United States General Accounting Office

GAO

Supplement to a Report to the Chairman, Subcommittee on Energy, Committee on Science, Space, and Technology, House of Representatives

Decmeber 1993

NUCLEAR SCIENCE

Developing Technology to Reduce Radioactive Waste May Take Decades and Be Costly

GAO/RCED-94-16S

FOREWORD

A number of concepts have been proposed that, if found to be technically and economically feasible, might reduce the volume and radioactive life of wastes destined for burial in a deep geological repository. These concepts involve transmuting (changing) constituents of the waste into elements with shorter radioactive lives or to nonradioactive elements through nuclear action in a reactor or an accelerator.

At the request of the Chairman of the Subcommittee on Energy, House Committee on Science, Space, and Technology, we reviewed five transmutation concepts--three using reactors and two using accelerators. The results of our review are contained in our report entitled Nuclear Science: Developing Technology to Reduce Radioactive Waste May Take Decades and Be Costly (GAO/RCED-94-16). This supplement to the report provides a more detailed description of concepts being proposed for transmuting commercial spent nuclear fuel.

The supplement contains information about the performance of the five transmutation concepts based on information supplied by the proponents of each concept in various reports or through interviews. Estimated costs and schedules are meant only to provide some indication of the magnitudes involved. Costs do not include escalation effects or discounting in a consistent way. Processing times do not include the effects of changing isotopic composition of the materials transmuted. None of the technologies is sufficiently well developed to make accurate predictions or comparisons possible.

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TRANSMUTATION CONCEPT

ABBREVIATIONS

ALMR	Advanced Liquid-Metal Reactor
ALWR	advanced light-water reactor
ANL	Argonne National Laboratory
ATW	Accelerator Transmutation of Waste
CLFR	Cleanup Fast Reactor
CURE	Clean Use of Reactor Energy
DOE	Department of Energy
FY	fiscal year
GAO	General Accounting Office
HTGR	high-temperature, gas-cooled reactor
IFR	Integral Fast Reactor
kWh	kilowatt-hour
LANL	Los Alamos National Laboratory
LINAC	linear accelerator
LMR	liquid-metal reactor
LWR	light-water reactor
PBR	Particle-Bed Reactor
PUREX	plutonium-uranium extraction
R&D	research and development
TRUEX	transuranic extraction

THE ADVANCED LIQUID-METAL/INTEGRAL FAST REACTOR

The advanced liquid-metal reactor (ALMR) actinide recycle system concept is a metal-fueled nuclear reactor that utilizes "fast" neutrons to produce the nuclear fission reactions on which its operation depends. The metal-fuel-cycle Integral Fast Reactor (IFR) program is a development of Argonne National Laboratory (ANL) near Chicago and its western branch, ANL-West, in Idaho. The purpose of the IFR project is to develop and demonstrate the essential features of a metal-fueled fast reactor and a metal-fuel-cycle process. The ALMR is a design project of General Electric Company at San Jose, California, to develop a commercial design for a modular nuclear power plant using the metal-fueled fast reactor.

This fast reactor concept differs in several ways from the light-water reactors (LWR) used in the current generation of nuclear power plants. The LWRs use slow or "thermal" neutrons instead of fast neutrons to produce the fission reactions. The LWRs are cooled by water instead of the liquid metal sodium, which is the coolant in the fast reactor. The LWRs cannot breed fuel--that is, they cannot produce more new fuel than they use--while the fast reactors can. Finally, the fast reactors can transmute--burn up--minor actinides, a group of transuranic by-products produced in nuclear reactor operation that are major contributors to the long-lived hazards of radioactive waste. The LWRs cannot effectively transmute the minor actinides, although they can use the major actinide plutonium as fuel, if the spent fuel from LWR operations is processed. At the present time, LWR spent fuel is not processed in the United States.

