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**What has "transmutation" to do with the disposal of radioactive wastes?**

**Several years ago Hilary Westmeier published an article about the question what to with radioactive waste. Her short paper is a straightforward compendium of principles that still are topical and worth reading.**

# What to do with radioactive waste?

By Hilary Westmeier

It seems increasing more likely that nuclear power could have a vital role to play in a world facing dramatic climatic changes and other crises related to the use of fossil fuels for energy. However, the main problem that we must solve in order to use nuclear energy for power with a clear conscience is what to do with long-lived radioactive waste. New ideas are now being explored.

By the year 2010 there will be a worldwide inventory of about 3000 tons of plutonium originating from civil applications of nuclear energy production plus another approximately 300 tons or more coming from military sources. In addition, there will be comparable amounts of other long-lived fission products. An overview over current production of radioactive waste in nuclear reactors is given in Figure 1.

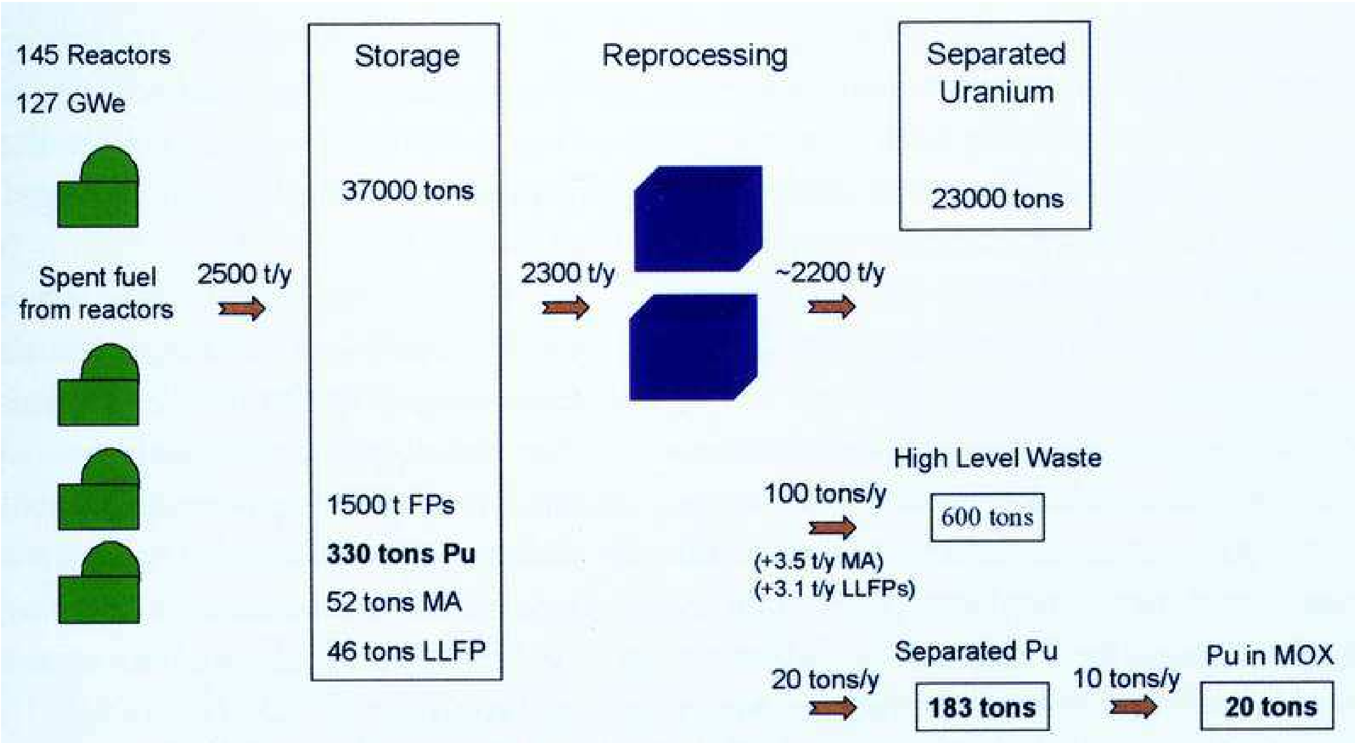


**Figure 1: Spent and processed fuel in the EU**
Cumulative production per annum from 145 reactors (127 GWe) currently (2001) in operation
*Source*: A European Roadmap for Developing Accelerator Driven Systems (ADS) for Nuclear Waste Incineration

