

The end of KEDO:

Why supplying a nuclear reactor to North Korea would have increased proliferation risks in East Asia

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Construction site of the KEDO light water reactor, Kumho Area, North Korea
(photo: http://www.kedo.org/lwr_construction_images.asp)

The termination of the planned KEDO project to construct two nuclear reactors in North Korea provides an important opportunity to reflect on the real proliferation risks of light water reactors.¹

Greenpeace and the Bush Administration rarely, if ever, agree on anything. But we both opposed supplying North Korea with a Light Water Reactor.² Why? Because a Light Water Reactor is neither a solution to North Korea's energy needs, and nor will it have reduced the risk of proliferation.

The discussion about the North Korean demand for nuclear reactor technology in exchange for abandoning its nuclear weapons program is premised on the misconception that Light Water Reactors are "proliferation resistant". An analysis of the technical aspects of Light Water Reactors, however, reveals that such conventional reactors do indeed present real risks of proliferation, while not solving the energy needs of North Korea.

This briefing has thus been prepared by Greenpeace International with the aim of clarifying false assumptions and statements that downplay the proliferation threat posed by nuclear reactor technology.

While inept negotiation with North Korea to solve the nuclear crisis has only assured that the situation has worsened, it is clear that supplying a nuclear reactor would only increase regional proliferation risks. Thus, Greenpeace has found a point of agreement with the Bush Administration's approach to the problem of a nuclear-armed North Korea – that providing nuclear reactors was solution to the crisis.

In summary:

- A 1,000-Megawatt Light Water Reactor typically produces between 200-250 kilograms of plutonium during each year of operation;
- There is no technical barrier to using so-called "reactor-grade plutonium" to manufacture nuclear weapons;
- Eight kilograms or less of so-called reactor-grade plutonium is sufficient for one nuclear device in the 1-20 kiloton range;
- Light Water Reactors can be operated in such a manner that weapon-grade plutonium can be obtained from spent fuel removed from the reactor after short periods of irradiation; and
- The billions of dollars required for a North Korean nuclear reactor program will not reduce the proliferation risk in the region, but will increase North Korea's access to plutonium, and further increase the region's spent nuclear fuel crisis.

¹ KEDO was terminated at its executive board meeting in November, 2005.

² Light Water Reactors are fuelled by enriched uranium and use of ordinary water, or "light water" as neutron moderator and coolant, and include boiling water reactors (BWRs) and pressurized water reactors (PWRs). Heavy water reactors, such as CANDU reactors, are fueled by natural uranium and use "heavy water," which has high concentrations of naturally occurring deuterium, as a neutron moderator.

Light Water Reactors and enhanced proliferation risk

Throughout the negotiations on North Korea's nuclear program between the Washington and Pyongyang, and in the Six Party Talks context, North Korea has requested to be supplied with a light water reactor (LWR) in exchange for abandoning its current nuclear program. In reporting on the negotiations, Light Water Reactors are commonly described as "more proliferation resistant", a term that is enjoying widespread use in the nuclear industry's aggressive public relations drive. An examination of the facts shows the claim for proliferation resistance to be completely unfounded and reveals that such reactors can be efficient producers of plutonium, an artificial isotope produced in a reactor during the nuclear chain reaction process.

Thus, a reactor in North Korea could expand that country's ability to add to its existing stockpile of weapons-usable materials, while also providing an important avenue for training of nuclear technicians and scientists. This is a lesson that countries aspiring to become nuclear weapons states well know – that the route to "going nuclear" can be accomplished via use of so-called civilian nuclear technologies.

In 1995, the Korean Peninsula Energy Development Organization (KEDO) was formed to carry out the terms of the October 1994 "Agreed Framework" between the United States and North Korea. This agreement allowed for export of an LWR to the north in exchange for terminating its nuclear weapons program. Due to numerous factors related to compliance with the agreement, the KEDO program was suspended and in January 2006 the program at Kumho was halted and workers withdrawn from the site. Thus, earlier efforts to supply an LWR ceased but North Korea has not given up on the dream of obtaining western nuclear power technology.³

A significant source of the confusion over the proliferation risks from LWR-produced plutonium has been perpetrated by Japan as it has pursued its nuclear power program, which includes large scale LWR operation, plutonium-producing "breeder" reactor research and the goal of commercial reprocessing (separation of plutonium from spent nuclear fuel). Senior officials inside the Japanese nuclear establishment are consistently on the record over the last decade denying the utility of reactor-grade plutonium (R-Pu) in the manufacture of nuclear weapons.⁴

³ For more information on the Korean Energy Development Organization (KEDO), see <http://www.kedo.org/>.

