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TITLE: ACCELERATOR-BASED CONVERSION (ABC) OF REACTOR AND WEAPONS PLUTONIUM

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ACCELERATOR-BASED CONVERSION (ABC)
OF REACTOR AND WEAPONS PLUTONIUM

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ABSTRACT

An accelerator-based conversion (ABC) system is presented that is capable of rapidly burning plutonium in a low-inventory sub-critical system. The system also returns fission power to the grid and transmutes troublesome long-lived fission products to short lived or stable products. Higher actinides are totally fissioned. The system is suited not only to controlled, rapid burning of excess weapons plutonium, but to the long range application of eliminating or drastically reducing the world total inventory of plutonium. Deployment of the system will require the successful resolution of a broad range of technical issues introduced in the paper.

INTRODUCTION

The residual plutonium from the operation of the world's nuclear reactors and from the world's nuclear weapons programs provides the substance to fashion nuclear weapons. In this paper, we describe a new technology that is capable of safely burning-up the world's plutonium, returning its energy of fission to the power grid, and ridding the world of the threat of its use in weapons. The concept, accelerator based conversion, uses an accelerator-driven subcritical system to destroy plutonium and produce power while eliminating key long-lived nuclides.

The method described also avoids waste of the material's energy. Significantly, the method provides for a final treatment of the dominant, long lived fission products and actinides in high level waste from the nuclear age. It will reduce the duration of radiation from tens of thousands of years to about 300 years and thereby offers a shorter term, more predictable management option for high-level waste.

In this paper, we mention the weapons potential of power reactor-produced plutonium, the accumulation of reactor plutonium and weapons plutonium, and the mine-back potential of various proposed methods of disposal along with environmental issues attendant to those methods. We also provide a technical overview of the ABC concept and some remarks about its safeguards, advantages, and costs.

WORLD EXCESS PLUTONIUM

The world's inventory of plutonium is increasing at a rapid rate and will require an active policy by leading nations to maintain positive control of its use or its disposal. Since weapons plutonium was prepared at high cost, it is difficult to consider it a hazardous waste or, at best, a material to be burned or permanently altered to prevent its misuse. Reactor-produced plutonium is currently increasing at around 80 MT per year. This yearly production is similar to the total amount of weapon's program material that is becoming excess in both the U.S. and the Soviet Union. Much of the world's plutonium resides in light-water reactor spent fuel pins that are planned for direct disposal in repositories such as Yucca Mountain. Several tens of tons of the plutonium will be recovered from spent fuel in the U.K., France, FSU, and Japan for use either as a mixed oxide fuel or as fuel in one of the breeder cycles. It will be largely a commodity to be recovered, packaged, stored, and possibly shipped around the world.

Table 1 shows the minimum critical mass of various plutonium isotopes and actinides. All plutonium isotopes have relatively small minimum critical masses. Any isotopic composition of plutonium from commercial nuclear reactors can function as a nuclear explosive with significant nuclear yields. This proliferation potential makes the existence of large inventories of plutonium a cause for concern.

In Figure 1, we show the present total inventory of plutonium and the rate at which it will accumulate if the number of power reactors continues unchanged. Currently, approximately 800 MT of plutonium has been generated by nuclear power reactors. At current discharge burnups this amount is increasing by 80 MT per year. At the future anticipated discharge burnup of 50,000 MWd/MTV this amount will increase by 60 MT per year. Examination of the constant nuclear power case reveals that by the year 2015 there will be nearly 2000 tons of plutonium deposited at hundreds of sites around the globe. Figure 1 also shows the reduction in inventory possible if the Accelerator-Based Conversion (ABC) system is introduced in an orderly way beginning in 2010. If ABC plants are introduced at approximately one and one-half per year until 15% of the LWR generating capacity is replaced by ABC plants, the lower curve is obtained. In the long term, ABC plants could be run on thorium to allow even further reduction in plutonium. The asymptotic part of the curve near the years 2080 to 2090 represents the small internal inventory of fissionable material present in operating LWRs and ABC plants needed to maintain operation and production of the current level of nuclear power.

The figure shows that the rate of plutonium accumulation can be decreased somewhat by using higher burnup (and possibly recycle). However, in all cases the accumulation of plutonium increases and never gets below 2000 tons.

Table 2 shows a selection of methods for disposing of excess plutonium. These options can be divided into three categories: permanent isolation, long-term storage, and destruction by fission. No one has identified a credible method for permanent, total isolation. There is significant effort underway to develop an acceptable repository for long-term storage. The major drawback to long-term storage is the need to hold the material until it has decayed. (Pu-239 has a 24,000 year halflife, so 240,000 years would be required.) The repository will be a high grade ore body where adequate concentrations of plutonium would be found. Chemical extraction might be rather easy with the right reagents. The only method that we believe provides for a complete and irreversible solution to the excess plutonium problem is its complete fission or burn-up in a nuclear system. For the reasons presented and discussed in this paper, we believe the ABC system provides the most complete and irreversible solution to the excess plutonium problem. There are four salient methods for fissioning excess plutonium. They offer various degrees of effectiveness in reducing world plutonium inventory. Light water reactors with a once-through fuel cycle are considered a baseline. They increase world plutonium inventory by 60 to 80 MT/yr. Mixed oxide fuel with multiple recycle stabilizes the world inventory at 2 to 3 times the current (800 MT) level. Fast reactor systems can also stabilize Pu inventory at 2 to 3 times the current level. Its ultimate performance is limited by the large inventory. The HTGR can be as effective in a once-through cycle as LWR's are in multiple recycle. Because of various novel features, the ABC system has the potential to limit world plutonium to a very low level.

PLUTONIUM DESTRUCTION REQUIREMENTS

The requirements for the system should be defined in advance to focus the energies of the technical community. A plutonium converter could solve a very troublesome problem if it: (1) provides proliferation resistance and renders reuse or recovery impossible, (2) transmutes key long-lived species to short-lived products, (3) is affordable and available, (4) prevents pollution in other power plants by returning energy to the grid, (5) drives and spins off technology.

TECHNICAL CHARACTERISTICS OF THE ABC SYSTEM

Figure 2 shows a schematic of the ABC system. The ABC system creates an intense neutron source through use of a proton accelerator. Its beam strikes a heavy metal target, thus generating tens of neutrons per incident proton. Material to be transmuted is located in a blanket region where source neutrons are multiplied via the fission of nuclear material. These neutrons are moderated, i.e., slowed to thermal energies, in this region to enhance their probability of nuclear reactions. Plutonium and transmutation products are introduced to the blanket region in a continuous fashion. The higher transuranic actinides and major long-lived fission product nuclides produced by burning the plutonium are recycled to the blanket and transmuted to shorter-lived or stable species. This capability substantially reduces the effective half life of the resultant waste stream.

The thermal energy released in plutonium fission is recovered from the blanket and converted to electric power using conventional conversion systems. A relatively small fraction of this power is required for the accelerator, so that a considerable fraction (>75%) of the gross electric power could be available to the grid. This design is appropriate for a system capable of burning or treating LWR spent fuel. A system aimed at destruction of weapons grade plutonium can operate with more favorable values because of its superior neutron economy. The reference design presented later in this paper addresses a two blanket system (as opposed to the 4 blanket system proposed for spent fuel transmutation) keyed to burning 50 tons of Pu in 40 years.

Two main technology avenues appear promising for viable systems that would achieve the goals of the ABC concept. One is an aqueous-based system that employs a heavy-water blanket (with some similarities to a CANDU-like system design) with aqueous-based chemical separations. The aqueous system is utilized as a reference ABC system for this discussion. The second avenue is a concept based upon components that can offer improved performance in areas such as neutron economy and overall system economics. A particularly attractive system (based upon Molten Salt Reactor and HTGR-like technology) involves use of a LiF/BeF$_2$ carrier medium (containing plutonium and other actinides in solution), contained in a graphite blanket that is cooled by helium, molten salt, or liquid lithium. Materials separations for this nonaqueous approach require further specification and development, but offer promise of being simpler than those employed in the aqueous system.

The following discussion summarizes each main component area of ABC. Later sections provide a technology status description and describe an effort aimed at development, demonstration, and construction of an ABC system. More technical detail is provided in Reference 3.

The reference aqueous ABC system would use a high-power, radio-frequency (rf), continuous-beam, linear accelerator (linac) that generates an 800-MeV proton beam with an average current around 190 mA. This beam is accelerated by a series of different structures containing microwave RF fields, with each structure optimized for high efficiency over its appropriate velocity range. The configuration consists of a 700-MHz coupled-cavity linac (CCL) injected at 20 MeV by a funneled beam launcher containing two 100-keV injectors each made up of an ion source, a radio frequency quadruple linac, and a drift tube linac. (Reference 1 describes accelerator components and requirements.) Many of these components have been developed and tested individually under the Strategic Defense Initiative program. The CCL then makes up most of the accelerator. The accelerator front end is optimized to prepare a high-current, low-emittance, well-controlled beam. The CCL parameters are chosen to assure low beam loss while maintaining a high conversion of rf power to beam power. This allows for "hands-on" maintenance. The overall accelerator concept has been reviewed by a DOE Energy Research Advisory Board panel as well as a JASON panel, both of which evaluated it as technically sound with no physics "showstoppers." Design of an accelerator with similar beam power and performance features is currently being designed under another DOE effort. Figure 3 illustrates such an accelerator and its principal components.

In the ABC system, the proton target serves as the mechanism for converting the beam energy into a neutron source via spallation processes. The proton beam is slowed and stopped as it interacts with the target whose composition is primarily a heavy metal (tungsten, lead, and uranium are possible target materials). In the process, tens of neutrons per proton (depending upon beam energy, target material, and geometry) are produced. Target design and performance requirements are determined by several factors. One is the requirement for compactness dictated by the need for high-source intensity per unit volume; this translates to a design requirement for high-power density. A second factor is a requirement for low neutron absorption. Another smaller, but still important, requirement is minimal long-lived radioactive spallation product generation. Finally, the target design must allow for adequate heat removal, both when the beam is on as well as during after-heat conditions. The reference ABC concept would employ a solid target[2] based upon direct experience from facilities at Los Alamos and Rutherford, England. It consists of a tungsten inner region surrounded by a lead multiplying region. Heavy water is used as a coolant for the inner tungsten region which is exposed to beam power on the order of 150 MW. Neutron yields are 18 neutrons/proton at a beam energy of 800 MeV. A nonaqueous system would use a flowing liquid metal such as lead as the spallation target.[3] Liquid lead possesses a good neutron yield, low neutron absorption, and serves as the heat transfer fluid. Flowing lead systems have been investigated at prototype scales in Germany and Canada. Neutron yields from such systems are expected to approach 25 neutrons/proton for an 800-MeV beam.

Liquid metal target concepts are also under development that use liquid lithium as a primary source of high-energy neutrons. These neutrons are multiplied in a uranium region surrounding the lithium core. This concept allows high neutron production efficiencies with a decrease in long-lived radioactive nuclide production compared to the base case.

