UNITED STATES NUCLEAR INDUSTRY COUNCIL
www.usnic.org

April 2, 2026

USNIC BEWG Briefing Paper

A Deep Geologic Repository Remains Necessary Even if Fuel Recycling Is Implemented

Overview

For more than five decades, nuclear power has supplied roughly one-fifth of United States (US) electricity.[1] [2] All used nuclear fuel produced during this period remains safely stored under regulated conditions at reactor sites or interim storage facilities. The materials and byproducts generated during nuclear fission remain contained within the fuel matrix and are managed in compliance with strict federal safety regulations.

International experience shows that the long-term management of nuclear byproducts ultimately requires deep geologic disposal.[3] At the same time, interest is growing in technologies that can recover useful materials from used nuclear fuel and reuse them as fuel materials or other uses such as medical isotopes. As the US considers expanding nuclear power generation and developing recycling technologies, it is important to recognize that recycling and geologic disposal address different functional aspects of the back end of the fuel cycle and one is not a replacement or substitute for the other.

Even with successful recycling programs, a permanent disposal pathway will remain necessary for the isolation from the environment of certain long-lived materials that make up a relatively small fraction of the overall materials originally contained in used nuclear fuel.

Role of Reprocessing and Recycling

Processes commonly described as reprocessing separate certain usable elements from used nuclear fuel. These recovered materials—such as uranium, plutonium, and other transuranic elements—can potentially be fabricated into new reactor fuel or used in specialized applications, including specialized isotopes used in medical and industrial applications.[4] [5]

Recycling refers to the subsequent step in which these recovered materials are incorporated into new fuel that can again produce energy in nuclear reactors.

These approaches can help extend fuel resources and support advanced reactor systems. However, they do not eliminate all radioactive byproducts created during nuclear fission.

Why Deep Geologic Disposal Remains Necessary

Some Materials Cannot Be Reused

Nuclear fission inevitably produces a range of radioactive elements that have no practical or economic reuse pathways. Certain fission and neutron activation products remain hazardous for extremely long periods and must be isolated from the environment over geological timescales. Even when recycling technologies recover valuable materials from used fuel, a residual waste stream remains that requires permanent deep geologic disposal.[6]

Additionally, recovery processes are not perfectly efficient. Small fractions of reusable materials remain in waste streams and must also be managed as radioactive waste.[7]

Recycling Capacity Will Lag Existing Inventories

The US has accumulated a large inventory of used nuclear fuel over decades of reactor operation and continues to generate additional material each year. Even if recycling technologies are deployed in the future, their initial throughput is expected to be limited.[8]

Global experience demonstrates that building and operating large-scale recycling facilities requires significant time and capital investment. As a result, recycling alone cannot quickly address the existing inventory of used fuel. As a result, a functioning geologic disposal program will therefore remain an essential component of the overall system for managing nuclear materials.

Not All Fuel Types Are Suitable for Recycling

Recycling facilities are typically optimized for specific fuel types and chemical compositions. The characteristics of used fuel—including burnup, cooling time, structural materials, and fuel form—affect whether it can be economically processed.[9]

Some fuel types may be better suited for direct disposal rather than recycling. For example, certain advanced reactor fuels are designed for exceptional durability and containment performance, characteristics that may make them less attractive candidates for chemical processing. Another example is damaged fuel, that may be undesirable to package and recycle. Consequently, even in a mature recycling system, a small portion of nuclear fuel will likely be destined for direct disposal.

Reactor Technology and Recycling Must Evolve Together

Maximizing the recovery and reuse of nuclear materials would require a reactor fleet capable of using a broader range of recycled fuel types. While today’s light-water reactors can utilize limited forms of recycled fuel, full utilization of many recovered materials would likely require advanced reactor designs—particularly systems that operate with fast neutron spectra.[10]

Although several companies are pursuing these advanced technologies, they will take time to develop and deploy at scale. In the near and medium term, the U.S. electricity system will likely rely heavily on proven commercial reactor designs. As a result, the demand for recycled fuel will likely develop progressively alongside the deployment of advance reactors and supporting fuel cycle infrastructure.

Accordingly, this fact reinforces the need for a parallel approach that includes both recycling development and progress toward geologic disposal.

Dilution and Near-Surface Disposal Are Not Viable Alternatives to Deep Geologic Disposal

Another concept sometimes discussed in the context of fuel recycling is whether the residual waste streams from reprocessing could be diluted or blended with other materials to qualify for disposal in low-level radioactive waste (LLRW) facilities. In the US, these facilities typically dispose of waste in engineered trenches or vaults located at shallow depths—generally on the order of tens of meters below the surface. By contrast, deep geologic repositories are typically located hundreds of meters underground in stable geologic formations and are specifically designed to isolate long-lived radioactive materials for geological timeframes.

While dilution or blending is allowed in limited circumstances for certain waste streams, the accepted international scientific consensus is that such measures do not represent an appropriate long-term management strategy for the residual wastes generated from nuclear fuel recycling, since in many cases long-lived constituents will still be present.

Dilution Does Not Reduce Long-Term Hazard

Dilution changes the concentration of radionuclides but does not change the fundamental risk posed by the radioactive materials themselves. Long-lived radionuclides remain present regardless of how widely they are distributed within a waste form.

Near-surface disposal systems rely on engineered barriers and institutional controls that are generally designed for timeframes of hundreds of years, consistent with the hazard profile of most LLRW. By contrast, certain fission products and activation products generated in nuclear fuel can pose a long term risk to the environment and biosphere. Managing these materials safely requires long-term passive isolation provided by stable geologic formations and multi-barrier repository systems.

International Practice Reinforces the Need for Geologic Repositories

Countries that operate large-scale recycling programs still plan for deep geologic disposal of the resulting waste streams. For example, France vitrifies high-level waste from recycling operations and plans to dispose of it in the Cigéo deep geologic repository, located approximately 500 meters underground. Similar repository strategies are under development or implementation in several other nuclear energy programs.

Policy Implication

For the aforementioned reasons, dilution or reclassification strategies cannot replace the need for a permanent deep geologic disposal pathway. Recycling may reduce the volume of certain waste streams and recover valuable materials, but it does not eliminate the generation of long-lived radioactive residues.[11]

Accordingly, progress toward establishing a U.S. deep geologic repository remains essential, regardless of whether recycling technologies are deployed in the future. Recycling and disposal should therefore be pursued as complementary components of a comprehensive nuclear fuel cycle strategy, not as substitutes for one another.

Conclusion

Deep geologic disposal is necessary, and recycling can also be very desirable. These are complementary, not competing elements of responsible nuclear fuel management.

Recycling technologies may help recover valuable materials, support advanced reactors, and enhance long-term resource sustainability. However, they do not eliminate the generation of radioactive waste and cannot fully address the existing inventory of used nuclear fuel.

For these reasons, establishing a permanent deep geologic repository remains a necessary component of the United States' long-term nuclear energy strategy.

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