⁴ Assertions that reactor-grade plutonium cannot be used for nuclear weapons include: Ambassador Ryuchi Imai - former representative of the Government of Japan to the UN Conference on Disarmament – Ambassador Imai has written that the reactor-grade plutonium shipped in 1992 from France to Japan "is quite unfit to make a bomb.", (Ryukichi Imai, Plutonium, Volume 2, October 1992, p. 18.)

And: "There is no scientific or engineering discussion about design, construction and so forth of fission nuclear weapon that leads any definitive conclusion about plutonium based fission weapons, either with WPU or RPU." ("Can Reactor Grade Plutonium Produce Nuclear Fission Weapons?," May 2001, Council for Nuclear Fuel Cycle, Institute for Energy, Economics Japan)

Such denials are hardly surprising because Japan has 56 light water reactors, one of the world's largest stockpiles of plutonium (5.6 tonnes held domestically and 37.4 tonnes in Europe⁵) and an advanced domestic reprocessing and uranium enrichment program. However, Japan's denial of the weapons potential of reactor-grade plutonium is factually wrong and designed to deflect attention from the proliferation threat posed by Japan's own nuclear program.

The feasibility of using reactor-grade plutonium for nuclear explosives was established decades ago. In 1976, the United States decided that releasing some additional information about nuclear weapons would actually aid in preventing their spread-- the purpose of the Nuclear Nonproliferation Treaty (NPT). A briefing was provided by the U.S. Energy Research and Development Administration (ERDA; now U. S. Department of Energy, DOE) to nations with active nuclear power programs, in order to increase their understanding of the utility of reactor-grade plutonium in the fabrication of nuclear weapons, and to advise that measures be adopted to protect and account for plutonium in spent fuel removed from nuclear power reactors⁶.

In 1977, ERDA declassified the fact that an underground nuclear weapons test had been conducted in 1962 in which weapon-grade plutonium had been replaced with reactor-grade plutonium, with successful results. The U.S. details were communicated directly to governments then pursuing plutonium programs, in particular Japan.⁷

In 1996, in order to address misinformation about its use in nuclear weapons, the DOE again affirmed that the U.S. had conducted a test with weapon-grade plutonium at the Nevada test Site in 1962.⁸

And: Hiroyoshi Kurihara, executive director of PNC, the state nuclear research agency developing fast breeder reactors and reprocessing stated that,

"...many Japanese experts express the opinion that reactor-grade plutonium could not be used for workable nuclear weapons." He speculated it "can be merely a nuclear fireworks, namely it produces glare and a big noise, but would not cause big disastrous effects of nuclear bombs....", and claimed that such a weapon would "fizzle like a firecracker. (Hiroyoshi Kurihara, International Workshop on Nuclear Disarmament and Non-Proliferation: Issues for International Action, March 1992, p. 109. The "fizzle like a firecracker" remark was made in his oral presentation at the workshop, as reported in "Separating myths from reality: awakening from Japan's 'plutonium dream,'" Paul Leventhal, President, Nuclear Control Institute, public forum on high-level nuclear waste and reprocessing nuclear fuel cycle issues research group, Aomori, Japan, April 16, 1996.)

⁵ Figures on Japan's plutonium stockpile at the end of 2004 can be found in the International Atomic Energy Agency's Information Circular 549, 4 November 2005, <http://www.iaea.org/Publications/Documents/Infcircs/2005/infcirc549a1-8.pdf>

⁶ This briefing took place at a meeting of the Atomic Energy Forum/American Nuclear Society, see "Reactor-Grade Plutonium Can be Used to Make Powerful and Reliable Nuclear Weapons: Separated plutonium in the fuel cycle must be protected as if it were nuclear weapons." Richard L. Garwin, Senior Fellow for Science and Technology, Council on Foreign Relations, New York, Draft of August 26, 1998.

⁷ Ibid.

