Nuclear terrorism potential: Research reactors vs power reactors?

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Abstract: This paper discusses three questions: 1. Could terrorists or others steal nuclear fuel from research reactors to make either a nuclear weapon of a "dirty bomb," a radiological dispersal device?
2. Could terrorists attack a research reactor with conventional explosives, for example, with a truck loaded with such explosives, in order to disperse radioactivity from the fuel of the reactor to an area down wind of the reactor?
3.How do *power* reactors compare with *research* reactors as targets for terrorist attacks?

The answer to the first two questions is a qualified yes. In the comparison called for in the third question, the low-enriched uranium in power reactors is unsuitable without major reprocessing for making nuclear weapons. However, the highly-enriched uranium burned in many research reactors around the world is suitable for making nuclear weapons if enough of it is available. Both power reactors and research reactors could be targets for terrorists trying to attack a reactor with a truck bomb for the purpose of dispersing radioactive material, or trying to steal such material for the purpose of making a dirty bomb. The variations from reactor to reactor in both attractiveness to terrorists and in protection of facilities are wide.

Introduction.

In public statements about nuclear terrorism, there have been repeated expressions of concern about what terrorist attacks on nuclear power reactors might do. Little has been said about research reactors. However, Siegfried Hecker, once director and now senior fellow at the US Government's Los Alamos National Laboratory, said recently:

> The "Atoms for Peace" program [started by the US in the 1950s] promoted nuclear research reactors to all parts of the globe…[Such] reactors, often fueled with HEU [highly-enriched in uranium 235 usable for making nuclear weapons], were in some cases located in politically unstable, technologically unprepared, and economically disadvantaged countries (currently 43 countries, including Uzbekistan, Ghana, …). [T]he current effort [to convert such research reactors to LEU, low-enriched uranium] is insufficient in light of the concerns raised by the events on 9/11….[1]

President Eisenhower proposed the "Atoms for Peace" program in a speech delivered in 1953. He suggested that the Soviet Union and the US transfer HEU to a new international organization to form an "atomic bank" from which other countries could withdraw HEU for their peaceful nuclear programs.[2] By then, Britain had tested a nuclear weapon, and Belgium, Canada, France, Sweden, Norway, Switzerland and Italy had the beginnings of national nuclear programs (some only for peaceful purposes and some for both peaceful and weapons purposes). The likelihood that Eisenhower's proposed program would cause proliferation of nuclear weapons, not just of peaceful uses, was apparently not well considered by Eisenhower and his top advisers before the speech was given. The possible connection between peaceful uses and weapons came as a surprise to one of those advisers, Secretary of State Dulles, after the speech was made. No nuclear-weapon scientists had been consulted before it was given.[3] Eventually, however, starting with this US initiative, the US, then the Soviet Union, and then France and other countries supplied research reactors and weapon-usable HEU for those reactors to many countries around the world.

Since 1978, the US Government has sought to convert the HEU-fueled reactors it supplied to low-enriched Uranium (LEU) fuel, less than 20 percent enriched in Uranium 235. Such fuel is not useful for making nuclear weapons. Armando Travelli of Argonne National Laboratory, who, as manager of this conversion program, has sought to expedite it, had this to say after September 11:

> In the past, our main concern was that rogue nations or terrorist groups would develop nuclear weapons and that, by threatening to use those weapons, they would secure for themselves political and economic advantages that could drastically alter the world balance of power. … Today we know that if nuclear weapons were to fall in the hands of those who organized the September 11 attacks, there would be no threats and no negotiations… [I]nnocent victims would die in a flash, without warning, killed by people driven by a twisted ideology and devoid of any respect for human life, including their own.[4]

Based on concerns such as these, this paper will consider the following questions seeking to compare potential terrorist threats to research reactors with those to power reactors:

1.Could terrorists or others steal nuclear fuel from research reactors to make either a nuclear weapon or a "dirty bomb," (a radiological dispersal device made up of conventional-explosives attached to radioactive materials in such a way that the explosion will disperse radioactivity over a wide area)?
2. Could terrorists attack a research reactor with conventional explosives, for example with a truck loaded with such explosives, in order to disperse radioactivity from the fuel of the reactor to an area down wind of the reactor?

