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THE SPALLATOR AND APEX NUCLEAR FUEL CYCLE A NEW OPTION FOR NUCLEAR POWER

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Summary

A new nuclear fuel cycle is described which provides a long term supply of nuclear fuel for the thermal LWR nuclear power reactors and eliminates the need for long-term storage of radioactive waste. Fissile fuel is produced by the Spallator which depends on the production of spallation neutrons by the interaction of high-energy (1 to 2 GeV) protons on a heavy-metal target. The neutrons are absorbed in a surrounding natural-uranium or thorium blanket in which fissile Pu-239 to U-233 is produced. Advances in linear accelerator technology makes it possible to design and construct a high-beam-current continuous-wave proton linac for production purposes. The target is similar to a sub-critical reactor and produces heat which is converted to electricity for supplying the linac. The Spallator is a self-sufficient fuel producer, which can compete with the fast breeder. The APEX fuel cycle depends on recycling the transuranics and long-lived fission products while extracting the stable and short-lived fission products when reprocessing the fuel. Transmutation and decay within the fuel cycle and decay of the short-lived fission products external to the fuel cycle eliminates the need for long-term geological age storage of fission-product waste.

Introduction

It is well known that Purex nuclear fuel reprocessing for the civilian power program was primarily derived from the need to produce weapons grade plutonium. Thus Pu-239 is solvent extracted with tributyl phosphate (TBP) from an aqueous nitrate solution of spent fission fuel and the Pu-239 is then recovered and concentrated for mixing with fresh uranium oxide to make up the fuel in a thermal nuclear power reactor. Actually no fuel reprocessing has been performed for the civilian power economy since deferment of reprocessing was instituted by the Non-proliferation Act of 1976. Thus, most of the reprocessing that has occurred was for the weapons program. The effluent high level waste from these production plants contain up to about 2% of the Pu-239 originally present in the spent fuel from the convertor reactor together with the fission products. The high-level waste from the fuel reprocessing plants have been stored to date, on-site in large engineered storage tanks. Much work is now being conducted to solidify this high level waste for placement in underground excavations for geological age storage in so-called waste isolation facilities. Because of the Pu-239 content, which has a 26,000 year half-life, this waste requires storage for a quarter of a million years (~10 half-lives) to decay to biologically acceptable background level, along with other long-lived transuranics (Pu, Am, Cm, Np, etc.). The longest-lived and biologically most hazardous fission products are Cs-137 and Sr-90, both of which have half-lives of approximately 30 years, require at least 300 years to decay to background. Actually the bulk of the present waste consists of 80 million gallons stored at the weapons materials production plants. The main radioactive products, in this aged waste consists of Pu, and Cs and Sr fission products. The civilian fuel as mentioned above is not being reprocessed presently, but is being stored in pools at the power reactor sites. Eventually these elements will either have to be reprocessed or disposed of.

Weapons materials require high concentrations (>20%) of the high grade-high purity fissile material (Pu-239, U-235 or U-233). For the thermal fission nuclear burner power reactors, for example, the light water reactors (LWRs), one does not need to concentrate fissile U-235 (natural) or Pu-239 (made from uranium 238) or even U-233 (made from thorium) to these higher levels for use in the power reactor fuel elements. The fissile fuel concentration in the fuel elements need only be in the order of 2% to 4% to be able to function in a light water power reactor LWR.

We are proposing an alternate new fuel cycle which eliminates the radioactive fission product waste effluent and thus avoids long-lived geological age radioactive waste storage[2,3] and supplies fissile fuel for the LWR power reactor. For all intents and purposes this fuel cycle does not have any radioactive waste effluent. Only non-radioactive stable waste which does not have to be stored in a waste isolation facility and can be disposed of in a normal fashion to the environment is produced by the system.

