Energie-Spiegel [engl. ed.]
Facts for the energy decisions of tomorrow

Publication Date:
2001

Permanent Link:
https://doi.org/10.3929/ethz-a-004958485

PAUL SCHERRER INSTITUT

PSI

ETH Eidgenössische Technische Hochschule Zürich

NO. 7 / JULY 2002

ENERGIE-SPIEGEL

FACTS FOR THE ENERGY DECISIONS OF TOMORROW

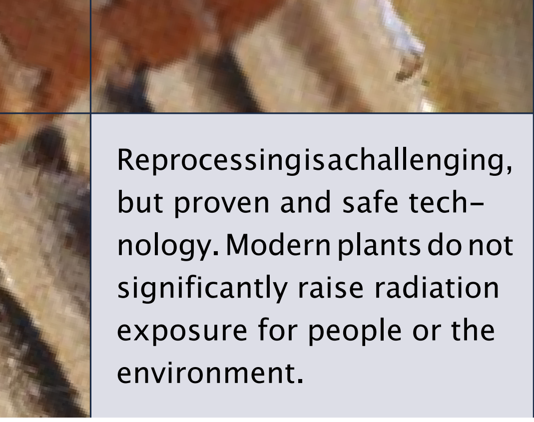
SYNOPSIS

The closing of material use cycles is a precondition of sustainability, sparing resources and avoiding mountains of trash. This also applies to nuclear energy. Instead of directly storing fuel rods, it is possible to reprocess them and recycle the uranium and plutonium that they contain. Recycling once means a reduction of 10-20% in the demand for natural uranium ore, and a reduction of up to 40% in the amount of plutonium destined for final storage. High-level radioactive waste is reduced by about 80%, although there is about a five-fold increase in amounts of low-level and medium-level radioactive waste.

Reprocessing is a controversial subject for discussion, because the sins of the past – the careless releases of radioactive emissions – are still present. However releases from present reprocessing plants are very low; modern emissions controls have been installed and releases to the ocean will shortly be fully discontinued. The danger of weapons proliferation is estimated differently from country to country; the separation of plutonium increases this danger in the short-term, but reduces it in the long-term because recycled plutonium is less suitable for weapons than the plutonium present in stored fuel. No real difference exists in the transport risks, although they are often classified as "unthinkable."

Compared to natural background radiation, the current burden on the biosphere from the entire nuclear fuel cycle is small, either with or without reprocessing. The calculated estimate of radioactivity released from a waste repository in the distant future is very small, whether it is based on recycled or directly stored waste. Reprocessing is important if one is concerned with the radiotoxicity of the waste and the storage period during which it must be safely contained. Once-through recycling reduces radio-toxicity only slightly more quickly to the level of natural uranium ore. With advanced recycling technology however, the radio-toxicity can fall about 100 times faster – even within several thousand years, and in France values of several hundred years have been considered possible. Such developments are pushed with international cooperation.

In the short-term therefore, there are no significant industry arguments either for or against reprocessing; usually it raises power generation costs only marginally. In the long-term, nuclear energy can contribute to a more sustainable energy supply for the world, if new technologies and fuel strategies stand ready to provide multi-cycle fuel reprocessing. A general ban on recycling would block research in Switzerland, international cooperation and new paths into the future.



Reprocessing is a challenging, but proven and safe technology. Modern plants do not significantly raise radiation exposure for people or the environment.

