OVERVIEW OF LOS ALAMOS CONCEPTS FOR ACCELERATOR TRANSMUTATION OF NUCLEAR WASTE (ATW)

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Presentation Overview

- Innovative Technical Approach
- Goals and Potential HLW Applications
- Application: LWR Long-Lived, High-Level Waste Transmutation
- Continuing Investigations
- Timelines
- Conclusions

Innovative Technical Approach Offers Major Advantages

ATW uses a high current accelerator to create an intense source of thermal neutrons. This technical approaches substantially different than most other transmutation concepts that use a fast neutron source (reactor or accelerator-based) and which tend to focus primarily on destruction of actinides.

This technical approach offers significant system advantages. It allows design of a concept that can efficiently transmute long-lived fission products present in high-level radioactive waste. Certain long-lived fission products such as technetium and iodine dominate long-term storage risk scenarios because of their high mobility. The system also transmutes actinide waste efficiently.

The high flux and large thermal transmutation cross sections lead to operating environments where material inventories resident in the transmute can be substantially smaller than other systems. These factors also create fast burn of material in the system.

Unique safety advantages are derived from the use of an accelerator-driven source of neutrons in conjunction with a subcritical blanket and lower resident inventories of radioactive materials. This latter feature can reduce significantly the radioactive material source term appropriate for accident scenarios. Low material inventories coupled with optimized chemical processing also provide environmental advantages. These are associated with potential minimization of waste streams and small inventories left in the system at its end of life.

Innovative Technical Approach Offers Major Advantages

ATW's accelerator-driven intense thermal neutron source yields the following advantages:

- Completeness - Transmutation of both long-lived actinides and fission products
- Speed of processing - Low material inventories and rapid burn
- Safety - Subcritical blanket, controlled accelerator drive and small radionuclide source term
- Environmental - Limited inventories and small end-of-life residues

General Features

Several major components would comprise ATW. An advanced, high current, medium energy (< 2 GeV) linear accelerator delivers a proton beam to a heavy metal (lead, tungsten, or uranium) production target. A range of proton currents appropriate tothespecific application can be used. Aheavywater moderator (several metersin diameter) surrounds the spallation target to slow the neutrons down to thermal energies. The result is a high thermal neutron flux -- greater than 2 to 3x1015 n/cm^2/sec over a large active volume. This high thermal flux enables several unique features for the ATW concept.

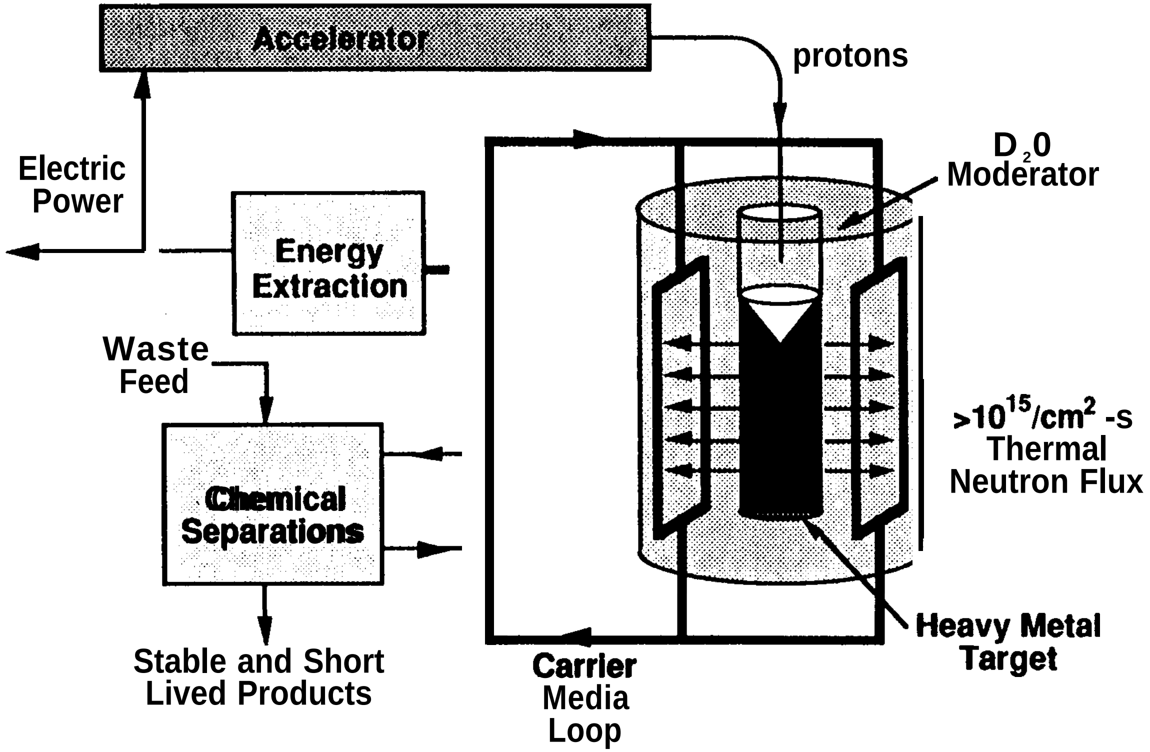
The ATW system can perform effectively with small resident material loadings. This results from the high efficiency thermal neutron interaction process (large cross sections) and from high neutron fluxes.

The flux and cross section allows design of a dilute (by volume), low inventory system that is coupled with continuous material feed. This later feature results from the high burnup rates that make a system that utilizes material in solid form (rods) generally impractical. Several options -- aqueous media, oxide slurries, molten salt --can be considered for carrier materials used in the flowing loops. Because of smaller required capacities, chemical partitioning processes can be investigated that can lead to highest decontamination factors.

When the material is a molten salt, such as lithium-berylium-fluoride, the salt's high thermal-to-electric conversion capabilities can be used to produce electricity efficiently. This choice potentially enables advanced fluoride or physical methods to be used for the removal of fission products from the actinide fuel.

General Features

- **Accelerator driven**
- **Central, intense neutron source**
- **High-fluxes of thermal neutrons**
- **Dilute, low material inventories**
- **Continuous material feed**
- **Advanced separations chemistry**



Accelerator

protons

D_2O
Moderator

Electric
Power

Energy
Extraction

Waste
Feed

Chemical
Separations

Stable and Short
Lived Products

$>10^{15}/cm^2$ -s
Thermal
Neutron Flux

Heavy Metal
Target

Carrier
Media
Loop

Goals and Potential HLW Management Applications

The ultimate goals of the ATW investigation and development effort are described in the Los Alamos National Report (LA-UR-91 -2601 “Nuclear Energy Generation and Waste Transmutation Using an Accelerator-Driven Intense Thermal Neutron Source”). The first concerns creation of a system that can destroy long-lived isotopes associated with high-level waste storage. The system should destroy long-lived migratory fission products that dominate risk in long-term storage scenarios. The system should also destroy high toxicity actinides that comprise significant fractions of nuclear waste. if the system operates at a high enough efficiency in both transmutation and separations components, then the possibility of on-site management of transmuted HLW may be technically feasible. By removing HLW constituents having long half-lives, the time scales appropriation for management and certification of wastes can be dramatically lessened. if long-lived constituents are removed from HLW, leaving mainly the shorter lived (half life< 30 years) strontium 90 and cesium 137, then management time scales can be reduced to a length of several hundred years. The possibility then exists for on-site, controlled management of such waste for a period of several centuries to allow decay to innocuous radioactivity levels. Material discharge and waste streams coming from transmutation would meet regulatory requirements suitable for land disposal.