Apex Fuel Cycle

The fuel cycle consists of chemically reprocessing LWR spent fuel which has been aged for 1 to 2 years. The reprocessing removes the stable non-radioactive (NRFP, e.g. the lanthanides, etc.) and short-lived fission products (SLFP) with half-lives of <1 to 2 years and returns, in dilute form, the long-lived transuranics (TU's, e.g., Pu, Am, Cm, Np, etc.) and long-lived fission products (LLFP's, e.g. mainly the 30 year half-life Cs, Sr, and 10 year Kr and 16 million year I, etc.) to be refabricated into fresh LWR fuel elements. The fissile transuranics (the odd mass-numbered) will fission and the fertile transuranics (the even mass-numbered) will be converted to fissile transuranics in the thermal nuclear power reactor. The TU's have large thermal neutron cross-sections and can either be readily fissioned or converted from fertile material (FM) to fissile fuel (FF) in the LWRs. Equilibrium concentrations of these materials are achieved in the fuel cycle within a relatively short period of time. Recycling the transuranics, which actually act as fuel, adds to the power capacity of the LWRs and does not detract from the neutron economy of the reactor. Because of their much lower cross-sections, the long-lived fission products (LLFPs) [mainly Cs-137 and Sr-90] are not readily transmuted in the LWRs. For these waste products we would be mainly relying on the decay process by storage within the fuel cycle. Some transmutation will occur in the Spallator and the LWRs which will shorten the recycle storage times for decay of the LLFPs to non-radioactive stable isotopes (NRFP). It is interesting to note that the main long-lived radioactive fission products formed in the fission process are the 30 yr half-life Cs-137 and Sr-90 isotopes so that no other hazardous long-lived nuclides are expected to be formed on recycling. Over the longer period of time the total inventory of Cs and Sr thus reaches asymptotic equilibrium values.

In order to implement the above fuel cycle, it may be possible to use conventional Purex reprocessing; however, we are proposing to improve and design the reprocessing chemistry to accomplish the goal set forth. A fundamental consideration is that the initial purpose of Purex was to produce pure Pu for weapons. Purex was, therefore, operated to allow Pu to spill over into the waste in order to prevent contamination of the Pu metal with fission products. In the concept proposed herein, the reverse is allowed for the civilian reactor fuel. Fission products are allowed to contaminate the fissile Pu, but Pu is not allowed to contaminate the waste. The purpose of this new reprocessing system is to extract the stable non-radioactive (NRFP) and shorter-lived fission products (SLFPs with <2 years half-life) and to allow the transuranics and long-lived fission products to remain in the fuel. Furthermore, in order to produce make up fissile fuel (FF) for fabricating fresh fuel elements for use in the thermal burner LWR power reactors, it is proposed to use the Spallator (linear accelerator spallation-neutron target reactor) to produce fissile material.[2] Isotopic enrichment of U-235 from natural uranium is not needed and the cycle functions in the same sense as a breeder.

Chelox Reprocessing

The new reprocessing chemistry which we call "Chelox" involves the use of a chelating agent to extract and separate the stable alkali and rare earth fission products from the higher valent uranium and transuranic oxides.[4]

This is accomplished mechanically by chopping up the LWR fuel elements and leaching the exposed spent UO_2 with the chelating agent. The chop-leach operation has been highly developed in the Purex process.[1] The advantages of chop-leach is that contamination due to escape of dry particulates and volatiles is minimized.

The β-diketonate chelating chemistry has been tried out in the laboratory for complexing and separating transuranics but has never been developed into a fuel processing scheme.[5] The basic physical chemistry of the process is available in the literature and has been extensively used as an analytical procedure.[4] At present, it is visualized that the UO_2 from the spent fuel elements will be contacted with the organic β-diketonate chelating agent at temperatures in the order of 100° to 200°C to extract most of the fission products and some transuranics, leaving the bulk of the uranium and plutonium undissolved. The metal complexing chelating agents have been successfully used in extraction of metallic ore bodies and analyzed by gas phase chromatography.[4] It is proposed to develop this basic analytical procedure into a process which can extract and partition the TUs and FPs. The type of diketonate and the reaction conditions will be one of the major objectives of the proposed research and development task. This R and D will determine the feasibility and the process conditions necessary to obtain the optimum desired separation and partitioning of the non-radioactive (NRFP) stable and short-lived isotopes (SLFP) from the long-lived transuranics (TUs) and fission products (LLFPs). Once the organometallic compounds of the stable and short-lived fission products (SLFPs) are formed these compounds will be separated and refined by distillation. Distillation is possible because of the widely differing vapor pressures and volatilities between the TUs and FP chelates.[4]

