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# A WORLDWIDE PERSPECTIVE ON ACTINIDE BURNING*

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# A WORLDWIDE PERSPECTIVE ON ACTINIDE BURNING

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## ABSTRACT

Worldwide interest has been evident over the past few years in reexamining the merits of recovering the actinides from spent light-water reactor (LWR) fuel and transmuting them in fast reactors to reduce hazards in geologic repositories. This paper will summarize some of the recent activities in this field. Several countries are embarked on programs of reprocessing and vitrification of present wastes, from which removal of the actinides is largely precluded. The United States is assessing the ideas related to the fast reactor program and the potential application to defense wastes.

A significant period of assessing the many issues is needed before a clear course can be taken. The collective insights of all major nuclear power countries may be brought together on this issue over the next decade. The dialogue and exchange of ideas and information are growing worldwide in a generally positive and upbeat perspective. The program is most likely a long-range effort which might be deployed in the next century.

## INTRODUCTION--BACKGROUND

Over the past two to three decades, individuals and organizations interested in the orderly and safe deployment of nuclear power stations and their supporting fuel cycle facilities have examined the role of the actinides in reprocessing, fuel recycle, and waste management. Historically, the studies largely focused on the minor actinides, americium and neptunium, since it was assumed that plutonium would normally be recycled either to thermal reactors or as fuel for fast breeder reactors. Separation of the actinides, sometimes known as partitioning, was considered an adjunct of reprocessing while "burning" connoted transmutation of the actinides in a nuclear reactor until the isotope fissioned resulting in the typical spectrum of relatively short-lived fission products. The concept, in many cases referred to as partitioning/transmutation (P/T), is again being widely examined and discussed by technical people and policy makers worldwide. The last major studies were done over a decade ago, but this renewed interest has gained momentum, and major programs are getting under way in several countries to once more examine the pros and cons. This paper provides some background on the subject, a brief view of the past work, and a picture of the emerging new looks at actinide burning in those countries that are again pursuing the subject.

## POTENTIAL ROLES IN NUCLEAR FUEL CYCLE--WASTE MANAGEMENT

While the minor actinides constitute about 10% of the total actinides (plutonium--the remainder), recycling the minor actinides does not generate a proportionate amount of power since, in certain cases, more than one neutron must be captured prior to fissioning. The neutronics are about an even trade-off. Thus, simplistically, P/T appears to be a somewhat more complex and costly fuel cycle than plutonium recycle, and studies have generally borne this out. Today, all studies which compare economics of plutonium recycle with direct disposal of spent fuel show a penalty for recycle, except where reprocessing facilities have already been committed and paid for.

All studies of P/T see some reduction in repository risk, and various methods have been examined to compare the benefits of lower repository risks with the slightly higher near-term operational risks and greater dollar costs. Within the framework of nuclear waste management, two roles are possible for partitioning: (1) reduction of repository risks, and (2) segregation of the alpha-active actinides from certain wastes to simplify and reduce the overall costs of managing those wastes. The latter appears to apply only to past wastes where practices resulted in addition of large amounts of chemicals to the wastes. These chemicals increase the cost of packaging and long-term storage; similar cost reductions may not be achievable where comprehensive waste treatment, including P/T and vitrification, are effectively planned.

Reducing Repository Risks

The actinides are characterized by typically very long half-lives. They become by far the largest radionuclide source term in time frames from 300 years, after the short-lived $^{137}Cs$ and $^{90}Sr$ have decayed, to over a million years. Removal and destruction of the actinides intuitively appear to significantly reduce repository risks. This was recently described by A. G. Croff (Croff, 1990) in which he based the risk comparison on emerging Environmental Protection Agency (EPA) release limits for high-level repositories, as shown in Figure 1. Here it may be seen that after decay of the short-lived fission products, removal of 99.9% of the actinides lowers the inventory to within about an order of magnitude of the EPA release limits. The limits are based on probabilistic assessments, and exact factors cannot be specified. In Figure 2, also from Croff's paper, the contribution of various radionuclides to the overall risk indices is shown. Here one can see that several long-lived fission products and reactor activation products control. It may be important to remove portions of these special radionuclides also. Removal of more than 99.9% of the actinides appears to be of little value.