⁸ DOE Factsheet, "Additional Information Concerning Underground Nuclear Weapons Test of Reactor-Grade Plutonium, U.S. Department of Energy, Office of Press Secretary, Washington, D.C., 1996

While the nuclear industry would prefer it not to be so, the plutonium produced in commercial nuclear power reactors is usable to manufacture nuclear weapons. In addition to ERDA, a range of specialists and official bodies have gone on the record clarifying the issue, including the U.S. National Academy of Science and the UK Royal Society (see Appendix 1). Even the International Atomic Energy Agency (IAEA) has declared: "There is no debate on this matter..."⁹ and has classified reactor-grade plutonium as a "direct use material" that "can be used for the manufacture of nuclear explosive devices without transmutation or further enrichment."¹⁰

In sum, there is no debate whatsoever in the U.S. or amongst other informed technical experts that reactor-grade plutonium is indeed weapons-usable. For more information, see Appendix 1.

Technical Feasibility

Almost all plutonium is produced in nuclear reactors, which are usually fuelled with uranium. A mixture of plutonium isotopes – Pu-239, -240, -241 and so on – is gradually produced in the reactor fuel during normal operations, when uranium is bombarded with neutrons during the nuclear chain reaction. This artificially-produced plutonium can be extracted from the spent fuel via reprocessing, whereby the highly radioactive spent fuel is dissolved in nitric acid and the plutonium removed in an expensive and dirty chemical process carried out in a heavily shielded facility. Plutonium-239 is the preferred isotope from which to make nuclear weapons given its inherent characteristics that make it more suitable for use in a nuclear chain reaction (fission), which produces the explosive force of a nuclear weapon.

The quality of plutonium produced in a uranium-fuelled LWR is largely dependent upon the length of time the fuel remains in the reactor – the so-called fuel burn-up. During reactor operation, uranium is converted to plutonium. If the uranium fuel is used only for a short period of time (so-called "low burn-up") the plutonium produced is purer in the preferred Plutonium-239 isotope and contaminated with fewer other radioactive by-products.

Plutonium from military plutonium production reactors, such as the K-Reactor which operated at the DOE's Savannah River Site was produced specifically for use in nuclear weapons and is thus called weapon-grade plutonium. The U.S. standard for weapon-grade plutonium consists of a plutonium mixture which is greater "than about 90% Plutonium-239."¹¹

Plutonium produced in commercial or civil nuclear-power reactors operated for the most economical production of electricity is called reactor-grade plutonium and is generally

⁹ "On the basis of advice provided to it by its Member States and by the Standing Advisory Group on Safeguards Implementation (SAGSI), the Agency considers high burn-up reactor grade' plutonium and in general plutonium of any isotopic composition with the exception of plutonium containing more than 80 percent Pu-238 to be capable of use in a nuclear explosive device. There is no debate on this matter in the Agency's Department of Safeguards." (Letter from Hans Blix, Director-General of the IAEA, to Paul Leventhal, NCI, November 1, 1990 (<http://www.nci.org>))

¹⁰ IAEA Safeguards Glossary, 2001 Edition, section 4.25, page 28, http://www-pub.iaea.org/MTCD/publications/PDF/nvs-3-cd/PDF/NVS3_prn.pdf

¹¹ U.S. Department of Energy, Nuclear Terms Handbook, 1993, page 81

considered a secondary function of reactor operation. In general, reactor-grade plutonium contains up to 60% Plutonium-239 with the rest being made up of Plutonium-240, Plutonium-241, and Plutonium-238. By definition, the Plutonium-240 content is “in the range of 15-25%.”¹² However, the higher levels of impure types of plutonium do not stop it from being used in a nuclear bomb and it can be substituted for weapons-grade plutonium in some weapons applications though with decreased yield.”¹³

Since 1945, the nuclear weapon states have produced weapon-grade plutonium for their nuclear weapons programs through operating dedicated production reactors at low fuel burn-up. However, the U.S. in 1962 as well as the UK in 1956 (and possibly India in 1998) used reactor-grade plutonium in nuclear weapons tests in order to prove the weapons-usability of this commercially produced fissile material. For more information, See Appendix 2.

How much plutonium?

Any light water reactor as currently operated in South Korea, Japan or possibly supplied to North Korea in the future, could yield plutonium for nuclear weapons in two ways. The reactor could be operated at low fuel burn-up, with frequent shut down and refueling, thus maximizing production of high-quality plutonium.

