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Hearing on "Advancing Technology for Nuclear Fuel Recycling: What Should Our Research, Development, and Demonstration Strategy Be?"

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Dr. Charles D. Ferguson
Philip D. Reed Senior Fellow for Science and Technology
Council on Foreign Relations

An Assessment of the Proliferation Risks of Spent Fuel Reprocessing and Alternative Nuclear Waste Management Strategies

Mr. Chairman, thank you for inviting me to testify on the nuclear proliferation challenges of reprocessing spent nuclear fuel and effective ways for reducing those proliferation risks through federal research, development, and demonstration initiatives. In this testimony, I also discuss nuclear waste management programs deployed by other nations and examine whether those programs represent alternative management strategies that the U.S. federal government should consider.

U.S. leadership is essential for charting a constructive and cooperative international course to prevent nuclear proliferation. An essential aspect of that leadership involves U.S. policy on reprocessing spent nuclear fuel. The United States has sought to prevent the spread of reprocessing facilities to other countries and to encourage countries with existing stockpiles of separated plutonium from reprocessing facilities to draw down those stockpiles. The previous administration launched the Global Nuclear Energy Partnership (GNEP), which proposed offering complete nuclear fuel services, including provision of fuel and waste management, from fuel service states to client states in order to discourage the latter group from enriching uranium or reprocessing spent nuclear fuel—activities that would contribute to giving these countries latent nuclear weapons programs. The current administration and the Congress seek to determine the best course for U.S. nuclear energy policy with the focus of this hearing on recycling or reprocessing of spent fuel and nuclear waste management strategies.

Here at the start, I give a brief summary of the testimony's salient points:

- Reprocessing of the type currently practiced in a handful of countries poses a significant proliferation threat because of the separation of plutonium from highly radioactive fission products. A thief, if he had access, could easily carry away separated plutonium. Fortunately, this reprocessing is confined to nuclear-armed states except for Japan. If this practice spreads to other non-nuclear-weapon states the consequences for national and international security could be dire. Presently, the vast majority of the 31 states with nuclear power programs do not have reprocessing plants.

- The types of reprocessing examined under GNEP do not appear to offer substantial proliferation-resistant benefits, according to research sponsored by the Department of Energy. However, more research is needed to determine what additional safeguards, if any, could provide greater assurances that reprocessing methods are not misused in weapons programs and whether it is possible to have assurances of timely detection of a diversion of a significant quantity of plutonium or other fissile material.

- Time is on the side of the United States. There is no need to rush toward development and deployment of recycling of spent nuclear fuel. Based on the foreseeable price for uranium and uranium enrichment services, this practice is presently far more expensive than the once-through uranium fuel cycle. Nonetheless, more research is needed to determine the costs and benefits of recycling techniques coupled with fast-neutron reactors or other types of reactor technologies. This cost versus benefit analysis would concentrate on the capability of these technologies to help alleviate the nuclear waste management challenge.

- In related research, there is a need to better understand the safeguards challenges in the use of fast reactors. Such reactors are dual-use in the sense that they can burn transuranic material and can breed new plutonium. In the former operation, they could provide a needed nuclear waste management benefit. In the latter operation, they can pose a serious proliferation threat.

Proliferation Risks

Reprocessing involves extraction of plutonium and/or other fissile materials from spent nuclear fuel in order to recycle these materials into new fuel for nuclear reactors. As discussed below, many reprocessing techniques are available for use. Regardless of the particular technique, fissile material is removed from all or almost all of the highly radioactive fission products, which provide a protective barrier against theft or diversion of plutonium in spent nuclear fuel. Plutonium-239 is the most prevalent fissile isotope of plutonium in spent nuclear fuel. The greater the concentration of this isotope the more weapons-usable is the plutonium mixture. Weapons-grade plutonium typically contains greater than 90 percent plutonium-239 whereas reactor-grade plutonium from commercial thermal-neutron reactors has usually less than 60 percent plutonium-239, depending on the characteristics of the reactor that produced the plutonium. The presence of non-plutonium-239 isotopes complicates production of nuclear weapons from the plutonium mixture, but the challenges are surmountable.[1] According to an unclassified U.S. Department of Energy report, reactor-grade plutonium is weapons-usable.[2]

