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Nuclear Waste Disposal for the Future: The Potential of Reprocessing and Recycling

This paper provides an overview of the relationship between reprocessing used nuclear fuel and recycling it, as well as the impact that reprocessing would have on radioactive waste disposal. It also briefly discusses the Global Nuclear Energy Partnership (GNEP).

Reprocessing and Recycling

The fuel in nuclear power plants is made of uranium, a naturally occurring radioactive element that is found only as an oxide or complex salt in such minerals as pitchblende and carnotite and must be processed before it can be used as fuel. Pure uranium is 0.7 percent uranium-235 (U-235), more than 99 percent uranium-238 (U-238), and a trace of uranium-234 (U-234), which is formed by radioactive decay of U-238. New fuel for a typical nuclear power plant is about 4.5 percent U-235 and 95.5 percent U-238.

Reprocessing is the chemical separation of used nuclear fuel into its major components. These include uranium, plutonium, minor actinides, and fission products, which result from splitting, or fissioning, atoms of U-235. The uranium recovered through reprocessing is about 0.6 percent U-235 and 99.4 percent U-238. The plutonium recovered from used fuel can be mixed with uranium to make mixed oxide fuel (MOX), which can be used as new fuel in a nuclear power plant.

There are numerous fission products, but four are of special interest:

- strontium-90 (Sr-90)
- cesium-137 (Cs-137)
- iodine-129 (I-129)
- technetium-99 (Tc-99).

The fission products Sr-90 and Cs-137 are very important in addressing waste disposal issues because they generate large amounts of heat for the first 50 to 80 years after disposal. Heat generation in the repository is an issue because heat combined with slight moisture from the surrounding rock could accelerate corrosion of the waste canisters if it comes into contact with them. To avoid this, the canisters must be placed far enough apart to allow for heat dissipation and to keep the hot, moistened air from contacting the canisters.

Because of the heat concern, the size of the repository is driven largely by the amount of Sr-90 and Cs-137 in the waste. Removing these elements from the fission products being placed in the repository would reduce significantly the amount of space needed in the repository during its ventilation, or open, period. If Sr-90 and Cs-137 were allowed to decay, or "age," outside the repository for about 100 years, the elements then could be placed in the repository using relatively little space.

I-129 and Tc-99 are very mobile isotopes that easily travel through geological formations. They also are two of the major contributors to the amount of radiation dose in the biosphere. Removing them from the fission products placed in the repository would reduce the potential radiation dose to the biosphere.

The minor actinides include two that are of significant importance to the repository: americium (Am) and neptunium (Np). Am occurs as a result of reactor operations when uranium absorbs a neutron but does not fission, and also as a decay product of plutonium. Am is the major long-term contributor of heat after the repository is closed, and Np is another major source of radiation dose to the biosphere. Removing both elements from the material to be placed in the repository could eliminate heat-generation concerns in the post-closure period. The result: a smaller, simpler repository.

Reprocessing Techniques

PUREX. The most widely used process is Plutonium Uranium Extraction, or PUREX. It was the primary method used in the United States before the federal government halted reprocessing of used nuclear fuel, and it currently is used in Britain, France, Japan and Russia. The biggest objection to the PUREX process is that it results in a pure stream of plutonium, a major concern for potential proliferation of nuclear weapons if the plutonium were stolen or diverted and used to make a nuclear device.

UREX. The Uranium Reduction Extraction, or UREX, process was developed as a replacement for PUREX. In this process, the plutonium remains mixed with the fission products and minor actinides. Only pure uranium is available. UREX+ later was developed to separate the uranium and fission products of concern (discussed previously) from the rest of the waste.

Pyroprocessing. Pyroprocessing is another version of UREX+. It was developed to reduce the liquid waste that remains in the UREX process.

Several other reprocessing methods are in development. These include fluoride volatility, fractional crystallization and plasma separation. Only PUREX has been developed to the commercial scale.

Why Reprocess Used Nuclear Fuel?

Just as interest in reprocessing has changed over the years, so have the reasons for doing it. In the 1960s and 1970s, the purpose was to recover uranium and plutonium for use as reactor fuel. Then increasing amounts of uranium were discovered, the price decreased and the projected number of reactors to be built declined. In the 1980s and 1990s, the primary goal of reprocessing shifted to proliferation resistance. Recovered plutonium would not be available to any country without appropriate safeguards. Later, U.S. policymakers abandoned reprocessing, concluding that this would avoid building up stockpiles of separated pure plutonium.