The processing of metal fuel using a special pyrochemical technique is being developed by Argonne National Laboratory. The pyrochemical processing includes electrorefining the fuel in a molten salt, a process similar to the one used in the production of the metal aluminum from its ore. In its breeder version, the ALMR operates as a fast breeder reactor and can have a processing plant built as an integral part of the facility so that the spent fuel elements are processed and the new fuel is manufactured on-site. The fuel may alternatively be processed at an off-site facility to improve economics; that is, the facility might serve several ALMRs.

The ALMR can be operated as an actinide "burner" (transmuter) instead of a breeder. Breeding is not desired when the objective is to eliminate the existing actinide fuel materials in LWR spent fuel rather than to produce more fuel. In the burner mode of operation, the ALMR uses as fuel plutonium and minor actinides that have been extracted from LWR spent fuel at a separate processing facility. Transportation of spent or processed fuel will be necessary in this case because the LWRs will not in general be located at the fast reactor site.

CLAIMED ATTRIBUTES OF THIS CONCEPT

Argonne National Laboratory and General Electric claim several advantages for this fast reactor concept as a long-lived radioactive waste transmuter. It separates the long-lived plutonium and minor actinide fuels from the rest of the radioactive waste and utilizes them to produce electricity. It provides convenient chemistry to incorporate some other long-lived radioactive materials--mainly, iodine-129 and technetium-99, which are not transmuted--into chemical forms that will be immobile when placed in a geologic repository. It maintains the fissionable materials in a form that is very hazardous and thus inhibits possible diversion or theft for nuclear weapons use. Finally, this technology is well advanced compared to any of the other transmutation concepts.

ESTIMATED DEVELOPMENT COST

The Department of Energy's (DOE) ALMR/IFR research and development (R&D) program is called the Advanced Liquid-Metal Reactor Actinide Recycle Program. It comprises three technology components: (1) an advanced liquid-metal-cooled reactor design and development program, (2) a closed metal-fuel-cycle processing and fabrication system development, and (3) a light-water reactor actinide recycle technology development program. DOE has prepared a 5-year plan to fund this program through 1998, at which time the technology and licensing approvals should be ready to support construction of a prototype plant that can be connected to a utility grid. Although appropriations to support this R&D plan appear at present uncertain, the funding levels in the plan indicate what the expected development costs would be assuming a favorable funding climate. During fiscal years (FY) 1993-98 the total cost to the government is $903.4 million divided among the three components: ALMR design and development, $477 million; IFR R&D, $291.9 million; and LWR actinide recycle, $134.5 million. According to program officials, nongovernment sources are expected to contribute an additional $73 million. These figures do not include the cost of a first-of-a-kind, full-size prototype module, which DOE proposes be shared with industry. An estimate of the cost of a first-of-a-kind, full-size ALMR plant is $2.9 billion (1993 dollars), and the IFR metal-fuel-recycle facility would cost about $1.3 billion (1993 dollars). However, program officials believe that much or all of the cost could eventually be recovered from the sale of the electricity that the plant would produce.

ESTIMATED OPERATING COST

The approximate cost of power from an ALMR producing electricity is variously estimated to be 35-60 mills per kilowatt-hour of power (mills/kWh) in 1991 dollars. This cost may turn out to be competitive with the cost of power from an advanced light-water reactor (ALWR). For the case of an ALMR used to transmute transuranic wastes from the first generation of LWR reactors, the cost could be somewhat higher because of the processing required for the LWR spent fuel. Using the estimates of Oak Ridge National Laboratory (Delene, Fuller, and Hudson) averaged for the period from 2010 to 2060 (cases ALMR0000 vs ALMRA001), the added cost could be 4 to 5 mills/kWh. Based on a value of 4.5 mills/kWh as the added cost of power for transmutation service, the cost of transmuting the transuranics is approximately $35 per gram of transuranic waste transmuted. At $35 per gram, the total cost of burning 875 metric tons of transuranic waste, which is expected to be produced by the current LWRs by the time they are all retired, is $30.6 billion (in 1991 dollars, neglecting any discounting). This estimate assumes that the alternative to power produced by the transmuter ALMRs is power produced by an advanced generation of light-water reactors. If no nuclear power other than that from transmuter ALMRs is permitted after the phasing out of the current generation of light-water reactors, the comparison of transmuter ALMR power cost must be made against the cost of the power source that would be used to substitute for the LWRs.