The blanket component of the ABC system surrounds the spallation target and contains the materials (plutonium, higher actinides, long-lived fission products) to be transmuted. The blanket moderates the system's neutrons and slows them down to thermal energies where probabilities for fission and capture are substantially increased. The system is subcritical, operating at multiplications of 10 to 20. Reaction rates are controlled by the accelerator. Because of the intense primary neutron source coupled with the blanket's high multiplication, degree of moderation, and low neutron absorption, high-thermal neutron fluxes (up to 5×10^{15} n/cm^2/s) can be produced in the system. Since thermal-energy transmutation cross sections of transuranics and fission products are large, the high-thermal flux allows large reaction rates at low material inventories.

The reference concept would use a heavy-water blanket[2] made up of double-tube structures that contain a flowing actinide-oxide dilute slurry (suspension). The suspension would be recirculated in the blanket for a period of time until a desired burnup is achieved. A low volume slipstream would be routed to separation steps (described in the next section) for actinide and fission product recovery followed by its reintroduction into the transmutation blanket. Aqueous carriers interface well with established chemical separations technologies. As a baseline, the slurry would be transported through an external heat exchanger for heat removal. Methods for in-core heat removal from this aqueous slurry are also under investigation. Fission products would be introduced into different portions in the blanket where transmutation rates can be maximized and overall system leakage would be minimized. Figure 4 illustrates an aqueous blanket coupled with a solid neutron target.

A nonaqueous ABC approach would utilize a graphite blanket[4] containing a fluoride-based molten salt in which actinides are dissolved at less than a few weight percent. This blanket would be maintained in a pool of molten salt. Heat removal is achieved by flow of the molten salt out of the blanket region into external heat exchangers also situated in the molten salt pool. Figure 5 illustrates this blanket concept. A small slipstream would be extracted and used to purify the molten salt carrier, extract actinides and return them to the blanket, as well as to separate fission products created during actinide burn. Key long-lived fission products would be further separated and recirculated in the blanket for transmutation to stable or short-lived products.

High neutron utilization efficiency is achieved by using a self-contained, small-capacity chemical processing facility to maintain appropriate fuel loading while removing by-products that may further transmute to unwanted species. Figure 6 provides a schematic of the separations and waste management/disposal components. Processing system requirements include operation at high-decontamination factors necessary to meet Class C or better low-level waste disposal requirements as well as minimized waste stream volumes. The reference aqueous system would employ two technologies for actinide separations[5] -- one involves plutonium-neptunium recovery using liquid ion exchange techniques, and the second which uses a solvent-extraction, reverse TALSPEAK process for americium-curium-lanthanide recovery. Extraction of long-lived fission products of interest (technetium, iodine, palladium,...) also occurs in this loop. After technetium and iodine are introduced into the blanket, further steps are used to separate out their transmutation by-products. Separation of ruthenium from technetium is achieved through an ozonolysis process[6] which appears capable of achieving separation factors of 10^5 or greater. Separation of xenon from iodine would rely on extraction of this gaseous product from solid iodine.[7] Separations of other long-lived products from their transmutation residues have not been defined. Separations for the nonaqueous system are less well developed than for the aqueous reference case. Possible separations could include use of techniques developed in the ORNL MSRE or could be based upon physical methods such as fractional crystallization and centrifugation.[8]

REFERENCE DESIGN FOR WEAPONS PLUTONIUM BURNING

For concreteness, a reference design has been chosen with rather extensive calculation of performance and properties. The material balance and power balance are shown in Table 3. The design features a single 800-MeV, 190-mA accelerator that drives two identical blanket assemblies. The system burns 50 tons of plutonium in 40 years. In the system, an additional ~100 kg of higher actinides and ~40 kg of long-lived fission products, ^{99}Tc, ^{129}I, and ^{135}Cs, are produced and burned annually. The power balance for the plutonium burner is also summarized in Table 3. The powers shown are peak nominal values. A capacity factor of 0.75 was assumed. The system incorporates a blanket neutron multiplication of 20 (although some designs do better), a thermal conversion efficiency of 32%, and an accelerator efficiency of 45%. The blanket system inventories were determined under conditions of equilibrium operation, a state which is approached rapidly (within 5 to 10 years) in the ABC system.

The plutonium feed rate balances the burn rate. Processing recovers plutonium and all higher actinides as well as selected fission products and repeatedly recycles them to the blanket until they are burned. It also removes the waste products from the blanket and reduces extraneous neutron capture.

New Operating Regime

In Table 3 we show that the in-blanket inventory of target material is greatly reduced in the ABC system compared to fast-neutron spectrum concepts by the fact that the rate per concentration is the product of the cross section times the neutron flux. Since flux level for the ABC system is increased and the cross section is maximized by thermalization, the concentration of blanket inventories can be reduced. This characteristic of high burnrate and low system inventory is an important feature of ABC that distinguishes it from other concepts. This feature impacts the ABC operation as well as the ultimate performance levels[9] illustrated in Table 3. Another change in operational characteristics is that the liquid carrier can be rapidly drained to a reservoir designed for cooling and protection in case of an emergency. Emergencies are also alleviated by low inventory of fuel and the fact that the fission products are continuously removed.

ABC PROVIDES FINAL AND INTERMEDIATE PROLIFERATION RESISTANCE

The system would accomplish the complete conversion of an easily utilized weapons material into a form that cannot be used as a nuclear explosive under any circumstances. Neutron interactions of other fissioning options leads to partial material conversion or dilution that can produce a product that is more difficult to misuse or which may not lend itself to efficient nuclear explosive designs; however, low-yield, high-consequence applications are still possible. Incomplete plutonium transmutation yielding, either fission-product or isotopic denaturing, or dilution does not provide the goal of conversion to a form that, under any circumstances, is not usable as a nuclear explosive. Only full transmutation of plutonium, as offered by the ABC system, meets the desired goal of full conversion.

In contrast to systems that simply dilute weapons grade plutonium, the ABC system would achieve complete burnup in a system that minimizes external handling of plutonium in any form, and produces wastes having only trace amounts of plutonium. The absence of fertile material in the system means that additional plutonium is not produced during operation. Plutonium is introduced into the system in an oxide or fluoride form and no external fuel fabrication is required. In order to achieve the high-plutonium burnup rates that are the goals of ABC, the plutonium/waste actinide mix produced during exposure in the high-neutron flux must be recycled back into the system's blanket. This is achieved via a separations step that is completely self-contained and integral to the system, which involves small amounts of material. Separations involving this material would be done remotely because of high-radiation levels involved. This material "lump" would contain plutonium mixed with a number of higher actinides and fission products which adds to its proliferation resistance during cooling.

Operational features of the ABC system also contribute to its proliferation resistance. In the ABC system, high burnup rates (on the order of 1 to 2 metric tonnes per year) are achieved using small inventories within the system. This small-inventory feature avoids situations where large amounts of plutonium-containing fuel components complicate safeguards and materials accountability procedures. Coupling advanced analytical chemical methods with ABC's small material inventories means that plutonium in all parts of the system can be tracked with high precision. Under such circumstances, capabilities for detection of material diversion should be improved substantially over systems where much larger amounts (tens of tonnes) of plutonium-containing material must be monitored.

The ABC system minimizes required transportation associated with plutonium conversion and thereby reduces opportunities for potential material diversion. A key design goal for an ABC system is elimination of any discharge stream (particularly ones containing plutonium) that would require management off the facility site. Fission in the ABC system would convert weapons-grade plutonium completely into fission products and higher actinides. The long-lived portion would be recycled into the system, burned, and the residue would be disposed of on-site. The majority of the fission products produced during plutonium conversion which are short-lived or stable would be stored and allowed to cool in engineered facilities until low levels of activity are reached. These operations could be site-contained and would not involve handling of materials attractive from a proliferation perspective.

Technology transfer should not be a major issue for the ABC system. Because of its higher level of technology sophistication and distinctive accelerator "footprint," the ABC concept is not as attractive as a reactor for clandestine production of fissile material. In addition, the low inventories in an ABC system and the absence of out-shipping of fissile materials makes the ABC system less vulnerable to diversion of those materials by either the owner or by non-owners.

In summary of proliferation resistance characteristics, the ABC system for conversion of 50 tons would require a system operating for a period of forty years. This mode of operation eliminates distribution of plutonium-containing material to multiple sites that convert plutonium in low "enrichment" environments. Plutonium could be introduced into the ABC system in one of several forms not requiring fuel fabrication. It would be burned completely using facilities that are completely site-contained. Separations would involve relatively small capacity systems. No discharge streams would leave the conversion site.

DEVELOPMENT, DEMONSTRATION, AND CONSTRUCTION EFFORT

The concept being put forward converts all plutonium, not just weapons plutonium, and therefore provides a policy alternative to long-term storage and disposal. The physical principles involved in the ABC concept are well established. The accelerator-driven burning of plutonium at high reaction rates and low inventories in a continuously processed blanket requires no new physics. The uniqueness of the ABC concept lies in the integrated performance of the accelerator, target/blanket, and processing system. These subsystems require further engineering development and the integrated system performance must be demonstrated. Under aggressive technology pursuit conditions, a three-phase effort can accomplish these tasks as well as complete construction of a plant facility in less than fifteen years. Figure 7 illustrates estimated timelines for design, demonstration, and construction under assumptions of aggressive technical development and funding.

The timelines associated with disposition of surplus plutonium should allow time for ABC development and demonstration as well as facility construction and licensing. A decade-like timeframe is also needed to retire surplus weapons, remove pit plutonium, and store it in secure facilities. Under the development plan outlined above, an ABC facility could be available for plutonium disposition in the 2007 to 2010 timeframe.

ABC COST ESTIMATES

Thus far our preliminary estimates of ABC system costs (capital and operating) indicate that they may not be largely different from other fission systems of similar capacity. Within the ABC system there are additional capital costs associated with the accelerator, the relatively small-scale materials separations subsystem, and facilities for long-term materials cooling and low-level waste disposal. These costs are partially offset by the absence of a fuel fabrication plant requirement. Additional cost requirements are introduced by possible on-site disposal and engineered storage. However, other nuclear options require long-term storage, the costs of which continue to increase. The impact and dollar value of having wastes with shorter effective half life and management times that could result from ABC are difficult to estimate and quantify. For initial systems designed more specifically for weapons plutonium burning, a smaller accelerator than our base case example may suffice because there will not be a backlog of fission products to process and transmute, as is the case for spent fuel burning.

REGULATORY ISSUES ASSOCIATED WITH ABC

The goals of ABC system operation involve plutonium disposition under conditions where only transportation of plutonium into the ABC site is required -- waste material discharge could be managed on-site. Feed plutonium shipment could be approached from two perspectives. For example, an ABC system could be built contiguous to the secured storage site so after initial receipt of materials, no other transportation would be required. Conversion of pit plutonium into oxide or fluoride forms required by ABC would occur on-site and would be subject to DOE and other environmental, safety, and health regulations associated with plutonium handling and processing or to similar regulations imposed by foreign governments for operation in other nations. Alternatively, plutonium metal could be shipped from an off-site storage facility to the ABC site where processing into the required chemical compound form would occur. Again such processes would be subject to DOE, IAEA or other governmental regulations for materials handling as well as applicable Department of Transportation regulations concerning material shipment.