The answer is a qualified yes -- to both questions. In sum, research reactor HEU can be used to make a nuclear weapon if enough of it is available and can be stolen. Security against terrorists wanting to steal HEU or radioactive material would likely be less for small, university-type research reactors that have smaller amounts of HEU and residual radioactivity than it would be for larger government- or industry-owned research reactors with larger amounts. One such small reactor would not likely have sufficient weapon-usable material in it or on site to make a nuclear weapon.

Fuel hijacked from research reactors could, however, be used to make a radiological dispersal device or dirty bomb. Suicidal truck bombers could also try attacking research reactors, hoping that the explosion of their conventional-explosive bomb could damage vital areas of the research reactor sufficiently to damage fuel elements and result in an uncontrolled release of radioactivity, resulting in dispersal of radioactivity over adjacent downwind areas.

3..How do *power* reactors compare with *research* reactors as targets for terrorist attacks?

The LEU fuel burned in power reactors is unsuitable for making nuclear weapons. Power reactors could hypothetically present attractive targets for terrorist truck bombers because they are likely to have more radioactive fuel in the reactor and the spent fuel pond than research reactors, and the entire fuel load contained in the core is likely to be much more radioactive than that contained in a research reactor. For dirty bomb makers, this fuel could be attractive, if they could remove it from the plant. However, unlike research reactor fuel, power reactor fuel rods are usually strongly attached together in large heavy assemblies, weighing about a ton per assembly and being more than ten feet long. Power reactors are better protected than most research reactors (particularly university ones) by large and heavy containment buildings, by site boundary barriers, by alarm systems triggered by sensors, and by well-trained armed guards. In addition, while the radioactivity of the fuel assemblies from a power reactor is relatively uniform, that from a research reactor can vary considerably from assembly to assembly. Thus some spent fuel elements from research reactors could be more easily stolen and could provide more attractive choices for potential dirty-bomb makers.

These points are explained in the discussion set forth below.

Research reactors vs. power reactors for making nuclear weapons.
According to the International Atomic Energy Agency (IAEA), there are 283 operating and 270 shut down HEU and LEU research reactors in 74 countries.[5] The total of these two figures is higher than the total number of power reactors in operation and closed down around the world. Most reactors of both kinds use fresh fuel elements made of uranium, not plutonium. The LEU in power reactors is too low in its uranium 235 enrichment to be useful directly for making nuclear weapons. But many research reactors burn HEU, which is useful for making nuclear weapons. In fact, almost half the operating research reactors in the world use HEU. According to the US Department of Energy (DOE), there are about 20,000 kg of HEU in operating and shut down civilian research facilities in 58 countries, sometimes in quantities large enough in one facility to make a nuclear weapon.[6]

Since 1978, the US has had a program to convert to LEU the research reactors it supplied to other countries, a program called Reduced Enrichment for Research and Test Reactors (RERTR).[7] Pursuant to it, 20 of the US-supplied HEU research reactors outside the US had been converted from HEU to LEU by March 2002. Except for one new HEU reactor in Germany, no new HEU-fueled research reactors have been built in the Western world since the RERTR program began.[8] But US-supplied HEU-fueled reactors have not yet been converted in countries such as Argentina, Austria, Canada, Germany, France, Greece, Israel, Italy, Jamaica, Japan, Mexico, Portugal, and Romania. Eleven university and other research reactors within the US have been converted. Only two US university research reactors still burn HEU fuel.[9] More US government and industry research reactors still do so.

Other countries including France and the Soviet Union also supplied HEU research reactors. In addition to the research reactors within these two countries, in the United Kingdom and in countries supplied by the US listed above, research reactors with HEU inventories are located in Australia, Chile, China, Czech Republic, Hungary, India, Iran, Kazakhstan, Libya, North Korea, Uzbekistan, Viet Nam and Yugoslavia. [10] Adding the figures for operating research reactors to those that are shut down but may still contain HEU fuel, there remain about as many HEU-fueled research reactors as LEU ones in the world.[11]

Delays in conversion of the HEU-fueled reactors to LEU fuel have resulted for technical and financial reasons. Designing LEU research reactor fuel that can accomplish the tasks that HEU fuel can accomplish has taken years of development that is still going on. There have been recent patent issues over the results of this research which have held up some conversions. The US program has been going for several decades but funding for the program was cut off for several years. The current US program is based on a 1996 DOE policy.[12] A similar Russian conversion program was also held up by funding problems and the need to develop an LEU fuel which would do essentially what the HEU fuels did for research purposes. Only recently, when funding became available from the US, was it possible to conduct research on what LEU fuel could be substituted in the Russian-built reactors.[13] Thus, for many reasons, the conversion programs have not moved forward as fast as post-September 11 concerns suggest they should have.

