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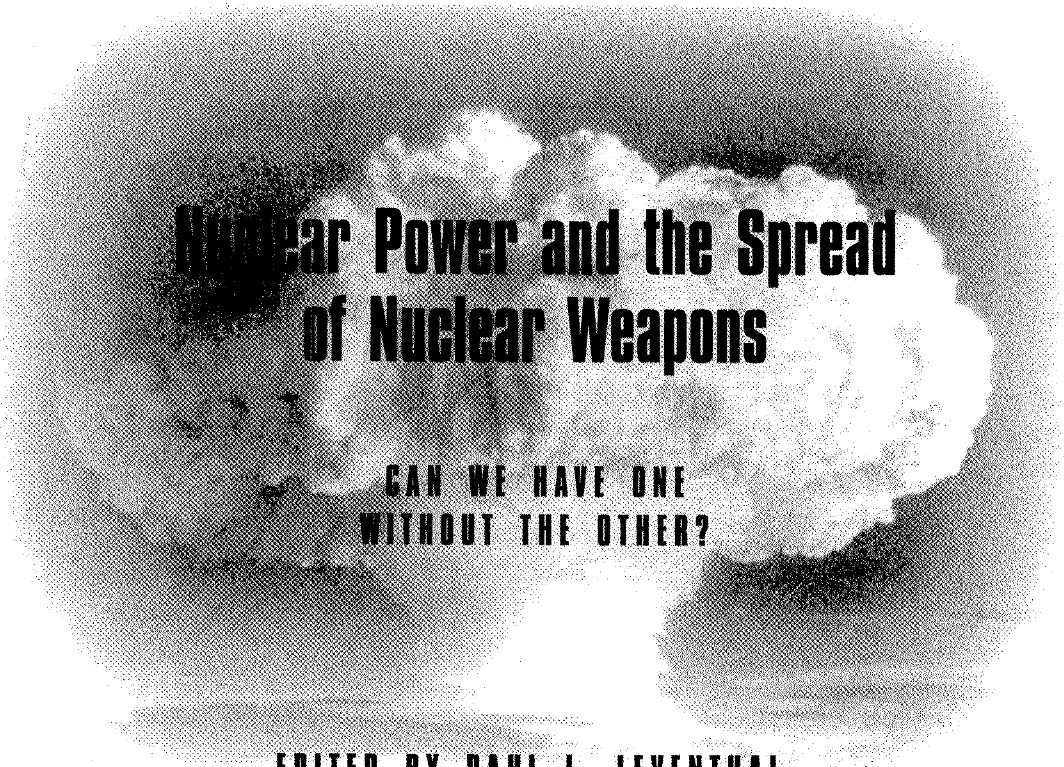

Nuclear Power and the Spread of Nuclear Weapons

CAN WE HAVE ONE WITHOUT THE OTHER?

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APPENDIX 2

Civilian Highly Enriched Uranium and the Fissile Material Convention

Codifying the Phase-Out of Bomb-Grade Fuel for Research Reactors

by Alan J. Kuperman

Introduction

Because of the availability of basic nuclear-weapons design information in the open literature and even on the Internet, the main obstacle to fabrication of a nuclear weapon today is the acquisition of sufficient weapon-usable fissile material—plutonium or highly enriched uranium (HEU). The degree to which a fissile material convention can prevent the spread of nuclear weapons, therefore, hinges on its ability to limit the production of, and access to, such materials. A convention that prohibits only the *un-safeguarded* production of weapon-usable fissile materials, but allows unlimited production and use of such materials under safeguards, falls short on two grounds: It permits continued production of weapon-usable material ostensibly for civil purposes that could later be quickly converted by states into weapons; and it permits continued civil commerce in fissile materials, perpetuating the risk of their acquisition by terrorist groups for weapons.

