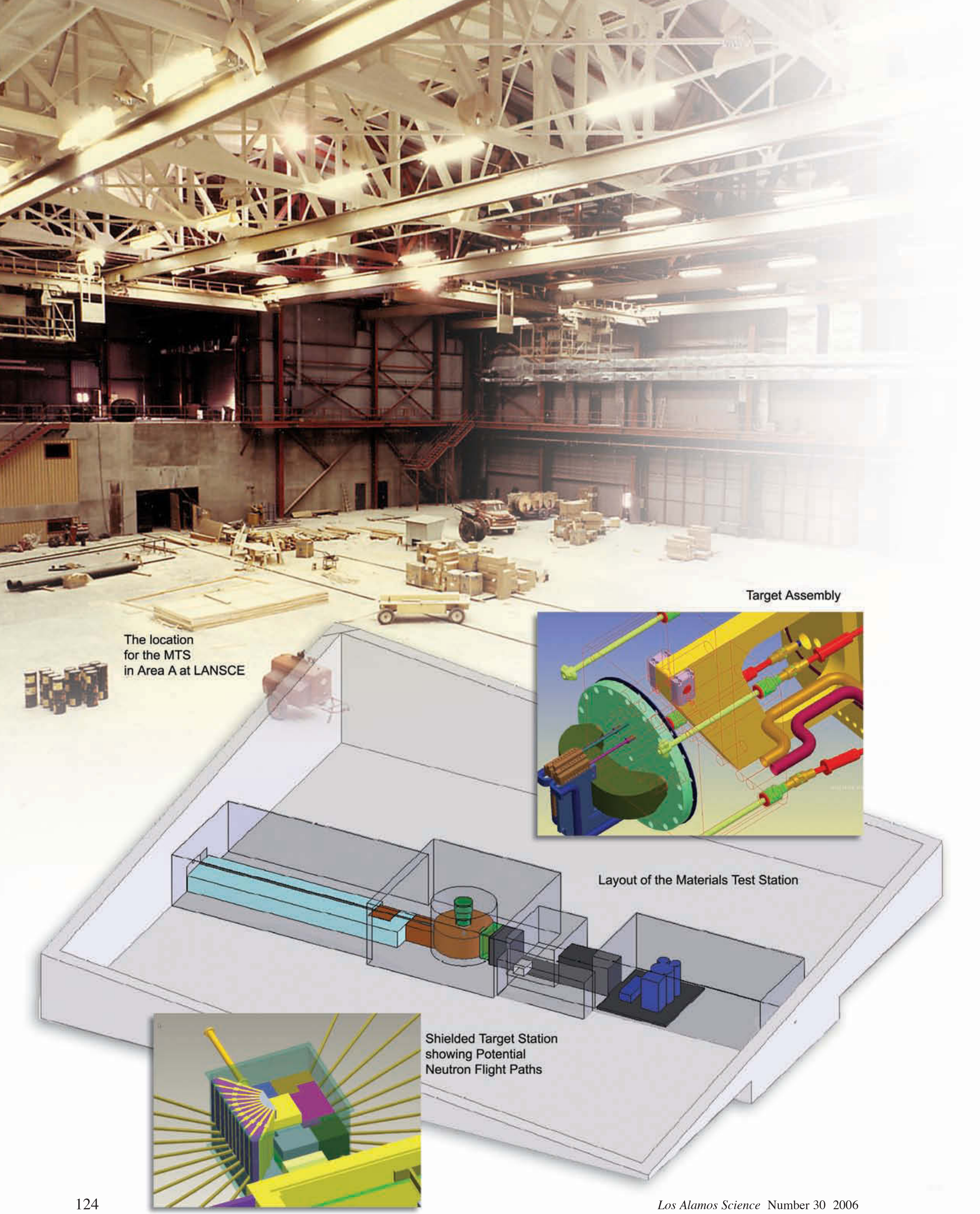
Target Assembly
The location
for the MTS
in Area A at LANSCE
Layout of the Materials Test Station
Shielded Target Station
showing Potential
Neutron Flight Paths

# The Role of LANSCE in the Nuclear Energy Future

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"A secure energy future for America must include more nuclear energy," President Bush said in June 2005 as he urged Congress to pass a strong nuclear energy bill before their August recess.

Nuclear energy is now on the agenda as a climate-friendly source of energy to meet the increasing global energy demand. The challenging issues that we need to address are the following: How do we expand nuclear energy in a way that does not increase the risk of nuclear material proliferation, and how do we minimize the amount of nuclear waste that is produced? The Advanced Fuel Cycle Initiative of the Department of Energy (DOE) is developing technologies that, in combination with systems that produce fast (high-energy) neutrons, will allow efficient separation and recycling of spent nuclear fuel. Fast neutrons are needed because they are very efficient at transmuting and destroying the long-lived radiotoxic components of the waste—mostly transuranics (elements heavier than uranium)—that build up during reactor operation and dominate waste disposal issues. Among the possible fast neutron systems, fast reactors (those using fast neutrons to sustain fission energy production) are the most likely solution for the transmutation and destruction of the long-lived waste. Transmutation fuels are very different from those normally used and are the current focus of many of the closed-fuel-cycle research and development activities. The proof of principle for the transmutation fuels depends on the availability of a neutron radiation source that can mimic the conditions that fast-reactor fuels and structures must safely withstand. The new Materials Test Station (MTS) scheduled to be constructed at the Los Alamos Neutron Science Center (LANSCE) will be the only facility in the nation that will be able to produce the necessary irriadiation capabilities until a new fast test reactor can be built.

Its unique neutron source—a nonreactor spallation neutron source driven by the proton beam at LANSCE—ensures that the MTS can safely create the conditions of pressure, temperature, energy density, and coolant properties that are prototypical for the proposed fast reactors. The MTS may be able to go beyond those conditions to test the limits of fuel and material failure. The ultimate goal of a fully closed fuel cycle that significantly reduces nuclear waste and better manages the nuclear materials is within reach. If that goal were implemented globally with a new provider/user state fuel service strategy, proliferation concerns could be fully addressed and a safe renaissance in nuclear energy could occur.

## Trends in Global Nuclear Energy—The Role of LANSCE

For decades, the world has recognized that nuclear-material management presents both significant advantages (energy production, health care, industrial growth, and zero greenhouse gas emissions) and significant concerns (nuclear-weapon proliferation and radioactive waste). Today, at least 33 countries utilize nuclear power, and every corner of the globe has been impacted by nuclear medicine. The international growth in nuclear energy is accelerating, along with research and development of closed-fuel-cycle technologies. Closed-fuel-cycle technologies are those that recycle and extract energy from the transuranics, elements heavier than uranium that are produced in reactors by neutron bombardment of uranium nuclei. The need to store nuclear waste for thousands of years stems from the presence of these transuranics. Their elimination through a closed fuel cycle is highly desirable because it would drastically reduce long-term storage requirements.

Closing the fuel cycle also addresses the issue of nuclear material proliferation as one of the major transuranics (plutonium) is recycled and never leaves the system. A new global governance regime, whereby the major industrialized nations provide fuel services to user nations, will allow the safe and controlled expansion of nuclear power to developing countries.