To make a nuclear weapon from uranium, the weapon's uranium-235 content must be more than 20 per cent, and a higher percentage uranium-235 makes it much easer to build a dependable weapon. This is particularly true for a terrorist group, which may not be well versed in the fine points of designing and manufacturing such weapons. Indeed, the higher the enrichment level of the HEU, the more manageable the weapon will be in weight and size, and the more likely it will be to explode rather than fizzle. Assuming a simple Hiroshima gun-type nuclear weapon without a sophisticated neutron reflector, something over 50 kg of 90 per cent or higher U^{235} HEU may be needed to make one nuclear weapon. More weapon-usable material would be needed if the uranium 235 enrichment levels were lower. On the other hand, if a neutron reflector and very-high enrichment HEU were used, or if an implosion weapon were made, the amount needed for a critical mass might be 15 to 25 kg.[14] According to DOE,

> Several kilograms of Plutonium, or several times that amount of HEU, are enough to make a bomb. With access to sufficient quantities of these materials, most nations and even some sub-national groups would be technically capable of producing a nuclear weapon.[15]

Most research reactors do not contain 15 –25 kg of 90 per cent uranium 235 HEU, though some government and industry reactors do. Combing HEU within a medium-sized government or industry reactor with the inventories of fresh and spent fuel available on site might produce enough. Moreover, if more than one research reactor exists in a country, that country could use the combined HEU content of its reactors to produce one or more weapons in a nuclear breakout situation. Iraq was trying to produce a nuclear weapon out of fresh *and* irradiated HEU fuel rods from one French-supplied research reactor and one Russian-supplied research reactor at the end of the Gulf War.[16]

There were 147 HEU-fueled research reactors operating in the year 2000, some of which had HEU enrichment of 50 to 90 per cent or more.[17] An IAEA estimate for 1997 was that HEU-fueled research reactors still outnumbered LEU-fueled reactors in Africa, the Middle East, Eastern Europe, Russia and in the industrialized countries of the Western Pacific rim, but not in Western Europe.[18]

Research reactor fuel becomes very radioactive if it is irradiated continuously for a long time in a high neutron-flux environment. However, research reactor experiments are often of short duration and the reactor may be shut down between experiments. Some research reactors may also operate at low power. Therefore, spent fuel in a research reactor pool may well include assemblies that are very radioactive, assemblies that are not radioactive at all, and others in between. Even *irradiated* fuel from research reactors may therefore be usable for making nuclear weapons if the enrichment is high enough, as was the case for the Iraqi bomb-making attempt..

Power reactors typically operate more than seventy-five per cent of the time. They are maintained in continuous operation as long as possible because they are needed to supply power, and they are typically not shut down for maintenance or to reload fresh fuel until some of the fuel in the reactor has been burned for so long that its reactivity has significantly decreased. Thus, the spent fuel taken from power reactors is usually highly radioactive, fairly uniform in its radioactivity level, and too dangerous to handle even for terrorists willing to take greater chances with their lives. Close exposure to the fuel for a short period will produce radiation sickness followed by death. On the other hand, research reactor fuel may be highly radioactive in some cases and much less radioactive in others. An educated terrorist with a dose rate meter could tell what used fuel could be handled without major immediate risk.

There was great concern about a research reactor holding at least 50 kilograms of HEU in Vinca, Serbia, during the fighting in the Balkans during the 1990s. In mid-2002, its fuel was finally transported to Russia as the result of cooperation between the new government of that country, and those of Russia and the United States. Research reactors with more than 20 kg of 90 per cent uranium 235 HEU exist in Argentina, Belarus, Belgium, Germany, Italy, Japan, Kazakhstan and Ukraine. The reactors in Belarus and Ukraine were built when those countries were part of the Soviet Union. The research reactor in Belarus has more than 370 kg of HEU, including enough 90 per cent HEU to make several bombs. One reactor in Ukraine contains 75 kg of 90 per cent HEU. Two kg of 90 percent HEU disappeared from a research reactor in the Abkhazia region of the former Soviet republic of Georgia during civil resistance there. HEU of somewhat lower enrichment level, probably stolen from one of the research reactors in Obninsk, Russia , was seized by police in Western Europe when arresting the alleged thieves, and LEU fuel rods were stolen from a research reactor in the Congo.[19]

In sum, HEU from research reactors, particularly the larger ones operated by government and industry, could well be the source of the fissionable material for a terrorist nuclear weapon if the nuclear fuel could be successfully diverted. But the LEU burned in power reactors and, in an increasing number of research reactors, cannot be directly used to make nuclear weapons.