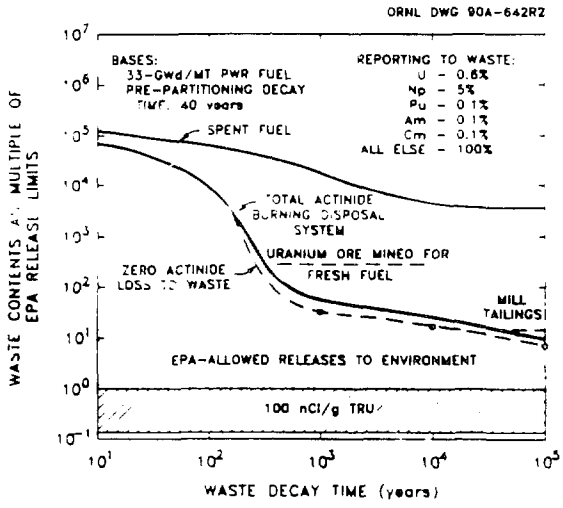
Fig. 1. Radionuclide inventory of repository relative to EPA disposal standard.

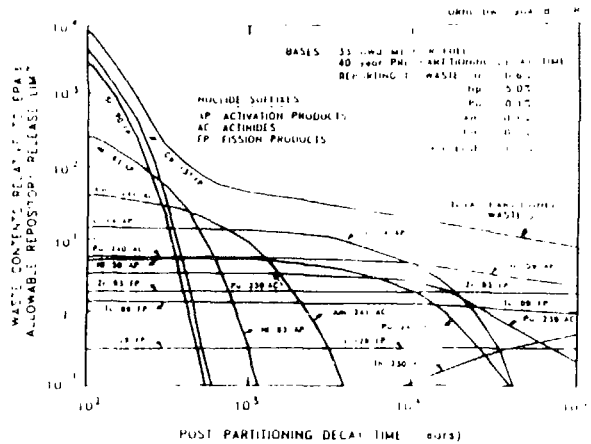
Fig. 2. Principal radionuclide contributors to repository inventory relative to EPA disposal standard.

Clearly this question is extremely complex. Many studies have shown that water-controlled migration of certain isotopes, principally $^{99}Tc$, control integrated total doses. The role and specific behavior of some half-dozen radionuclides, in addition to the actinides, must be examined to provide a comprehensive perspective on repository risks.

Segregating Alpha-active Wastes

At least three types of repositories are envisioned for future disposal of nuclear wastes: (1) the deep geologic repository for spent fuel and/or high-level wastes from reprocessing; (2) regional low-level repositories for short-lived wastes from reactor operations, medical wastes, etc.; and (3) a geologic repository for wastes containing more than 100 nano-curies/gram of alpha activity. Generally in the United States, the latter wastes come from operations in which plutonium in defense programs has been handled with relatively little fission product activity. A special repository, the Waste Isolation Pilot Plant, has been built for those wastes. Such wastes would be acceptable in the deep geologic high-level repository, but disposal there is more costly. Thus, incentives may exist to segregate alpha activity from certain existing wastes so that the remaining radionuclides may be disposed of in a low-level near-surface repository or in a smaller volume in the geologic repository.


ORNL DWG 90A-642R2
BASES:
33-GWd/MT PWR FUEL
PRE-PARTITIONING DECAY
TIME, 40 years
REPORTING TO WASTE:
U - 0.6%
Np - 5%
Pu - 0.1%
Am - 0.1%
Cm - 0.1%
ALL ELSE - 100%
SPENT FUEL
TOTAL ACTINIDE
BURNING DISPOSAL
SYSTEM
URANIUM ORE MINED FOR
FRESH FUEL
ZERO ACTINIDE
LOSS TO WASTE
MILL
TAILINGS
EPA-ALLOWED RELEASES TO ENVIRONMENT
100 nCi/g TRU
WASTE CONTENTS AS MULTIPLE OF
EPA RELEASE LIMITS
WASTE DECAY TIME (years)


NUCLIDE SUFFIXES
AP ACTIVATION PRODUCTS
AC ACTINIDES
FP FISSION PRODUCTS
POST PARTITIONING DECAY TIME (years)

This practice is being examined for the management of wastes from the Hanford site where potentially very substantial sums may be saved through segregating the bulk chemical constituents and fission products from the alpha wastes.