One of the possible chelating agents is organically 6,6,7,7,8,8,8-heptafluoro-2,2-dimethyl-3,5-octanedione, briefly referred to as fod. The chelating reaction of spent UO_2 fuel can be represented as follows:

$$UO_2 + FPs + TUs + fod = UO_2 + TU(fod) + FP(fod)$$

Fod is a stable organic liquid which can be readily handled in the atmosphere. For process purposes, closed reaction vessels are preferred since elevated temperatures will be necessary. By extraction of the UO_2 and distillation of the organo-metallic chelate, a separation and partitioning will be obtained, whereby stable (NRFP) and short-lived products (SLFPs) and the long-lived fission products (LLFPs) will be distilled out from the transuranics (TUs). The vapor pressures of the lanthanide chelates have values of over 10 mm Hg at 200°C while that of the uranium and plutonium chelates are as low as 10^{-3} mm Hg,[5] thus the relative volatility is large (~10^4) and a very large separation factor becomes possible. The fod reagent may be recovered by either extraction with another solvent or by hydrogen reduction. If these are not efficient, the chelated organo-metallic compound can be roasted back to oxide and the fluorine gas will be recovered for reforming the fod chelating agent. The detailed process chemistry has yet to be worked out in an R and D program. Because of the relatively small mass of fission products, the cost per unit of power produced in the total fuel cycle is negligible. Fod is made from relatively cheap organic materials, e.g. acetone, propionic acid, and fluorine, so that make up of fod losses should not be costly.

The organic chelating agent is stable in the presence of air and water to temperatures of more than 100°C, however, the radiation stability of the chelating agent must also be determined. Some decomposition can be tolerated because of the relative low cost of the reagent in the total fuel cycle cost. Fluorine substitution in the organic structure of the chelating agent increases its chemical and radiation stability. It is important to note that fod is only one of a number of reagents of the β-diketonate class, so that there is a large degree of flexibility in process design with this class of compounds.

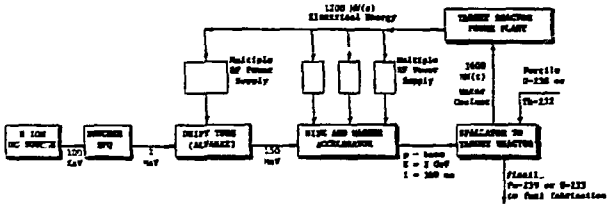
The recovered uranium, plutonium, transuranic and long-lived fission products (Cs and Sr) are mixed together and fabricated back into a fuel pellet. In this fabrication procedure, make up fertile and, if desired, fissile fuel are added to the mixed oxide for production of an LWR zircaloy clad fuel element. If U-235 from an enrichment plant is available, this can be used to makeup fissile fuel. However, this would eventually deplete all the natural U-235 and the nuclear industry would then come to a halt unless a breeder reactor becomes available. It is preferred to have a Spallator make up the fissile material inventory for assuring long-term fuel supply for an LWR power reactor economy. The Chelox process can also be applied to the fast breeder cycle, however, because of the advantageous LWR economics, present deployment and acceptability, a Spallator supplying fuel to a number of LWRs is preferred.

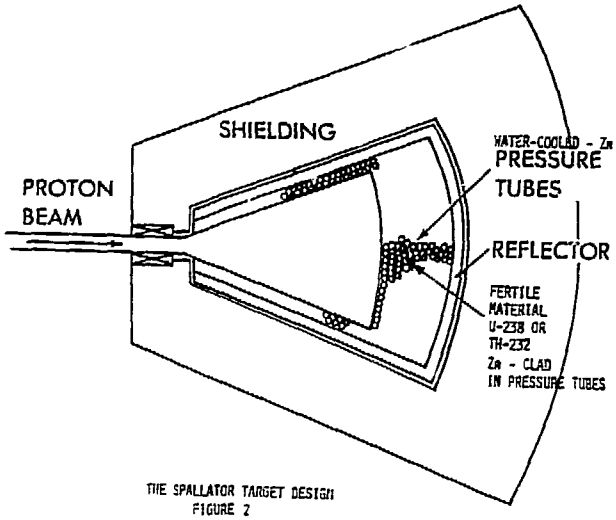
The Spallator for Fissile Fuel Production