The potential proliferation threats from reprocessing of spent nuclear fuel are twofold. First, a state operating a reprocessing plant could use that technology to divert weapons-usable fissile material into a nuclear weapons program or alternatively it could use the skills learned in operating that plant to build a clandestine reprocessing plant to extract fissile material. Second, a non-state actor such as a terrorist group could seize enough fissile material produced by a reprocessing facility in order to make an improvised nuclear device—a crude, but devastating, nuclear weapon. Such a non-state group may obtain help from insiders at the facility. While commercial reprocessing facilities have typically been well-guarded, some facilities such as those at Sellafield in the United Kingdom and Tokai-mura in Japan have not been able to account for several weapons' worth of plutonium. This lack of accountability does not mean that the fissile material was diverted into a state or non-state weapons program. The discrepancy was most likely due to plutonium caked on piping. But an insider could exploit such a discrepancy. For commercial bulk handing facilities, several tons of plutonium can be processed annually. Thus, if even one tenth of one percent of this material were accounted for, an insider could conceivably divert about one weapon's worth of plutonium every year.

Location matters when determining the proliferation risk of a reprocessing program. That is, a commercial reprocessing plant in a nuclear-armed state such as France, Russia, or the United Kingdom poses no risk of state diversion (but could pose a risk of non-state access) because this type of state, by definition, already has a weapons program. Notably, Japan is the only non-nuclear-armed state that has reprocessing facilities. Japan has applied the Additional Protocol to its International Atomic Energy Agency safeguards, but its large stockpile of reactor-grade plutonium could provide a significant breakout capability for a weapons program. (Chinese officials and analysts occasionally express concern about Japan's plutonium stockpile.) Since the Ford and Carter administrations, when the United States decided against reprocessing on proliferation and economic grounds, the United States has made stopping the spread of further reprocessing facilities especially to non-nuclear weapon states a top priority.

Another top priority of U.S. policy on reprocessing is to encourage countries with stockpiles of separated plutonium to draw down these stockpiles quickly. This drawdown can be done either through consuming the plutonium as fuel or surrounding it with highly radioactive fission products. Global stockpiles of civilian plutonium are growing and now at about 250 metric tons—equivalent to tens of thousands of nuclear bombs—are comparable to the global stockpile of military plutonium. More than 1,000 metric tons of plutonium is contained in spent nuclear fuel in about thirty countries.

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[1] Richard L. Garwin, "Reactor-Grade Plutonium can be used to Make Powerful and Reliable Nuclear Weapons," Paper for the Council on Foreign Relations, August 26, 1998, available at: http://www.fas.org/rlg/980826-pu.htm. J. Carson Mark, "Explosive Properties of Reactor-Grade Plutonium," *Science and Global Security*, 4, 111-128, 1993.

[2] *Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material and Excess Plutonium Disposition Alternatives,* DOE/NN-0007 (Washington, DC: U.S. Department of Energy, January 1997), pp. 38-39.

While no country has used a commercial nuclear power program to make plutonium for nuclear weapons, certain countries have used research reactor programs to produce plutonium. India, notably, used a research reactor supplied by Canada to produce plutonium for its first nuclear explosive test in 1974. North Korea, similarly, has employed a research-type reactor to produce plutonium for its weapons program. Although nonproliferation efforts with Iran has focused on its uranium enrichment program, which could make fissile material for weapons, its construction of a heavy water research reactor, which when operational (perhaps early next decade) could produce at least one weapon's worth of plutonium annually, poses a latent proliferation threat. To date, Iran is not known to have constructed a reprocessing facility that would be needed to extract plutonium from this reactor's spent fuel. Further activities could take place in the Middle East and other regions. For instance, according to the U.S. government, Syria received assistance from North Korea in building a plutonium production reactor. In September 2009, Israel bombed this construction site.