Alternatively, the reactor could be operated principally for electricity production (the stated intention of North Korea), with conventional refueling of one-third of the reactor core with fresh uranium fuel every 18 months, resulting in some fuel being in the reactor for over 3 years. Plutonium produced in this manner would be so-called reactor-grade plutonium. North Korea would likewise have two options for producing plutonium using a LWR:

- In the dedicated production mode, a North Korean 1000-Megawatt reactor would be able to produce between 200-250 kg plutonium operating at low burn-up in one full year of operation. This compares with current production in the range of a few tens of kilograms from its existing research reactor program. The plutonium would be weapons-grade quality – sufficient for about 25-30 nuclear weapons.
- As a by product of electricity generation, and at relatively high burn-up, the discharged spent fuel after 2-3 years operation will yield around 275-350 kilograms of reactor-grade plutonium.– sufficient for up to 45 nuclear weapons, though with perhaps reduced yield.

Even more interesting is the situation at the start of operation. At the end of the first refueling cycle all the fuel will have been irradiated for only one cycle and will be of lower burn-up than after 2-3 years, due to “staggering” of refueling.¹⁴ The first cycle is also normally a bit shorter

¹² Ibid., page 62

¹³ Ibid., page 62

¹⁴ The issue of plutonium production in LWRs was covered extensively last year in a study by Miller and Gillinsky: “A Fresh Examination of the Proliferation Dangers of Light Water Reactors,” Victor Gilinsky, Marvin Miller, Harmon Hubbard, October 22, 2004, The Nonproliferation Policy Education Center, Washington, D.C., <http://www.npec-web.org/Frameset.asp?PageType=Single&PDFFile=Report041022%20LWR&PDFFolder=Reports>

than the later ones so the plutonium is even higher in Plutonium-239 content—about 84 percent Plutonium-239. At the end of the first cycle the 75-tonne core will contain about 330 kilograms of plutonium, or more than 40 weapons' worth. The IAEA has produced a "Conversion Time Table", which highlights the ease with which separated reactor-grade plutonium can be converted to a form that may be used for military purposes. According to the IAEA, the estimated conversion time is in the order of 1 – 3 weeks,¹⁵ which clearly underscores the proliferation risk associated with plutonium produced via a commercial nuclear program.

Technical Capacity to produce weapons

Even though the International Atomic Energy Agency continues to actively promote global nuclear power expansion, including light water reactor operation, its current Director General Mohamed ElBaradei stated in December 2004,

"The fundamental issue is that countries look at know-how as a deterrent. Once you get into areas of deterrence, you get into security and insecurity.....If you have nuclear material, the weapon part is not far away."¹⁶

The degree to which the obstacles to the use of reactor-grade plutonium can be overcome depends on the sophistication of the state or group attempting to produce a nuclear weapon. At the lowest level, a potential proliferating state or non-state actor using designs and technologies such as those used 60 years ago on Nagasaki could build a nuclear weapon from reactor-grade plutonium. Problems caused by the premature fission of reactor-grade plutonium could actually be advantageous to unsophisticated weapons developers in that need for a "neutron generator" to start the fission process could possibly be eliminated. A weapon from reactor-grade plutonium could give an assured, reliable yield of one or a few kilotons, and a probable yield much greater than that.

At the other end of the spectrum, advanced nuclear weapons states such as the U.S. and Russia, using modern designs, could produce weapons from reactor-grade plutonium having

Miller and Hubbard stated, "Consider a mode of operation closer to commercial operation. Because of the staggering of the refueling, at any refueling once the reactor has been operating for a time, one-third of the core (about 25 tons in our example) will have been in the reactor for three cycles, one-third will have been in the reactor for two cycles, and one-third will have been in the reactor for one cycle. The plutonium in the one-cycle fuel would have a much higher content of the most desirable plutonium-239 isotope than the three-cycle fuel—over 80 percent as opposed to about 55 percent. This plutonium is often called "fuel-grade" to distinguish it from the better weapons-grade stuff and the less desirable reactor-grade. At each normal refueling the operator has available 25 tons of uranium containing about 5 kilograms plutonium per ton, or about 125 kilograms of plutonium with about 80 percent plutonium-239, not bad material for bombs. (There is more plutonium per ton than in the earlier example because the irradiation time is longer.) In fact, this characterization understates the usefulness of the one-cycle material for weapons because what really counts is the amount fissile fraction—the sum of plutonium-239 and plutonium-241—which in the case of spent fuel removed after one refueling cycle is nearly 85 percent."