These by-products of the nuclear fuel cycle remain highly radioactive, dangerous and toxic for millions of years, and therefore, mankind has to ensure that none of these materials is ever released into the environment. Several schemes have been considered for dealing with the long term handling of radioactive waste. The most practical and promising ones are:

1) Rocketing into an infinite orbit in space. This is a very final solution that is unfortunately presently not acceptable because of the risk and indeed incidence of launching failures.

2) The re-cycling of plutonium (only Pu) for use as fuel for nuclear power plants. The drawback is that some 20% of the plutonium plus other long-lived fission products would still remain. Nevertheless there are such plants in operation, for example in Japan.

3) Underground burial. This is the current practice in several countries. Appropriate sites fulfilling all criteria for secure depository - far from groundwater, no volcanic or seismic activity, etc - do not exist all over the world, and are in fact few. A promising site is in the Yucca Mountain area in Nevada and was recommended by the US president to Congress for approval just three weeks ago. However, it seems that this relatively cheap and final method is unacceptable to many countries worldwide because they are not convinced that the radioactive material can be safely encapsulated over geological times.

A decade ago, a Russian Tolstov and an American Bowman independently proposed a fourth solution to the dilemma of growing amounts of unwanted radioactive material. Their idea was simple and elegant. Why not convert the long-lived radioactive species into shorter-lived daughters that would have to be safeguarded for only several tens or hundreds of years instead of millions? That is, transmutation.

The technology itself is not so simple but it certainly is feasible. The simple sketch below in Figure 2 illustrates the essentials of a transmutation setup. First, one needs a particle accelerator that delivers a high energy proton beam with a current of several tens of milli-amperes. This beam is aimed at a target consisting of some heavy material such as lead. The protons interact with the target material inducing spallation reactions and thereby producing fast neutrons. These neutrons are slowed by a moderator to energies that allow them to interact with radioactive wastes to produce shorter-lived materials. These transmutation products will decay within several years into stable non-radioactive isotopes of zero radiotoxicity. Such a system is called an Accelerator Driven System (ADS) or Accelerator Driven Transmutation Setup (ADTS).

An expansion of the ADTS idea was presented by Nobel prize winner Carlo Rubbia and his co-workers in the mid-nineties. Briefly, his idea is to include an Energy Amplifier to enhance the ADTS so that it produces the energy needed to run the accelerator and maybe even extra energy in a self-sustaining cycle.

From theoretical considerations, we have a fairly good idea of how to carry out the transmutation of radioactive wastes and how to design and build the hi-tech facilities that would be needed to do this on a commercial scale. However, the experimental data needed to confirm expectations, estimations and theoretical calculations are for the large part still missing.