The United States has been trying to balance the perceived need by many states in the Middle East for nuclear power plants versus restricting these states' access to enrichment and reprocessing technologies. Presently, as an outstanding example, the U.S.-UAE bilateral nuclear cooperation agreement is before the U.S. Congress. Proponents of this agreement tout the commitment made by the UAE to refrain from acquiring enrichment and reprocessing technologies and to rely on market mechanisms to purchase nuclear fuel. However, the last clause in the agreement appears to open the door for the UAE to engage in such activities in the future:

Equal Terms and Conditions for Cooperation

> The Government of the United States of America confirms that the fields of cooperation, terms and conditions accorded by the United States of America to the United Arab Emirates for cooperation in the peaceful uses of nuclear energy shall be no less favorable in scope and effect than those which may be accorded, from time to time, to any other non-nuclear-weapon State in the Middle East in a peaceful nuclear cooperation agreement. If this is, at any time, not the case, at the request of the Government of the United Arab Emirates the Government of the United States of America will provide full details of the improved terms agreed with another non-nuclear-weapon State in the Middle East, to the extent consistent with its national legislation and regulations and any relevant agreements with such other non-nuclear-weapon State, and if requested by the Government of the United Arab Emirates, will consult with the Government of the United Arab Emirates regarding the possibility of amending this Agreement so that the position described above is restored.[3]

Such a request for amendment could be around the corner because Jordan is seeking to conclude a bilateral nuclear cooperation agreement with the United States, and it has

[3] Agreement for Cooperation between the Government of the United States of America and the Government of the United Arab Emirates Concerning Peaceful Uses of Nuclear Energy, May 21, 2009.

expressed interest in keeping open the option to enrich uranium. Jordan has discovered large quantities of indigenous uranium and may want to "add value" to that uranium through enrichment. Jordan or any other Middle Eastern state has not yet expressed interest in reprocessing. U.S. leadership and practice in this issue will serve as an example for other states interested in acquiring new nuclear power programs.

Proliferation-Resistant Reprocessing

Can reprocessing be made more proliferation-resistant? "Proliferation resistance is that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material or misuse of technology by the host state seeking to acquire nuclear weapons or other nuclear explosive devices."[4] No nuclear energy system is proliferation proof because nuclear technologies are dual-use. Enrichment and reprocessing can be used either for peaceful or military purposes. However, through a defense-in-depth approach, greater proliferation-resistance may be achieved. Both intrinsic features (for example, physical and engineering characteristics of a nuclear technology) and extrinsic features (for example, safeguards and physical barriers) complement each other to deter misuse of nuclear technologies and materials in weapons programs. The potential threats that proliferation-resistance tries to guard against are:

- "Concealed diversion of declared materials;
- Concealed misuse of declared facilities;
- Overt misuse of facilities or diversion of declared materials; and
- Clandestine declared facilities."[5]

For each of these threats, a detailed proliferation pathway analysis can be done in order to measure the proliferation risk and to determine the needed, if any, additional safeguards. The U.S. Department of Energy has sponsored such analysis for proposed reprocessing techniques considered under GNEP.[6] These techniques include UREX+, COEX, NUEX, and Pyroprocessing, and they have been compared to the PUREX technique, which is the commercially used method. PUREX separates plutonium and uranium from highly radioactive fission products. It is an aqueous separations process and thus generates sizable amounts of liquid radioactive waste. UREX+, COEX, and NUEX are also aqueous processes. UREX+ is a suite of chemical processes in which pure plutonium is not separated but different product streams can be produced depending on the reactor fuel requirements. COEX and NUEX are related processes. COEX co-extracts uranium and plutonium (and possibly neptunium) into one recycling stream; another stream contains pure uranium, which can be recycled; and a final stream contains fission products. NUEX

[4] Office of Nonproliferation and International Security, *A Nonproliferation Impact Assessment for the Global Nuclear Energy Programmatic Alternatives*, National Nuclear Security Administration, U.S. Department of Energy, Draft, December 2008, p. 26.
[5] Ibid, p. 28.
[6] See, for example, many of the references cited in Office of Nonproliferation and International Security, *A Nonproliferation Impact Assessment for the Global Nuclear Energy Programmatic Alternatives*, National Nuclear Security Administration, U.S. Department of Energy, Draft, December 2008.

separates into three streams: uranium, transuranics (including plutonium), and fission products. Pyroprocessing uses electrorefining techniques to extract plutonium in combination with other transuranic elements, some of the rare earth fission products, and uranium. This fuel mixture would be intended for use in fast-neutron reactors, which have yet to be proven commercially viable.