## Nuclear Energy: A Sustainable Carbon-Free Energy Source

Globally, burning fossil fuels is the primary source of energy for transportation and electricity. Transportation requires approximately one-third of the total energy obtained from this source. Such a strong reliance on heavy fossil fuels and the resulting emissions of carbon dioxide are causing global environmental impacts. A transition to noncarbon-emitting technologies is needed now, and nuclear energy is considered one of the primary climate-friendly sources of energy for the future. A recent Massachusetts Institute of Technology report calls for expansion of nuclear power to help solve the pending environmental crisis (Deutch et al. 2003). This study advocates a greatly expanded nuclear-power sector, growing from the current power base of 366 gigawatt-electric (GWe) to a worldwide capacity of 1000 GWe by mid-century and eliminating up to 25 percent of carbon emissions. The driving force behind this recommendation is that the "nuclear option should be retained precisely because it is an important carbon-free source of power." The directors of the nation's premier national laboratories have called for a similar expansion of nuclear power, aimed at achieving a sustainable nuclear-fuel cycle to control materials proliferation and waste generation (Six Laboratory Group 2003). The resulting large reduction in carbon emissions makes it imperative that nuclear power play a significant role in the future energy mix.

> "*Nuclear energy is the only available technology that can replace fossil fuels on a large scale*." —Patrick Moore, founder of Greenpeace, keynote address to the American Nuclear Society, November 2005.

Consistent with the desire to reduce greenhouse emissions, the transportation sector is aggressively pursuing hybrid vehicle technology as well as hydrogen fuel cell technology for future vehicles. The problem is that hydrogen is not an energy source, but rather a storage medium. It takes energy to produce hydrogen, and the current method (burning methane in the presence of steam) produces carbon dioxide as a byproduct. Once again, nuclear energy is the front and center option for producing hydrogen cleanly, and the DOE Nuclear Hydrogen Initiative is researching the best and most efficient options for doing so.

## The Components of Spent Nuclear Fuel

A major challenge to increased use of nuclear power is the disposition of the spent nuclear fuel, which contributes to long-term radiotoxicity (a potential source of negative health effects in the long term) and thermal heat load in a nuclear-waste repository. In the once-through fuel cycle shown in Figure 1a, a typical nuclear-fuel assembly from a light-water reactor is discharged about 18 months after generating about 41 megawatt-days of energy per kilogram of fuel. It is called "spent" fuel because uranium-235, the fissile isotope of uranium, has been fissioned, or "spent," to the extent that a nuclear chain reaction can no longer be sustained. The composition of the spent-fuel assembly is shown in Figure 1b. A large fraction (95.5 percent) is the original uranium fuel, which exhibits very low radioactivity. The products of uranium fission (primarily cesium and strontium) make up about 3.3 percent of the waste and are intensely radioactive. However, because of their relatively short half-lives, they decay to stable elements in about 300 years and thereafter represent no long-term environmental challenge. Technetium and iodine are long-lived fission products that contribute to long-term radiotox-

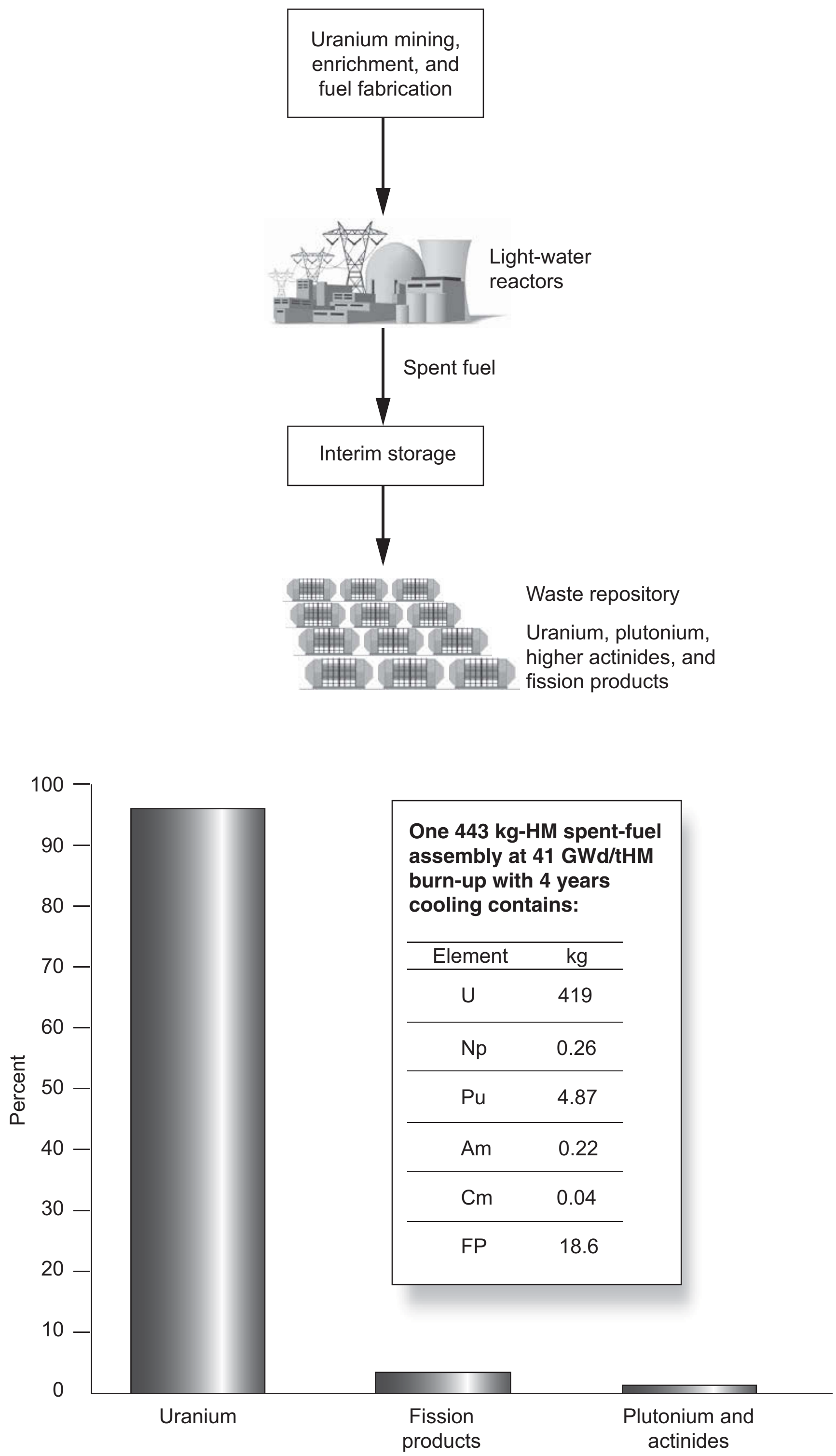


**Figure 1. The Once-through Fuel Cycle and Constituents of Spent Fuel**
**(a) For the once-through or "open" fuel cycle, spent fuel from light-water reactors is stored and then sent to the repository. (b) Plutonium and the other very long-lived radioactive elements make up only about 1% of the spent fuel from a typical light-water reactor.**

icity and therefore must be dealt with separately. During the fuel's residence in the reactor, transuranic elements (plutonium, neptunium, americium, and curium) are created through neutron interactions with uranium. They make up only about 1 percent of the waste but are radioactive for several hundred thousand years and contribute significantly to the long-term heat load. Essentially, it is this 1 percent fraction of the spent fuel that is the primary challenge of nuclear waste and proliferation.

Because only the transuranics and some fission products require isolation for long periods, opportunities exist for significantly reducing the number of repositories through spent fuel recycling. For example, uranium can be separated and reused or stored; the intensely radioactive fission products can be separated and allowed to decay away; and transuranic elements, which are mostly fissile, can be recycled and fissioned in a neutron environment, providing an important additional source of energy.

