STRATEGIC INSIGHTS

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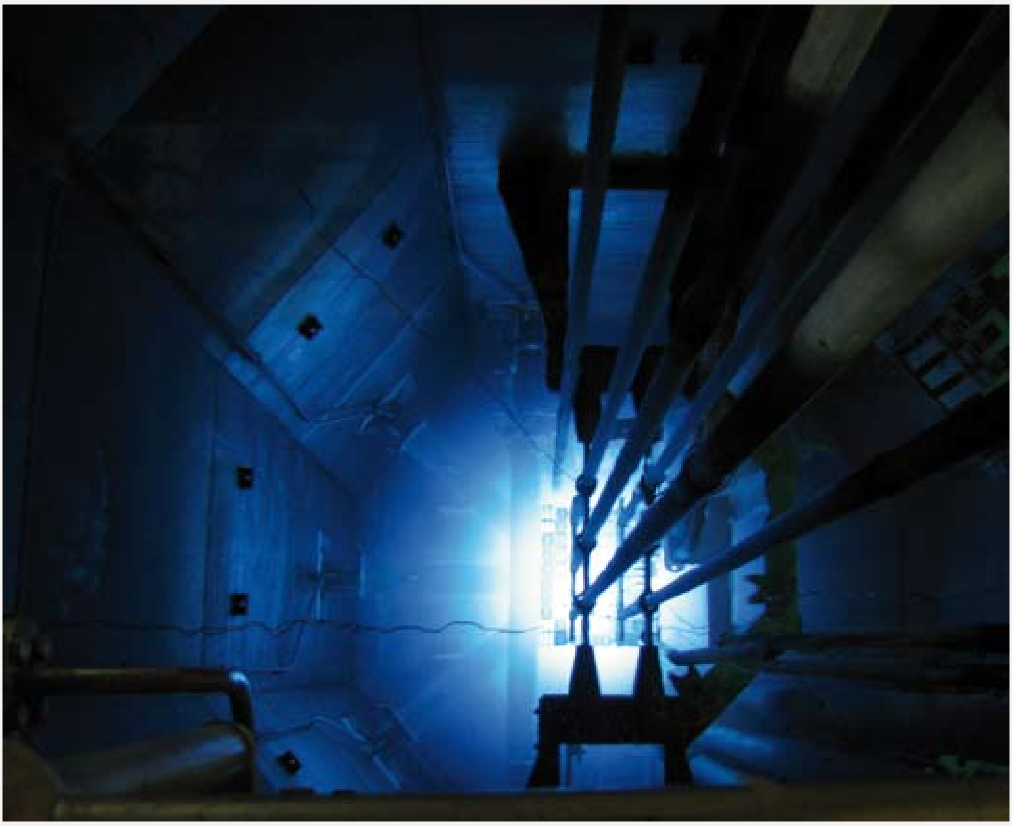
Australian uranium exports and security:
Preventing proliferation

by Dr Andrew Davies

The government has recently put the issue of Australia's future nuclear industry firmly on the table, and has established a taskforce to review uranium mining, processing and nuclear energy in Australia. This ASPI *Strategic Insight* examines the impact that any change to Australia's place in the nuclear supply chain might have on the proliferation of nuclear weapons. It examines the issues that need to be managed if Australian-sourced nuclear materials are to be sold to a wider customer set without leading to a growth in the number of nuclear weapon armed states.



A nuclear reactor at power. The blue glow is 'Cherenkov radiation' caused by emitted sub-atomic particles travelling faster than the speed of light in water. The intensity of Cherenkov radiation is also used to characterise the remaining radioactivity of spent fuel rods. Photo courtesy International Atomic Energy Agency (IAEA)

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We begin by describing the physical properties of nuclear materials, and how they pertain to the generation of power and the production of weapons. Then we look at some case studies of past nuclear weapon programs, both successful and unsuccessful, which shed light on what is required to quarantine nuclear material into peaceful energy programs. This allows us to conclude by suggesting some decisions that Australia can make in order to continue to be a responsible nuclear supplier.

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Ultimately, it will be a combination of political, economic, ecological and strategic factors that are weighed up in any decision to change Australia's current posture on the export and processing of uranium and the domestic exploitation of nuclear power. This paper does not discuss the political or environmental aspects of nuclear power and makes no attempt to address the viability or otherwise of other non-fossil energy sources.

Australia and the world uranium market

The world reserves of uranium will provide for perhaps five decades of power generation at current demand projections. Australia has the world's largest reserves of uranium ore, totalling almost a quarter of known deposits (Table 1) and 40% of the uranium that is easily exploitable. Production of uranium from Australian mines has increased markedly in recent years, with an increase of 19% in 2004 alone.

Australia currently exports uranium as yellow cake, which is essentially uranium oxide that has undergone only first stage processing into nuclear fuel. At current market values, the cost of fuel loaded into reactors is approximately twice the ex-mine cost, the balance being due to the cost of enrichment and fabrication into reactor-ready fuel units. Drawing an analogy with the one-time practice of exporting raw wool to Manchester for value-adding, the Prime Minister has recently suggested that Australia could enhance its export earnings from uranium by performing the later steps in the process here. To understand what that might mean from a proliferation point of view, we will first have to digress into the arcane world of nuclear physics.

Table 1: World uranium deposits

	Tonnes U	Percentage of world
Australia	1,143,000	24%
Kazakhstan	816,000	17%
Canada	444,000	9%
USA	342,000	7%
South Africa	341,000	7%
Namibia	282,000	6%
Brazil	279,000	6%
Niger	225,000	5%
Russian Fed.	172,000	4%
Uzbekistan	116,000	2%
Ukraine	90,000	2%
Jordan	79,000	2%
India	67,000	1%
China	60,000	1%
Other	287,000	6%
World total	4,743,000	

Source: World Nuclear Association—Supply of Uranium, June 2006

Reactors and uranium

There are currently two elements used as sources of energy in nuclear reactors, uranium and plutonium. Plutonium does not occur in any useable quantity in nature, but is a product of the 'burning' of uranium in reactors. Since all nuclear energy production begins with uranium, that is where we start, before returning to discuss plutonium later.