The Spallator employs a linear accelerator (LINAC) to generate a high energy proton (1 to 2 GeV) which impinges on a UO_2 target and produces spallation neutrons which can be absorbed in fertile material to produce fissile Pu-239.[2,6] The neutron yield is sufficient so that one 600 MW(e) beam Spallator can supply nine 1000 MW(e) LWRs with fuel throughout the

life span of the LWR power reactors. High energy and fast fission produce heat in the target which can be converted to steam to generate the electrical energy necessary to drive the accelerator. The Spallator is a self-reliant machine with internal circulation of power. In contrast to the breeder it is not a net producer of power, nor is it a net consumer of power. It only produces fissile fuel for burner (thermal) power reactors. The fast breeder reactor (FBR) is a dual purpose machine since it produces fuel in addition to power, whereas the Spallator is a single purpose machine producing only fuel and is thus decoupled from the utility power grid.

The Spallator consists of two major parts: a linear accelerator (LINAC) and a spallation target. Over the past 50 years the LINAC has been developed into a highly reliable and efficient research tool. Figure 1 shows the main features of the accelerator. There is much confidence that a high current (300 ma at 2 GeV proton) continuous wave (CW) production accelerator can be constructed at a reasonable cost.[6] The target is essentially a subcritical assembly resembling a power reactor without control rods. Figure 2 shows the target reactor design for the Spallator. Water cooled pressurized Zr tubes house Zr clad UO_2 target assemblies. The proton beam is magnetically spread into a fan shape which scans the target tubes by means of a magnet drive. The pie shape of the target is to produce a "hohlraum" to minimize leakage of reflected neutrons. In this manner, the energy density of the beam on the target is also maintained at a level which prevents damage to the target structure.





THE SPALLATOR TARGET DESIGN
FIGURE 2

Table 1 indicates the design characteristics and the production capacity of the Spallator. The basic neutron yield for a UO_2 target from spallation, and high energy and fast fission, has been calculated to be equivalent to a net production of 94 fissile atoms per GeV-proton and is backed up by experiment and neutronic model calculations.[7,8] The fuel to moderator volume ratio in the target is 2.37. There is a power producing region in the Spallator which is behind the under moderated production section and has a fuel to moderate volume ratio of 0.5. The peaking power density is not any higher than in an LWR. The yield indicated is for re-enriching the spent UO_2 from the LWRs which would have fissile concentration of approximately 2.5%. The target reactor is designed to provide just enough heat to power the accelerator. A conservative accelerator efficiency of 50% (line energy to beam energy) and a target power cycle efficiency of 33% were assumed. At a 75% plant factor the production rate of the machine is 3300 Kg/yr of Pu which is enough to provide fuel on an equilibrium basis for nine 1000 MW(e) LWRs. Although the Spallator target is subject to decay heat it is a subcritical assembly which shuts down when the beam is turned off. In this respect it is safer than an LWR.

TABLE 1

THE SPALLATOR

ACCELERATOR SPALLATION REACTOR

PRODUCTION CAPACITY AND DESIGN CHARACTERISTICS

PROTON ENERGY	- 2 GeV
NET FISSILE ATOM YIELD FOR UO_2/Zr CLAD - H_2O COOLED	- 94 FISSILE ATOMS/GeV-PROTON
CURRENT CW	- 300 MA
BEAM POWER	- 600 MW
ACCELERATOR EFFICIENCY	- 50%
POWER TO ACCELERATOR	- 1200 MW(E)
POWER GENERATED IN TARGET	- 3600 MW(T) (SELF-SUFFICIENT)
PLANT FACTOR	- 75%
Pu239 FISSILE FUEL PRODUCTION RATE	- 3300 KG/YR
FISSILE FUEL NEEDED FOR 1-1000 MW(E) LWR 75% P.F. AND 0.6 C.R.	- 360 KG/YR
NO. OF 1000 MW(E) LWRS SUPPORTED	- 9

