RESEARCH REACTORS & NUCLEAR WEAPONS

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https://nuclear.foe.org.au/research-reactors-nuclear-weapons/

UPDATE – 2018

Apologies for all the dead web-links in this paper. If you can't find a particular article or paper, email jim.green@foe.org.au

A few updates to the paper below:
– Since 2006, North Korea has repeatedly tested nuclear weapons using plutonium produced in a small reactor (based on the UK Magnox design) variously described as an 'experimental power reactor' or a research reactor or a dedicated military reactor.
– The Arak research reactor under construction in Iran was a source of international concern and work on the reactor was stopped as one component of the 2015 Joint Comprehensive Plan of Action.
– The US launched military strikes on research reactor/s in Iraq in 2003.

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ACRONYMS & ABBREVIATIONS

AAEC - Australian Atomic Energy Commission
ANSTO - Australian Nuclear Science and Technology Organisation
ASNO - Australian Safeguards and Non-proliferation Office
HIFAR - High Flux Australian Reactor

HEU - Highly enriched uranium, enriched to 20% or more uranium-235.
IAEA - International Atomic Energy Agency
LEU - Low enriched uranium, less than 20% uranium-235 but more than the 0.7% uranium-235 in natural uranium
MW(th) - Megawatts (millions of watts) of thermal power
MW(e) - Megawatts (millions of watts) of electrical power
NPT - Treaty on the Non-Proliferation of Nuclear Weapons.
RERTR - Reduced Enrichment for Research and Test Reactor program
UK - United Kingdom
US - United States of America

INTRODUCTION

Nuclear research reactors are used for a plethora of medical, scientific and industrial purposes, and they continue to play a support role for nuclear power programs.

In addition, research reactors can be - and have been - used in support of nuclear weapons programs in several ways:

- production of plutonium
- diversion of fresh highly enriched uranium (HEU) research reactor fuel or extraction of HEU from spent fuel
- production of radionuclides (other than plutonium) for use in weapons (e.g. tritium)
- weapons related research
- development of expertise for parallel or later use in a weapons program
- justifying the acquisition of other facilities capable of being used in support of a weapons program, such as enrichment or reprocessing facilities
- establishment or strengthening of a political constituency for weapons production.

Issues raised by the dual-use civil/military capabilities of research reactors include the limitations of the international safeguards/non-proliferation regime including export controls, and actual and potential development of proliferation resistant technologies such as low enriched uranium (LEU) fuels.

The risks posed by research reactors in relation to weapons proliferation needs to be seen in the broader context of debates over the use of research reactors - and alternative technologies such as particle accelerators - for scientific, medical and industrial applications. Also relevant are public health and environmental issues associated with reactors and the spent nuclear fuel and other radioactive wastes they generate.

This paper does not address the broader debates; it is focussed on illustrating the uses of research reactors and associated technologies in nuclear weapons programs (in particular covert weapons programs):

- the following section summarises those uses
- subsequent sections address plutonium production and separation, and HEU, in more detail
- a number of case studies of the links between research reactor programs and weapons programs are then provided
- the appendix summarises the Reduced Enrichment for Research and Test Reactors program, which has the aim of ending the use of HEU for research reactor fuel or for targets for radioisotope production

THE LINKS: RESEARCH REACTORS & NUCLEAR WEAPONS

This section covers the following issues:
- covert and overt weapons programs
- cover from nuclear power and/or nuclear research programs
- research reactors as 'sweeteners'
- the various uses of research reactors in weapons programs
- fissile material
- weapons related research
- training
- production of radionuclides for use in weapons
- 'bomb lobbies'
- 'dirty' bombs
- theft, smuggling, and terrorism
- perceptions

Covert and overt weapons programs:

There are several reasons why a number of states have chosen to clandestinely pursue a nuclear weapons program under the guise of, and in association with, a civil nuclear program as opposed to an overt, dedicated weapons program:
- nuclear technology and materials are generally much easier to acquire from supplier states if the stated purpose is peaceful and if the recipient country is a signatory to the Nuclear Non-Proliferation Treaty (NPT); attempts can then be made to circumvent or break conditions imposed by the IAEA and/or the supplier state (or expertise gained through the acquisition and operation of safeguarded facilities can be used in a parallel weapons program)
- avoiding external political reaction or economic sanctions or domestic political opposition
- avoiding a pre-emptive military strike (e.g. Israel's bombing of Iraq's Osirak research reactor in 1981).

There are varying patterns of covert weapons programs involving research reactors (or nuclear research programs more generally). Some of the main variables are:
- pursuit of weapons within the umbrella of the NPT to a greater or lesser extent (e.g. Iraq, North Korea, Romania, Taiwan, Yugoslavia) or outside the NPT (e.g. India, Israel, Pakistan)
- attempts to acquire or produce either HEU or plutonium or (most commonly) both
- systematic, determined pursuit of weapons (e.g. Iraq, India, Israel, Pakistan) as opposed to attempting only to lower the lead time for weapons as a contingency (e.g. Australia) (proliferation is best thought of as a continuum taking into account not only possession of weapons but also other factors such as possession of nuclear materials, facilities, and expertise)

Cover from nuclear power and/or nuclear research programs:

Weapons have been pursued under the cover of nuclear power and/or nuclear research programs. The power and research routes each have their advantages and disadvantages (Fainberg, 1983; Holdren, 1983; Holdren, 1983a).

The nuclear power route has the following advantages:

- much greater plutonium production in power reactors compared to research reactors
- the development of an enrichment capability solely to service research reactors is likely to be viewed as suspicious, whereas development of enrichment technology in conjunction with nuclear power is more easily justified
- the development of a large scale reprocessing capability is more easily justified if connected to a nuclear power program (although the development of a modest capability to process irradiated targets is fairly common, e.g. to separate radioisotopes for medical applications)
- a wider range of nuclear expertise will be developed through a nuclear power program than a research reactor program, thus facilitating weapons production.

Pursuit of a covert weapons program under cover of a research reactor program has its own advantages:
- if only a small arsenal of nuclear weapons is desired, or if the intention is not to systematically pursue weapons production but merely to expedite weapons development at some indeterminate stage in the future, then a research reactor program has the advantage of being far less expensive than a nuclear power program. The Australian Science and Technology Council argued in a 1984 report: "Should a country decide to embark on a weapons program it is unlikely to use a civil power reactor to do so. This is because such a use would be inefficient both in terms of producing weapons usable material and in terms of electricity generation. It is therefore much more likely that a research reactor, or other non-power reactor, would be used for this purpose."
- irradiated fuel elements from research reactors are more easily handled than spent fuel from power reactors. Bunn, Holdren and Weir (2002, pp.4-5) note that irradiated HEU from research reactors poses a proliferation and terrorism threat "because at many research reactors the fuel was only lightly irradiated, has been cooling for many years, and is in fuel elements of modest size, meaning that the fuel elements are not sufficiently radioactive to be self-protecting against theft ..."
- smaller nuclear research facilities generally attract less interest in terms of safeguards inspections and, more generally, smaller nuclear research facilities arouse less suspicion of military intent
- detection of secret, small scale nuclear facilities is generally more difficult than detection of larger facilities associated with nuclear power programs
- nuclear power programs require a large number of trained personnel, whereas it is considerably easier to assemble personnel to run an research reactor program.

The power and research routes to nuclear weapons are not mutually exclusive. In several countries - such as South Africa, Pakistan, Argentina and Brazil - research reactor programs have been developed as a forerunner to, or in parallel with, nuclear power programs, and the power program has then become entangled in a covert weapons program. In other cases, such as Iraq and Israel, a research reactor program has been used in support of a covert weapons program without the intermediary of nuclear power (although in both countries, stated interest in nuclear power accelerated the weapons program by facilitating technology transfers).

Research reactors as 'sweeteners':

Research reactors have sometimes used by suppliers as 'sweeteners' in the hope of securing more lucrative sales at a later date. Canada's supply of a heavily subsidised, large research reactor to India is a notable example. Professor Gary Milhollin (1996) from the University of Wisconsin and the Wisconsin Project on Nuclear Arms Control, said in 1996: "And there is the problem of "sweeteners." These are the sensitive items that are thrown in to "sweeten" big reactor deals. They are the equivalent of nuclear candy bars. The magnets that China is giving Pakistan are probably sweeteners - greasing the skids for the reactor China is building there. And Iran has been trying very hard to get sweeteners from Russia as part of its reactor deal - that is clear. Iran failed to get a centrifuge plant, but it is still trying to get a large research reactor. The reactor would operate at about 30 to 40 megawatts, exactly the size that India and Israel used to make the plutonium for their first fission bombs."

The various uses of research reactors in weapons programs:

Research reactor programs can be used to assist in the manufacture of nuclear weapons in several ways:
- plutonium production (requiring a reactor and also some capacity to separate plutonium from irradiated materials)
- diversion of fresh HEU fuel or separation of HEU from spent fuel
- production of radionuclides (other than plutonium) for use in weapons (e.g. tritium)
- weapons related research
- development of expertise for parallel or later use in a weapons program
- justifying the acquisition of other facilities capable of being used in support of a weapons program, in particular enrichment or reprocessing/separation facilities, but also various other facilities such as fuel fabrication plants which can facilitate weapons production by minimising reliance on foreign suppliers
- establishment or strengthening of a political constituency for weapons production (a 'bomb lobby').

Research reactors have a chameleon quality: they can be used for peaceful purposes or, to a greater or lesser degree, they can be used in support of a weapons program. The high power Fast Flux Test Facility (FFTF) at Hanford in the US illustrates the point. The reactor, which first operated in 1980, was built to support the US fast breeder power program by providing fuels and materials irradiation services. From 1983 to 1992, it was used to test nuclear fuels, materials and components, to produce medical and industrial radioisotopes, and to support fusion research. After 1992, the reactor was shut down but was on standby to produce plutonium-238 for power generators in space probes or to produce tritium for nuclear weapons. A plethora of possible future uses for the reactor were proposed and debated, including medical, scientific and industrial applications, and other applications related to nuclear power and nuclear weapons. However, in December 2001, the US Department of Energy decided to permanently close the reactor.

Fissile material:

For fissile material acquisition or production, the most useful research reactors are medium to high power reactors fuelled with natural uranium or very lightly enriched uranium (thus producing considerable quantities of plutonium), or medium to high power reactors which use considerable quantities of HEU fuel (which can be diverted before irradiation, or HEU can be extracted from spent fuel). Reactors in these relatively high risk categories number several dozen out of a total of approximately 287 operational research reactors in the world. (HEU and other nuclear materials stored at closed research reactor sites also pose risks.)