Uranium as it occurs naturally consists primarily of two isotopes. The most abundant isotope is U-238, which makes up 99.3% of uranium ore. The much rarer U-235 isotope constitutes only 0.7% of ore but plays a key role in the nuclear fuel cycle. Both isotopes produce energy in reactors through a process of induced fission. A chain reaction cannot be sustained in U-238 alone, and the presence of U-235 is essential for power production in order to maintain a controlled chain reaction. In fact, in a large enough sample of pure U-235, the reaction would continue unabated, producing a runaway production of enormous quantities of energy—a nuclear explosion. Because of this property, U-235 is termed a *fissile* material. (The reader who wishes to find out more about isotopes, chain reactions and the concept of critical mass before reading further can find a short summary with the publication on the ASPI website www.aspi.org.au, or can read the relevant entries on en.wikipedia.org.)

With the right balance of the two isotopes and environmental conditions, a sustained reaction, finely balanced between running out of control and dwindling to nothing, can be produced. Each fission event produces several neutrons. On average, exactly one of them induces another fission event. In that way, the reaction is sustained until a significant proportion of the fuel has been used.

The energy liberated from fission produces large quantities of heat. As in fossil-fuel driven power stations, the heat generated can be used to produce steam, which is then used to drive turbines and generate electricity. The waste heat produced by reactors is a signature that can be used to identify

Tomari nuclear power plant under construction, Tomari, Japan, October 2004. Photo courtesy International Atomic Energy Agency (IAEA) operating cycles. About one third of the heat produced is converted to electricity, while the rest is lost into the environment. Overhead thermal imaging then makes it easy to identify when a nuclear reactor is running.

Some reactor designs use naturally occurring uranium as fuel. To sustain a chain reaction in natural uranium, the neutrons from earlier fissions must be slowed down ('moderated') by another substance. Otherwise, they would be absorbed by the U-238, which would render a chain reaction impossible. The usual moderators are heavy water or ultra-pure graphite. Such reactors are in the minority for energy production purposes, constituting only about 10% of the world's power reactors. However, as we shall see, they are quite suitable for the production of weapons-grade plutonium.

Instead of using natural uranium for power production, an alternative is to enhance the proportion of U-235 in the fuel before it is loaded into the reactor. That process is called enrichment. The typical proportion of U-235 used in reactors is 3–8%, or about 5 to 10 times the natural abundance. Such fuel is termed low-enriched uranium and is useful for power generation, but cannot be used in a nuclear weapon. Weapons require much higher enrichment levels, typically well over 90%. This is a critical point for our purposes.

Reactors that run on enriched uranium can use 'light water' (normal water) or other substances for moderation and cooling. Modern light water reactors designed for power production are the most proliferation-proof reactors on the market. It is very costly to run them for short periods, and removing the fuel load is a major operation that is highly visible upon inspection. That is why light water reactors were promised to North Korea as part of the international reaction to their suspected nuclear weapons program, to which we return later.

Uranium enrichment

Enrichment is an industrial process that can be achieved by a variety of means. Because the physical properties of the two main uranium isotopes vary only slightly, the enrichment process is necessarily painstaking and requires multiple stages, each one building incrementally on the previous. Today the most common technique is via high-speed centrifuges, which use the inertial forces of rotation to separate the slightly different masses of the two main isotopes. Spun at supersonic speeds, the centrifuges must be precisely machined and balanced and require high quality materials in their construction. (As we shall see, these technical requirements are at the heart of some claims made about Iraq's WMD program.)

Other techniques have been developed for enrichment, but the only other commercial technique in use today is gaseous diffusion, a technique dating back to the Manhattan Project during WWII. Uranium fluoride gas is forced through a membrane that preferentially favours the passage of one isotope over the other. A promising technique for the future is the use of lasers tuned to frequencies specific to one isotope, though as yet there are no practical applications. Regardless of the technique, uranium enrichment requires technological and industrial resources far beyond the capability of any non-state terrorist group.

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A critical observation for our purposes is that uranium enrichment does not require a nuclear reactor. The steps involved require chemical and mechanical processes that can be made to look externally like many standard industrial activities. Heat signatures and building types would not necessarily be recognisable as being nuclear fuel related.

Plutonium

Plutonium is an element that is very rare in nature and, for practical purposes, is only produced in reactors by conversion from uranium. Plutonium is formed within the fuel elements of reactors or in purpose-built 'blankets' of uranium placed around reactor elements (see the discussion of 'breeder reactors' below). It can be a by-product of power production, or produced deliberately either as second generation fuel or for weapons. There is over 1,000 tonnes of plutonium in existence, the bulk of which is reactor-grade material in civil power programs.

Isolation of plutonium from the unburnt uranium and by-products of the reaction process, many of which are highly radioactive, is called reprocessing. It requires a number of complex chemical and metallurgical steps. An industrial-sized plant is necessary to produce a significant quantity and only nations or large commercial entities have the resources required. Like uranium enrichment, plutonium separation is well beyond the capacity of non-state terrorist groups.

The production of plutonium within reactors allows for the 'breeding' of fuel. With careful design, a reactor can be run for many years on uranium fuel while producing plutonium by irradiating large quantities of U-238 placed around the core. When the reactor is powered down, the plutonium can be recovered through reprocessing for use as a fuel in its own right. With the right operating regimes, such reactors can actually produce more new fuel than they consume. A breeder reactor might run for a decade generating useful power and then have produced enough fuel to run another reactor for another decade.

Power programs can also utilise a combination of uranium and plutonium, so-called mixed oxide fuels (MOX). Because of the fissile properties of the plutonium, MOX can essentially replace up to a third of the enriched uranium in a reactor with little impact on the reactor's operating cycle. Plutonium recovered by reprocessing spent reactor fuel can be used to produce MOX. Re-use of material in this way can increase the efficiency of energy production from the original uranium. If the unburnt uranium from spent fuel is also recycled, the efficiency gain can be increased further. Mixed oxide fuels are currently produced in Britain, France, Russia, India and Japan.

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To some extent, power generation and weapons material production are competing requirements. Of the commonly produced plutonium isotopes, only Pu-239 is fissile and therefore suitable for weapon design. The slightly heavier and more radioactive Pu-240 acts as a contaminant for weapon purposes. The presence of Pu-240 is likely to cause a premature instigation of the nuclear chain reaction and lower—but not eliminate—the resultant explosive yield of the weapon. As well as making for a low-yield device, Pu-240 is also more radioactive and produces more heat than Pu-239, making it much less easy to handle and fabricate into weapons.

