United States Government Accountability Office

GAO

Report to the Chairman, Subcommittee on Emerging Threats and Capabilities, Committee on Armed Services, U.S. Senate

July 2004

# NUCLEAR NONPROLIFERATION

# DOE Needs to Take Action to Further Reduce the Use of Weapons-Usable Uranium in Civilian Research Reactors


GAO-04-807

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Highlights

Highlights of GAO-04-807, a report to the Chairman, Subcommittee on Emerging Threats and Capabilities, Committee on Armed Services, U.S. Senate

## Why GAO Did This Study

Nuclear research reactors worldwide use highly enriched uranium (HEU) as fuel and for the production of medical isotopes. Because HEU can also be used in nuclear weapons, the Department of Energy's (DOE) Reduced Enrichment for Research and Test Reactors program is developing low enriched uranium (LEU), which would be very difficult to use in weapons, to replace HEU. To date, 39 of the 105 research reactors in the United States and abroad targeted by DOE have converted to LEU fuel. GAO was asked to examine (1) the status of the remaining research reactors in converting to LEU fuel, (2) DOE's progress in developing new LEU fuels for reactors where conversion is not yet technically feasible, (3) DOE's progress in developing LEU for the production of medical isotopes, and (4) the status of DOE and Nuclear Regulatory Commission (NRC) efforts to improve security at research reactors.

## What GAO Recommends

GAO recommends that DOE consider converting the 6 U.S. university research reactors, remove the HEU fuel from the reactors after their conversion, and evaluate providing additional incentives to foreign research reactors to convert to LEU. DOE agreed with our recommendations. GAO did not fully evaluate, and is not making recommendations on, DOE and NRC efforts to improve security at research reactors.

www.gao.gov/cgi-bin/getrpt?GAO-04-807.

To view the full product, including the scope and methodology, click on the link above. For more information, contact Gene Aloise at (202) 512-3841 or aloisee@gao.gov.

## What GAO Found

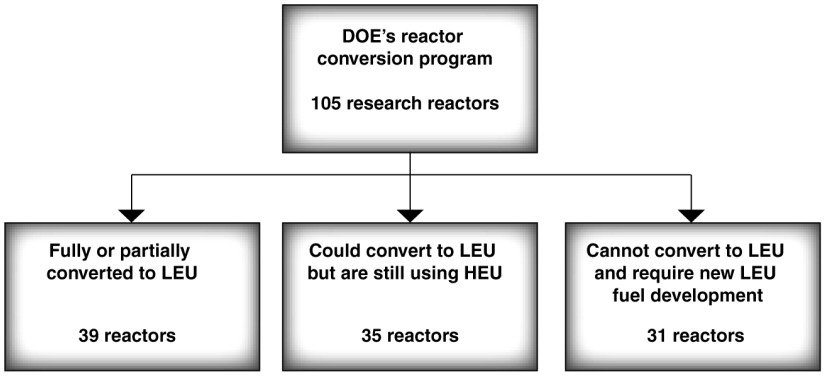
Currently, conversion to LEU fuel is technically feasible for 35 of the 66 research reactors in DOE's program that still use HEU fuel, but most do not have plans to convert. In the United States, 8 research reactors, including 6 university research reactors, have not converted because DOE has not provided the necessary funding. Of the 20 foreign research reactors that use U.S.-origin HEU fuel, 14 do not have plans to convert because they have a sufficient supply of HEU fuel and either do not want to incur the additional cost of conversion or do not have the necessary funding. Finally, only 1 of 7 Russian-supplied research reactors that could use LEU fuel is scheduled to convert.

Conversion to LEU fuel is not technically feasible for 31 research reactors worldwide that still use HEU fuel. DOE has experienced technical setbacks in fuel development that have postponed the conversion of the 31 reactors until 2010 at the earliest. One fuel failed unexpectedly in testing, and DOE may cancel further development, depending on the results of additional tests. Initial testing of another LEU fuel produced positive results, but additional testing is required and the fuel will not be developed until 2010 at the earliest.

Separately from the development of LEU fuel, DOE is developing LEU to replace HEU in the production of medical isotopes. DOE has not yet completed the work that would enable conversion of large-scale medical isotope production to LEU. One reactor has converted to LEU for small-scale production. However, large-scale producers are concerned that the cost of converting to LEU could be prohibitive.

DOE and NRC have taken steps to improve security at foreign and U.S. research reactors. While operators at most research reactors we visited said that security had been upgraded through DOE or NRC efforts, we observed areas where further improvements could be made. Recognizing the possible need for further improvements, DOE and NRC are engaged in separate efforts to assess and improve security.

**Conversion Status of Research Reactors Included in DOE's Reactor Conversion Program**




Source: Argonne National Laboratory.

# Contents

# Figures



## Abbreviations

| | |
|---|---|
| Argonne | Argonne National Laboratory |
| DOE | Department of Energy |
| HEU | highly enriched uranium |
| INEEL | Idaho National Engineering and Environmental Laboratory |
| LEU | low enriched uranium |
| NDF | Nonproliferation and Disarmament Fund |
| NRC | Nuclear Regulatory Commission |
| RERTR | Reduced Enrichment for Research and Test Reactors program |

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**United States Government Accountability Office**
**Washington, D.C. 20548**

July 30, 2004

The Honorable Pat Roberts
Chairman, Subcommittee on
Emerging Threats and Capabilities
Committee on Armed Services
United States Senate

Dear Mr. Chairman:

Nuclear research reactors located throughout the world play a vital role in medicine, agriculture, industry, and basic scientific research. Many of the research reactors use highly enriched uranium (HEU) in one of two ways, either as fuel or as an ingredient for the production of medical isotopes used to treat cancer or conduct medical diagnoses. HEU is also a key component in the construction of nuclear weapons—it takes as little as 25 kilograms of HEU to build a nuclear weapon. The amount of HEU located at research reactors worldwide ranges from several kilograms to in excess of 20 kilograms.

The United States has a long-standing policy of reducing and, to the extent possible, eliminating the use of HEU in civilian research reactors. To support this policy, the Department of Energy (DOE) initiated the Reduced Enrichment for Research and Test Reactors (RERTR) program in 1978 to develop the technology to reduce and eventually eliminate the use of HEU in civilian research reactors worldwide.[1] DOE's Argonne National Laboratory (Argonne) is the technical lead for the program and conducts research and development to find alternatives to the two uses of HEU in research reactors. The program's goal is to replace HEU with low enriched uranium (LEU), which would be very difficult to use in nuclear weapons.[2] The Secretary of Energy reiterated DOE's support for the reactor conversion program and committed to the conversion of all U.S. civilian research reactors by 2013 in a speech on May 26, 2004.

To achieve the program's objectives, Argonne conducts extensive tests on new LEU fuels and materials for isotope production to find suitable

[1]In this report, we refer to the RERTR program as the reactor conversion program.

[2]HEU is enriched in the isotope uranium-235 to 20 percent or greater. LEU is enriched to less than 20 percent.

alternatives that do not negatively affect research reactors' performance, operating costs, or operational safety. Part of Argonne's strategy is to have multiple fuels under development to address the unique fuel needs of the different types of research reactors included in DOE's reactor conversion program. Research reactors are designed for different purposes and have operating characteristics that affect their ability to convert to LEU. As a result, an LEU fuel that can be used in one research reactor may not be suitable for another.

The scope of DOE's reactor conversion program includes LEU fuel development for 105 research reactors located in the United States and 40 other countries. Since the inception of the program through July 2004, 39 of the 105 reactors have either converted or are in the process of converting to LEU. Argonne officials estimate that prior to converting to LEU, these 39 research reactors used over 240 kilograms of HEU fuel per year, enough to build about 10 nuclear weapons. In contrast, they estimate that the remaining 66 research reactors, which have not converted to LEU, continue to use over 800 kilograms of HEU fuel per year. Thirty-five of these reactors could convert using currently available LEU fuels, and Argonne is developing new LEU fuels for 31 research reactors that cannot convert using any of the fuels already developed. In particular, after screening a large number of potential LEU fuels, Argonne has identified two fuels, dispersion fuel and monolithic fuel, for further testing and development. Both of these fuels use an alloy of uranium and another metal called molybdenum and differ in how the fuel is manufactured. Dispersion fuel consists of spherical particles of uranium-molybdenum alloy that are randomly dispersed in a thin layer of aluminum. In contrast, monolithic fuel consists of a thin sheet of solid uranium-molybdenum alloy.[3]

The reactor conversion program also develops LEU alternatives for six medical isotope producers, all located outside the United States, that use an estimated 85 kilograms of HEU per year in their production processes. The use of HEU for medical isotope production is separate from the type of fuel used in research reactors. Developing the technology to convert to LEU for medical isotope production requires a technical effort that is separate from the development of new LEU fuels.

[3]In this report, we use the terms "dispersion fuel" and "monolithic fuel" to refer specifically to the new LEU fuels being developed by the reactor conversion program that use an alloy of uranium and molybdenum.

Concerned about the potential theft or diversion of HEU from research reactors, DOE and the Nuclear Regulatory Commission (NRC) are engaged in efforts to monitor and improve security at research reactors, many of which are located on university campuses or other facilities used by students and researchers. Since 1974, DOE has engaged in efforts to improve nuclear material security in over 50 countries, including security over nuclear material at research reactors. In the United States, NRC regulates research reactors to ensure an acceptable level of safety and security and conducts regular inspections to ensure compliance with regulations on safety and security.

In response to your request concerning the use of HEU at civilian research reactors, we examined (1) the status of research reactors worldwide in converting to LEU fuels developed by DOE's reactor conversion program, (2) the program's progress in developing new LEU fuels for use in research reactors that cannot convert to currently available LEU fuels, and (3) the program's progress in developing LEU for use in the production of medical isotopes. In addition, because HEU continues to be used and stored at research reactors worldwide, we gathered information on the status of DOE and NRC efforts to improve the security of research reactors in the United States and other countries.