## Spent Fuel Options: The Once-through Cycle

The current U.S. strategy for nuclear-waste disposal is to send spent fuel directly to the Yucca Mountain underground nuclear-waste repository (to be built in Nevada pending final approval) without processing or recycling (see Figure 2). Initially implemented during the Carter administration, a directive that prohibited reprocessing and plutonium separation essentially required the nuclear industry to adopt the once-through fuel-cycle scheme. Even though this directive was later rescinded by President Reagan, the commercial U.S. nuclear industry has not pursued reprocessing for economic reasons: The current price of enriched uranium is a relatively small fraction

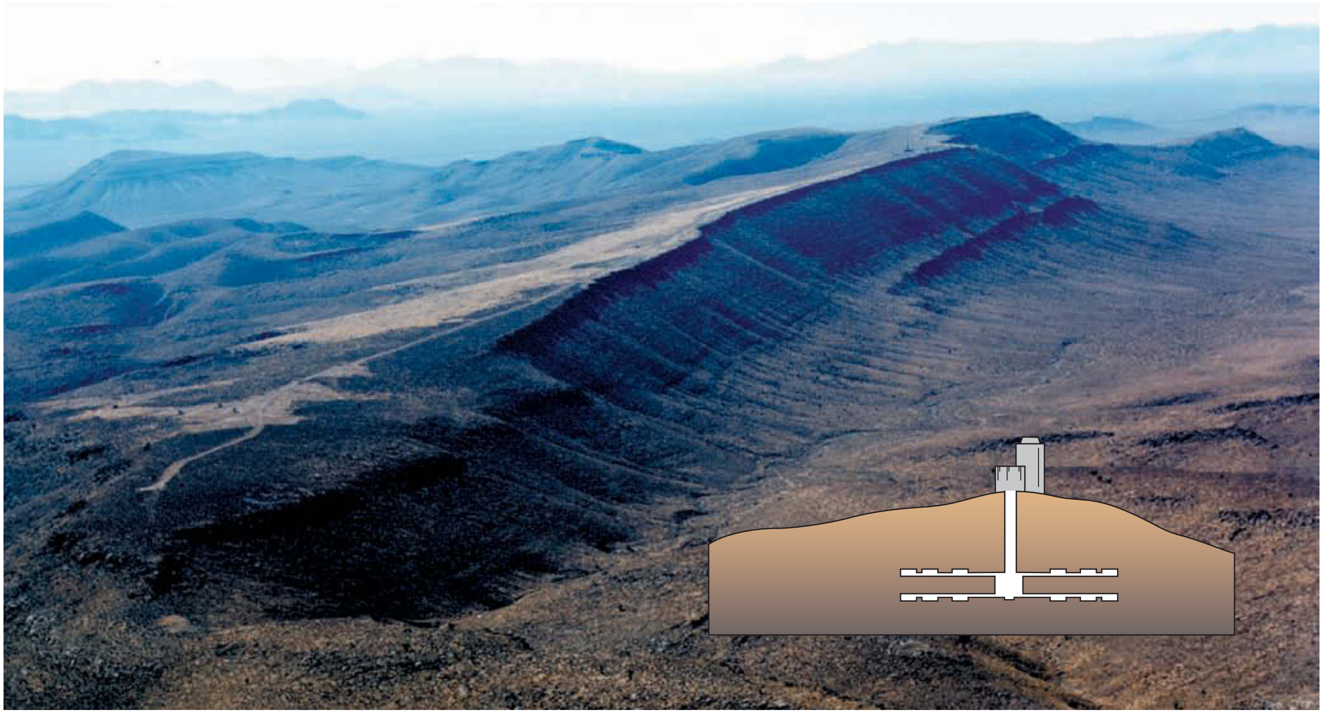

**Figure 2. The Planned Nuclear Waste Repository at Yucca Mountain**
**The planned geologic repository at Yucca Mountain, Nevada, is designed to hold 63,000 tonnes of commercial spent nuclear fuel. A decision on a second repository is needed by 2010 in order to keep pace with the accumulation of waste. The inset suggests the many tunnels belowground that will house the waste.**

of the total cost of the reprocessing operation. In the once-through, or "open," fuel cycle, the requirement to isolate spent fuel for thousands of years derives from the small fraction of long-lived radiotoxic constituents present in the spent fuel assemblies that are left intact at disposition and are not reprocessed or recycled (Figure 1).

**Repositories Needed for the Once-through Cycle.** Currently, the United States is generating 2100 tonnes of spent nuclear fuel per year. At this generation rate, Yucca Mountain's legislated capacity (63,000 tonnes) will only hold 30 years' worth of spent nuclear fuel and this limit will be reached in 2015. Yucca Mountain's technical limit, as opposed to its legislated limit, is estimated to be two to three times greater, and expanding its legislated limit may offer a solution for additional spent-fuel disposal in the near term. However, many growth scenarios for nuclear energy would require commissioning similar repositories at a much more frequent rate than every 30 years to dispose of the increasing inventories of spent fuel. As pursued in a once-through fuel cycle, the direct disposal of spent fuel requires geologic formations that can ensure safe containment of nuclear products for millennia. Such environments must protect the biosphere from catastrophic release of transuranics (plutonium, neptunium, americium, and curium) and long-lived fission products. These environments must also be sufficiently robust to deal with long-term heat management issues and to offer protection from possible covert efforts to recover nuclear-weapon materials, such as plutonium.

The disposition of spent fuel is also a global problem. Assuming a conservative energy growth, the International Atomic Energy Agency (IAEA) estimates that, worldwide, spent-fuel inventories will be greater than 400,000 tonnes by 2020. Direct disposal of this amount of fuel would require seven repositories the size of the Yucca Mountain repository, and none exist today. According to other IAEA projections, by 2050, the installed global nuclear-power capability could be three to six times larger than it is at present. Under such scenarios, as many as 30 Yucca Mountain–equivalent repositories would be needed by mid-century, with the number rising to 100 by century's end. This is clearly an unsustainable condition.

In the once-through fuel cycle, the fuel discharged from a reactor does not run the risk of being diverted because of its high radiation level resulting from the buildup of fission products. This self-protection feature, however, disappears within

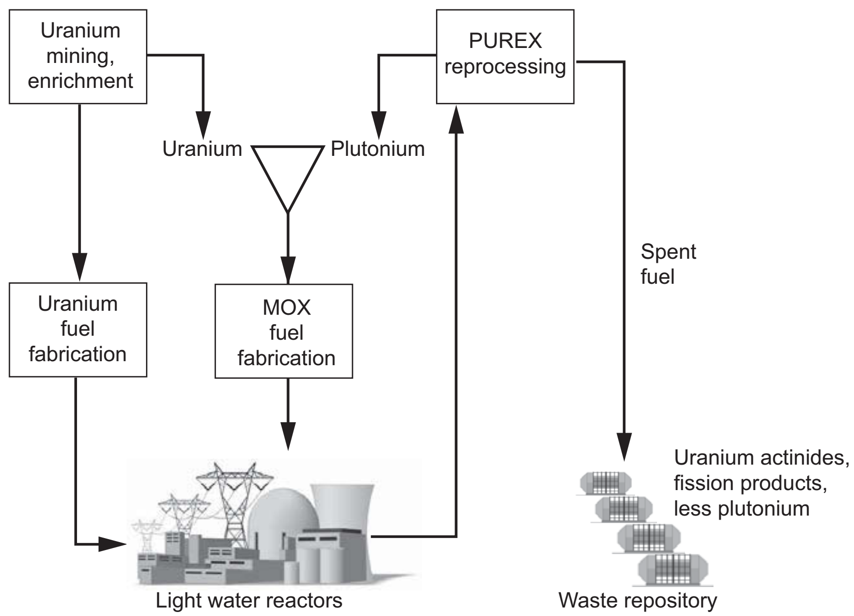


**Figure 3. The MOX Intermediate Fuel Cycle**
**In the conventional plutonium recycle scheme, spent uranium fuel is reprocessed, and plutonium is extracted and reused in mixed-oxide fuel. France uses this scheme to reduce their waste volume by a factor of 4 over the once-through cycle.**

