Report of the
ADVANCED NUCLEAR TRANSFORMATION TECHNOLOGY SUBCOMMITTEE
of the
NUCLEAR ENERGY RESEARCH ADVISORY COMMITTEE

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BURTON RICHTER, CHAIR
DARLEANE C. HOFFMAN
SEKAZI K. MTINGWA
RONALD P. OMBERG
JOY L. REMPE

I. INTRODUCTION

The February 25 and 26 meeting of the Advanced Nuclear Transformation Technology Subcommittee of NERAC marked an important milestone for the program; the completion of the first phase of what we have come to regard as a three-phase program. This first phase has defined specific program goals, evaluated various systems against these program goals, carried out exploratory R&D, and determined the most promising directions for future work. It now appears that transmutation can meet the program goals, though with a much different view of how it might be done than existed at the beginning of the effort. The work has cost about $60 million to date.

Two further phases will be required before proceeding to a demonstration program. A second phase would include focused R&D and testing on critical technologies, and the engineering and systems studies necessary to develop reliable budgets for the third phase. This program would take five to six years and cost about $500 million in total.

The third phase that could follow a successful second phase would be the development of a scalable demonstration of a transmutation system. This effort is roughly estimated to take about 15 years, at a total cost of $4 to $7 billion. There is broad international interest and a potential for significant cost sharing.

In this report, we summarize what has been done, what is ready to be done, and what might be done in the long term. Since our first meeting in January 2000 the program has evolved to the point where its potential can be clearly seen. It is now time for a decision on its future.

It is appropriate to note here that relations between the committee, DOE, and the laboratories have been excellent. Our advice has been followed as far as it can be subject to Congressional direction and funding limitation.

II. PHASE ONE

A. Evolution and Criteria: The first phase can be summarized as establishing criteria, carrying out systems studies, and exploratory R&D leading to a selection of one or two options for further work. It has taken about two and a half years at a cost of about $60 million ($9 million in FY2000, $34 million is FY2001, and $20 million through the first half of FY2002). The criteria against which the program efforts were to be evaluated were set out at our first meeting. At the beginning, the focus was on a pure accelerator-driven system (ADS) that took spent fuel from the nation's civilian reactors and transmuted the long-lived components in a sub-critical reactor system. The committee recommended that the program be broadened because a pure ADS system would be entirely new, would require a huge infrastructure, would be expensive, and would take a long time to begin to have any significant impact. The work was broadened to include what have come to be called multi-tier systems that use various combinations of fission reactors and/or ADS to accomplish the task. It is now clear that the criteria can be met and the time has come to limit the number of options to those that are most promising. Before describing these, it is useful to describe what can be done to meet the criteria, given a successful development program.

> RADIOLOGICAL IMPACT OF PLUTONIUM AND HIGHER ACTINIDES: The committee believes that the minimum goal should be reduction of the radiological impact of spent fuel to below that of the ore from which it came in a time period equal to or less than the Nuclear Regulatory Commissions licensing period, now set at 10,000 years. To accomplish this the maximum allowable amounts of plutonium and higher actinides in the final waste stream must be, for example, roughly less than 1.0% to meet the standard in 10,000 years, 0.5% to meet it in 5,000 years, or 0.2% in 1,000 years. The program becomes ever more challenging the lower the percentage allowed. The specific target should be a policy decision.
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> THE REPOSITORY: The legislated limit on the capacity of the first repository using only the once-through fuel cycle is 63,000 tons of spent fuel. The nation's existing reactors will produce this amount by the year 2015. With no expansion of nuclear power in the U.S., the amount of spent fuel will reach twice the limit in 40 years and reach it sooner if nuclear power expands. It appears that transmutation can reduce the mass of long-lived material going to the repository by a factor of about 20 and the

volume by a factor of about four. A successful program, therefore, should sharply decrease the amount that has to be spent on repositories in the long term.

PROLIFERATION: Without some sort of spent fuel processing and transmutation, the world's plutonium inventory at a constant level of nuclear power will continue to increase, limited only by the lifetime of plutonium. With transmutation of plutonium, the inventory can be stabilized at an equilibrium level lower than exists now, and be in an isotopic form that makes weapons of mass destruction considerably more difficult to build. This decrease in quantity is balanced by an increased availability of plutonium in the system from material in process.

BENEFITS TO NUCLEAR POWER: The benefit of a reduction of concern on the hazards of spent fuel is clear. The economics of a transmutation system can only be roughly estimated now, and these estimates are highly uncertain. The Europeans have made the most detailed attempt at costing, and their estimates range from an increasing in the cost of electricity of a few percent to 15%, including their estimated real costs of a repository.