To address these objectives, we analyzed documentation on the reactor conversion program from DOE and Argonne, including information on the status of reactors in converting to LEU, development of LEU fuels, and development of LEU for medical isotope production. We visited research reactors in the United States, Belgium, Germany, the Netherlands, Poland, Portugal, Romania, Russia, and Ukraine; attended an annual international conference on DOE's reactor conversion program; and obtained information on the status of developing LEU fuels and LEU for the production of medical isotopes from reactor conversion program officials at Argonne. We also discussed the status of the program and security of HEU at foreign and domestic research reactors with foreign officials in the countries we visited and with DOE and NRC officials. However, we did not evaluate the effectiveness of the security at research reactors or DOE and NRC efforts to improve security. We conducted our review from July 2003 to July 2004 in accordance with generally accepted government auditing standards.

You also asked that we examine two other DOE programs closely related to the reactor conversion program: the Foreign Research Reactor Spent Nuclear Fuel Acceptance program and the Russian Research Reactor Fuel

Return program. The Foreign Research Reactor Spent Nuclear Fuel Acceptance program is intended to recover and store U.S.-origin research reactor fuel, including both HEU and LEU, from 41 eligible countries throughout the world. The Russian Research Reactor Fuel Return program assists in the return of Russian-origin research reactor fuel to Russia, mostly from countries of the former Soviet Union and Central and Eastern Europe. Together with DOE's reactor conversion program, these programs support the objective of reducing and eventually eliminating the use of HEU for civilian applications. As agreed with your office, we will address these two programs in a follow-on report.

## Results in Brief

According to Argonne's analysis, conversion to LEU fuel is technically feasible for 35 of the 66 research reactors in DOE's reactor conversion program that still use HEU fuel, but most do not have plans to convert. In the United States, 8 research reactors, including 6 university reactors, could convert to LEU fuel, but DOE has not provided the necessary funding (estimated by DOE at about $5 million to $10 million per reactor). In addition, a university research reactor that converted to LEU in 2000 is still storing HEU fuel because DOE has not removed it. DOE officials said they have not made the conversion of the 6 university research reactors a priority because the reactors use only a small amount of HEU fuel. Officials at NRC, which regulates most of the U.S. research reactors included in DOE's reactor conversion program, said that they consider the conversion of the university reactors a security enhancement and one of their priorities and that the delay is purely a matter of funding. Operators of the 6 reactors said they would convert to LEU fuel when DOE provides the funding. DOE's reactor conversion program cooperates closely with operators of foreign research reactors and promotes conversion from HEU to LEU. Ultimately, however, it is the owners of the foreign reactors that make the decision to convert to LEU. Of the 20 foreign research reactors that use U.S.-origin HEU fuel, 14 do not have plans to convert to LEU because they generally have a sufficient supply of HEU and either do not want to incur the additional cost of conversion or do not have the necessary funding. Finally, since DOE's reactor conversion program initiated cooperation with Russia in 1993, no research reactors that use HEU fuel supplied by Russia have converted. Only 1 of 7 Russian-supplied research reactors that could use LEU fuel is scheduled to convert. DOE officials said that 5 other Russian-supplied reactors are also likely to convert to LEU fuels that are currently available or are expected to become available within the next year.

Technical setbacks in developing new LEU fuels have postponed the conversion of 31 research reactors worldwide that cannot use currently available LEU fuels until 2010 at the earliest. According to Argonne officials, unexpected failures that occurred when testing dispersion fuel—the worst they have ever experienced during fuel development—could render the fuel unusable for most research reactors. As a result of the test failures, Argonne has delayed the completion of dispersion fuel until 2010 and may recommend that DOE cancel further development altogether if the fuel cannot be sufficiently improved. Canceling development of dispersion fuel would leave monolithic fuel as the reactor conversion program's only remaining option for converting the remaining 31 reactors. Initial testing of monolithic fuel has produced positive results, and if tests continue to be successful, it should perform better than dispersion fuel. However, the development process is still at the beginning stages; additional testing is required, and the fuel will not be developed until 2010 at the earliest. Argonne officials said that the current fuel development schedule is already compressed and that no further acceleration is possible. Rather, any technical problems would likely result in further delays. Furthermore, if both fuels fail, Argonne is not working on any other LEU fuel that could replace HEU in the remaining research reactors.

DOE's reactor conversion program has not yet completed the work that would enable conversion of large-scale medical isotope production to LEU, and large-scale producers are concerned that the cost of converting to LEU could be prohibitive. Currently, one reactor in Argentina has converted from using HEU to LEU for the small-scale production of medical isotopes. Argonne officials said that further development is necessary on using LEU for large-scale production. Large-scale producers have built expensive facilities designed to produce medical isotopes using HEU. Any attempt to adapt the facilities to use LEU would involve additional costs. Furthermore, using LEU instead of HEU would increase the amount of waste generated by the production process. Argonne officials said they are working to overcome these challenges and expect to complete development of LEU for large-scale medical isotope production in 2 to 3 years. Two large producers of medical isotopes told us that conversion to LEU would be difficult and costly, and one of them is currently assessing the economic feasibility of conversion.

While operators at most research reactors we visited said that security had been upgraded through DOE or NRC efforts, we also observed areas where further improvements could be made. Recognizing the possible need for further improvements, DOE and NRC are engaged in separate efforts to

assess and improve security at foreign and domestic research reactors, respectively. A DOE task force established in 2004 is currently gathering information on all research reactors worldwide, including reactors that have been shut down, and prioritizing the need for increased security at reactors based on a number of factors, including how much HEU is stored on site. According to DOE officials, the task force addresses the need to combine data from different sources to identify potential security gaps. The task force has submitted a report to the Secretary of Energy with recommendations for possible implementation by DOE. The task force efforts are in addition to assistance that DOE has provided since 1974 to other countries to improve security at their research reactors. In the United States, NRC is conducting assessments of the security at research reactors under its jurisdiction and may increase security requirements based on the results of the assessments. NRC took actions after the attacks of September 11, 2001, to improve the security at domestic research reactors—for example, by requiring that some reactors consider installing additional physical barriers.

We are making recommendations to the Secretary of Energy and the Administrator of the National Nuclear Security Administration to consider placing a higher priority on converting the 6 U.S. university research reactors that are able to convert with existing LEU fuel, to place a high priority on removing the HEU fuel from the reactors after their conversion and transporting it to the appropriate DOE facility, and to evaluate the costs and benefits of providing additional incentives to foreign research reactors that currently use U.S.-origin HEU fuel to convert to LEU.

We provided draft copies of this report to the Departments of Energy and State and to NRC for their review and comment. DOE, State, and NRC generally agreed with the recommendations in our report and provided detailed comments, which we incorporated into the report as appropriate.

## Background

Nuclear research reactors are used for training and research purposes throughout the world. Research reactors are generally smaller than nuclear power reactors, ranging in size from less than 1 to 250 megawatts compared with 3,000 megawatts generated by a typical power reactor. In addition, unlike power reactors, many research reactors use HEU fuel instead of LEU in order to produce the appropriate conditions in the reactor cores for conducting a wide variety of research. DOE has identified 161 operating research reactors that were designed to use HEU fuel and has included 105 of them in the reactor conversion program. The research reactors included in the program are spread out among the United States and 40 other countries, including Canada, France, Germany, and Russia (see fig. 1).

**Figure 1: Locations of 105 Research Reactors Included in DOE's Reactor Conversion Program**


| Western and Eastern Europe | Number of Reactors |
|---|---|
| Austria | 2 |
| Belgium | 1 |
| Bulgaria | 1 |
| Czech Republic | 2 |
| Denmark | 1 |
| France | 5 |
| Germany | 5 |
| Greece | 1 |
| Hungary | 1 |
| Netherlands | 3 |
| Poland | 1 |
| Portugal | 1 |
| Romania | 1 |
| Slovenia | 1 |
| Sweden | 2 |
| Switzerland | 1 |
| Turkey | 1 |
| Ukraine | 1 |
| United Kingdom | 3 |

Source: Argonne National Laboratory.


Western and
Eastern Europe
Russia
14
Kazakhstan
2
North Korea
1
Japan
5
Taiwan
1
Vietnam
1
Philippines
1
Iran
1
Israel
1
Libya
2
Pakistan
1
Uzbekistan
1
Australia
1
South Africa
1

In addition to the 105 research reactors covered under the reactor conversion program, DOE has targeted six medical isotope producers that use HEU as an ingredient in their production processes, including four large medical isotope producers located in Belgium, Canada, the Netherlands, and South Africa.

For a variety of reasons, DOE has excluded from its reactor conversion program 56 research reactors that use HEU fuel, including 9 in the United States. Some of the reactors are used for military or other purposes, such as space propulsion, that require HEU. Others are located in countries such as China that so far have not cooperated with the United States on converting their reactors to LEU. Finally, the time and costs associated with developing LEU fuel for some of the reactors may exceed their expected lifetime and usefulness.

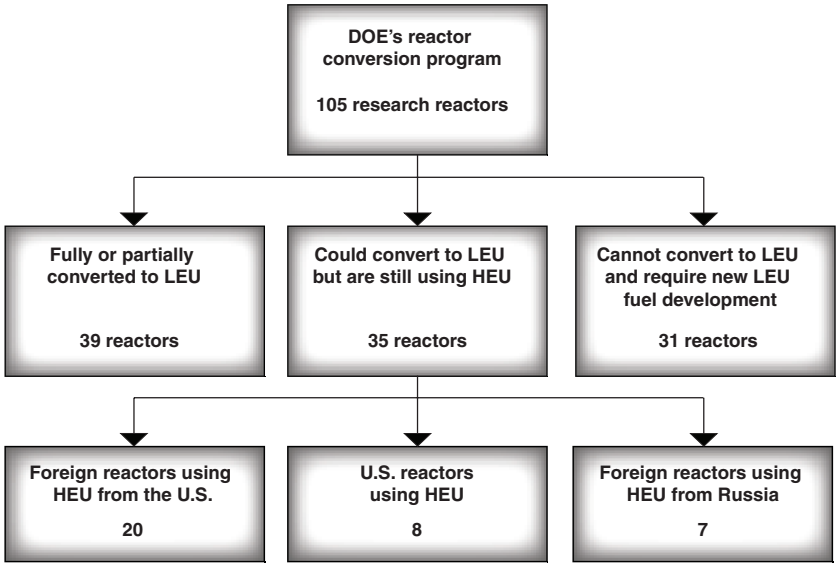
The United States has historically provided nuclear technology to foreign countries in exchange for a commitment not to develop nuclear weapons. Starting in 1953, the Atoms for Peace program supplied research reactors and the fuel needed to operate them to countries around the world. The research reactors supplied by the Atoms for Peace program initially used LEU fuel, but many countries gradually switched from LEU to HEU in order to conduct more advanced research. In addition, HEU fuel could remain in the reactor core longer and was less expensive than LEU fuel. By the late 1970s, most research reactors were using HEU fuel and the United States was exporting about 700 kilograms of HEU a year to foreign research reactors. Like the United States, the Soviet Union also exported research reactors and the HEU fuel to operate them to other countries.