¹⁵ IAEA Safeguards Glossary, 2001 Edition, Table 1, page 19 – "Estimated Material Conversion Times for Finished Pu or U Metal Components," http://www-pub.iaea.org/MTCD/publications/PDF/nvs-3-cd/PDF/NVS3_prn.pdf

¹⁶ Interview with Roula Khalaf, Financial Times, 9 December 2004

reliable explosive yields, weight, and other characteristics generally comparable to those of weapons made from weapons grade plutonium.¹⁷

In order to construct a nuclear weapon, a reprocessing facility is required to separate the plutonium. (North Korea now possesses such a facility but could be required to abandon it under a future deal which might be reached.) However, it cannot be presumed that a country interested in nuclear weapons will be barred from extracting militarily significant amounts of plutonium from spent fuel from its LWRs simply because it lacks a large-scale reprocessing capability. There are two interesting designs for “quick and simple” reprocessing plants for such a purpose, one carried out at Oak Ridge in 1977 and another at the Sandia National Laboratory in 1996.

D.E. Ferguson, a reprocessing expert at the U.S. Department of Energy’s Oak Ridge National Laboratory (ORNL) concluded that such a plant could be in operation four to six months from the start of construction. He thought the first 10 kilograms of plutonium metal (about two bombs’ worth) could be produced about one week after the start of operation. Once in operation, the small plant could process the radioactive fuel rods removed from about one PWR fuel assembly per day.¹⁸ This translates into production of about 5 kilograms of plutonium per day.¹⁹

In 1996, a team organized by the Sandia National Laboratories (SNL) – run by the U.S. Department of Energy with a primary mission is to develop, engineer, and test components of nuclear weapons – evaluated a design for a minimal reprocessing plant, as part of a report that assessed the proliferation resistance of various alternatives for the disposition of stocks of weapons-grade plutonium. In particular, a simplified flow diagram outlining a process to recover plutonium from either LWR fuel or from plutonium-uranium mixed oxide fuel (MOX) was provided, with the steps characterized as representing “...a relatively simple process that might be operated by an adversarial group in makeshift or temporary facilities such as a remotely located warehouse or a small industrial plant.”

This Sandia “Proliferation Vulnerability Red Team Report”²⁰ also estimated that six skilled people would be required and that the preparation lead time for the facility would be about 6 months, with about 8 weeks needed after start-up to produce the first “significant quantity” (SQ) of plutonium. According to the IAEA, the SQ for plutonium is 8 kilograms, this being “the

¹⁷ “Japan, Nuclear Weapons, and Reactor-grade Plutonium,” Marvin Miller Security Studies Program & Department of Nuclear Engineering, Massachusetts Institute of Technology, presented to seminar at Nuclear Control Institute March 27, 2002, <http://www.nci.org/02NCI/04/mm-jpu-paper.htm>

¹⁸ A PWR fuel assembly consists of pellets of uranium fuel inserted into metal 4-meter fuel rods, with the rods arranged and secured in a square bundle. Such bundles, or assemblies, are either in arrays of 14x14 or 17x17 fuel rods on a side, resulting in about 179-264 fuel rods per fuel bundle, with about 121-193 fuel bundles in the reactor core.

¹⁹ Oak Ridge National Laboratory, Division Director of the Chemical Technology Division, 28-page memorandum on a quick and simple reprocessing plant, August 30, 1977

²⁰ Sandia National Laboratories, Proliferation Vulnerability Red Team Report, SAND97-8203, October 1996

approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded.²¹

Safeguards

The IAEA currently does not have complete, real-time camera monitoring of either fresh or spent fuel storage areas in countries such as North Korea (where no IAEA inspectors are at present). The IAEA only reviews camera tapes at sites at which it does have cameras once every 90 days – a period within which materials could be diverted to a nuclear weapon program..