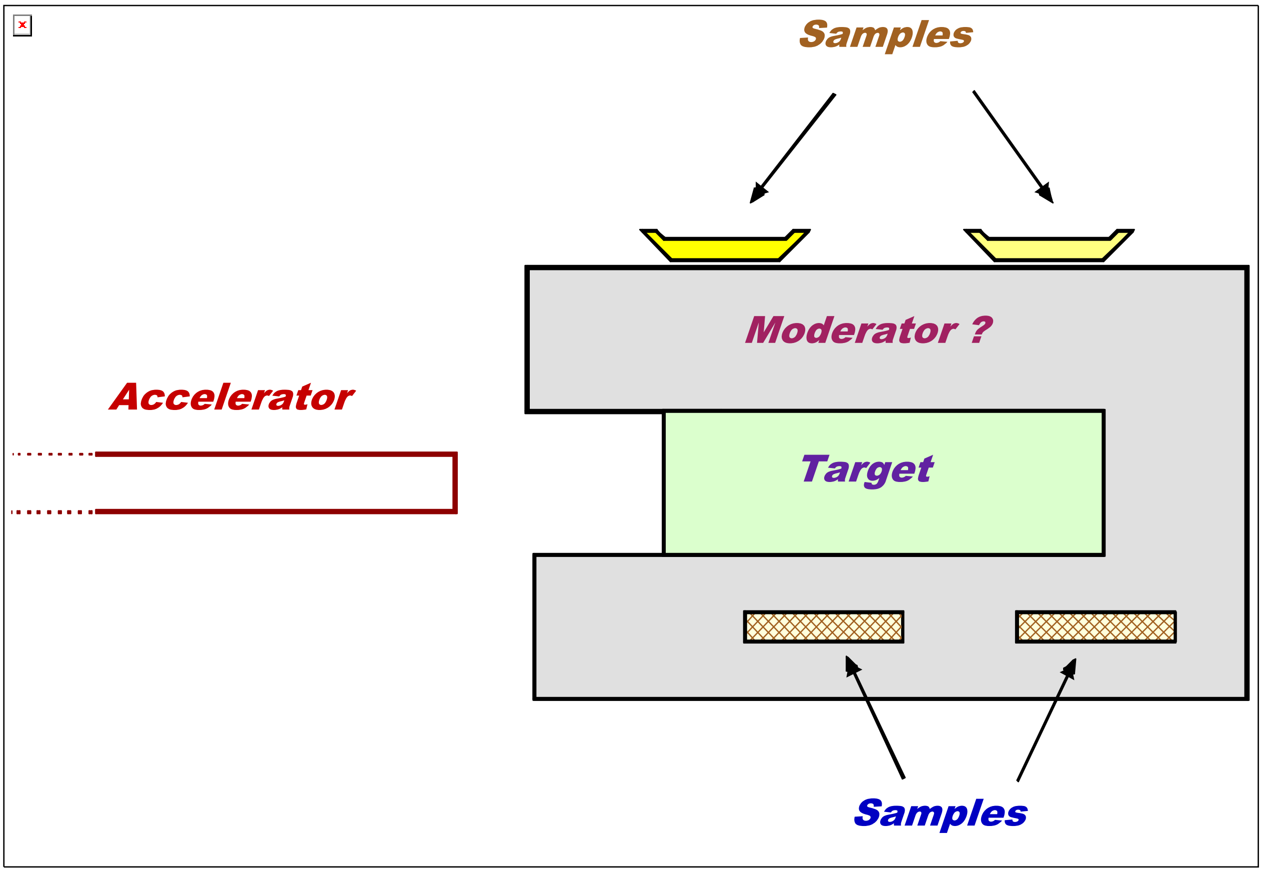


Figure 2: Schematic display of essentials in an Accelerator Driven Transmutation setup. The target may be of very complex composition and the use and nature of a neutron moderator must be investigated.

As far as I know there are only two groups carrying out experimental research on integral data for transmutation setups. One is a multi-national group at CERN in Switzerland and the other is a large multi-disciplinary research project on transmutation between twelve countries and centered at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia. A sub-group of this project, called the DuMa (Dubna-Marburg) collaboration, in which I am now involved, has measured relative probabilities for transmutation reactions under different conditions at the Synchrophasotron and Nuclotron accelerators in the High Energy Laboratory at JINR for several years.

The project is multi-facetted, and has been looking at the neutron production rates and yields induced by various proton beam energies in the range of 0.5 to 7.4 GeV; the use of different target materials and moderators; neutronics, for example, the study of the neutron spectrum and neutron densities and transport characteristics; and thermometrics, i.e. how much heat is produced and where.

Some of our most recent results have been very promising in terms of clarifying the characteristics of an experimental transmutation facility. Measurements on lanthanum, an element used as an indicator of the outcome of the transmutation process, showed that if optimum transmutation rates are to be achieved and utilized, then the geometric size of any moderator-type ADTS will have to be very small - less than half a meter in diameter. We estimated best transmutation rates with the reasonable assumption that transmutation cross sections are similar for various isotopes of interest in radioactive wastes and that the transmutable material will completely surround the spallation target in an optimal configuration. If we assume in addition that the accelerator proton beam is provided at the present technological limit of approximately 100 milli-amperes, then it should be possible to transmute several grams of highly radiotoxic material per day in one facility. An advanced ADTS, however, in which for example plutonium is used as the spallation target material and as a fissioning reactor core for energy production and as a transmutation sample at the same time may well destroy a hundred grams of plutonium a day. However, the thermal stress to which the system is exposed is a significant and often limiting constraint in ADTS design. For the hypothetical system just presented, the total power dissipated in the small spallation target is 100 MW from the beam alone. There is at present no appropriate technology for handling with this kind of high heat production in such small volumes, and one needs new design inputs.