ESTIMATED SCHEDULE FOR DEVELOPMENT AND IMPLEMENTATION

The schedule for development and implementation depends on government policy. The schedule described here is consistent with the ALMR development called for in the Energy Policy Act of 1992. DOE's draft 5-year plan indicates completion of the ALMR actinide recycle system development at the end of calendar year 1998. At about this time, construction of a prototype ALMR module could begin, using the design included in the R&D plan. Subsequently, if a commercial first plant could be built as an actinide burner, it could possibly begin transmuting the actinides in LWR spent fuel by 2014, provided that separated actinides from processed LWR fuel are available. The draft 5-year plan calls for initiation of a prototype LWR processing facility design by the end of 1998, if earlier phases have been successfully completed. If the design can be completed and the plant brought on line in 7 years, the feed material for the ALMR burner would become available in a timely fashion.

ESTIMATED TIME REQUIRED TO TRANSMUTE EXISTING SPENT FUEL

Separating out the transuranic actinides in LWR nuclear waste and transmuting them reduces the amounts of these materials that will be transferred to a repository when the wastes are disposed of there. As a result, the repository may benefit through reduced heat loads, increased waste storage capacity, easier engineering design criteria, and possibly greater public acceptance. However, at any given time, only part of the actinides are in the repository. The rest are in nuclear power plants, where they serve as the nuclear fuels. In an economy partially dependent on nuclear power, some actinides will always be present in these nuclear plants, especially in ALMRs, which require much larger inventories of fuel than LWRs producing the same power. Two measures of the effectiveness of a waste transmutation system are (1) the extent to which it minimizes the amounts of long-lived waste sent to the repository and (2) the amounts that are present in the nuclear plants, including the transmuters. The objective of the scenario considered here is to introduce enough ALMRs to eliminate the inventory of transuranic actinides produced in the current generation of LWRs. A secondary objective could be to maintain enough ALMRs to transmute actinides produced by a new generation of ALWRs. Only the first objective is treated here.

The scenario adopted is deployment of ALMRs, beginning with operation of one 1,395 megawatts-electric plant in 2014, followed by the addition of 18 more plants to total 27 gigawatts-electric by 2030. In 2030, the current generation of LWRs will have ceased operation, leaving spent fuel containing approximately 90,000 metric tons of heavy metal and 875 metric tons of transuranic actinide elements. The ALMRs will use the actinides to fuel their operation and will be gradually phased down in number from 19 to zero as the inventory of remaining LWR spent fuel declines. This scenario thus separates the spent fuel produced by the current generation of LWRs from any future generation of nuclear power plants and concentrates on transmuting the long-lived transuranic actinides that these LWRs have produced. The power plant selected as the actinide burner in the scenario contains three power blocks, each containing three ALMR modules. The overall plant produces 1,395 megawatts-electric and has a conversion ratio of 0.65, which means that it produces 0.65 new fuel atoms for each fuel atom consumed. Under these conditions, the inventory of actinides will be reduced to about 1 metric ton of actinides by 2240. If ALMRs with conversion ratios of less than 0.1 are used, the reduction to 1 metric ton can be achieved by 2110. In either case, the LWR actinide waste will be incorporated into the ALMRs within 25 to 50 years after 2030. It should be possible to reduce the 1 metric ton of transuranic actinide waste remaining after the ALMR transmutation by using a small reactor constructed specifically for the purpose. The amount of residual transuranic actinides in the waste scheduled for repository disposal will be determined by the efficiency of the processing steps but should be well under 1 metric ton.

MAJOR TECHNICAL CHALLENGES TO OVERCOME

Several major technical challenges remain to be overcome to achieve success with this method of transmutation:

1. Complete the qualification of the fuel. So far, the results of tests have been positive, but questions still remain about fuel segregation and fuel clad interactions.