If the aim of running a reactor is to produce power, nuclear fuel is left in the reactor for about three years. The residual fuel contains 'reactor-grade plutonium', with sufficient levels of Pu-240 to render the material unsuitable for weapons. However, when a reactor is used for creating 'weapons-grade plutonium', the fuel rods are cycled through relatively short running periods (months rather than years) at low power. If the timing is right, the fuel will contain a small quantity of plutonium, of which a high proportion (over 90%) will be Pu-239. Therefore, any nation with a large number of reactors will, at any given time, have a certain proportion of fuel that has been irradiated for only a short time, and thus be in possession of weapons-grade plutonium—albeit *in situ* in one or more reactor cores. Conversely, weapons-grade plutonium can be degraded by using it in MOX fuel for reactors, which will produce higher proportions of Pu-240, a useful technique for degrading unwanted or unserviceable plutonium warheads.

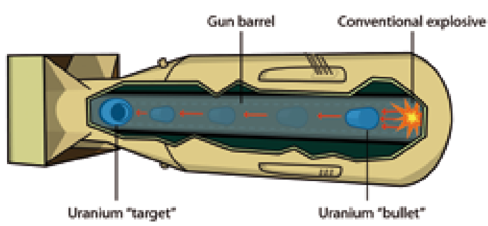
The 'spoiler' properties of Pu-240 have been used, in part, to develop protocols to limit nuclear weapon proliferation, with short run cycles held to be one indicator of intent to produce weapons. However, we must note an important caveat here. The term 'low-yield' must be understood in context. An explosion the equivalent of one thousand tons of high explosive (one kiloton) is 'low-yield'—but would cause devastation due to blast, heat and radiation over an area of several square kilometres. That is a weapon of mass destruction by any measure. At least one non-weapons-grade plutonium bomb has been successfully detonated in a test admitted to by the US, and possibly others by the UK. Thus, while reactor-grade plutonium is not optimal for a weapon, it could provide a sufficiently desperate state with the means to acquire a device that will yield at least a couple of kilotons, and possibly more. However, the strong preference of a weapon designer would be for weapons-grade plutonium.

Weapon designs

The fissile isotopes U-235 and Pu-239, if available at sufficient purity and in sufficient quantities to form a critical mass, can be used to produce high-yield nuclear weapons. Designs of weapons using each material must take into account their different physical properties. We limit ourselves here to first generation designs. More sophisticated designs are possible, including hydrogen or thermonuclear bombs, but first-time developers will rely on the simplest approaches.

Figure 1 shows a schematic design for a 'gun-design' weapon, suitable for creating an explosion with weapons-grade uranium. There are no great technical obstacles in designing and building the device, and the hardest part, by far, is acquiring the approximately 25–35 kg of 90% U-235 required for a chain reaction. This design is the basis of the 'Little Man' bomb dropped on Hiroshima in 1945. The project team was so confident of its success that no test explosion was conducted beforehand. For that reason, if a sufficient quantity of weapons-grade uranium fell into the hands of a terrorist group with engineering expertise, the construction of a nuclear weapon might be within their abilities. The required critical mass would have a volume less than half of that of a soccer ball.

Figure 1: Schematic of a first-generation U-235 'gun design' weapon

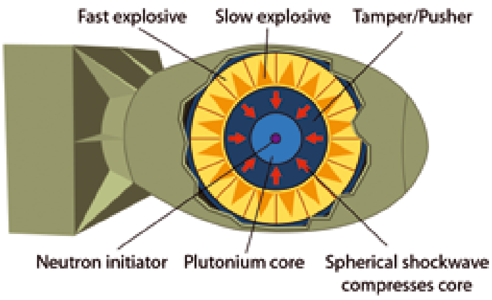


Two sub-critical masses are fired together via a conventional explosive to form a super-critical mass. Once the pieces come together a chain reaction is initiated and an explosion results. Graphic courtesy of Wikimedia Commons

Figure 2 shows an implosion bomb design used to produce an explosive chain reaction in a mass of plutonium or uranium. Gun designs do not work for plutonium due to premature reactions caused by traces of Pu-240 invariably present in material of any grade. Instead, shaped conventional explosives are arranged in a spherical shell around a plutonium core. When they are detonated, the resultant shockwave compresses the plutonium beyond critical density and a nuclear explosion is initiated. This design is less straightforward than the gun design. The first atomic test in July 1945 was of the implosion type and verified the design before the 'Fat Boy' bomb was dropped on Nagasaki. The reactor-grade plutonium device mentioned earlier would necessarily have utilised an implosion design.

While the implosion design is more complex than the gun design, modern technologies make most aspects much more tractable than in 1945. Advantages of pursuing this type of weapon include the mass of fissile material required (as little as 4 kg with careful design). However, fabrication of an implosion weapon is beyond non-state terrorist groups, even if they could obtain the plutonium or uranium required. A terrorist group would therefore not be able to produce a nuclear explosion from plutonium of any kind, though it might be used in the construction of a conventionally triggered 'dirty bomb'.

Figure 2: An implosion design for a Pu-239 weapon



Graphic courtesy of Wikimedia Commons

Grable Test of Operation UPSHOT-KNOTHOLE in Nye Country, Nevada, USA, 25 May 1953. © APL/Corbis/Stocktrek

The Nuclear Non-Proliferation Treaty

Given time and access to uranium supplies, most modern industrialised nations would be able to produce nuclear weapons. Many countries, including Australia, have at some time investigated the possibility of developing such weapons, only to abandon the idea for various reasons. Those reasons include the lack of a strategic need for nuclear weapons, the cost of the program, international disapprobation and, as we shall see, in some cases the efforts of teams of well-trained inspectors from the international community. Some states have actually relinquished nuclear weapons in their possession.

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In no case does an insurmountable technical obstacle seem to be the reason for abandonment of a weapons program. After all, the Manhattan Project developed two different types of nuclear weapons in the space of three years using 1940s technology and no prior knowledge. It is true that the project involved the world's best scientists, who were well-resourced and supported by an extensive industrial base. However, now much of the basic information required is available in the public domain, and technologies required to support weapons production are increasingly available.