Civil commerce in HEU presents a particular concern because such material has a low background radiation level, making it easier to handle and fabricate into nuclear weapons. Indeed, as Manhattan Project physicist Luis Alvarez wrote in his memoirs:

> With modern weapons-grade uranium, the background neutron rate is so low that terrorists, if they had such material, would have a good chance of setting off a high-yield explosion simply by dropping one half of the material onto the other half. Most people seem unaware that if separate HEU is at hand it's a trivial job to set off a nuclear explosion . . . [E]ven a high school kid could make a bomb in short order.[1]

Moreover, civil HEU has historically been used as a fuel in nuclear research reactors, often located on university campuses that lack the physical security measures employed at many nuclear powerplants and government weapons facilities. The threat posed by continued civil commerce in HEU was underscored dramatically by the disclosure that Iraq, in 1990, diverted bomb-grade uranium fuel from safeguarded research reactors for a crash program to build nuclear-weapon components.

Fortunately, an international cooperative effort, starting in the late 1970s, has made great strides in reducing civil commerce in HEU by converting reactors to non-weapon-usable, low-enriched uranium (LEU) fuels, and by eschewing new HEU-fueled reactors. This effort, known as the Reduced Enrichment for Research and Test Reactors (RERTR) program, headquartered at the U.S. Argonne National Laboratory, has laid the groundwork for the total phase-out of civil commerce in HEU for research reactors.

To preserve the progress of the last two decades and eliminate remaining HEU commerce within the next decade, four further steps are needed. First, development work must continue on the ultra-high-density LEU fuels necessary to convert a few high-power research reactors that still require HEU fuel, and the operators of these reactors must fulfill their pledges to convert as soon as suitable LEU fuel is available. Second, all future research reactors must be designed to use LEU fuel. Unfortunately, Germany has violated this principle with its new FRM-II—the first large research reactor designed to use HEU fuel in the Western world since the RERTR program was created more

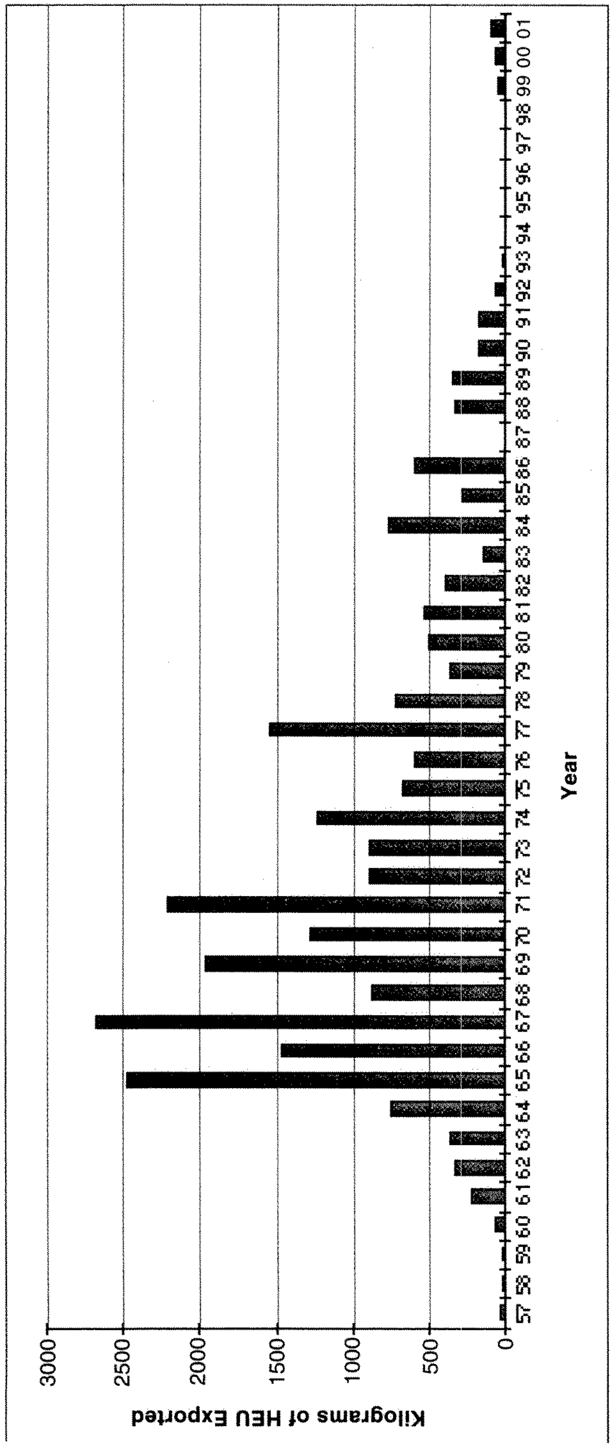
than two decades ago—and this decision must be rectified. Third, the RERTR principle should also be applied to medical-isotope production—which is the only other significant civilian use of HEU besides reactor fuel—by requiring conversion of all such production to reliance on LEU, rather than HEU, targets. Finally, the proposed fissile material convention should be broadened to codify the phase-out of HEU commerce and the moratorium on any new HEU-fueled reactors.