A second part concerns creation of an advanced energy production concept that can rectify major obstacles facing nuclear power. To do this requires up-front management of the nuclear wastes produced during operation. Concurrent and efficient transmutation of long-lived nuclides produced during operation is key to creation of a nuclear energy source with minimal, long-lived HLW. Accelerator-drive coupled with a fission blanket allows this possibility by creating enough extra neutrons in the system to destroy long-lived fission products. The accelerator feature also allows the system to utilize natural fuels such as thorium and uranium for which long-term (thousands of years) supply exist.

Application of an ATW system to HLW management programs can have a significant impact. An ATW system applied to cleanup of long-lived defense HLW at a DOE site such as Hanford could provide management options that minimize or eliminate HLW leaving the site. Long-lived nuclide destruction could also aid creation of more robust on-site waste storage forms. The impact of an ATW system on geologic repository storage could be significant. It could delay or potentially avoid altogether the need for a second geologic repository. It could also reduce the performance required of a geologic repository, e. g. reduce the waste isolation period from 10,000 years to a period of around 500 years. The latter is the mid-range of expected containment by engineered barrier systems and may lead to a situation where repository design could proceed without reliance on natural barriers.

Goals and Potential HLW Applications

- Ultimate goals of ATW development

  - On-site management of transmuted HLW
  - Advanced energy system

- ATW technology development can complement HLW programs

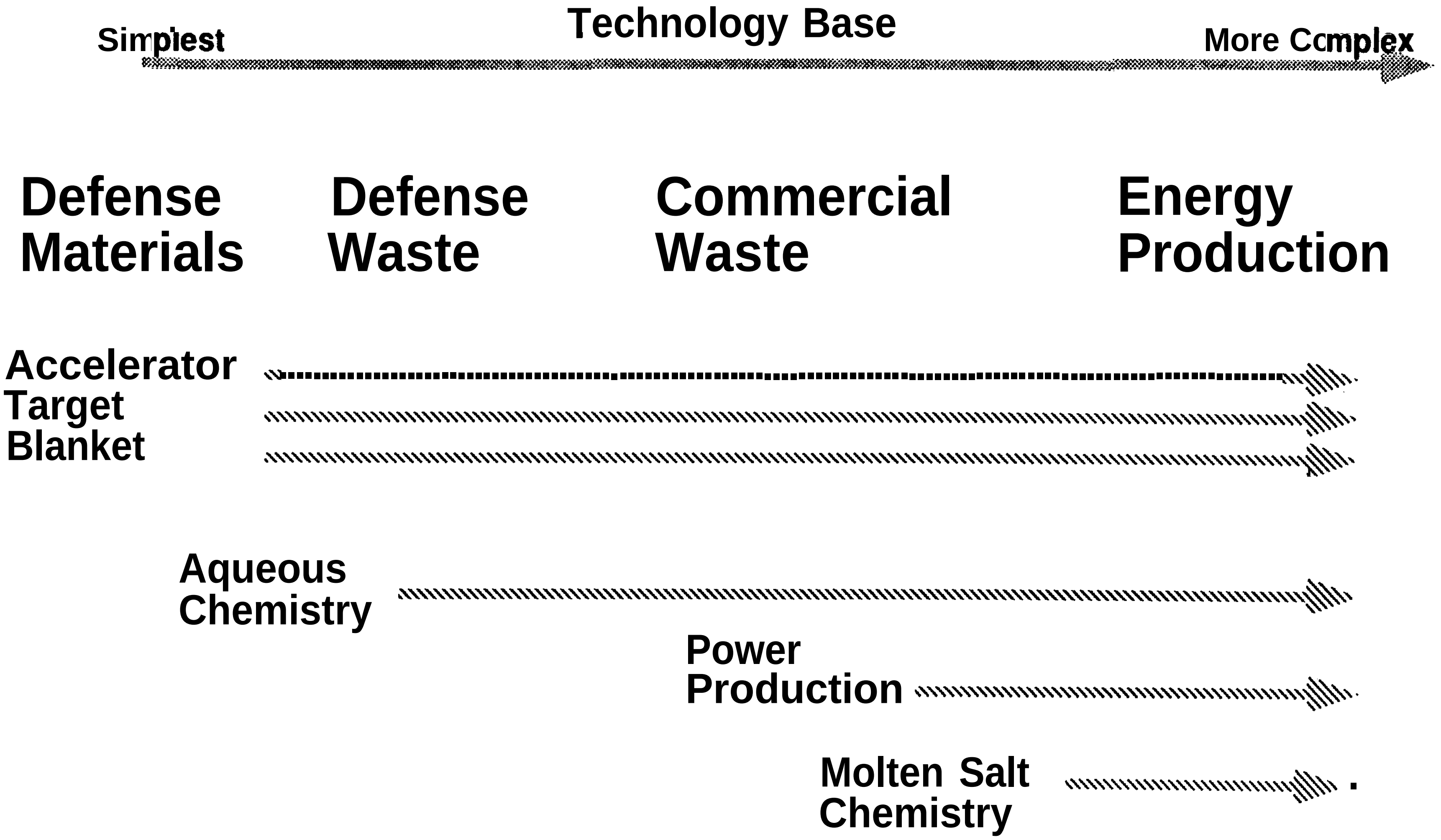
  - DoE Site Cleanup

  - Geologic Repository
    - Reduction of defense HL waste load
    - Delay or potentially avoid 2nd repository need
    - Reduce performance requirements

Technology Applied to a Spectrum of National Needs

ATW application development involves a staged approach. Specific technology development can impact a major problem area and at the same time allow components to be developed for a next application stage. A relevant example is that of defense waste applications. The ATW system components developed for it and proven during DOE site cleanup share a high degree of commonality with a system that could be applicable to destruction of commercial high level waste. This system, in turn, shares all of its components with a system that could ultimately be used to produce energy with no long-lived high-level waste stream.

Technology Applied To A Spectrum of National Needs



Technology Base

Simplest

More Complex

Defense Materials

Defense Waste

Commercial Waste

Energy Production

Accelerator

Target

Blanket

Aqueous Chemistry

Power Production

Molten Salt Chemistry

Application: LWR Long-Lived HLW

Credible and practical ATW system has been developed to illustrate technologies, performance levels, and to provide information in areas such as material balance. In developing it, we have adopted an approach that builds the system around demonstrated technologies (or extensions to them) that will allow us to achieve a desired, credible level of performance. This approach has led us to concentrate on the use of nuclear components and chemistry components that largely exist today but which can be adapted to take advantage of ATW's technical features. The system is not optimized and thus there are numerous options that will provide substantial performance improvements. These will be described.

This base-case ATW system consists of four target-blanket modules that can transmute the plutonium, higher actinide, technetium, and iodine yearly discharge from 7.53000 MW_T light water reactors. The blanket consists of a series of pressurized tubes in a heavy water blanket. Very clean separation process flowsheets have been developed for the separation of fission products introduced into the system from their transmuted by-products. Actinide separations have been built around aqueous processes, optimized to achieve very high separation factors and minimal waste streams.