Lack of access to suitable quantities of fissile material is the most likely show-stopper for aspirant states. If a technologically advanced nation with a reliable source of uranium set out to build nuclear weapons, and was heedless of the political consequences, the probability is high that it would succeed in doing so. It is therefore a tribute to the success of the international efforts to limit the spread of nuclear weapons that there are only nine states declaring themselves or believed to be in possession of nuclear weapons—and one of those may be lying. (See Table 2)

One of the most successful tools for non-proliferation efforts has been the Nuclear Non-Proliferation Treaty (NPT). The NPT is an international agreement intended to limit the spread of nuclear weapons. First open for signature in 1968, there are now 188 states who are signatories to the treaty. The most notable exceptions are India, Pakistan and Israel, all nuclear-armed states. As we shall see, North Korea withdrew from the treaty after being a signatory. In 1995, the signatories agreed by consensus to extend the treaty indefinitely and without conditions. The so-called 'three pillars' of the NPT are non-proliferation, disarmament, and the right to peacefully use nuclear technology.

The first pillar, non-proliferation, has been very successful. Transfers of nuclear materials and technologies from state to state are done only in conjunction with a safeguards regimen of inspections and supervision from the International Atomic Energy Agency (IAEA). Within the NPT framework, there is no known example of governmental transfer of nuclear weapon technology or unsafeguarded nuclear materials to any non-nuclear-weapon state. However, there have been instances where businesses or private parties have exported sensitive technologies. For that reason, the NPT has been supplemented by other agreements, and the Nuclear Suppliers Group, a consortium of some 30 nations, has adopted tighter controls on nuclear-related dual-use goods.

The second pillar of disarmament has been much less successful. The NPT recognises that the US, UK, Russia, France and China were (then) the only states known to be in possession of nuclear weapons. However, it obliges them to 'pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament'. The nuclear arsenals of those states, with the exception of China, have declined in recent years. However, there is little reason to believe that any of them seriously contemplate relinquishing their nuclear weapons entirely. However, South Africa did entirely dismantle its nuclear arsenal on acceding to the NPT in 1994, and Ukraine and other ex-Soviet republics returned nuclear weapons on their territories to Russia.

The final pillar, the right to use nuclear energy peacefully, is the aspect of the NPT we are most concerned with here. Nuclear power programs as allowed under the NPT can provide states with cover for the development of expertise and technologies critical for the development of nuclear weapons. Every signatory always has the option of giving ninety days notice of withdrawal from the treaty, and then leveraging the expertise, infrastructure and technology already acquired to develop weapons. We can draw some valuable insights on how such 'break-out' risks can be minimised by looking at past weapons programs. Some case studies provide useful pointers to counter proliferation measures and, conversely, what determined states can do to circumvent constraints placed on them.

Figures in Table 2 vary somewhat between public sources, but below are typical estimates.

Israel

Israel provides a good 'control experiment' for proliferation considerations. Israel methodically and covertly constructed a nuclear weapons program. There was essentially no external hindrance and the main constraint was the desire to remain covert. Commencing in 1957 with considerable French help, Israel built a reactor at Dimona and resolutely rebuffed any external attempts to conduct rigorous inspections, or indeed any serious discussion, of its purpose. The reactor first began producing plutonium in 1964.

Declassified US documents show that there was considerable disquiet and background diplomatic activity in Washington, albeit to no great effect. By 1968, the CIA assessed that Israel had already developed nuclear weapons. Many sources now claim that Israel had two deliverable nuclear weapons during the June 1967 Arab-Israeli war. There is ambiguous evidence of a nuclear test in the South Atlantic Ocean in 1979, which is ascribed in some quarters to a joint Israeli-South African nuclear test.

Table 2: Nuclear weapons states and their weapons stockpiles

Country	First test	Weapons stockpile
The United States	1945	10,300 (about half operational)
Russia (Soviet Union)	1949	6,000 (estimated – plus about 10,000 non-operational)
United Kingdom	1952	around 200
France	1960	350
China	1964	410 (est.)
India	1974	80 (est.)
Pakistan	1998	40 (est.)
North Korea	none	Claims to have weapons. Between 0 and 10
Israel	1979(?)	Undeclared state – possibly 100s of weapons

Source: The Bulletin of Atomic Scientists website

This provides a very good benchmark of what a technically savvy country can do when left to its own devices. The time from breaking ground for a reactor to producing nuclear weapons was about a decade. The NPT was not in place during the development of Israel's nuclear weapons and Israel has never been a signatory to the treaty.

North Korea's nuclear program

In the 1990s, North Korea (DPRK) operated a single 'research' heavy water reactor. International inspectors noted that the DPRK had operated undeclared plutonium reprocessing facilities, leading to suspicion that fuel was being cycled through the reactor quickly and then being processed to recover weapons-grade plutonium. In the mid-1990s, some 8,000 fuel rods were quarantined by inspectors and sealed, and the DPRK plutonium program was effectively shut down in return for shipments of fuel oil and the promise of construction of light water reactors less suitable for production of weapons-grade material.

After much wrangling, a contract to construct the light water reactors was signed. But in 2002, it emerged that the DPRK had covertly instigated a centrifuge-based uranium enrichment program, presumably as a second avenue to the production of nuclear weapons. Elements within nuclear armed Pakistan (the so-called Khan network) had provided assistance in return for missile technology. When the uranium project came to light, fuel oil shipments were stopped and work on the light water reactors suspended. Further escalating the concern, in December 2002 the DPRK removed the seals from the quarantined fuel rods and ordered IAEA inspectors out of the country. In January 2003, North Korea announced its withdrawal from the NPT. Since then, the DPRK has restarted its small reactor and claims to have reprocessed the irradiated fuel rods to recover weapons-grade plutonium. In 2005, the DPRK declared that it has nuclear weapons. Later that year, press reports sourced to US intelligence discussed what appeared to be preparations for a nuclear test but that has not eventuated. The exact status of the DPRK nuclear weapons program remains unclear, at least outside intelligence circles (and quite possibly within).

North Korea may have succeeded in developing nuclear weapons despite concerted efforts to prevent them.

The lessons to be drawn here are mixed. On one hand, an international inspection regimen successfully identified suspicious patterns of behaviour and temporarily isolated dangerous material. On the other hand, by renouncing the treaty and disallowing international inspections, the DPRK may have succeeded in developing nuclear weapons despite concerted efforts to prevent them.

Iraq's nuclear program

Iraq's nuclear weapons program provides a valuable case study. In 1981, Israel attacked and severely damaged Iraq's nuclear reactor at Tamuz. The Israelis (and probably others) suspected that Iraq was planning to use the reactor to do research on plutonium for nuclear weapons. The IAEA issued a strong condemnation to the contrary, pointing out that the reactor was in compliance with international safeguards, and that inspections had found no evidence of breaches of the IAEA safeguards agreement. The IAEA called on Israel to place its own reactors under international safeguards, which still has not happened.