Oddly, the IAEA is now considering expanding the intervals between these inspections (for nations other than Iran) from 90 days to a year as a way to rationalize its meager resources and to entice nations to allow the IAEA more intrusive inspection rights under the so-called “Additional Protocol,” which places some limited additional requirements on countries under inspection by the IAEA.²² The thinking here is that since it would take a nation about a year to construct an enrichment or reprocessing plant, the IAEA can afford to extend the time between inspections. This argument, however, assumes two things: first, that the IAEA can determine in advance which nations do not have covert enrichment and reprocessing plants and, second, that IAEA inspectors could detect covert reprocessing and enrichment plant construction in a timely fashion. Yet, neither assumption is warranted. IAEA safeguards are designed to provide the illusion that nuclear facilities and the material they contain can be used for peaceful purposes without diversion to military use.

Spent fuel volumes – regional context

Any additional spent fuel that would be generated by North Korean Light Water Reactors is dwarfed by the existing and still growing stocks in South Koreaⁱ and Japan. Combined, they produce over 1800 tons of spent fuel each year, discharged to their reactor cooling ponds for interim storage, and in the case of Japan, spent fuel is currently planned to be reprocessed at the massive new Rokkasho-mura reprocessing plant, capable of separating up to 8 tonnes of plutonium per year.²³

South Korean interest in reprocessing dates back to the 1970s, though the U.S. has never allowed reprocessing to take place under the terms of the U.S.-Republic of Korea nuclear cooperation agreement. While options for large-scale reprocessing of spent fuel have been frustrated since then, interest in reprocessing undoubtedly continues. As Japan’s moves

²¹ IAEA Safeguards Glossary, 2001 Edition, Table II (amounts of Significant Quantities) and section 3.14, definition of “significant quantity,” both page 19

²² “Model Protocol Additional to the Agreement(s) between the State(s) and the International Atomic Energy Agency for the Application of Safeguards,” Information Circular 540, September 1997, <http://www.iaea.org/Publications/Documents/Infcircs/1998/infcirc540corrected.pdf>

²³ See Proliferation report: sensitive nuclear technology and plutonium technologies in the Republic of Korea and Japan, international collaboration and the need for a comprehensive fissile material treaty - Shaun Burnie, Greenpeace International. - Paper presented to the International Conference on Proliferation Challenges in North-east Asia: The Korean Peninsula and Japan, National Assembly, Seoul, Republic of Korea, April 28th 2005.)

ahead with the opening of the Rokkasho-mura plant²⁴, the sustainability of blocking South Korean spent fuel reprocessing is definitely to be questioned. South Korea may eventually clamour for a change in the nuclear cooperation agreement with the U.S. in order to allow for reprocessing, much like the deal Japan secured in the late 1980s.

South Korean stocks of spent fuel, projected to be over 18,000 tons by 2020, would yield tens of tonnes of plutonium if reprocessed. In addition, supplying North Korea with a light water reactor would only further add to the burden of spent fuel and plutonium stocks in North East Asia. See Appendix 3.

Conclusions

The end of the KEDO project provides an important opportunity to reflect on the common misperception that a light water reactor will be less of a proliferation threat than North Korea's existing research reactors. In fact, operation of an LWR in North Korea will enhance the country's capacity for plutonium production and therefore could increase the number of warheads it can possibly produce. Supplying a nuclear reactor to North Korea or any other country contains the inherent risk that the reactor and associated technology will be used to obtain nuclear weapons material. This was true at the dawn of the nuclear age and remains true today. The example of North Korea is important to consider when the IAEA and global nuclear industry are advocating large-scale expansion of nuclear power to combat global climate change.

The end of KEDO should determine that a future solution to the situation with North Korea should preclude nuclear power, and rather should include new ways to address the energy needs of that country. In addition to modernization of existing antiquated generating stations and the distribution grid, a thorough analysis must be made of the energy situation, with an eye towards application of renewable energy technologies, conservation and efficiency on both a large and small scale.

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²⁴ On March 31st 2006, formal testing of spent fuel for the first time was initiated at the Rokkasho plant. In the first 17 months, 430 tons of spent fuel is to be reprocessed.