Background

In the late 1970s the international community belatedly came to the realization that the fuel used in many nuclear research reactors—bomb-grade, highly enriched uranium—could be stolen or diverted for nuclear weapons by nations or terrorists. The RERTR program was established in 1978 to develop substitute fuel of higher-density, low enriched uranium, which is not suitable for weapons. As the substitute fuels were developed, existing reactors would be converted to LEU and new reactors would be designed to use LEU. The RERTR program has proved remarkably successful, facilitating the conversion of dozens of reactors worldwide from bomb-grade to non-weapon-usable fuel and sharply reducing international commerce in HEU.

Outside the United States, some forty-two research reactors with power of at least 1 megawatt were built that originally relied on U.S.–supplied HEU fuel.[2] To date, forty either have converted to LEU, are in the process of converting, have pledged to convert as soon as suitable LEU fuel is available, or have shut down—which has enabled a sharp decline in U.S. HEU exports.[3] Because the United States has historically been the major exporter of fresh HEU for civilian use, and in recent years the sole exporter except for a single Russian transaction with France, this translates into a sharp reduction in total international commerce in bomb-grade uranium. Indeed, as can be seen in figure A1, from 1993 to 1999, there were virtually no exports except minimal quantities for use in production of medical isotopes. HEU exports are currently experiencing a small, temporary resurgence, because the United States has agreed to provide HEU fuel on an interim basis for

Figure A1. RERTR Program Suceeds—U.S. Exports Decline Sharply



Sources: 1993 Neclear Regulatory Commission report to Congress persuant to the Energy Policy Act of 1992, subsequent NRC export data, submissions by Nordion Inc. to NRC, and data provided by Transnuclear Inc. personal communication to author, January 16, 2002.
Note: * Does not include 1994 export to France of surplus Fort St. Vrain HEU fuel, because this material was required to be blended down LEU as a condition of its export.

a few years to three high-power research reactors in exchange for their pledge to convert as soon as suitable LEU fuel is available.[4]

In addition, the United States has taken steps to reduce its own use of highly enriched uranium. In 1986, the U.S. Nuclear Regulatory Commission ordered the conversion of all licensed, domestic research reactors. Of the twenty-five such reactors operating at the time, ten already have been converted, six are in the process of converting, five ceased operation prior to conversion, three require development of higher-density LEU fuels to enable conversion, and one is a very low power (100kw) private reactor that does not require fresh HEU fuel and is not scheduled for conversion.[5] The U.S. Department of Energy also operates two of its own HEU-fueled reactors, which are not licensed by the NRC. One of these, the HFIR, cannot convert to currently available LEU fuels, according to a recent feasibility study. The other, the ATR, has proposed but not yet carried out its conversion feasibility study. Overall, at least thirty-three reactors located in or supplied by the West already have completed conversion from HEU to LEU.[6]

In recent years, the United States also has entered into agreements with Russia and China to work on conversion of research reactors operating in, and supplied by, these countries. However, progress in achieving actual conversions of these reactors has been painfully slow, which indicates a need for renewed initiative in Washington, Moscow, and Beijing. The United States also is developing a system for production of molybdenum-99 for medical isotopes using LEU targets rather than HEU targets, which currently constitute the main civilian demand for bomb-grade uranium other than reactor fuel.