2. Demonstrate all aspects of safe performance.

3. Demonstrate the fuel cycle for the ALMR fuel processing on an engineering scale.

4. Demonstrate the processing of the LWR spent fuel. Relatively little work has been done to develop this technology.

In addition, almost all conventional liquid-metal reactor designs exhibit a positive coolant (sodium) void coefficient, and it is unclear whether any reactor (in this case, the ALMR/IFR) with such a feature can successfully be licensed for commercial operation in the United States.

THE LOS ALAMOS NATIONAL LABORATORY'S ACCELERATOR

The Los Alamos National Laboratory (LANL) Accelerator Transmutation of Waste (ATW) concept is a project to use neutrons produced by a high-energy, high-current proton linear accelerator to transmute transuranic actinides and long-lived fission products. In the process, a large current (up to 0.25 amperes) of protons is accelerated to high energy (as high as 1,600 million electron volts). LANL has an aqueous and a nonaqueous version of the ATW. The aqueous version is described first.

The protons strike a target material and produce a shower of neutrons that slow to "thermal" energy in a tank of heavy water that surrounds the target. Most of the thermal neutrons are absorbed in transuranic actinides or long-lived fission products that flow in solutions or slurries through pipes located in the heavy water tank. Absorption of neutrons stimulates nuclear fission in the nuclei of actinide nuclei or alternatively converts long-lived iodine-129 and technetium-99 into short-lived or stable products. The nuclear fission releases heat, which is used to produce electricity by means of power-generating equipment that is coupled to cooling loops through heat exchangers. Part of the electricity produced in this way is used to supply energy to run the linear accelerator. The rest is available for sale to an electric utility. The cooling loops also include cleanup elements that remove the short-lived and stable materials that are produced during the processing.

CLAIMED ATTRIBUTES OF THIS CONCEPT

LANL claims several advantages for this transmuter concept. It is a subcritical system, which offers additional protection against criticality accidents. Also, the high concentrations of thermal neutrons produced from the linear accelerator target in the heavy water tank make possible rapid transmutation of actinides with much smaller actinide inventories in the transmuter than are required for the ALMR. This intense thermal neutron flux is a basis for the unique features of ATW. Furthermore, the thermal neutrons can transmute iodine-129 and technetium-99, which the ALMR cannot do efficiently. These radionuclides are major contributors to long-term risks associated with repository storage because they are more likely to be leached out of a repository than actinides. Finally, this process uses continual material feed and waste removal rather than batch refueling like the ALMR and thus can allow a smaller-capacity processing system.

ESTIMATED DEVELOPMENT COST

The development program proposed comprises three phases. The first phase would consist of component technology tests and development and general concept design and is estimated to cost

$120 million. The second phase would demonstrate integrated system operation and performance at a scientific scale and would cost about $600 million. The third phase would cover construction and operation of an engineering demonstration/production plant at a DOE site such as Hanford. Phase three is estimated to cost around $2 billion. All of these estimates are preliminary because a complete conceptual design of ATW does not exist.

ESTIMATED OPERATING COST

The approximate cost of power from an aqueous ATW with 1,600 megawatts-electric capacity and 75 percent annual operation at thermal efficiency of 30 percent is reported by LANL to be 56.5 mills per kilowatt-hour of power in 1991 dollars, including the cost of preparing the LWR spent fuel for transmutation. (We estimate the cost of power will be substantially higher than the 56.5 mills estimated by LANL, but we are reporting LANL's estimate.) Furthermore, LANL has reported that it would cost $137 per gram to transmute the transuranics from the spent LWR fuel and that one ATW could transmute 1,560 kilograms per year. At $137 per gram, it would cost about $120 billion to transmute the 875 metric tons of transuranics contained in spent fuel accumulated until 2030.