Appendix 1 – Weapons-Usability of Reactor-Grade Plutonium

“A militarily useful “low technology” nuclear explosive using reactor grade plutonium could be designed to produce nuclear yield in the kiloton range.” **Robert W. Selden, Los Alamos National Laboratory, November 1976.**

“Although plutonium of any isotopic composition is inherently difficult to handle, only a marginal increase in difficulty is involved in handling reactor-grade plutonium in the fabrication of nuclear weapons.” **U.S. Department of State “Guidance on the Use of Reactor Grade Plutonium for Weapons Fabrication,” issued to U.S. Embassies worldwide, November 1976.**

“The difficulties of developing an effective design of the most straightforward type are not appreciably greater with reactor-grade plutonium than those that have to be met for the use of weapons-grade plutonium.” **J. Carson Mark, former Director, Theoretical Division at Los Alamos National Laboratory, 1993.**

“In short, it would be quite possible for a potential proliferator to make a nuclear explosive from reactor-grade plutonium using a simple design that would be assured of having a yield in the range of one to a few kilotons, and using an advanced design. Theft of separated plutonium, whether weapons-grade or reactor-grade, would pose a grave security risk.” **Committee on International Security and Arms Control of the U.S. National Academy of Sciences, 1994.**

“We are aware that a number of well-qualified scientists in countries that have not developed nuclear weapons question the weapons-usability of reactor-grade plutonium. While recognizing that explosives have been produced from this material, many believe that this is a feat that can be accomplished only by an advanced nuclear-weapon state such as the United States. This is not the case. Any nation or group capable of making a nuclear explosive from weapons-grade plutonium must be considered capable of making one from reactor-grade plutonium.” **American Nuclear Society, “Protection and Management of Plutonium,” August 1995.**

“While reactor-grade plutonium has a slightly larger critical mass than weapon-grade plutonium, this would not be a major impediment for design of either a crude or sophisticated nuclear weapon. ... In short, reactor-grade plutonium is weapons-usable, whether by unsophisticated proliferators or by advanced nuclear weapons states. Theft of separated plutonium, whether weapons-grade or reactor-grade, would pose a grave security risk.” **U.S. Department of Energy, “Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives,” January 1997.**

“The nations signing the NPT, and the nuclear power industry worldwide, would be delighted if plutonium produced by nuclear reactors that operate to generate electrical energy were not usable to make nuclear weapons, but the facts are otherwise.” **Dr. Richard Garwin, Council on Foreign Relations, August 1998.**

"The existence of plutonium stocks, in whatever form, is of concern on two counts: radiotoxicity and proliferation risk. Whilst not underestimating radiotoxicity risks, the chance that the stocks of plutonium might, at some stage, be accessed for illicit weapons production is of extreme concern. The current stockpiling policy should not be maintained without careful study of the alternatives." **Royal Society of Britain, "Management of Separated Plutonium," February 1998.**

The U.S. Nuclear Regulatory Commission, which licenses nuclear facilities in the U.S., has stated that:

"...So far as reactor-grade plutonium is concerned, the fact is that it is possible to use this material for nuclear warheads at all levels of technical sophistication. In other words, countries less advanced than the major industrial powers but, nevertheless, possessing nuclear power programs can make very respectable weapons. ...Of course, when reactor-grade plutonium is used there may be a penalty in performance that is considerable or insignificant, depending upon the weapon design. But whatever we might once have thought, we now know that even simple designs, albeit with some uncertainties in yield, can serve as effective, highly powerful weapons - reliably in the kiloton range." **Victor Gilinsky, "Plutonium, Proliferation and Policy" Commissioner, U.S., Nuclear Regulatory Commission, MIT, November 1, 1976, p.10-11.**

Appendix 2 – Technical Aspects of Weapons Using Plutonium

The critical mass of a fissile material, such as plutonium, is the minimum mass necessary to sustain a nuclear chain reaction, or fission.. If the mass is more than required for a critical reaction (that is, super-critical), the fission chain reaction is sustained for as long as the mass of plutonium remains super-critical.

A nuclear explosion occurs when a mass of plutonium or plutonium oxide (a powder form) that is less than critical is compressed by a symmetrical shock wave to make it super-critical. Such compression reduces the volume of the mass of plutonium, increasing its density. As the critical mass is inversely proportional to the square of the density, increasing the density by compression will reduce the mass required for critical assembly. If the mass of plutonium is held together long enough, enough fission reactions will take place to produce an explosion, which is essentially an uncontrolled chain reaction.