In order to achieve the program's objective of reducing the use of HEU in civilian research reactors, Argonne is developing new LEU fuels in cooperation with counterparts in other countries, including Argentina, France, and Russia. Developing LEU fuels involves testing fuel samples in research reactors to determine how the fuels behave under normal operating conditions. Fuel manufacturers and reactor operators around the world participate in the program by manufacturing and testing LEU fuels. Owners of foreign research reactors fund conversion of their reactors from HEU to LEU. In 1993, Argonne expanded the reactor conversion program to include cooperation with Russia on the conversion of Russian-supplied research reactors to LEU fuel. The Soviet Union had independently initiated a program in 1978 to reduce the enrichment of HEU fuel in research reactors but suspended the program in 1989 due to lack of funding. Russian-supplied research reactors use fuels manufactured in

Russia that are not interchangeable with fuels used by U.S.-supplied research reactors. Therefore, DOE's reactor conversion program differentiates between U.S.-supplied and Russian-supplied research reactors.

Since the reactor conversion program's inception in 1978, 39 of the 105 research reactors included in the program have either converted or are in the process of converting to LEU fuel. (See app. II for a list of converted research reactors.)[4] Of the remaining 66 research reactors that still use HEU fuel, 35 can convert using currently available LEU fuels but have not done so, and 31 cannot convert to any currently available LEU fuels and still require HEU in order to conduct the research for which they were designed (see fig. 2).

**Figure 2: Conversion Status of 105 Research Reactors Included in DOE's Reactor Conversion Program**




Source: Argonne National Laboratory.

[4]In comments on a draft of this report, the State Department also noted that a growing number of new and planned research reactors have decided to use LEU fuel.

A research reactor can begin the conversion process after a suitable LEU fuel is developed and available commercially. The decision to convert from HEU to LEU also depends on research reactor owners having the necessary financial resources, including for the purchase of new fuel. In the United States, NRC regulations require that research reactors under its jurisdiction, including reactors operated by universities, convert to LEU fuel when an LEU fuel that can be used to replace HEU fuel has been developed and when federal funding is made available for the conversion.[5] The conversion process begins with analyses to determine whether the reactor can safely convert and the impact of conversion on the reactor's performance. After the analyses are completed and regulatory approval for conversion is obtained, the operator can remove the HEU from the reactor and replace it with the new LEU fuel. The HEU fuel can be disposed of once it has been removed from the reactor core and has cooled.

## Many Domestic and Foreign Research Reactors Are Still Using Weapons-Usable Uranium Even Though They Could Operate on Low Enriched Uranium

According to Argonne's analysis, conversion to LEU fuel is technically feasible for 35 of the 66 research reactors worldwide that still use HEU fuel. However, only 4 of the reactors—3 foreign reactors that use U.S.-origin HEU and 1 Russian-supplied reactor—currently have plans to convert. Eight U.S. research reactors, including 6 university reactors, could convert to LEU fuel, but according to DOE officials, DOE has not provided the funding to convert them. In addition, DOE has not removed HEU fuel from a university research reactor that has been storing HEU since it converted to LEU in 2000. According to Argonne officials, of the 20 foreign research reactors that currently use U.S.-origin HEU fuel, 14 do not have plans to convert to LEU because they generally have a sufficient supply of HEU and either do not want to incur the additional cost of conversion or do not have the necessary funding. Finally, since DOE's reactor conversion program initiated cooperation with Russia in 1993, no research reactors that use HEU fuel supplied by Russia have converted. According to Argonne officials, only 1 of 7 Russian-supplied research reactors that could use LEU fuel is scheduled to convert. They said that 5 other Russian-supplied reactors are likely to convert to LEU fuels that are currently available or are expected to become available within the next year.

[5]10 C.F.R. § 50.64. The NRC regulates most of the U.S. research reactors included in DOE's reactor conversion program, with the exception of 4 DOE research reactors.

## Eight Research Reactors in the United States Could Convert to Low Enriched Uranium but Still Use Weapons-Usable Uranium

In the United States, there are 6 university research reactors and 2 other research reactors that could convert to LEU fuel but still use HEU fuel. Although DOE has funded the conversion of 11 university research reactors to LEU fuel, the last university reactor converted in 2000. DOE officials said DOE has not provided the funding to convert the 6 remaining U.S. university reactors. DOE recently added 2 other domestic reactors to the reactor conversion program, and neither of these reactors currently has plans to convert to LEU, also because DOE has not provided the necessary funding. (See table 1 for a list of the 8 reactors.)

**Table 1: U.S. Research Reactors Using HEU Fuel That Could Convert to LEU**

| Reactor |
|---|
| Oregon State University |
| Purdue University |
| Texas A&M University |
| University of Florida |
| University of Wisconsin |
| Washington State University |
| General Electric NTR Reactor |
| DOE NRAD Reactor |

Source: Argonne.

Note: The amount of HEU fuel used by these research reactors ranges from 0 to 0.2 kilograms per year. Reactors that use zero kilograms of HEU per year use HEU fuel but operate at such low power levels that they use up the fuel very slowly and can operate for many years or for their entire lifetime without replacing fuel.

In addition, the university research reactor that converted to LEU in 2000 is still storing HEU fuel because DOE has not removed it. Because the reactor now uses LEU fuel and has no need for HEU, the reactor operator told us that he is eager to return the HEU to DOE for long-term storage and disposal. DOE has a separate program that supports university research reactors, including provision of DOE-owned fuel, and funds their conversion to LEU and removal of spent fuel.[6] According to the DOE

[6]DOE's Office of Nuclear Energy, Science and Technology administers the program for supporting domestic university reactors. The program has an annual budget of about $18 million and provides a variety of assistance such as research grants, tuition assistance for nuclear engineering students, and funding to upgrade reactor facilities.

official in charge of the university reactor support program, the program has limited funding, and requests for additional funding to support conversion have not been approved by the Office of Management and Budget. Furthermore, the university reactor support program did not receive additional funding to remove HEU fuel from the research reactor that converted to LEU in 2000 until fiscal year 2004, after a group of domestic research reactor operators successfully lobbied Congress to add $2.5 million to the program's budget to pay for the removal of spent fuel from the reactors.

Officials at NRC, which regulates the 6 university reactors, told us that they consider the conversion of the reactors to LEU, the timely removal of HEU fuel after conversion, and the removal of HEU from the reactor that converted to LEU in 2000 as a security enhancement and one of their priorities. NRC officials said that converting the 6 reactors is technically feasible and that the delay in converting the reactors is purely a matter of funding and should be expedited by DOE. However, DOE officials said that DOE had not made the conversion of these reactors a priority. Furthermore, while operators at all 6 universities told us they are willing to convert to LEU fuel, they said it is not a high priority because they do not consider their HEU fuel to be a likely target for theft. For example, one reactor operator explained that the reactor is structured in such a way that the HEU is located inside a concrete enclosure that even experienced reactor staff need almost 2 days to access. These 6 reactors use only a small amount of HEU fuel—less than a kilogram per year, which is not enough to make a nuclear weapon. In contrast, there are other research reactors included in DOE's reactor conversion program that are larger than the 6 university reactors and use tens of kilograms per year.

Nevertheless, operators of the 6 university research reactors said they would convert to LEU when DOE provides funding. Furthermore, the DOE official in charge of the university reactor support program said that converting domestic university reactors is an issue of U.S. nonproliferation policy. He said that converting domestic reactors to LEU would support U.S. efforts to influence foreign reactors to convert to LEU in accordance with the U.S. nonproliferation policy to reduce the use of HEU in civilian research reactors worldwide. Although they did not consider conversion a priority from a security perspective, two of the university reactor directors we spoke with recognized the importance of converting university reactors to LEU as part of U.S. nonproliferation policy.

According to DOE officials, conversion for each reactor is projected to cost between $5 million and $10 million. However, a project engineer at DOE's Idaho National Engineering and Environmental Laboratory who tracks DOE expenditures on conversions of U.S. university reactors had originally told us that conversion would cost between $2 million and $4 million per reactor, depending on the type of reactor. DOE could not provide documentation to support either of the estimates. DOE officials said that conversion costs for 4 of the university reactors are higher because their fuel is no longer manufactured in the United States and must be purchased in France.[7]

Other than funding, there are no significant obstacles to converting the 6 university reactors to LEU. Based on our visits to 3 converted university research reactors and interviews with Argonne officials and the operators of the 6 remaining university reactors, converting to LEU does not reduce the performance of the reactors to the point that they cannot be used to conduct research and train students effectively. Operators at 5 of the 6 university reactors still using HEU fuel told us they expected performance to be adequate after conversion. In addition, operators of converted reactors told us that using LEU instead of HEU reduced security concerns and had a minimal impact on the cost of operating the reactors. Argonne officials said that one of their objectives when providing technical assistance to convert reactors to LEU is to complete the process with only minimal effects on performance and operating costs. In fact, two reactor operators (one in Rhode Island and one in Massachusetts) told us that performance at their reactors had improved as a result of conversion.