Table 2 gives an estimate of the Spallator cost and Table 3 shows a comparative cost analysis for 1) a Spallator providing fuel for 9 LWRs, 2) a conventional LWR economy without Pu recycle, 3) an LWR economy with Pu recycle, and 4) 6 breeders providing fuel for 3 supported LWRs to provide a total equalized power generation of 9000 MW(e). The breeder has a doubling time of approximately 20 years. The Spallator/LWR economy indicates a 15% lower total lifetime capital investment than the breeder/LWR economy mainly because each breeder costs 70% more than each LWR[9] and the inventory of fissile material for the breeder is higher than for the LWR. It also appears that under present cost assumptions, the Spallator is competitive with the present U-235 fueled LWRs even with reprocessing. Besides being more economical, the Spallator allows the utilities to continue using LWR technology which has become commercialized, is safe and is licensable. The fast breeder reactor has not yet reached this position.

TABLE 2

THE SPALLATOR

ACCELERATOR SPALLATION REACTOR

CAPITAL INVESTMENT
1980 DOLLARS

LINEAR ACCELERATOR = $1000/KW(E)* x 600 MW =	$600 x 10^6
TARGET = 1200 MW(E) x $1000/KW(E)* =	1,200 x 10^6
TOTAL COST	$1,800 x 10^6

* BASED ON REF. (2) AND (6), THE EARLIER ESTIMATES INDICATED A UNIT COST FOR THE ACCELERATOR OF $560/KW(E) OF BEAM POWER. FOR THIS COMPARATIVE ESTIM TE WE PRACTICALLY DOUBLED THE COST TO $1000/KW(E) TO ACCOUNT FOR ESCALATION AND CONTINGENCIES.

** TARGET COST IS ASSUMED TO BE EQUAL TO AN LWR POWER REACTOR IN TERMS OF UNIT POWER GENERATION.

TABLE 3

NUCLEAR ENERGY ALTERNATIVE SYSTEMS COMPARISON

Lifetime Capital Investment 1980 Dollars

		Spallator 1 S/9 LWRs	LWR No Recycle	LWR With Recycle	Breeder (LMFBR) 6 Breeders/3 LWR
No. of Reactors (1000 MW(e))		9	9	9	9
Capital Cost ($1000/KW(e))	LWRs	$9.0 x 10^9	$9.0 x 10^9	$9.0 x 10^9	$3.0 x 10^9
	Breeders	———	———	———	$10.2 x 10^9*
Capital Cost of Spallator		$1.8 x 10^9	———	———	———
Nat. U Feed (30 Yrs)		Negligible	54,000 MT	18,000 MT	Negligible
Enriched Fuel - MT U-235		———	243 MT (3.0%)	81 MT (33%)	———
Total Cost of Nat. U Feed at $40/lb		———	$4.3 x 10^9	$1.4 x 10^9	———
Cost of Enrichment, $100/SWU		———	$2.9 x 10^9	$1.6 x 10^9	———
Fissile Material Inventory***		61 MT	47 MT	47 MT	59 MT
Fissile Inventory Cost at $40/gm		$2.4 x 10^9	$1.9 x 10^9	$1.9 x 10^9	$2.3 x 10^9
Cost of Reprocessing Plant**		$0.3 x 10^9	———	$0.3 x 10^9	$0.3 x 10^9
Cost of Fuel Fabrication Plant**		$0.3 x 10^9	Negligible	Negligible	$0.3 x 10^9
Cost of Waste Storage		Negligible	$1.4 x 10^9	Negligible	Negligible
Total Cost		$13.8 x 10^9	$19.5 x 10^9	$14.2 x 10^9	$16.1 x 10^9