Today both of these goals are in play. With the increasing cost of uranium and enrichment services, and the potential for many new reactors, supply concerns are returning. This situation also makes recovered plutonium more valuable for MOX fuel. Interest in proliferation-resistant reprocessing techniques is returning. Finally, the ability to reduce the volume and toxicity of the waste prior to its placement in a repository is a major consideration.

Can Reprocessing Meet All Our Goals?

Reprocessing alone is not sufficient to reduce the volume and toxicity of used fuel, ensure adequate supplies of uranium, and achieve proliferation resistance. Accomplishing these goals also will require recycling and destroying (in a new type of reactor) the separated waste products so they no longer require a repository.

Recycling the uranium and plutonium will require re-enrichment facilities for the uranium and the construction of a MOX fabrication facility. Power reactors must be licensed to use MOX fuel. The separated fission products Sr-90 and Cs-137 will need a storage facility ("aging pad") to allow for radioactive decay until the heat generation rate is acceptable for the repository. Another facility will be needed for the transmutation of the I-129 and Tc-99 in order to destroy them. In addition, a fast-spectrum reactor must be designed and brought into commercial operation to consume any remaining plutonium, along with the minor actinides, such as Am and Np.

Based on where our nation is today, we will require the following new infrastructure:

- uranium re-enriching facility
- fuel fabrication facility for re-enriched uranium

- fuel fabrication facility for MOX fuel
- modified reactors to burn MOX fuel
- reactor licensing to burn MOX fuel
- a new regulatory basis for MOX fuel
- storage facilities (aging pads) to allow for radioactive decay of Cs-137 and Sr-90
- transmutation facilities for I-129 and Tc-99
- fabrication facilities for the actinide-based fuel
- advanced fast-spectrum reactors to burn the actinides
- a regulatory basis for building and operating fast-spectrum reactors.

Absent the infrastructure needed to recycle the materials that are separated in reprocessing, there is no benefit to reprocessing at this time.

Global Nuclear Energy Partnership

The Global Nuclear Energy Partnership (GNEP) is the Bush administration's proposal for advancing nuclear energy in the United States and around the world, while addressing concerns about proliferation and waste disposal.

As envisioned, the United States will partner with other countries in the world that have commercial uranium enrichment and reprocessing facilities to ensure that these services will be available to any other country of the world that would like to pursue nuclear energy. The GNEP countries will provide nuclear power reactors and nuclear technology to any interested country. In return, the accepting country will agree not to pursue enrichment or reprocessing technology development. The United States would agree to take back the used nuclear fuel for reprocessing if it is in the interest of the participating country.

In order to address proliferation concerns, this program would limit the expansion of enrichment and/or reprocessing technology, while allowing for the expansion of nuclear energy. It also would provide for addressing the global waste disposal issue by requiring the return of used nuclear fuel. The used fuel could be disposed of as currently practiced in the United States or reprocessed and the waste streams recycled as previously discussed. The net result is that the actinides would be consumed in the advanced burner reactors, and only some fission products and minor actinides ultimately would require disposal in a repository.

Impact on Waste

The concept of reprocessing with recycling has the potential to reduce significantly the physical size of the repository and the toxicity of the waste going to it. This would simplify the repository design because it would reduce the challenge of retaining radiation inside it. The use of these processes also would extend the time before a second repository would be necessary. Depending on the future growth of nuclear energy and advances of other renewable energy technologies, recycling may eliminate the need for a second repository.

The time required for this to occur is the biggest problem. There is no near-term benefit. This is because there is no existing infrastructure to support the program and, in some cases, the technology is not available to accomplish what is envisioned. As discussed previously, there could be substantial long-term benefits—reducing the size of the repository needed and reducing the peak radiation dose from the facility. However, it will take time to develop the infrastructure and technologies to the commercial level.

Once the new technologies are in place, reprocessing would be of greater benefit for recently discharged used fuel than for used fuel already in storage because it would make it possible to remove the Am and plutonium. The longer the used fuel is out of the reactor, the greater the buildup of Am and the lower the value of the plutonium for MOX fuel. Therefore, reprocessing should be considered first for recently discharged used fuel. Any excess processing capacity could be used to address the older used fuel.

None of this will work without completing the infrastructure, including the development of the regulatory basis. The entire project is expected to take 35 to 50 years to complete.

Conclusion

Regardless of time and infrastructure development, none of this will substitute for the Yucca Mountain repository. Even with the application of all the envisioned technologies, there still will be fission products and minor actinides requiring disposal. Additionally, the Department of Defense has radioactive waste that requires disposal.

Reprocessing and recycling have great potential to lessen the waste burden—but they cannot eliminate it.