The key to the RERTR program's success has been two core tenets: spent-fuel return and universality. The U.S. policy of accepting the return to the United States of U.S.–origin spent fuel (both LEU and HEU) through 2009, from operators cooperating with the RERTR program, is based on three grounds. First, it reduces the vulnerability of spent HEU fuel to theft or diversion for nuclear weapons. Second, it honors longstanding U.S. commitments, made originally when the fuel was exported. Third, it helps induce cooperation with the RERTR program, by providing a financial and political incentive for operators to convert their reactors—i.e., they do not have to find an alternate disposal method for their spent fuel until after 2009. The take-back policy extends to LEU spent fuel in order to avoid imposing on reactor operators an additional, perverse penalty for conversion from HEU to LEU—i.e., loss of the right of spent fuel return. The stipulation that spent fuel would be accepted only from reactor operators cooperating with the RERTR program was added—at the recommendation of the Nuclear Control Institute—when the take-back program was renewed in 1996, in order to induce a few remaining foreign operators to convert their reactors. This provision, in combination with the U.S. Energy Policy Act of 1992 that required such cooperation as a condition of interim HEU supply, has helped in obtaining conversion commitments from the operators of the HFR-Petten in the Netherlands, the BR-2 in Belgium, the ILL-Grenoble in France, and the FRJ-2 in Germany.

The principle of universality also has been crucial to the RERTR program by eliminating discrimination as potential grounds for non-cooperation. The principle has been applied to the program's three fundamental premises: (1) those reactors that can convert to existing LEU fuel must do so; (2) for remaining reactors, advanced fuel will be developed, to which they must convert when it is successfully qualified; and (3) no new reactors will be constructed to use HEU fuel. Reactor operators have been willing to convert to non-weapon-usable fuel—and to accept the economic and performance penalties of doing so—because the universality principle guaranteed that they would not be put at a competitive disadvantage with respect to neutron research, medical-isotope production, or other reactor activities.

In keeping with this principle, at least thirteen large new research reactors (with power at least 1 MW) constructed since 1980 have commenced operations with LEU fuel, including a 20-megawatt reactor in Japan, 30-megawatt reactors in South Korea and Indonesia, and two U.S. research reactors. (See figure A2.) In addition, another eight research reactors have been designed to use LEU fuel, including the next generation of high-power reactors in China and France.[7] In the same vein, in 1995, the United States abandoned plans for a new HEU-fueled research reactor, the Advanced Neutron Source, despite the pleas of U.S. neutron researchers. The Clinton administration stated at the time that it made this decision at least partly because the bomb-

Figure A2. Large Reactors(>1MW) Constructed after 1980

LEU

Country	Construction Start	Power (MW)	Name
Peru	1980	3	RP-10
Malaysia	1981	1	Triga
Bangladesh	1981	3	Triga
Indonesia	1983	30	RGS-GAS
Japan	1985	20	JRR-3M
China	1986	1	PPR
China	1986	5	NHR-5
South Korea	1987	30	Hanaro
United States	1987	1	McClellan
United States	1987	1	Triga (U. Texas)
Algeria	1987	1	NUR
Canada**	1990	10	Maple 1
Egypt	1993	22	ETRR-2
Canada**	1998	10	Maple 2
Morocco*	1999	2	Triga
Thailand	Not by 2001	10	MPR-10
France	Not by 2001	100	RJH
China	Not by 2001	60	CARR
Taiwan	Not by 2001	20	TRR-11
Canada	Not by 2001	40	CNF
Australia	Not by 2001	20	"Replacement"

HEU

Country	Construction Start	Power (MV)	Name
Libya	1980	10	IRT-1
USSR***	1982	10	RBT-10/1
USSR***	1983	10	RBT-10/2
China	1986	5	MJTR
Germany*	1996	20	FRM-11

Sources: IAEA and RERTR program.