The critical mass of reactor-grade plutonium oxide is about 35 kilogrammes if the mass is spherical, while that of reactor-grade plutonium metal is about 13 kilogrammes. A sphere of plutonium oxide containing enough plutonium for a critical mass would be about 18 centimeters in diameter; a metal sphere containing enough plutonium for a critical mass would be about 12 centimeters in diameter. Such a sphere would be placed in the center of a mass of a conventional high explosive contained in a nuclear weapon, which would be detonated in such a manner as to compress the plutonium to super-criticality.

If the sphere of plutonium metal (or plutonium oxide) is surrounded by a shell of beryllium or uranium, neutrons which escape from the sphere without producing a fission event are

reflected back into the sphere. Such a reflector, therefore, reduces the critical mass by a factor of two or more.

Because the shell of reflecting material is heavy, it also acts as a tamper. When the high explosives are detonated, the shock wave causes the tamper to collapse inwards. Its inertia helps hold together the plutonium during the explosion to prevent the premature disintegration of the fissioning material and thereby to obtain a larger explosion.

Key differences between reactor grade and weapons grade plutonium, as highlighted by Carson Mark in a briefing²⁵ prepared for the Nuclear Control Institute, are, in summary:

The "bare sphere" critical mass for R-Pu is about 13 kg, vs. 10 kg for W-Pu (both alpha-phase metal of density 19.6 g/cc); the larger critical mass for R-Pu means that about 30% more R-Pu metal is needed than W-Pu to build a weapon. The alpha-particle radioactivity of R-Pu contributes 10.5 watts of heat per kg R-Pu, vs. 2.3 W/kg for W-Pu. The greater heat evolution (68 watts for half a bare-sphere critical mass of R-Pu, vs. 11 watts for half a bare-sphere critical mass of W-Pu) means that the thick high-explosive that surrounds the plutonium and any additional metal shells in a simple implosion weapon will overheat if R-Pu is substituted for W-Pu. Mark estimates the amount of aluminum heat conductor that would suffice to cool the R-Pu. So-called In-Flight Insertion devices that were used in early nuclear weapons would allow adequate cooling of the plutonium until it is inserted into the high explosive a few minutes before detonation. The continuing neutron emission from spontaneous fission of Pu-240 contributes 360 neutrons per second per gram of R-Pu, vs. about 66 neutrons per second per gram of W-Pu.

According to Mark, as the fissionable material is being compressed so that it becomes critical, a neutron injected at the worst possible time would cause the earliest model of implosion weapon to have an explosive yield between 1 and 2 kilotons (that is, between 1000 tons and 2000 tons of high explosive such as TNT) rather than the full yield of some 20 kilotons when neutron injection is optimally timed to occur near the time of maximum criticality.

Appendix 3: Cumulative Spent Nuclear Fuel in Korea

Year	PWR		CANDU		TOTAL	
	<i>Annual</i>	<i>Cumul</i>	<i>Annual</i>	<i>Cumul</i>	<i>Annual</i>	<i>Cumul</i>
1997		1,823		1,410		3,233
2000	203	2,376	376	2,256	579	4,632
2005	258	3,518	376	4,136	634	7,654
2010	332	5,067	376	6,016	708	11,083
2015	464	7,177	282	7,708	746	14,885
2020	5+5	9,497	282	9,118	746	18,615

²⁵ J. Carson Mark, "Reactor-Grade Plutonium's Explosive Properties," Nuclear Control Institute, August 1990.

Volumes of spent fuel: The more nuclear power the more spent fuel the more plutonium and thus a greater challenge of what do with spent fuel. By 1997, 3,200 MT of spent nuclear reactor fuel had accumulated in South Korea and it is estimated that by the year 2015 it may increase to 15,000 MT. This would yield between 90 and 130 tons of plutonium – depending upon fuel burn-up. Temporary on-site storage facilities are expected to reach capacity by 2016, if technical improvements are not made in the next ten to fifteen years. It is difficult to accurately assess the impact of emerging realities in Korea and thus hard to determine future strategies for managing spent nuclear fuel and radioactive waste. It seems likely, however, that the "wait and see" approach of the Korean government will continue to prevail for the foreseeable future. To some extent this can be explained by the fact that in Korea spent nuclear fuel is not considered waste, but instead is seen as a precious source of energy, if not a "strategic asset."