Bunn, Holdren, and Wier (2002, p.51) state: "While there are hundreds of small civilian sites in the world with HEU or plutonium, the number that have enough fresh HEU or separated plutonium for a bomb in one place is substantially smaller - in the range of a few dozen or less worldwide, making the problem potentially manageable. (That number increases significantly if sites with enough HEU for a bomb in forms that are irradiated, but not radioactive enough to deter a terrorist willing to incur substantial radiation doses, are also included, as research reactor spent fuel is typically far smaller and less radioactive than power reactor spent fuel.)"

While the development of enrichment and reprocessing technology is more easily justified in conjunction with power reactors rather than research reactors, there are numerous examples of such facilities being developed (or maintained or expanded) ostensibly to support a civil research reactor program while also being connected to covert weapons programs. Examples include:
- the construction of hot cells in numerous countries, used for peaceful purposes such as separating medically-useful radioisotopes from irradiated targets but in a number of cases also capable of being used to separate plutonium
- Yugoslavia's attempt to acquire a reprocessing plant, ostensibly to treat spent fuel from research reactors
- Argentina's pursuit of enrichment technology which, while kept secret for some years, was later justified with reference to research reactor requirements
- fuel fabrication plants in North Korea, Iraq and Yugoslavia
- the construction of a Plutonium Fuel Chemistry Laboratory in Taiwan
- South Africa's enrichment plant at Pelindaba, used to produce HEU for weapons, which was publicly justified with reference to the 20 MW(th) Safari I research reactor (particularly when US supplies of HEU were suspended from 1975) and power reactors.

Weapons related research:

As well as the potential for research reactors to be used for nuclear weapons production via the plutonium or HEU routes, research reactors can be used for weapons related research. For example, the 19 MW(th) Purnima research reactor in India was essential for theoretical calculations relating to nuclear explosions and thus played an important role in the Indian nuclear weapons program (Reiss, 1988, ch.7).

Whereas only the larger research reactors use considerable quantities of HEU (and a declining number of reactors are HEU fuelled) or produce considerable quantities of plutonium, a greater number of reactors - including low and zero power reactors and critical assemblies - can be useful for weapons related research. For example, a critical assembly was used for an experiment in support of the weapons program in South Africa in the late 1970s (Albright, 1994).

Training:

In addition to specific experiments and projects pursued to advance a nuclear weapons program, research reactors allow for the training of staff whose expertise is likely to be of value should a decision be made to systematically pursue a weapons program. Thus, in Australia in 1962, the federal Cabinet approved an increase in the staff of the Australian Atomic Energy Commission (AAEC) from 950 to 1050 because, in the words of the Minister of National Development, William Spooner, "a body of nuclear scientists and engineer skilled in nuclear energy represents a positive asset which would be available at any time if the government decided to develop a nuclear defence potential." (Reynolds, 2000, p.194.)

Production of radionuclides for use in weapons:

A number of radionuclides of use in nuclear weapons can be produced in research reactors. In some cases, the same nuclide has both peaceful and military uses. Examples include:
- polonium-210, which has industrial uses but can also be used as a neutron initiator in nuclear weapons. A safeguarded research reactor was used for this purpose in Iraq (and research reactors may have been used in other countries for this purpose).
- tritium, a radioactive isotope of hydrogen which has medical uses but is first and foremost used in nuclear weapons (to generate neutrons to initiate the fission reaction, or to enhance or "boost" the yield

of a fission weapon, or in thermonuclear/fusion weapons). Tritium can be produced by neutron bombardment of lithium-6, or as a by-product of the operation of a heavy-water-moderated reactor when neutrons bombard deuterons. Countries where research reactors may have been - or might yet be - used for tritium production in support of a weapons program include India, Iraq, Israel and Pakistan.

'Bomb lobbies':

Civil nuclear programs often add to the political constituency for nuclear weapons. One of the clearest illustrations of this point is the situation which prevailed in Australia in the 1950s and 1960s, when the most persistent, determined and technically literate advocate of weapons production was Philip Baxter, Chair of the AAEC. Writing in the Nonproliferation Review, Jim Walsh (1997) noted that, "By the mid-1960s, the AAEC became the leading voice on nuclear affairs. The chair of the AAEC was Sir Philip Baxter, credited by friend and critic alike for his bureaucratic acumen and influence over government policy. ... Baxter personally supported the concept of an Australian nuclear weapons capability and, perhaps more importantly, viewed the military's interest in nuclear weapons as consonant with the AAEC's need to expand its programs and budget."

'Dirty' bombs:

Research reactors are potentially useful for the production of radioactive materials for a 'dirty' radiation bomb (in which radioactive materials are dispersed by conventional explosives).

Professor Gary Milhollin (2002), from the University of Wisconsin Law School and the Wisconsin Project on Nuclear Arms Control, considers a research reactor a more likely source of radioactive material for use in a radiation bomb than power reactors: "A research reactor would be a better source. Many countries use such small reactors to irradiate material samples, and it might be possible to insert some material into one of these reactors secretly, irradiate it, and then withdraw it and put it in a bomb. The difficulty would then lie in making the bomb effective. Highly radioactive materials have short half-lives; thus, any bomb would have to be used right away, and one would not be able to build up a stockpile. If enough radioactivity were packed into the bomb to injure a substantial number of victims, the too-hot-to-handle problem would arise. If the radioactive charge were diluted, the bomb would lose its effect. Saddam Hussein actually made and tested such a bomb in the 1980's, but when UN inspectors toured the test site in the 1990's they could find no trace of radiation from it."

'Dirty' radiation bombs were produced and three test bombs were exploded in Iraq in 1987, using materials irradiated in the IRT and/or Tammuz II research reactors.

Theft, smuggling, and terrorism:

Most countries pursuing a covert nuclear weapons program have attempted to develop an indigenous capacity to produce HEU and/or plutonium, but the potential for states (or sub-national groups) to steal large quantities of fissile material, e.g. from ex-Soviet states, has become an issue of increasing concern. The future of plutonium use (and production) in fast breeder reactors and/or its use in MOX fuel for conventional reactors may also increase opportunities for theft or illicit purchase of fissile material.

Bunn and Bunn (2001) note that "Theft of insecure HEU and plutonium, in short, is not a hypothetical worry: it is an ongoing reality, not only from the former Soviet Union but from other states as well." Examples related to research reactors include:

- two kilograms of HEU stolen from a research reactor in Georgia which has never been recovered (Trei, 2002)
- 19.9% enriched uranium stolen from a research reactor in the Congo was recovered by police in Italy and Belgium in 1998 (Bunn and Steinhausler, 2001)
- in 2001, 600 grams of 66% enriched HEU of unknown origin was recovered in Colombia (Bunn and Steinhausler, 2001).

There are numerous examples of insecure HEU stockpiles at nuclear research facilities. Bunn, Holdren, and Wier (2002, p.47) list the following examples:
- a facility near Belgrade with sufficient fresh 80% enriched HEU for a gun type bomb or several implosion type bombs with inadequate funds to provide adequate security
- an impoverished research facility in the Ukraine with 75 kgs of 90% enriched HEU
- a research facility in Belarus with more than 300 kgs of HEU but little funding to provide effective security.

Matthew Bunn (2000, pp.78-79) discussed the ex-Soviet states in an April 2000 paper: "Scattered through the former Soviet Union are nearly two dozen small, underfunded civilian nuclear research facilities possessing HEU in amounts ranging from a few kilograms to hundreds of kilograms or more. Some of these are within Russia, but there are research facilities that still have weapons-usable HEU in Ukraine, Kazakhstan, Belarus, Latvia, and Uzbekistan as well. Many of these facilities no longer have the money to protect the HEU appropriately, or to do the research that once required HEU. Indeed, it was at sites like these that some of the worst desperation was observed after the August 1998 financial crisis - guards leaving their posts to forage for food, electricity being cut off because bills had not been paid, and the like."

Terrorist threats have been made against research reactors, including the following:
- on November 11, 1972, a DC-9 plane was hijacked in the US, the hijackers threatened to ditch the plane into the Oak Ridge nuclear research reactor, the plane circled the reactor plant for one hour, the reactor was shut down and the plant was evacuated (except for essential personnel)
- in 1983, nine sticks of gelignite, 25 kilograms of ammonium nitrate, three detonators and an igniter were found in an electrical sub-station inside the boundary fence of the Australian Atomic Energy Commission; two detonators failed, and one exploded but did not ignite the main charge; two people were charged over this incident.

Bunn, Holdren, and Wier (2002, p.51) urge reassessment of the costs and benefits of continued operation of many research reactors: "... only a fraction of the hundreds of research reactors still in operation around the world are genuinely needed, for research, training, and isotope production. It is absurd and unsafe for facilities that are so poor they do not have a telephone, or have dead rats floating in the spent fuel pool, to be attempting to run a research reactor. An international effort should be put in place to help countries assess the real benefits and dangers posed by their research reactors, and assist in shutting down and decommissioning those facilities where the benefits no longer outweigh the costs and risks."

Perceptions:

In addition to the practical uses of research reactors in weapons programs, reactors (and reactor trained personnel and reactor derived expertise) may be used to create the impression of a weapons capability or movement in the direction thereof. This situation prevailed in Indonesia under Sukarno in 1964-65, when the government's claims of major progress towards a weapons capability lacked credibility in any event but would have been still more implausible if not for the existence of a 250 kilowatt (th) TRIGA Mark-II reactor. The reactor first went critical on October 17, 1964, the day after China exploded its first nuclear weapon. (Cornejo, 2000.)

There is also the possibility that research reactors (and associated technologies and expertise) will generate the perception of intent to develop nuclear weapons even where no such intent exists. IAEA employees Elbaradei and Rames noted in the IAEA Bulletin in 1995: "The materials, knowledge, and expertise required to produce nuclear weapons are often indistinguishable from those needed to generate nuclear power and conduct nuclear research." In light of this technological overlap, perceptions are of course important.

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PLUTONIUM PRODUCTION & SEPARATION

The most direct use of research reactors in weapons programs is the production of fissile plutonium via neutron irradiation of uranium-238. While plutonium is the primary concern (as far as is known, the fissile material in all nuclear weapons in existence today is plutonium and/or HEU), other possibilities should be noted:
- production of fissile uranium-233 by neutron irradiation of thorium-233. This may become an issue of greater concern if a thorium fuel cycle is developed and spreads (Friedman, 1997).
- production of fissile isotopes of neptunium or americium in uranium fuelled reactors (Rothstein, 1999).

