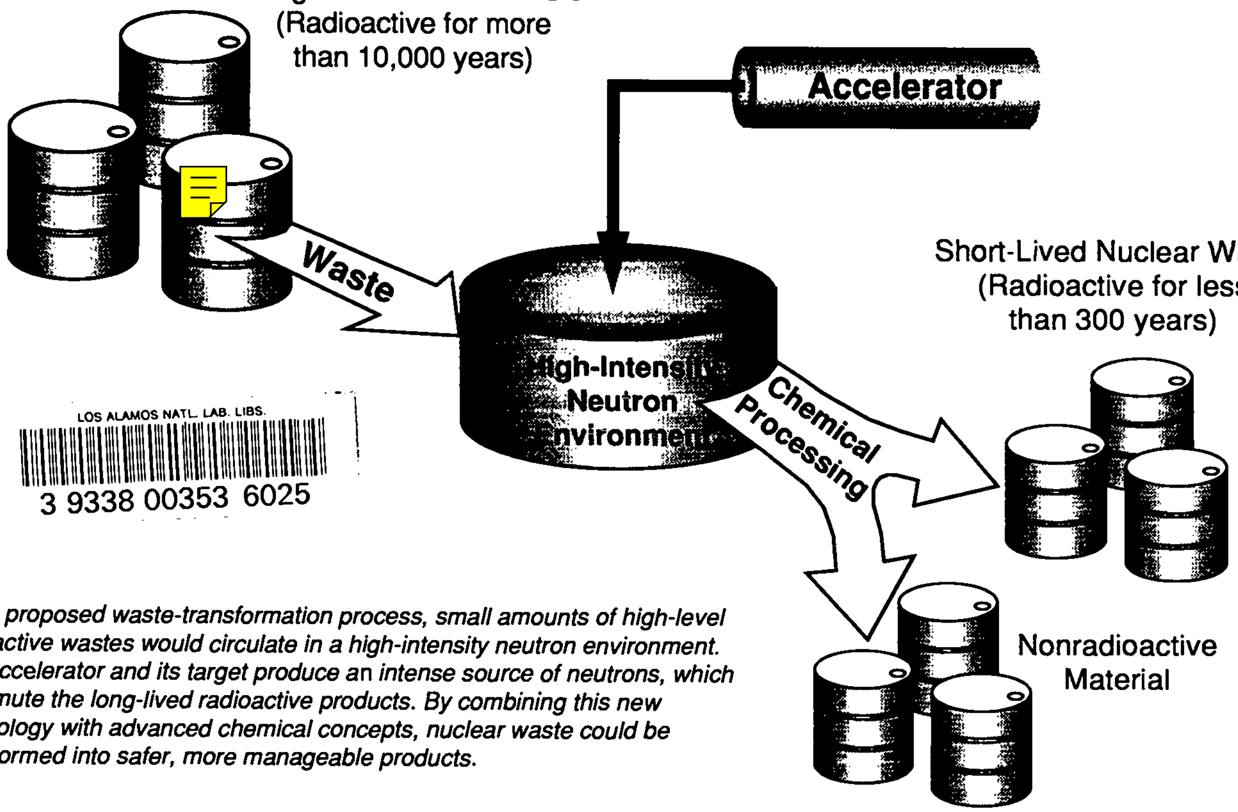
MINI REVIEW

Los Alamos
NATIONAL LABORATORY



In our proposed waste-transformation process, small amounts of high-level radioactive wastes would circulate in a high-intensity neutron environment. The accelerator and its target produce an intense source of neutrons, which transmute the long-lived radioactive products. By combining this new technology with advanced chemical concepts, nuclear waste could be transformed into safer, more manageable products.

Destroying Nuclear Wastes: Combining new technology with an old concept to reduce the storage life of radioactive wastes

James D. Doss

The environmental challenge

How will the Department of Energy (DOE) dispose of its large inventory of high-level radioactive waste? This nuclear waste has been generated over several decades at various DOE sites where nuclear materials have been produced for defense purposes. Currently, these wastes are stored in tanks that were designed for temporary use.