Notes:

* Reactor is at least partially constructed but has yet to begin operations.

* Reactor has undergone some low-power testing, but has yet to be licensed for full-power operations.

*** These two Soviet-era reactors in Russia did not actually increase commerce in fresh HEU fuel because they utilize fuel that previously was partially irradiated in the neighboring SM-3 reactor. The dates indicated for construction start of these two reactors are taken from the IAEA, but actual construction may have started prior to 1980, as indicated in figure A3, given that the reactors went critical in 1983 and 1984.

n. b. Press reports also indicate possible plans to construct a 10 MW research reactor in Vietnam and Myanmar, but there is no information on their planned fuel.

grade fuel presented "a non-proliferation policy concern."[8] The only reactors built to use HEU fuel after establishment of the RERTR program were during the cold war in communist China, the Soviet Union, and Libya—at a time when these countries were not observing international nonproliferation norms. The proposed FRM-II would be the first large research reactor built to use HEU fuel since 1980 in a country that claims to observe international nonproliferation norms.

Steps Needed to End HEU Commerce Completely

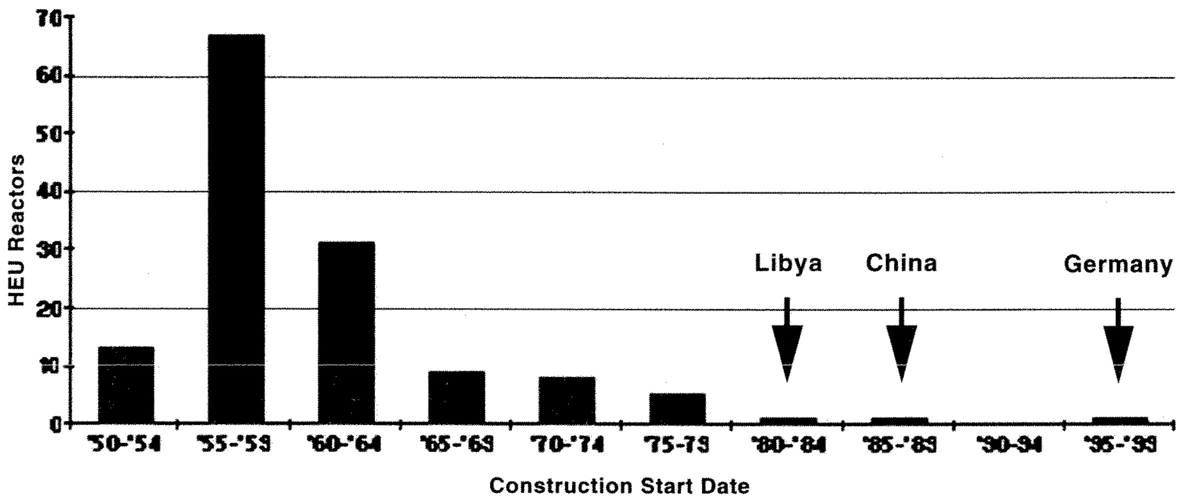
1. *Advanced Fuel Development and Conversion of Remaining Reactors*—The RERTR program, and an independent French effort, are continuing to develop ultra-high-density LEU fuels necessary to convert the few remaining high-power research reactors that still require HEU fuel. LEU fuel of density 6 g/cc is scheduled for qualification in 2004 and density 8 g/cc in 2006. These fuels should enable conversion of all remaining HEU-fueled reactors around the end of the decade. In addition, there is one HEU-fueled reactor that can convert to existing LEU fuel but so far is not scheduled to do so, the Safari I in South Africa. International leverage is limited, because the operator has its own stocks of HEU (mostly from South Africa's dismantled nuclear weapons), but efforts should be made to bring the operator into conformance with the international norm.

