 mSv they would have received from unavoidable natural sources, and the legal limit of one mSv from nuclear plants in normal operation. In two places the doses were higher – between 10 and 50 mSv. The report noted that probably over 30 per cent of the dose to Japanese citizens exposed to the contamination would have been received during the first year, with less than 70 per cent to follow over a period of about 15 years. This is based on the experience of the Chernobyl accident of 1986, allowing for variation in the actual mix of isotopes released.

In prefectures that border Fukushima people have likely received doses of between 0.1 and 10 mSv. Elsewhere in Japan the doses were between 0.1 and 1 mSv with the majority of this estimate coming from the assumption that they ate nothing but food sourced from Fukushima prefecture.

Around the world the dose from the accident's releases was put at below 0.01 milliSieverts. This is "below (and often far below) the dose levels regarded by the international radiological community as very small."[24]

Ongoing issues: There are still a number of ongoing issues regarding the safety of the Fukushima nuclear plant including how to manage spent nuclear fuel pools on the site and determining the state of the nuclear fuel within the three containment chambers of units 1,2 and 3.

Japan inspects radioactive materials in food every day, and restricts distribution of food that fails to meet provisional regulation values taking into consideration the spread of contamination. The government also monitors drinking water quality and the radiation levels of industrial products produced across the country.

Long-term effects: It is still too early to determine the long-term effects, if any, of the radiation release following the March 2011 earthquake and tsunami.

U FACTS

Compared to the accident at Chernobyl in 1986, the Fukushima (earthquake/tsunami event) affected far fewer people directly in terms of radiation exposure. For example, 530,000 workers were involved in the Chernobyl recovery, compared to 4000 involved in Fukushima, and these received approximately 25 per cent of the radiation exposure of Chernobyl workers (average 33 milliSieverts compared to 120 milliSieverts). 15,000 fewer people were evacuated from a 30km exclusion zone in Fukushima, and while evacuees from Chernobyl averaged 500 milliGrays of exposure to the thyroid, all 1080 evacuees screened for thyroid exposure in Fukushima had been exposed to less than 100 milliGrays per person.

Source: ARPANSA: 2011 Fukushima Dai-ichi Nuclear Power Plant Accident – Health and the Environment.

The Japanese government plans to track the long-term health of more than two million people, including 300,000 children who were under the age of 18 at the time of the event. This data will be shared with the United Nations Scientific Committee on the Effects of Atomic Radiation.[25]

In terms of the effect of the incident on the nuclear industry, a raft of design and safety improvement measures have been identified in the time since the event. Primarily to do with assessing and strengthening defences against extreme events such as earthquakes and tsunamis, and the responses to them, these and other changes are outlined in the "Action Plan on Nuclear Safety" endorsed by all member states of the IAEA in November 2011.

Further Reading

International Atomic Energy Agency Fukushima Monitoring Database:
iec.iaea.org/fmd/

World Health Organisation: Preliminary Dose Estimation from the nuclear accident after the 2011 Great East Japan Earthquake and Tsunami:
www.who.int/ionizing_radiation/pub_meet/fukushima_dose_assessment/en/index.html

United Nations Scientific Committee on the Effects of Atomic Radiation:
www.unscear.org/unscear/en/fukushima.html

8.4 Learning from disaster

The legacy of major incidents and accidents has resulted in the development of more effective design and safety regimes. It has also seen the development of more accurate prevention, diagnosis and prognosis techniques surrounding the effects of radiation exposure. These tragedies have fostered greater international cooperation and collaboration on a wide range of issues impacting the nuclear industry worldwide, and, like the lessons garnered from airline accidents, have helped the industry progress towards ever safer performance levels.

[24] World Health Organisation (2012) *Preliminary Dose Estimation from the nuclear accident after the 2011 Great United Nations Scientific Committee on the Effects of Atomic Radiation (2012) Background Information for Journalists: UNSCEAR assessment of the Fukushima-Daiichi accident*

[25] United Nations Scientific Committee on the Effects of Atomic Radiation (2012) Background Information for Journalists: UNSCEAR assessment of the Fukushima-Daiichi accident

9. Glossary

ALARA – is an acronym for "as low as reasonably achievable," which means making every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as practical.

ALARP – stands for "as low as reasonably practicable", and is a term often used in the milieu of safety-critical and safety-involved systems. The ALARP principle is that the *residual risk shall be as low as reasonably practicable*.

Atomic Fission – Division of a heavy atomic nucleus into two fragments of roughly equal mass, accompanied by the release of a large amount of energy.

Bunding – structure designed to prevent inundation or breaches, for example a liquid containment facility that prevent leaks and spillage from tanks and pipes.

Daughter elements – an element that results from the radioactive decay of another element. For example, technetium-99 is the daughter element created by the decay of molybdenum-99.

Fauna – is all of the animal life of any particular region or time.

Flora – Plants considered as a group, especially the plants of a particular country, region, or time.

The American Heritage® Dictionary of the English Language, Fourth Edition copyright ©2000 by Houghton Mifflin Company. Updated in 2009. Published by Houghton Mifflin Company.

Gray – The SI unit for the energy absorbed from ionizing radiation, equal to one joule per kilogram.

Hydrothermal – Of or pertaining to heated water, to its action, or to the products of such action.

Igneous – derived by solidification of magma or molten lava emplaced on or below the earth's surface.

Isotopes – are atoms that contain the same number of protons but a different number of neutrons. The number of protons (the automic number) is the same for each isotope, e.g. carbon 12 carbon 13 and carbon 14 each have six protons, but the number of neutrons in each isotope differs.

Nuclide – A nuclide is an atom with a specific number of protons and neutrons in the nucleus, for example carbon-13 with six protons and seven neutrons. The *nuclide* concept (referring to individual nuclear species) emphasizes nuclear properties over chemical properties, while the *isotope* concept (grouping all atoms of each element) emphasizes chemical over nuclear.

Orebody – Generally, a solid and fairly continuous mass of ore, which may include low-grade ore and waste as well as pay ore, but is individualised by form or character from adjoining country rock.

McGraw-Hill Dictionary of Scientific & Technical Terms, 6E, Copyright © 2003 by The McGraw-Hill Companies, Inc.

Radionuclide – A nuclide that has artificial or natural origin and that exhibits radioactivity.

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Radium – is an alkaline earth metal that is found in trace amounts in uranium ores. Its most stable isotope, 226 Ra, has a half-life of 1601 years and decays into radon gas.

Radon gas – is formed as part of the normal radioactive decay chain of uranium. Uranium has been around since the earth was formed and its most common isotope has a very long half-life (4.5 billion years). Uranium, radium, and thus radon, will continue to occur for millions of years at about the same concentrations as they do now.

Sedimentary – Rock formed at or near the Earth's surface by the accumulation and lithification of fragments of preexisting rocks or by precipitation from solution at normal surface temperatures. Sedimentary rocks can be formed only where sediments are deposited long enough to become compacted and cemented into hard beds or strata.

For more information on sedimentary rock, visit Britannica.com. Britannica Concise Encyclopedia. Copyright © 1994-2008 Encyclopædia Britannica, Inc.

Sievert – The SI unit for the amount of ionizing radiation required to produce the same biological effect as one rad of high-penetration x-rays, equivalent to a Gray for x-rays.

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