Research reactors vs. power reactors for making "dirty bombs."
Radiological dispersal devices, "dirty bombs," are easier to make than nuclear weapons. One such potential device constructed by Chechens to scare the Russian authorities consisted of a container of radioactive material from medical or industrial sources which was attached to conventional explosives. It was not exploded apparently because its makers wanted to gain Russian attention rather than cause major disruption by dispersing radioactive material. Irradiated research reactor fuel, if available, could have been used for such a weapon, one that would probably not then kill anyone not close enough to be killed by the high explosives. If effective as intended, however, it would disperse radioactive materials over a much wider area than the area in which people could be injured by the explosive force of the bomb. Such dispersal might cause cancers eventually, and, at the time, would likely cause panic well beyond the irradiated area and might require removal of the population from that area until the dispersed radioactive materials were cleaned away. The disruption to regular and business life over a wide area and the economic loss could be great.[20]

Radioactive materials from hospitals and industrial plants rather than research or power reactors could be used for producing dirty bombs. They might be more readily available for potential dirty-bomb makers than radioactive fuel from reactors. However, typical hospital and industrial sources contain only a few grams of radioactive materials, and their dispersal by an explosion would be unlikely to cover a wide area. A knowledgeable radiological-weapon maker who wanted wider dispersal and disruption would have a choice. He or she could attempt to collect many grams of radioactive material from many different hospital and industrial sources, and attach or mix them with conventional explosives in such a way that an explosion would scatter radioactivity over a wide area. Or he or she could attempt to steal irradiated fuel rods from a poorly protected university reactor site, and attach them to the high explosives. Small amounts of radioactive materials from hospital and industrial sources could well be easier to steal, but collecting many sources from many places would likely be necessary. Doing so might well take longer and involve more risks of apprehension than stealing used fuel rods from a poorly-protected, shut-down, university research reactor.
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Building a radiological weapon from either of these types of sources may be within the reach of many terrorists whereas making a nuclear weapon would take much greater information, technical resources and skill. The arrest of an alleged el-Qaeda terrorist

who is reported to have studied how to make radiological weapons suggests the possible threat.[21]

Spent power reactor fuel that has been irradiated for a long time may be so radioactive that it would be too hot to handle even for suicidal terrorists. The same may be true of fuel from many large government or industrial research reactors. If the gamma ray and neutron dosage was high enough, the radiation could affect the central nervous system fairly quickly and make the bomb maker unconscious. But this level of radioactivity typically results from the high burn-up which happens in power reactors and many large government and industry research reactors more often than in small university-type research reactors. Thus, for fashioning dirty bombs intended to frighten and disrupt, reactor fuel from university reactors, or from little-used industry or government research reactors, could be more attractive to terrorists than fuel from power reactors.

With spent fuel from either a power reactor or a research reactor, terrorists would need to know the dose rate of the material to ensure against radiation sickness effects while working with it. Assuming the theft of research reactor fuel that had not been irradiated for too long a time, or that had been out of the reactor long enough for its radioactivity to have cooled significantly – both of which are more likely with small university and some government and industry research reactors than with power reactors -- making radiological weapons out of burned research fuel is the more likely option.

Research reactors vs. power reactors as terrorist attack targets.

The typical power reactor is likely to have much more radioactive spent fuel in cooling ponds, and to contain much more radioactivity within its core than do the typical university research reactors and some less-used large research reactors owned by government and industry. A power reactor would likely be a more attractive target for a suicidal terrorist truck bomber or airplane pilot because the radioactive dispersal possibilities could be large, if the attack was successful in breaking through the reactor's containment building or into the spent fuel pool, or causing sufficient damage to vital areas of the reactor. The dispersal seems far beyond what might be achieved in a successful terrorist attack involving a vehicle crash and explosion at a typical research reactor. On the other hand, from the terrorists' point of view, a university reactor may appear much more vulnerable because its protection barriers against attack are likely to be much lower than those of power reactors or government or industry reactors, and it is more likely to be located within or near a populated area.