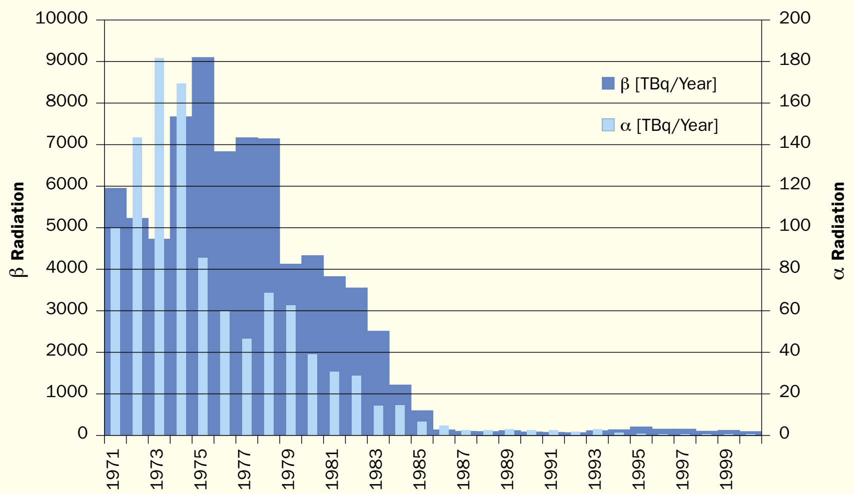
Better than its Reputation

Uranium and plutonium from used fuel rods can be mixed with fresh uranium, formed into new fuel pellets and fabricated into new fuel rods. This "once-through recycling" is practiced today in Switzerland, by the use of so-called mixed-oxide (MOX) fuels. Worldwide, 438 nuclear power plants annually produce approximately 10,500 THM, or tonnes of heavy metal (uranium and plutonium). Of this, about 3000 tonnes are reprocessed, and the rest is destined directly for final storage (the so-called once-through fuel cycle). A final repository for high-level radioactive waste will only become urgent in several decades, and in the meantime approximately 250,000 THM of waste have accumulated. Reprocessing now takes place in France (La Hague) and England (Sellafield), and on a smaller scale in Japan, Russia and India. This total capacity can reprocess up to a total of 5000 THM per year. New plants are being built in China and Japan, and should provide a further 1000 THM annually from 2005 on.

Cleaner than in the Past Reprocessing has often been strongly criticized, due to massive past environmental pollution. Before the mid-eighties, the plants in Sellafield and La Hague released significant quantities of radioactivity. In the meantime, official standards and highly efficient control measures have been installed in both locations. The emissions to water today lie very close to zero (Figure 1). Both plants have signed the *Convention on the Protection of North Atlantic Waters (OSPAR), and will soon close all seawater intakes under official supervision.

No Significantly Higher Risk The OECD has calculated the cumulative radioactive burden of the entire nuclear fuel cycle for the general populace and occupational exposure (with and without reprocessing). These calculations show that the cumulative doses are very low, and reprocessing does not lead to significantly higher burdens. Plant operation is only allowed so long as official boundary values are not exceeded. The annual dose for individuals in the general population may not exceed a maximum of 1 milliSievert (1 mSv). The actual burden lies far below this limit. For comparison, the average annual individual dose from natural background radiation in Switzerland is 2.4 mSv, while the dose from a 20-hour flight is about 0.1 mSv. The total of radioactive materials shipped remains about the same with reprocessing, so there should be little objection on this basis.

Radioactive Releases from Sellafield into the Ocean (Fig. 1)



Resource Savings With once-through recycling, there are savings of about 10-20% in the demand for natural uranium, savings of about 40% in the amount of waste plutonium produced and a nine-fold reduction in waste uranium – as long as the separated uranium is reused in a reactor. The amount of actinides produced is increased somewhat, and the amount of fission products remains unchanged. Reprocessing means about 5 times less high-level radioactive waste, but about 5 times more low-level and medium-level waste. The end-storage costs therefore remain approximately the same. Recycled plutonium (separated from used MOX fuel) is also less suited for misuse in weapons (proliferation), compared to plutonium from a once-through fuel cycle.

A Look into the Future Advanced reprocessing methods, such as actinide separation and multiple recycling in critical fast reactors and sub-critical accelerator-driven systems (ADS) will hardly reduce the heavy radiological burden on the biosphere from the final repository over the long term, but they will reduce the time over which the radio-toxicity of the waste falls off to the level of natural uranium ore (see Figure 2). The transformation of long-lived actinides into short-lived isotopes is called transmutation. PSI pursues general research to further develop technology that is necessary for the PSI-Neutron Source (SINQ) as well as for ADS. The perspective for the next 20 to 50 years is that resource extension and reduction of the demand for a final repository are inseparably linked. Present developments of nuclear systems assume that reprocessing (with new technologies) will be necessary. This is a reason that the USA has changed its previous position (based on strategic reasons) against reprocessing. Reprocessing will be explicitly considered in the new energy policies of the USA, and is also a part of the international research program (including the EU).

Promising Developments

Chemical separation processes for reprocessing are continuously being further developed, and new processes are already in the test phase.

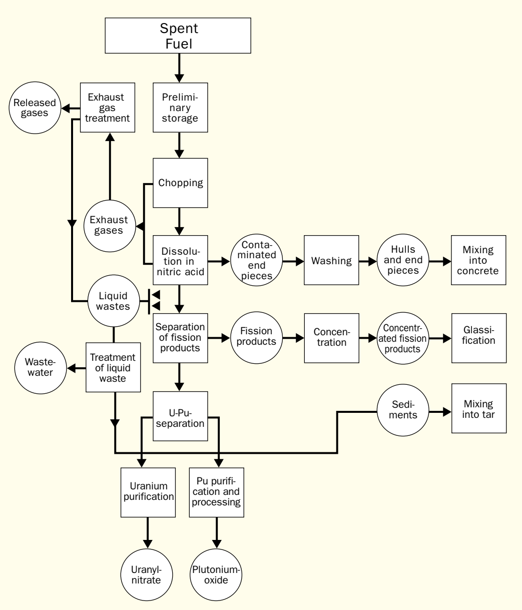
After 3 to 4 years use in a reactor, nuclear fuel contains about 1% of lightly enriched uranium 235, the plutonium produced by reactor operation, and a small fraction of radioactive "ash" (fission products, approximately 4%). These groups of materials are separated from each other through reprocessing. The fuel elements must be stored initially, first at the power plant and then at the reprocessing facility in pools of water. This reduces the radioactivity and the decay heat produced by the fission products (in the first five years by factors of 300 and 1000, respectively). Although this makes the chemical and technical processing easier, all the following steps must take place within massive shielding. First the fuel elements are mechanically chopped up and then dissolved in a bath of hot concentrated nitric acid (HNO_3).