The radioactive components of these wastes fall into two general categories: fission products and actinides. Actinides are heavy elements; examples are neptunium-237, americium-241, and americium-243. (The numbers 237, 241, and 243 represent the atomic weights of specific isotopes of neptunium and americium.) Fission products result from the fission (splitting) of a heavy nucleus, such as uranium or plutonium. Typical fission products found in defense wastes are technetium-99 and iodine-129.

While there are several views about how to deal with these wastes, there is wide agreement on one point: If our environment is to be protected, it is essential for the United States and several other nations to develop effective strategies for dealing with long-lived, high-level nuclear wastes.

One answer: Long-term storage

Of all the earlier proposals to deal with this problem, long-term geological storage has received the most attention, and for good reason. For decades, many scientists have accepted the view that long-term storage in underground chambers represents the most straightforward solution to the high-level nuclear waste disposal problem. A considerable effort has been expended to locate and develop safe storage areas.

While such repositories may be a straightforward solution, questions have been raised about how we can be sure of the stability of the repositories over tens of thousands of years. There are concerns that, over such long periods of time, unpredictable geological effects or unexpected technical problems with waste containers might lead to exposure of nuclear waste to the biosphere. Even if such events seem very unlikely, it is our society's responsibility to reduce the probability of exposure by any reasonable technique available. Geological repositories would be much more attractive if it were possible to significantly reduce the storage time required for the activity of the waste to reach a low level. It appears that just such a solution may be possible. Understanding how the proposed solution works is easier if we first consider how nuclear waste naturally changes into harmless materials over very long periods of time.

Natural transmutation

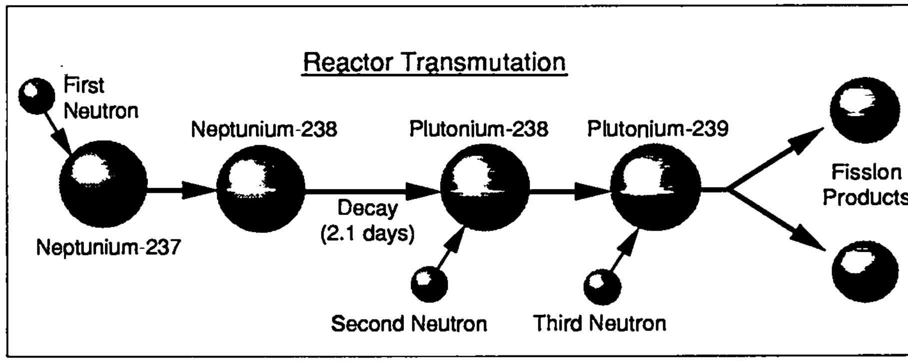
Transmutation generally refers to a variety of nuclear processes by which one element is changed into another. All radioactive wastes are eventually "transmuted" into nonradioactive materials without human intervention. We must, of course, keep the waste isolated from our environment for long periods of time while this natural process occurs. This natural transmutation process is called "decay." The time required for one-half of the radioactive material to decay is the "half-life" of that particular substance.

We could apply similar language to many everyday experiences. For example, suppose we heat a cup of coffee in a microwave oven until the liquid boils. After we remove the cup from the oven, the coffee will gradually cool until it reaches the temperature of its surroundings, i.e., "room temperature." If it takes about 10 minutes for the coffee to cool to a level halfway between boiling and room temperature, we might use the scientist's language and say that the heated cup of coffee had a 10-minute "half-life" as it "decayed" toward room temperature. If we performed the same experiment with a cup of any beverage, we would see a similar result; all would cool at about the same rate.

When we consider the decay or "cooling" of radioactive materials, however, we find a remarkable contrast in behavior. To illustrate this difference, imagine that a heated cup of coffee cools in a few minutes, but a hot cup of tea requires tens of thousands of years to cool! This fantasy illustrates how different radioactive materials decay to a level of low activity in vastly different periods of time.

One radioactive material will decay to low levels in days, while another will require tens of thousands of years or more to decay to safe levels. For example, iodine-129 has a half-life of 17 million years, while iodine-131 has a half-life of only eight days. It is, of course, those long-lived components of radioactive waste that provide the greatest challenge for geologic repositories.

Can we speed up this natural radioactive decay process?