Protection barriers for nuclear fuel in research reactors vs. those for power reactor fuel.

Both irradiated and fresh nuclear fuel are likely to be less well protected from terrorist attacks at university research reactors, than at power reactors -- for many reasons:

First, typical research reactor fuel elements are much smaller than those for power reactors. The large size (perhaps ten feet long) and weight of power reactor fuel assemblies (perhaps one ton) mean a crane or other heavy machinery is needed to move an assembly. Taking the fuel assembly apart is not easy. Research reactor fuel elements may be four feet long, and weigh a few tens of pounds. They can be disassembled, and can typically be moved by one person, properly shielded.

Second, university research reactors tend to be located in or near cities, -- in places where there are many people going back and forth. Government and industry research reactors are more likely to be somewhat removed from populations, though some are not. Power reactors tend to be both farther from cities and more likely to be surrounded by fences and open areas, which provide some opportunity to observe potential attackers at a distance.

Third, power reactors are ordinarily in operation except for maintenance or when the fuel needs to be changed. Operating personnel are likely to be present during the day even when the reactor is shut down, and guards are present both day and night. Many university research reactors are shut down and left unused for significant periods with only skeleton staff nearby. Power reactors are typically guarded by professional guards hired and trained for the purpose. That may also be true of government and industry research reactors which are often in operation most of the time. University reactors, with intermittent operation, may rely on the university campus police who are usually present elsewhere. When the research reactor is not in operation, they are not likely to check it often.

Fourth, as we have seen, the irradiated fuel removed from university research reactors could be less radioactive than that discharged from power reactors. Moreover, many research reactors are not used as much as their suppliers or owners originally expected or are operated at a lower power level than originally anticipated. Indeed, many university reactors are no longer operated. If the fuel has been removed, as is the practice in the US, they are not likely to constitute a risk. But, this is not a uniform practice. There is probably a great deal of irradiated research reactor fuel around the world that is stored in or near research reactors, fuel that is not too hot to handle for some terrorists.

Finally, research reactors, particularly those at universities, tend to have less effective security protection than power reactors and their fuel. Inadequate protection may result for several reasons :

- There is no treaty requiring any level of protection for power or research reactors from terrorists. The relevant treaty, the Convention on Physical Protection of Nuclear Material, only provides protection standards to protect nuclear material from being stolen while it is in international transport. A consensus of most of the treaty's parties to amend it to cover material used or stored domestically -- and to prohibit sabotage as well as theft -- was achieved in general terms in May of 2001. However, except for some general principles, no *standards* for domestic protection were specified in this consensus agreement. Such standards exist in the treaty now for international transport and for storage while awaiting international transport. But the parties have been unable to agree to apply those or any other specific standards to regular domestic operations. Without such standards, the amendment has less value because it will not require governments to strengthen their specific regulatory requirements for nuclear security.[22]