In order to produce significant volumes of plutonium in the reactor fuel, the most useful reactors are those fuelled with natural uranium or very low enriched uranium, i.e. reactor fuels with a high proportion of uranium-238.

Alternative methods of producing plutonium are to insert uranium targets in or near the reactor core or to surround the reactor core with a "blanket" of uranium. Plutonium can be extracted from the target or blanket after irradiation. This method will be preferable if the reactor fuel is HEU and thus plutonium production in the fuel is low; the target can be made of natural uranium, depleted uranium or LEU to increase plutonium production. (International Physicians for the Prevention of Nuclear War / Institute for Energy and Environmental Research, 1992.) Another method of plutonium production is to replace reflector elements with fertile material targets (Zuccaro-Labellarte and Fagerholm, 1996).

These various methods of producing plutonium are not mutually exclusive; two or more methods might be used concurrently.

The volume of plutonium produced depends on a number of variables including the uranium enrichment level, the reactor power level, the irradiation time, reactor design, and the method of production (fuel, target, blanket, reflector). Consequently it is not possible to definitively state a power level necessary for production of volumes of fissile plutonium capable of being manufactured into a workable nuclear weapon. Generally, only the more powerful research reactors are capable of annual plutonium production in the kilograms or tens of kilograms range, and a large majority of research reactors are incapable of producing quantities of plutonium sufficient for nuclear weapons.

According to Milhollin and White (1991), the plutonium production rate for medium power research reactors is approximately one gram of plutonium per megawatt-day; they use the 10-15 MW(th) LEU fuelled research reactor in Algeria as an example, estimating an annual production capability of approximately 4.5 kilograms annually. The plutonium production rate can vary significantly depending on variables other than power rating, however. For example, spent fuel elements from the HEU fuelled 10 MW(th) High Flux Australian Reactor (HIFAR) contain only about 0.5 grams of plutonium (Coleby, 1986). The total production of plutonium over the 40 year lifetime of the HIFAR reactor has been only about one kilogram.

The IAEA's safeguards system requires that all research reactors operating at power levels above 25 MW(th) are evaluated with respect to their capability to produce at least one "Significant Quantity" of plutonium (or uranium-233) per year. (A Significant Quantity is defined by the IAEA as "the approximate quantity of nuclear material in respect of which, taking into account any conversion process involved, the possibility of manufacturing a nuclear explosive device cannot be excluded." For safeguards purposes, one Significant Quantity is defined as eight kilograms of plutonium or uranium-233 or 25 kilograms of uranium-235. Greater or lesser amounts may be required to produce a weapon depending on factors such as the chemical form, compression and shape of the fissile material or the use of neutron reflectors in the weapon.)

As at 1996, there were about 30 thermal research reactors with power levels of 10 MW(th) or higher which were subject to IAEA safeguards. About 10 operated at power levels exceeding 25 MW(th), thus attracting additional safeguards measures with respect to clandestine production scenarios. (Zuccaro-Labellarte and Fagerholm, 1996.)

As at May 2000, the IAEA's Research Reactor Database (which includes both safeguarded and unsafeguarded reactors) listed 28 operational research reactors with a power level of 25 MW(th) or more (<www.iaea.org/worldatom/rrdb>). These reactors are located in France (6), Russia (4), Japan (3), India (3), USA (2), Belgium, Canada, China, Israel, Kazakhstan, Netherlands, Indonesia, Poland, South Korea and Sweden. In addition, research reactors with a power level of 25 MW(th) or more were planned or under construction in China (2), Russia and France.

According to Milhollin and White (1991), "The best way to avoid military use of a research reactor is to make it small enough so that its plutonium production is negligible." However, low power reactors are not entirely benign. For example, the HEU fuelled IRT research reactor in Iraq, which originally operated at two MW(th) but was later upgraded to five MW(th), was involved in the Iraqi weapons program in several ways:

- a fuel element from the reactor was used for a plutonium extraction experiment
- on three other occasions, fuel elements were fabricated from undeclared uranium dioxide in an Experimental Reactor Fuel Fabrication Laboratory, they were secretly irradiated in the IRT reactor and then chemically processed in an unsafeguarded Radiochemical Laboratory containing hot cells
- the reactor was used to make polonium-210 for neutron initiator research, using bismuth targets
- the reactor was used to produce small quantities of plutonium-238, which could have been used for

neutron initiator research instead of short lived polonium-210
- the reactor could potentially have produced sufficient plutonium for one weapon over a period of several years using fuel and/or a uranium blanket and/or uranium targets; this risk, albeit small, was increased by the fact that IAEA inspections of the reactor were infrequent because of the low risk status of the reactor
- HEU fuel for the IRT reactor, and the 0.5 MW(th) Tammuz-II reactor, was diverted during Iraq's 1990-1991 'crash program'
- 'dirty' radiation bombs were produced and three test bombs were exploded in Iraq in 1987, using materials irradiated in the IRT and/or Tammuz II research reactors (the more powerful IRT reactor was the better suited of the two reactors for the purpose).

The US military clearly believed the IRT and Tammuz II reactors represented a proliferation threat and bombed them in 1991.

Low power reactors may also be useful for research or training in support of a weapons program, or for the production of radioisotopes such as polonium-210 or tritium.

Tied in with plutonium production is the question of reprocessing facilities for plutonium extraction. The longstanding view that reprocessing is a legitimate part of the nuclear fuel cycle - and perhaps a necessary step in the longer term - has condoned the establishment of reprocessing facilities in a number of countries and has assisted in a number of covert weapons programs. A number of countries - including India, Israel, Iraq, and Pakistan - have sought help from advanced supplier states to develop reprocessing/separation facilities. North Korea apparently succeeded in constructing a reprocessing facility with little or no foreign assistance. A number of other countries have expended some effort towards the establishment of reprocessing facilities, and in some cases, such as Taiwan, South Korea, Argentina and Brazil, these efforts are likely to have been motivated, at least in part, by ambitions to develop nuclear weapons.

Because of the high level of radioactivity involved, extraction of fissile material from spent fuel or other highly irradiated material (e.g. targets) is demanding, time-consuming, and potentially extremely dangerous. It requires heavily shielded facilities and generates large quantities of nuclear and chemical wastes. Nevertheless, this scenario is of particular concern at about 15 research reactors under IAEA safeguards due to large accumulated quantities of spent fuel, and it is of importance at more than 10 others. (Zuccaro-Labellarte and Fagerholm, 1996.)

The use of hot cells - shielded radiochemical laboratories with remote handling equipment for examining and processing radioactive materials - is closely related to research reactors. Hot cells can, if adequately equipped, be used to extract plutonium from spent fuel. Hot cells are "dual-use" facilities: they can be used for radioisotope processing, and other non-military purposes, as well as for plutonium separation. There are several examples of research reactors and hot cells being used in connection with covert nuclear weapons programs, e.g. Iraq, Romania, Yugoslavia, and North Korea (where hot cells may have been used for plutonium separation in addition to the larger Radiochemical Laboratory).

Spent research reactor fuel stockpiles have grown steadily in many countries, and efforts to address this problem in the coming decades could involve the spread of reprocessing technology. For example, the Australian government considered developing a small reprocessing plant in the mid to late 1990s to treat research reactor spent fuel.

Examples of the research reactor / plutonium connection include:

Algeria. The secret construction of a high power research reactor in Algeria, and adjacent hot cells, may have reflected military interests.
Argentina. The construction of several research reactors laid the foundation for Argentina's nuclear power program and for its covert weapons program. One military option considered from the late 1960s to the early 1980s included a plan to build a large research reactor which could produce unsafeguarded plutonium.
Brazil. Brazil's covert weapons program appeared to be at an end with its 1997 signing of the NPT. Yet in the same year, it was reported that plans to construct a small reactor for plutonium production had been reactivated. Once this project came to public light, the Brazilian army announced that it would be discontinued.
Canada. The NRX and NRU research reactors were used in the 1940s and 1950s to produce plutonium for the nuclear weapons programs of the US and the UK.
India. Two high power research reactors have produced most or all of the fissile material for India's nuclear weapons.
Iraq. Military strikes on Iraqi research reactors by Israel, Iran and the US limited Iraq's potential to produce plutonium and consequently uranium enrichment was the primary focus of the covert weapons program. Nevertheless, hot cells were used to separate small quantities of plutonium from research reactor fuel elements. In addition, diversion of HEU research reactor fuel has been a significant proliferation risk and was central to Iraq's "crash program" in 1990-91.
Israel. The high power Dimona research reactor is central to Israel's nuclear weapons program.
North Korea. A five MW(e) "experimental power reactor", together with a "Radiochemical Laboratory" capable of plutonium separation, were key facilities in North Korea's covert weapons program.
Pakistan. A 50 MW(th) research reactor has been under construction for many years at Khushab, and is reported to have begun operation. It is producing (or will produce) Pakistan's first supply of unsafeguarded plutonium.
Romania. Little is known about the covert nuclear weapons program carried out under the Ceausescu regime, but it is known that hot cells were used for experimental plutonium extraction from irradiated research reactor fuel. Supply of HEU research reactor fuel from the US was terminated because of the risk of diversion.
Taiwan. A high power research reactor, and a small reprocessing facility, were implicated in Taiwan's covert weapons program.
Yugoslavia. Several research reactors were constructed in support of Yugoslavia's covert weapons program. Hot cells were used for small scale plutonium separation from research reactor spent fuel. Plans to construct an "experimental research reactor" for plutonium production formed part of the covert weapons program in the 1970s. Yugoslavia's possession of plutonium in fresh, slightly irradiated and spent fuel remains a proliferation concern.

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HIGHLY ENRICHED URANIUM

Weapon grade uranium contains over 90% of the isotope uranium-235. Uranium enriched to lower levels has been used in nuclear weapons, e.g. the Hiroshima bomb used 80-85% enriched uranium, and one of South Africa's weapons used 80% enriched uranium. Uranium with a substantially lower percentage of uranium-235 could be used for weapons but with significant costs such as increased weight and decreased yield.

There are several ways in which civil nuclear programs can facilitate the acquisition or production of HEU for weapons:
- diversion of fresh HEU research reactor fuel
- extraction of HEU from spent research reactor fuel
- construction of enrichment facilities justified (partly or entirely) with reference to a research reactor program, with clandestine production of HEU for weapons.

Commonly available chemical engineering equipment is adequate for extraction of fissile material from fresh or slightly irradiated fuel. The IAEA pays particular attention to facilities where the fresh fuel contains HEU or plutonium, for which no further transmutation or enrichment would be needed for use in a nuclear weapon. As at 1996, about 20 research reactors under IAEA safeguards were using such direct use fissile material in amounts of one or more Significant Quantity. (Zuccaro-Labellarte and Fagerholm, 1996.)