ESTIMATED SCHEDULE FOR DEVELOPMENT AND IMPLEMENTATION

The schedule adopted here assumes that the LANL ATW development plan begins in FY 1994. The Phase I component technical development and concept design would last 4 years, through FY 1997. Phase II work, using an Integrated Test Facility, would begin in FY 1997 and extend through FY 2001. The Phase III design and construction of the engineering demonstration plant would begin in FY 2000 and extend through FY 2007. Allowing 2 years for operation and evaluation of the demonstration plant and simultaneous design of a full-scale production plant, and then 6 years for construction of the first full-scale plant, the first ATW system would be ready to begin operation in about 2016.

ESTIMATED TIME TO TRANSMUTE EXISTING SPENT FUEL

If the same scenario used for transmuting LWR spent fuel waste in ALMRs is applied to ATWs, the number of ATWs would increase from 1 to 19 during the period from 2016 to 2030. By 2030, current LWRs will have ceased operations, leaving 875 metric tons of actinides and accompanying long-lived fission products for disposal. During the buildup period from 2016 to 2030, 207 metric tons of actinides will be consumed in ATWs, leaving 668 metric tons for transmutation after 2030. In this case, the 19 units can continue to operate until most of the actinides and the fission products, technetium and iodine, are consumed, because the phaseout of ATWs will be necessary only during the last few years of LWR waste transmutation. The process will be essentially complete by 2055. It would be more economical to build fewer than 19 ATWs and take somewhat longer to complete the transmutation of LWR wastes in order to avoid having to amortize the capital cost of some ATWs over a short time period.

MAJOR TECHNICAL CHALLENGES TO OVERCOME

So far, only preliminary feasibility calculations and a few laboratory experiments have been done on the ATW concept. Major R&D funding has not been available. Some confirmation of the low-energy performance of the linear accelerator has been completed through related work on a Strategic Defense Initiative project, but operation at high energy and high current cannot be demonstrated until new equipment becomes available. Experimental work must be undertaken on the target end of the ATW, including the proton target, the heavy water tank, and the loops containing the circulating liquids and slurries. The chemistry of the actinide and fission product partitioning and loop processing is largely undemonstrated, as are the management and disposal of the final waste materials. Corrosion and radiation damage to materials under the extreme conditions in the ATW will have to be tested. In summary, although technical feasibility studies to date have been encouraging, this concept is in a very early stage, and almost all of the specific R&D is yet to be accomplished.

THE NONAQUEOUS VERSION OF THE ATW

The nonaqueous version of the ATW uses a high-current, high-energy accelerator as a source of protons for a spallation target and a subcritical assembly for additional neutron multiplication, just as the aqueous version does. However, graphite (that is, "nonaqueous") rather than heavy water thermalizes the neutrons in the system, and helium rather than the heavy water is the coolant in one concept under evaluation. The proton target is a liquid, such as lead or lithium, rather than tungsten, and the transuranic and fission products to be transmuted are contained in molten salt loops with circulation outside the critical assembly for processing. LANL claims that the nonaqueous version would be more efficient and less costly to operate than the aqueous but might take slightly longer to transmute the existing spent fuel. We estimate that the spent fuel could be transmuted by 2060. The nonaqueous ATW would transmute actinides, technetium-99, iodine-129, and perhaps other fission products as well. The nonaqueous version of the ATW, like the aqueous, is still in the very early stages, and almost all of the R&D is yet to be done.

THE BROOKHAVEN NATIONAL LABORATORY'S PHOENIX ACCELERATOR

The Phoenix transmutation concept of Brookhaven National Laboratory comprises a linear accelerator (LINAC) with a subcritical target assembly as a transmuter of minor transuranic actinide constituents (neptunium, americium, curium) of LWR spent fuel waste. The LINAC is similar to the design proposed for the ATW but uses less than half of the proton current required by the ATW. In Brookhaven's Phoenix design, the proton beam impinges on a subcritical sodium-cooled lattice of fuel rods containing oxides of minor actinides previously separated from spent LWR fuel. The protons interact with the heavy actinide nuclei to produce showers of neutrons that in turn cause additional nuclear fissions in other actinide nuclei. Each proton ultimately will lead to the fission of 170 to 350 actinide nuclei. The Phoenix target assembly also will include separate water-cooled targets containing iodine-129, which will be transmuted to stable forms of the element xenon by the neutrons.