2. *No New HEU-Fueled Reactors*—As noted, Germany's new FRM-II, scheduled to begin operation in 2002, would violate a two-decade international moratorium against new HEU-fueled reactors. As such, it would threaten the RERTR regime in several ways. First, it would generate commerce in more than 400 kgs of bomb-grade HEU fuel in its first decade. German officials recently announced a plan to lower the fuel's enrichment after the first decade—from 93 percent to 50 percent—but even this moderately lower enriched fuel would still qualify as HEU and be usable for weapons. Second, the FRM-II has contracted with Russia to supply the HEU fuel, which encourages Russia to view HEU exports as a lucrative business and to look for additional customers. Increased availability of HEU, combined with Germany's violation of the RERTR program's fundamental principle of universality, could cause other reactor operators to abandon their planned conversions to LEU or, if they already have converted to LEU, to convert back to HEU. In addition, when other countries build new research reactors, as Vietnam and Myanmar have proposed to do, they may well demand the right to use HEU fuel based on the German precedent. All of this additional HEU commerce would increase risks of nuclear terrorism and nuclear proliferation, just when the world should be reducing such risks in the wake of the terrorist attacks of September 11, 2001.

Fortunately, technical studies by Argonne National Laboratory conclude that the FRM-II can be redesigned to produce equivalent experimental performance using LEU fuel, and would actually enjoy a slightly increased fuel-cycle length.[9] This redesign can be achieved *using LEU fuel that exists today and has been qualified since 1988*—without additional fuel development. Conversion to LEU need not entail substantial delays in completion of the reactor or major increase in cost.[10] The reactor could be redesigned to use already-qualified LEU fuel within a year, and relicensing this new design might require another year. The new design would require a slightly larger reactor core, so that any already completed work constraining the size of the core would have to be modified. Not a single experiment has been identified that would be precluded by conversion to LEU. An LEU-fueled FRM-II also would be no less safe overall than the current HEU design. For all these reasons, the Nuclear Control Institute recently urged German prime minister Gerhard Schroeder to ensure that the FRM-II is converted to LEU prior to its startup.[11]

3. *Convert Medical Isotope Production to LEU*—While the RERTR program has successfully been reducing HEU commerce for reactor fuel, the other major civil application of HEU has been increasing—for use as targets in production of medical radio-isotopes. Such production can and should be converted to LEU. Australia already produces isotopes with LEU, and the RERTR program has enabled Indonesia also to develop successfully an LEU target for medical-isotope production. (In addition, Argentina has worked with the RERTR program toward developing another type of LEU target.) Because of the moderate economic penalties associated with converting medical-isotope production from HEU to LEU targets, the best chance of

Figure A3. International Moratorium on Building HEU-Fueled Reactors since 1980 (Germany Slated to Join Libya and China as Violator)



Source: *Nuclear Research Reactors in the World,* December 1994, IAEA, Vienna.
Note: Research reactors of at least one megawatt. Construction start date for two Russian reactors that went critical in 1983 and 1984 is uncertain; included in graph during 1975–1979 period.

Figure A4. Status of Conversion of U.S. Reactors and Foreign Reactors Using U.S. Fuel (Does Not Include Chinese- and Russian-Supplied Reactors)

Location	No. of Reactors	Converted, Converting or Shut Down	Unable to Convert to Existing LEU Fuel	Able to Convert to Existing LEU Fuel but Refusing
United States (at least 1 MW and all university reactors)	22	17	5*	0
Foreign (at least 1 MW) using U.S.–origin HEU	42	38	3**	1***