Extracting HEU from spent fuel is far more complicated and hazardous than extracting it from fresh or slightly irradiated fuel. HEU from spent fuel might need further enrichment to make it suitable for weapons, and contaminants might reduce the usefulness of HEU extracted from spent fuel.

Nevertheless, spent fuel can be a source of large quantities of HEU. For example, as at 1993 the inventory of spent fuel at the Lucas Heights research reactor plant in Sydney contained over five Significant Quantities of uranium-235, with fresh fuel stocks usually maintained at less than one Significant Quantity. (Australian Safeguards Office, 1993.)

An estimated 20 tonnes of HEU exists at 345 operational and shut-down civilian research facilities in 58 countries, sometimes in sufficient quantities for weapons production (Bunn, Holdren and Wier, 2002).

Uranium enrichment techniques are complex and extremely costly. Moreover, in addition to enrichment facilities, producing enriched uranium may necessitate a uranium supply, facilities for milling and conversion, and a method to convert enriched uranium hexafluoride or enriched uranium tetrachloride into solid uranium oxide or metal.

Despite the complexity and costs, Argentina, Brazil, Iraq, South Africa, and Pakistan all selected uranium enrichment as their primary route for acquiring fissile material (Albright, 1993).

Generally, a nuclear power program provides a far more plausible rationale for the pursuit of a domestic enrichment capability than a research reactor program. Nevertheless, there are several cases where the construction, or continued operation, of enrichment facilities has been justified with reference to research reactor fuel requirements. Argentina is the most striking example. Moreover, the justifications given for enrichment technology cannot easily be separated. In Australia, for example, uranium enrichment research was pursued for numerous reasons from the mid 1960s to the mid 1980s - "value adding" to uranium exports, ensuring an ongoing supply of HEU fuel for the HIFAR research reactor, the possibility of indigenous production of LEU fuel if nuclear power was introduced, and last but not least, at least some of those involved in the development of enrichment technology in the 1960s and 1970s (such as AAEC Chair Philip Baxter) supported it because of the military potential.

HEU is discussed further in Appendix 3, which deals with the Reduced Enrichment for Research and Test Reactors program.

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CASE STUDIES: RESEARCH REACTORS & NUCLEAR WEAPONS PROGRAMS

These case studies, arranged alphabetically, cover Algeria, Argentina, Australia, India, Iraq, Israel, North

Korea, Pakistan, Romania, Taiwan, and Yugoslavia.

Other countries could also be used to illustrate various links between research reactor programs and weapons proliferation, including Brazil, Iran, Libya, Norway, South Africa, South Korea, Sweden, and Syria. In addition, the declared nuclear weapons states have used research reactors in support of their weapons programs in various ways.

ALGERIA

In early 1991, US intelligence agencies discovered that Algeria was secretly building a large research reactor, known as Es Salam, about 150 kilometres south of Algiers. This raised suspicions since the reactor appeared to be unusually large in relation to Algeria's rudimentary nuclear research program, and it was not subject to IAEA safeguards. The Algerian regime said the reactor was being supplied by China and it had a power rating of 10-15 MW(th). A reactor of that size, using LEU fuel, might produce a few kilograms of weapon grade plutonium annually. In addition, roughly 1.5 kilograms of plutonium could be produced annually by irradiating natural uranium targets in the reactor. The reactor first went critical in February 1992 and was commissioned in December 1993. In January 1992, Algeria agreed to place the Es Salam reactor under IAEA safeguards, and inspections began the same month. The Algerian regime nominated several peaceful purposes for the reactor including medical research.

A second construction phase was completed by mid 1996, with the completion of a Chinese-supplied hot cell facility and an underground tunnel connecting the reactor to the hot cells. Underground waste storage tanks, and a building containing six liquid storage tanks, were also built in the mid 1990s. A large building near the reactor appears to be unused, has no announced function, and was possibly built to house a small reprocessing plant.

In May 1997, work began on a third construction phase including a radiopharmaceutical production facility and other auxiliary facilities. It was stated that the radiopharmaceutical production facility would allow production of cobalt-60 even though cobalt-60 can be purchased cheaply from many suppliers. The hot cells, or the radiopharmaceutical production facility, might be used to extract plutonium from irradiated fuel or targets.

A one MW(th) reactor was supplied to Algeria by Argentina in the 1980s, located about 20 kilometres east of Algiers. The reactor itself was of little significance in terms of weapons proliferation (partly because of its limited capacity, partly because the reactor was subject to a site-specific safeguards agreement with the IAEA) but it was a stepping stone for more dangerous facilities. All the more so because, as the Argentinian nuclear agency Invap notes on its website <www.invap.com.ar>, the project involved "genuine transfer of technology", with over 50 Algerian professionals and technicians, and a number of Algerian firms, involved in the project.

Further discussions were held with a view to Argentina supplying Algeria with another reactor and hot cells, but these discussions did not progress. Argentina did however supply a fuel-fabrication plant, located in Draria, which could potentially be used to produce targets for plutonium production although it is subject to IAEA safeguards.

In 1995, Algeria formally acceded to the NPT. IAEA inspections discovered that about three kilograms of enriched uranium, several litres of heavy water, and several pellets of natural uranium supplied by China had not been declared to the IAEA. The IAEA does not have the authority to inspect all facilities at the nuclear site south of Algiers, and some questions remain unresolved. Many of these questions could be resolved if Algeria agrees to additional inspections under the IAEA's Additional Model Protocol. Considerable quantities of plutonium could be produced without breaching NPT commitments.

Despite the information available about Algeria's nuclear program, it remains unclear whether a nuclear weapons program was underway in the 1980s and 1990s, or whether there are currently plans to produce and separate plutonium for nuclear weapons.

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ARGENTINA

A civil/military nuclear program was pursued by Argentina from the 1950s. After a military junta seized power in 1976, and motivated in part by Brazil's 1975 deal with West Germany to obtain extensive nuclear fuel cycle facilities, Argentina's nuclear program expanded and the military objective became more pronounced. Argentina rejected IAEA inspections of most of its nuclear facilities, and at the time refused to sign the Treaty for the Prohibition of Nuclear Weapons in Latin America and the Caribbean (the Treaty of Tlatelolco) or the NPT.

The first Argentine research reactor was manufactured and assembled in Argentina using US plans. Several more research reactors were constructed, some with little or no foreign assistance. By the late 1960s, Argentina had developed the infrastructure to support a nuclear power plant, and in 1968 it purchased a 320 MW(e) power reactor from the West German firm Siemens.

One military option considered from the late 1960s to the early 1980s included a plan to build a 70 MW(th) research reactor which could produce unsafeguarded plutonium. Another option was diversion of plutonium from safeguarded power reactors.

In the late 1960s, Argentina, possibly with assistance from an Italian firm, built a laboratory scale reprocessing facility at Ezeiza. This facility was closed in 1973 after intermittent operation and the extraction of less than one kilogram of plutonium. In 1978, the Argentine nuclear agency CNEA began construction of a second reprocessing facility at Ezeiza that had a design capacity of 10-20 kilograms of plutonium per year. The stated intention was to reprocess spent fuel from power reactors and to use plutonium in the same reactors or in breeder reactors which were (ostensibly) under consideration. Due to economic constraints, and political pressure from the US, construction on the second Ezeiza reprocessing plant was halted in 1990.

Argentina announced in 1983 that a gaseous diffusion uranium enrichment plant had been under construction since 1978 - although Argentina's nuclear power reactors did not require enriched uranium fuel - and that the plant had already produced a small amount of enriched uranium. Argentina claimed that the enrichment plant was built to service research reactors. An official involved in building the plant said that Argentina had thrown off Western intelligence agencies by encouraging them to look for a nonexistent plutonium production reactor. The enrichment plant is capable of producing up to 500 kilograms per year of 20% enriched uranium or about 10 kilograms per year of 80% enriched uranium. However it is believed that the plant produced only small amounts of LEU and no weapon grade uranium. Before building the enrichment plant, Argentina had been supplied with enriched uranium by China and the Soviet Union.

Argentina has supplied nuclear equipment to several countries suspected of pursuing covert nuclear weapons programs. A report from the Carnegie Endowment for International Peace stated (Jones et al., 1998): "The restoration of democratic governance in 1983 did little to change the liberal export policy of the Argentine military, especially as it pertained to North Africa. In 1985, Argentina and Algeria concluded an agreement under which Argentina exported a one MW(th) research reactor that went critical in 1989 - Algeria was not a NPT member and had no safeguards agreement at the time. Under a second agreement, discussed in 1990 but never concluded, Argentina would have sent an isotopic production reactor and hot cell facility to Algeria."

Extensive nuclear cooperation between Argentina and Libya is believed to have taken place. Argentina was also closely involved in the development of Iran's nuclear industry in the 1980s and 1990s. Other recipients of nuclear exports from Argentina include Brazil, Egypt, India, Peru and Romania. In the early to mid 1990s, as military influence over the nuclear industry waned, export controls were tightened.

From the late 1980s, Argentina and Brazil allowed joint inspections of each other's nuclear facilities, and this agreement was formalised in 1991. In the mid 1990s, Argentina and Brazil joined the Treaty of Tlatelolco, the Nuclear Suppliers Group, and the NPT.

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AUSTRALIA

During the 1950s and 1960s, the Australian government made several efforts to obtain nuclear weapons from the US or the UK. Nothing eventuated from the negotiations although the UK was reasonably supportive of the idea at times.

From the mid 1960s to the early 1970s, there was greater interest in the domestic manufacture of nuclear weapons. The government never took a decision to systematically pursue a nuclear weapons program, but it repeatedly took steps to lessen the lead time for weapons production by pursuing civil nuclear projects. Consideration was also given to delivery systems - for example the 1963 contract to buy F-111s bombers from the US was partly motivated by the capacity to modify them to carry nuclear weapons.

The Australian Atomic Energy Commission's (AAEC) major research project from the mid 1950s to mid 1960s concerned the potential use of beryllium (or beryllium compounds) as a moderator in civil reactors. The AAEC's first reactor, the High Flux Australian Reactor (HIFAR), was one of the instruments used for this research. Historian Wayne Reynolds (2000, p.27) suggests that the beryllium research may also have been connected to British interest in thermonuclear weapons.

In 1962, the federal Cabinet approved an increase in the staff of the AAEC from 950 to 1050 because, in the words of the Minister of National Development William Spooner, "a body of nuclear scientists and engineer skilled in nuclear energy represents a positive asset which would be available at any time if the government decided to develop a nuclear defence potential." (Reynolds, 2000, p.194.)