Application: LWR Long-Lived High-Level Waste

- Objective - To devise credible and practical system

- Approach

  - Utilize technologies or extensions that provide credible performance

  - Identify options for improved performance

- Base Case

  - Four aqueous blanket modules that transmute plutonium, higher actinides, technetium, and iodine discharge from approximately eight 3000 MW_T LWRS

  - Pressurized system in heavy water moderator

  - Clean separations for fission product transmutation

  - Aqueous actinide separations based on solvent extraction and ion exchange

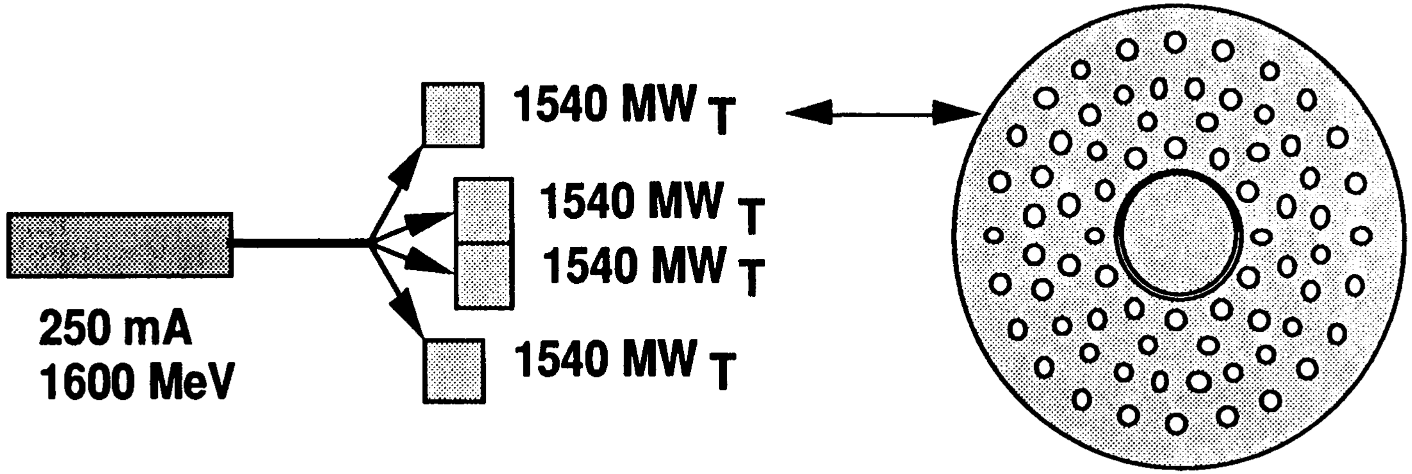
Base Case

The base case ATW system is driven by a single 250 mA, 1600 MeV accelerator which requires 900 MW of electrical power. The proton beam from this accelerator supports four separate target/blanket modules. Each blanket module produces about 1.5 GW of thermal power from actinide fission for a total system power of 6 GW. This system will burn the actinide waste from approximately 7.5 LWRs, i.e., about 2450 kg per year. Each blanket also provides the excess neutrons to transmute the technetium-99 and iodine-129 from 7.5 LWRS (about 250 kg per year) to stable products. The thermal-to-electric conversion efficiency is 30%, which yields about 1000 MW of net electrical power available to the grid.

Base Case

Transmutes Pu,
Higher Actinide,
Tc, I Discharge
from 7.5 LWRs

4 Aqueous
Blankets
(1540 MW_T ea)



Base Case (Target/Blanket Module)

The target/blanket module for the base case system consists of two thermally isolated systems; the target and the blanket. The target design is heavy-water-cooled solid tungsten and lead with a total thermal power from beam deposition of 100 MW. The blanket surrounding the target is a heavy water moderated lattice of CANDU-like pressure tubes containing an actinide-oxide/heavy water slurry. Flow of the slurry through an external heat exchanger carries about 1540 MW of power out of the blanket.

The target and blanket are intimately coupled neutronically. Efficient utilization of the spallation neutrons requires that most of the neutrons are absorbed productively in actinides (for large neutron multiplication) or fission products with minimal parasitic absorption in transmutation products, structure, or target.

The lattice design was based on unit-cell calculations to provide the maximum multiplication versus pressure tube size, lattice pitch and actinide slurry concentration. These were 5-cm-radius, 23.8 cm, and 75 g/liter, respectively. The actinide isotopics were equilibrium values calculated as a function of spectrum and flux level. Flux-weighted cross sections were used in one-dimensional calculations to calculate the full blanket performance. A three blanket region concept was used: 1) a 2-cm-thick decoupling region surrounding the target containing 1 molar Tc-99/heavy water solution to minimize thermal neutron return; 2) a 150-cm-thick multiplying region with 250 actinide slurry-bearing pressure tubes surrounded by 0.15 molar Tc-99 in the heavy water moderator; and 3) a 50-cm-thick reflector/absorber region containing 0.15 molar Tc-99 in heavy water.

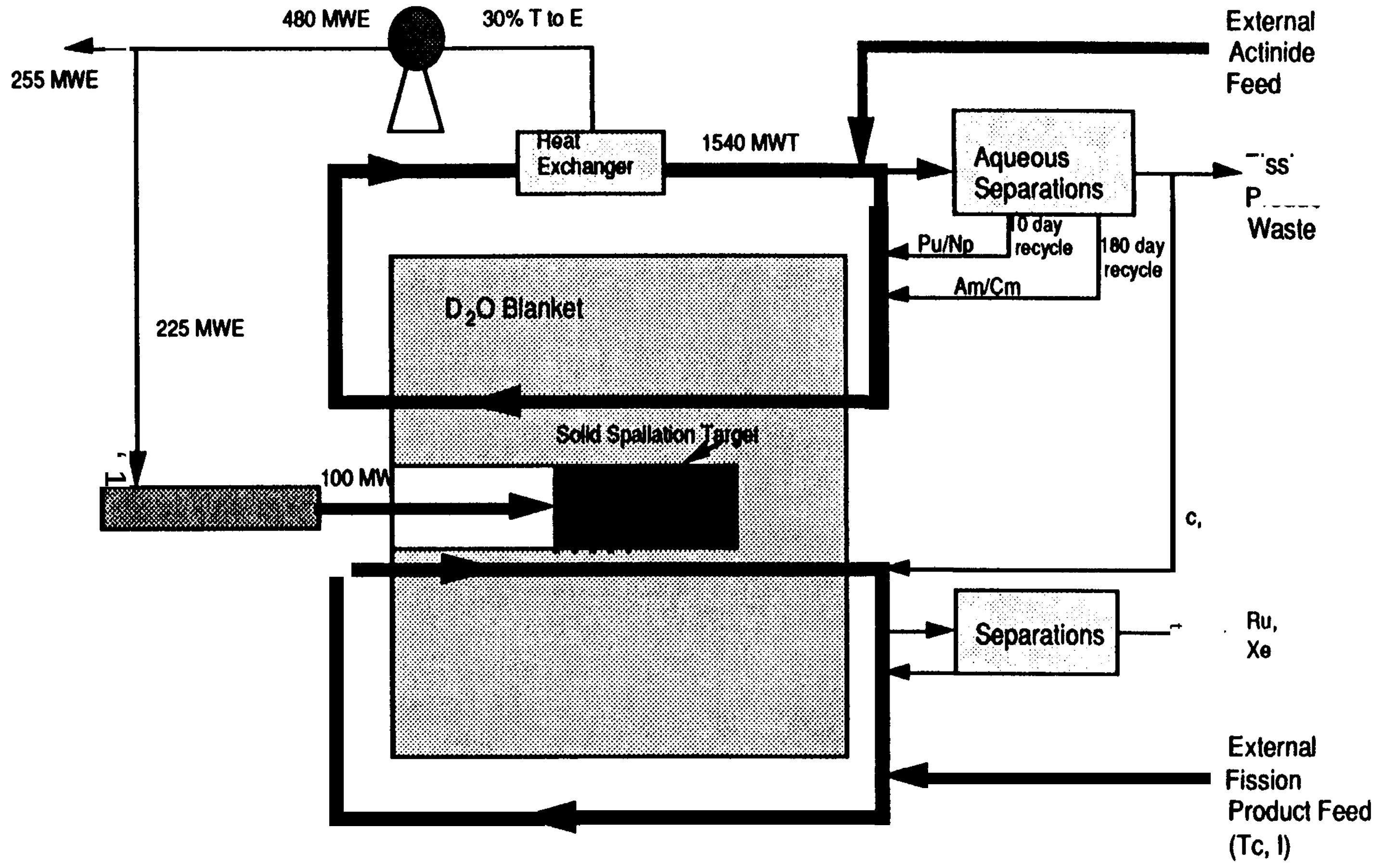
The current processing concept incorporates individual processing loops for the fission products as well as two processing loops for the actinides. Two loops are used for the actinides to reduce the total system inventory. One loop is the primary feed loop for LWR actinides; the actinide blanket residence time in this loop is 30 days with a 10-day cooling/processing time outside of the blanket. The processing removes the neptunium and plutonium from the remaining actinides and fission products for quick recycle to the blanket. The remaining actinides, primarily americium and curium, are cooled for 180 days, then separated form the fission products and recycled to the blanket to form a second loop. The actinides in this loop have a 180-day blanket residence time and a 180-day cooling/processing time.