According to Argonne officials, 2 other reactors in the United States (the DOE NRAD and General Electric NTR reactors) could convert to LEU but are not currently planning to do so. The officials said they recently added these 2 reactors to the scope of the reactor conversion program so that the program would be comprehensive in its coverage of civilian research reactors that use HEU. The NRAD research reactor is a DOE reactor, and DOE would have to fund the purchase of new LEU fuel if a decision were made to convert the reactor. According to a DOE official responsible for the reactor, the budget for the NRAD reactor is limited, and purchasing new LEU fuel to convert the reactor would take funding away from other

[7]If DOE provides funding for converting these 4 university reactors, the schedule depends on the ability of the French manufacturer to supply the fuel in a timely manner. However, the French supplier is not accepting new requests for reactor fuel until 2007.

activities at the facility where the reactor is located. The DOE official considers the conversion of this reactor a lower priority because it has a sufficient supply of HEU fuel to last for the life of the reactor and because the facility has other nuclear material that would be more attractive to terrorists than the HEU fuel in the reactor. The General Electric NTR is a privately owned reactor and is also not required to convert until DOE provides funding.

## Twenty Foreign Research Reactors Continue to Use Weapons-Usable Uranium Fuel

Fourteen of the 20 foreign research reactors that currently use U.S.-origin HEU fuel do not have plans to convert to LEU. According to Argonne officials, these reactors generally have a supply of HEU sufficient to last many years (in some cases for the life of the reactor) and either do not want to incur the additional cost of conversion or do not have the necessary funding. Three of the reactors are planning to convert to LEU, and 3 others currently plan to shut down (or, in the case of 2 reactors, convert to LEU fuel if they do not shut down). See table 2 for a list of the 20 reactors.

**Table 2: 20 Foreign Research Reactors Still Using HEU Obtained from the United States**

| Country | Reactor | Status |
|---|---|---|
| Argentina | RA-6 | Conversion planned |
| Canada | Slowpoke-Alberta | |
| | Slowpoke-Halifax | |
| | Slowpoke-Saskatchewan | |
| France | MINERVE | |
| | Ulysee-Saclay | |
| Germany | FRJ-2 | Conversion planned |
| Israel | IRR-1 | Shutdown planned |
| Jamaica | Slowpoke | |
| Japan | KUCA | |
| | UTR-10 Kinki | |
| | KUR | Shutdown or conversion planned |
| Mexico | TRIGA | |
| Netherlands | HFR Petten | Conversion planned |
| | LFR | |
| Portugal | RPI | Shutdown or conversion planned |

*(Continued From Previous Page)*

| Country | Reactor | Status |
|---|---|---|
| South Africa | SAFARI | |
| United Kingdom | Consort | |
| | Neptune | |
| | Viper | |

Source: Argonne.

Note: The amount of HEU fuel used by these research reactors ranges from 0 to 38.3 kilograms per year. Reactors that use zero kilograms of HEU per year use HEU fuel but operate at such low power levels that they use up the fuel very slowly and can operate for many years or for their entire lifetime without replacing fuel.

Some of the foreign research reactors would like to convert but do not have the necessary funding. For example, the operator of a research reactor in Jamaica told us that converting to LEU would improve the reactor performance but that purchasing LEU fuel for the reactor would cost $1.5 million, which is more than the reactor operator can afford. Therefore, the reactor operator is planning to continue using its current supply of HEU, which will last possibly 20 years. Similarly, according to Argonne officials, the reactor operator in Mexico would be willing to convert to LEU but does not have the necessary funding. While funding may not be an issue for other foreign reactors, many of them are designed to operate on a small amount of fuel meant to last for the life of the reactor. Converting to LEU would require the disposal of the fuel that the reactor operator had already purchased and is still usable. According to Argonne officials, operators of certain reactors in France, Japan, the Netherlands, and the United Kingdom do not have plans to convert because the reactors have lifetime cores that do not need to be replaced.

To support the objective of the reactor conversion program to reduce and eventually eliminate the use of HEU in research reactors, the United States has implemented policies designed to influence foreign research reactors to convert to LEU. For example, DOE's Foreign Research Reactor Spent Nuclear Fuel Acceptance program provides foreign reactors that use HEU fuel of U.S.-origin the opportunity to return their spent fuel to the United States if they agree to convert their reactors to LEU fuel. In addition, the Energy Policy Act of 1992 authorizes NRC to approve the export of HEU to foreign research reactors only if the recipients agree to convert the reactors once a suitable LEU fuel is developed.[8] Since there are limited suppliers of HEU fuel and few options for disposing of spent fuel, the U.S.

[8]42 U.S.C. § 2160d.

policies in support of the reactor conversion program have been effective in influencing some research reactors to convert to LEU. In particular, of the 20 foreign reactors that can convert to LEU but are still using HEU, the 2 that use the greatest amount of HEU per year are planning to convert by 2006. One research reactor in the Netherlands (HFR Petten) formally agreed with the United States to convert to LEU in order to continue receiving U.S.-origin HEU fuel until conversion could take place and to ship spent fuel back to the United States. The U.S. policies in support of conversion were effective in influencing the reactor operator because the reactor uses 38 kilograms of HEU fuel per year and regularly needs to obtain new HEU fuel and dispose of spent fuel. Similarly, the FRJ-2 reactor in Germany has an agreement with DOE to convert to LEU fuel as a condition of returning spent fuel to the United States.

However, U.S. policies in support of the reactor conversion program do not influence foreign reactors using so little HEU that they can operate for many years without replacing their fuel or disposing of spent fuel. While Argonne provides technical assistance for conversion, current DOE policy precludes purchasing new LEU fuel for foreign reactors that use U.S.-origin HEU fuel. Under this policy, purchasing new LEU fuel—which, according to a DOE project engineer, is the main cost of conversion—is the responsibility of the reactor operator. According to a DOE official, DOE has paid for new LEU fuel only once, in Romania, in exchange for the return of Russian-origin HEU fuel to Russia. DOE spent $4 million to purchase LEU fuel for the Romanian reactor, which is still only partially converted and requires more LEU fuel before conversion is complete. DOE officials said that current DOE policy allows purchasing LEU fuel for research reactors that use Russian-origin HEU fuel in exchange for returning the HEU to Russia. However, DOE does not have a similar policy for research reactors that use U.S.-origin HEU fuel. DOE officials said they are considering revising this policy to allow purchasing LEU fuel for U.S.-supplied research reactors.

## Only One of Seven Russian-Supplied Reactors That Can Use Low Enriched Uranium Is Scheduled to Convert

According to Argonne officials, 7 Russian-supplied research reactors, all located outside Russia, could convert using LEU fuels that are currently available or are expected to become available within the next year. However, only 1 of the 7 reactors, located in Ukraine, is scheduled to convert.[9] (See table 3 for a list of the 7 reactors.)

**Table 3: Seven Foreign Research Reactors Using HEU from Russia That Could Convert to LEU**

| Country | Reactor |
|---|---|
| Bulgaria | IRT-Sofia |
| Germany | ZLFR |
| Hungary | VVR-SZM |
| Libya | IRT-1 |
| Libya | Critical Facility |
| Ukraine | VVR-M |
| Vietnam | DRR |

Source: Argonne.

Note: The amount of HEU fuel used by these research reactors ranges from 0 to 13.9 kilograms per year. Reactors that use zero kilograms of HEU per year use HEU fuel but operate at such low power levels that they use up the fuel very slowly and can operate for many years or for their entire lifetime without replacing fuel.

The Ukrainian reactor operators told us that they expect to begin conversion to LEU at the end of 2004 at the earliest and that they are currently analyzing the safety of converting to LEU with the assistance of DOE's reactor conversion program. Unlike many of the U.S.-supplied research reactors that are not planning to convert because they have an adequate supply of HEU, the Ukrainian reactor is running out of HEU fuel and will have to place an order for new fuel by the end of 2004. The reactor operators told us they support conversion to LEU fuel because the negative impact on the reactor's performance will be tolerable, the operating costs will be about the same after conversion to LEU, and converting to LEU would eliminate the threat that HEU could be stolen from the facility. The reactor operators are scheduled to complete the safety analysis in

[9]The reactor conversion program includes 28 Russian-supplied reactors—14 in Russia and 14 outside Russia (primarily in countries of the former Soviet Union and Eastern Europe). Conversion of 21 of the reactors, including the 14 in Russia, requires development of new LEU fuels.

November 2004 and then submit an application to obtain approval for conversion from the Ukrainian nuclear regulatory authority. However, Argonne officials said the schedule for converting the Ukrainian reactor is ambitious and conversion of the reactor could be delayed. According to Argonne officials, if the Ukrainian reactor does not get regulatory approval for conversion to LEU before it runs out of fuel, it may decide to place an order with the Russian supplier for more HEU fuel instead.

According to DOE officials, 5 other Russian-supplied reactors that can use LEU fuel are likely to convert. Conversion of the reactors in Bulgaria and Libya depends on the commercialization of the Russian-origin LEU fuel, which DOE expects to take place in 2004. DOE has also engaged in discussions on conversion with the operators of the research reactor in Vietnam. According to Argonne officials, conversion of the research reactor in Hungary requires at least several more years of analysis. In particular, the reactor must test an LEU fuel sample before the Hungarian government approves conversion, and this process will take several years. Argonne officials said the research reactor in Germany has a sufficient supply of HEU fuel and therefore is not planning to convert to LEU.