Despite the glut in the uranium market overseas, the Minister for National Development announced in 1967 that uranium companies would henceforth have to keep half of their known reserves for Australian use, and he acknowledged in public that this decision was taken because of a desire to have a domestic uranium source in case it was needed for nuclear weapons.

The intention to leave open the nuclear weapons option was evident in the government's approach to the NPT from 1969-71. Prime Minister John Gorton was determined not to sign the NPT, and he had some powerful allies such as Philip Baxter, Chair of the AAEC. The Minister for National Development admitted that a sticking point was a desire not to close off the weapons option. When the Government eventually signed (but did not ratify) the NPT in 1971, it was influenced by an assurance from the Department of External Affairs that it was possible for a signatory to develop nuclear technology to the brink of making nuclear weapons without contravening the NPT.

In the late 1960s, the AAEC set up a Plowshare Committee to investigate the potential uses of peaceful nuclear explosives in civil engineering projects. Plans to use peaceful nuclear explosives were never realised, partly because of the implications for the Partial Test Ban Treaty (to which Australia was a signatory), and the Plowshare Committee was disbanded in the early 1970s.

In 1969, Australia signed a secret nuclear cooperation agreement with France. The Sydney Morning Herald (June 18, 1969) reported that the agreement covered cooperation in the field of fast breeder power reactors (which produce more plutonium than they consume). The AAEC had begun preliminary research into building a plutonium separation plant by 1969, although this was never pursued.

A split table critical facility - built in 1972 at Lucas Heights but conceived in the late 1960s - was connected to the interest in fast breeder reactors and was possibly connected to the interest in weapons production. The facility was supplied by France. It proved to be difficult to secure supplies of enriched uranium or plutonium for experiments using the critical facility, which was widely regarded as a "white elephant" and was later dismantled.

In 1968, government officials and AAEC scientists studied and reported on the costs of a nuclear weapons program. They outlined two possible programs: a power reactor program capable of producing enough weapon grade plutonium for 30 fission weapons annually; and a uranium enrichment program capable of producing enough uranium-235 for the initiators of at least 10 thermonuclear weapons per year.

In 1969, federal Cabinet approved a plan to build a power reactor at Jervis Bay on the south coast of New South Wales. There is a wealth of evidence - some of it contained in Cabinet documents - revealing that the Jervis Bay project was motivated, in part, by a desire to bring Australia closer to a weapons capability. After Gorton was replaced as leader of the Liberal Party by William McMahon in 1971, the Jervis Bay project was reassessed and deferred. The Labor government, elected in 1972, did nothing to revive the Jervis Bay project, and Australia ratified the NPT in 1973.

Even before the cancellation of the Jervis Bay project, Baxter was making efforts to promote an Australian uranium enrichment plant, building on a small enrichment research program begun in secret at the AAEC in 1965. Baxter's interest in the plant was largely military, as revealed by his written notes calculating how much HEU - and how many HEU weapons - could potentially be produced with an expanded enrichment program. Early, experimental work would of course have to be expanded to achieve Baxter's aim, and the process modified, but these were not insurmountable obstacles. As Tony Wood (2000), former head of the AAEC's Division of Reactors and Engineering, noted: "Although the Australian research team contained only a small number of centrifuge units, it is not a secret that one particular arrangement of a large number of centrifuge units could be capable of producing enriched uranium suitable to make a bomb of the Hiroshima type."

Dr. Clarence Hardy (1996, p.31), a senior scientist at the AAEC (and from 1987 its successor the Australian Nuclear Science and Technology Organisation - ANSTO) from 1971-1991, has noted that the enrichment project was given the code name "The Whistle Project" and was carried out initially in the basement of Building 21. Former AAEC scientist Keith Alder (1996, p.30) noted that the enrichment project was kept secret "because of the possible uses of such technology to produce weapons-grade enriched uranium". The project was not publicly revealed until a passing mention was made of it in the AAEC's 1967-68 Annual Report.

A feasibility study into a joint Australian/French enrichment program was nearing completion in 1972 but collaboration with the French on nuclear matters was not supported by the incoming Labor government.

Since the early 1970s, there has been little high level support for the pursuit of a domestic nuclear weapons capability. However, there have been indications of a degree of ongoing support for the view that nuclear weapons should not be ruled out of defence policy altogether and that Australia should be able to build nuclear weapons as quickly as any neighbour that looks like doing so. For example, this current of thought was evident in a leaked 1984 defence document called The Strategic Basis of Australian Defence Policy.

Bill Hayden, then the Foreign Minister, attempted to persuade Prime Minister Bob Hawke in 1984 that Australia should develop a "pre-nuclear weapons capability" which would involve an upgrade of Australia's modest nuclear infrastructure. Hayden's views found little or no support. Moreover the AAEC's uranium enrichment research, by then the major project at Lucas Heights, and pursued in the post-Baxter period with the aim of "value adding" to Australia's uranium exports, was terminated by government directive in the mid 1980s.

Several reasons can be given for the declining interest in nuclear weapons acquisition or production from the early 1970s onwards. Arguably, the development of the military alliance between the US and Australia is the key reason. Australia effectively became a nuclear weapons state "by proxy", relying on the US nuclear umbrella.

A new reactor and the 'national interest'

A new 14-20 MW(th) research reactor is planned for Australia, to replace the only operating reactor, HIFAR, at the Lucas Heights site operated by ANSTO.

The Department of Foreign Affairs and the Australian Safeguards Office (1998) state that the operation of a research reactor "first and foremost" serves "national interest requirements". However there is probably little or no residual interest in the direct production of weapons. The proposed new reactor will be LEU fuelled and is unlikely to be capable of producing substantial quantities of plutonium.

At the most general level, the federal government argues that the expertise and experience derived from the operation of a new reactor will facilitate Australia's contribution to international efforts to prevent nuclear weapons proliferation. In many countries it is argued that research reactors pose little or no risk in relation to weapons proliferation, but Australia appears to be treading new ground in asserting that a reactor will benefit non-proliferation initiatives. It is an argument which is difficult to reconcile with the international experience since World War II, which shows that research reactors are a recurring weapons proliferation problem.

At a more concrete level, the "national interest" issues include maintaining Australia's place on the Board of Governors of the IAEA, and maintaining a base of nuclear expertise to monitor and assess nuclear developments overseas.

The government claims that operating a nuclear research reactor is necessary to consolidate Australia's position on the Board of Governors of the IAEA. That claim is open for debate, and in any case the IAEA position raises numerous problems, not least the active role played by the IAEA in the promotion of dual-use nuclear technologies. Moreover, to maintain Australia's position on the IAEA Board of Governors, Australia is expected to promote dual-use technologies (such as research reactors) and the products of dual-use technologies (such as reactor produced radioisotopes).

Another of the government's "national interest" objectives is to consolidate the military alliance with the US. The link between a reactor, ANSTO and the US alliance has not been publicly discussed with any clarity or depth by successive governments or by government agencies such as ANSTO and the Australian Safeguards and Non-proliferation Office. In addition to vague and somewhat cryptic comments on the matter, specific issues have been raised, such as the claim that Australia needs an independent base of nuclear expertise to determine and ensure "appropriate arrangements for nuclear ship visits as part of our alliance obligations". (Department of Foreign Affairs and the Australian Safeguards and Non-proliferation

Office, 1998.)

The key issues in relation to the link between a reactor, ANSTO and the US alliance have been neatly summarised by Jean McSorley (1998): "Is it that Australia is determined to keep its regional seat on the IAEA because it is part of the 'deal' that Australia plays a leading role in the (Asia Pacific) region's nuclear industry and, in lieu of having nuclear weapons, continues to be covered by the US nuclear umbrella? Taking part in 'overseeing' the activities of other nuclear programmes must meet an objective of the wider security alliance by playing an intelligence-gathering role - a role which the US probably finds it very useful for Australia to play. The pay-back for this is through its defence agreements with the US, that Australia gets to be a nuclear weapons state by proxy."

Efforts to improve the NPT/IAEA safeguards system since the debacle of Iraq have focussed largely on diplomatic/political issues (e.g. expanded inspection rights), on technologies (such as environmental sampling and video surveillance) which do not require reactor experience or expertise, and on the provision of adequate funding for safeguards programs. Australia's contribution in these fields is not dependent on the operation of a reactor.

In some respects the operation of a research reactor weakens Australia's hand. For example, a new reactor will involve the expenditure of funds which would more profitably (in terms of non-proliferation goals) be spent on technical projects (such as video surveillance and environmental sampling) and diplomatic/political initiatives. Moreover, the Australian government would be better placed to enunciate a more sober and less compromised view on the benefits and costs (including the proliferation risks) of research reactors if not for the domestic political imperative to stress the benefits and downplay the costs.

Another opportunity cost associated with the operation of a reactor, and in particular the plan to spend several hundred million dollars on a new reactor, is the lost opportunity to take a leading role (in the region if not the world) in the development of non-reactor technologies (such as particle accelerators) for medical, scientific and industrial applications. The development and promotion of non-reactor technologies would itself represent a useful, if modest, non-proliferation initiative.

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INDIA

India's nuclear research and power programs laid the foundation for its 1974 nuclear test explosion. The test explosion used plutonium produced in the 40 MW(th) research reactor known as Cirus (Canada-India-Reactor-United-States), which was supplied by Canada (construction began in 1955, first criticality was achieved in 1960). The US supplied heavy water for the reactor. The conditions imposed by Canada and the US - that the reactor and heavy water be used only for peaceful purposes - were circumvented with the assertion that the test related to India's interest in "peaceful" nuclear explosives for civil engineering projects.

The 100 MW(th) Dhruva research reactor, which became fully operational in 1988, is also believed to have been used to produce plutonium for weapons. Dhruva, like Cirus, is a heavy water moderated and natural uranium fuelled reactor. The Cirus and Dhruva reactors are estimated to be capable of producing about 25-35 kilograms of plutonium annually. India probably has enough plutonium for 60-100 nuclear weapons, most of it believed to be in separated form.

India has a number of unsafeguarded power reactors. These are thought to have supplied only a small fraction of the plutonium for India's weapons program to date, with the majority produced by the Cirus and Dhruva research reactors. However, at least as much plutonium is contained in the spent fuel of unsafeguarded power reactors as has been produced by Cirus and Dhruva.

The Cirus and Dhruva reactors may also have been used for tritium production. (Tritium may also have been extracted from irradiated heavy water moderator in power reactors.)

Other research reactors - in particular the 19 MW(th) Purnima reactor - were used to conduct research crucial to the development of a weapons capability.