Base Case (Target/Blanket Module)

Aqueous Chemistry

Inventory per Blanket
- **325 kg Actinide**
- **100 kg FP**

1000 MW net power Production



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Accelerator

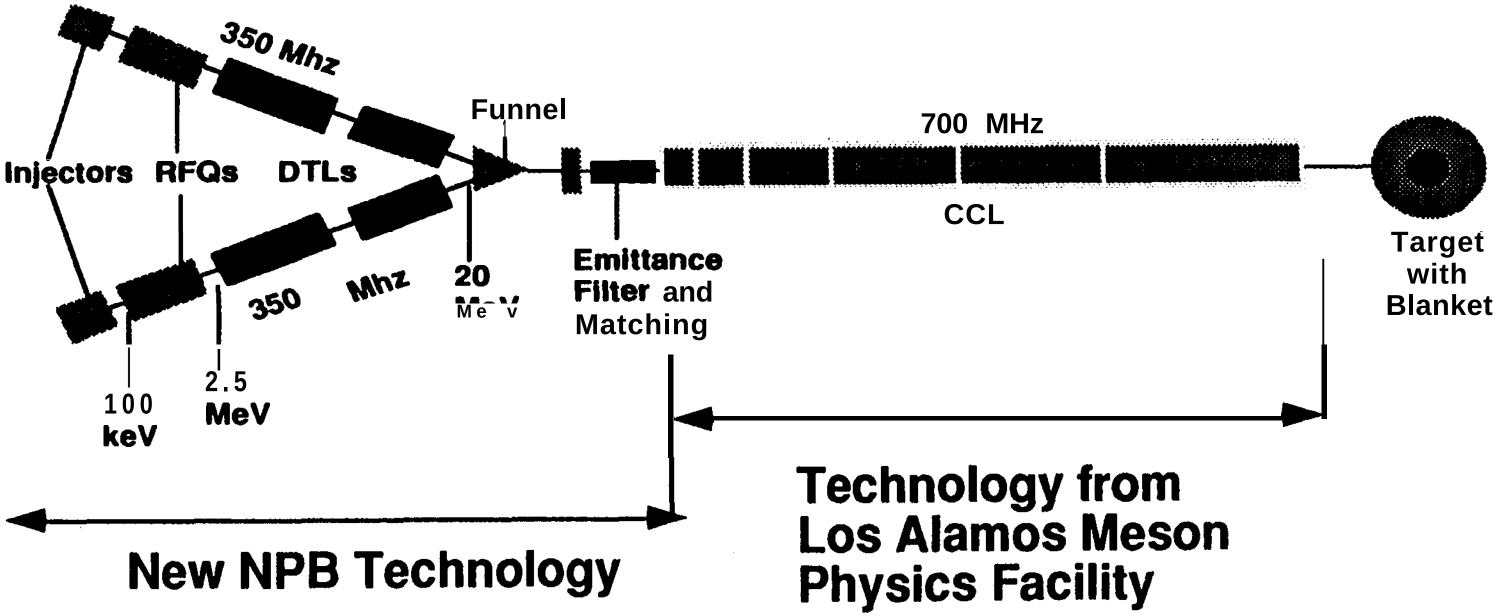
The transmutation accelerator is a high-power, radio-frequency, continuous beam linear accelerator (linac) that generates a 1600 MeV proton beam with an average current of 250 mA. The configuration shown here consists of a 700- Mhz coupled-cavity linac (CCL) injected at 20 MeV by a funneled beam launcher. The later is made up **of two 100-keV injectors each containing 125 mA proton sources, two radiofrequency quadruple linacs (RFQs), and two drift-tube linacs (DTLs).** A funnel, similar to that tested recently at Los **Alamos,** is used to combine the **two beams which are then accelerated to 1600 MeV in a coupled-cavity linac. 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 radiofrequency power to beam power. We also select a very large ratio of the accelerating-structure aperture to beam diameter to assure low enough beam loss for "hands-on" maintenance. Beam performance has been confirmed by sophisticated multi-particle computer simulations. The overall accelerator concept was reviewed in 1990 by a DOE Energy Research Advisory Board panel, which evaluated it as technically sound with no physics uncertainties.

Accelerator

(Los Alamos Report LA-UR-91-2797)

- 1600 MeV 250 mA system would drive 4 target/blanket modules
- Accelerator design incorporates recent major technology advances
- Design reviewed by DOE Energy Research Advisory Board:" The continuous wave RF linac approach is technically sound" (Ref: DOE/S-0074 (Feb. 1990))



Blanket System

The linear accelerator operates at 1600 MeV at a continuous-wave current of 250 mA. The primary proton beam is then split into four beams, each having a current of 62.5 mA. Each of the four beams is directed into four separate target/blanket modules. A modular design approach allows maintenance or replacement of components with relative ease and adds to the overall reliability of the system. The modules have separate cooling loops for their respective targets, moderators, and blankets, and operate independently from each other.

The high-energy proton beam strikes a centrally located spallation target to produce an intense source of neutrons. The solid tungsten/lead target is surrounded by an annulus of technetium in D_2O, an actinide slurry region, and a D_2O reflector. The target design is comprised of heavy-water-cooled tungsten rods. The power density is very high, and therefore requires sub-cooled boiling as the heat-transfer mechanism. Because of the intense proton and neutron environment, the target assembly will require routine replacement.