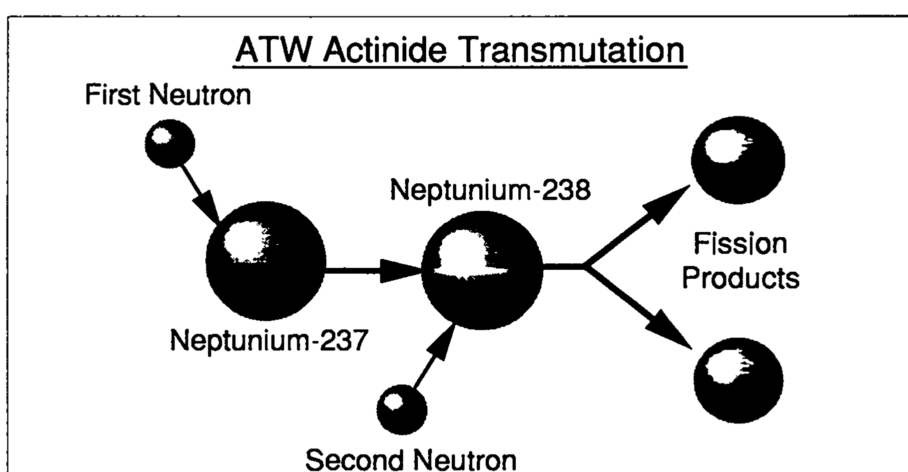


Transmutation of an actinide such as neptunium in the relatively low neutron flux available in reactors in an inefficient process that requires three neutrons for each transmutation.

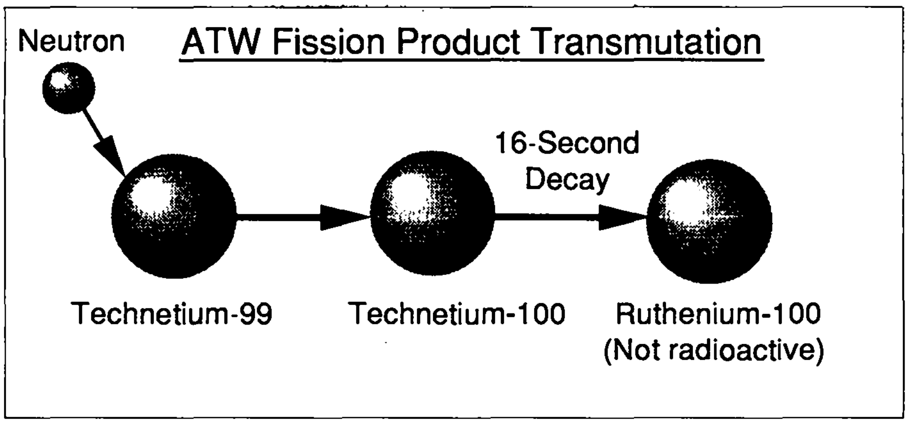
Artificial transmutation

Scientists have known for decades that it is possible to speed up the natural decay of nuclear waste by directing neutrons into the waste where these particles can interact with the nuclei of the radioactive atoms. The radioactive nucleus absorbs the neutron and is transmuted into another element by nuclear processes. The end product of some transmutations will not be radioactive, while others will be radioactive but with a different half-life than that of the original material.

Artificial transmutation has been produced in scientific experiments for decades, and there have been several proposals to use either nuclear reactors or particle accelerators ("atom smashers") for producing neutrons to transmute the



ATW transmutation of actinides is a highly efficient process. Because of the intense neutron flux, a second neutron is readily available to convert the neptunium-238 to fission products. Without this neutron, the neptunium would follow the longer decay path (typical in reactors) to an isotope of plutonium. The resultant fission products can be transmuted to stable isotopes by further neutron capture.



After absorbing a neutron, the technetium isotope is converted into another isotope that rapidly decays into stable ruthenium. (Technetium-99 is a common constituent of defense wastes.)

nuclear waste into a more acceptable form. The techniques proposed earlier, while intriguing, were not effective in transmuting both the fission products (like technetium) and actinides (like americium) found in nuclear waste.

It is also necessary to load rather large batches of waste material into the transmutation container for the process to be effective. Handling these large quantities of waste material in the reactor environment and in the required chemical separation processes would be a major technical challenge.