India's stated interest in using plutonium for power production, and the development of facilities such as a fast breeder test reactor and a mixed uranium-plutonium oxide (MOX) fuel fabrication plant, have provided further civil cover for India's military plutonium program. The ostensibly civil plutonium program has also been used to justify the development of reprocessing facilities.

India is reported to have used Cirus, Dhruva and one other reactor to produce kilogram quantities of fissile uranium-233 by irradiating thorium. Uranium-233 production will be increased significantly if India proceeds with the development of power reactors using thorium-233 fuel.

India has only a limited capacity to enrich uranium.

India has not a signatory to the NPT or the Comprehensive Test Ban Treaty.

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IRAQ

A civil research reactor program, plus plans to develop nuclear power, facilitated a covert weapons development program in Iraq from the early 1970s to the early 1990s which employed thousands of people spread across numerous sites.

Iraq signed the NPT in 1968 and ratified it in 1969. NPT accession was a plus for the covert weapons program because it greatly facilitated technology transfer while continued violations of legally binding NPT obligations went undetected.

Major research programs were undertaken into electromagnetic isotope separation and gas centrifuge enrichment techniques, and other enrichment methods were also investigated - chemical enrichment, gaseous diffusion, and laser isotope separation.

The enrichment projects variously relied on indigenous development of technology, deals with foreign contractors prepared to circumvent export controls, and the acquisition of freely available information and materials. If not for the 1991 Gulf War and events thereafter, Iraq may have been able to produce sufficient HEU for its first weapon in the mid 1990s.

Since so much of the enrichment work was covert, there was little or no effort or need to justify the enrichment work with reference to enriched uranium fuelled research reactors. Nevertheless, the operation of those reactors may have been used on occasions to justify requests to potential suppliers, or by suppliers to justify their actions.

In 1980, Iraq announced that IAEA inspections would be temporarily suspended because of the Iran-Iraq war, and 26 pounds (about 12 kilograms) of HEU were removed from the core of the low power Tammuz II research reactor and stored in an underground canal.

In 1981, an Israeli strike on the Al Tuwaitha site destroyed the 40-70 MW(th) French-supplied Osirak reactor (a.k.a. Tammuz-1), which was shortly to begin operation. Plutonium production is likely to have been a motive for the purchase of the reactor. This was one of several attempts to bomb nuclear facilities involving Iraq:
- in 1971, when a small research reactor was awaiting shipment from France to Iraq, its core was sabotaged in a warehouse and the person supposed to certify its quality was murdered in a Paris hotel
- Iran bombed the Al Tuwaitha nuclear complex in September 1980 but inflicted little or no damage
- Iraq bombed Iran's Bushehr nuclear plant (which included two partly-built power reactors) at least six times between March 1984 and November 1987
- the US bombed two small, safeguarded nuclear reactors (the 5 MW(th) IRT-5000 Soviet-built pool-type reactor, and a French-supplied 0.5 MW(th) critical facility called Tammuz-II), and other nuclear sites such

as uranium hexafluoride conversion and centrifuge enrichment pilot facilities, in Iraq in 1991
- Iraq launched Scud missiles at the Israeli Dimona plant in 1991.

On several occasions, covert attempts to produce and separate small quantities of plutonium in IAEA safeguarded facilities took place at Tuwaitha. One exercise involved extracting plutonium from a fuel element removed from the IRT-5000 reactor. On three other occasions, fuel elements were fabricated from undeclared uranium dioxide in an Experimental Reactor Fuel Fabrication Laboratory, they were secretly irradiated in the IRT-5000 reactor and then chemically processed in an unsafeguarded Radiochemical Laboratory containing hot cells. Only tiny quantities of plutonium were separated. The plutonium separation capacity of the hot cells was probably too small to be of use in the weapons program except on an experimental basis.

In 1984, a project was established with the objective of designing and building a 40 MW(th) natural uranium fuelled, heavy water moderated and cooled reactor modelled on the Canadian NRX reactor. By that time, there was no longer any hope that France would rebuild the Tamuz-1 reactor destroyed by the Israeli air force in 1981. The reactor project appears not to have progressed beyond theoretical studies; the emphasis was on uranium enrichment. Related projects - also undeclared - concerned reprocessing and the production of plutonium metal, but only small quantities of separated plutonium and plutonium metal were produced.

Although the IRT reactor's power level was low - five MW(th) - it could have produced sufficient plutonium for one weapon over a period of several years in the fuel and/or a uranium blanket and/or targets. This risk, albeit small, was amplified by the fact that IAEA inspections of the reactor were infrequent because of the low risk status of the reactor. The IAEA (1997, p.53) states that the IRT reactor was of "very limited usefulness as a plutonium production reactor" but made a "useful" contribution to the nuclear weapons research and development program.

The IRT-5000 reactor was used to make polonium-210 for neutron initiator research, using bismuth targets. It was also used to produce small quantities of plutonium-238, which could have been used for neutron initiator research instead of short lived polonium-210.

Iraq developed a capability to produce small quantities of lithium-6, which, when subjected to neutron irradiation, yields tritium. This suggests an interest in developing "boosted" fission weapons and/or a longer term interest in hydrogen weapons.

'Dirty' radiation bombs were produced and three test bombs were exploded in Iraq in 1987. The bombs used materials (such as zirconium) irradiated in the Tammuz II and/or IRT reactors. (Atomic Energy Agency (Iraq), 1987.) The results were not promising and the project was discontinued (Broad, 2001).

After Iraq's invasion of Kuwait in 1990, a crash program was initiated with the aim of diverting approximately 36 kilograms of IAEA safeguarded unirradiated and irradiated HEU from the IRT-5000 and Tammuz II research reactors. The program called for chemical processing to extract HEU, construction of a 50-machine gas centrifuge cascade to further enrich some of the HEU, and conversion of the HEU chemical compounds to metal buttons suitable for a weapon. The crash program had not advanced to any great degree by January 1991, when the Gulf War began, but some progress had been made such as the installation of a chemical solvent plant in hot cells at Tuwaitha. The program may have continued after the Gulf War until such time as it became clear that research reactor fuel was to be removed from Iraq - the first shipment took place in November 1991.

While Iraq's nuclear research program provided much cover for the weapons program, stated interest in developing nuclear power was also significant. According to Khidhir Hamza (1998), a senior nuclear scientist involved in Iraq's weapons program: "Acquiring nuclear technology within the IAEA safeguards system was the first step in establishing the infrastructure necessary to develop nuclear weapons. In 1973, we decided to acquire a 40-megawatt research reactor, a fuel manufacturing plant, and nuclear fuel reprocessing facilities, all under cover of acquiring the expertise needed to eventually build and operate nuclear power plants and produce and recycle nuclear fuel. Our hidden agenda was to clandestinely develop the expertise and infrastructure needed to produce weapon-grade plutonium. ... Under cover of safeguarded civil nuclear programs, Iraq managed to purchase the basic components of plutonium production, with full training included, despite the risk that the technology could be replicated or misused."

Professed interest in developing fusion technology was also useful, as discussed by Hamza (1998): "Iraq took full advantage of the IAEA's recommendation in the mid 1980s to start a plasma physics program for "peaceful" fusion research. We thought that buying a plasma focus device ... would provide an excellent cover for buying and learning about fast electronics technology, which could be used to trigger atomic bombs."

Prescient warnings were voiced in 1981 following Israel's attack on the Osirak reactor. On June 13, 1981, US Rep. Edward Markey (D-Mass.) called the IAEA "an international charade ... riddled with loopholes" and said it was "possible for a country which is under IAEA inspections to take all the necessary steps to build a bomb and escape detection. In fact, the IAEA gave a convenient cover to the Iraqi bomb program". (Quoted in Nucleonics Week, June 18, 1981, p.4). Sigvard Eklund, then IAEA Director General, defended the IAEA somewhat clumsily, stating that, "You can't be accused of murder because you have acquired a gun." (Nucleonics Week, June 25, 1981, p.3.)

IAEA safeguards inspector Roger Richter resigned in 1981, having written to the US State Department the year before stating: 'The most disturbing implication of the Iraqi nuclear program is that the NPT agreement has had the effect of assisting Iraq in acquiring the nuclear technology and nuclear material for its program by absolving the cooperating nations of their moral responsibility by shifting it to the IAEA. These cooperating nations have thwarted concerted international criticism of their actions by pointing to Iraq's signing of NPT, while turning away from the numerous, obvious and compelling evidence which leads to the conclusion that Iraq is embarked on a nuclear weapons program." (Quoted in MacLachlan and Ryan (1991); see also Nucleonics Week, June 25, 1981, p.3.)

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ISRAEL

The Israeli nuclear weapons program was launched in 1956, in the wake of the Suez crisis. The natural uranium fuelled IRR-2 (Dimona) research reactor, supplied by France, is central to the program. Estimates of the power of the IRR-2 reactor range from 40-150 MW(th). The reactor has been used to produce plutonium, the fissile material in most or all of Israel's estimated 100-200 nuclear weapons. Israel is not a signatory to the NPT but signed the Comprehensive Test Ban Treaty in 1996.

The IRR-2 reactor may also have been used to produce tritium.

France also supplied information on the design and manufacture of nuclear weapons, and assisted in the construction of other facilities at the Dimona site including a reprocessing plant.

Israel has made some progress in the development of laser enrichment technology, but plutonium from the Dimona reactor is still the primary source of fissile material for the weapons program.

There are no power reactors in Israel, although the pretense of a nuclear power program may have facilitated the transfer of materials and expertise from France and other countries.

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NORTH KOREA

North Korea's covert weapons development program proceeded under cover of a planned nuclear power program in the 1980s following the acquisition of research reactors in the 1960s and 1970s.

The majority of North Korea's nuclear facilities are at the Yongbyon Nuclear Research Centre, including a five MW(e) (20-30 MW(th)) "experimental power reactor", a large-scale reprocessing plant for plutonium extraction (only partially completed but functional nonetheless), a number of hot cells that can be used for plutonium extraction, a high explosive testing facility, a fuel fabrication plant, a partially completed 50 MW(e) power reactor, a four MW(th) research reactor and a critical assembly. A 200 MW(e) power reactor was partially built at Taechon.

The three reactors were based on the gas graphite moderated, natural uranium fuelled Magnox design - suitable for co-generation of electricity and plutonium. North Korea appears to have pursued these reactor construction projects with only minimal foreign assistance. Similarly, the partially completed reprocessing plant was built with minimal foreign assistance.