However, after the 1991 Gulf War, suspicion about other activity in Iraq in the late 1980s led to IAEA inspections being used by the international community as a 'bloodhound' to sniff out covert activities. Before then, inspections had been limited to declared sites that were subject to safeguards under the NPT. After the ceasefire, it became apparent that Iraq's program had been more vigorous than previously suspected. (This intelligence failure may have contributed to the WMD no-show fiasco a decade later, where absence of evidence was interpreted as evidence of evasion.) IAEA inspections were widened, taking advantage of provisions in UN Security Council resolutions allowing for 'any time, anywhere' inspections.

Despite being conducted in often-acrimonious circumstances with claims and counter-claims levelled by all parties, the inspections revealed a covert uranium enrichment program and a nuclear weapons design program. Iraq had a cadre of personnel with knowledge and experience of nuclear techniques and a viable bomb design. All it lacked was a quantity of fissile material. Iraq had made a start on two approaches to enrichment, with the main effort being directed towards an electromagnetic technique originally developed as part of the Manhattan project, but long since abandoned as inefficient elsewhere. Basic research work may have been nearing completion, because large scale facilities were under construction when the 1991 war broke out, though only a few separators were in place and little fissile material could have been produced.

Post-war, a series of inspections and activities to dismantle the program were in place. By 1998, the IAEA teams had managed to quash Iraq's program to the point where it was effectively non-existent. Despite that, claims from Western intelligence agencies (most notably the US, but others as well) continued to assert the presence of active Iraqi efforts to develop nuclear weapons. In February 2003, US Secretary of State Colin Powell told the United Nations that 'Since 1998, [Saddam's] efforts to reconstitute his nuclear program have been focused on acquiring … sufficient fissile material to produce a nuclear explosion. To make the fissile material, he needs to develop an ability to enrich uranium'.

The strongest evidence for these claims was Iraqi procurement activities. Aluminium tubes of high material quality and precision manufacture were posited to be for high speed centrifuges. In fact, this seems to be an illustrative example of the march of technology. It was once true that such high-grade components would be reserved for very specialised tasks, given the cost and difficulty of their manufacture. Today, however, computer assisted manufacturing and machining techniques have lowered the cost and allowed for other applications of the same technology. The tubes were apparently intended to be the bodies of rockets.

Inspectors examine the remains of Electro Magnetic Isotope Separation (EMIS) equipment that had been salvaged from a bombed building, Iraq, 1991–1998. Photo courtesy International Atomic Energy Agency (IAEA)

... intelligence gathering and assessments are no substitute for having skilled inspectors on the ground.

Again, there are several lessons to be drawn from this case study. Firstly, intelligence gathering and assessments are no substitute for having skilled inspectors on the ground. Also, determined inspectors with solid international support backed by coercive efforts can effectively dismantle a nuclear weapons program, albeit with considerable effort. Secondly, uranium enrichment is much easier to hide than plutonium production via a reactor. Finally, we can note that dual-use technologies are appropriately named.

Some of the lessons learned from Iraq were incorporated into the negotiation of *additional protocols* to the NPT, a regime that allows international inspectors to make 'any time' inspections of both declared and undeclared facilities. The additional protocols are designed to allow the IAEA to build a comprehensive qualitative picture of the entire nuclear industry and infrastructure of a country, in addition to quantitative safeguards on nuclear materials.

Iran's nuclear program

Our final case study is necessarily incomplete because it is still a live issue. Claims and counter-claims abound, but a few facts appear clear. Iran has been operating a nuclear research program since the 1970s, and until recently there had been no evidence of any activity that was non-compliant with NPT requirements. However, in 2000, Iran declared its intention to build a facility to convert uranium from ore to gas (a precursor to enrichment). In 2002, other activities including uranium enrichment came to light, primarily as a result of disclosures by a dissident group inside Iran.

Iran's undeclared activities included the importation of a quantity of uranium from China in the early 1990s (shortly before China signed the NPT) and the construction of a small scale enrichment facility that was declared to the IAEA only after exposure in 2002. Worryingly, traces of highly-enriched uranium, far above levels required for power generation, were found by inspectors at another facility. The most likely explanation for that material is that it originated in Pakistan, the source of some of the equipment. Iran is also building a heavy water reactor, allegedly for research purposes, that is similar to those used by India and Pakistan to produce plutonium for weapons.

Given that there is no sound economic reason for Iran to turn to nuclear power—it has large reserves of fossil fuels and little uranium— there are good reasons to be suspicious of its nuclear programs. Russia has offered Iran a complete service for nuclear fuel, from the provision of enriched uranium through to the recovery and reprocessing of spent fuel, rendering an indigenous capability unnecessary. Yet Iran persists with its indigenous enrichment programs.

International attempts to regulate Iranian nuclear activities continue at the time of writing, and some possible concessionary noises have come from Iran. Incentives to comply with international safeguards are likely to include the supply of light water reactors, complete fuel services and possibly other non-nuclear benefits. A range of punitive options exist, but their likely effectiveness is debatable. The fact remains that Iran currently has a sophisticated nuclear industry, and has the ability to produce both enriched uranium and (un-separated) plutonium, albeit in quantities insufficient for weapons production in the short term. If it chooses to do so, the Iranian Government can give 90 days notice to withdraw from the NPT. After that, it can turn its nuclear program to fissile material production in support of weapon production. A careful reading of the available open source evidence suggests that Iran cannot produce a uranium-based nuclear weapon today, but may be able to do so within three to eight years, with the actual time depending on its ability to expand its enrichment capability.

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This is a troubling case study. While Iran had appeared to be compliant with NPT obligations, it had still managed to develop a covert program of high sophistication, with the cooperation of elements from within an existing nuclear-armed state in some activities. In terms of leverage, it remains to be seen whether Iran can be convinced to make its programs open and verifiable. The best hope appears to be a concerted effort by the United Nations Security Council, but unanimity may be required to make substantial progress, and that seems to be lacking at present.