B. System Choices: In our last report to NERAC we indicated that nine system options were under consideration. Systems studies and further R&D on separation and fuel technologies indicate that this number can be sharply reduced. The most economic system should make maximum use of existing infrastructure and require the minimum amount of new systems at the back end. After the first burn of enriched uranium fuel in a reactor, about 30% of the energy produced from uranium fission in this round remains in the plutonium and minor actinides that are produced. If one were to simply invent some kind of new reactor that could consume this material, one of these new devices of the same size as the original reactors would be required for each three light-water reactors, an uneconomical system with a very large new infrastructure.

It appears that the proper choice is one in which MOX-like fuel would be recycled many times in existing light-water reactors (LWRs) where approximately one-third of the core can be used for this purpose. After multiple recycles, the isotopic mix of the remaining plutonium and the minor actinides become too difficult to consume in an LWR and so are sent to a special final burner, which could be either a fast-spectrum reactor or an ADS (further R&D on accelerators would not be needed until a decision on going to a demonstration is made). It is not clear which would be best since considerable work on separation technology and fuel development still has to be done. This system requires roughly one special back end burner for each seven to ten light-water reactors. The French have studied this alternative in some detail.

There are variations of this system that depend on the future directions of nuclear reactor development. Generation IV reactor studies have as options fast spectrum reactors, gas reactors, and advanced water reactors. In either of these first two options, the multiple MOX recycles in the existing light-water reactors can be replaced by a partial core loading in the new systems, but a final specialized fast reactor or ADS is likely to be needed. Advanced water reactors are simply a continuation of the main-line option. Thus, the main-line option seems to be the best for the existing fleet of reactors and for handling whatever new generation reactor is chosen by industry.

It is worth noting here that international collaboration has been very important in phase one and experiments, completed or in progress, have allowed DOE to avoid costs of $100 million, more than has been spent by DOE on the program to date. It is also worth noting that the program is playing an important role in training new students in nuclear science, engineering and related disciplines. Approximately 100 students have been or are involved in the phase one effort.

III. PHASE TWO

Congress has asked for an estimate of the total life cycle cost of a transmutation system. We do not believe that can be done reliably at the present time. What can be done is to give the roughest of estimates of the cost to bring a transmutation system to the point of deployment. These numbers are large: $4 billion for the fast reactor back end, and $7 billion if an ADS is required. It does not make sense to ask for such a commitment now when many uncertainties remain.

We see a second phase of the program as an R&D effort focused mainly on separation technologies, fuels, and more detailed systems analysis. Separation will most likely require both aqueous processing (UREX) and pyroprocessing. The problem is development of the technologies for a clean separation of fission fragments from uranium, and a separation of both from plutonium and the higher actinides with very low processing losses to the waste stream. Depending on the details of the system studies, it may be necessary to separate the higher actinides from the plutonium for separate treatment. For these reasons, both types of processing are likely to be required. Fuels are also novel whether they are for multi-recycles in LWR's, for fast reactors or for accelerator-driven systems.

The cost estimate for Phase Two made by the program people at DOE and the laboratories is that such an effort will take five to six years and have a total cost of around $500 million. This program should lead to a single option for further development in a next and final, pre-deployment phase.

IV. PHASE THREE

At the end of phase two a decision must to be made on proceeding to a scalable demonstration project for a single option. This must include processing, separation, fuel fabrication, and proof of operability. It will require a major commitment of funds. The decision point is five or six years from now and that should allow further consideration of Generation IV directions to be folded in.

Phase three will be a multi-billion dollar program probably taking about 15 years to carry out. It might be done faster if the final burner were a fast reactor where a considerable amount is known about the technology, and might take longer if the final burner were an ADS where we have no operating experience. Actual U.S. funds required for the program will be strongly dependent on what sort of international cooperation and cost sharing can be worked out with potential foreign partners.
We note that some of the major facilities that would be required in phase three already exist and might further shorten the program. There are mothballed facilities available such as the Barnwell Purex plant that could be brought into operation for phase three and scaled up for deployment, for example.

V. SOME FINAL COMMENTS

No program can proceed without allowing processing of spent nuclear fuel and separation into its major components.

The program will not get anywhere without stable funding, and the Administration and Congress should consider whether phase two in its entirety is something to which they wish commit.

The contraction in proposed funding in the FY2003 budget will in essence terminate the program. Important personnel involved in the program at the laboratories are being reassigned to other activities, and program direction has been moved back to Washington. If there is to be a future for this work some stability in funding is required, people will have to be brought back or replaced, and an appropriate management structure involving program leadership from the field will have to be set up.