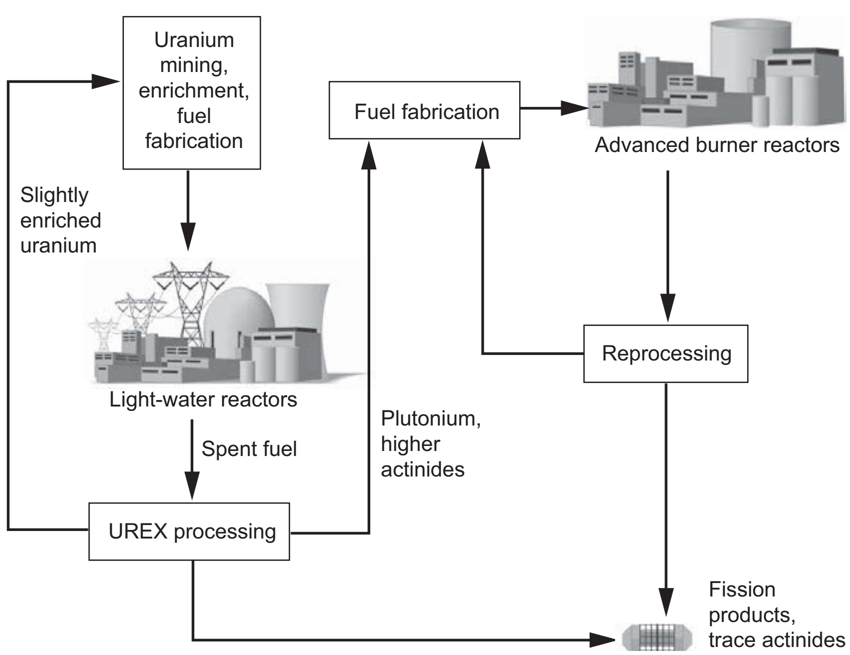


**Figure 4. The Closed Fuel Cycle**
**In a closed fuel cycle, the transuranics are extracted from the spent fuel and transmuted in fast-spectrum reactors.**

about 100 years as the short-lived fission products decay away and the radiation level in the spent fuel drops. After such a period, a large geologic repository containing thousands of fuel elements becomes, literally, a plutonium mine because the plutonium in the spent fuel remains intact for thousands of years. A repository the size of Yucca Mountain would contain more than 600 tonnes of plutonium. Consequently, the only permanent solution to the risk of plutonium being diverted is its destruction.

## New Closed-Cycle Technologies to Increase Repository Capacities

The capacity of the Yucca Mountain repository is largely driven by the heat load of the spent fuel. Removal of specific isotopes that dominate the heat load can significantly increase the capacity of the repository. For example, if both the short-lived isotopes of cesium and strontium and the long-lived isotopes of plutonium and americium were removed from the waste, the repository's capacity could be increased by more than a factor of 50. It is therefore important to develop technologies aimed at efficiently separating and then destroying the heat-producing elements in the waste.

**An Intermediate Option for Spent Fuel: MOX.** The separation of uranium and plutonium from the spent nuclear fuel is a widely known technology already used in several countries. France, Great Britain, Japan, and Russia reprocess their spent fuel and partially recycle it into new fuel. Plutonium is separated from the waste, mixed with uranium to make mixed-oxide fuel (MOX), and then reintroduced as fuel in their reactors (see Figure 3). The world's industrial-scale experience in repro-

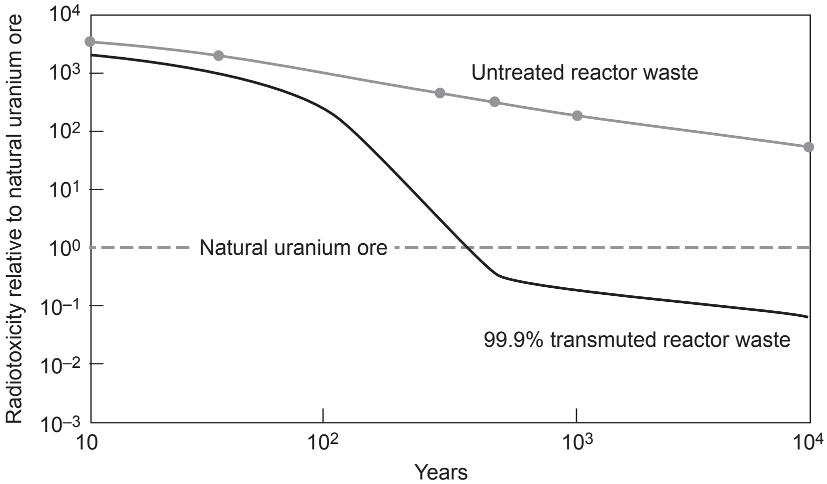


**Figure 5. Reduced Radiotoxicity of Transmuted Reactor Waste**
**The radiotoxicity of transmuted reactor waste declines precipitously after 100 years and thereby allows repository capacity to increase by a factor of 50. Gains in separation efficiency can increase this value further.**

cessing and fabricating MOX comes from those facilities. The resulting high-level waste volume from a single MOX recycle is about a factor of 4 less than that from the once-through system. At the same time, the amount of fissile plutonium is reduced by roughly 20 percent, and in the process, a significant amount of energy is recovered. Recycling the plutonium in a MOX recycle adds only about 2 to 3 percent to the cost of electricity. Although some gains are being made with one MOX recycle, its impact on long-term waste management is limited because most of the high-level transuranic waste remains.

**Advanced Fuel Cycle Initiative and the Closed Fuel Cycle.** More significant reductions in residual waste can be made with a fully closed fuel cycle (Figure 4). The United States develops partitioning and transmutation technologies aimed at destroying high-level transuranic waste more efficiently under the Advanced Fuel Cycle Initiative (AFCI) of the DOE. Within the AFCI, the DOE is collaborating with other countries to pursue this goal. Research is being conducted on UREX, a uranium extraction process that does not produce a pure plutonium stream but does efficiently separate uranium and partition fission products and transuranics to minimize waste. An essential feature of the closed fuel cycle is the transmutation of the higher actinides in reactors with fast neutron energy spectra. Robust fuel forms for transuranics are now being developed so that they can be transmuted efficiently. Once the recycled transuranic fuels have been fabricated, reactors with thermal neutron energy spectra (light-water reactors), fast reactors, or accelerator-driven systems can be used for transmutation.

Multiple studies show that the transmutation performance in systems with fast versus thermal neutron energy spectra is fundamentally different. Fast-neutron systems (either fast reactors or accelerator-driven systems) are more “efficient” at destroying actinides because fewer neutrons are lost to the neutron capture reactions that lead to the buildup of higher actinides. Thus, in the closed fuel cycle, the fast system can be utilized for repeated recyclings without concern for the buildup of higher actinides. Thus, as shown in Figure 4, fast reactors are the preferred option for “continuous recycle” fuel-cycle strategies designed to improve waste management and/or resource utilization. The optimal combinations of these technologies depend on country-specific considerations with respect to nuclear energy use and waste management strategies.

Studies funded by the DOE, as well as those conducted in Europe and Japan, indicate that the cost of nuclear energy using a closed fuel cycle (including partitioning of the waste, storage of the fission products, and recycling and transmuting the plutonium and minor actinides) is 10 to 20 percent higher than the cost of electricity using a once-through fuel cycle. However, because of reduced radioactivity, this extra cost is potentially offset by the savings realized by the reduction in the number of repositories (see Figure 5).