- In 1999, the IAEA issued revised recommendations for protecting nuclear material from sabotage. These are in IAEA Information Circular 225, Revision 4. This revision contains general provisions such as: "The objective of the physical protection system should be to prevent or delay access to or control over the nuclear facility or nuclear material through the use of a set of protective measures including physical barriers or other technical means [e.g., security alarms, closed –circuit TV cameras, electronic sensors, finger-print identification devices, etc.] or the use of guards and response forces so that the guards or response forces can respond in time to prevent the successful completion of sabotage." These recommendations then list some detailed recommendations on how to guard against sabotage of *power* reactors. But they contain no such recommendations for *research* reactors. Moreover, unless they are brought into force by the bilateral agreement of the reactor supplier and the recipient country, they remain only general recommendations. Unless national legislation or regulations or bilateral supply agreements require them, research reactor operators may ignore them.
- Information Circular 225, Revision 4 also contains recommendations for protection against theft of nuclear material by terrorists. These apply wherever the nuclear materials are located within a country, including storage at or within research reactors. They say that the level of protection should be based upon what *the country perceives the threat to be*. This is called the "design basis threat." Unlike the US regulations issued for reactors by the Nuclear Regulatory Commission, these recommendations do not specify any minimum threat to guard against.[23] Circular 225 divides nuclear material into categories and specifies the strongest protection recommendations for the most sensitive categories, one of which is HEU of 5 kg or more. Irradiated reactor fuel is not in this category but in the next most strongly protected category. The Circular then sets forth some useful suggestions for protection against "unauthorized removal of nuclear material in use and storage."[24] Again, however, these remain only recommendations except for countries subject to nuclear supply agreements where the supplier country has required adherence to the recommendations, or where the country has otherwise adopted them through national regulations or legislation. In general, supply agreements suggest simply that the recipient country take these recommendations into account.
- The Nuclear Suppliers' Guidelines, negotiated among various nuclear suppliers including the US and Russia, summarize what protection against unauthorized use should be provided by recipients of the suppliers' nuclear reactors and material. The Guidelines specify that HEU and spent fuel rods should be used and stored within a *protected area,* "an area under constant surveillance by guards or electronic devices surrounded by a physical barrier with a limited number of points of entry under appropriate control, or any area with an equivalent level of physical protection." HEU of five kg or more should, in addition, be used and stored within a *highly protected area* inside the outer *protected area* with "access restricted to persons whose trustworthiness has been

determined and which [area] is under surveillance by guards who are in communication with response forces. Specific measures taken in this context should have as their objective the detection and prevention of any assault, unauthorized access or unauthorized removal of material." The Guidelines suggest that these standards "should be" the subject of negotiation between the suppliers and recipients of nuclear reactors and nuclear fuel.[25] Provisions relating to them appear in many supply agreements, but they are not public knowledge or required to be submitted to IAEA inspectors so that the inspectors can check whether the protections have in fact been provided. Moreover, they are not applicable to university-type research reactors unless the total HEU present in or near the reactor is 5 kg. or more. Because of provisions in federal legislation and US practice, US agreements with foreign recipients usually call for the possibility of occasional US inspections of the facility to observe, among other things, the protection the recipient provides.[26] The Suppliers' Guidelines themselves do not call for inspections, and other suppliers may not ask for them. Moreover, this requirement did not prevent the theft of US-supplied LEU-fueled research reactor fuel from the reactor in the Congo.

- National statutes and regulations on physical protection of reactors vary a great deal around the world. A year 2000 survey by the Nuclear Energy Agency of the international Organization for Economic Cooperation and Development (OECD) showed major differences from country to country.[27] The twenty-nine countries in the survey, mostly well-developed countries with significant nuclear programs, seemed to have a wide variety of security requirements set forth in reactor licenses, regulations, statutes and royal decrees. The summary did not compare the requirements to the regulatory recommendations of the IAEA, and it is not possible to do that effectively from the information provided. The variations in regulatory requirements raise questions about such compliance. In most cases, the OECD nuclear programs began long before the current IAEA physical protection recommendations and Nuclear Suppliers' Guidelines were issued, and some of the OECD respondents to the survey were themselves nuclear suppliers. The differences in regulatory requirements probably produce many differences in actual protection practices, and may help explain why some OECD countries have been unwilling to agree on any new, required, international physical protection standards to be included in the Convention on Physical Protection of Nuclear Material, as reported above.
- In a survey conducted by Stanford University, similar country variations appeared in actual physical protection practices for HEU (five kg or more). Six of the responses to a questionnaire, mostly from less-developed countries than those covered by the OECD survey, relate to government research reactors. The countries were located in Latin America, Central and South Asia, and Eastern and Western Europe. Four of the five that answered questions on threat perception said their facilities faced major threats of armed violence from outsiders, and that collusion by insiders (possibly involuntary collusion) with the outsiders was feared as well. But, despite considerable similarities in *threat* perceptions, there were great variations in the *level of protection* provided (fences, walls, doors, windows) for the protected area and the inner areas within

the protected areas where the HEU was stored or used. For example, one respondent confirmed that the outer protected area could be accessed by climbing a wall or walking around the end of a fence or by crawling through a duct through a wall or something similar. Others described varying degrees of stronger protection. For the inner area, all said there were guards, at least during working hours. But two did not provide guns for the guards. Three said that during hours when the area was not in use for experiments or other purposes, instead of guards there were "standard locks or better at critical access points." Another three, these with more nuclear experience and resources, said they used "ID actuated locks or better" when guards were not present. Contrast this with the Nuclear Suppliers Guidelines recommendation described above which recommend, for both spent fuel and HEU of more than 5 kilograms, "constant surveillance by guards or electronic sensors."[28]