Extraction The highly radioactive fuel solution is cooled and separated from the undissolved solids in a centrifuge. Then the uranium and plutonium are bound and precipitated from solution by the addition of tributyl phosphate (T BP), leaving behind the fission products and the actinides Americium and Curium. Finally the plutonium is chemically separated from the uranium. The solution containing the uranium is further separated from Neptunium and any remaining fission products and traces of plutonium. Finally a uranyl nitrate solution is produced with a decontamination factor (DF) of over a million (DF = the ratio of radioactive impurities before and after the separation). The plutonium solution is purified just as efficiently. With the wet chemical PUREX process (Plutonium/Uranium Extraction), over 100,000 tonnes of irradiated fuel has been processed in the last 40 years. Yields for uranium and plutonium approach 99.9%. New extraction methods using bis-trianyl-pyridine have already reached uranium and plutonium yields in the laboratory of 99.1% and 97.5%, respectively.

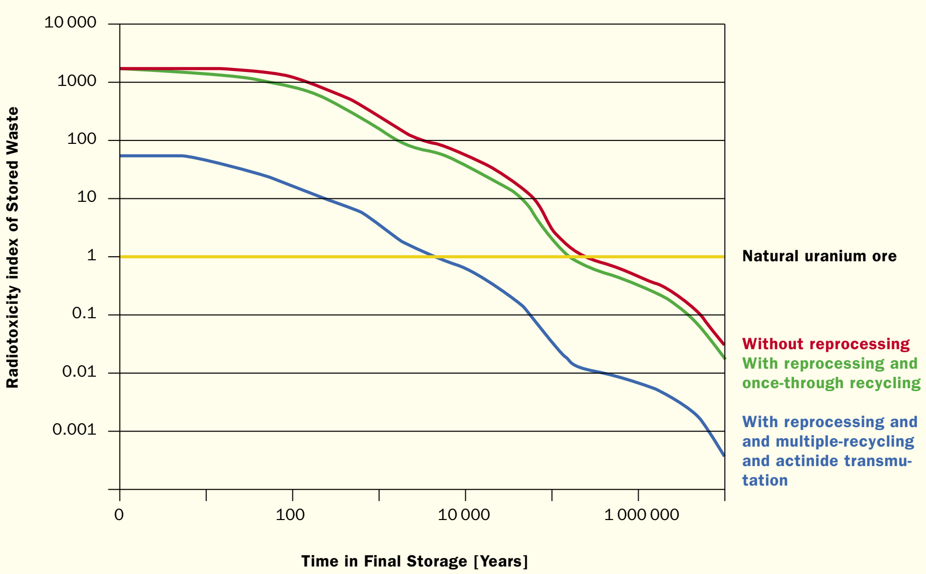
The waste from the first cycle is concentrated through evaporation and then stored. Neptunium is also produced from the uranium purification, as well as radioactive waste from the continuous purification. This raw waste is very radioactive and produces considerable amounts of decay heat. It therefore cannot be immediately transformed into a form suitable for final storage, but must be kept as a viscous liquid, and cooled in controlled, interim storage for at least two years. When the fuel elements are cut up and during the dissolution process, fission product gases and iodine are released. These gases are carefully captured via filter systems.

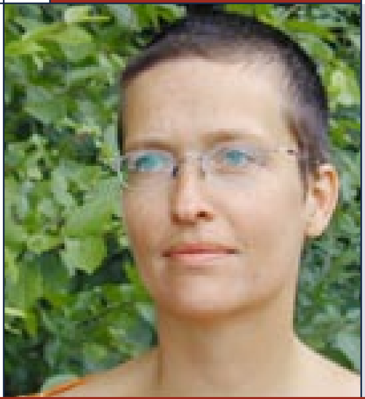
Developments - In additional to wet solvent reprocessing, there are also so-called dry or pyrochemical processes. These have been developed as part of the research program on fast breeder reactors. These reprocessing technologies are less liable to diversion and weapons proliferation. Industrial experience is lacking, but is being gained in pilot plant installations (e.g. the electrometallurgical processing of fuel from the US breeder program which began in September 2000).