## Fast-Neutron Testing at LANSCE for Closed-Fuel-Cycle Technologies

The DOE has launched two major programs to explore options for advanced nuclear-energy systems, the AFCI and the Generation IV (GEN-IV), Reactor Program. Both programs are to determine fuel and material performance limits as a first step in designing fast-neutron-spectrum systems that reduce or eliminate transuranics from nuclear waste. These programs will eventually field major system demonstrations for reprocessing and transmutation. The AFCI is tasked with the development of fuels and materials for transmutation in advanced burner reactors. The goal is to develop new fuels, containing significant quantities of actinides, that can achieve very high burnup,[1] operating safely in a fast-spectrum reactor.

Different fuel forms (such as oxides, metals, or nitrides) will be used, as well as different formulations of constituents. Their success in transmuting long-lived transuranics cannot be judged until they have been irradiated and tested. In addition to actinide-bearing fuels, transmutation also requires development of new advanced structural materials for cladding core components.

Before major systems, such as a new fast-spectrum transmutation reactor, are implemented, the performance of the actinide-bearing fuels and cladding must be proved. A concerted effort is required involving the irradiation of candidates in prototypic environments, postirradiation examinations in hot cells, data analysis, and validation of detailed models that will eventually be used to simulate high-burnup performance (through science-based prediction) and develop the next generation of advanced materials. Reactor core materials must be stable and predictable during prototypic irradiation conditions as well as those that would obtain during design basis accidents. Listed here are several technical issues that affect performance: fuel restructuring and densification, migration of constituents, gas evolution, fuel swelling and fuel-to-cladding interactions, loss of ductility in the cladding, irradiation-induced swelling, gas generation, and creep strength. Only through testing in a prototypic environment can these issues be resolved.

[1] Burnup is the energy extracted per unit mass of nuclear fuel. In typical light-water reactors, burnup is about 50 megawatt-days per kilogram (MWd/kg) in the discharged fuel. Higher burnups (greater than 200 MWd/kg) are possible in fast reactors. Fissile depletion, cladding strain, internal pressure, and fuel-to-clad interaction are the limiting factors used to obtain the maximum burnup of fuels.

**DOE's AFCI Materials Test Station at LANSCE.** To achieve the goals outlined above within reasonable cost and on schedule, a domestic fast-neutron testing capability is now needed. To fill this major gap, the AFCI has funded the design phase of the Materials Test Station (MTS) at LANSCE. This facility will provide the necessary irradiation capability for performing time-efficient testing. The MTS, combined with the planned refurbishment of the LANSCE accelerator, will provide a long-term reliable irradiation capability. Because of the unique features of its nonreactor spallation neutron source, the MTS can safely provide prototypic coolant, pressure, and temperature conditions of the proposed fast reactors. MTS can also provide a test bed for other DOE programs, including the space reactor and fusion energy systems.

**The MTS to Test Safety and Efficiency of Fast Reactor Fuels.** From experience, we have learned that all reactor materials undergo profound changes in their important engineering properties because of changes in their crystalline structure. The latter set of changes is caused by long-term neutron irradiation during reactor operation. The performance of fuels and structural materials under neutron irradiation is expected to set the limits for the design of future nuclear-energy systems. These limits can be measured and understood through the irradiation of candidate materials in the proposed MTS at LANSCE, in combination with postirradiation examinations and data analysis. These capabilities will provide validation data for ab initio fuel and material performance models that will be used to design the next generation of high-burnup fuels and radiation-tolerant materials.

To meet research requirements, the MTS will allow irradiating samples in versatile configurations. The facility will provide temperature control and a choice of coolants. (See the box "Capabilities of the Materials Test Station" on page 136.) The MTS will be placed in a large experimental area at the end of the LANSCE accelerator, where 800-million-electron-volt (MeV) protons will be used to create fast-spectrum neutrons through spallation reactions on a tungsten target. The preconceptual MTS configuration is shown in Figure 6. The spallation target that produces neutrons, the neutron reflector, and the sample irradiation components are all contained in a vacuum vessel that eliminates the production of contaminated air. The initial target configuration will employ water-cooled tungsten technology, which has been used in several other applications at Los Alamos and elsewhere and is well proven.

The spallation target assembly and the sample assembly containing irradiation experiments are introduced horizontally into the vacuum vessel. The sample assembly will provide temperature control to the irradiation experiments, and with future additions, could accommodate special coolant needs with closed loops. Because the MTS is not a reactor, there is no possibility of reactivity feedback effects on the neutron source from the fission neutrons produced in the fuel. The spallation neutron source thus eliminates a potential safety concern and provides the capability to perform controlled run-to-failure tests on advanced transmutation fuels.

The MTS is designed to accommodate an initial proton current of 1 milliampere on target and has the added ability to handle twice this current. At proton energies of 800 MeV, the initial milliampere current translates into a beam power of 800 kilowatts. At this design value, a fast-spectrum flux of $1 \times 10^{15}$ neutrons per centimeter squared per second (n/cm$^2$-s) is achievable in the central irradiation region (Figure 7). (In a fast-spectrum flux, the energies of the neutrons are greater than 0.1 MeV.)