## CONCLUSIONS FROM PRIOR STUDIES

The major earlier study was done at the Oak Ridge National Laboratory (ORNL) approximately 15 years ago with participation by a broad spectrum of organizations throughout the United States. That study (Croff et al., 1980) compared the long-term repository risk reduction from actinide burning with contemporary fuel cycle risks without actinide burning and the related costs for each option. Conclusions were similar to those reached by other assessments in Europe (*IAEA Technical Report Series 214*, 1982). Although risks were not substantially different, incentives did not exist under the assumptions used for the study which was based on a comparison of a fuel cycle with plutonium recycle to one which also included recovery and transmutation of the minor actinides. Results might have been different had those options been compared with the present policy of direct-disposal in which the risks in the front-end operations of mining and milling would be included.

## IMPETUS FOR A NEW EXAMINATION FROM JAPAN'S OMEGA PROJECT

In 1988, Japan instituted a new program called "OMEGA" to examine actinide burning and related topics (*Atoms in Japan*, 1988) after a study by two working groups set up by their Atomic Energy Committee (AEC). The policy envisioned about ten years of systematic research and development (R&D) on partitioning and transmutation in joint efforts with government and industry. The intention was to undertake a long-term program to assess if a better means of handling nuclear wastes could be found. International collaboration was sought the following year when Japan proposed to the Organization for Economic Development (OECD) countries that periodic symposia be held to exchange information on the topic. The OECD accepted the proposal in principle, and initial technical exchange meetings have been held. Japan has committed sizeable resources to this, principally in their development organizations: Japan Atomic Energy Research Institute, the Power Reactor and Nuclear Fuel Development Corporation, and in the Central Research Institute of the Electric Power Industry. While the subject was discussed informally in many places during this period, the general attitude was skepticism until quite recently. However, recognition of this major commitment by Japan was a major factor that coalesced views throughout the world that a serious study of the subject was again warranted.

## PRESENT VIEWS IN OTHER NUCLEAR COUNTRIES

At this stage, policies on pursuing actinide burning are still not firm. Various views have been expressed and are summarized in the following paragraphs. The topic was widely discussed in papers in the Third International Conference on Nuclear Fuel Reprocessing and Waste Management, RECOD '91, in Sendai, Japan, in April of this year. The only broad consensus appeared to be that further study in today's framework was appropriate. All also appear to direct efforts to the future so as not to disturb ongoing efforts. In the case of the United States, this means not impeding the geologic repository program. In Europe and Japan, this means to proceed with reprocessing and vitrification of current wastes, including the minor actinides, while decisions for the future relevant to actinide partitioning are made. While many views concerning this new look at actinide burning are quite similar, all are not in common. The principal objectives and programs appear to be the following:

1. To assess and compare options for the nuclear fuel cycle and nuclear waste disposal, seeking means to better and acceptable options which could foster a climate for future nuclear power.

2. To carry out broad development programs for relevant recovery and transmutation options in order to resolve the technical issues and understand the costs for such processes.

3. To perform comprehensive systems analyses comparing relevant fuel cycle options.

4. To integrate these efforts with the planning for future repository programs in order to reach orderly consistent decisions.

Japan

The OMEGA policy and programs have been described in very broad, general terms. The goals are not specific nor are the timetables fixed. An interesting informal philosophy has emerged that sees the value of the OMEGA program in educating and training a new generation of nuclear fuel cycle experts in Japan while they assess the merits of the various options. Even if the choice reverts to today's policies, a new generation has been trained. The policy will ensure long-term R&D rather than seek an early choice of options.

