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The Nuclear Alchemy Gamble: An Assessment of Transmutation as a Nuclear Waste Management Strategy

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Let me begin by telling you what transmutation is and how its proponents say it will solve the problem of nuclear waste management. Transmutation simply means transforming one element or isotope into another. In the context of nuclear waste management, the goal is to transform long-lived radioactive materials into short-lived radioactive materials. If it were possible to do this for all of the long-lived radionuclides, this would make the management of nuclear waste easier because it would reduce the amount, and the radioactivity, of waste requiring long-term geologic isolation. Some early transmutation proposals even suggested that a deep geologic repository could be avoided altogether. Transmutation is also supposed to solve the problem of proliferation by using the weapons-usable materials, particularly the plutonium contained in the spent fuel from current nuclear reactors.

However, even if all of the technologies deemed necessary by its proponents are developed, this scheme cannot be realized. Even proponents of the scheme now acknowledge that a geologic repository would still be needed for much of the residual long-lived waste, including elements like plutonium and neptunium, as well as fission and activation products. In fact, only two of the dozen or so long-lived fission and activation products can be effectively transmuted. Huge volumes of "low-level" and transuranic waste will also be created. Moreover, proliferation dangers would increase due to repeated separation of plutonium and other transuranic materials in reprocessing plants. New reactor types will be necessary and they will create new safety risks. So after hundreds of billions of dollars in investment, the existing problem will not be solved and new ones will be created.

How then is transmutation proposed to occur? Transmutation requires a nuclear reactor of some type to generate the requisite flux of neutrons. The transmutation reactions occur when a neutron strikes the nucleus of the atom being transmuted. The nucleus either absorbs the neutron to become a new radionuclide or it fissions. However, these nuclear reactions can also transform short-lived radionuclides into long-lived radionuclides, defeating the purpose of transmutation.

Furthermore, when uranium, which is approximately 94% of the mass of the spent fuel, is placed in the reactor it forms more plutonium. Therefore, in order for transmutation to work, only those radionuclides that can be fissioned or can be effectively transmuted from long-lived ones to short-lived ones must be selectively put into the reactor.

The figure on the easel shows the various stages of the transmutation process and the fate of the different materials. There are a number of different technologies, both for the separation of the radioactive materials and for the reactor. We will be describing some of these technologies later. However it should be noted that many transmutation proposals would use a mix of different technologies and not just one type of reprocessing and one type of reactor.

First the spent fuel from current nuclear reactors is sent to a reprocessing facility where it is separated into different streams. The plutonium, and in some cases a similar group of elements called the minor actinides, such as americium and neptunium, is fabricated into fuel for the transmutation reactor. The plutonium and minor actinides can either absorb a neutron or they can fission. Because the radionuclides that are created in absorbing a neutron can be more problematic than the original one, the goal of transmutation is to fission as much of the plutonium and other actinides as possible. In some cases two long-lived fission products, technetium-99 and iodine-129, are also turned into targets for transmutation (in this case, by absorbing a neutron). The materials to be transmuted are then put into nuclear reactors for irradiation. The spent fuel from this reactor is then sent back to a reprocessing facility to be separated again and the process is repeated again and again until a substantial reduction of the mass of the radionuclides is obtained.

That explains what is supposed to happen to those radionuclides that can be transmuted in an ideal system. What about the other radionuclides? As I have mentioned, the uranium cannot be transmuted. In fact, the question of how to deal with the uranium is a crucial one for protection of public health and the environment. Putting uranium in shallow land burial, as has been proposed in the United States, is highly inappropriate for environmental reasons. The current path of deep geologic disposal without any separation and transmutation is preferred if a sound scientific program of repository development can be put into place.

The reprocessing facility would also separate a group of radionuclides called the medium-lived fission products, most notably strontium-90 and cesium-137. These medium-lived fission products also pose a vexing problem for transmutation because they are very hot and, therefore, contribute greatly to the limits placed on the amount of waste that can go into a repository. These would either have to be sent to the repository, negating some of the potential gains made by transmutation, or stored for a hundred years or more, which has a number of uncertainties, risks and costs associated with it.