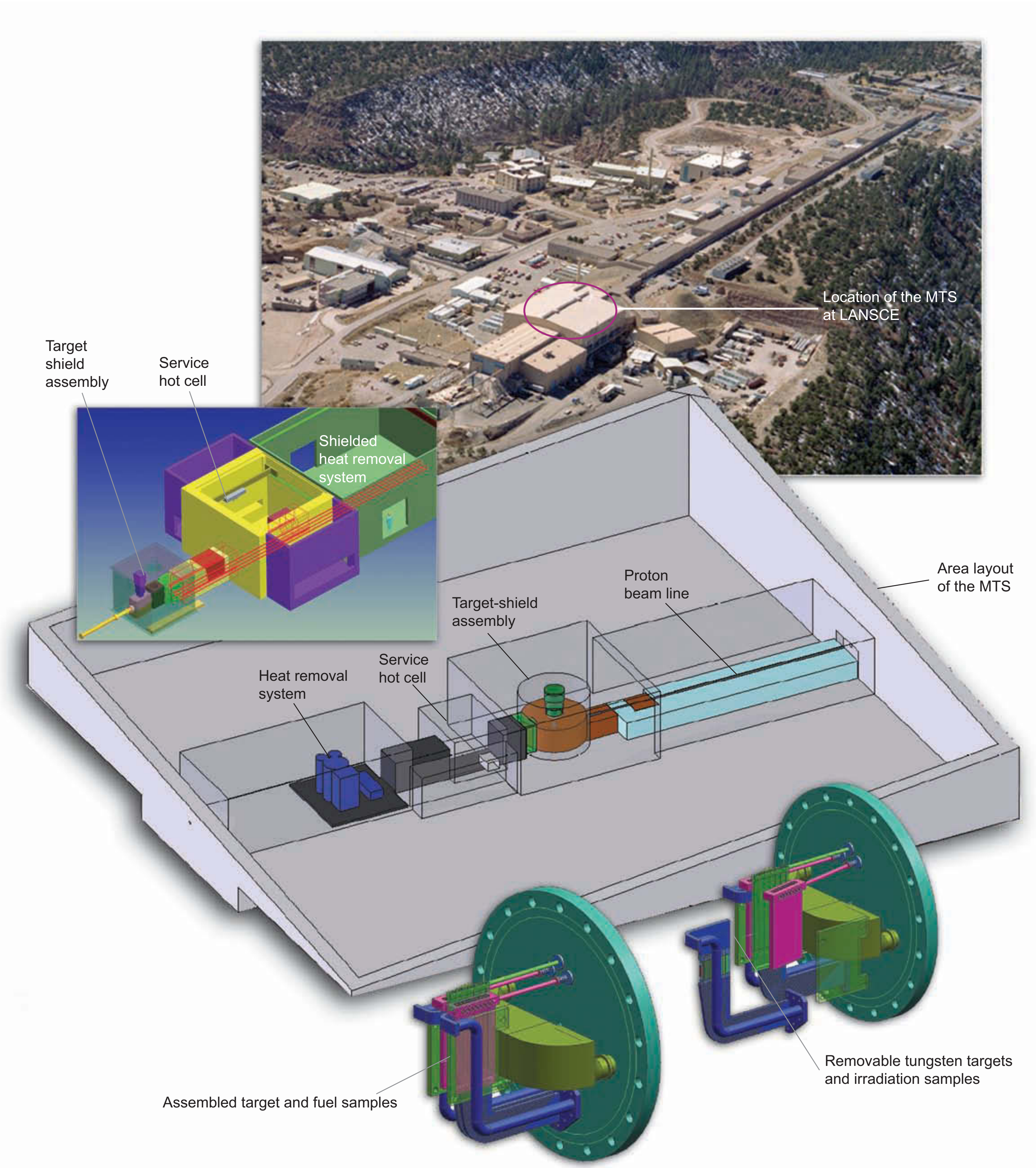


**Figure 6. Materials Test Station (MTS) at LANSCE**
**The preconceptual configuration of the MTS within Area A is shown as well as views of the cooling system, the split target, and experimental assemblies.**

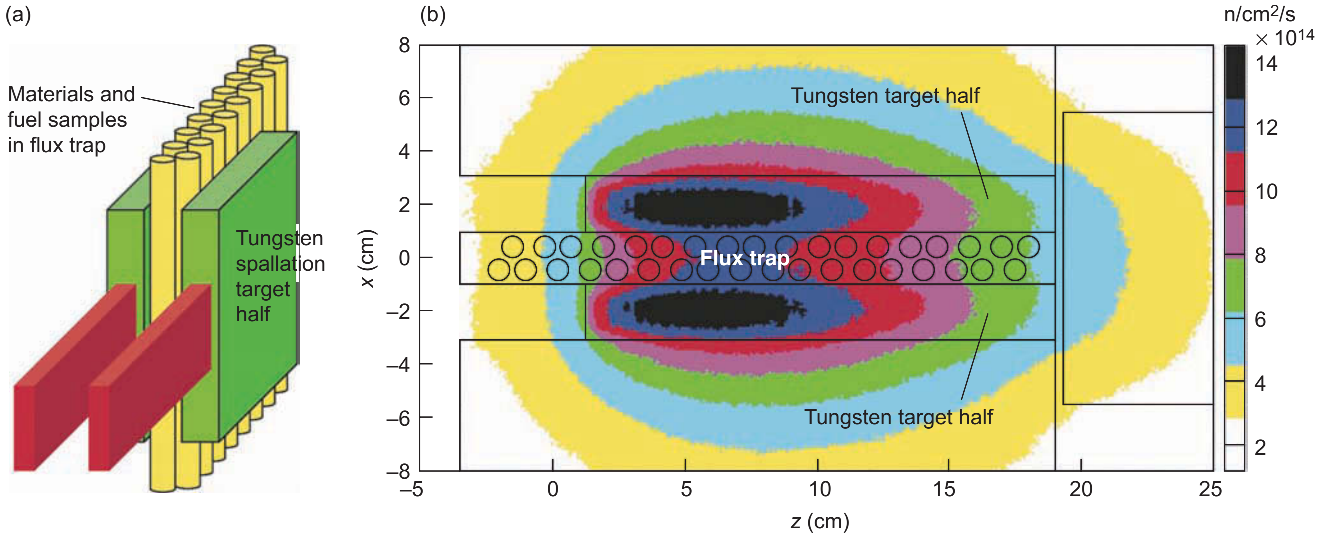


**Figure 7. Calculated Neutron Flux in the Split Tungsten Target**
**The split tungsten target arrangement shown in (a) and (b) ensures an intense neutron flux in the central flux-trap region, providing experimenters with an environment that is similar to that in a fast reactor.**

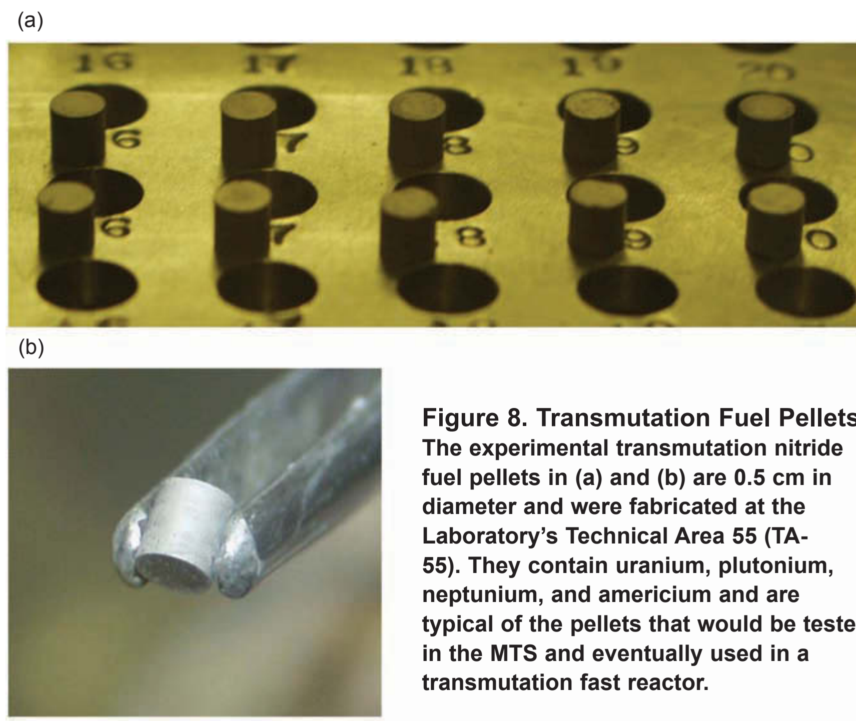


**Figure 8. Transmutation Fuel Pellets**
**The experimental transmutation nitride fuel pellets in (a) and (b) are 0.5 cm in diameter and were fabricated at the Laboratory's Technical Area 55 (TA-55). They contain uranium, plutonium, neptunium, and americium and are typical of the pellets that would be tested in the MTS and eventually used in a transmutation fast reactor.**

As shown in Figure 7, the tungsten neutron source is split into two identical target halves. The protons from the LANSCE accelerator are directed equally to the target halves, producing an intense source of neutrons. Each proton striking a tungsten atom releases approximately 15 neutrons. The central flux-trap region, where the neutron flux is most intense, will contain fuel and material samples. Experimental fuel pellets, such as those shown in Figure 8, will be contained in small temperature-controlled "rodlets" that will allow researchers to mimic fast-reactor conditions. More than 200 fuel pellets and 1000 material samples can be irradiated in a given campaign.