A new transmutation concept

An improved technique for particle accelerator transmutation has been conceived in Los Alamos. The concept is called Accelerator Transmutation of Waste, or ATW. In this new concept, an accelerator generates an intense neutron flux* by directing a beam of subatomic particles (protons) into a target made of a heavy metal such as tungsten or lead. The interaction of the beam with the target produces very large numbers of neutrons; these neutrons then enter a surrounding heavy-water moderator (or "blanket"), which slows them down. The system would be designed so these "slow" neutrons could interact with radioactive waste circulating through the moderator.

Because the slow neutrons produced by this approach are very numerous, they are more likely to interact with and transmute the two general classes of nuclear waste components mentioned earlier: fission products and actinides. Fission products are transmuted to nonradioactive substances or to short-lived radioactive nuclei by absorbing a neutron. For destroying actinides such as neptunium, the intense neutron flux initiates a new physical process. In this approach, a single radioactive nucleus can experience two neutron interactions in a short period of time, a process which rapidly converts it to fission products. This technique is very efficient for actinide destruction and is strikingly different from the processes that occur in lower-flux reactor systems. (The Los Alamos concept is so novel that the DOE has applied for a patent on the method.)

While waste products circulate in the blanket, neutrons are absorbed and transmutation occurs. As the waste is converted into nonradioactive, stable isotopes, these end products are continuously removed from the waste flow system and new radioactive waste is introduced for treatment. Efficient separations are required for this step; advanced chemical processes currently under consideration are expected to accomplish this separation effectively.

This approach, using an extremely intense source of accelerator-produced slow neutrons, represents a significant advance over previous proposals for transmutation of nuclear wastes. In addition to its capability to burn both actinides and fission products, this method requires much less waste material in the system (than did earlier reactor or accelerator proposals) for the same transmutation rate. Moreover, ATW has additional intrinsic safety features.

Inherent safety advantages

By using a particle accelerator to produce neutrons, the Los Alamos concept avoids the criticality problems associated with nuclear reactors. There would be no possibility of a runaway nuclear event.

Whenever nuclear waste is stored or treated, it is always a good safety practice to have limited amounts of waste in a single container. The Los Alamos concept would provide high transmutation rates with less than 100 kilograms (about 220 pounds) of waste residing in the system, compared with loads in the range of 10,000 kilograms (11 tons) required in earlier transmutation proposals. Reducing the amount of nuclear waste in the system by a factor of 100 is clearly an important safety advantage.