Neutronics analyses show that each target/blanket module can burn the actinides and fission products from approximately two light-water reactors and produce approximately 1542-MW_t power. The balance-of-plant design is based on existing heavy-water reactor technology employed in the CANDU reactor system. Here, the fuel is contained in double-walled pressure tubes that pass through the blanket. It is necessary to use the liquid fuel approach for actinide burning in ATW to take advantage of the high neutron flux and the rapid burn rates, as well as facilitate the continuous processing. To prevent the radioactive liquid fuel from coming into contact with the steam loop that drives the turbine-generator set, an intermediate light-water heat-transfer loop is added. The additional intermediate loop adds another degree of safety margin in case of accidental radioactive release from a rupture from the liquid fuel primary loop. The heat from the intermediate loop is transferred to a light-water secondary loop for steam generation. In this concept, energy produced in the blanket from the fission of the actinides is recovered and used to produce electricity with about 30% thermal efficiency. This recovery of useful energy greatly reduces the overall cost of the facility.

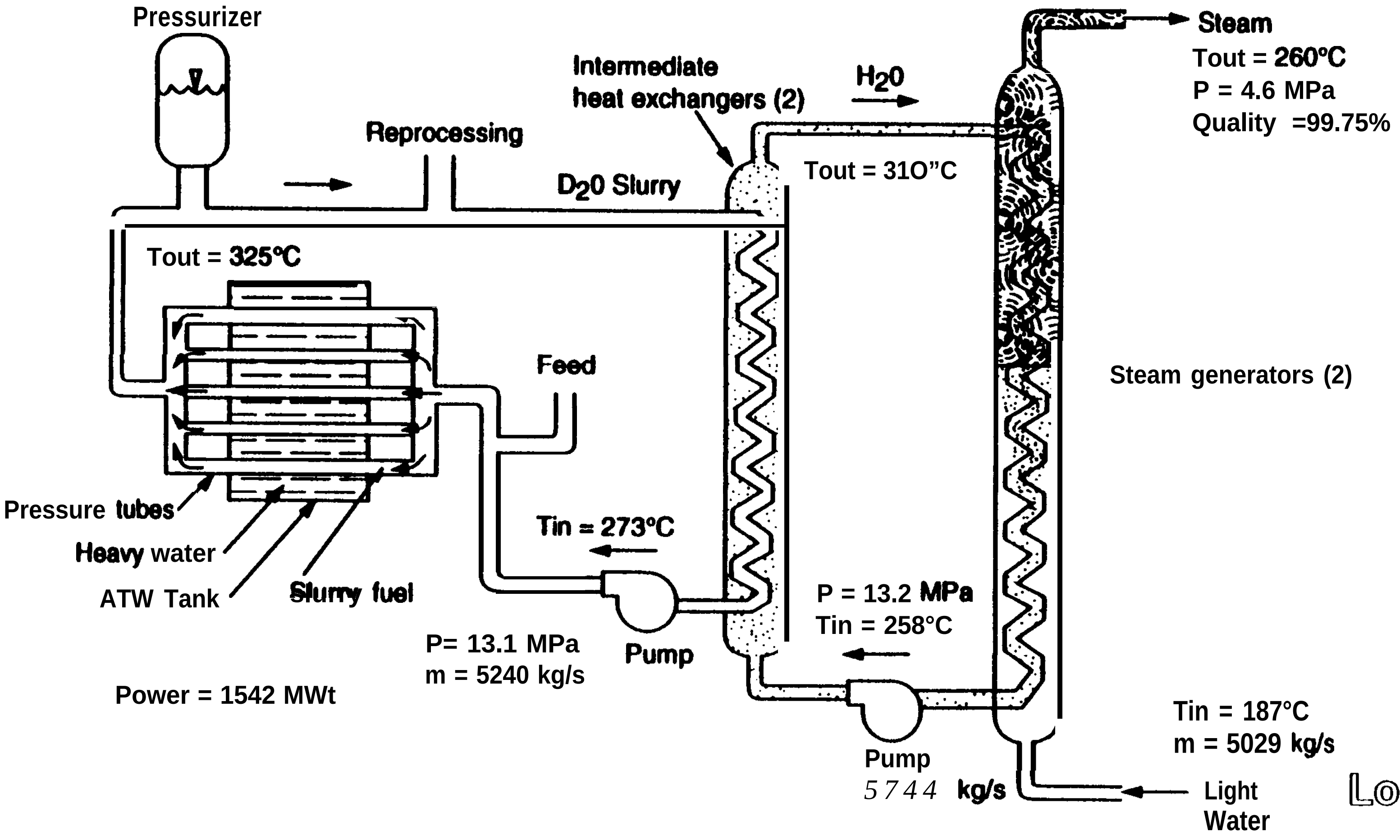
The target/blanket design is evolving in an effort to enhance the safety, reliability, and efficiency (with respect to neutron utilization). For example, it may be possible to keep the actinide slurry within the blanket region, and transfer heat to the heavy-water moderator that is pumped outside the blanket. This retention will greatly reduce the overall volume of actinide slurry and reduce the risk of spills outside the blanket.

Another option that is being considered is the use of a flowing liquid lead target. The use of such a target adds complexity to the design but has the potential to increase the neutron utilization efficiency. In addition, if greater accelerator currents are required, the liquid target can more easily remove the heat.

Blanket System

(Los Alamos Report LA-UR-92-46)

- **CANDU -like technology forms reference nuclear system design basis**
- **250 pressurized assemblies,**
- **325 kg actinide,100 kg technetium,iodine per target/blanket**
- **Transmutation rate/yr - 625 kg actinides, 75 kg FP**



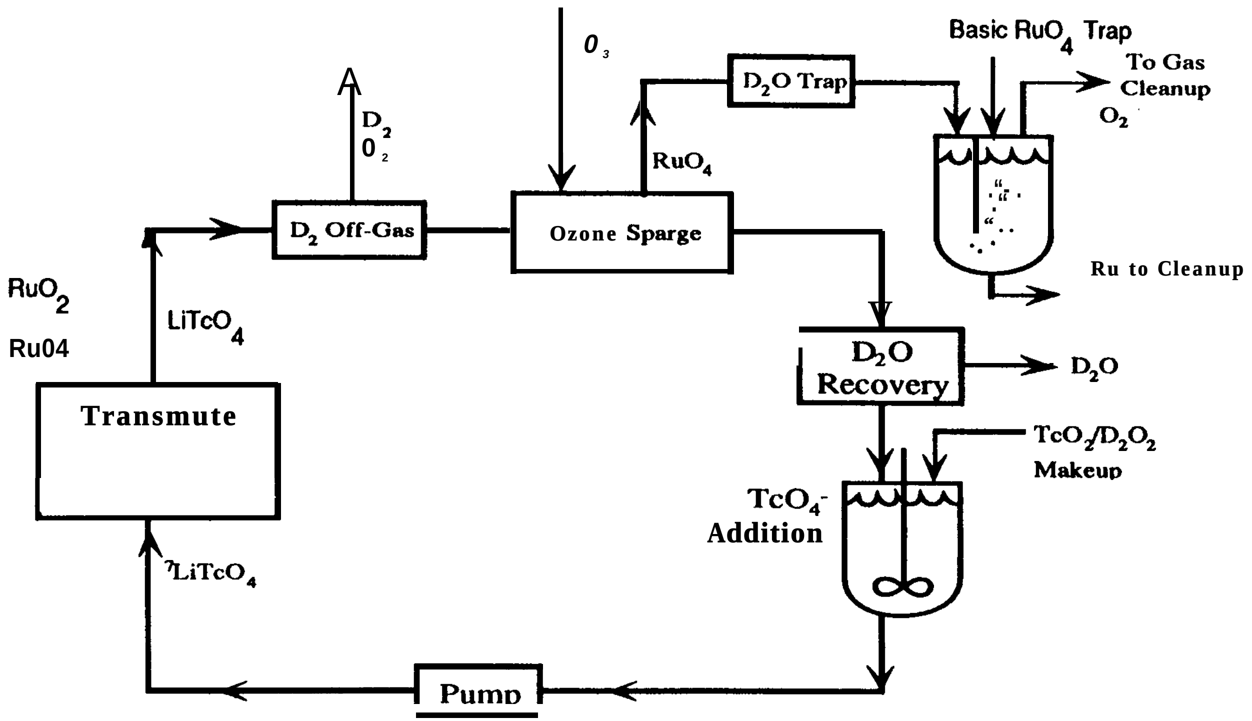
Clean Separation Flowsheets For Fission Product Transmutation