**Prototypical Fast-Neutron Energy Spectrum at the MTS.** The neutron energy spectra of typical fast reactors are compared with the energy spectrum at the future MTS in Figure 9. The Pressurized-Water Reactor (PWR) spectra are typical of commercial power reactors in the United States. Most fission neutrons are "born" with energies between 2 and 3 MeV. But as shown, most neutrons in the PWR are in the low-energy range because of slowing-down elastic collisions with the hydrogen in the water coolant. In a typical fast reactor—curve labeled FFTF (for Fast Flux Test Facility) in Figure 9—the neutron spectrum contains none of the low-energy neutrons because there are no materials present in the reactor core that slow them down (coolants are typically sodium or lead). As mentioned before, the fast-spectrum neutrons are much

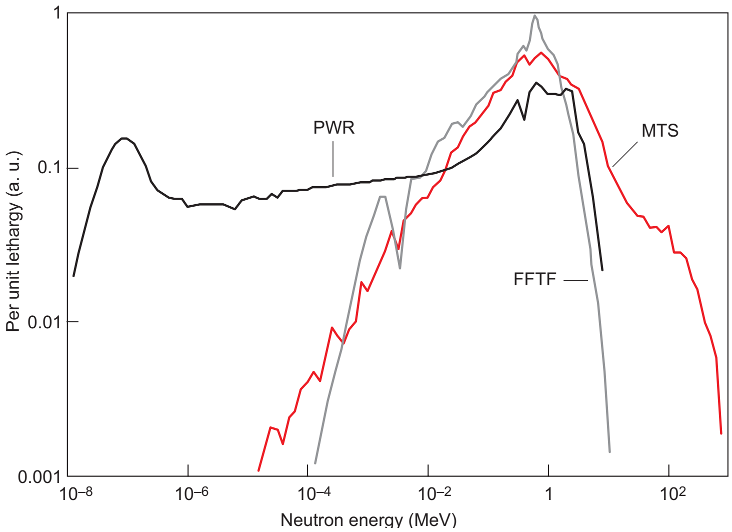


**Figure 9. Comparison of Neutron Spectra at the MTS and Existing Fast-Flux Reactors**
**Neutron flux per unit lethargy is plotted as a function of neutron energy for the MTS and existing fast-flux reactors. Note that the MTS spectrum is very close to that of fast-flux reactors except for a larger contribution at the high-energy end.**

more efficient for transmutation and are therefore the focus of our research efforts.

The MTS neutron spectrum is similar to that of a fast reactor, but the MTS has an additional high-energy tail beyond 10 MeV. These high-energy neutrons (about 5 percent of the total number) produce a moderate amount of hydrogen and helium gas in structural materials. Therefore, the ratios of the helium atoms to the displaced atoms in structural materials irradiated at the MTS are higher than those at typical fast-spectrum reactors. Thus the MTS irradiation environment is slightly more severe than that of a fast reactor and therefore will yield conservative results regarding the limits of performance.

Among the domestic facilities currently available, none meet the minimum requirements for fast-spectrum irradiations. Because of the shutdown of FFTF and the Experimental Breeder Reactor II, the only two facilities remaining for irradiations are the Advanced Test Reactor at Idaho National Laboratory and the High Flux Isotope Reactor at Oak Ridge National Laboratory, both of which are thermal-spectrum reactors (spectra similar to the PWR in Figure 9). These facilities provide some irradiation data but cannot provide the fast-spectrum irradiation environment needed to evaluate fuel performance. Most fission reactions in a fast reactor are induced by neutrons with energies greater than 0.1 MeV, and there are essentially no fissions induced by neutrons in the thermal range. A similar distribution of fissions is observed for the MTS with the addition of some fissions induced by neutrons above 10 MeV from the high-energy tail of the neutron spectrum. In a thermal reactor neutron energy spectrum (in this case a typical light-water reactor), essentially all fissions are induced by thermal neutrons (neutrons with energies less than 0.625 eV). Thus, to investigate the fuel failure mechanisms that affect fast-reactor fuel performance, such as the fuel–clad interaction, either a new fast test reactor or a facility like the MTS is needed.

**The MTS to Begin Operations in 2009.** Given approximately \$60 million in construction funds over the next three years, the MTS will begin materials and fuels irradiation at the $1 \times 10^{15}$ n/cm$^2$/s level in fiscal year (FY) 2009. With the additional enhancements to the LANSCE accelerator, irradiations at the $2 \times 10^{15}$ n/cm$^2$/s level will commence in 2012. At this level, each 8-month irradiation campaign will test fuels to 6 percent burnup, which, combined with detailed analysis, will provide the data and information for proof of performance. As shown in Figure 10, these data will directly support the AFCI/Gen-IV research programs and development of the fast-spectrum transmuters.

The GEN-IV Program is developing a fast-reactor technology to achieve significant advances in proliferation resistance and sustainable energy production to meet the long-term energy needs of the country. Several technology options (using gas, lead, or sodium coolant) are being assessed. A selection is expected around 2012 and a demonstration reactor in 2025.

**The MTS to Double Its Power with 2012 LANSCE Beam Upgrade.** Enhancements of the beam current at LANSCE (LANSCE-E) are currently being considered for future upgrades beyond the refurbishment stage (LANSCE-R). Studies have shown that the average beam power delivery to MTS can be increased by a factor of 2 over what is currently achievable by doubling the length of the pulses without changing the pulse rate (in other words, by increasing the duty factor). These upgrades could occur as early as 2012. The neutron intensity

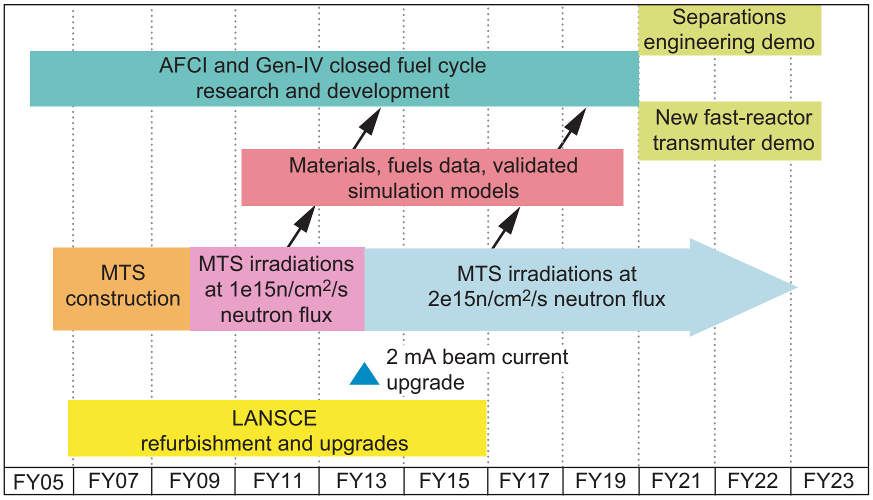


**Figure 10. Timeline for the MTS**
**The MTS will start operations in FY 2009 at the 800 kW power level, and with an accelerator upgrade in FY 2014, the power level will double. Fuels and materials irradiation data will support the development of the fast reactor transmuter demonstration.**

from the spallation target will increase by a similar magnitude (up to $2 \times 10^{15}$ n/cm$^2$/s), enhancing the irradiation capability at the MTS. The heat removal systems at the MTS will be designed for easy upgrades to accommodate the higher power. The target and sample assemblies are also being designed for easy upgrading.

## Conclusions

Global and national energy needs require a safe, efficient, and proliferation-resistant nuclear-energy supply that does not produce greenhouse gases. No single energy resource will meet the future demand in an economically and environmentally acceptable way. We must increase energy efficiency and implement a portfolio of clean energy sources, including nuclear sources. The argument against partitioning and transmutation of materials is that separated plutonium results in a diversion risk. The argument in favor of partitioning and transmutation is that the separated plutonium is ultimately destroyed, avoiding an inexorable buildup of inventories and a considerable long-term risk for diversion of materials. Closing the fuel cycle with partitioning and transmutation will play a central role in minimizing this risk.