## Technical Setbacks in Developing New Fuels Limit Progress in Converting the Largest Remaining Research Reactors

Technical setbacks in developing new LEU fuels have postponed the conversion of 31 research reactors worldwide that cannot use currently available LEU fuels until 2010 at the earliest. Argonne is pursuing the development of LEU dispersion fuel and LEU monolithic fuel to convert these reactors. Argonne officials said the failures during testing of dispersion fuel are the worst they have ever experienced during fuel development. As a result, Argonne has delayed completion of dispersion fuel until 2010 and may recommend that DOE cancel further development altogether if solutions cannot be found. This would leave the reactor conversion program with only one alternative LEU fuel—monolithic fuel. According to Argonne officials, monolithic fuel has performed well in the one test conducted so far. However, many more tests are required. Because of lessons learned from dispersion fuel failures, Argonne recently delayed the projected completion date of monolithic fuel from 2008 to 2010 in anticipation of the need for additional tests. Argonne officials said they have compressed the development schedule of both dispersion and monolithic fuel as much as possible and any further technical problems will result in additional delays. Moreover, Argonne is focusing all LEU fuel development efforts on dispersion and monolithic fuel, and if both fuels fail, no LEU fuel will be available to convert the remaining reactors in the reactor conversion program.

## DOE May Cancel Development of One Low Enriched Uranium Fuel That Has Had Significant Problems

The 31 research reactors worldwide that cannot convert to currently available LEU fuels include some of the largest reactors in terms of amount of HEU used per year. Argonne officials estimate the reactors use a total of about 728 kilograms of HEU per year. Many of the 31 reactors are used to conduct advanced scientific research that could not be done if they were to convert to currently available LEU fuels. Representatives of 8 of the research reactors told us they need HEU fuel to operate and conduct research until LEU fuel with the right performance characteristics is developed. (See table 4 for a list of the 31 reactors.)

**Table 4: 31 Research Reactors That Cannot Convert Using Currently Available LEU Fuels**

| Country | Reactor |
|---|---|
| Belgium | BR-2 |
| Czech Republic | LWR-15 |
| | VR-1 |
| France | ORPHEE |
| | RHF |
| Germany | FRM-II |
| Kazakhstan | VVR-K |
| | VVR-K Critical Facility |
| North Korea | IRT-DPRK |
| Poland | MARIA |
| Russia | IRT-MEPhI |
| | IR-8 |
| | IRT-T |
| | VVR-TS |
| | VVR-M |
| | IVV-2M |
| | MIR-M1 |
| | CA.MIR-M1 |
| | SM-3 |
| | CA.SM-3 |
| | RBT-6 |
| | RBT-10/2 |
| | PIK |
| | PIK Physical Model |

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| Country | Reactor |
|---|---|
| United States | Massachusetts Institute of Technology (MITR) |
| | University of Missouri (MURR) |
| | National Institute of Standards and Technology (NBSR) |
| | DOE HIFR |
| | DOE ATR |
| | DOE ATRC |
| Uzbekistan | VVR-CM |

Source: Argonne.

Notes: The amount of HEU fuel used by these research reactors ranges from 0 to 120 kilograms per year. Reactors that use zero kilograms of HEU per year use HEU fuel but operate at such low power levels that they use up the fuel very slowly and can operate for many years or for their entire lifetime without replacing fuel.

Research reactors located in the Czech Republic, Kazakhstan, North Korea, Poland, Russia, and Uzbekistan are Russian-supplied reactors.

DOE's reactor conversion program has run into problems in developing new LEU fuels intended to replace HEU in these research reactors. The most serious problems have occurred in tests of dispersion fuel, the development of which began in 1996. According to Argonne officials, dispersion fuel would be usable in the Russian-supplied research reactors and 1 U.S. reactor.[10] Most recently, tests of the dispersion fuel have revealed weaknesses that would make the fuel unsuitable for use in research reactors. In particular, when samples of dispersion fuel were tested in research reactors, the fuel failed unexpectedly under reactor operating conditions the fuel was designed to withstand.

A number of factors illustrate the seriousness of the problems with the dispersion fuel. First, according to Argonne officials, the same problems have been encountered in separate tests and under different operating conditions in reactors in the United States, Belgium, France, and Russia. Second, the problems were unexpected and worse than encountered in

[10]The development of LEU dispersion fuel also has important consequences for U.S.-supplied foreign research reactors that have already converted to LEU and participate in the Foreign Research Reactor Spent Nuclear Fuel Acceptance program. Many of these reactors had planned to switch to LEU dispersion fuel from the LEU fuel they are currently using because spent dispersion fuel could be disposed of through reprocessing. With the program scheduled to stop accepting fuel in 2009 and development of dispersion fuel delayed until 2010, foreign research reactors that have already converted to LEU fuel that cannot be reprocessed may not have a way to dispose of spent fuel. We will address this issue in more detail in a forthcoming report on the program.

previous LEU fuel development efforts. Finally, if the failures were serious enough, the fuel could leak radioactive material into the reactor coolant and cause facility contamination. If this occurred, the dispersion fuel would not be approved for use in research reactors.

Argonne officials said that, as a result of these test failures, they have delayed projected completion of dispersion fuel from 2006 until 2010 to allow time for additional development and testing. Argonne officials plan to pursue options to modify dispersion fuel to make it resistant to failures. However, they said they would also consider recommending that DOE cancel further development of dispersion fuel if it is determined the fuel cannot be sufficiently improved. In addition, because of the problems encountered in the development of dispersion fuel, Argonne has shifted its primary focus to the development of monolithic fuel.

## More Time Is Needed to Develop an Alternative Low Enriched Uranium Fuel

Initial testing of monolithic fuel has produced positive results under the same operating conditions under which dispersion fuel failed. According to Argonne officials, if they are successful in developing monolithic fuel, it will offer better reactor performance than dispersion fuel and could be used to convert the remaining research reactors in the reactor conversion program to LEU.

Nevertheless, the successful development of this fuel is still uncertain, and Argonne has not yet demonstrated that all remaining research reactors still using HEU could convert to it. Argonne officials said they began developing monolithic fuel relatively recently, in 2000, and to date have conducted only one test. Additional testing could reveal problems that have not yet surfaced. Furthermore, this fuel requires development of a new manufacturing method because the methods used to manufacture other research reactor fuels are not suitable for monolithic fuel. Argonne is conducting research on different manufacturing options but has not yet demonstrated that monolithic fuel can be manufactured on a large scale. Three reactor operators hoping to convert to this fuel told us it is impossible to predict whether the new LEU fuel will be successfully developed and that creating a reliable LEU fuel could take many years more than expected.

Development of monolithic fuel may be delayed if Argonne encounters any problems in the fuel development process. Argonne officials said they have already delayed projected completion from 2008 to 2010 to allow time for additional testing. The schedule for developing monolithic fuel does not

factor in any technical problems that may occur during testing but rather assumes that every phase of development will be successful. Argonne officials said they have already compressed the schedule as much as possible and that it would be difficult to significantly accelerate fuel development any further because each set of tests requires a fixed amount of time. The officials also stated that fuel development would have been delayed even further had Congress not increased funding for the reactor conversion program from $6.1 million in fiscal year 2003 to $8.5 million in fiscal year 2004, which enabled Argonne to pursue a more aggressive fuel development schedule. Assuming no further delays in fuel development, Argonne officials said the first research reactors could begin ordering new LEU for conversion within 6 months of completing the development of either dispersion fuel or monolithic fuel in 2010.

## Support for Conversion to Low Enriched Uranium Fuel Varies among Research Reactor Operators

In our visits to foreign and domestic research reactors that cannot convert to currently available LEU fuels, we found that reactor operators' response to the prospect of conversion to LEU fuels varies widely. For example, the operator of the BR-2 reactor in Belgium said it had agreed to convert to LEU when feasible as a condition for continuing to receive U.S.-origin HEU fuel. In contrast, a new German reactor at the Technical University Munich designed to use HEU (the FRM-II reactor) may still not be able to convert to LEU even if Argonne is successful in developing monolithic fuel. The reactor operator has agreed to convert to a lower enrichment of HEU that is less usable in nuclear weapons. However, during our visit to the reactor, the operator said it had no plans to convert the reactor to LEU fuel because conversion would require expensive reconstruction.

Argonne has contracted with Russia to work jointly on development of new LEU fuels, but DOE has not negotiated a formal agreement with the Russian government to convert research reactors in Russia to LEU. DOE's reactor conversion program includes 14 research reactors operating in Russia that, combined, use 225 kilograms of HEU fuel per year. In 2002, the Secretary of Energy and Russia's Minister of Atomic Energy issued a joint statement identifying acceleration of LEU fuel development for both Russian-supplied and U.S.-supplied research reactors as an area where joint cooperation could lead to reduction in the use of HEU. However, the Russian officials responsible for developing LEU fuels told us they are focusing on converting Russian-supplied reactors in other countries first. The officials also do not consider the conversion of research reactors in Russia to LEU a priority because security has been improved at the reactors and the reactors need HEU fuel to conduct advanced research.

Furthermore, Russian officials told us that under Russian law, operators of HEU reactors in Russia are not required to convert to LEU. In fact, since 1986, Russia has been building a new research reactor that is designed to use HEU fuel rather than LEU.

Three U.S. research reactors (at the Massachusetts Institute of Technology, the University of Missouri, and the National Institute of Standards and Technology) where conversion is not currently feasible fall under NRC regulations that would require conversion to LEU if the reactor conversion program is successful in developing new LEU fuels.[11] Furthermore, the Secretary of Energy committed to the conversion of all U.S. research reactors by 2013 in a speech on May 26, 2004. However, without federal funding to support the conversion, the reactors may continue to use HEU. For example, the operator of the Massachusetts Institute of Technology reactor said that conversion to LEU could be delayed even after a new LEU fuel is developed if DOE does not provide funding in a timely manner.

## Using Low Enriched Uranium for Medical Isotope Production Is Feasible, but Concerns over Cost Could Limit Its Use

The reactor conversion program has demonstrated the potential for using LEU to produce medical isotopes on a small scale, but large-scale producers are concerned that the cost of conversion could be prohibitive. With assistance from the reactor conversion program, one reactor in Argentina used for the production of medical isotopes converted from HEU to LEU in 2003. However, Argonne officials said the conversion was feasible only because the reactor produces medical isotopes on a small scale, using a relatively small amount of material in the production process. (Prior to converting to LEU, the Argentine reactor used less than a kilogram of HEU per year. In contrast, four large medical isotope producers targeted by the reactor conversion program, located in Belgium, Canada, the Netherlands, and South Africa, each use as much as 25 kilograms of HEU per year.) Argonne is still working to overcome problems with using LEU that limit the ability of the Argentine reactor to increase its production capacity.