Many options have been investigated for separating technetium from its transmutation product, ruthenium. Options that we have considered include: 1) volatilization of Tc as Tc_2O_7; 2) fluoride volatility of the hexafluorides, TcF_6 and RuF_6; 3) electrochemical separation; 4) solvent extraction; 5) magnetic separation; 6) conversion of Ru to solid RuO_2 followed by filtration from pertechnetate solution; 7) ion exchange; and 8) ozonolysis to form volatile RuO_4. Presently, the last three options appear to be the most promising, and of these, the ozonolysis scheme appears to produce the least waste. The ozonolysis flowsheet is shown here and is discussed in greater detail in LA-UR-92-39 and LA-UR-92-89.

We have not explored as many flowsheet options for I/Xc separations. Currently, the preferred option involves transmutation of of I_2 with continuous removal of the gaseous xenon transmutation product. This flowsheet is discussed in LA-UR-92-64.

Clean Separation Flowsheets for Fission Product Transmutation (LA-UR-92-39, LA-UR-92-89, LA-UR-92-64)

- Continuous transmutation by-product extraction
- High separation factors (> 10^5)
- Minimal waste streams



Actinide Flowsheet Uses Proven Aqueous Processes

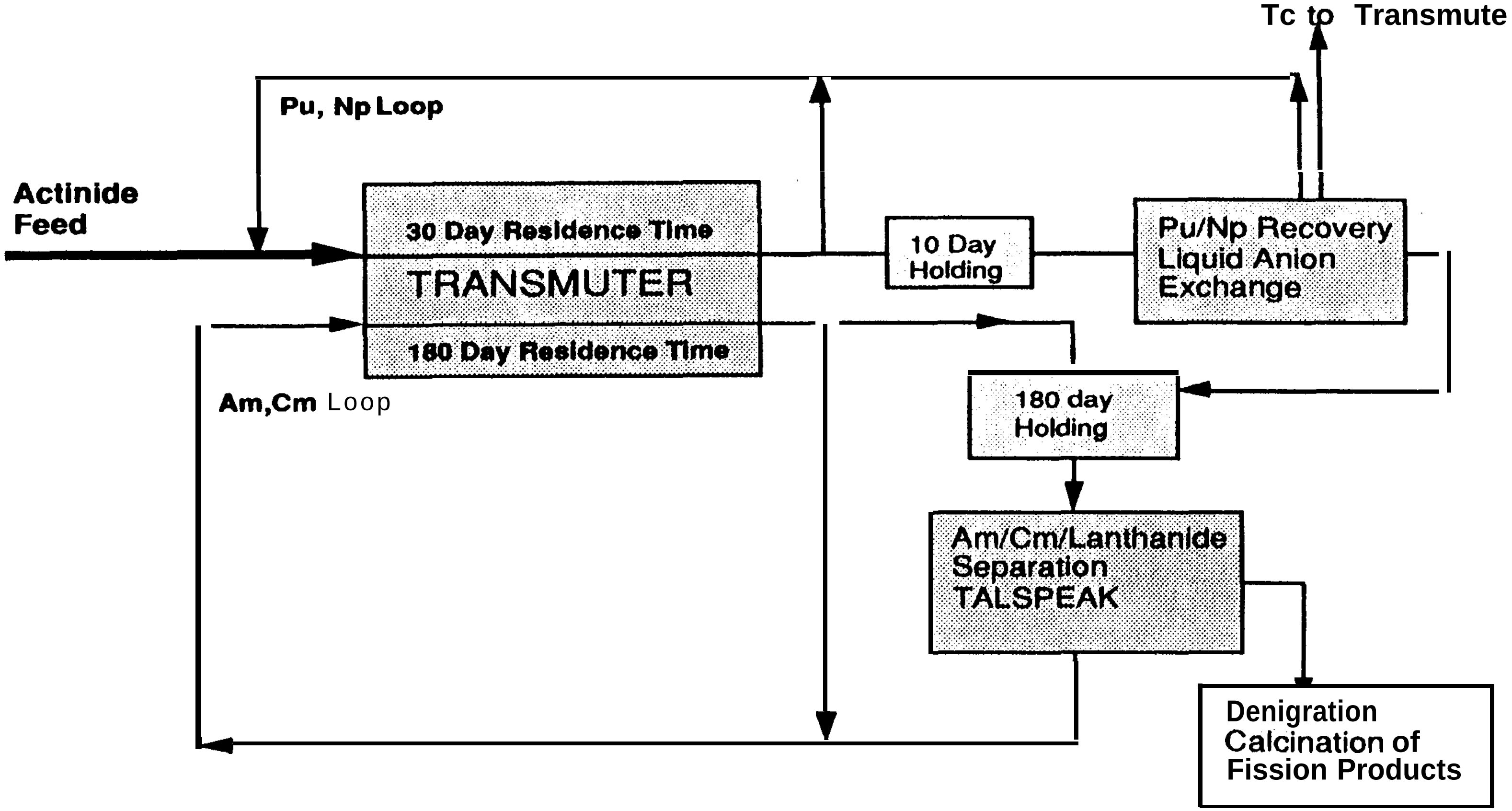
To establish a high performance level in the blanket, a constant fissile concentration with a low neutron poison inventory must be maintained. This requires that the plutonium and neptunium be returned to the blanket with approximately a ten day cool-down time. The initial processing step must be robust and selective for plutonium and neptunium. To accomplish this, a liquid anion exchange process using a quarternary amine was chosen. it has the features of high selectivity for plutonium and neptunium, very low affinity for typical neutron poisons and the extractant is more radiation stable than tributyl phosphate used in the PUREX process. Also, the degradation products are weaker extractants than the original ligand and therefore do not extract fission products such as zirconium or add strong completing agents to the aqueous that can disrupt the extraction system. Furthermore, the thermal decomposition products of the extractant are gases and do not add to the waste. A further advantage of this process is that technetium produced during fission is well-extracted and can be easily sent to the technetium transmutation loop.

The americium, curium, lanthanides and higher actinides produced during transmutation will be processed to separate the lanthanides, which are neutron poisons, from the transmutable transplutonium elements. Because of the high heat produced from the fission product lanthanides, this fraction will be separated from the plutonium and neptunium and cooled for an additional 180 days. At this point, a reverse TALSPEAK process will be used to separate the lanthanides from the transplutonium elements. Thermal denigration to produce product oxide for return to the transmute and spray calcination for the waste streams were chosen because they do not add inerts to the final solid waste stream.

All of the components of the base case flowsheets have been successfully tested with either high-level wastes or spent fuels in gram to kilogram quantities. All of the features of the flowsheet have been documented in the literature. For more detail see LA-UR-92-63.