North Korea became a party to the NPT in 1985 but did not allow IAEA inspections until 1992. North Korea admitted in 1992 that it had separated about 100 grams of plutonium in March 1990 and that the plutonium came from failed fuel elements from the five MW(e) reactor. The Yongbyon reprocessing plant (which North Korea calls a Radiochemical Laboratory) and possibly also hot cells were used to separate the plutonium.

Inspections and tests by the IAEA, coupled with North Korea's refusal to comply with some requests from the IAEA, raised suspicions that larger volumes of plutonium, possibly enough for 1-2 weapons, have been separated from spent fuel which may have been unloaded from the five MW(e) experimental power reactor in 1989.

The reactor's inventory of spent fuel was unloaded in May 1994, and that spent fuel contains between 17-33 kilograms of (unseparated) plutonium; it has been stabilised and "canned" by the US and is stored under IAEA safeguards in North Korea.

If completed, the 50 MW(e) reactor would be capable of producing much larger volumes of plutonium than the five MW(e) reactor, as would the 200 MW(e) reactor. It is believed the plan was to use the 50 MW(e) reactor primarily as a plutonium factory, and to use the 200 MW(e) reactor primarily for electricity generation and as a back-up for plutonium production.

Following a protracted international controversy, North Korea and the US signed an "Agreed Framework" in October 1994. Among other things the Agreement provided for a verified freeze of the activities at the North Korean facilities believed to have supported the weapons program, the eventual dismantling of those facilities, removal of some material including spent fuel from the five MW(e) reactor, and the construction of two power reactors of a design less suitable for producing weapon grade plutonium than the Magnox design of the three power reactors built or partially built by North Korea. Progress on implementation of the Agreed Framework has been stop-start and it remains a long way from fruition as at 2002.

North Korea has a four MW(th) IRT research reactor as well as a critical assembly and a sub-critical assembly, all supplied by the Soviet Union and all under IAEA safeguards. These research reactors do not seem to have been involved in the weapons program to any significant degree. However it is likely that a small quantity of plutonium was separated in the 1970s, before IAEA safeguards were applied, using the IRT research reactor to produce the plutonium and hot cells (also supplied by the Soviet Union) to separate it.

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PAKISTAN

Pakistan launched a covert nuclear weapons program in the aftermath of the Indo-Pakistani war in the early 1970s. Pakistan was able to accumulate the equipment and expertise to produce weapons with the help of weak Western export controls, the cover of civil nuclear power and research programs, and Chinese support. Pakistan is not a signatory to the NPT or the Comprehensive Test Ban Treaty.

While there have been ongoing efforts to develop plutonium production and separation capabilities, the emphasis of the covert weapons program has been on uranium enrichment. In 1978 France broke off an agreement to supply an enrichment plant, but a large scale gas centrifuge enrichment plant was built at Kahuta nonetheless, using stolen European designs, some Libyan funding and some equipment bought by "dummy" companies from European and North American suppliers. The Kahuta enrichment plant is believed to be the source of all or nearly all of Pakistan's fissile material for the weapons program. Pakistan probably has sufficient HEU for 30-52 nuclear warheads (although there is considerable uncertainty in those estimates).

In the 1970s, Pakistan planned to use power reactor/s to produce plutonium for weapons. However in 1978 France pulled out of an agreement to build a reprocessing plant because of the weapons implications. Efforts to complete the plant without further French assistance struck insurmountable obstacles.

A 50 MW(th) natural uranium fuelled, heavy water moderated research reactor has been under construction for many years at Khushab, with the potential to provide Pakistan with its first supply of unsafeguarded spent fuel. Former Prime Minister Bhutto described the Khushab reactor as "a small reactor for experimental purposes". The reactor has been built with Chinese assistance. There have been several reports in recent years that construction of the Khushab reactor has been completed, and also reports that it has begun operation. The Khushab reactor is estimated to be capable of generating 10-15 kg of weapon grade plutonium annually, enough for 1-2 weapons. The availability of unsafeguarded plutonium would permit Pakistan to develop smaller and lighter nuclear warheads which would facilitate Pakistan's development of warheads for ballistic missiles.

In addition, Pakistan might use the Khushab reactor to irradiate lithium-6 targets to produce tritium to use as a neutron initiator in weapons, for boosted fission weapons or, in the longer term, for hydrogen weapons.

In tandem with the construction of the Khushab reactor, Pakistan's capacity to reprocess spent fuel has steadily expanded, with the largest reprocessing plant located at Chasma. Weapon grade plutonium from the Khushab reactor's spent fuel could be extracted at the nearby Chasma reprocessing plant, if that facility becomes operational, or at the New Labs reprocessing facility in Rawalpindi - both unsafeguarded facilities.

Pakistan's power reactors, which are subject to IAEA safeguards, have had little or no direct connection to the weapons program in terms of plutonium production. However one possible source of heavy water for the Khushab reactor is diversion of heavy water supplied by China for the Kanupp power reactor.

Two research reactors, both significantly less powerful than the Khushab reactor, are under IAEA safeguards. One of these reactors, PARR-I, may have been used clandestinely to produce tritium for the weapons program.

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ROMANIA

Romania ratified the NPT in 1970, but a covert nuclear weapons program was pursued under the Ceausescu regime. Little information is publicly available on the weapons program, but it is known that hot cells were used for experimental plutonium extraction from irradiated research reactor fuel.

After Ceausescu's overthrow in 1989, the weapons program was terminated. Supply of HEU for a 14 MW(th) Triga research reactor was terminated by the US in the late 1980s because of the possibility of HEU diversion; the reactor was shut down from 1989-91 and it was converted to enable the use of LEU fuel.

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TAIWAN

Taiwan launched a nuclear weapons program in the 1960s in response to China's weapons program. A plan for a dedicated weapons program - involving the purchase of a heavy water reactor, a heavy water production plant, and a plutonium separation plant - was rejected in favour of a nuclear program more easily portrayed as having peaceful intentions.

Taiwan signed the NPT in 1968. Work on the Canadian supplied 40 MW(th) natural uranium fuelled, heavy water moderated Taiwan Research Reactor (TRR) began in 1969 and the reactor began operating in 1973. The reactor had the capacity to produce more than 10 kilograms of weapon grade plutonium annually, although actual production was less. The limited scope of the research program associated with the reactor caused international consternation.

In 1969, work also began on a plant to produce natural uranium fuel, a reprocessing facility, and a plutonium chemistry laboratory.

A small reprocessing facility was built adjacent to the TRR reactor. Its declared purpose was to process spent fuel from a zero power reactor that used US supplied HEU fuel and/or the TRR reactor. Another, still smaller reprocessing laboratory was built, which could have been used to research various aspects of reprocessing irradiated material. A small number of spent fuel elements may have been reprocessed, but the amount of plutonium involved was far short of the amount required for a nuclear weapon. Taiwan also tried to purchase a large reprocessing plant but was unsuccessful.

The so-called "Plutonium Fuel Chemistry Laboratory" was used for experimental scale production of metallic plutonium using 1075 grams of separated plutonium that Taiwan had received from the US in 1974. Plutonium in metallic form is rarely if ever used in civil nuclear programs.

In the late 1970s, under pressure from the US, most of the reprocessing facilities were dismantled, and 863 grams of US supplied plutonium were returned to the US.

In 1987 Taiwan began secretly building hot cell facilities in violation of safeguards commitments. In early 1988, after a visit to the facility, US officials pressured Taiwan to dismantle it. Evidently no plutonium had been separated. The TRR reactor was also shut down in the late 1980s, again under pressure from the US. Spent fuel elements from the TRR reactor, containing about 78 kilograms of plutonium, had been shipped to the US by 1997, although some spent fuel from the TRR reactor remained in Taiwan.

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YUGOSLAVIA

Covert weapons programs were pursued on two occasions in Yugoslavia, under cover of nuclear research and nuclear power programs, though on neither occasion did the program reach an advanced state.

The first covert program was conceived in the late 1940s and was pursued until the mid 1960s. Yugoslavia pursued a program of nuclear research consistent with the ambition to become a nuclear weapons state. The cornerstones of the early program were three nuclear research centers established from 1948-50. The research/weapons program included the construction of a zero power critical assembly (built to acquire reactor expertise if Yugoslavia were to pursue the plutonium path) and a Soviet designed and built 6.5 MW(th) heavy water moderated "RA" research reactor capable of using uranium fuel enriched to 80% uranium-235. Heavy water and HEU for the reactors were provided by the Soviet Union. As a step towards independence from foreign suppliers, the Vinca Laboratory developed the capability to fabricate uranium oxide fuel elements for the RA research reactor.

Reprocessing technology was also pursued. Intensive negotiations between Yugoslavia and Norway took place with a view to the supply of a reprocessing plant, ostensibly to reprocess spent fuel from the RA research reactor. The engineering blueprints for the plant were delivered to Yugoslavia in 1962 but the reprocessing plant had not been built by the time Yugoslav political leaders lost interest in the weapons program in the mid 1960s.

Nevertheless, a laboratory scale reprocessing facility, equipped with four hot cells, was in operation by 1966. Small scale separation of plutonium from spent fuel from the RA reactor took place.

Although the emphasis was on developing the means to produce and separate plutonium, uranium enrichment was also studied using a small cyclotron to research electromagnetic isotope separation techniques, and a calutron. (A civil particle accelerator research program also provided useful cover for Iraq's pursuit of electromagnetic enrichment technology.)

A second push towards a nuclear weapons capability began in 1974, partly in response to the Indian test explosion of that year. The covert weapons program was pursued despite Yugoslavia's formal accession to the NPT in 1970. It was decided to pursue weapons under the cover of an expanded nuclear power program. (At the time, one power plant was under construction in Slovenia.)

Two parallel nuclear programs were pursued - one military, one civil. The program dedicated to weapons included projects into the nuclear explosive components for weapons including a neutron source to initiate the chain reaction, computer modelling, and exploratory studies of aspects of underground nuclear testing.

The "peaceful" program involved 11 projects. Its major activities were clearly related to the weapons program, including the design of a plutonium production reactor (referred to as an experimental research reactor), uranium metal production, development of an expanded plutonium reprocessing capability, design and construction of a zero power fast breeder reactor, and heavy water production.

The nuclear weapons program was effectively terminated in 1987 for reasons which remain unclear. The extent of the progress made between 1974-87 also remains unclear.

Yugoslavia retains highly skilled physicists, chemists, and engineers who obtained extensive experience in a broad range of nuclear activities during the first and second phases of the covert weapons program.

Although Yugoslavia continues to receive IAEA inspectors, the country's status as a NPT signatory remains unclear. Belgrade resists formally acceding to the NPT, arguing that it should be accepted as the sole successor to the Socialist Republic of Yugoslavia.