Argonne officials said they are 2 to 3 years away from completing work that would allow the large medical isotope producers to convert from HEU to LEU. Argonne officials said they have developed LEU materials that can be used by all medical isotope producers and only the adaptation of the

[11] 10 C.F.R. § 50.64.

production processes from using HEU to LEU remains. They said that adapting the medical isotope producers' processes, each of which is unique in some aspect, is technically feasible and is just a matter of time. One reason why the production processes must be modified is that almost five times more LEU than HEU is required to produce the same amount of medical isotopes. The increased amount of nuclear material creates obstacles to conversion. For example, using LEU would produce more waste, which in turn could increase the burden of treating and storing the waste. In addition, the facilities, chemical processes, and waste management systems for producing medical isotopes are customized to use HEU and would require modifications to accommodate LEU.

In discussions with the two large medical isotope producers in Belgium and Canada, both cited a number of factors that would make conversion to LEU costly and difficult, including the fivefold increase in the amount of LEU that would be required to achieve the same level of output when using HEU. As part of its technical analysis, the Canadian producer is currently conducting an assessment of converting to LEU to determine whether conversion would be economically feasible. The Canadian producer currently uses U.S.-origin HEU and, under U.S. law, must agree to convert to LEU when a suitable LEU alternative is developed.[12] (The other three large medical isotope producers currently receive their HEU from countries other than the United States and are therefore not subject to U.S. requirements to convert to LEU.) U.S. law also allows for an exception to the requirement to convert to LEU if conversion would result in a large percentage increase in operating costs. Officials at DOE and NRC, which implements the law governing U.S. HEU exports, acknowledge that medical isotope producers operate on small profit margins, and as a result, the cost of converting to LEU may be prohibitive. However, Argonne officials said that conversion to LEU could result in a more economic process. DOE officials said they would not accept a statement by the Canadian producer that conversion of medical isotope production to LEU is not economically feasible without documentation to support that conclusion.

[12]42 U.S.C. § 2160d.

## DOE and NRC Are Addressing Security at Foreign and Domestic Research Reactors

Research reactor operators at most reactors we visited said that security had been improved because of DOE or NRC efforts. However, DOE and NRC have recognized the need to further improve security at research reactors throughout the world, including in the United States, and are engaged in separate efforts to assess research reactor security and its effectiveness.

At the foreign research reactors we visited, we observed security improvements to storage areas for HEU fuel, systems for controlling personnel access to the reactors, and alarm systems, including motion detectors and camera monitoring. DOE provided assistance to some of the foreign reactors to make the security improvements; other reactor operators had made the improvements with their own funding based on DOE recommendations. At U.S. research reactors, we saw physical security improvements around the reactor buildings, such as new fences and concrete barriers. Several operators of university research reactors told us they were using funding from DOE's university reactor support program to purchase new security equipment.

We also observed areas where further improvement could be made. For example, we visited one foreign research reactor's facility for storing spent HEU fuel where DOE had provided only minimal assistance to improve security. According to DOE officials, DOE has generally not provided assistance to improve the security of spent HEU fuel because it is radioactive and too dangerous for potential terrorists to handle. DOE has placed a higher priority on protecting fresh fuel—fuel that has not been irradiated in a reactor—because it is easier to handle. However, operators of the fuel storage facility said that the spent fuel had been in storage for a long time and had lost enough radioactivity to be handled and potentially stolen.

During a visit to another foreign research reactor, we observed a new alarm system monitoring the entrance to the reactor building, a fresh fuel vault, and motion detectors that had been installed with DOE assistance. DOE is in the process of adding further enhancements to the security of the facility. However, we also observed that the fence surrounding the facility was in poor condition, security guards at the front gate were unarmed, and there were no guards at the reactor building, which we entered without escort. At another research reactor, DOE identified security weaknesses and offered assistance to make security improvements. However, according to the U.S. embassy in the country where the reactor is located,

the improvements had not been made as of March 2004 because the reactor operator did not act on DOE's offer of assistance. We discussed examples that raised questions about security of foreign research reactors with DOE officials during meetings on March 12 and 22, 2004, and they agreed that DOE needs to do more to address potential security concerns.

Recognizing that the security at some research reactors may need to be improved, DOE established a task force in 2004 to identify the highest risk reactors and to develop options for improving security at reactors believed to be of greatest concern. The task force is currently gathering information on all research reactors worldwide, including reactors that are shut down, and prioritizing them based on a number of factors, including how much HEU is stored on site, the vulnerability of the reactors to theft of HEU or sabotage, plans for conversion to LEU and removal of HEU fuel, and the potential terrorist threat to countries where the reactors are located. The scope of the initiative comprises 802 research reactors and associated facilities, including 128 facilities possessing 20 kilograms or more of HEU on site.[13] DOE officials said the task force addresses the need to combine and coordinate information from different sources within DOE, which did not have a comprehensive database prior to the task force to document visits and security observations made by various DOE program officials to foreign research reactors. According to DOE officials, the task force has submitted a report to the Secretary of Energy with recommendations for possible implementation by DOE, such as expediting conversion to LEU and providing additional assistance to foreign research reactors to improve security. According to task force members, security assistance to foreign reactors could be provided by DOE, the International Atomic Energy Agency, or countries other than the United States.

NRC is also engaged in efforts to assess and improve the security at the U.S. research reactors it regulates. NRC took actions after the attacks of September 11, 2001, to improve security at U.S. research reactors—for example, by requiring some reactor operators to consider installing additional physical barriers and strengthening screening requirements for entrance to facilities. In addition, NRC is conducting assessments of the security at the research reactors it regulates and may increase security

[13]The task force is looking at all research reactors worldwide, while the reactor conversion program targets operating research reactors that use HEU. Not every research reactor that possesses HEU is part of the conversion program because some of the reactors have military applications that require HEU fuel or use a unique HEU fuel that would require a separate LEU fuel development effort.

requirements based on the results of the assessments. According to NRC officials, the agency's security evaluations of U.S. research reactors will be completed in December 2004. Based on the results of the evaluations, NRC will decide to strengthen current regulations, leave regulations as they are, or address security concerns at each reactor on a case-by-case approach.

## Conclusions

While several research reactors are scheduled to convert to LEU fuel in the next few years, progress in converting many remaining reactors has stalled. In part, converting these reactors is a matter of completing development of new LEU fuels, which has been delayed by unforeseen technical problems. However, if DOE's reactor conversion program is to achieve its objective to reduce and eventually eliminate the use of HEU in civilian research reactors, DOE may need to re-evaluate its policies with regard to the program. Many of the research reactors that could use currently available LEU fuels have not converted because they lack incentives, funding, or both. Until recently, the policy of DOE's reactor conversion program has been to provide technical assistance to support conversion of research reactors to LEU but not to pay for conversion or, in particular, purchase new LEU fuel. In the case of six U.S. university reactors, DOE has not made purchasing LEU fuel for conversion (and completing the conversion process at another reactor by removing HEU fuel and shipping it to a DOE facility for disposal) a high priority. While many of the U.S. reactors that could convert to LEU use only a small amount of HEU per year, converting them would demonstrate DOE's commitment to the nonproliferation objective of the reactor conversion program.

DOE has generally expected the operators of foreign research reactors that use U.S.-origin HEU fuel to purchase new LEU fuel with their own funds. The policies DOE has relied on to influence operators to convert to LEU—requiring that reactor operators agree to convert as a condition of receiving U.S. HEU exports or returning spent fuel to the United States—do not work for reactors using so little HEU that they can operate for many years without replacing their fuel. Without funding for conversion, it is possible these reactors could continue using HEU for years. DOE may need to consider offering additional incentives to foreign reactors, including purchasing new LEU fuel, to influence them to convert to LEU.

Regardless of progress in converting domestic and foreign research reactors to LEU in the near term, delays in completing the development of new LEU fuels mean that other research reactors will continue to use HEU until at least 2010. If the reactor conversion program experiences

additional problems in one or both of the two LEU fuels currently under development, some research reactors could be left without a viable option for conversion to LEU. Given the continuing use of HEU at these research reactors, DOE and NRC efforts to evaluate and improve reactor security are essential components of the overall effort to reduce the risk of proliferation of HEU at civilian research reactors.

## Recommendations for Executive Action

In order to further reduce the use of HEU in research reactors in the United States and abroad, we recommend that the Secretary of Energy and the Administrator of the National Nuclear Security Administration take the following three actions:

- consider placing a higher priority on converting the six remaining university research reactors in the United States that can use currently available LEU fuel;
- once a reactor has been converted, place a high priority on removing the HEU fuel and transporting it to the appropriate DOE facility; and
- evaluate the costs and benefits of providing additional incentives to foreign research reactors that use U.S.-origin HEU fuel to convert to LEU, particularly to reactor operators that are willing to convert but do not have sufficient funding to do so.

## Agency Comments and Our Evaluation

We provided draft copies of this report to the Departments of Energy and State and to NRC for their review and comment. Comments from the Departments of Energy and State are presented as appendixes III and IV, respectively. NRC's written comments were not for publication. DOE, State, and NRC generally agreed with the recommendations in our report and provided detailed comments, which we incorporated into the report as appropriate.

In its comments, DOE noted that the United States has 11 more research reactors to convert to the use of LEU fuels, with conversion currently feasible for 6 of the reactors. However, DOE's February 2004 project execution plan for its reactor conversion program identifies 14 U.S. research reactors still using HEU fuel that are included in DOE's reactor conversion program, with conversion currently feasible for 8 of the

reactors. We used the number of reactors from DOE's project execution plan in our report.