Actinide Flowsheet Uses Proven Aaueous Processes (Los Alamos Report LA-UR-92-63)

- Fast recycle of Pu/Np to minimize processing inventories
- Aqueous solvent extraction and ion exchange technologies
- $>10^5$ separation factors
- Liquid discharge < TRU levels
- Waste volumes and recycle options under investigation



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Preliminary **Material Balance**

The base-case ATW system has been designed using current, credible technology. Even so, the performance of the system in terms of the waste it produces relative to the waste it destroys is very encouraging. The waste produced by the system includes radioactive species created in the spallation target, radioactive fission products created by actinide burning, activation products created in the structural components of the transmute, and wastes from chemical processing. We have not yet estimated the waste generated in preparing the feed for transmutation. However, much of the chemical flowsheet developed for processing the material from the actinide flowloops of the transmute can be applied to feed preparation. We have not yet developed quantitative estimates of the radioactive wastes that will be generated by neutron activation of the structural materials in the transmute. Such estimates will require very detailed target/blanket designs.

The base-case system destroys 2500 kg of actinides and 300 kg of long-lived fission products (technetium and iodine) each year. We estimate that approximately 30 grams of long-lived radionuclides will be produced in the spallation target for each kilogram of feed transmuted. Most of this amount can be eliminated by isotopic enrichment of the tungsten target or by choice of an alternate material such as lead or tantalum. The transmutation of each kilogram of Tc and I will produce an equal mass of Ru and Xe transmutation products. These products may contain small amounts of untransmuted material, making them, at worst, class C wastes. The transmutation of each kilogram of actinides will produce approximately 900 grams of stable and short-lived ($\tau \leq 30$ yr) isotopes and 65 g of long-lived isotopes (^{135}Cs, ^{107}Pd, ^{93}Zr, . .-.). In addition, decomposition products from the liquid anion exchange and TALSPEAK processes will give rise to wastes. The anion exchange wastes can be incinerated to gaseous N2, C02, and H20. TALSPEAK residues will include phosphates that will be part of a solid waste stream. We estimate this solid waste stream to be approximately 156 g per kg of actinide burned. Analysis has shown that significant quantities of water will be produced during chemical processing. This will give rise to a non-TRU liquid waste stream of about 250 L per kg of actinide burned. For more details see LA-UR-92-63.

Preliminary Material Balance

The base-case ATW system contains consistent and credible components that produce desired performance levels

- **Yearly transmutation rate -2500 kg actinides, 300 kg Tc, 1**

- **Per kilogram of material burned /year** (Los Alamos Report LA-UR-92-82)
  - Produce **30 g** of radionuclides in the spallation target ($\tau_{1/2} \geq$ **30** years)

- **Per kilogram fission products burned/yr**
  - **-1** kg Class C or better transmuted by-product discharge

- **Per kilogram of actinide burned/yr**
  - Produce < 250 L of non-TRU liquid discharge (mainly water)
  - Produce N_2, $C0_2$
  - Produce 156 g inerts (phosphates, sodium, ash,)
  - Produce **65 g** of radionuclides with $\tau \geq 30$ years (^{135} Cs, ’^{07} Pd, ‘^{3}**Zr**)

Substantial Improvements Over The Base Case Are Possible

The use of a lead target as a spallation neutron source when compared to tungsten has two advantages; one is the slightly higher neutron production per incident proton and the other is the significantly lower absorption cross section. Depleted uranium gives substantially higher production but presents the issues of long-lived nuclide production and large target thermal powers.

The key to enhanced neutron economy in the blanket is the reduction in parasitic capture, primarily in the structure. Blanket concepts using heavy water cooled molten salt tubes at lower pressures or a molten salt in a He-cooled graphite lattice offer significant potential in reducing structural absorption. The key to lower blanket inventories is higher neutron fluxes. The higher neutron fluxes can be obtained only in higher power density, lower parasitic blanket design concepts. A heavy-water cooled in-blanket slurry or the molten salt in a He-cooled graphite lattice avoids the large external inventories in heat exchanger loops.

Advanced separations can aid system performance by allowing quick removal of fission product absorbers that affect neutron economy and by further reducing wastes produced by the system. in a molten salt medium rapid separation of fission products from actinides may be possible using centrifugal methods that take advantages of the significant density differences for these classes of elements. in an aqueous system, solvent extraction systems that directly separate trivalent actinides from the trivalent lanthanides and other fission products with high specificity to replace the TALSPEAK process is an important advanced technology. Bench scale studies have demonstrated this actinide-lanthanide separations approach. The advantages of replacing the TALSPEAK process would be to decrease the number of processing steps with an ensuing waste reduction, especially if the phosphorous containing extractants could be replaced.

Finally a molten salt carrier for the actinides offers a significant advantage in overall system performance due to high temperature and low pressure operation. The potential for thermal conversion efficiencies greater than 40'% in a net power to the grid mode of operation yields significant economic advantages.

Substantial Improvements Over the Base Case Are Possible

- **Enhanced Target Performance**

- **Better Neutron Utilization and Material Inventory Reduction**
    - Reduced absorption blanket
    - High flux operation optimization
    - In-core cooling of actinide carrier material

- **Advanced Separations**
    - Physical separations
    - Advanced aqueous methods

- **System Performance**
    - Molten salt for high conversion efficiency

Conclusion: Numerous pathways exist for superior performance

Potential Strategies for Dealing with Additional Long-lived Fission Products

Unlike reactor-based transmutation schemes, accelerator-based systems are not limited by their neutron economy in what they can transmute. Although we have focused on the transmutation of 99Tc and ^{129}I, the neutron economy of the ATW system allows transmutation of other long-lived fission products as well. The decision of which of these other long-lived fission products to transmute will be based on the tradeoffs between cost and benefit. For example, it may be desirable to transmute ^{135}Cs because of its high mobility in the environment. The transmutation of this species is complicated by the presence of stable ^{133}Cs and shorter-lived ^{137}Cs. We have considered two approaches to this situation. in the first, we have explored the possibility of using isotope separation to isolate ^{1}35CS for transmutation. We have initiated discussions with industry on the use of the plasma separation process (PSP) for Cs isotope separation. The cost of this option needs to be evaluated. The second approach would be to simultaneously transmute ^{133}Cs, ^{135}Cs, and some ^{137}Cs. Early analyses indicate ^{1}35CS burn without creation of additional long-lived material from capture on ^{133}Cs and ^{134}Cs. This approach would obviously be more costly in terms of the neutrons required.

Similar considerations can be applied to other long-lived fission products such as ^{79}Se, ^{93}Zr, ^{107}Pd, and ^{126}Sn. The cost of transmuting these species needs to be examined in the context of the environmental hazard that they represent. The hazards may also be mitigated through means other than transmutation. For example, conversion of the palladium to a metallic form might effectively prevent its migration into the environment.

Potential Strategies for Dealing With Additional Long-lived Fission Products

Destruction of other long-lived fission products not limited by neutron economy. Choice depends on economic tradeoffs

- **^{135}Cs - Importance in geologic storage risk scenarios; major defense HLW component**

  1) Isotope separation using plasma separation process (PSP) technologies

  2) Burnup of cesium feed in transmute:

- **Other long-lived radionuclides require assessment of impacts on storage scenarios, trades of additional transmutation cost factors**

Continued Investigations

Until now ATW efforts have been primarily concerned with technical investigations associated with development of consistent designs. Issues such as those shown here have been briefly considered. As the design becomes more complete, these investigations become the basis for a substantial increase in effort. For example, development of the detail in chemical processing flowsheets will allow us to better determine strategies and forms for dealing with wastes produced by the system. Likewise costing model components in areas such as the blanket and chemical processing components will utilize system technical knowledge that is now becoming available. With more system details available, more complete analyses of the environmental and safety aspects of ATW can proceed. Finally our beginning assessments of proliferation and regulatory environments described in Los Alamos report (LA-UR-91-2601) will also be expanded.