Locating an ABC system on a governmental reservation will require that the system be subject to the regulatory requirements associated with siting and operation of current nuclear power plants. Additional regulatory requirements will be introduced by the chemical processing and on-site disposal and storage components associated with ABC. However, the ABC system possesses several features that could be attractive in terms of overall system safety enhancement and which could positively impact its regulatory environment. They are the following. (1) The accelerator-driven nuclear system operates below criticality and has rapid system response times (accelerator response times are on the order of 10 microseconds). (2) The liquid fuel system allows the fuel to be drained automatically in the event of an accident to containment where the passive capabilities necessary for dealing with after heat can be readily optimized. (3) The continuous removal of fission products results in a lower inventory in the power generation region than that of existing reactors. Specifically, fission products are removed continuously as compared with reactors where they may build up for periods on the order of three years. (4) No actinides are discharged from the fuel system.

SUMMARY

The described ABC system provides complete elimination of weapons plutonium and if deployed on a global scale it will result in an adequate draw-down of total world plutonium. It reaches this goal with a minimum of radioactive material transporation and with easier material tracking since only one ABC system is required to convert 50 tons of excess weapons plutonium. We believe that the subcritical assemblies and other novel features open the way to improved nuclear safety and that the development of these beam controlled systems will lead to valuable technology spinoffs along the way.

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Table 1. Fissile Nuclide Properties

Materials	Critical Mass kg	Heat Production w/kg
^{235}U	47.9	nil
^{237}Np	58.5	nil
^{238}Pu	10.2	556.7
^{239}Pu	10.4	1.9
^{240}Pu	36.9	6.9
^{241}Pu	12.8	13ß
^{242}Pu	79.6	0.1

Table 2. Potential Methods for Disposing of Excess Plutonium

Disposition Option	Method	Comments
Permanent isolation	Rocket into the sun	Unacceptable risk of accidents.
	Dilute and spread in the oceans	Counter to current environmental perspectives.
Long-term storage	Store in a geologic repository	On the order of 240,000 years of storage required for material decay.
	Denature and vitrify	Cannot "denature" plutonium; however, can vitrify with other materials and store.
Plutonium Fission	MOX fuel burn	Can reduce mass by up to 75%. Expensive to convert and requires increased safeguards.
	ABC	Essentially complete conversion of plutonium and dominant long-lived fission products. Technology demonstration and cost evaluation required.

Table 3. ABC Reference Design for Weapons Plutonium

Power Balance	
System Thermal Power (MW_{th})	4260
Thermal Power Per Blanket (MW_{th})	2130 (each)
Gross System Electric Power (MW_e)	1365
Accelerator Beam Power (MW)	146
Thermal Power Per Target (MW_{th})	73 (each)
Accelerator Power Requirement (MW_e)	325
Net System Electric Power (MW_e)	1040
Material Balance	
Pu Burn Rate (kg/yr)	1250
Pu Fission Rate (kg/yr)	1152
Higher Actinide Fission Rate (kg/yr)	98
Fission Product Burn Rate (kg/yr)	39
Fission Product to Waste (kg/yr)	1211
Other Parameters	
Blanket Neutron Flux (Average)	5×10^{15} n/cm^{2}s
Per Blanket Pu Inventory	80 kg
Per Blanket Inventory of Higher Actinides	150 kg
Total System Actinide Inventory (blanket heat exchangers, processing plant)	~500 kg

Figure 1. World Plutonium Inventory
(Constant Nuclear Power Demand)