Since reprocessing is the accepted starting point, partitioning would deal with the liquid high-level wastes from reprocessing and insoluble residues from dissolution. In addition to the recovery of actinides for recycle and transmutation, recovery of other radionuclides such as $^{99}$Tc and $^{131}$I and potentially valuable non-radioactive noble metals will be investigated. The program is directed at the longer term with the expectation that wastes in the short-term would be vitrified without removal of the minor actinides. During RECOD '91, several technical papers discussed initial results of laboratory R&D and studies. (Suzuki, 1991) (Morita et al., 1991) (Naito et al., 1991) (Uchiyama et al., 1991) (Kitamoto and Suzuki, 1991). No clear conclusions have yet emerged.

France

Recognized as the clear leader in reprocessing, France is placing on-line at LaHague over the next two years a major new plant and an enlarged, revamped plant that will be the largest reprocessing facility in the world. Wastes are being vitrified. While these new facilities have been commissioned without removal of the minor actinides, the potential merit is noted and planned R&D for partitioning described. Prior work has been focused on managing neptunium so that it follows the plutonium and is completely removed from the uranium product as a means of simplifying handling. Work will follow (Lefevre et al., 1991) on developing separation processes for the minor actinides from liquid high-level wastes. Vitrified wastes containing actinides cannot be retreated.

United Kingdom (U.K.)

With similar fuel cycle programs and a large reprocessing plant coming on-line at Sellafield in the next two to three years, the U.K. perspective is similar to that in France. Wastes are now being vitrified for eventual disposal in a geologic repository, so actinide partitioning becomes a longer-range issue. The British Nuclear Fuels Limited, plc (BNFL), the U.K. commercial fuel cycle company, has started a new five-year R&D program primarily seeking cost savings for future plants (Allardice, 1990). Because of the widespread dialogue now under way, partitioning is planned as one minor element of this program.

Russia

Fuel cycle programs in Russia were summarized at the recent RECOD '91 meeting revealing past and ongoing work on reprocessing and partitioning using conventional aqueous methods (Nikipelov, B.V., 1991) (Oyama, 1991) (Dubrovsky et al., 1991). To date, approximately 2000 tons of spent LWR fuel from the VVERs have been reprocessed in addition to large quantities of fuel from weapons production plants. Egorov (Egorov, 1991) described a broad range of work on partitioning spent fuel into many waste streams that could be dealt with in specific fashion to handle a particular problem. In addition to the actinides, the heat-producing strontium and cesium can be separated as well as technetium and iodine. The program includes development and pilot plant work but does not appear to include widespread deployment of these processes.

## DIVERSE OPINIONS IN THE UNITED STATES

No single view has yet emerged in the United States from the initial reexamination of partitioning. Instead, a diverse set of opinions is evident, driven in many cases by the perspective of the individual and organization. On one hand, those most directly associated with the efforts to build and operate a geologic repository see this as one more issue to further confuse and make their mission difficult. The fact that the United States has moved so far from reprocessing and plutonium recycle adds a dimension to this that makes such an undertaking much more formidable. Others see the present delays in the repository program as a window of opportunity to seriously examine the merits and issues with utilizing partitioning to reduce repository risks. In the meantime, little work has been done and several pathways to continue examining the issue and the merits are evident. The views from several points are summarized below

Utilities--Electric Power Research Institute (EPRI) Study

In response to a request from their utility management group, an EPRI team, supported by subcontractors and with some participation by the Department of Energy (DOE) laboratory staff, prepared a near-term evaluation of transuranic burning (Rodwell et al., 1991). While supporting and encouraging DOE long-term efforts to develop liquid metal fast reactors and to assess whether to include transuranic burning in that context, the report concluded that adopting the concept to all present spent LWR fuel would accrue only modest benefits over the whole fuel cycle. Furthermore, it is likely that near-term deployment would incur a large cost penalty, encounter major institutional difficulties, multiply licensing hurdles, and amplify political and public opposition to nuclear power. The report also concluded that eventually plutonium from thermal reactors would be substantially cheaper as fuel for fast reactors than enriched uranium.

The conclusions are in line with what might be anticipated as the position of utilities, who are very concerned that such a new fuel cycle policy would hamper efforts to complete the geologic repository at Yucca Mountain. To the utilities and EPRI, the issues with deployment seem to outweigh any possible advantage in risk reduction for the repository.