Reprocessing Flow Chart (Fig. 3)



Decay of Radiotoxicity in Final Storage (Fig. 2)





Ines Günther-Leopold studied chemistry at Martin Luther University, and did her dissertation on the analysis of how plant compounds bind heavy metal elements. Since 1997 she has been on the scientific staff of the Laboratory for Materials Processes in the Nuclear Energy and Safety department at PSI. She specializes in using mass spectroscopy to determine the elemental and isotopic composition of activated materials and nuclear fuels.

"Image Correction Needed"

You work in an area that is unusual for a wife and mother. How do you deal with this? I'm not afraid in my work with radioactivity, because one learns how to understand the risks and the consequences of possible errors. Well structured working habits, the best possible planning of experiments, and good cooperation with colleagues are imperative for safety, and help to minimize risks and avoid possible mistakes.

How do you stand on the issue of reprocessing? Where do you see the opportunities and problems? The operation of this demanding technology and the high quantities of radioactive materials involved holds dangers, above all else the risk of human error. Moreover, the necessary transportation has been difficult to accept in some countries (e.g. Germany). I would have a bad feeling if Switzerland sent its spent fuel to a country for reprocessing where the standards are not equal to those that apply here. The security standards that are necessary in any country must be strengthened in areas where political or economic crises are present. Nevertheless, I endorse reprocessing for three important reasons:

- Reprocessing can lower the isolation time necessary for nuclear waste, which reduces the final storage problem.
- Sustainability commands us, in principal, to save our resources, even when they are still readily available and easy to use, as in the case of natural uranium. Plutonium produced in a nuclear reactor and unused uranium should be put back into the fuel cycle; simply storing it in the ground is really a waste.
- Reprocessing reduces the amount of plutonium over the long term.

Does the Switzerland need its own reprocessing plant? The construction of a reprocessing plant is only really economically attractive in countries with a heavy use of nuclear energy and many reactors. The nuclear power sector in Switzerland is too small for its own reprocessing plant. Cooperation with foreign countries (France and Great Britain) makes the most sense.

You often hear that reprocessing plants are very polluting. Is this correct? The negative public image of reprocessing has resulted from a series of past incidents. It will take much effort to correct this image. Current installations have become much cleaner. A fundamental mistrust remains over the technical controllability of such a plant, and whether basic safety standards will be observed. It is difficult to counter such a feeling with only scientifically confirmed facts. Therefore modern technology builds on robust, failure-tolerant systems, as well as good staff training and supervision.

Do you see nuclear energy as having a place in a sustainable energy supply for Switzerland? Yes. The search for real alternatives for electricity generation that are free of CO_2 is still not very successful. Nuclear energy can provide an important contribution to the worldwide power supply and environmental problems.

Do you have a wish for Swiss energy policies? A mature technology proven over many years should not be abandoned for reasons of political ideology, closing off paths for the future. It is also important to use the potential for energy savings to a much greater extent. I hope that the Swiss electorate will understand that it has a genuine chance to help design our future, and will take the chance to inform itself in this area and increase voter turnout.

IMPRESSUM

ENERGIE-SPIEGEL ,or Mirror On Energy, is the newsletter of the GaBE project at PSI. GaBE is the abbreviation for Ganzheitliche Betrachtung von Energiesysteme, which translates as Comprehensive Analysis of Energy Systems. The Energie-Spiegel appears every four months. Contributors to this edition include K. Foskolos, Prof. Dr. W. Kröger, Dr. S. Hirschberg

Circulation
15 000 copies

Responsible for Content
Paul Scherrer Institut
GaBE
Dr. Stefan Hirschberg
5232 Villigen PSI
Tel. 056 310 29 56
Fax 056 310 44 11
stefan.hirschberg@psi.ch
www.psi.ch/GaBE

Editor
Ruth Schmid

Subscriptions and Distribution
christina.daum@psi.ch

Layout
Monika Schlapbach

Energy Systems Analysis at PSI
The GaBE project performs comprehensive znalysis of energy systems. It is a joint project of the Paul Scherrer Institute, Villigen, and the ETH Zürich. Its goal is to analyze present and future energy systems in a comprehensive and detailed way, considering in particular health, environmental and economic criteria. On the basis of Life Cycle Assessment (LCA), energy-economic models, risk analysis, pollution transport models, and finally multi-criteria decision analysis, it is possible to compare different energy scenarios to create a basis for political decision-making.

GaBE works closely with other institutions, including:

- ETH Zürich
- EPF Lausanne
- Massachusetts Institute of Technology, MIT
- University of Tokyo
- European Union, EU
- International Energy Agency, IEA
- Organization for Economic Cooperation and Development, OECD
- United Nations Organization, UNO