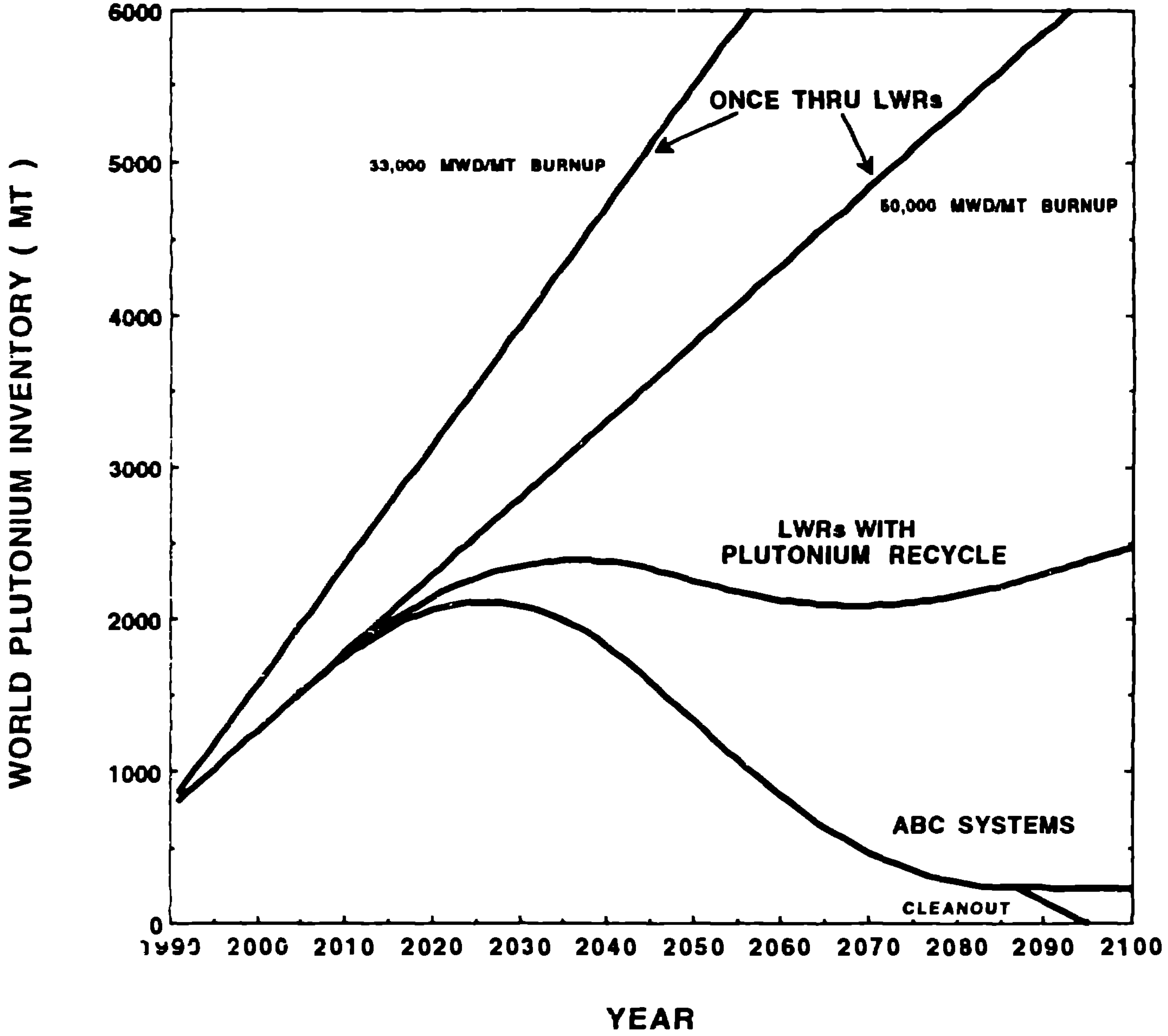


Figure 1. General Features
ABC System

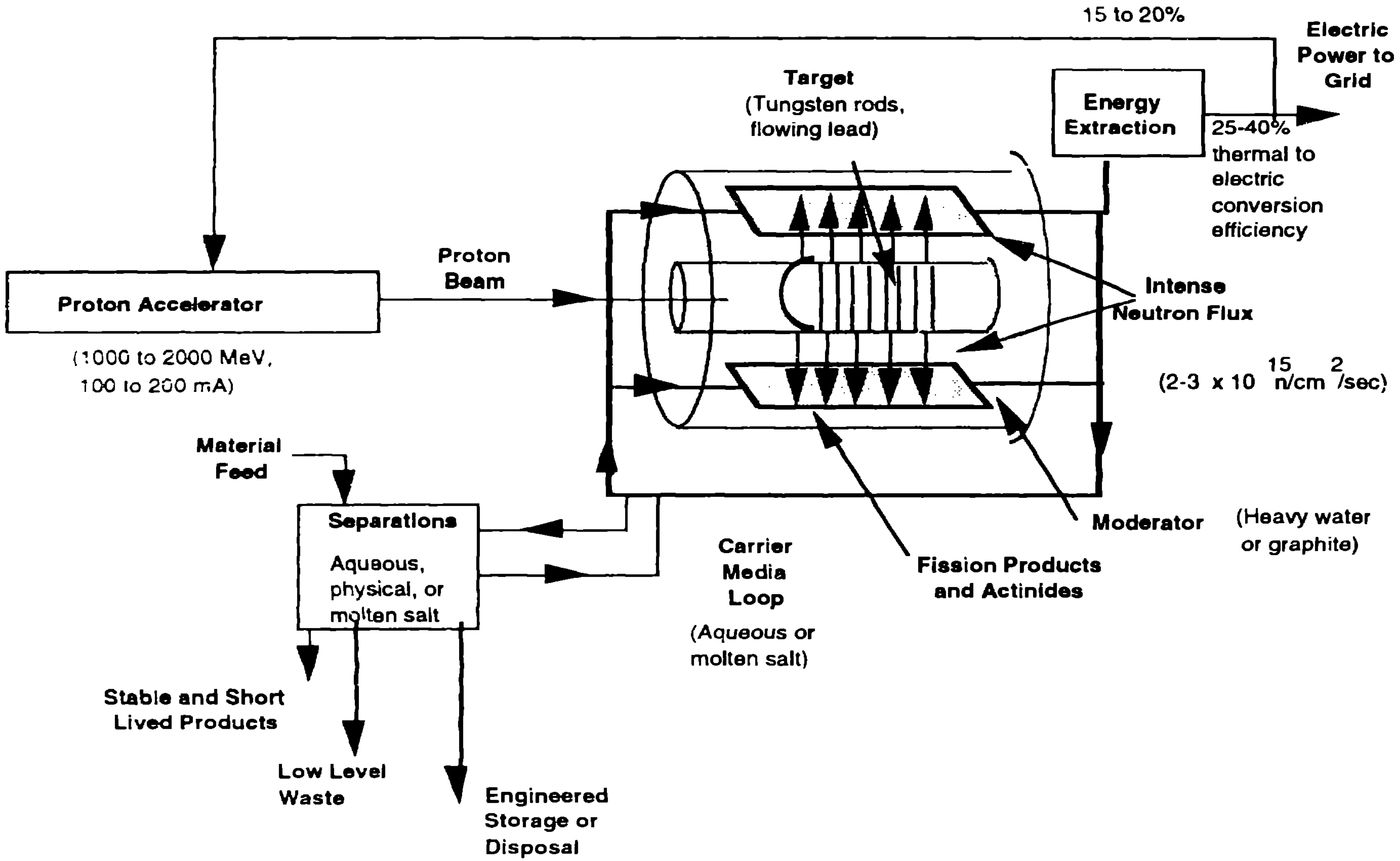
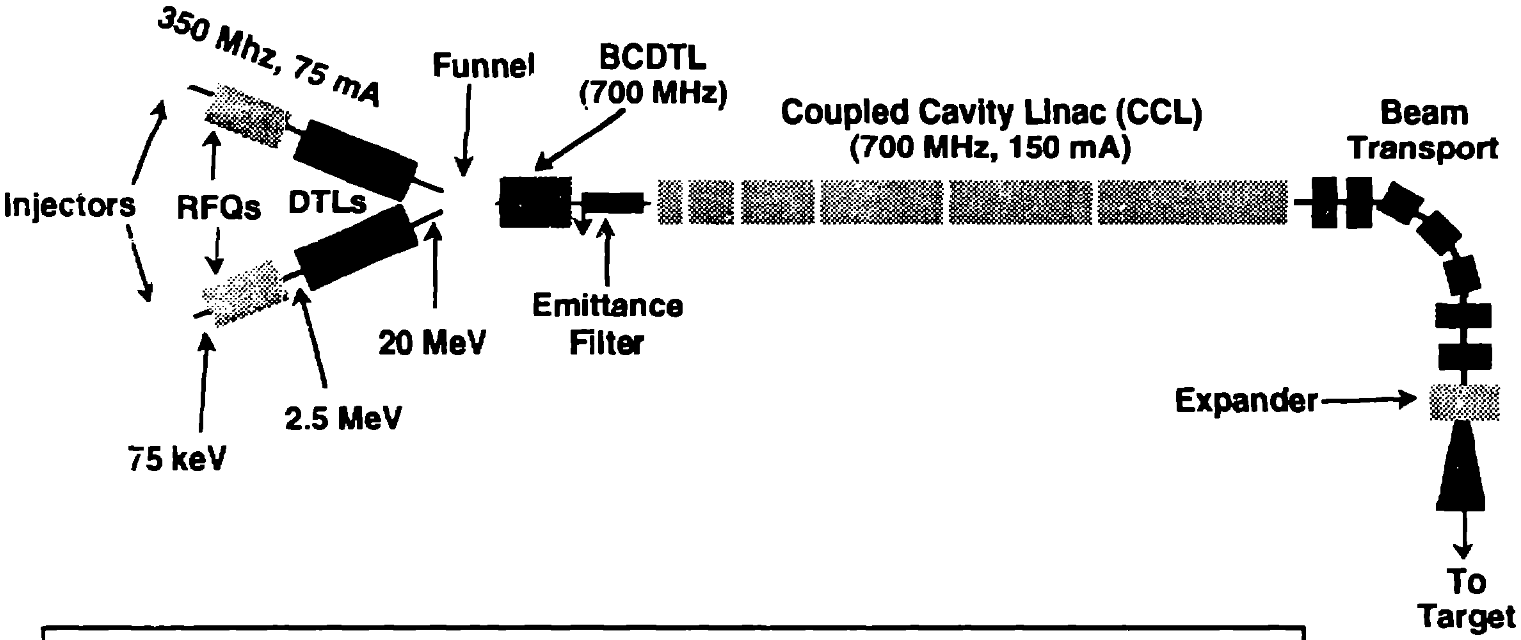


Figure 3. ABC Accelerator



Beam Energy (Typ)	800 MeV
Beam Current	~ 200 mA
Beam Power	~ 160 MW
Power Required	~ 350 MW