Notes:
* DOE's ATR reactor (at INEL) and HFIR (at ORNL), the Department of Commerce's NIST (formerly NBSR) reactor, and the university reactors at MIT and University of Missouri–Columbia.
** Belgium's BR-2 reactor and France's ILL-Grenoble and Orphee reactors. The first two have pledged to convert as soon as suitable LEU fuel is available.
*** South Africa's Safari I reactor.
n.b. U.S. university reactors are being converted even if they had low-power (less than1MW) and lifetime HEU cores that did not require fresh fuel. This is in recognition of the extreme vulnerability of university reactors to theft, due to traditionally lax security on most campuses. Other low-power reactors in the United States and elsewhere are not now planned for conversion under the RERTR program, because they do not require fresh shipments of HEU.

getting producers to convert is if they all sign a pledge to convert, so that no producer can gain a competitive advantage by continuing to use HEU. The Nuclear Control Institute has proposed such a pledge and has worked with the RERTR program, the U.S. State Department, and several producers to achieve its universal adoption.[12] The world's largest isotope producer, Canada's Nordion Inc., has indicated its intention to convert to LEU, but so far the other major producers have not.

Conclusion

The RERTR program is one of the unsung heroes of the international nuclear non-proliferation regime and a major bulwark against nuclear terrorism. Since 1978, the program has made great progress in reducing HEU commerce. If the international community provides its full support, the RERTR program can within the decade fulfill its goal of eliminating civil commerce in bomb-grade uranium. However, if Germany operates a new reactor with HEU fuel, South Africa refuses to convert its reactor to available LEU fuel, or medical-isotope producers refuse to convert their processes to LEU targets, the progress of the RERTR program would be seriously undermined and a resurgence of HEU commerce could soon follow. Any unnecessary commerce in bomb-grade uranium represents an unacceptable security risk, especially in light of the increased terrorist threat environment after September 11, 2001. The fissile material convention presents an ideal opportunity to lock in the gains of the RERTR program—by broadening the proposed convention to codify both the phase-out of HEU commerce and the international consensus against construction of new HEU-fueled reactors.

Appendix 2

Originally prepared for a symposium, "The Scope of a Fissile Material Convention," United Nations Institute for Disarmament Research and the Oxford Research Group, Geneva, Switzerland, August 29, 1996. Revised January 16, 2002.

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1. Luis Alvarez, *Adventures of a Physicist* (Basic Books, 1987), p. 125.

2. Lower-power reactors are less of a concern because they contain less HEU fuel and do not require any fresh HEU fuel during their lifetime. However, in the United States, as an extra precaution, even lower-power licensed research reactors were required to convert to LEU fuel under a 1986 order.

3. The first exception is South Africa's Safari I reactor. However, its operator has now completed a study indicating that conversion is feasible, and the facility's governing board is due to consider conversion in early 2002. The second exception is France's Orphee reactor. However, it is expected to be shut down soon after France commences operation of its new Jules Horowitz reactor, which is designed to use LEU fuel.

4. The U.S. Energy Policy Act of 1992 prohibited export of HEU unless three conditions were satisfied, including such a conversion pledge. The first reactor is the HFR-Petten, in the Netherlands, which will convert to already qualified LEU fuel by 2006. See Ann MacLachlan, "Petten Director Says Study Clears Way for Start of LEU Conversion this Summer," *Nuclear Fuel*, May 31, 1999, p. 6. The second reactor is the BR2, in Belgium. See Ann MacLachlan, "U.S. Agrees to Continue HEU Shipments to BR2 After Belgians Agree to Convert," *Nuclear Fuel*, November 29, 1999. The third reactor is the ILL-Grenoble, in France. See Ann MacLachlan, "U.S. May Resume HEU Fuel Supply as France's ILL Studies Conversion," *Nuclear Fuel*, November 30, 1998, p. 3.