Phoenix relies heavily on chemical separation processes to partition the LWR waste and to separate the constituents after transmutation. The reference Phoenix design uses the aqueous plutonium-uranium extraction (PUREX) and transuranic extraction (TRUEX) processes to prepare the accelerator target material from spent LWR fuel and to reprocess the targets after they have been irradiated. Phoenix does not transmute plutonium, uranium, or technetium. These materials (after separation from spent LWR fuel) are stored for eventual incorporation into current or future nuclear reactors. Phoenix also includes a waste stream of fission products destined for a geologic repository. Strontium-90 and cesium-137 are included in this waste stream, after an interim storage period to permit them to partially decay.

CLAIMED ATTRIBUTES OF THIS CONCEPT

Brookhaven National Laboratory claims that one Phoenix proton-accelerator-subcritical lattice can transmute the minor actinides from 75 LWRs. The transmuter is proposed as part of a more general radioactive waste treatment system based on partitioning LWR fuel into a number of key components. If the spent fuel partitioning and transmutation are fully implemented, Brookhaven claims that the time required to reduce toxicity of the radioactive waste stream below that of uranium ore will be reduced from more than 10,000 years to approximately 30 years. In addition, Phoenix will be able to generate 850 megawatts-electric for sale.

ESTIMATED DEVELOPMENT COST

Brookhaven reports an estimate of $20 billion for development of separations technology and facilities to supply the Phoenix transmuter and related components of the waste treatment system.

The director of the proposed transmutation project estimates that development of the accelerator for the Phoenix system would cost $1 billion to $2 billion and development of the power plant, an additional $7 billion.

ESTIMATED OPERATING COST

No estimates of operating cost for a Phoenix system are available from Brookhaven. The cost may be similar to the cost of operating the ATW.

ESTIMATED SCHEDULE FOR DEVELOPMENT AND IMPLEMENTATION

Brookhaven estimates that it would take 15 to 20 years to put this technology on line. This development period is similar to the schedules for ALMR/IFR and ATW.

ESTIMATED TIME TO TRANSMUTE EXISTING SPENT FUEL

Brookhaven proposes that Phoenix be used to transmute only the minor actinides, plus iodine-129, and not plutonium. Therefore, the scenario for spent fuel waste burnup in this case is not comparable to those for the ALMR and ATW. One full-scale Phoenix system can transmute 2.6 metric tons per year of minor actinides. The total inventory of minor actinides built up in LWR spent fuel by the time all units have ceased operation is expected to be about 58 metric tons. Therefore, one Phoenix system can complete transmuting the inventory of minor actinides in less than 25 years. Operation may have to be extended somewhat to complete the simultaneous transmutation of the iodine-129. If a program to develop and deploy the Phoenix system were initiated in the near future, a Phoenix transmuter and associated processing equipment might begin operation around 2015, and the minor actinides and iodine-129 would be gone sometime between 2035 and 2050. However, 817 metric tons of plutonium would still remain.

MAJOR TECHNICAL CHALLENGES

Very little experimental work has been carried out on the Phoenix concept. One major challenge is to demonstrate and confirm the expected operation of the target subcritical lattice under the intense proton bombardment that it would receive. Measuring nuclear performance and radiation damage properties will require extensive testing. Demonstrating required high-energy, high-current performance of the LINAC is another major challenge, as it is for the ATW. Completing work on the chemical processing required for this option is a third major challenge.