Japan

Japan is not a nuclear weapons power. However, should it choose to do so, it is very well placed to become one. That is because the Japanese nuclear power cycle runs on a combination of uranium and plutonium fuels. As a result, Japan has a well-developed capability to separate plutonium. For example, stockpiles of reactor-grade plutonium have grown to over 40 tonnes. Given the nation's very high technological competence, the conclusion is that Japan could very quickly develop nuclear weapons if it chose to do so, perhaps on a time scale of months. Some commentators refer to Japan as a de facto nuclear power as a consequence. This observation is in no way an indictment of Japan, which has consistently adhered to international protocols. Instead, the circumstance is a consequence of the technical choices made in the civilian power program and the possession of the technologies required to isolate fissile material.

General observations

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The conclusion we can draw from our case studies is that the most effective way to prevent further proliferation of nuclear weapons is to prevent would-be proliferators from obtaining fissile material and the means of producing and isolating it in sufficiently large quantities. Iraq had the knowledge and weapon design required, but did not have the means to produce the required quantity of fissile material. North Korea developed plutonium reprocessing technology and a reactor to produce the raw material. Iran is developing enrichment technology, allegedly for peaceful purposes, but probably with an eye to weapons development. The ability to produce highly enriched uranium and/or separated plutonium is the biggest obstacle to nuclear weapon aspirants.

It is also important to note that none of the nuclear weapons programs in the case studies began life as a civilian power program (although that is Iran's cover story). Constructing power reactors and diverting material into nuclear weapons programs is, though technically possible, a difficult and inefficient path. Instead, countries tend to either construct heavy water 'research' reactors for the production of weapons-grade plutonium or attempt to produce weapons-grade enriched uranium directly. The monitoring of civilian power programs continues to be important in order to maintain the difficulty of moving material and technologies across to weapons programs and to protect against any attempt to recover fissile material from reactor fuel.

Finally, the case studies show that treaties and inspection regimes are not foolproof, despite general success in the community of nations. However, they remain an important part of the collective approach to non-proliferation. By accurately tracking nuclear materials as they travel through the world's power industries, it is possible to detect any attempt to divert materials into weapons programs. Such steps form part of a 'defence in depth' approach to curbing proliferation. Promoting the use of proliferation-resistant light water reactors is also part of that strategy.

Global Nuclear Energy Partnership

With the benefit of hindsight, it would have been better if the NPT had been framed with the whole nuclear fuel cycle, including enrichment and separation, as part of the strictly controlled framework. Recognition of that in light of the uncovering of the Iraqi nuclear weapons program led to the additional protocols. More recently, it is the basis for the proposed Global Nuclear Energy Partnership (GNEP) initiative announced by President Bush. We return to this point later to examine implications for an expanded Australian industry.

The rationale behind GNEP is that the world can improve security by making it unnecessary for new entrants into nuclear power to develop indigenous enrichment facilities. That would reduce the number of handling steps and facilities required to operate a power program, and would simplify the task of verifying compliance with protocols. In that sense, the availability on the world market of low-enriched uranium for power generation actually becomes a net positive from a security point of view. The lack of an ability to enrich uranium removes the easiest break-out path to a nuclear weapon; a gun-type device using weapons-grade uranium.

We can make the same point about plutonium separation. If it was only performed as a service by countries already possessing the technology as a trusted supplier servicing several customers, there would be no need for recipient nations to develop the capability. In that case, if all reactor loads were under international inspection and accounting regimes, there would be little scope for covert weapons programs, even using reactor-grade plutonium. The downside to this proposal is that spent reactor fuel would need to be shipped to reprocessing plants for treatment. That would raise environmental and political concerns, but the lack of a plutonium separation capability removes the possibility of developing an implosion device.

Following a similar line of reasoning, the Carnegie Endowment for International Peace has called for the cessation of *all* production of highly-enriched uranium and separation of plutonium. While such an approach would certainly make weapons production of any kind much more difficult, it is hard to see how it could be practically realised, especially given the investment by some countries into breeder reactors (which manufacture plutonium for fuel use) and/or MOX fuel cycles.

An objection to the GNEP approach is that it is only likely to work with countries that are not a great problem anyway. Because of booming energy demand and long-standing political divisions, it is possible that not all customers would trust established suppliers to make the fuel available upon demand. Those countries with least confidence in their ability to maintain a stable, long-term relationship with the suppliers group would have the incentive to continue to develop their own enrichment and/or reprocessing facilities. That is true, and some nations may choose for other, less pure, reasons to pursue that route. But it is still in the interest of the international community to minimise the number of countries that do so. Every country that could be persuaded to accept pre-enriched or reprocessed nuclear fuels would constitute a security gain.

Implications for Australia

We can now put all this together in the context of a possible future role for Australia as a bigger player in the world of nuclear power generation. It is a safe bet that any increased Australian role in the nuclear industry will be via an approach that also emphasises security. Australia has for decades been a responsible exporter of uranium and a very strong advocate of international controls on nuclear technology and materials. In addition, we have negotiated bilateral agreements with all of the countries we export uranium to or exchange nuclear materials and technologies with. Most recipients are also signatories to the post-Iraq IAEA additional protocols. (See Table 3)

In the previous section we argued that limiting the number of countries with the ability to produce and isolate fissile material was a security positive, and that it is desirable to prevent new entrants into that area. Of course, that reasoning also applies to Australia. While Australia's record on non-proliferation issues is rock solid since the early 1970s, technical choices that we make in developing a value-adding nuclear industry would also give us a potential 'break-out' capability whether that was our intention or not. What is true for Japan is also true for us.

What is true for other countries is true for us. We would become another nation in possession of the ability to produce and isolate fissile material.

That point is unlikely to be missed by other countries, especially those in Australia's region. There are states that have little or no existing nuclear infrastructure. Some might welcome the opportunity to purchase a full nuclear fuel service, while others may feel threatened by Australia's expertise. At the very least there would be diplomatic issues to be managed to reaffirm Australia's bona fides. At worst, other states may be tempted to develop a capability of their own as a balance. Either way, there is a decline in global security—as there is every time a new entrant to the world of fissile material expertise appears. In this context, we ask rhetorically what Australia's position might be if another regional country that was fully compliant with the NPT and with an additional protocol in place announced that it was planning to develop an enrichment capability.

The logical extension of the argument above would be for Australian uranium to be enriched only in countries that already possess the technology to do so, and then exported only to countries that are NPT signatories and that have an additional protocol in place. (The latter is, of course, the current policy.)