Can these reprocessing techniques meet the highest proliferation-resistance standard of the "spent fuel standard" in which plutonium in its final form should be as hard to acquire, process, and use in weapons as is plutonium embedded in spent fuel?[7] The brief answer is "no" because the act of separating most or all of the highly radioactive fission products makes the fuel product less protected than the intrinsic protection provided by spent fuel. In fact, Dr. E.D. Collins of Oak Ridge National Laboratory has shown that the radiation emission from these reprocessed products is 100 times less than the spent fuel standard.[8] In other words, a thief could carry these products and not suffer a lethal radiation dose whereas the same thief would experience a lethal dose in less than one hour of exposure to plutonium surrounded by highly radioactive fission products. But these methods may still be worth pursuing depending on a detailed systems analysis factoring in security risks on site and during transportation, the final disposition of the material once it has been recycled as fuel, as well as the costs and benefits of nuclear waste management.

According to DOE's draft nonproliferation assessment of GNEP, "for a state with pre-existing PUREX or equivalent capability (or more broadly the capability to design and operate a reprocessing plant of this complexity), there is minimal proliferation resistance to be found by [using the examined reprocessing techniques] considering the potential for diversion, misuse, and breakout scenarios."[9] Moreover, the DOE assessment points out that these techniques pose additional safeguards challenges. For example, it is difficult to do an accurate accounting of the amount of plutonium in a bulk handling reprocessing facility that produces plutonium mixed with other transuranic elements.[10] This challenge raises the probability of diversion of plutonium by insiders.[11]

Another set of considerations is the choice of reactors to burn up the transuranic elements. The DOE draft assessment examined several choices including light water reactors, heavy water reactors, high temperature gas reactors, and fast-neutron reactors. Only the fast-neutron reactors offered the most benefits in terms of net consumption of

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7 Committee on International Security and Arms Control, National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*, Washington, DC: National Academy Press, 1994.

8 E.D. Collins, Oak Ridge National Laboratory, "Closing the Fuel Cycle Can Extend the Lifetime of the High-Level Waste Repository," American Nuclear Society 2005 Winter Meeting, November 17, 2005, p. 13.

9 *A Nonproliferation Impact Assessment for the Global Nuclear Energy Programmatic Alternatives*, p. 69.

10 J.E. Stewart et al., "Measurement and Accounting of the Minor Actinides Produced in Nuclear Power Reactors," Los Alamos National Laboratory, LA-13054-MS, January 1996, p. 21.

11 Ed Lyman, "U.S. Nuclear Fuel Reprocessing Initiative: DOE Research Shows Technology Does Not Reduce Risks of Nuclear Proliferation and Terrorism," Fact Sheet, Union of Concerned Scientists, February 2006.

transuranic material. This material would have to be recycled multiple times in fast reactors to consume almost all of it. This is called a full actinide recycle in contrast to a partial actinide recycle with the other reactor methods. The benefit from a waste management perspective is that the amount of time required for spent fuel's radiotoxicity to reduce to that of natural uranium goes from more than tens of thousands of years for partial actinide recycle to about 400 years for the full actinide recycle.

The challenge of the full actinide route, however, is that fast reactors can relatively easily be changed from a burner mode to a breeder mode. That is, these reactors can breed more plutonium by the insertion of uranium target material. The perceived need for breeder reactors has driven a few countries such as France, India, Japan, and Russia to develop reprocessing programs.

Alternative Nuclear Waste Management Programs of Other Nations

Has reprocessing programs, to date, helped certain nations solve their nuclear waste problems? The short answer is, "no." Before explicating that further, it is worth briefly examining why these countries began these programs. About fifty years ago, when the commercial nuclear industry was just starting, concerns were raised about the availability of enough natural uranium to fuel the thousands of reactors that were anticipated. Natural uranium contains 0.71 percent uranium-235, 99.28 percent uranium-238, and less than 0.1 percent uranium-234. Uranium-235 is the fissile isotope and thus is needed for sustaining a chain reaction. However, uranium-238 is a fertile isotope and can be used to breed plutonium-239, a fissile isotope that does not occur naturally. Thus, if uranium-238 can be transformed into plutonium-239, the available fissile material could be expanded by more than one hundred times, in principle. This observation motivated several countries, including the United States, to pursue reprocessing.