All of the long-lived fission products that cannot be transmuted would be sent to the repository. This includes some radionuclides that are important because of their potential to reach the environment from a repository. As I stated earlier, only two of the dozen or so long-lived fission and activation products can be effectively transmuted. In addition, the residual long-lived radionuclides and actinides that could not be transmuted because of inefficiencies in the separation and transmutation stages would also be sent to the repository.

As you can see from the diagram, the various steps in the transmutation process also generate both low-level waste and intermediate-level waste, called "transuranic waste" in the United States. This additional waste will have to be disposed of. Furthermore, the large number of reprocessing facilities, fabrication facilities, and reactors would themselves eventually have to be decommissioned and disposed of in some manner. In the proposed program for the United States alone there would be approximately eight reprocessing facilities, eight fabrication facilities and 68 reactors which would have to undergo decommissioning and disposal.

My colleague Annie Makhijani will now cover two of the reactor technologies that have been proposed for transmutation purposes: thermal reactors, which are currently used commercially, and breeder reactors, which have been developed but never commercialized successfully. I will then discuss the third type of reactor under consideration for transmutation: sub-critical reactors that also use an accelerator. These systems have not even reached the development stage.

{Statement of Annie Makhijani is presented}

In addition to the reactor technologies described by Annie, there is another set of technologies proposed, based in part upon previously developed breeder reactors, but still very much at the early experimental stage. In some cases these exist only on paper. Accelerator Transmutation of Waste (ATW) would use reactors that are not critical on their own, unlike current power reactors or even previous breeder reactors. These reactors require a supplemental source of neutrons to keep the chain reaction going and these neutrons are produced when an accelerated proton hits a target made of a heavy metal such as lead or bismuth. Despite the fact that these reactor designs exist only on paper, they would be an important part of any transmutation program which seeks to substantially reduce the amount of plutonium or other actinides present. Because they do not rely on the fuel itself to maintain the chain reaction, these systems hold out the promise of reaching deeper reductions and can also use mixtures of isotopes that might be difficult to use in a critical reactor. ATW systems are, in effect, the Holy Grail of transmutation. Thus, understanding the problems and limitations of these systems is key to understanding the limitations of transmutation.

It must first be reiterated that these systems cannot overcome some of the fundamental limitations of transmutation which I spoke about earlier. They cannot transmute the uranium or some of the other long-lived radionuclides. They will also create new waste. Furthermore, many of the basic technologies are still being developed. Getting all of these various pieces to work together will also be an enormous challenge. Thus, it is not clear that this is even a viable option. ATW is also not cheap. A U.S. transmutation program based solely on ATW would cost tens of billions of dollars to develop over the course of nearly three decades. By piling one optimistic assumption upon another, such as 60-year reactor lifetimes, ATW proponents claim that in the long run electricity sales would approximately offset the hundreds of billions needed to build and operate these facilities. A closer look shows that they are far more likely to have net costs of one hundred to two hundred billion dollars (undiscounted), and possibly more. While not claiming to be "too cheap to meter," the claims about ATW do have some of the same flavor of that now discredited nuclear energy prediction.

The sub-criticality feature of these reactors is supposed to increase their safety and some designs have even been called inherently safe. However, as noted by Professor Lidsky of MIT in the press release, ATW systems may, in some ways, pose far greater safety risks than current reactors.

ATW would also raise the same kinds of non-proliferation concerns that arise from the use of PUREX reprocessing, the technology in use today for commercial reprocessing. ATW would use a new reprocessing technology called pyroprocessing, which has progressed slightly beyond the experimental stage. This reprocessing technique has been touted as being more proliferation resistant than the PUREX system because it does not separate plutonium on its own. Instead, all of the transuranic elements are separated as a group. However, as we describe in our report, this does not allay the concerns about the proliferation risks of reprocessing. In fact, in some respects, pyroprocessing may be more problematic. It is done in more compact facilities and the process itself makes verification difficult. There may, therefore, be greater difficulties than at present in verifying whether materials have been diverted for weapons use.

In conclusion, ATW, like all other transmutation schemes, has fundamental limitations and a number of associated problems. Transmutation will not solve the nuclear waste problem and could, in fact, make it worse. The waste transmutation program should be ended now, in its early phase, before needless expenditures and risks have been incurred.