Table 3: Australia's bilateral safeguard agreements as of June 30, 2005

Country	Date of bilateral safeguard agreement	Australian uranium exports	Additional protocol	Uranium enrichment capability	Plutonium separation capability
Republic of Korea	2 May 1979	✓	✓		
United Kingdom	24 Jul 1979	✓	✓	✓	✓
Finland	9 Feb 1980	✓	✓		
United States	16 Jan 1981	✓		✓	✓
Canada	9 Mar 1981	✓	✓		
Sweden	22 May 1981	✓	✓		
France	12 Sep 1981	✓	✓	✓	✓
Euratom*	15 Jan 1982	✓		✓ (Netherlands, Germany)	✓ (Belgium+)
Philippines	11 May 1982				
Japan	17 Aug 1982		✓		✓
Switzerland	27 Jul 1988		✓		
Egypt	2 Jun 1989				
Russia	24 Dec 1990			✓	✓
Mexico	17 Jul 1992				
New Zealand	1 May 2000		✓		
Czech republic	17 May 2002		✓		
United States (covering Taiwan and China)	17 May 2002			✓ (China)	✓ (China)
Hungary	15 Jun 2002		✓		
Argentina	12 Jan 2005				

* European Atomic Energy Community—an organisation composed of the members of the EU.

+ Belgium's MOX facility is being decommissioned in 2006.

Sources: Columns 1–4 from Australian Safeguards and Non-Proliferation Office Annual Report 2004–2005, columns 5–6 from the website http://www.wise-uranium.org/efac.html, August 2006

Australia as a supplier of value-added nuclear materials

Geographically, Australia is well placed to become a nuclear service centre for the Southeast Asian region, and possibly beyond. The US has indicated that Australia (and Canada) would be looked upon favourably as value-adding members of the GNEP arrangement.

If Australia was to make the judgement that the economic gain was worth the diplomatic and possibly security cost and go the way of enriching uranium, it would have to be accompanied by the utmost transparency and careful diplomacy in order to minimise any negative perceptions that might arise. Transparency should not present a problem. Australia has an additional protocol in place and existing Australian nuclear facilities and waste holdings are routinely opened to international inspectors.

Given a decision to develop a value-adding nuclear industry, the approach that would best preserve security would be for Australia to become a 'one-stop shop' for uranium

Ranger treatment plant, with mine pit beyond. Photo courtesy Energy Resources of Australia

and its derivatives. Australia would provide a service from mining through enrichment and fabrication in the first instance, and then reprocessing irradiated fuel (uranium and plutonium) into second generation fuels. There would be no need for other new entrants into nuclear industries to develop enrichment or separation capabilities. All nuclear material and processes would have to be under strict IAEA safeguarding, and the current policy of requiring recipients to be NPT and additional protocol signatories would be retained. (It is not clear that this approach is economically viable, and the transport and other overheads might work against it, but that is for others to canvas.)

Table 4 shows the balance sheet for an enrichment industry for Australia. A similar argument applies to plutonium separation.

Table 4: Pros and cons of enriching uranium in Australia

Export enriched uranium		Export nuclear materials through existing third party enrichment facilities	
Benefits	**Risks**	**Benefits**	**Risks**
Possible economic gain through value-adding. Allows customer nations access to nuclear fuel without enriching their own.	Adds one more nuclear-capable country to the globe. Sets regional precedent for establishment of capability. Reaction of neighbours may be negative and may stimulate response in kind.	No additional security issues to be managed. No stimulus for regional countries to develop enrichment capabilities.	Possible loss of economic opportunities to value-add to exports.

A further step, albeit one bound to be politically sensitive, would be the return of all spent fuel for processing and long-term storage. There are some positive security aspects to this approach, to be balanced against local environmental concerns about shipping and storing highly radioactive material. As we have seen, even reactor-grade plutonium represents a security risk, albeit much reduced from weapons-grade material. However, there is no compelling reason to demand such a step from a proliferation viewpoint. Australian-sourced nuclear material is never made available outside international supervision. If that is adequate for the monitoring of nuclear fuel during the time it is being used for power production, then it is also adequate for spent material, especially when combined with restrictions on plutonium separation expertise.

China and India

Recent media reports have discussed the possibility of the export of Australian uranium to China and India. Now-declassified US reports strongly implicate China in the proliferation of nuclear weapons technology and design to Pakistan from the 1970s through to the early 1990s. However, China is now a signatory to the NPT and has been involved in trying to curb North Korea's nuclear weapons program and trade in sensitive technologies. Australia now accepts that China meets all of our requirements for the export of nuclear material. The two nations have signed agreements on nuclear material transfer and nuclear cooperation. Australian nuclear material is to be quarantined from military weapons programs under the agreements. Export of uranium to China does not have any practical detrimental effect on Australia's security. Indeed, by tying such exports to continued support for non-proliferation, the net effect is probably positive.

India, however, is not a signatory to the NPT. Indeed, while possessing nuclear weapons, it is impossible for a state other than the original five nuclear powers to accede to the treaty. Despite that, US President Bush has recently indicated that he will ask Congress to change US law to allow nuclear trade with India. The stated reason is that India is a responsible non-NPT signatory that deserves to be brought into the fold. As well, the proposed nuclear deal is part of a US strategy to develop a broader economic and strategic relationship with India. Under the proposed arrangement, India's civil nuclear facilities would be brought under international safeguards while the military program would remain internal. The net security gain is, at best, marginal.

For reasons argued above in the Chinese context, the provision of Australian uranium to Indian power programs would make no difference to their weapons program. The US position of essentially conceding that India can act outside the NPT with impunity risks sending a message to other countries (or at least those not deemed to be 'rogue states') that developing nuclear weapons carries few practical downsides. To be balanced against that is the desirability of fostering a closer economic relationship with India as the world's largest democracy and a rising major power.

From Australia's point of view, nuclear trade with India would require a change of policy and the Foreign Minister indicated in Parliament in March that 'We have no current intentions to change our policy on uranium sales'. He also welcomed the opening up of India's civil nuclear program to IAEA inspection. Previously Mr Downer had argued that Australia's preferred position was for India to one day sign the NPT as a non-nuclear weapon state, presumably at which point Australia would consider India as an export destination for uranium. He added that exporting to India as a non-signatory to the NPT would open up questions of whether we would also sell uranium to Pakistan and Israel. The government's current position gives precedence to a strict approach to non-proliferation over a potential economic gain.

As with China, export of uranium to India would make little or no practical difference to its weapons programs. But accession to the NPT and adoption of an additional protocol should be a condition for India to receive Australian uranium.