- The variation in *actual* practices for protection despite IAEA recommendations or Nuclear Suppliers' Guidelines was confirmed by experts who were participants in the first ten missions of the IAEA's "International Physical Protection Advisory Services" to review security at nuclear facilities -- mostly in Eastern Europe where particular countries had requested assistance. The experts reported that their visits to nuclear sites showed that physical protection practices "*will vary from State to State. Differences in culture, perceived threat, financial and technical resources, and national laws* are some of the reasons for variations."[29]
- Given these differences in the way states respond to similar threat perceptions; given the lower level of financial resources and importance usually provided to university and some little-used government and industry research reactors as compared with power reactors; given the lack of specific provisions for protection from sabotage of research reactors compared with power reactors in, for example, the IAEA recommendations; and given the intermittent operation of university and some government research reactors as compared with power reactors; it should not be surprising that the actual practices for protection of research reactors are considerably weaker than those for power reactors.

Conclusion. If all this is true, research reactors and their fuel are more likely than power reactors to be the targets of well-informed terrorists seeking to make dirty bombs or nuclear weapons. Moreover, though they typically have much less highly radioactive nuclear material that could be dispersed by a truck bomb attack, their radioactive fuel is likely to be much easier for terrorists or thieves to handle and less likely to be adequately protected than that of power reactors.

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[1] Prepared Statement of Siegfried S. Hecker to US Senate Foreign Relations Committee, Hearing on "Increasing our Nonproliferation Efforts in the Former Soviet Union, April 23, 2002.

[2] U.S. "Atoms for Peace" Proposal: Address of President Eisenhower to the General Assembly, December 8, 1953, in Department of State, *Documents on Disarmament, 1945-1959* (GPO: 1960), p.393.

[3] G.C. Smith, adviser to Dulles, in J.A. Thompson, ed. *Gerard Smith on Arms Control* (U.Md.Press, 1987), p.117; G. Bunn, *Arms Control by Committee,* (Stanford U.Press, 1992), pp.84-85.
[4] Armand Travelli, "Progress of the RERTR Program in 2001," Proceedings of the International Conference on Research Reactor Fuel Management, Ghent, Belgium, March 17-20, 2002.
[5] See International Atomic Energy Agency, *Nuclear Research Reactors in the World,* Ref. Data Series 3 (Sept. 2000).
[6] US Department of Energy, *FY 2003 Budget Request: Detailed Budget Justification:Defense Nuclear Nonproliferation* (Feb. 2002) Http://www.cfo.doe.gov/budget/03budget/content/defnn/nuclenonpl.pdf.
[7] R. L. Civiak, *Closing the Gaps: Securing High Enriched Uranium in the Former Soviet Union and Eastern Europe,* (Federation of American Scientists, 2002), p,25,
[8] Travelli, "Progress of the RERTR Program in 2001,"above.
[9] Armando Travelli, "Status and Progress in the RERTR Program in the Year 2000," Paper presented to the 2000 International Meeting on Reduced Enrichment for Research and Test Reactors, Las Vegas, Nevada, October 1-6, 2000.
[10] International Atomic Energy Agency , Research Reactor Database, www.iaea.org.