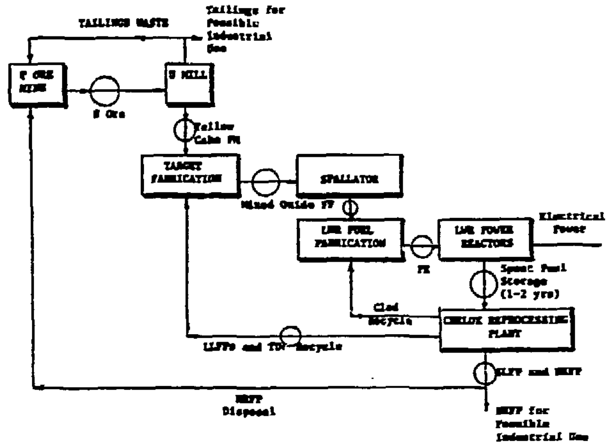
* There is a projected 70% cost differential between a 1000 MW(e) LWR ($1 x 10^9) and a 1000 MW(e) LMFBR ($1.7 x 10^9);

** Estimated total cost of reprocessing plant is $1.5 x 10^9 for reprocessing fuel from 60 LWRs. Hot Fuel Fabrication Estimated to be Equal to Reprocessing.

*** Fissile Material Inventory for 1 S/9 LWRs = 58 MT (23.4 in core and 23.4 out-of-core) for 5 Breeders/3 LWRs 59 MT (29.4 in-core and 29.4 out-of-core) - (1 LWR core contains 2.6 MT; 1 LMFB core contains 3.6 MT).

A flow sheet of the entire APEX process concept is given in the attached Figure 3. The Chelox fuel reprocessing scheme is shown in Figure 4. It should also be noted that the non-radioactive (NRFP) and short-lived fission products (SLFP of <1 to 2 years half-life) are stored in tanks for periods in the order of 20 years to decay these isotopes to background before disposing of them to the environment or placing them back into the U mines as stable non-radioactive fission products (NRFP). These may also be used for new stable isotope sources which are not available in nature.

Figures 5 and 6 show calculations for recycling the transuranics and the Cs and Sr in accordance with the flowsheet shown in Figure 3. As can be seen, the TUs quickly reach equilibrium on recycling and also add fissile fuel in the normal wa .hat a thermal reactor converts fertile to fiss fuel which then fissions and produces power. V . internal fuel cycle storage of the Cs and S ..hese are decayed and reach near asymptotic values the fuel cycle as given by the data shown in F .ure 5. The neutron economy penalty in the LWR .. small because of the small thermal neutron cross sections and limiting the concentration through decay in intermediate process storage vessels. Most of the conversion of the Cs and Sr is by means of the decay mechanism and a smaller portion is by transmutation through neutron absorption in the Spallator and LWRs. Any transmutation will hasten the approach to an equilibrium concentration value for the LLFPs.



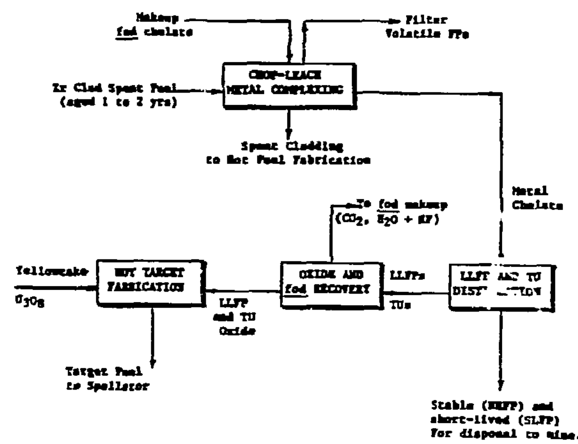
Legend

- Storage
FM - Fertile Material (U-238)
FF - Fissile Fuel (Pu-239, U-235, TUs)
NRFP - Non-radioactive fission product
SLFP - Short-lived fission products (<1 yrs)
LLFP - Long-lived fission products (Cs, Sr, Kr, I, etc.) 2 yr.
TU - Transuranics (Pu, Am, Cm, etc.)
FE - LWR Fuel Element

APEX NUCLEAR FUEL CYCLE
for U/Pu fuel cycle

Includes 1) Spallator for generating Pu fissile fuel, 2) Chelox reprocessing for recycling radioactive waste, 3) LWRs for generating power and eliminates enrichment and need for long-term geological-age storage of long-lived radwaste. System can be modified for application to the Th/U-233 fuel cycle.