In general, the question of what to do with countries other than the original five that have developed nuclear weapons is a vexing one. It is in the interest of the international community to encourage non-proliferation, which argues for an approach that includes such countries in the NPT. That is Australia's position. It is a principled stance that makes good security sense. However, the NPT cannot accommodate nuclear-armed states other than the original five in its current form and redrafting would be required. While it can be argued that it would set a bad precedent to retrospectively recognise those countries as nuclear powers, the reality is that global security would be improved if they were treaty signatories. Of course, nuclear-armed states within the NPT must make a commitment to disarm, and new nuclear-armed members would be no different.

Disarmament is a laudable goal but, realistically, India is not going to relinquish its nuclear weapons while it has two nuclear-armed neighbours, one of whom is allowed by the NPT to retain them for the foreseeable future. We suggest, albeit with no real optimism, that the second pillar of the NPT is an area where the international community might nonetheless apply extra effort.

If India could be accommodated within the NPT, then so too could Pakistan at a later time. Like China before it, Pakistan could make the transition from a proliferant to a responsible, albeit nuclear-armed, member of the NPT. There is no doubt that having Pakistan in the NPT would be a positive security development. Therefore, on balance, we conclude that it is preferable to have India within the NPT, nuclear-armed or not.

One point of leverage is access to supplies of nuclear materials, which could be made contingent upon membership of the NPT and adoption of an additional protocol, as with Australia's current policy. Any potential economic loss should not be the deciding factor. On balance, the Australian Government should insist that accession to the NPT and adoption of an additional protocol be a pre-requisite for exports of uranium to India or other nuclear-armed states.

Note that the situation of North Korea and Iran is quite different from India, Pakistan and Israel. North Korea opted out of the NPT when its covert activities were discovered, while Iran attempted to maintain a nuclear research program separate to its declared activities. Iran seems not totally beyond redemption at the time of writing, and full compliance with the NPT and the additional protocols is still possible. North Korea's actions render it essentially a pariah state, and nothing short of full disclosure of its activities, open access to all nuclear facilities and surrender of all weapons-grade material would suffice to bring it back into the fold.

Conclusions

There is little doubt that increased global interest in nuclear energy is a potential economic opportunity for Australia. However, the laws of physics impose a necessary overlap between the technologies required to generate nuclear energy or to produce nuclear weapons. It is therefore incumbent upon us to adopt a defence-in-depth approach that can minimise the possibility of a would-be proliferant nation being able to use a civil power program to develop the expertise and technologies required to 'break out' into a nuclear weapons program.

Australia's current position on exporting nuclear material is responsible and consistent with its long-standing commitment to international approaches to non-proliferation of weapons of mass destruction. The practical result is that exporting uranium to selected customers need not contribute to the proliferation of nuclear weapons. Our main conclusions are:

- For countries that are committed to non-proliferation with established uranium enrichment and/or plutonium separation capabilities under international supervision, the export of Australian nuclear material is of no security concern.
- Australia should work with the international community to modify the NPT to allow India and other non-NPT nuclear-armed states to join. Any Australian uranium exports to those states should be contingent upon treaty signature and adoption of an additional protocol.
- If Australia was to develop the capability to enrich uranium and/or separate plutonium, it would make it more difficult to argue against the development of that capability by other countries and risks provoking just such a response.
- For exports to countries with no existing capability to enrich uranium or separate plutonium, the best security solution is to export uranium through NPT-signatories that already possess those capabilities. Those third parties will perform the enrichment.
- If Australia was to develop a value-adding nuclear industry through uranium enrichment and/or plutonium reprocessing, it would need careful diplomacy and the utmost openness and transparency.
- There is no security imperative for providing a service for the long-term storage of waste, provided it is under international supervision wherever it is stored.

Sources and further reading

This report draws entirely on open source material.

The material on uranium economics is extracted from the very comprehensive World Nuclear Association report *The Global Nuclear Fuel Market—Supply and Demand 2005–2030*. A nice summary of that report can be found at the Uranium Information Centre website: http://www.uic.com.au/nip36.htm

The internet provides a wide range of information on nuclear physics, reactors and weapons. The material on offer ranges from simple conceptual explanations through to technical scientific and engineering discussions. Some of it is wrong, but among the best sources are the sites of the IAEA site (iaea.org), The Federation of American Scientists (fas.org), The Bulletin of Atomic

Scientists (thebulletin.org/index.htm) and various entries on the increasingly valuable Wikipedia (en.wikipedia.org), from whence came the excellent schematic weapon diagrams.

For physics students, the nuclear weapons FAQ at nuclearweaponarchive.org contains a thorough technical discussion of fission weapon and criticality physics.

A good source on the NPT is the UN site un.org/Depts/dda/WMD/treaty and it is also discussed in detail at fas.org./nuke/control/npt. Australia's position on WMD non-proliferation is articulated in the DFAT publication *Weapons of Mass Destruction—Australia's Role in Fighting Proliferation*, available on their web site www.dfat.gov.au.

The Carnegie Endowment report referred to is *Universal Compliance—A Strategy for Nuclear Security*. It may be found at www.carnegieendowment.org.

The National Security Archive (of the USA) (www.gwu.edu/~nsarchiv) contains a wealth of fascinating archival material. The site features well-written essays on various topics that are often nuclear related. Recent features covered the role played by China in Pakistan's nuclear weapons program and the intelligence failure regarding the surprise of India's first nuclear test in 1974. The essays are extensively cross-referenced to pertinent original documents, including (sometimes censored) declassified material.

Richard Rhodes' Pulitzer Prize winning book *The Making of the Atomic Bomb* is an outstanding history of the discovery of fission and the Manhattan Project.

Important disclaimer

About the Author

Dr Andrew Davies is a theoretical physicist by training, and published research papers in the area of high-energy particle physics while at the University of Melbourne and the Australian National University. Andrew joined the Analytic Studies Group in the Department of Defence in 1994. He worked on a range of scientific studies in support of Defence decision making, including submarine detection for the RAN, Army firepower options and RAAF stand-off weapons effectiveness. He led the Capability Analysis Branch within Defence Headquarters for a time, before moving into the world of signals intelligence and information security with the Defence Signals Directorate, where he held a number of positions. Andrew joined the Australian Strategic Policy Institute as director of the Operations and Capability Program in 2006.

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