Continued Investigations

- Waste form/management determinations
- Cost model development
- Proliferation and safeguards issues assessment
- Evaluation of ES&H concerns
- Assessment of regulatory requirements

Timeline
Defense Waste Application

Development of the ATW concept for application in an area such as defense waste cleanup would proceed in three phases. The first phase would consist of component technology development and general concept design. Key measurements of fundamental data (e. g. neutron yield, and chemical separation factors) along with beginning demonstration of individual components (such as target performance, low-energy accelerator components) would occur. Creation of a consistent point design and rigorous system material balance would be priority efforts. Environmental, safety, regulatory, and more-detailed costing studies would begin during this phase. The effort would require funding at the level of about 30 million dollars per year and would last for four years. This phase will produce information required to make a decision as to whether to proceed to the second phase of development, the Scientific Integrated Test.

This second phase would demonstrate integrated system operation and performance at a scientific scale. We roughly estimate the cost of this phase at about $500 M which includes capital costs for a facility that would be used for testing and operational experience. After an initial operational period of the Scientific Integrated Test facility, a decision would be made as to whether to initiate the final phase of development, the engineering demo/production plant. For an application at a DOE site such as Hanford, we estimate such a facility capital cost to be around $2B.

All phases of an ATW application effort will require significant industry teaming and participation. This is especially true for the second and third phases of the plan illustrated here where industry would take the lead in implementation and application of the system.

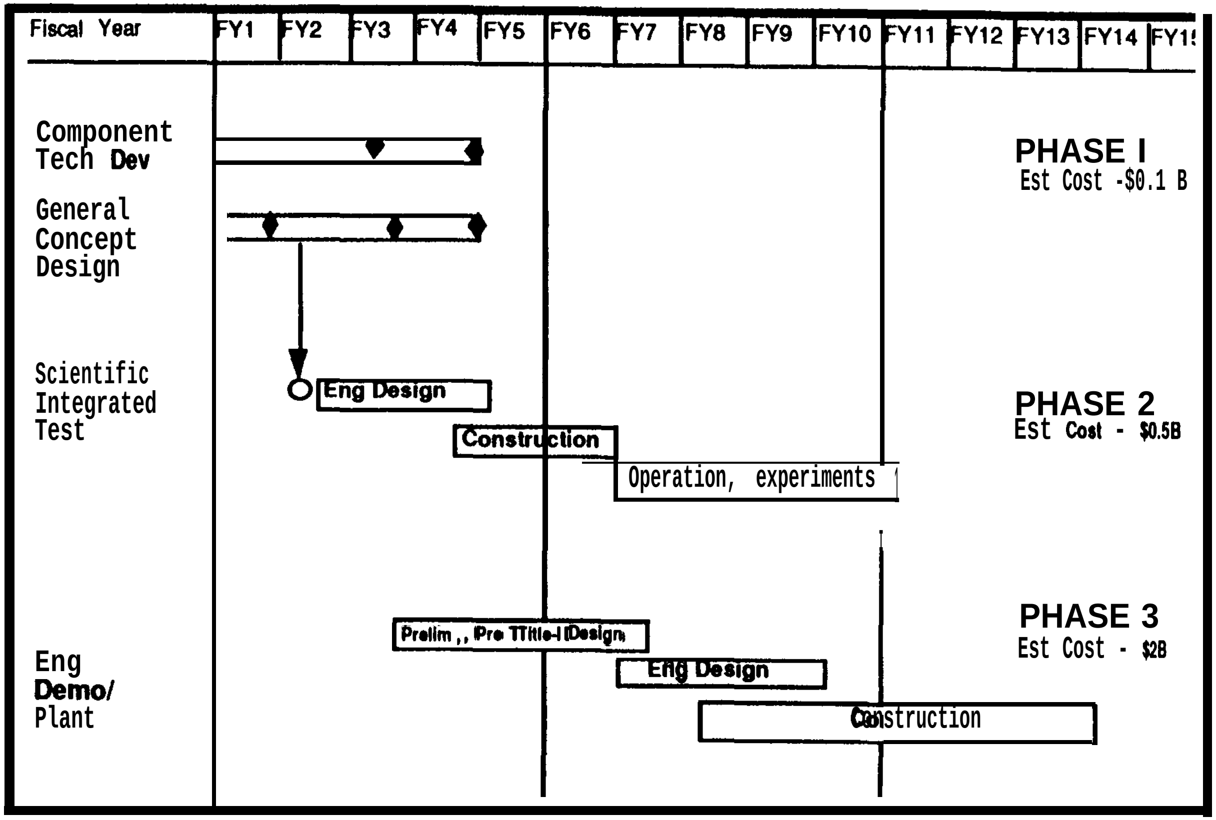
An operating ATW system could be developed and constructed in a period of 12 to 15 years given a vigorous technology-driven effort. The period could be further shortened by initiating engineering design of the demo/production plant at an early stage. Increased technical risk would be associated with this approach.

Timeline
Defense Waste Application

- Phase 1 (4 years)
  - Key data experiments
  - Individual component demos
  - Consistent point design
  - Rigorous material balance
  - Cost, regulatory, ES&H, studies
  - ~ $ 30 M/yr

- Requires substantial industry participation

- Results, decisions feed integrated test, plant phases (Phase 2, 3)



Summary

This presentation has described the Los Alamos ATW concept which offers the promise of a technically attractive system for nuclear waste transmutation. The advantages offered by ATW are significant -- completeness for transmuting both long-lived fission products and actinides, low inventories, rapid burnup, and enhanced safety and environmental attributes. The presentation focussed on an example of an ATW system aimed at transmutation of long-lived fission products and actinides from LWR spent fuel discharge. Using demonstrated technical components, a system has been developed that achieves very good performance with an overall material balance assessment that is attractive. Numerous options exist for significant improvement of this system to further reduce material inventories and wastes produced during chemical separations.

A number of issues -- development of waste management strategies, realistic cost models, assessment of regulatory impacts, . . . -- have been initially investigated but more effort aimed at them is required in the facets of ATW development.

The ATW effort has received modest funding over the past two years. In order to truly be able to develop and demonstrate the technology that makes it unique, a larger effort, starting with a vigorous program of research, development, demonstration, and design is needed. Initiating such an effort can demonstrate a technology that has potential benefits, not only in radioactive waste destruction, but in a wide range of additional, nationally important application areas.

Summary

- ATW's accelerator-driven intense thermal neutron source allows important advantages
    - Completeness
    - Low inventory and speed
    - Safety and environmental advantages

- Base case - Good performance; significant improvements possible

- ATW technology can be applied to an important spectrum of national needs

- Research, development, demonstration effort needed as the next step

Conclusion

ATW offers a viable technical means of dealing with major long-lived radionuclides that dominate longer-term risks associated with management of HLW. For this reason this system can complement and enhance present efforts aimed at long-term geologic disposal of high-level nuclear wastes as well as other HLW management applications.

Conclusion

- ATW can enhance geologic repository or other high-level waste management applications through its capability for destruction of long-lived actinide and fission products