United States Department of Energy (USDOE) in Three Roles

The USDOE has carried on a dialogue on the merits and issues with the concept among its own staff and with many contractors and other organizations for the past two to three years. Efforts to find common grounds and a unified position have been sought, but since goals of the various parts of DOE vary widely, a variety of views on the subject has surfaced. Mechanisms to address the issues with outside respected review groups have been sought. Recently, the National Academy of

Sciences/National Research Council Board on Radioactive Waste Management undertook such a review, which will probably be ongoing for many months.

Repository Program. The Office of Civilian Reactor Waste Management has responsibility for developing a geologic repository. Their views tend to coincide with that of the utilities--the present concept of direct spent fuel disposal has been "accepted"; major changes can only raise issues and result in delays.

Liquid Metal Reactor (LMR). Most supporters of the LMR see P/T as a very positive concept since it is commonly recognized that fast reactors are the preferred transmutation method. Furthermore, it pushes ahead the concept for a closed fuel cycle. A few fear that a broad examination of P/T now will reach negative conclusions which, in turn, will detract from the LMR development program.

Management of Defense Wastes. From an entirely different perspective, partitioning may find a role in management of existing defense wastes. At the Hanford site, preliminary studies have shown that substantial sums (billions of dollars) might be saved through segregation of actinides from certain wastes. The savings accrue because the large volumes of low-level wastes which remain may be treated for final disposal in lower cost surface repositories. A vitrification facility will be required for many high-level wastes, but it could be smaller and the number of packages eventually transferred to Yucca Mountain considerably reduced. The technology for removing the actinides from the Hanford wastes requires significant development and demonstration both because such processes have never been fully developed but also because of the wide variety of wastes there. This technology is seen as widely applicable to future civilian spent fuel if the concept is adopted.

Other Views

From knowledgeable people around the country, other views have been expressed. Pigford reexamined a large number of issues associated with actinide burning (Pigford, 1990). In addition to the familiar points that water leaching was the dominant risk from a repository (while actinides tend to remain fixed in the repository), he presented a view on costs of reprocessing which appears unduly pessimistic.

While many believe that reprocessing costs are continuing to escalate rapidly, a recent and widely reported BNFL study shows that costs for their major new reprocessing plant, Thermal Oxide Reprocessing Plant, had increased only 12% in addition to escalation due to inflation in the period from 1973, when the original design and cost estimate were prepared, to final costs as known today. In a framework in which other major nuclear countries have justified investments in large sums in reprocessing and plutonium recycle, a view that the United States could not do similarly appears unwarranted. Obviously at today's uranium prices and assuming the repository program will proceed as presently planned, recycle is somewhat more expensive than direct disposal.

In addition, a recent major study in the United Kingdom, probably the most definitive nuclear fuel cycle study ever done, has shown that fuel cycle costs are only approximately 25% of total power costs no matter which type of fuel cycle was chosen. (Rodwell et al., 1991). The fact that recycle adds a few percent to total costs under today's framework loses sight of the fact that in the future recycle will be much more important if large-scale use of nuclear power continues.

Other studies (Croff et al., 1990) (Burch et al., 1991) conclude that a careful systems study of all the technical and institutional issues may show significant potential for the concept, including major assistance in the repository through lower absolute risks and simplified licensing.

## PROJECTING THE FUTURE

Any projection of major near-term movements toward actinide burning is premature and unrealistic. However, the movement around the world to carefully examine this has gathered more momentum than seemed likely two to three years ago. Japan will use considerable resources in examining the technical issues and will probably continue the program as long as other prominent countries show indication of interest. The present momentum should continue these efforts for at least three to five years. By that time, a longer-term perspective on fast reactors should be visible in Europe, Japan, and the United States. If any give up completely, then the cascading effects could be to cut way back on the remaining efforts. In that event, near-term prospects for continuing technical work and assessment of actinide burning would be very unlikely. On the other hand, recent recognition of the potential enormous consequences of global warming and the continuing slow expansion in the needs for electric power should have a positive impact. With long-term commitment to nuclear power, the concept endorsed in Japan's OMEGA project appears very sound--to carefully reexamine the nuclear fuel cycle. If a better fuel cycle such as with actinide burning is found, it should be adopted. If not, then the search has been worth the effort to validate concepts presently utilized.

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