Figure 4. Aqueous-Based ATW/ABC Target-Blanket Concept

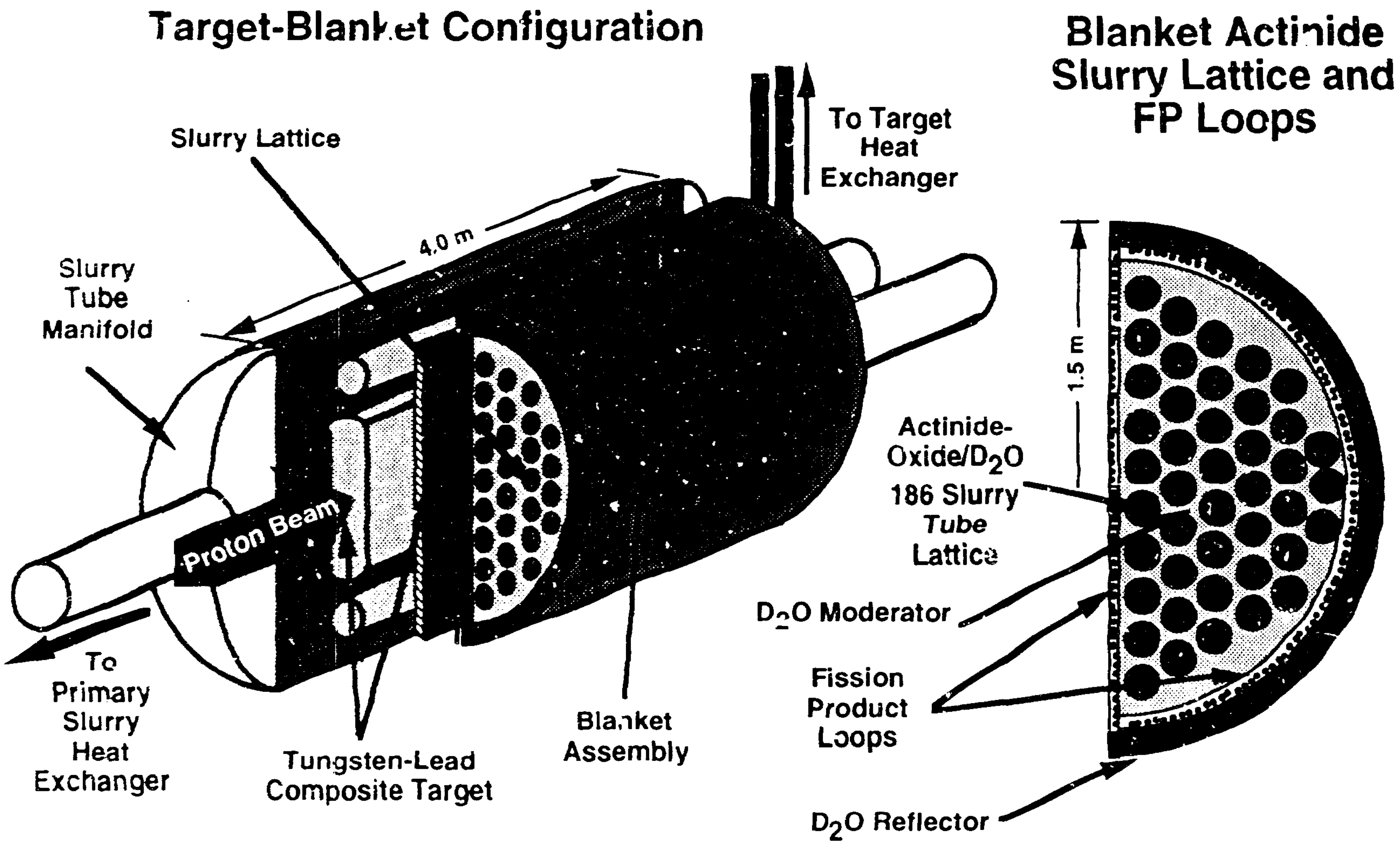


Figure 3. Schematic Layout of the Non-Aqueous Target/Blanket Assembly

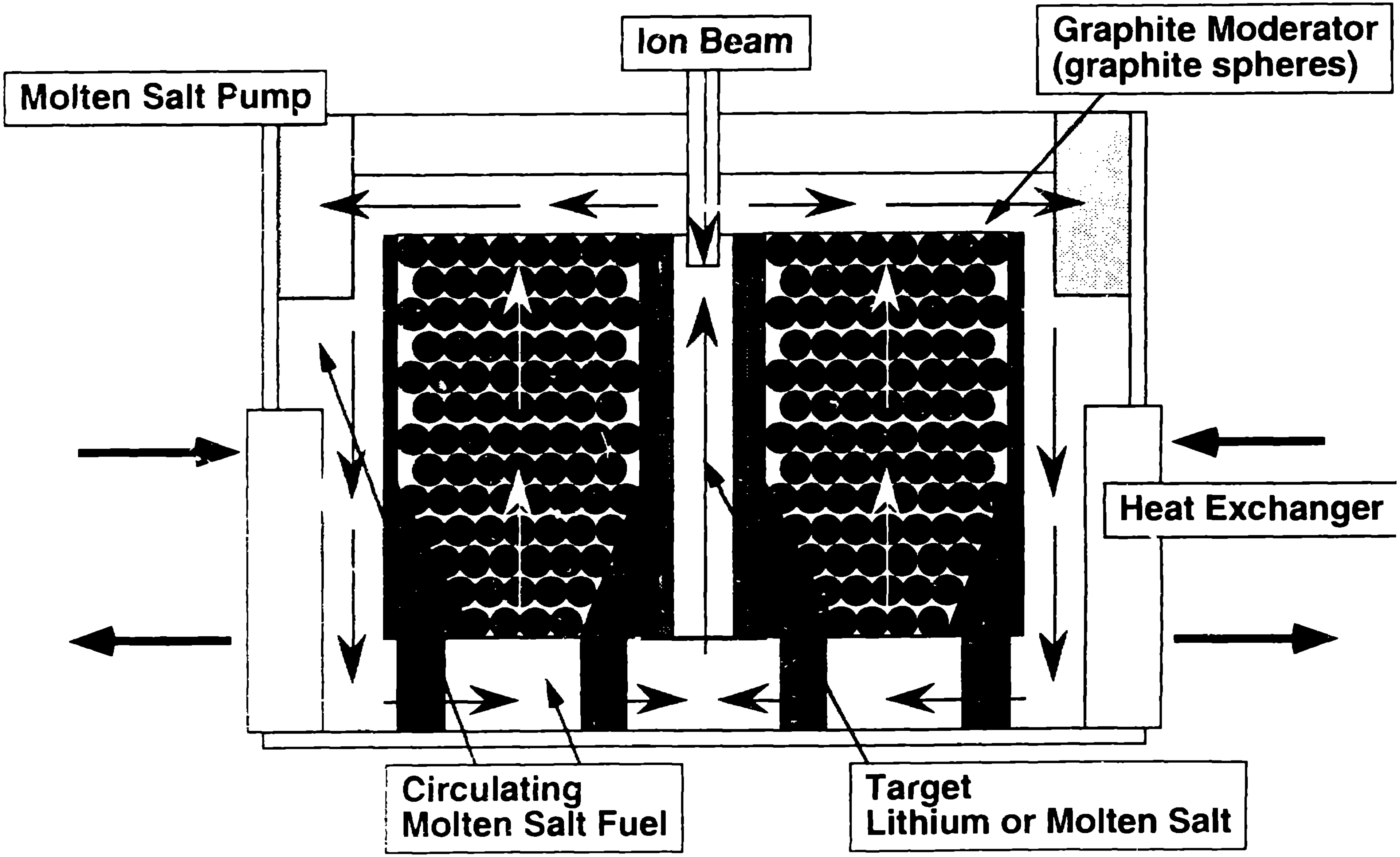
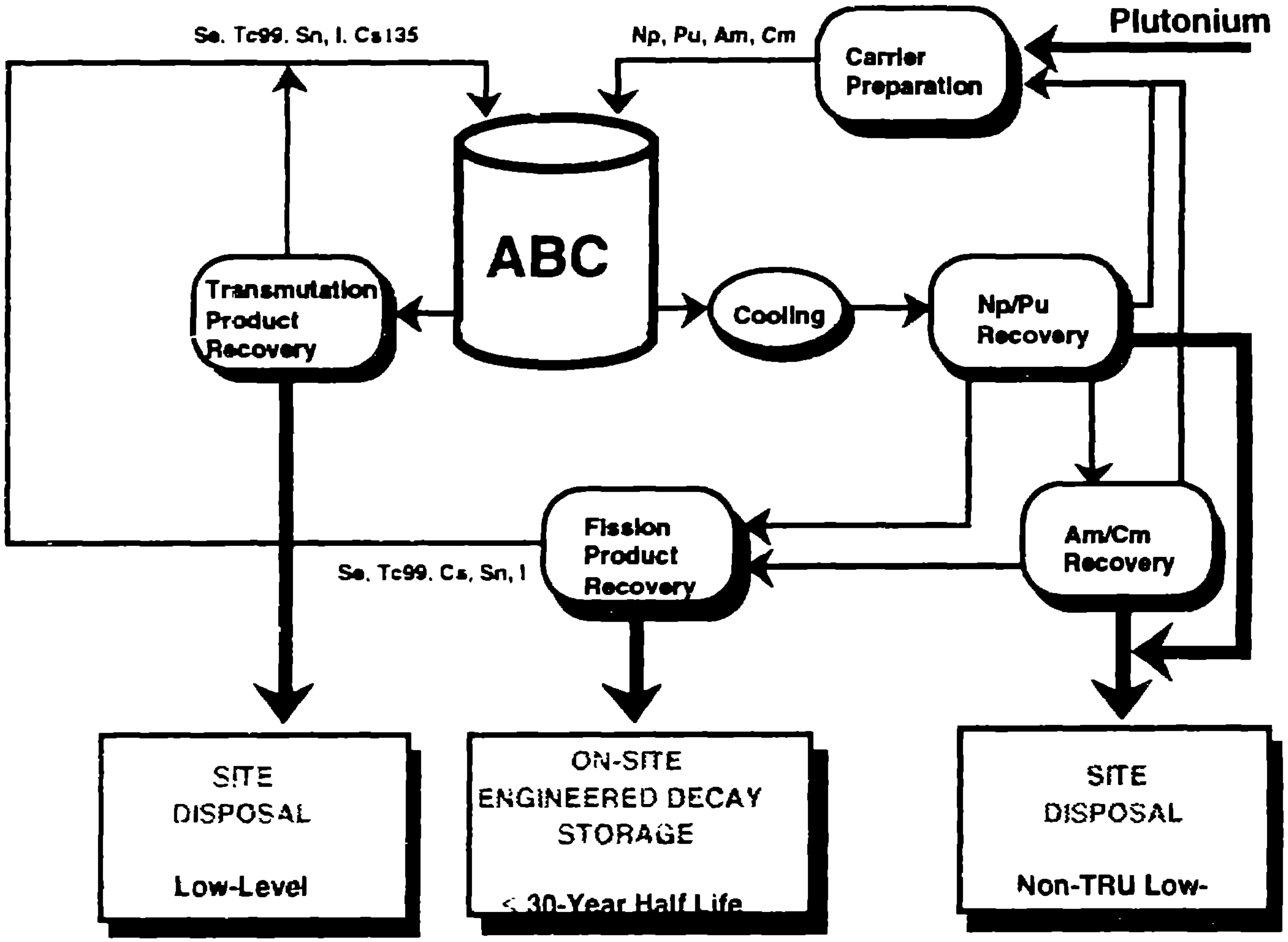


Figure 6. ABC Chemical Processing and Waste Management



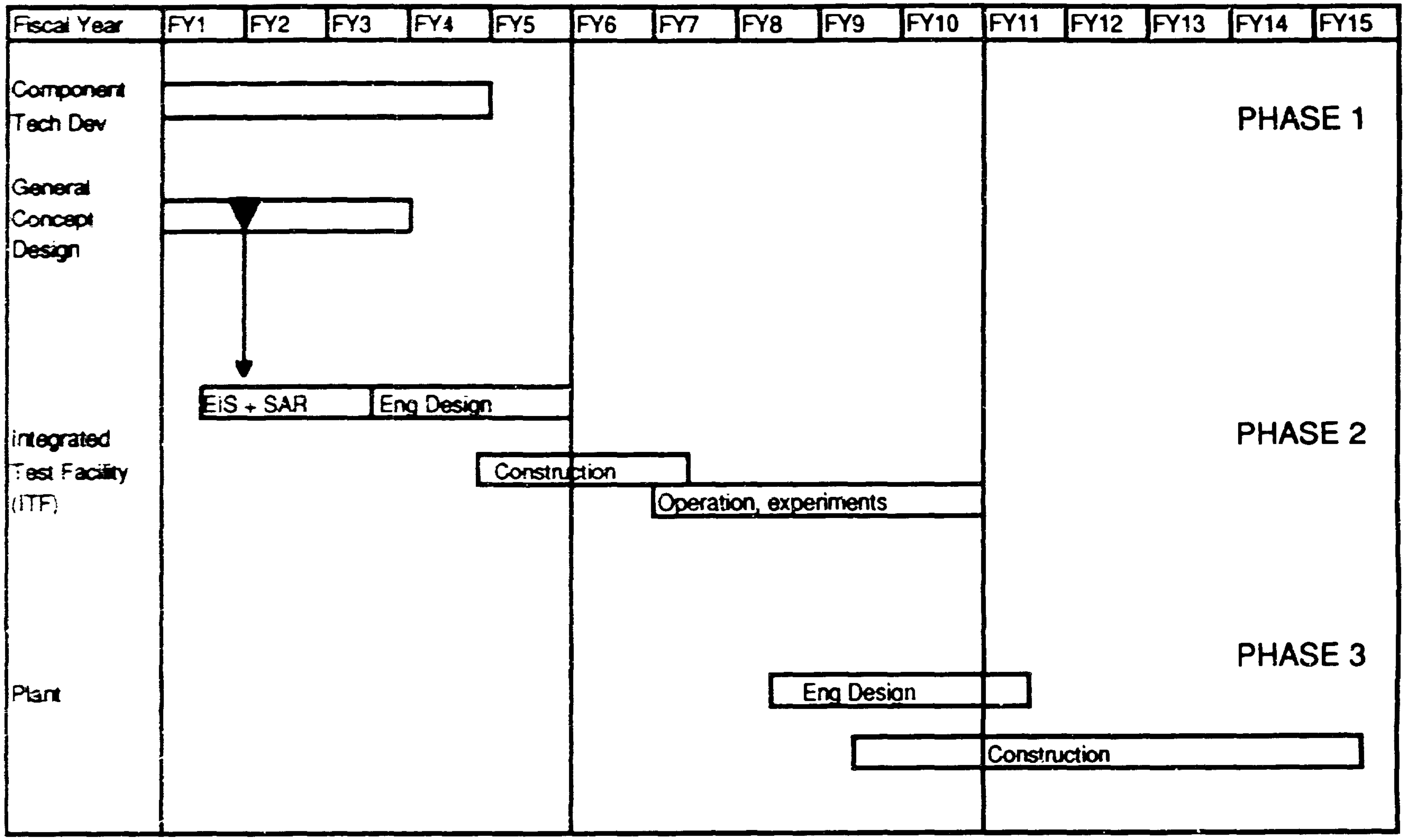


Figure 7 - ABC Development Plan

Accelerator Based Conversion (ABC) is a novel concept for burning waste and excess plutonium, returning its energy to the power grid and leaving very little long-lived radioactive legacy.

Figure 1

Reactor-Grade Plutonium Will Give Nuclear Explosive Yield

The original implosion assembly system used in the Trinity test in 1945 was capable of obtaining 20 kilotons from weapons-grade plutonium. ....it may be seen that such an assembly system would be capable of bringing reactor-grade plutonium of any degree of burn-up to a state in which it could provide yields in the multi-kiloton range.

J. Carson Mark*

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* *NPT at the Crossroads*, Nuclear Control Institute, August 1990

Fissile Nuclide Properties

Materials	Critical Mass kg	Heat Production w/kg
^{235}U	47.9	nil
^{237}Np	58.5	nil
^{238}Pu	10.2	556.7
^{239}Pu	10.4	1.9
^{240}Pu	36.9	6.9
^{241}Pu	12.8	13B
^{242}Pu	79.6	0.1