In its comments, State questioned DOE's cost estimate for converting U.S. research reactors where conversion to LEU fuel is currently feasible. State noted that DOE's cost estimate of $5 million to $10 million per reactor where conversion to LEU fuel is currently feasible seems much too high, especially in comparison with DOE's expenditures of about $0.4 million to $1.6 million per reactor to convert 11 U.S. university reactors to LEU fuel between 1984 and 2000. State wrote that the DOE office that administers the program for supporting U.S. university research reactors has been reluctant to fund the conversion of more research reactors and has a tendency to overstate the potential costs to deflect pressure to spend money on conversions. We asked DOE officials what support they had for the cost estimate. In response, a DOE official said that DOE does not have documentation to support its cost estimate.

In another comment, State suggested we include recognition of the growing number of new and planned research reactors around the world that have been designed to use LEU fuel. State wrote that modern world-class reactors do not need HEU fuel to conduct high-quality research. DOE officials also provided information on the use of LEU fuel in new research reactors constructed since the inception of its reactor conversion program in 1978. Although our report does not focus on new research reactors designed to use LEU fuel, we agree that this is a positive development in keeping with the objective of DOE's reactor conversion program and we added a footnote recognizing these new reactors.

## Scope and Methodology

To review the progress of the reactor conversion program, we analyzed program documentation, including DOE's February 2004 *RERTR Program Project Execution Plan*. We also interviewed key DOE, Argonne, NRC, and State Department officials; conducted site visits to foreign and U.S. research reactors and interviewed reactor operators by telephone; and attended an annual international conference organized by DOE's reactor conversion program.

For site visits and telephone interviews, we selected foreign and domestic research reactors from three categories: reactors that had converted to LEU, reactors that could convert using currently available LEU fuels but were still using HEU, and reactors that could not convert using currently available LEU fuels. Within each of the three categories of reactors, we selected a nonprobability sample of reactors based on a number of criteria such as reactor types, including U.S.-supplied reactors, Russian-supplied reactors, and reactors that use HEU in the production of medical isotopes.[14] We visited 5 research reactors in the United States, including 3 that had converted to LEU and 2 that cannot convert to currently available LEU fuels and are still using HEU. We conducted phone interviews with reactor operators from 1 other U.S. reactor that cannot use currently available LEU fuels and all 6 of the U.S. university research reactors that can convert to LEU but are still using HEU. We also visited 10 foreign research reactors in Belgium, Germany, the Netherlands, Poland, Portugal, Romania, Russia, and Ukraine. These included 2 converted reactors, 4 reactors that can use LEU fuel but have not yet converted, and 4 reactors that still require HEU. (See table 5.)

**Table 5: Number of Research Reactors Selected for Site Visits or Phone Interviews**

| | U.S.-supplied | | Russian-supplied | | |
|---|---|---|---|---|---|
| **Reactor status** | **In the U.S.** | **Abroad** | **In Russia** | **Abroad** | **Total** |
| Converted | 3 of 11 | 2 of 28 | - | - | **5 of 39** |
| Convertible | 8 of 8 | 3 of 20 | - | 1 of 7 | **12 of 35** |
| Not yet convertible | 4 of 6 | 2 of 4 | 2 of 14 | 1 of 7 | **9 of 31** |
| **Total** | **15 of 25** | **7 of 52** | **2 of 14** | **2 of 14** | **26 of 105** |

Source: GAO.

In our site visits and telephone interviews, we asked a standard set of questions (depending on the conversion status of the reactor) on technical aspects of converting to LEU, cost of conversion, impact of conversion on reactor performance, and assistance provided by DOE's reactor conversion program.

[14]Results from nonprobability samples cannot be used to make inferences about a population because, in a nonprobability sample, some elements of the population being studied have no chance or an unknown chance of being selected as part of the sample.

To review the progress in developing new LEU fuels for use in research reactors, we conducted in-depth interviews with Argonne officials responsible for managing LEU fuel development; operators of reactors that plan to convert to new LEU fuels when they are developed; and fuel development experts at the Bochvar Institute in Russia, which is collaborating with Argonne. At the annual international conference organized by DOE's reactor conversion program, we participated in sessions on LEU fuel development, and we reviewed technical papers on the progress of fuel development. For technical expertise, we relied on GAO's Chief Technologist, who participated in meetings with Argonne officials and reviewed the information that Argonne provided. We used the interviews and annual conference to also review progress in the development of LEU for use in the production of medical isotopes. In addition, we interviewed two of the four large medical isotope producers (in Belgium and Canada) that are currently using HEU to produce medical isotopes and that would be candidates for conversion to LEU once Argonne completes development.

To gather information on DOE and NRC efforts to improve research reactor security, we interviewed officials at those agencies and discussed security improvements with reactor operators we interviewed. We also observed security improvements at research reactors we visited. However, we did not evaluate the effectiveness of the security at research reactors or DOE and NRC efforts to improve security.

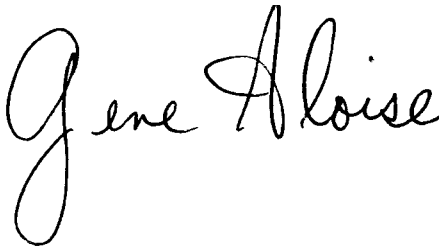
We obtained data from DOE and Argonne on the conversion status of the 105 research reactors included in the reactor conversion program, the amount of HEU used per year by the 105 reactors (including the amount used prior to conversion for the 39 research reactors now using LEU), and DOE expenditures for the reactor conversion program since its inception in 1978. All amounts are in constant 2003 dollars, unless otherwise noted. We assessed the reliability of data we obtained through discussions with Argonne officials. We also obtained responses from Argonne officials to a series of data reliability questions covering issues such as quality control procedures and the accuracy and completeness of the data. Based on our assessment, we determined that the data we obtained from DOE and Argonne was sufficiently reliable for our purposes.

We conducted our work from July 2003 to July 2004 in accordance with generally accepted government auditing standards.

We are sending copies of this report to the Secretary of Energy; the Administrator, National Nuclear Security Administration; the Secretary of State; the Chairman, NRC; the Secretary of Homeland Security; the Director, Office of Management and Budget; and interested congressional committees. We will also make copies available to others upon request. In addition, this report will be available at no charge on the GAO Web site at http://www.gao.gov.

If you or your staff have any questions about this report, please call me at (202) 512-3841. Key contributors to this report include Joseph Cook, Jonathan McMurray, Kirstin B.L. Nelson, Peter Ruedel, F. James Shafer Jr., and Keith Rhodes, GAO's Chief Technologist.

Sincerely yours,

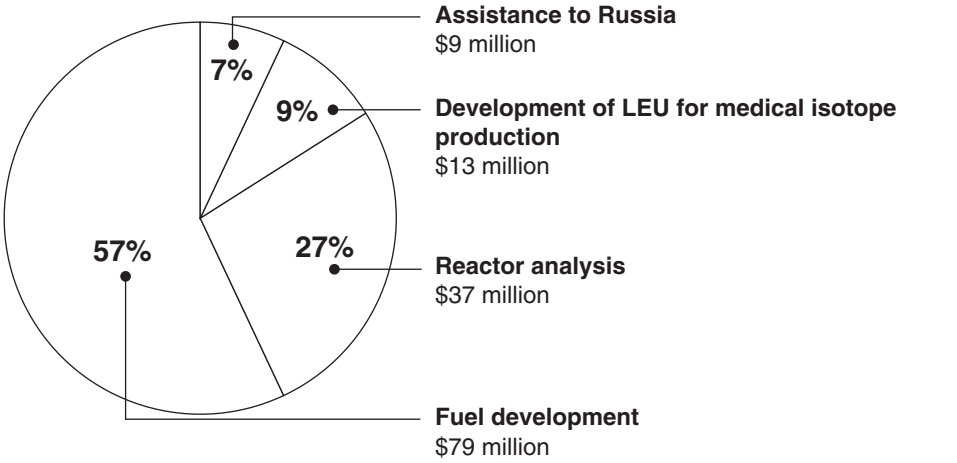


Gene Aloise
Acting Director, Natural
Resources and Environment

# Reactor Conversion Program Expenditures and Projected Costs

DOE estimates that the reactor conversion program will cost approximately $213 million through the program's projected end in 2012.[1] Expenditures since the program's inception in 1978 through fiscal year 2003 totaled approximately $139 million in constant 2003 dollars. (See fig. 3.)

**Figure 3: Reactor Conversion Program Expenditures, Fiscal Years 1978 to 2003**




Source: GAO analysis of Argonne National Laboratory data.

Costs for the reactor conversion program are broken into four categories:

- Fuel development includes all of the activities associated with testing and analyzing new LEU fuels, such as the LEU dispersion and monolithic fuels that are currently under development. This activity also includes developing the methods for manufacturing new LEU fuels. Most of the reactor conversion program costs over the life of the program are in this category.

- Reactor analysis includes studying the conversion of individual research reactors, both domestic and foreign, once a suitable LEU has been developed. For example, Argonne provides technical assistance to research reactors to determine the impact of conversion on the reactors' performance and safety. This category does not include the cost of

[1]Dollar figures cited throughout appendix I are in constant 2003 dollars, unless otherwise noted.

purchasing LEU fuel for research reactors. For example, the responsibility for purchasing LEU fuel for U.S. university reactors belongs to another program in DOE that is separate from the reactor conversion program.

- Development of LEU for medical isotope production includes activities associated with testing and analyzing LEU materials to replace HEU in the production of medical isotopes. This activity also includes development of manufacturing and waste management processes for using LEU instead of HEU and technical assistance to medical isotope producers.

- Assistance to Russia includes funding to support research and development on new LEU fuels for Russian-supplied reactors. It also includes analysis of the impact of conversion to LEU on Russian-supplied reactors. The assistance to Russia was previously funded through a one-time grant of approximately $1.7 million, about two-thirds of which has been spent, from the State Department's Nonproliferation and Disarmament Fund (NDF).

In addition to the $139 million spent by the reactor conversion program, DOE's university reactor support program spent approximately $10 million between 1984 and 2000 to convert 11 university research reactors in the United States, according to an official at the Idaho National Engineering and Environmental Laboratory (INEEL). The cost of converting each reactor varied from around $400,000 to $1.6 million and was primarily for the cost of fabricating the fuel. The costs varied depending on the type of fuel and where it was manufactured.