How far away are we from the first viable transmutation plant as sketched in Figure 3?

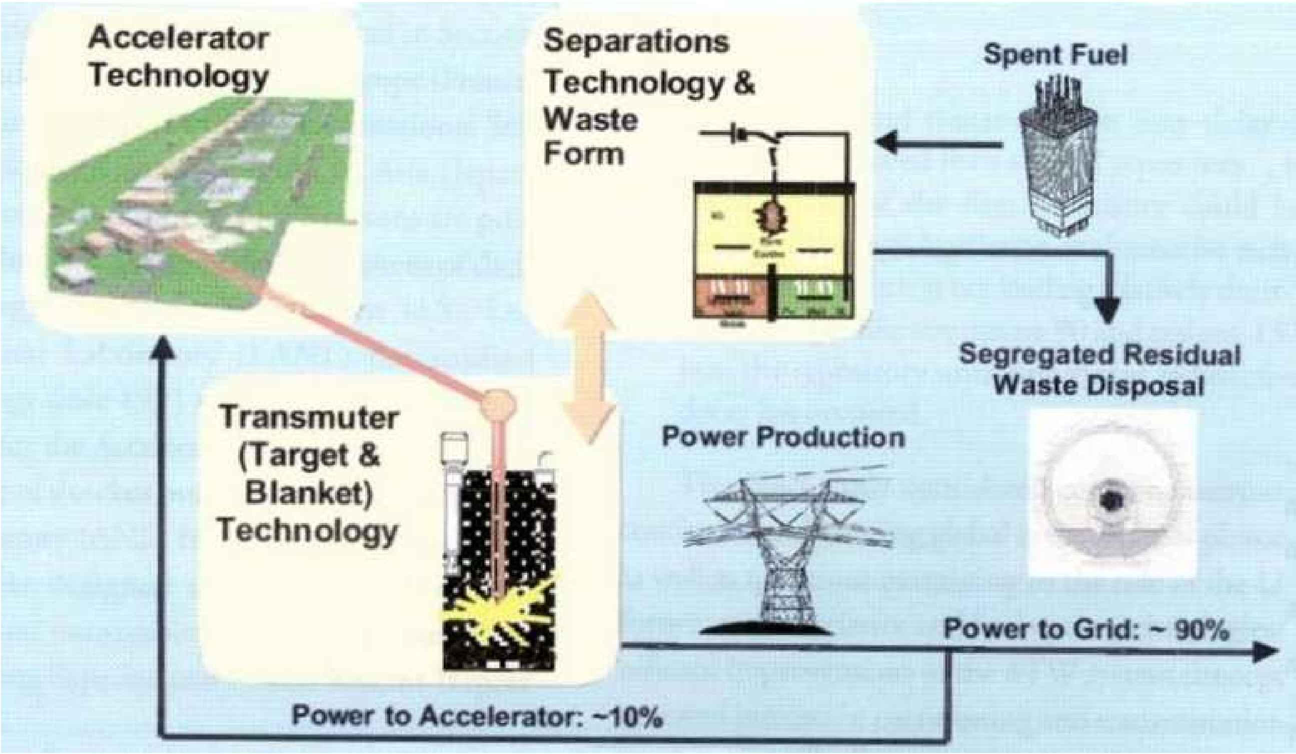


**Figure 3: Components of an ADS System**
*Source:* A Road map for Developing Accelerator Transmutation of Waste Technology
A Report to Congress DOE/RW-0519, Department of Energy, USA