A related motivation was the desire for better energy security and thus less dependence on outside supplies of uranium. France and Japan, in particular, as countries with limited uranium resources, developed reprocessing plants in order to try to alleviate their dependency on external sources of uranium. They had invested in these plants before the realization that the world would not run out of uranium soon. By the late 1970s, two developments happened that alleviated the perceived pending shortfall. First, the pace of proposed nuclear power plant deployments dramatically slowed. There were plans at that time for more than 1,000 large reactors (of about 1,000 MWe power rating) by 2000, but even before the Three Mile Island accident in 1979, the number of reactor orders in the United States and other countries slackened off although France and Japan launched a reactor building boom in the 1970s that lasted through the 1980s. By 2000, there was only the equivalent of about 400 reactors of 1,000 MWe size. Second, uranium prospecting identified enough proven reserves to supply the present nuclear power demand for several decades to come.

Because there is plentiful uranium at relatively low prices and the cost of uranium enrichment has decreased, the cost of the once-through uranium cycle is significantly less than the cost of reprocessing. However, because fuel costs are a relatively small portion of the total costs of a nuclear power plant, reprocessing adds a relatively small amount to the total cost of electricity. In France, the added cost is almost six percent, and in Japan about ten percent. Nonetheless, in competitive utility markets in which consumers have choices, most countries have not chosen the reprocessing route because of the significantly greater fuel costs. France and Japan have adopted government policies in favor of reprocessing and also have sunk many billions of dollars into their reprocessing facilities. The French government owns and controls the electric utility Electricité de France (EDF) and the nuclear industry Areva. Despite this extensive government control, a 2000 French government study determined that if France stops reprocessing, it would save $4 to 5 billion over the remaining life of its reactor fleet.[12] EDF assigns a negative value to recycled plutonium.

While France's La Hague plant is operating, Japan is still struggling to start up its Rokkasho plant, which is largely based on the French design. Thus, the costs of the Japanese plant keep climbing and will likely be more than $20 billion. While the Japanese government wants to fuel up to one-third of its more than 50 reactors with plutonium-based mixed oxide fuel, local governments tend to look unfavorably on this proposal.

Only a few other nations are involved with reprocessing. Russia and the United Kingdom operate commercial-scale facilities. China and India are interested in heading down this path. But the United Kingdom is moving toward imminent shut down of its reprocessing mainly due to lack of customers. Moreover, the clean up and decommissioning costs are projected to be many billions of dollars. Russia and France also lack enough customers to keep their reprocessing plants at full capacity. In early April, I visited the French La Hague plant and was told that it is only operating at about half capacity. France only uses mixed oxide fuel in 20 of its 58 light water reactors. Presently, less than 10 percent of the world's commercial nuclear power plants burn MOX fuel. As stated earlier, the demand for MOX fuel has not kept up with the stockpiled quantities of plutonium.

With respect to nuclear waste management, an important point is that reprocessing, as currently practiced, does little or nothing to alleviate this management problem. For example, France practices a once-through recycling in which plutonium is separated once, made into MOX fuel, and the spent fuel containing this MOX is not usually recycled once (although France has done some limited recycling of MOX spent fuel). The MOX spent fuel is stored pending the further development and commercialization of fast reactors. But France admits that this full deployment of a fleet of fast reactors is projected to take place at the earliest by mid-century. France will shut down later this year its only fast reactor, the prototype Phénix. Perhaps around 2020, France may have constructed another fast reactor, but the high costs of these reactors have been prohibitive. In effect, France has shifted its nuclear waste problem from the power plants to the reprocessing plant.

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[12] *Economic Forecast Study of the Nuclear Option* (Planning Commission, Government of France, 2000), section 3.4.