The largest of the research reactors has been shut down, and the plutonium reprocessing program appears to be inactive.

In addition to its experienced work force, Yugoslavia's greatest weapons asset today is its 48.2 kilograms of fresh 80% enriched HEU fuel and 10 kilograms of lightly irradiated HEU. In addition, reprocessing of spent fuel could yield more than five kilograms of plutonium. All of this material is under IAEA safeguards.

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APPENDIX:
REDUCED ENRICHMENT FOR RESEARCH AND TEST REACTOR PROGRAM

Diverting HEU, by extracting it from fresh or spent fuel, is a proliferation issue of particular relevance to research reactors because they account for the bulk of the civil trade in HEU. The level of uranium enrichment for power reactor fuel rarely exceeds 3-5% uranium-235, which is far short of the level of enrichment necessary for weapons production. Many research reactors, by contrast, have been fuelled with HEU. HEU became readily available and was used not only for high power research reactors but also for low power reactors for which LEU would have been sufficient if not ideal (Muranaka, 1983).

The US has been the main supplier of HEU and exported over 25 tonnes to 51 countries for use in research reactors (Takats et al., 1993). A number of countries known to have covertly pursued weapons programs have been supplied with HEU research reactor fuel, including Yugoslavia, South Korea, Israel, Romania, Taiwan, Libya and South Africa. Supply of HEU research reactor fuel and/or HEU isotope production targets from the US to various countries has been suspended a number of times over the years because of concerns about the potential for diversion or theft (e.g. South Africa, Mexico, Israel, Romania).

Proliferation concerns gave rise to the Reduced Enrichment for Research and Test Reactors (RERTR) program, a US initiative which emerged from the 1978 US Nuclear Non-Proliferation Act. (Details of the program can be found on the website of the Argonne National Lab, <www.td.anl.gov/Programs/RERTR/RERTR.html>. See also Travelli, 2000.)

The RERTR program aims to eliminate the use of HEU for research reactor fuel and also for isotope production targets. Further impetus for the program came in 1992 with the Schumer Amendment which bans US supply of HEU to countries refusing to cooperate with the RERTR program.

The primary aim of the RERTR program is the conversion of HEU fuelled reactors to enable the use of LEU fuels - immediate conversion to LEU fuel if possible, development of suitable LEU fuel types for other research reactors, and preventing new HEU fuelled reactors being built.

The US is central to the RERTR program because it has been the main supplier of HEU fuels, and actual or threatened refusal to supply HEU fuel has given the US considerable leverage. In addition to restricting the supply of HEU, the US administration has used another strategy to encourage compliance with the RERTR program - making take-back of US origin spent fuel conditional on compliance with the program. The spent fuel take-back program has has been an important incentive and will remain so. Spent fuel take-back amounting to up to 20 tonnes from a total of 41 countries is planned and some shipments have already taken place (including some from Australia). In addition to encouraging compliance with the RERTR program, US spent fuel take-back has acted as a disincentive for the horizontal proliferation of reprocessing technology. Australia is one of a number of countries involved in the US spent fuel take-back program which is not considered to be at risk of pursuing nuclear weapons programs; these countries have been primarily interested in ridding themselves of spent fuel for which no alternative arrangements exist.

An issue arising from the spent fuel take-back program is whether the US will reprocess spent fuel, use alternative treatment technologies, or use long term storage. Reprocessing would involve separation of weapons usable materials from spent fuel. For aluminum clad spent fuel assemblies containing HEU, the most likely option is the further development and use of a "melt and dilute" process which would involve melting the spent fuel in an oven, with conversion of the melted material into LEU ingots.

As at 1998, of 65 reactors with a power level of at least one MW(th) and using US supplied HEU fuel, 54 had been converted to LEU fuel, were in the process of conversion, or were not considered suitable for conversion because of plans to permanently shut down the reactor. Suitable LEU fuel types were not available for eight of the 65 reactors, and the operators of three reactors were refusing to convert their reactor. (Kuperman and Leventhal, 1998.)

The numbers of research reactor operators unable or unwilling to convert their reactors has been reduced still further since 1998. Of the above-mentioned 65 reactors, only two operators continued to reject the conversion norm outright as at late 1999 - Germany's FRJ-2 reactor (which has sufficient HEU fuel on hand for the next few years, after which it may be shut down) and France's Orphee reactor. In addition, a small number of research reactors still cannot use existing LEU fuel types, so further development of high density LEU fuel types remains important to the RERTR program.

Successes of the RERTR program in recent years include the following:
- operators of several reactors (e.g. Netherlands Petten reactor, Belgian BR-2 reactor, South African Safari I reactor) have announced their willingness to cooperate with the RERTR program despite earlier reluctance
- France and China have announced that their next-generation, high power research reactors will use LEU fuel
- the US government cancelled its planned Advanced Neutron Source, which was to have used HEU fuel
- several types of LEU research reactor fuels have been developed, thus facilitating conversion, and further research is ongoing to develop LEU fuels for reactors which have not yet been converted (and for new reactors)
- the US has conducted feasibility studies on converting government research reactors, to complement the ongoing conversion of US university research reactors
- US university reactors are being converted even if they are low power (less than one MW(th)) and even if they have enough HEU in their cores for their remaining lifespan. This is in recognition of the low security at university reactors.

Apart from the US, the only other significant supplier of HEU research reactor fuel (and HEU fuelled research reactors) has been the USSR/Russia, which has supplied large quantities of HEU to western and eastern European countries. This supply has been greatly reduced, and possibly stopped altogether, but containment of this source of HEU remains an issue of concern.

Russia has cooperated with the RERTR program to enable conversion of reactors located in Russia and of reactors supplied by the Soviet Union to a number of countries including Yugoslavia, North Korea, Libya, Poland and Vietnam. A related concern is the status of HEU in ex-Soviet states and HEU exported by the Soviet Union / Russia. Russian progress on meeting RERTR objectives has been considerably slower than US progress, with lack of funding being one major constraint. Unresolved issues with respect to Russia and other ex-Soviet states include: lack of data about research reactor numbers, types, operational status, etc.;

the status and future handling of fresh HEU fuel stockpiles; and physical protection and the potential for theft or illicit sale of HEU. (On the RERTR program in Russia, see Arkhangelsky, 2000; on the risks associated with HEU stockpiles in ex-Soviet States, see Bunn, 2000, esp. pp.78-79.)

A threat to the RERTR programs is the FRM-II research reactor under construction in Germany with plans to use HEU fuel. The reactor was scheduled for start-up in 2001 but controversy surrounding the project has forced delays and operation before 2003 is unlikely. In October 2001, the German state of Bavaria and the federal Ministry of Environment agreed to convert the FRM-II reactor from to "medium" enriched fuel (50% uranium-235) before the end of 2010. According to the World Information Service on Energy (2001), the reactor will use up to 360 kilograms of 93% enriched fuel by the end of 2010 (less if start-up continues to be delayed). The possibility of modifications to the reactor which would allow the use of LEU (<20% uranium-235) fuel continues to be debated. With no prospect of HEU supplies from the US, a possible source of HEU for the FRM-II reactor is the European Supply Agency (an institute of Euratom, the European Commission's agency for dealing with nuclear materials). The Technical University of Munich, owner of the reactor, has already acquired a small amount of US origin HEU within Europe and is seeking additional supplies. Russia is also considered a possible supplier of HEU by FRM-II project managers. The reactor is the first research reactor in the Western world (with power of at least one MW(th)) built to use HEU fuel since the establishment of the RERTR program. (Libya and China are the only other countries in which construction of HEU fuelled reactors has begun since the RERTR program began in 1978.)

Beyond the specific threats to the RERTR program are broader issues concerning HEU:
- stockpiles of HEU from military programs, in the US and Russia in particular, amount to hundreds of tonnes, a vastly greater quantity than has been used in research reactors. The blending down of some of this material, and the disposal of some of it as waste, is expected to take some decades and even if those plans proceed without significant disruption, significant HEU stockpiles and large numbers of HEU weapons will remain (similar points apply to plutonium stockpiles and plutonium weapons).
- HEU production for research reactors has only ever been a marginal business; the commercial enrichment industry producing LEU for power reactors has been unaffected by the RERTR program and enrichment technology could spread with further proliferation risks (the same applies to reprocessing and plutonium).
- it remains possible that countries with a covert military agenda will partly or entirely justify their pursuit of enrichment technology with reference to LEU fuelled reactors.

HEU TARGETS

In addition to conversion from HEU to LEU fuels, efforts have been made to eliminate the use of HEU targets for isotope production. Here the issue of greatest concern is the use of HEU targets to produce targets to produce fission-product radioisotopes - in particular molybdenum-99, which decays to form technetium-99m, the most commonly used isotope for diagnostic nuclear medicine.

About six countries use HEU targets for isotope production, employing a total of approximately 50 kilograms of HEU targets annually, typically enriched to 93% uranium-235. Australia is alone in using LEU targets to produce molybdenum-99 (although it should be noted that significant safety and waste management problems are associated with ANSTO's molybdenum-99 production and processing operations). Several new molybdenum-99 producers may emerge in the coming years and there is some concern that the use of HEU targets could become more widespread. (Vandegrift et al., 1999.)

Whether existing and new producers will switch to LEU or non-uranium targets depends in part on progress with research into alternative targets, and on economic and political issues. When compared to HEU, LEU targets result in larger waste streams with higher concentration uranium solutions. Some producers are concerned about the cost implications of the increased waste streams. Cost implications may vary significantly between producers depending on the adjustments required.

According to Kuperman (1999), the major producers of molybdenum-99 - Institut National des Radioelements (IRE) in Belgium, MDS Nordion in Canada, and Mallinckrodt in the Netherlands - are responsible for up to 90% of HEU commerce associated with medical isotopes. These three producers have been reluctant to adopt LEU target technology, partly for fear of putting themselves at a competitive disadvantage vis-a-vis their competitors. Nevertheless, all three producers have shown some willingness to switch to LEU targets in recent years, partly because there is no certainty of ongoing availability of HEU targets from the US or other sources.

According to Kuperman (1999), Belgium's IRE agreed to irradiate and process prototype LEU targets but without making a firm commitment to convert, while Mallinckrodt also expressed an interest in cooperating with the RERTR. In June 1999, the US Nuclear Regulatory Commission approved the export of 130 kilograms of 93.3% enriched HEU to Canada over a five year period for isotope production. Supply is conditional on demonstrated efforts to develop suitable LEU targets for the Canadian reactors; whether this condition is being taken seriously is a matter of some controversy.

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