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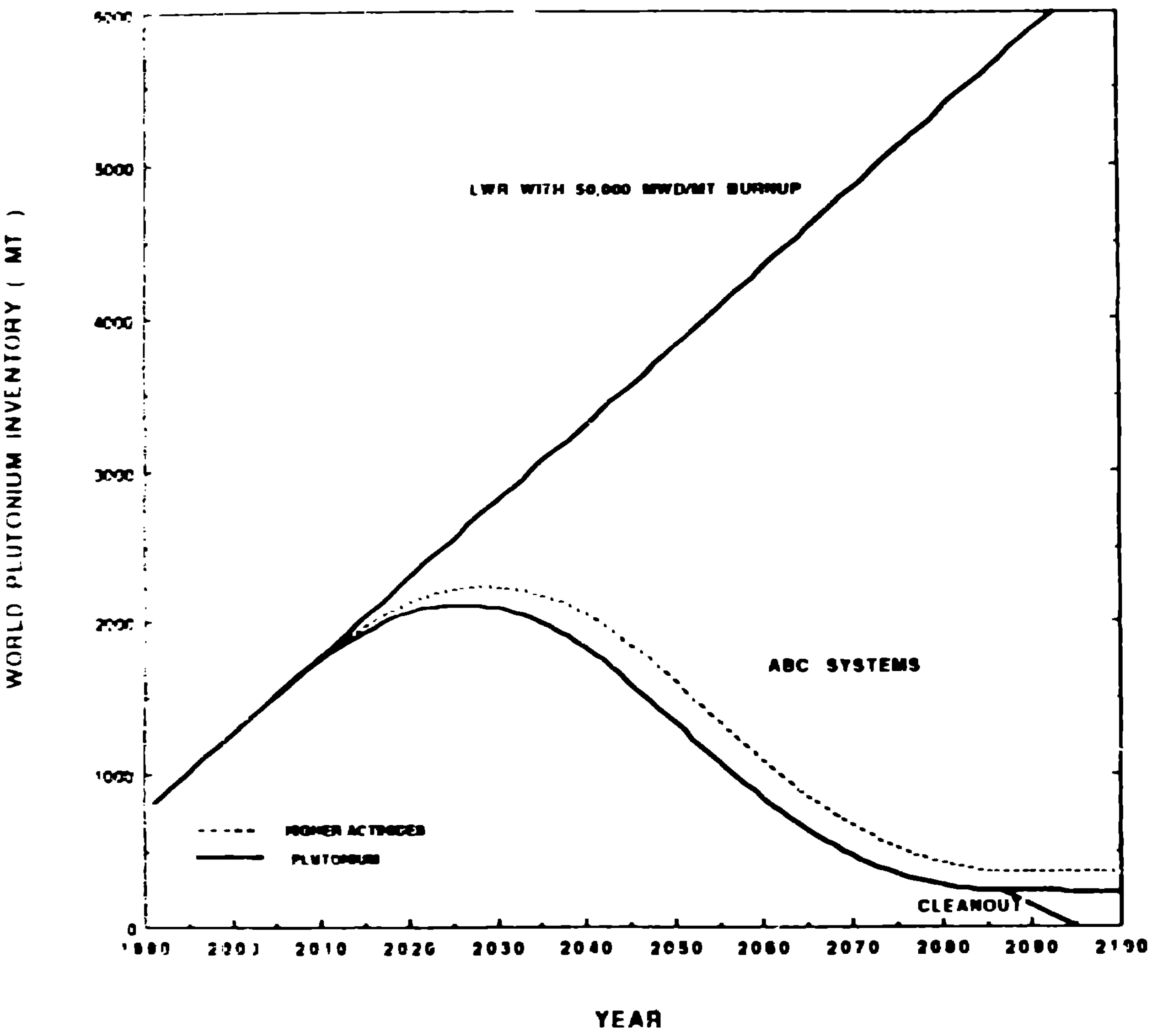
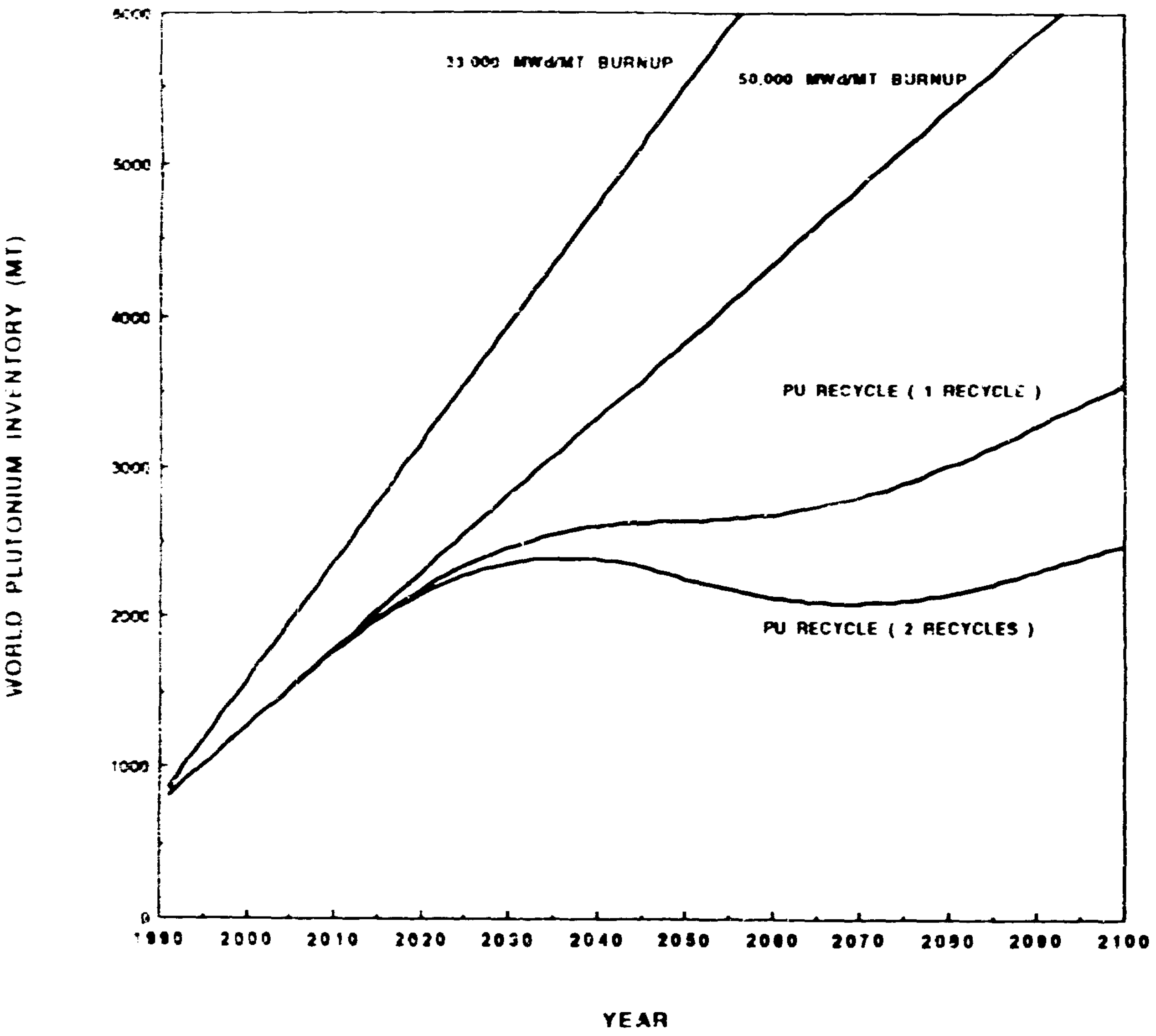
Figure 2

WORLD PLUTONIUM INVENTORY WITH ABC UNITS
(CONSTANT NUCLEAR POWER DEMAND)



WORLD PLUTONIUM INVENTORY



Potential Methods for Disposing of Excess Plutonium

Disposition Option	Method	Comments
Permanent isolation	Rocket into the sun	Unacceptable risk of accidents.
	Dilute and spread in the oceans	Counter to current environmental perspectives.
Long-term storage	Store in a geologic repository	On the order of 240,000 years of storage required for material decay.
	Denature and vitrify	Cannot "denature" plutonium; however, can vitrify with other materials and store.
Plutonium Fission	MOX fuel burn	Can reduce mass by up to 75%. Expensive to convert and requires increased safeguards.
	ABC	Essentially complete conversion of plutonium and dominant long-lived fission products. Technology demonstration and cost evaluation required.

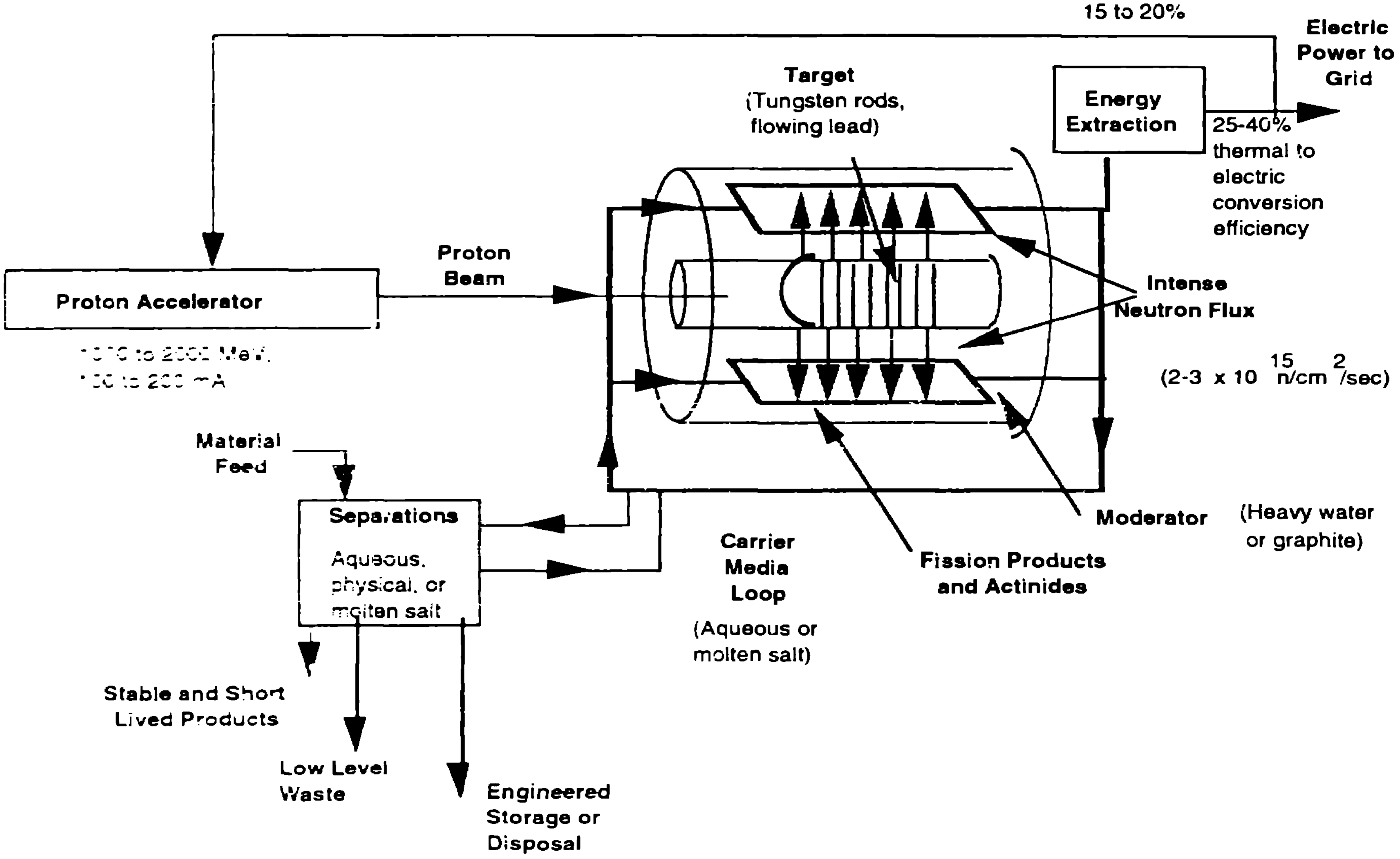
Figure 5

Methods for Fissioning Excess Pu

Fission Method	In-Core Inventory	Effect on World Plutonium Inventory	Comments
Once Thru LWRs	500 Kg	Increases Pu inventory by 80 MT/year	Current world situation is 325 GWe of nuclear power mostly composed of once thru LWRs
LWR (MOX Recycle)	1 MT	Multiple recycles stabilizes world Pu at approximately 2-3 times current level.	Involves reprocessing and proliferation issues
IFR (Fast Reactor)	10 MT	Can stabilize world Pu inventory at approximately 3 times current level	New generation of technology. Requires chemistry still under development.
HTGR	1 MT	Once thru system is as effective as multiple recycle in LWRs	New generation of technology. Has positive safety features.
ABC	500 Kg	Reduces world Pu inventory to as low as desired levels.	New generation of technology. Has potential to significantly change long term waste disposal problem.