France’s practice of transporting plutonium hundreds of miles from the La Hague to the MOX plant at Marcoule poses a security risk. While there has never been a theft of plutonium or a major accident during the hundreds of trips to date, each shipment contains many weapons’ worth of plutonium. Thus, just one theft of a shipment could be an international disaster.

No country has yet to open a permanent repository. But the country with the most promising record of accomplishment in this area is Sweden. A couple of weeks ago, Sweden announced the selection of its repository site but admits that the earliest the site will accept spent fuel is 2023. Sweden had carefully evaluated three different sites and obtained widespread community and local government involvement in the decision making process. France touts the benefits of the volume reduction of recycling in which highly radioactive fission products are formed into a glass-like compound, which is now stored at an interim storage site. By weight percentage, spent fuel typically consists of 95.6% uranium (with most of that being uranium-238), 3% stable or short-lived radioactive fission products, 0.3% cesium and strontium (the primary sources of high-level radioactive waste over a few hundred years), 0.1% long-lived iodine and technetium, 0.1% long-lived actinides (heavy radioactive elements), and 0.9% plutonium. But the critical physical factor for a repository is the heat load. For the first several hundred years of a repository the most heat emitting elements are the highly radioactive fission products. The benefit of a fast reactor recycling program could be the reduction or near elimination of the longer-lived transuranic elements that are the major heat producing elements beyond several hundred years.

Other countries may venture into reprocessing. Therefore, it is imperative for the United States to reevaluate its policies and redouble its efforts to prevent the further spread of reprocessing plants to non-nuclear-weapon states. In particular, the Republic of Korea is facing a crisis in the overcrowded conditions in the spent fuel pools at its power plants. One option is to remove older spent fuel and place it in dry storage casks, but the ROK government believes this option may cost too much because of the precedent set by the exorbitantly high price paid for a low level waste disposal facility. Another option is for the ROK to reprocess spent fuel. While this will provide significant volume reduction in the waste, it will only defer the problem to storage of MOX spent fuel, similar to the problem faced by France. This option will run counter to the agreement the ROK signed with North Korea in the early 1990s for both states to prohibit reprocessing or enrichment on the Korean Peninsula. A related option is to ship spent fuel to La Hague, but a security question is whether to ship plutonium back to the ROK. France would require shipment of the high level waste back to the ROK. Thus, the ROK will need a high level waste disposal facility. The main reason I raise this ROK issue at length is that the ROK and the United States have recently begun talks on the renewal of their peaceful nuclear cooperation agreement, which will expire in 2014. The United States has consent rights on ROK spent fuel because either it was produced with U.S.-supplied fresh fuel or U.S.-origin reactor systems. The ROK is seeking to have future spent fuel not subject to such consent rights by purchasing fresh fuel from other suppliers and by developing reactor systems that do not have critical components that are U.S.-origin or derived from U.S.-origin systems. The bottom line is that the United States is steadily losing its leverage with the ROK and other countries because of declining U.S. leadership in nuclear power plant systems and nuclear waste management.

Concerning lessons the United States can learn from other countries' nuclear waste management experience, the first lesson is that a fair political and sound scientific process is essential for selecting a permanent repository. Sweden demonstrates the effectiveness of examining multiple sites and gaining buy-in from the public and local governments. The second lesson is that reprocessing, as currently practiced, does not substantially alleviate the nuclear waste management problem. However, more research is needed to determine the costs and benefits of fast reactors for reducing transuranic waste. Any type of reprocessing will require safe and secure waste repositories.

While the United States investigates the costs and benefits of various recycling proposals through a research program, it has an opportunity now to exercise leadership in two waste management areas. First, as envisioned in GNEP, the United States should offer fuel leasing services. As part of those services, it should offer to take back spent fuel from the client countries. (Russia is offering this service to Iran's Bushehr reactor.) This spent fuel does not necessarily have to be sent to the United States. It could be sent to a third party country or location that could earn money for the spent fuel storage rental service. Spent fuel can be safely and securely stored in dry storage casks for up to 100 years. Long before this time ends, a research program will most likely determine effective means of waste management. The spent fuel leasing could be coupled to the second area where the United States can play a leadership role. That is, the United States can offer technical expertise and political support in helping to establish regional spent fuel repositories. A regional storage system would be especially helpful for countries with smaller nuclear power programs.