5. In addition, the University of Michigan Ford Nuclear Reactor converted to LEU fuel in 1984, prior to the NRC order. Jim Matos, "U.S. University Reactors Using or Formerly Using HEU Fuel: LEU Conversion Status as of December 2001," RERTR Program, Argonne National Laboratory, undated document obtained January 2002. "Non-Power Reactor HEU to LEU Conversion Program," chart, U.S. Nuclear Regulatory Commission, updated September 29, 1998, by Theodore Michaels, U.S. NRC. The three reactors that cannot yet convert to existing LEU fuels are the university reactors at MIT and University of Missouri–Columbia, and the Department of Commerce's NIST (formerly NBSR) reactor. The small private reactor is operated by General Electric. In the past, some foreign critics have complained about the pace of U.S. conversions. In reality, U.S. conversion efforts have surpassed those overseas. All U.S. research reactors that required fresh HEU fuel, and which can use existing LEU fuel, have been converted or are in the process of doing so, as is true overseas. But in addition, the United States has converted most of its reactors with "lifetime" cores of HEU fuel that do not require refueling, which has not occurred overseas.

The foreign criticism is accurate, however, in that the United States has not credibly demonstrated an intention to convert its remaining five high-power HEU-fueled reactors as soon as suitable LEU fuel is developed. The U.S. Department of Energy could help demonstrate this intention by preparing a conversion feasibility study for its ATR reactor in Idaho.

6. Armando Travelli, RERTR program, Argonne National Laboratory, personal communication to author, January 16, 2002.

7. Shi Yongkang et al., "The China Advanced Research Reactor Project," and Yuan Luzheng et al., "Preliminary Study of Core Characteristics for the Scheduled CARR," presented at the Fifth Meeting of the Asian Symposium on Research Reactors, Taejon, Korea, May 29–31, 1996. A. Ballagny, "The Jules Horowitz Reactor: A new test reactor for fuels and materials," presented at the 1997 International Meeting on Reduced Enrichment for Research and Test Reactors, Jackson Hole, Wyo., October 5–10, 1997.

8. "DOE Facts: A New Neutron Source for the Nation," U.S. Department of Energy, February 1995, p. 1.

9. N. A. Hanan and J. E. Matos, "Fluxes at Experiment Facilities in HEU and LEU Designs for the FRM-II," presented at the 1997 International Meeting on RERTR, Jackson Hole, Wyo., October 5–10, 1997.

10. The director of the FRM-II project, Dr. Klaus Boening, is quoted estimating that a redesign to 32 MW would cost 50–100 million DM. (Jeanne Rubner, "Warnung vor deutschem Sonderweg," *Suddeutsche Zeitung*, April 7, 1998, p. 10.) In light of the fact that he opposes such conversion, this is unlikely an under-estimate. The projected total construction cost of the current design is now at least 720 million DM. Thus, if one accepts Boening's estimate, the extra cost imposed by conversion represents no more than a 7 to 14 percent marginal increase. Such a level of additional cost traditionally has been accepted by states and reactor operators as a necessary and acceptable trade-off for sustaining the nonproliferation and anti-terrorism benefits of LEU fuel and the RERTR program.

11. Letter from Alan J. Kuperman and Paul L. Leventhal to The Honorable Gerhard Schroeder, October 29, 2001, regarding "Risk of Terrorism at Bavaria's FRM-II Reactor." (www.nci.org/01nci/10/schroederletter.htm)

12. Alan J. Kuperman, "A Level Playing Field for Medical Isotope Production—How to Phase Out Reliance on HEU," presented at 22nd International Conference on Reduced Enrichment for Research and Test Reactors, Budapest, Hungary, October 7, 1999. (www.nci.org/q-r/rertr99.htm) See also, Alan J. Kuperman and Paul L. Leventhal, "Forging Consensus to Phase Out HEU for Medical Isotope Production: A Proposed Path Forward," presented at 23rd International Conference on Reduced Enrichment for Research and Test Reactors, Las Vegas, Nev., October 2, 2000. (www.nci.org/q-r/rertr-2000.htm)