Figure 6

General Features
ABC System



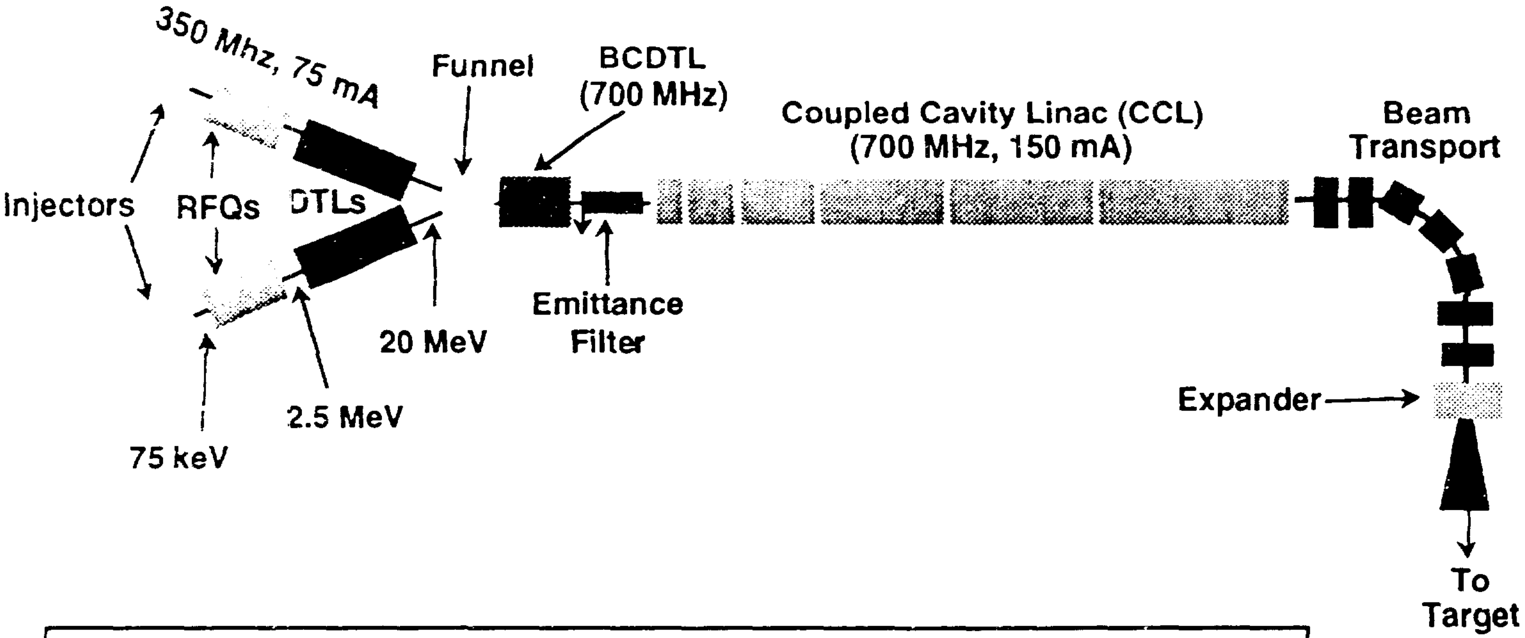
Issues and Requirements

A plutonium converter could solve a very troublesome problem if it:

1. Provides proliferation resistance and renders reuse or recovery impossible.
2. Transmutes key long-lived species to short-lived products.
3. Is affordable and available.
4. Prevents pollution in other power plants by returning energy to the grid.
5. Drives and spins off technology.

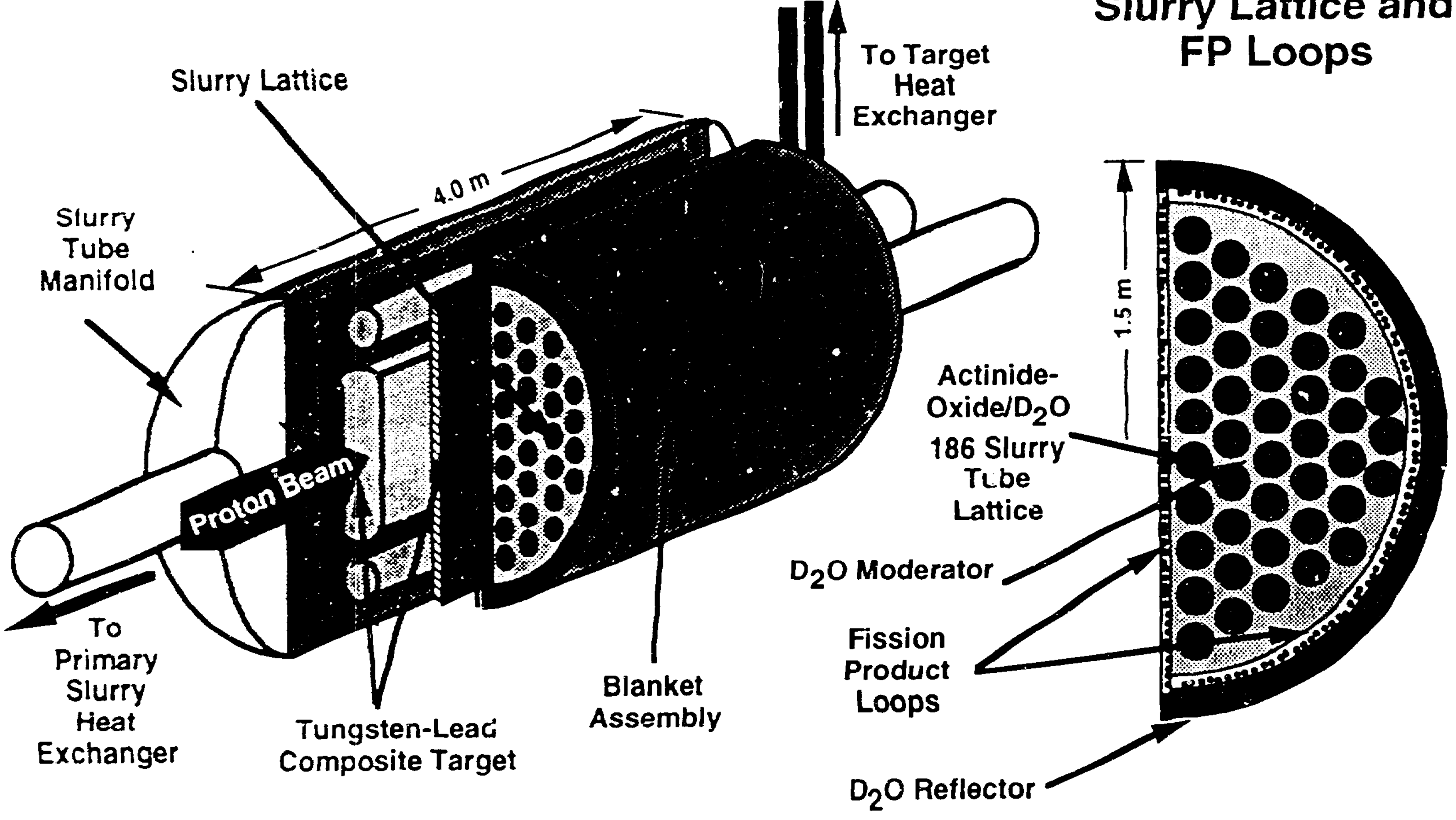
Figure 7

ABC Accelerator



Beam Energy (Typ)	800 MeV
Beam Current	~ 200 mA
Beam Power	~ 160 MW
Power Required	~ 350 MW

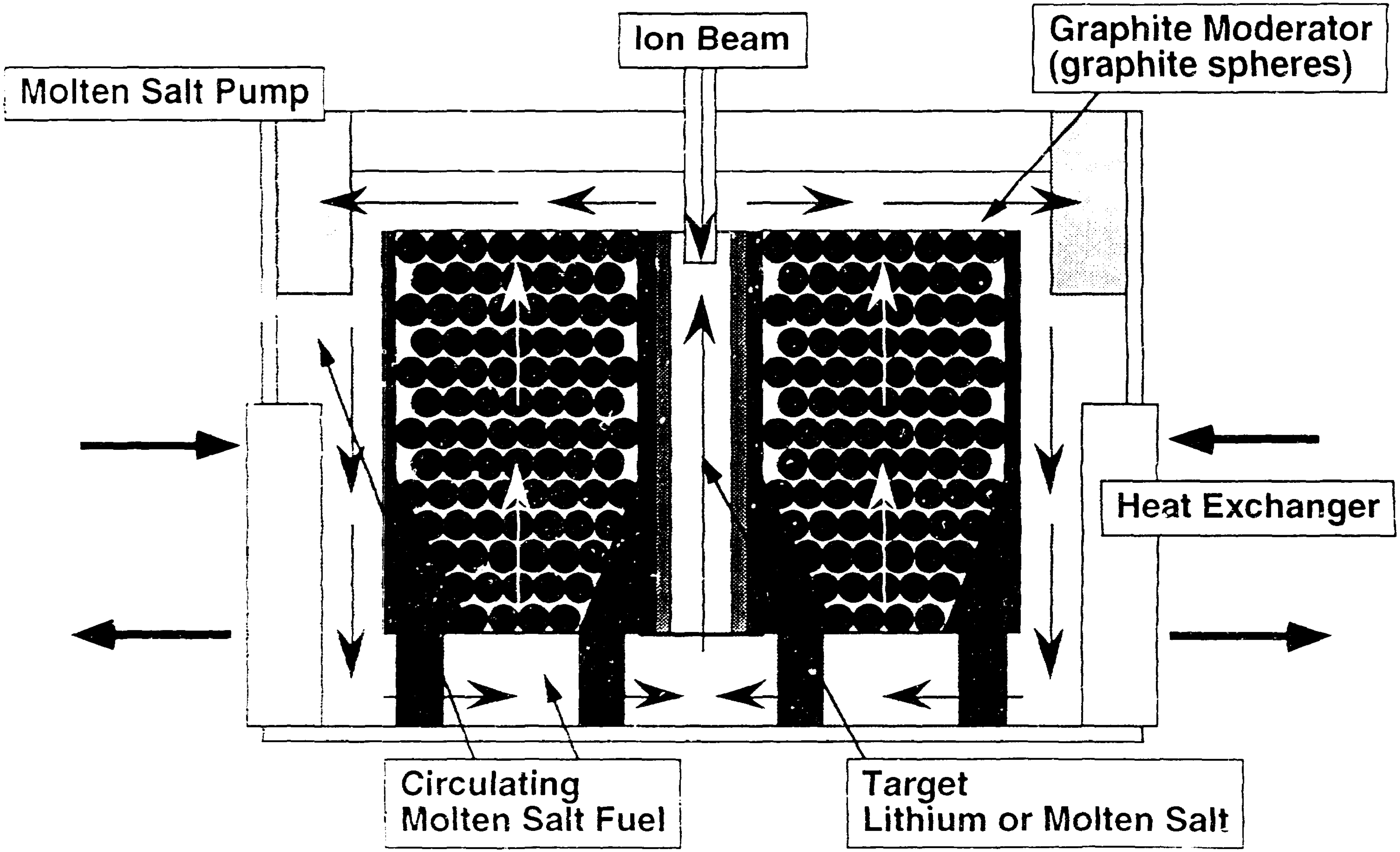
AQUEOUS-BASED ATW /ABC TARGET-BLANKET CONCEPT



Target-Blanket Configuration

Blanket Actinide Slurry Lattice and FP Loops

Schematic layout of the non-aqueous target/blanket assembly



Chemical Separations Enable The Complete Burn-Up of Plutonium and Long-Lived Rad Waste