FIGURE 3



Legend

fod - fluorinated B-diketonate
FM - fertile material (U-238 or Th-232)
FF - fissile fuel (Pu-239, U-235, U-233 and TUs)
NRFP - non-radioactive fission products
SLFP - short-lived fission products (<2 yrs)
LLFP - long-lived fission products (>2 yrs)
TU - transuranics

CHELOX FUEL REPROCESSING SYSTEM

FIGURE 4

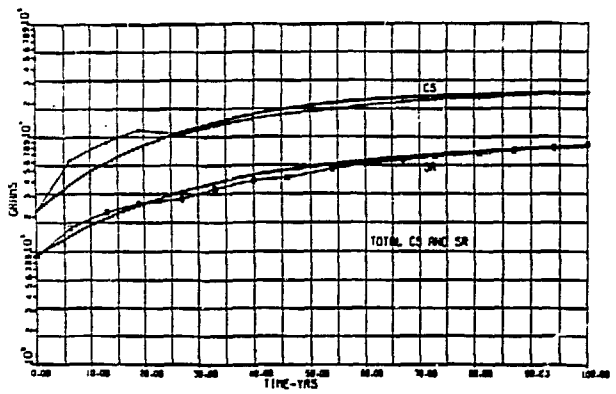


FIGURE 3

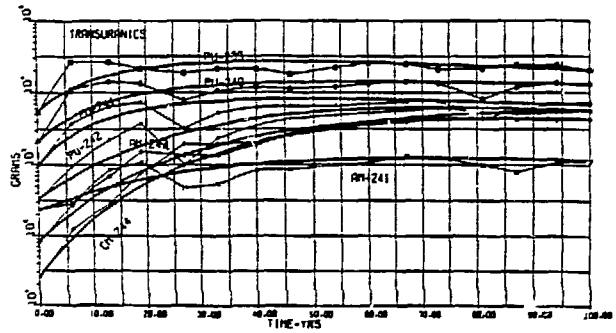


FIGURE 4

The above process concept can also be applied very advantageously to a thorium/U-233 fuel cycle. The Spallator would produce the U-233 inventory from natural thorium. Furthermore, since the conversion ratio in the U-233 LWR cycle is higher than in the U/Pu-239 LWR cycle, more LWRs can be supplied from each Spallator. There is also an advantage of the Th/U-233 fuel cycle in that no long-lived transuranics such as Pu-239 are formed.

The advantages of the APEX fuel cycle with Chelox reprocessing are several-fold as follows:

1. A non-aqueous fuel reprocessing system is proposed in contrast to that of the aqueous Purex process with all its difficulties of handling highly corrosive reagents.

2. We can afford to leave a small amount of stable fission products in the low concentration fissile fuel recycled so that high decontamination factors required of the discard stable waste product is more easily obtained. This is in contrast to the conventional Purex waste, which has to be sharply separated from the plutonium in order to maintain high Pu purity (a hold-over from weapons production). As a result, residual Pu remains in the effluent waste. Additional decontamination of the waste by going through a second TBP extraction cycle is possible with Purex, but evidently has not been found worthwhile for the weapons program or even for further cleanup of the waste for the civilian power program.

3. The temperature of the Chelox process is not very high, reaching a maximum in the order of 250°C in the chelate process. A chop and leach operation with the chelating agent is preferred because of less particulate contamination and lower temperature reprocessing.

4. The handling of radioactively hot recycled fuel elements can be a deterrant to fissile fuel diversion for weapons. Additionally, remote handling of non-aqueous concentrated fissile material may be less hazardous than remotely handling corrosive liquids and gases.

5. The entire process scheme supports a long term LWR economy so that, the electrical utilities do not have to learn a new technology and install new and more expensive reactors, e.g., the liquid metal fast breeder reactor (LMFBR).