Recommendations

- Continue to discourage separation of plutonium from spent nuclear fuel.
- Limit the spread of reprocessing technologies to non-nuclear weapon states.
- Draw down the massive stockpile of civilian plutonium.
- Support a research program to assess the costs and benefits of various reprocessing technologies with attention focused on proliferation-resistance, safeguards, and nuclear waste management. Compare the costs and benefits of reprocessing to enrichment, factoring in the proliferation risks of both technologies.
- Increase funding for safeguards research.
- Promote safe and secure storage of spent fuel until the time when reprocessing may become economically attractive.

- Evaluate multiple sites for permanent waste repositories based on political fairness and sound scientific assessments. Obtain buy-in from the public and local governments.

- Use secure interim spent fuel storage employing dry storage casks to relieve build up on spent fuel pools.

- Provide fuel leasing services that would include take back of spent fuel to either the fuel supplier state or a third party.

- Develop regional spent fuel storage facilities.

- Obtain better estimates on the remaining global reserves of uranium.

- Provide research support for developing more efficient nuclear power plants that would produce more electrical power per thermal power than today's fleet of reactors. Similarly, research more effective ways to make more efficient use of uranium fuel and reduce the amounts of plutonium-239 produced.

Biography

Dr. Charles D. Ferguson is the Philip D. Reed senior fellow for science and technology at the Council on Foreign Relations (CFR). He is also an adjunct professor in the security studies program at Georgetown University, where he teaches a graduate-level course titled "Nuclear Technologies and Security," and an adjunct lecturer in the national security studies program at the Johns Hopkins University, where he teaches a graduate-level course titled "Weapons of Mass Destruction Technologies." His areas of expertise include arms control, climate change, energy policy, and nuclear and radiological terrorism. At CFR, he specializes in analyzing nuclear energy, nuclear nonproliferation, and the prevention of nuclear terrorism. He has written the Council Special Report *Nuclear Energy: Balancing Benefits and Risks*, published in April 2007. Most recently, he served as the project director for the CFR-sponsored Independent Task Force on U.S. Nuclear Weapons Policy, chaired by William Perry and Brent Scowcroft. The task force report was published in April 2009.

Prior to arriving at CFR in September 2004, Dr. Ferguson worked as the scientist-in-residence at the Monterey Institute's Center for Nonproliferation Studies (CNS). At CNS, he co-authored (with William Potter) the book *The Four Faces of Nuclear Terrorism* (Routledge, 2005). He was also the lead author of the award-winning report *Commercial Radioactive Sources: Surveying the Security Risks*, which was published in January 2003 and was one of the first post-9/11 reports to assess the radiological dispersal device, or "dirty bomb," threat. This report won the 2003 Robert S. Landauer Lecture Award from the Health Physics Society.

Dr. Ferguson has consulted with the International Atomic Energy Agency, the Los Alamos National Laboratory, Sandia National Laboratories and the National Nuclear Security Administration. He served as a physical scientist in the Office of the Senior Coordinator for Nuclear Safety at the U.S. Department of State, where he helped develop U.S. government policies on nuclear safety and security issues. He has also worked on nuclear proliferation and arms control issues as a senior research analyst and director of the nuclear policy project at the Federation of American Scientists.

After graduating with distinction from the United States Naval Academy, he served as an officer on a fleet ballistic missile submarine and studied nuclear engineering at the Naval Nuclear Power School. Dr. Ferguson has written numerous articles on energy policy, missile defense, nuclear arms control, nuclear energy, nuclear proliferation, and nuclear terrorism. These publications have appeared in the *Bulletin of the Atomic Scientists*, the *Christian Science Monitor*, *Issues in Science and Technology*, the *International Herald Tribune*, the *Los Angeles Times*, the *National Interest* online, the *Wall Street Journal*, and the *Washington Post*. He has also authored or coauthored several peer-reviewed scientific articles and published in top physics journals. He holds a PhD in physics from Boston University.