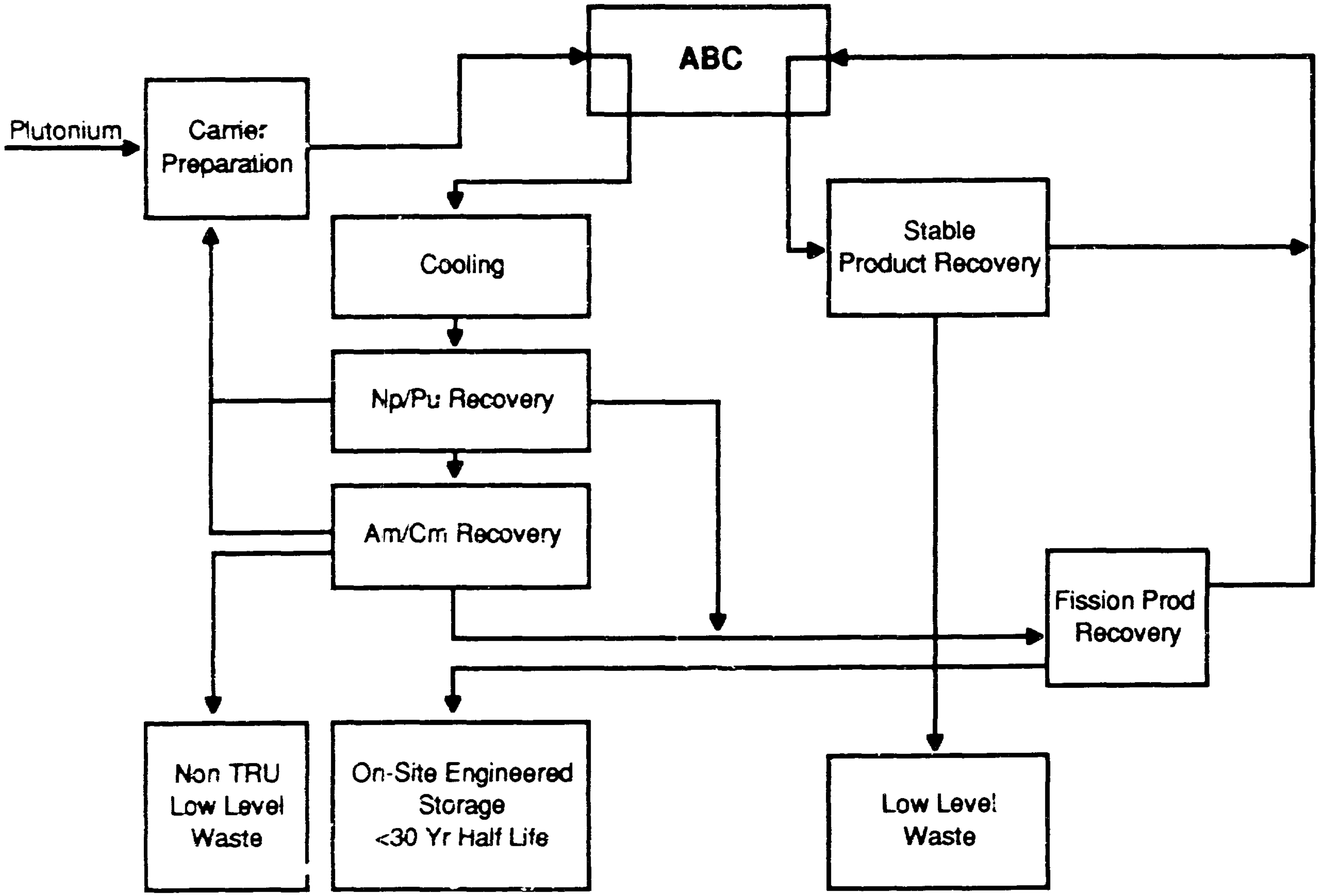


Figure 10

ABC Reference Design

Power Balance

System Thermal Power (MW$_{th}$)	4260
Thermal Power Per Blanket (MW$_{th}$)	2130 (each)
Gross System Electric Power (MW$_{e}$)	1365
Accelerator Beam Power (MW)	146
Thermal Power Per Target (MW$_{th}$)	73 (each)
Accelerator Power Requirement (MW$_{e}$)	325
Net System Electric Power (MW$_{e}$)	1040

Material Balance

Pu Burn Rate (kg/yr)	1250
Pu Fission Rate (kg/yr)	1152
Higher Actinide Fission Rate (kg/yr)	98
Fission Product Burn Rate (kg/yr)	39
Fission Product to Waste (kg/yr)	1211

Other Parameters

Blanket Neutron Flux (Average)	5×10^{15} n/cm^{2}s
Per Blanket Pu Inventory	80 kg
Per Blanket Inventory of Higher Actinides	150 kg
Total System Actinide Inventory (blanket heat exchangers, processing plant)	~500 kg

Figure 11

ABC Provides Final and Intermediate Proliferation Resistance

Arena	ABC	Others
Transportation to the processor	Very few protected routes needed. Each ABC converts 2.5 tons/year.	MOX would require multiple plants, extensive storage, and transportation systems.
At the processor	Small inventory. No new plutonium produced.	MOX or storage systems would contain much material in core and in cooling.
Transportation away from processor	None. Burn-up is complete. On-site storage of final ashes.	Hot transport required.
Final storage or repository	No plutonium or fissionable material in final product.	Repository must be rich ore body or be very large.

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Figure 13

ABC Development Plan

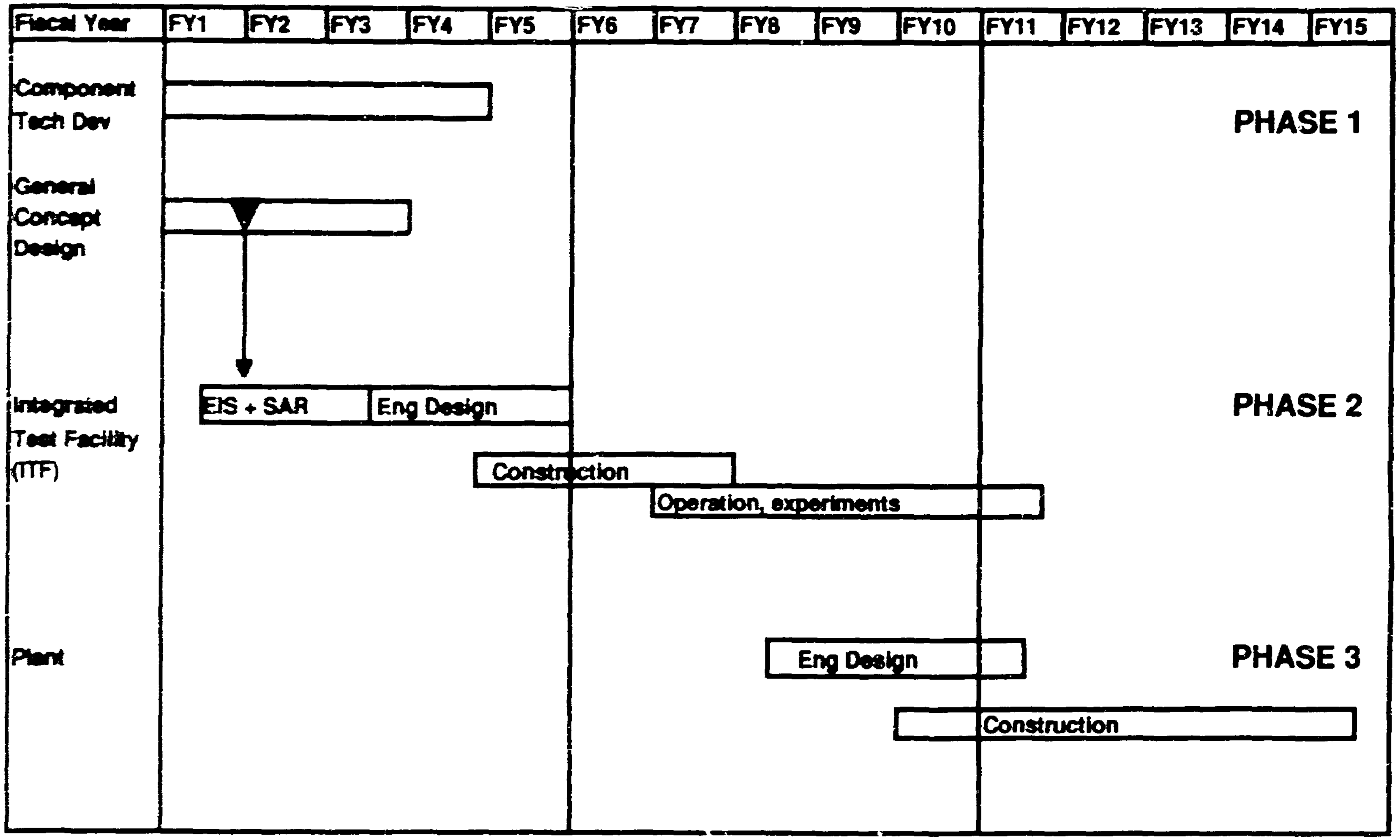

Figure 14

Summary of ABC Features

- Complete elimination of weapons plutonium.
- Minimization of radioactive material transportation.
- Easier material tracking. Only one ABC system is required to convert 50 tons of excess plutonium.
- Drawdown and control of world plutonium accumulation from power reactors.
- Enhanced safety.
- Drives and spins off technology.

Figure 15