6. The process system concept can be equally applied to uranium or thorium in an LWR fuel cycle economy, through the production of either Pu-239 from uranium or U-233 from thorium in the Spallator. A long term supply of fuel is available without the necessity of developing the liquid metal fast breeder reactor (LMFBR).

7. The objective of the concept is that only stable fission products are discarded as a waste so the public does not have to be concerned about long-term terrestrial geological age storage of long-lived radioactive waste.

Tables 4 and 5 list additional advantages of the APEX fuel cycle with Spallator fuel production and Chelox reprocessing. The system solves the problem of fuel supply and waste management for a long-term LWR power reactor economy. It is recommended that a research and development program be initiated to (1) develop the reprocessing chemistry of the organic chelating process, (2) develop in detail the entire APEX fuel cycle flowsheet design, and (3) make a realistic economic assessment.

TABLE 4

ADVANTAGES OF APEX NUCLEAR FUEL CYCLE

- Produces long-term supply of nuclear fuel for the LWR power reactor economy.
- Produces initial reactor inventory for fuel cycle; either fissile Pu-239 from natural U-238 or fissile U-233 from natural Th-232.
- Eliminates need for long-term geological-age storage of radioactive fission product and transuranic waste.
- Eliminates need for enrichment plant.
- Potentially more economical than a fast breeder reactor (FBR) power and fuel cycle.
- Utilities need no new power reactor technology.
- The conventional LWR power reactor technology is sustained. The utilities need essentially no new licensing and safety procedures.
- Relatively low temperature, non-aqueous, non-corrosive, non-mechanical, reprocessing (Chelox) of fuel is employed.
- APEX uses near term technology. No need to demonstrate a scientific principal (e.g. fusion).

TABLE 5

APEX IS A SAFER ECONOMICAL AND MORE PROLIFERATION RESISTANT FUEL CYCLE

- ALL FISSILE MATERIAL IS MAINTAINED IN DILUTE FORM (<4%).
- INVENTORY IS THE LOWEST OF ANY FUEL CYCLE (LESS THAN BREEDER).
- THERMAL REACTORS ARE A KNOWN TECHNOLOGY WITH AN EXCELLENT SAFETY RECORD.
- SPALLATOR TARGET IS A SUBCRITICAL REACTOR.
- SPALLATOR PRODUCES FUEL ONLY ON DEMAND - IT IS A SINGLE PURPOSE MACHINE. LAFER WHICH IS A DUAL PURPOSE MACHINE PRODUCES POWER AS WELL AS FUEL.
- THE SPALLATOR IS AN INDEPENDENT MACHINE - DECOUPLED FROM ANY POWER GRID EXCEPT FOR STARTUP; UNLIKE LAFER AND ENRICHMENT PLANT WHICH DEPEND ON THE POWER GRID.
- FISSION PRODUCT CONTAMINATION OF FISSILE MATERIAL IS ALLOWABLE IN CIVILIAN FUEL CYCLE. Pu FOR WEAPONS REQUIRES HIGH PURITY; CONTAMINATION OF Pu IS NOT ALLOWABLE RESULTING IN Pu CONTAMINATION OF FISSION PRODUCT WASTE.
- FUEL ELEMENTS IN AND OUT OF REACTOR ARE RADIOACTIVE, MAKING THEM MORE DIFFICULT TO DIVERT FOR PRODUCING WEAPONS MATERIAL - ALSO Pu IS ISOTOPICALLY CONTAMINATED MAKING IT A POOR WEAPONS GRADE MATERIAL.

It is realized that we are recommending a new approach for the nuclear industry which may take a good deal of development funds and a number of years to reach commercialization, however, it should take much less than the almost 40 years it took the U.S. to get to the present position, with the same unsolved problems of fuel and waste still facing us. Unless the nuclear industry takes a new approach and solves the problems of concern to the public, we may not have a nuclear industry to be concerned about. There is still some opportunity for the country and industry to attempt to take a path divergent from the well-known path. We may find it to be a short-cut to establishing a firmer nuclear industry. The APEX system with Spallator and Chelox appears potentially technically sound and economically viable.

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