THE BROOKHAVEN NATIONAL LABORATORY'S PARTICLE-BED REACTOR

The Particle-Bed Reactor (PBR) nuclear waste burner is a nuclear waste transmuter concept proposed by Brookhaven National Laboratory. The fuel for the nuclear reactor consists of plutonium and minor actinides that have been extracted from LWR spent fuel. The fuel is contained in small graphite-coated particles that constitute the "particle bed" referred to in the reactor title. The structural components of the core of the PBR are made of materials like graphite that can withstand high temperatures. The core is cooled by helium, an inert gas. The fuel particles are not embedded in a matrix material but are present in loose form so that they constitute a particle fluid that can flow into and out of cavities in the fuel elements. The PBR can achieve very high thermal neutron concentrations (high thermal neutron fluxes) and can therefore be an effective actinide and fission product transmuter. Brookhaven proposes that an R&D program be undertaken to develop this concept as an actinide and fission product transmuter. If the R&D program is successful, Brookhaven proposes that PBR waste burners be built in modules producing 1,080 megawatts of thermal power. They may be used to produce electrical power, but the operating cycle is so short--about 20 days--that effectiveness in this application is somewhat questionable. Reprocessing the PBR fuel will require special techniques to separate the actinide and fission product constituents from the carbon particles. Brookhaven has not decided whether to undertake aqueous or nonaqueous processing of the fuel to achieve these separations.

CLAIMED ATTRIBUTES OF THIS SYSTEM

Brookhaven claims that the PBR will destroy actinides and long-lived fission products from LWRs and defense wastes. The concept is attractive because it has low radioactive inventories, destroys both actinides and long-lived fission products, should be low in cost, and has various safety features.

ESTIMATED DEVELOPMENT COST

Brookhaven presents a five-phase R&D program for the PBR. Phase 1 is a scoping/feasibility study lasting 2 years and costing $5 million (1992 dollars). Phase 2 covers preliminary design and component R&D. It will last 5 years and cost $50 million (1992 dollars). Phase 3 is engineering design and component validation; it will take 3 years and cost $150 million (1992 dollars). Phases 4 and 5 include demonstration of PBR waste burner system design, construction, and operation. The waste burner system includes the PBR reactor and the particle processing/fabrication system. It does not include the LWR fuel reprocessing facilities. Phases 4 and 5 will take 6 years and cost about $1 billion (1992 dollars).

ESTIMATED OPERATING COST

No information is available on the operating cost of the PBR.

ESTIMATED SCHEDULE FOR DEVELOPMENT AND IMPLEMENTATION

The schedule for development of the PBR waste burner system totals 16 years. If an R&D program is initiated in the near future, the demonstration plant can be built and tested by 2010. Operating the demonstration plant will require the availability of plutonium, transuranics, strontium, cesium, technetium, and iodine from a PUREX/TRUEX facility constructed to reprocess LWR fuel. A large-scale reprocessing plant of this kind has not been built and operated in the United States up to the present time. Using PBR program data, we estimate that if the PBR demonstration is successful and the feed from LWR spent fuel is available, a construction program for PBRs can begin about 2010. If 1 new PBR is started each year until 20 are in operation, the waste-burning operation can begin about 2015 and build to full scale by 2035. Each PBR will burn 132 kilograms of minor actinides and 205 kilograms of plutonium per year. The 58 metric tons of minor actinides produced by all of the LWRs during their operation will be gone by 2050. However, transmutation of the much larger amount of plutonium (817 metric tons) will require continued operation of 20 PBRs until 2160. The technetium-99 and iodine-129 also will have to be destroyed during this time. PBR program officials describe other spent fuel transmutation scenarios involving as many as 70 PBRs. The use of more PBRs would make inventory disposal times correspondingly shorter.

MAJOR TECHNICAL CHALLENGES TO OVERCOME

The PBR is based on the high-temperature, gas-cooled reactor (HTGR) fuel particle technology. However, the particle composition differs in detail and would have to be tested using plutonium and minor actinides as the metal constituents. The structural components of the fuel element also are quite different from those in the HTGR and will require demonstration for the functions that they will have to serve. Other major challenges will be demonstrating the PUREX/TRUEX partitioning of the LWR fuel, fabricating and reprocessing the PBR fuel, and assessing the radiation damage effects to the core materials. Finally, the hydraulics of the coolant flow through the particle beds will have to be demonstrated. In summary, the entire PBR waste burner system is only at a conceptual stage at the present time and will have to be demonstrated in its entirety.