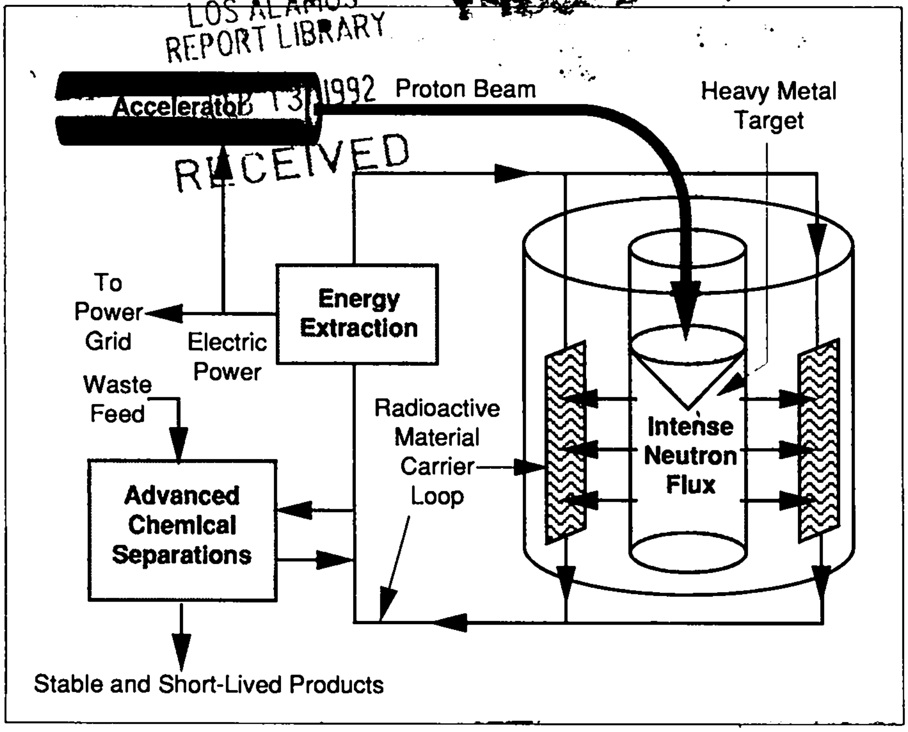
The technology investment

This new approach requires a more powerful controlled source of neutrons than has normally been available in any laboratory, a source so intense that it would have been considered impractical to achieve only a few years earlier. Fortunately, major advances have been made in the design of more powerful particle accelerators, partly as a result of the federal government's long-term investment in accelerator research at Los Alamos. It is now possible to build a particle accelerator that is capable of generating the intense neutron source required to transform this innovative concept into a physical reality.

Earlier Los Alamos research efforts have already utilized particle accelerator beams to generate intense sources of neutrons. Two of the most powerful neutrons sources in the world exist today in Los Alamos—the Manuel Lujan, Jr. Neutron Scattering Center and the Weapons Neutron Research Facility. Current Los Alamos research efforts in advanced chemical separations of radionuclides provide an important science and technology background for the development of new, efficient processing methods applicable to ATW.

By artificial transmutation, one can significantly speed up the conversion of nuclear waste to the desired end-products. It is the *nuclear equivalent of drop-*

*The number of particles moving through a specified area (usually one square centimeter) in one second is called the particle "flux."



The ATW system would combine a high-current accelerator, an intense neutron source, and advanced separation chemistry to provide safe and efficient transmutation of nuclear waste.

ping an ice cube into our fictitious cup of hot tea that was slow to cool.

The significant achievement is that most high-level waste components would be transmuted to stable (nonradioactive) products and the storage time for the remaining radioactive component would be decreased from tens of thousands of years to only a few hundred years, making high-level waste storage a far more attractive proposition. It would no longer be necessary to be concerned about the integrity of waste containers over many thousands of years or of geologic events (earthquakes, changes in ground water level, etc.) that might occur in the distant future.

The transmutation process described here produces some radioactive and waste residues. Our preliminary analyses indicate that such material can be safely stored in near-surface facilities because of the low levels of residual activity.

First use: Transmuting nuclear waste at Hanford

A possible location for an initial demonstration installation would be near a large source of high-level nuclear waste. A considerable amount of nuclear waste has accumulated during more than 40 years of plutonium processing at the DOE's Hanford plant in Washington. Our transmutation concept and Hanford's waste-treatment needs appear to be a reasonable match. Because a transmutation facility could be built at the Hanford site, cross-country transport of large amounts of nuclear waste for processing, storage, or final disposal at another site would be unnecessary. That portion of the processed waste producing short-term radioactivity would, of course, require appropriate on-site storage.

Much work to be done

It is an essential part of the scientific method to have other scientists review one's work and search for flaws in the ideas and methods. In addition to undergoing careful scrutiny by many scientists at Los Alamos, these concepts have been reviewed by a panel of distinguished scientists from other institutions, who represent academia, industry, and government. While these scientists have found no obvious flaws in the theoretical framework of the Los Alamos transmutation concept, many i... technical details remain to be w... before the expected performan... concept can be accurately assessed.

A wide range of cost–benefit factors must be addressed and optimized in the design process. The design should result in a system that can meet performance requirements at a cost that is attractive when compared with other feasible waste disposal options. In addition, the process of transmuting the nuclear waste will induce radioactivity into materials at the accelerator target. A transmutation facility obviously must dispose of much more waste (or a more objectionable form of waste) than is generated as a consequence of its operation. While this goal appears to be realistic, considerable effort will be expended to optimize the relationship between the amount of nuclear waste treated and waste generated.

The first major step is the development and demonstration of principal components of the chemical processing system, target-blanket system, and particle accelerator. The second step will be to demonstrate an integration of the technology. The technical developments, while challenging, do not call for unrealistic advances over existing technology.

The need to clean up high-level nuclear wastes without creating unacceptable risks is an urgent challenge to our society. Several nations are already considering a variety of possible solutions, ranging from long-term geologic storage to nuclear transmutation. The advanced transmutation method described here represents a potentially useful technique for dealing with these problems.

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