In order to make an ADTS a technical possibility, a combination of several hi-tech facilities must be built which together will result in the safe, effective and economical operation of the concept. There must be a high purity, high throughput chemical reprocessing plant with an associated isotope separation facility. The highly enriched long-lived radioactive waste must then undergo transmutation in an extremely high neutron field which is maintained by a high-flux proton accelerator. We already have much of the technology and experience for the individual units, but as I have said, the vital experimental work for the final design of commercial ADTS is only just beginning. It is certainly premature to speculate on the cost of such a transmutation setup, but considering the known estimates of costs for the individual facilities (reprocessing plant, isotope separation, accelerator, reactor), it would probably end up in the region of several hundred billion dollars. In order to make such an ADTS a possibility that is feasible also from the budgetary point of view one will have to envisage an even bigger and more complex project. The advanced concept would incorporate Rubbia´s Energy Amplifier where the spallation reactions would proceed in an environment that resembles a conventional nuclear reactor core where the spallation neutrons would feed both the transmutation and the fission reactions in the core. That means that the thermal energy released in the fission process would be used for the generation of electricity which in turn would be used to operate the accelerator and the other associated plants, and would greatly reduce the cost of running the facility.

Transmutation systems that can handle realistic quantities of radioactive wastes seem to be a long way off. Nevertheless our research group is satisfied that if nuclear power is to play a significant role in relieving some of the energy and environmental problems that the world is facing, then our data will in turn contribute to solving the problem of how to deal with long-lived radioactive waste.

In the meantime a new concept for transmutation of nuclear waste has been presented and it is being pursued. The new principle is called “dual strata” waste incineration in which one makes effective use of the new generation of nuclear fission reactors called Generation IV. A sketch of a dual strata system is shown in Figure 4 below.

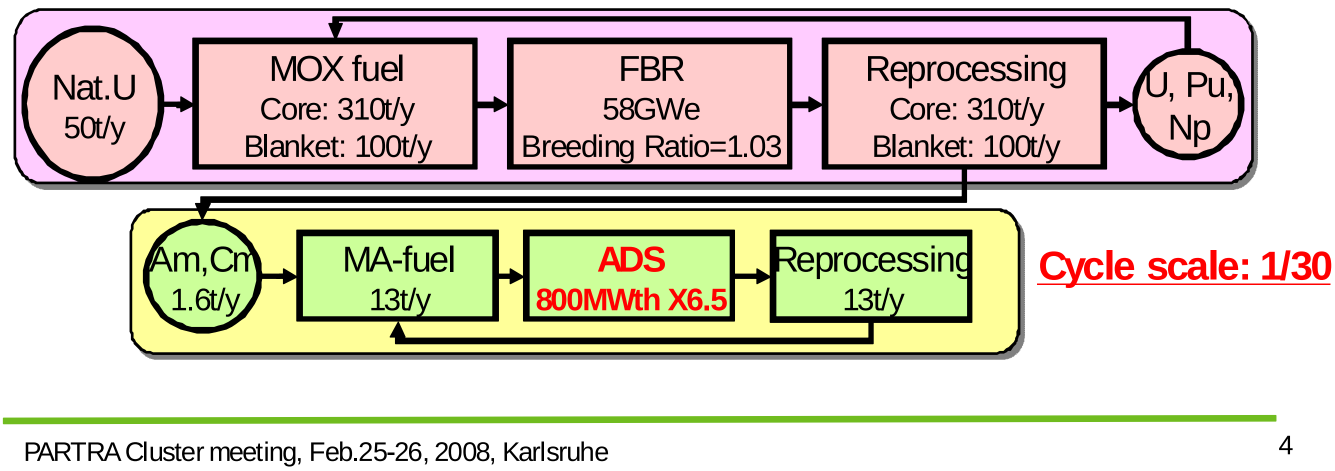


**Figure 4:** Schematic of a dual strata transmutation system. Quelle: PARTRA meeting, 2008

A mixture of uranium, plutonium and neptunium oxide fuel is burnt in the core of a Gen IV power reactor, which is a reactor operating with fast neutrons (called FBR = fast breeder reactor in the figure) and producing energy. A fast reactor burns significantly more fuel before rods must be exchanged than present LWR or similar reactors. The FBR can be constructed so that its neutron multiplication ratio is below unity and the core is only operative when supported by an external (accelerator driven) neutron source. In the reprocessing plant after the reactor one has to make only group separation of elements and produce mixed oxide fuel which is completely proliferation resistant, i.e. one cannot use it for military or other hostile purposes. The separated element mixture together with natural uranium is again used for fuel production.
The elements americium and curium are less favorably burnt in a fast reactor and they are transmuted in a parallel running accelerator driven system, instead.