WESTINGHOUSE-HANFORD'S CLEAN USE OF REACTOR ENERGY

The Westinghouse-Hanford Clean Use of Reactor Energy (CURE) concept is an integrated system of chemical processes and transmutation technologies for processing LWR spent fuel. It is designed to eliminate most long-lived waste components by partitioning and transmutation and thus to produce waste streams of low long-term disposal risk. CURE examines a variety of chemical processes and transmutation methods. The reference system comprises aqueous processing of LWR spent fuel, combined with fissioning of transuranic elements in an oxide-fueled fast reactor, which CURE calls a Cleanup Fast Reactor (CLFR). The CLFR differs in fuel type and fuel-processing technology from the ALMR/IFR, which uses metal fuel and nonaqueous pyrochemical processing. The CLFR can transmute technetium-99 and iodine-129 in special metal hydride cells that slow neutrons into an energy range where they interact strongly with these two fission products. The transmutation of strontium-90 and cesium-137 in a CLFR is not believed to be feasible.

CLAIMED ATTRIBUTES OF THIS CONCEPT

The proponents believe that the CURE concept combines the superior transmuting properties of a fast reactor for transuranics with the potential for fission product transmutation in specially modified cells in the reactor. It also relies on the proven performance of oxide fuel in a fast reactor and aqueous processing methods for partitioning radioactive waste components. It includes extensive proposals for partitioning and disposing of problem nuclides in the waste.

ESTIMATED DEVELOPMENT COST

Westinghouse-Hanford proposes two levels of R&D effort to demonstrate technologies involved in CURE. A basic, highly focused R&D program to resolve nine critical CURE system technical issues will cost about $68 million (in 1990 dollars). A more complete R&D program covering all technical issues except isotopic separation of cesium and strontium isotopes will cost about $146 million. These R&D costs do not include construction of a demonstration CLFR or an aqueous reprocessing facility. The R&D cost associated with transmutation testing assumes availability of Hanford's Fast Flux Test Facility reactor and also assumes that only a small fraction of reactor costs would be dedicated to the transmutation program.

ESTIMATED OPERATING COST

The CURE report includes an electrical power cost comparison between the present once-through LWR power production system and an equilibrium system that includes LWRs and enough CLFRs to keep up with the processing system waste streams (about a 4:1 ratio of LWRs to CLFRs). The cost of electricity with the CURE system is projected to be about 6 to 10 percent more than that for the LWR system; most of the cost difference would come from operation of CLFRs versus LWRs.

ESTIMATED SCHEDULE FOR DEVELOPMENT AND IMPLEMENTATION

Westinghouse indicates that the schedule for completing the basic R&D program is 5 to 10 years. No estimate is given for the more complete R&D schedule, but it seems reasonable that a CURE system could be ready for deployment by 2015. Westinghouse has considered a scenario to phase out nuclear power using burnup versions of the CLFR. This scenario begins the elimination of LWR spent fuel in 2030 and requires somewhat less than 100 years to reduce the inventories of technetium-99 and iodine-129 by a factor of about 100. The report did not develop reduction estimates for the transuranic elements.

MAJOR TECHNICAL CHALLENGES TO OVERCOME

Chemical processing technology needs include demonstrating a number of processes to separate components of the waste, especially the applicability of the TRUEX process to high-level waste solutions. Waste management/disposal technology needs include demonstrations of decontamination, interim storage, and final disposal of a number of liquid and solid waste streams. Target fabrication techniques and key cross-section measurements also must be developed. One of the most important factors, because of its high technical risk, is the ability to license the CLFR reactor concept. Almost all conventional liquid-metal reactor designs exhibit a positive coolant (sodium) void coefficient, and it is unclear whether any reactor with such a feature can ever be licensed in the United States. (See also the section on the major challenges for the ALMR/IFR.) For that reason, the CURE proponents believe that subcritical cores driven by an external source of neutrons (such as the linear accelerator-boosted concepts) must be developed. Such development would increase the R&D development costs and potentially the final system operating costs as well.

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