[11] IAEA, *Nuclear Reactors of the World,* above.
[12] U.S. Department of Energy, Assistant Secretary for Environmental Management, "Record of Decision on Nuclear Weapons Nonproliferation Policy Concerning Foreign Reactor Spent Nuclear Fuel," May 13, 1996; Travelli, "Progress of the RERTR Program in 2001,above; Civiak, p.26-27, pp. 26-27..
[13] Civiak, above, pp.26-27.
[14] For the purposes of its safeguards system, the IAEA has designated 25 kg. as a "significant quantity"—"The approximate quantity of nuclear material in respect to which, taking into account any conversion process involved, the possibility of manufacturing a nuclear explosive device cannot be excluded." http://www.iaea.org/worldatom/inforesource/other/safgeuards/pia3810.html. US experts believe that approximately 15 kg. of HEU enriched to 90 per cent or more in uranium 235 is sufficient to make a nuclear weapon. See the quotation in the text above from DOE that is cited in the next endnote.
[15] U.S. Department of Energy, Office of Arms Control and Nonproliferation, *Final Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives,* DOE/NN-0007 (Washington, DC: DOE, January 1997), p. vii; see M. Bunn, J.P. Holdren, and A. Weir, *Securing Nuclear Weapons and Materials: Seven Steps for Immediate Action* (Project on Managing the Atom: Belfer Center for Science and International Affairs, 2002), p5.
[16] See Travelli, "Progress of the RERTR Program in 2001, above; F. von Hippel, "Recommendations for Preventing Nuclear Terrorism," *FAS Public Interest Report, Journal of the Federation of American Scientists*, v.54, no.6 (Nov./Dec.2001).
[17] IAEA, *Nuclear Reactors of the World,* above.
[18] I. Ritchie, "Technical and Administrative Preparations Required for Shipment of Research Reactor Spent Fuel to its Country of Origin," International Atomic Energy Agency-Argonne National Laboratory Training Course, Lecture L.1.2 (January 1997), text at figures 8,9, 10. Australia and Japan are the two industrialized countries of the Eastern Pacific rim.
[19] For data in this paragraph, see Database on Nuclear Smuggling, Theft and Orphan Radiation Sources, Center for International Security and Arms Control, Institute for International Studies, Stanford University, Stanford, CA, USA. See also Bellona Foundation, "Stanford Database Tracks Lost Radwaste to Stem Nuclear Terrorism," Bellona Web, http://www.bellona.no/en/international/russi/nuke-weapons/nonproliferation/24099.html; Civiak, *Closing the Gaps*, above, pp. 23-27; M. Bunn, J.P. Holdren, and A. Wier, *Securing Nuclear Weapons and Materials: Seven Steps for Immediate Action,* (Project on Managing the Atom, Belfer Center for Science and International Affairs, Harvard University, 2002), p.47.
[20] See M. L. Wald, "Fear Itself Is the Main Threat of a Dirty Bomb, Experts Say," *New York Times,* June 11, 2002 (National ed.), p. A18.
[21] See T. Bridis, "U.S. Arrests Alleged Bomb Terrorist," Associated Press, June 10, 2002, available on that day on wysiwyg://19/http://story.new.yahoo.com…2061/ap_on_go_ca_st_pe/terror_arrest_14.
[22]See M. Bunn and G. Bunn, "Strengthening Nuclear Security Against Post September 11 threats of Theft and Sabotage," *Journal of Nuclear Materials Management,* v. 30, no.3 (Spring 2002), p48, 51; G. Bunn and L. Zaitseva, "Efforts to Improve Nuclear Material and Facility Security," in 2002 SIPRI Annual Report, App. 10D (2002). Negotiations to amend the Convention on Physical Protection of Nuclear

Material have continued since these reports were written but they have not produced a draft treaty amendment that would provide any specific standards for domestic protection of weapon-usable material like those for material in international transport already in the treaty.

[23] INFCIRC 225/Rev.4, par. 6.1.1.

[24] INFCIRC 225/Rev.4, par.6.2 and Table: Categorization of Nuclear Material.

[25] See Nuclear Suppliers Group, *Guidelines for Nuclear Transfers,* IAEA Information Circular 254, Rev.4, Add.1, 1996, par. 3 and Annex C.

[26] See Nuclear Nonproliferation Act of 1978, 42 U.S.Code Sect. 2155(d) and 2156(3).

[27] Nuclear Energy Agency, *Nuclear Legislation: Analytical Study: Regulatory and Institutional Framework for Nuclear Activities* (NEA: Organization for Economic Cooperation and Development, 2000).

[28] G.Bunn, F.Steinhausler, L.Zaitseva, "Could Terrorists or Thieves Get Weapons Usable Material for Research Reactors and Facilities?", Paper for Institute of Nuclear Materials Management 43rd Annual Meeting, June 2002.

[29] Mark Soo Hoo, David Ek, Axel Hageman, Terry Jenkins, Chris Price, and Bernard Weiss, "International Physical Protection Advisory Service: Observations and Recommendations for Improvement," *Proceedings of the 42n Annual Meeting of the Institute of Nuclear Materials Management* (Northbrook, IL. July 2000). (Emphasis added).