A major challenge to the increased use of nuclear power is global nuclear-material management. Recent world events clearly show that the containment of nuclear-weapon technology is no longer credible because this technology is available to almost any country willing to accept the associated high economic and political costs. Plutonium, an important weapon component, is produced by all nuclear reactors and can be chemically separated from spent nuclear fuel. Thus, it is important to control or avoid producing separated plutonium and enriched uranium that can be used in weapons so that they cannot be diverted for covert use. Managing special nuclear materials in a transparent fashion is essential if nuclear energy is to realize a renaissance.

Unfortunately, it appears that separations and enrichment technologies are being pursued in a few countries for nonpeaceful purposes. It is clear that the general know-how for implementing nuclear-material technology exists and is readily available, even under the present import-export control measures of the global Nuclear Suppliers Group. Thus, policies to promote the once-through open cycle as a strategy to prevent nuclear proliferation have not accomplished their intended purpose.

International organizations share U.S. concerns about global nuclear-material management. The Director General of the IAEA, Mohamed El Baradei, published an editorial (ElBaradei 2004) presenting his views on reducing global proliferation risks. They include the need to revisit the limitations of the 1970 Treaty on the Nonproliferation of Nuclear Weapons, to strengthen inspections by the IAEA, and to consider a “multinational approach to the management and disposal of spent fuel and radioactive waste.”

The proposed concept of “supplier and user states” for nuclear energy has significant merit, and the associated details must be fully assessed to determine practical implementation options. This new nuclear governance regime could involve supplier states or regional supply centers that are under strict international control and safeguards.

With careful and judicious planning, a future can be envisioned, perhaps by mid century, in which domestic nuclear power is a significant contributor to a clean energy portfolio, providing half of our nation’s electricity. Globally, an advanced fuel-cycle technology can be fully implemented with a limited number of countries providing fuel services to others while nuclear materials are tracked and managed under strict international control. Partitioning and transmutation are key elements of the advanced fuel cycle in order to reduce to the maximum the waste needing long-term isolation.

With continued support, LANSCE will play a major role in the development of our nuclear-energy future. With the construction and operation of the MTS, fuels and materials research will be performed that is essential to the implementation of fast-spectrum transmuters and to the closing of the nuclear fuel cycle. The studies at MTS will be a first step in opening up a sustainable nuclear-energy option to the United States.

## Acknowledgments

The authors would like to acknowledge Eric Pitcher, Rick Wood, Eric Schneider, Keith Woloshun, Mike James, Jack Edwards, Mahlon Wilson, Stuart Maloy, John Eddleman, Rich Sheffield, Kurt Schoenburg, and Paul Lisowski for their assistance, design information, and analysis of the MTS.

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# Capabilities of the Materials Test Station (MTS)

To be fully certified, the candidate fuels and structural materials of a fast-flux reactor must be proven through testing in a prototypic environment. That is, the new fuels must be characterized, fabricated, and irradiated in a fast-neutron spectrum. Then their performance must be examined for undue damage to fuel cladding and other structural elements and for major restructuring of the fuel. To provide adequate data, the conditions produced at the MTS must mimic the unique and varied conditions in various fast-flux reactor designs, including high power density, very high temperatures, very high radiation doses, and corrosive conditions.

## Neutron Fluxes, Volumes, Temperature Controls, and More

The MTS provides the essential attributes necessary for a fast-neutron-spectrum test facility plus the added capability to run experiments in prototypic coolants.

The most important parameter, the neutron flux, which determines the rate of fission in the fuel, and therefore the power density and temperature, must be at least $10^{15}$ neutrons per square centimeter per second ($n$/cm$^2$-s) to equal the flux at which typical fast-reactor systems operate. The MTS achieves this level with the LANSCE accelerator delivering 1 milliampere of current. With a doubling of the current in 2012, twice the neutron flux, $2 \times 10^{15}$ $n$/cm$^2$-s, will be achieved in the flux trap.

Another important parameter is the ratio of fast to thermal neutrons—the flux of fast neutrons (energies greater than 0.1 MeV) divided by the flux of thermal neutrons (energies less than 0.625 eV). In typical fast reactors there are essentially no thermal neutrons, and the fast-to-thermal ratio is 75,000 or greater. The MTS achieves this ratio so that most fissions and structure damage observed in a test come from fast neutrons. This will test the mechanical integrity of the fuel/cladding system.

Regarding radiation damage to structures, it is desirable to achieve 10 displacements per atom (dpa) per year or higher because most changes in structure performance occur at this level. The helium generation rate is another parameter pertaining to radiation damage. In fast reactors it ranges from 0.2 to 0.5 atom parts per million (appm) He for each displacement per atom (dpa). For fusion systems this is closer to 10. For Accelerator Driven Systems, structures directly in the proton beam may endure 150.

The MTS achieves 10 dpa per year initially and 20 dpa per year after the LANSCE upgrade. The generation rate for helium is variable and ranges from 0.5 to 20 appm/dpa, thus making the MTS a unique environment for researchers.

High irradiation temperatures must be achieved for both the fuel and structures, and as shown Table I, the relevant range is quite large. Testing

**Table I. Characteristics of the MTS**

| Attribute | Value |
|---|---|
| Fast neutron flux | $1 \times 10^{15}$ n/cm$^2$/s – $2 \times 10^{15}$ |
| Fast to thermal ratio | 75,000 |
| dpa per year | 10 |
| Helium generation to dpa ratio in structures | 0.5–10 appm He/dpa |
| Irradiation temperature fuel | 1000°C–2000°C |
| Irradiation temperature structures | 350°C–600°C |
| Active control of structure temperature | Yes, within 10°C |
| Fuel power density | Up to 1600 W/cc |
| Fuel pellet diameter | 0.5–1.0 cm |
| Fuel pellet stack height in rodlet | 5–10 cm |
| Fuel irradiation volume | 200 pellets |
| Fuel material | Oxide, nitride, metal, dispersion |
| Fuel to clad bond | Helium, sodium, or lead |
| Coolant closed loops | Sodium, lead, or helium |

at higher structure temperatures (up to 600°C) and higher fuel temperatures (2000°C) is desirable. The MTS meets those conditions, as well as the ability to control the temperature during irradiation.

Most fast reactor and transmutation fuels have small diameters (~0.5 centimeter) and operate at high power densities—up to 1000 watts per cubic centimeter (W/cc). The MTS has the ability to test fuels at power densities up to 1600 W/cc, if needed.

The typical rodlets used for fuel tests will have a 2-inch (5-centimeter) fuel pellet stack. A relatively uniform flux over this height is desirable so that the different pellets experience similar irradiation conditions. Experimenters need to be able to irradiate 30 to 40 pellets (each roughly 5 millimeters in diameter by 5 millimeters in height) in the peak flux region. The MTS meets these volume and size requirements easily. Also the MTS has the capability to run some fuel tests to failure, allowing the absolute limits of the fuel integrity to be explored in defining the performance envelope.

The ability to test a variety of fuel types and fuel-to-cladding bonds is required because these features affect performance. The materials and fuels shown in Table I are those that currently require testing, although researchers may want to test other configurations in the future. The MTS can accommodate these needs and operate with several test-material configurations simultaneously.

Finally, the coolant types and the temperatures of prototypic corrosion and environmental conditions for cladding and structures tested at the MTS should cover the range of possibilities of the different fast-spectrum systems. To meet these needs, the MTS design includes the capability for closed coolant loops to provide flowing coolant conditions for corrosion studies under prototypic irradiation conditions. Most likely, the closed loops will be used for liquid-metal coolants, such as lead alloys or sodium, although helium gas is also a possibility.