DOE's projected costs for completing the reactor conversion program total about $74.7 million.[2] (See table 6.) This amount includes $26.3 million for reactor analysis, $25.8 million for fuel development, $4.8 million for the development of LEU for medical isotope production, and $17.8 million for assistance to Russia.

[2]The projected costs for the reactor conversion program are not in constant 2003 dollars. Argonne adjusted these costs for inflation with an increase of 5 percent for every year after 2004 and using 2004 as the base year.

**Table 6: DOE's Projected Costs to Complete the Reactor Conversion Program (in thousands)**

| Fiscal Year | Reactor analysis | Fuel development | Development of LEU for medical isotope production | Assistance to Russia | Total |
|---|---|---|---|---|---|
| 2004 | $1,125 | $4,122 | $890 | $2,404 | **$8,541** |
| 2005 | 1,586 | 4,286 | 946 | 2,709 | **9,527** |
| 2006 | 1,494 | 3,426 | 1,000 | 3,604 | **9,523** |
| 2007 | 1,692 | 4,526 | 986 | 2,917 | **10,121** |
| 2008 | 3,259 | 3,023 | 638 | 1,984 | **8,904** |
| 2009 | 3,835 | 2,189 | 200 | 1,680 | **7,903** |
| 2010 | 5,320 | 2,284 | 75 | 1,064 | **8,743** |
| 2011 | 4,784 | 1,544 | 60 | 842 | **7,230** |
| 2012 | 3,250 | 409 | 0 | 560 | **4,219** |
| **Total** | **$26,345** | **$25,809** | **$4,795** | **$17,763** | **$74,712** |

Source: GAO analysis of Argonne data.

DOE's cost estimates are based on the assumption that at least one of the two LEU fuels that Argonne is developing will be successful and will be used for the reactor conversion program. DOE also assumes that Russia and other countries will continue to assist Argonne in conducting fuel tests as necessary for fuel development. DOE's estimates do not include the cost of purchasing new LEU fuel to convert research reactors. These costs are expected to be funded by other DOE programs or by the operators of foreign research reactors.

# 39 Research Reactors That Converted to LEU Fuel under the Reactor Conversion Program

| Country | Reactor | Fully converted | Partially converted |
|---|---|---|---|
| Argentina | RA-3 | X | |
| Australia | HIFAR | | X |
| Austria | ASTRA | X | |
| | TRIGA | | X |
| Brazil | IEA-R1 | X | |
| Canada | MNR | | X |
| | NRU | X | |
| | Slowpoke-Montreal | X | |
| Chile | La Reina | | X |
| Colombia | IAN-R1 | X | |
| Denmark | DR-3 | X | |
| France | OSIRIS | X | |
| Germany | BER-II | X | |
| | FRG-1 | X | |
| Greece | GRR-1 | | X |
| Iran | NRCRR | X | |
| Japan | JMTR | X | X |
| | JRR-4 | X | |
| Netherlands | HOR | X | |
| Pakistan | PARR | X | |
| Philippines | PRR-1 | X | |
| Romania | TRIGA | | X |
| Slovenia | TRIGA | X | |
| Sweden | R2 | X | X |
| | R2-0 | X | |
| Switzerland | SAPHIR | | X |
| Taiwan | THOR | X | |
| Turkey | TR-2 | | X |

*(Continued From Previous Page)*

| Country | Reactor | Fully converted | Partially converted |
|---|---|---|---|
| United States | Georgia Institute of Technology | X | |
| | Iowa State University | X | |
| | University of Massachusetts at Lowell | X | |
| | Manhattan College Zero Power Reactor | X | |
| | University of Michigan | X | |
| | Ohio State University | X | |
| | Rhode Island Nuclear Science Center | X | |
| | Rensselaer Polytechnic Institute | X | |
| | University of Missouri at Rolla | X | |
| | University of Virginia | X | |
| | Worcester Polytechnic Institute | X | |

Source: Argonne.

Note: The amount of HEU fuel used by these research reactors prior to conversion ranged from 0 to 70.1 kilograms per year. Reactors that use zero kilograms of HEU per year use HEU fuel but operate at such low power levels that they use up the fuel very slowly and can operate for many years or for their entire lifetime without replacing fuel.

# Comments from the Department of Energy

Department of Energy
National Nuclear Security Administration
Washington, DC 20585

JUL 14 2004

Mr. Gene Aloise
Acting Director
Natural Resources and Environment
General Accounting Office
Washington, D.C.

Dear Mr. Aloise:

The National Nuclear Security Administration (NNSA) appreciates the opportunity to have reviewed the General Accountability Office (GAO) Draft Report, NUCLEAR NONPROLIIFERATION: DOE Needs To Take Action To Further Reduce the Use of Weapons-Usable Uranium in Civilian Research Reactors." We understand that the intent of this audit was for GAO to review the risks to national security of highly enriched uranium used in research reactors in Russia and countries of proliferation concern.

NNSA agrees with the recommendations contained within the draft report and notes that the U.S. has converted eleven of its research reactors to the use of Low Enriched Uranium (LEU) fuel – by far the largest number of reactor conversions in any single country. The U.S. has eleven more reactors to convert to the use of LEU fuels with six of these reactors currently being capable of using LEU fuels.

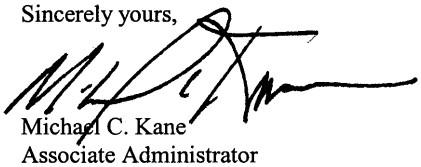
On May 26, 2004, in Vienna, Austria, the Secretary announced the Global Threat Reduction Initiative. The principal mission of the Initiative is to identify, secure, remove, or facilitate disposal of vulnerable high-risk nuclear and other radioactive materials around the world that pose a threat to the international community. This mission will be carried out by, among other things, accelerating ongoing nuclear material removal and research reactor conversion efforts. This will include accelerating efforts to convert the six domestic University research reactors that can convert using currently existing fuels. The new Office of Global Threat Reduction will work with other offices, such as the Office of Nuclear Energy, Science & Technology, as well as the Nuclear Regulatory Commission, in order to achieve this goal

Conversion of the remaining five domestic reactors is not possible until higher-density LEU fuels have been developed, qualified, and made commercially available. Once such fuels are available, we will complete conversion of all U.S. research reactors.

Through the U.S. Highly Enriched Uranium (HEU) minimization policy, we are working to ensure that no nation has a reason to continue to use HEU in civil nuclear activities. In order to achieve the goal of minimization and eventual elimination of the civil use of HEU, we are working through the RERTR program to convert reactor cores from HEU to LEU. Under the Initiative, we will work closely with the Department of State, other U.S. agencies, and our international partners to address holdouts to our efforts through a revised, re-invigorated, and comprehensive diplomatic and operation action plan, to include incentives. This strategy is intended to encourage full participation in the program.

Should you have any questions related to this response, please contact Richard Speidel, Director, Policy and Internal Controls Management. He may be contacted at 202-586-5009.

Sincerely yours,



Michael C. Kane
Associate Administrator
for Management and Administration

# Comments from the Department of State

**United States Department of State**

*Assistant Secretary and Chief Financial Officer*

*Washington, D.C. 20520*

JUL - 1 2004

Ms. Jacqueline Williams-Bridgers
Managing Director
International Affairs and Trade
General Accounting Office
441 G Street, N.W.
Washington, D.C. 20548-0001

Dear Ms. Williams-Bridgers:

We appreciate the opportunity to review your draft report, "NUCLEAR NONPROLIFERATION: DOE Needs To Take Action To Further Reduce the Use of Weapons-Usable Uranium in Civilian Research Reactors," GAO Job Code 360374.

The enclosed Department of State comments are provided for incorporation with this letter as an appendix to the final report.

If you have any questions concerning this response, please contact Allan Krass, Action Officer, Bureau of Nonproliferation, at (202) 646-3272.

Sincerely,

Christopher B. Burnham

cc: GAO – James Shafer
NP – John Wolf
State/OIG – Mark Duda
State/H – Paul Kelly

Department of State Comments on GAO Draft report:
NUCLEAR NONPROLIFERATION: DOE Needs To Take Action To Further Reduce the Use of Weapons-Usable Uranium in Civilian Research Reactors
(GAO-04-807, GAO job Code 360374)

The Department of State (DOS) thanks the General Accounting Office (GAO) for the opportunity to respond to their review of Nuclear "Nonproliferation: DOE Needs to Take Action To Further Reduce the Use of Weapons-Usable Uranium in civilian Research Reactors". The report is generally fair and accurate. State has only one criticism and one suggestion for additional content.

The criticism involves the parenthetical statement near the bottom of p. 4 that it will cost $5 to $10 million to convert each of the eight remaining US research reactors. This seems much too high, especially in view of the statement on p. 37 that DOE spent only about $10 million to convert 11 reactors between 1984 and 2000. Cost per reactor ranged from $0.4 to $1.6 million, with an average of less than $1 million. The DOE office that manages research reactors, Nuclear Energy Affairs (NE) has been reluctant to fund more conversions and has a tendency to overstate the potential costs to deflect pressure to spend money on them. Maybe there's a good reason why the final 8 should be 5 to 10 times more expensive to convert than the first 11, but frankly we doubt it.

State's suggestion is to include recognition of the growing number of new and planned research reactors that have decided to use low enriched uranium (LEU). This represents an understanding that modern world class reactors do not require high enriched uranium (HEU) to do high quality research and isotope production. The only exception to the rule is the reactor in Munich that GAO visited. It resisted for nearly a decade US efforts to get it to use LEU. The resistance was predicated on technical grounds, and the operators of the Research (Forschungs) Reactor Munich (FRM-II) still insist that only HEU is satisfactory for a high quality reactor. But more and more countries are taking the other path, and there are new reactors in South Korea and Canada and planned reactors in Thailand, France, China, Australia and Morocco that are designed to use LEU. This should be mentioned, perhaps on p. 6 at the end of the discussion on new fuel development, and perhaps again on p. 31 just before the recommendations section.

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