*Tank SY-102 Remediation Project –
Flowsheet and Conceptual Design Report*

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LIST OF ACRONYMS

ANL	Argonne National Laboratory
BV	Bed volumes
“CLEAN”	Extensive Pretreatment with Material Recycle
CPU	Compact Processing Unit
D&D	Decontaminate and Decommission
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DSSF	Double Shell Slurry Filtrate
DST	Double-Shell Tank
DTPA	Diethylenetriaminepentaacetic acid
EC	Equipment Cost
EPA	U.S. Environmental Protection Agency
HFIR	High Flux Isotope Reactor
HLW	High-Level Radioactive Waste
HWVP	Hanford Waste Vitrification Plant
LANL	Los Alamos National Laboratory
LLW	Low-Level Radioactive Waste
NRC	U.S. Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PFD	Process Flow Diagram
PFP	Plutonium Finishing Plant
P&IDs	Piping & Instrumentation Diagrams
PLC	Programmable Logic Controller
PNL	Pacific Northwest Laboratories (Battelle)
RCRA	Resource Conservation and Recovery Act
SCADA	Supervisory Control And Data Acquisition
SST	Single-Shell Tank
TPDC	Total Plant Direct Cost
TRU	Transuranic
TWRS	Tank Waste Remediation System
WAC	Waste Acceptance Criteria
WHC	Westinghouse Hanford Company
WIPP	Waste Isolation Pilot Plant

TANK SY-102 REMEDIATION PROJECT – FLOWSHEET AND CONCEPTUAL DESIGN REPORT

by

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ABSTRACT

The U.S. Department of Energy established the Tank Waste Remediation System (TWRS) to safely manage and dispose of radioactive waste stored in underground tanks on the Hanford Site. A major program in TWRS is Pretreatment which was established to process the waste prior to disposal. Pretreatment is needed to resolve tank safety issues and to separate wastes into high-level and low-level fractions for subsequent immobilization and disposal. There is a fixed inventory of actinides and fission products in the tank which must be prepared for disposal. By segregating the actinides and fission products from the bulk of the waste, the tank's contents can be effectively managed. Due to the high public visibility and environmental sensitivity of this problem, real progress and demonstrated efforts toward addressing it must begin as soon as possible. As a part of this program, personnel at the Los Alamos National Laboratory (LANL) have developed and demonstrated a flowsheet to remediate tank SY-102 which is located in the 200 West Area and contains high-level radioactive waste. This report documents the results of the flowsheet demonstrations performed with simulated, but radioactive, wastes using an existing glovebox line at the Los Alamos Plutonium Facility. The tank waste was characterized using both a tank history approach and an exhaustive evaluation of the available core sample analyses. This report also presents a conceptual design complete with a working material flow model (using Aspen Plus™ modeling software), a major equipment list, and cost estimates.

A high-salt, low acid flowsheet was demonstrated by Los Alamos as feasible for remediation of the SY-102 tank. It produces relatively low waste volumes, can be accomplished with conventional chemical processing equipment, and takes advantage of the components of the waste to increase the efficiency of the TRU elements recovery. The construction costs are reasonable and competitive with the costs of building new tanks. The Title I design can be started within the next Fiscal Year without a large amount of additional experimental work. However, tests with actual waste are desirable to finish flowsheet verification.

I. INTRODUCTION

The U.S. Department of Energy (DOE) established the Tank Waste Remediation System (TWRS) to safely manage and dispose of radioactive waste, both the current inventory and any waste generated in the future while restoring the Hanford Nuclear Reservation. Radioactive waste is stored in underground double-shell tanks (DST) and single-shell tanks (SST) on the site. A major program in TWRS is pretreatment which was established to process the waste prior to disposal using the Hanford Waste Vitrification Plant (HWVP). Pretreatment is needed to resolve tank safety issues and to separate wastes into high-level and low-level fractions for subsequent immobilization and disposal. Due to the high public visibility and environmental sensitivity of this problem, real progress and demonstrated efforts toward addressing it must begin as soon as possible. However, for the same reasons, the approach must also be technically sound so that the program continues to move forward and show progress while avoiding any major set backs.

As a part of this program, personnel at the Los Alamos National Laboratory (LANL) working with representatives from Westinghouse Hanford Co. (WHC), the site contractor, and Battelle's Pacific Northwest Laboratories (PNL), have developed and demonstrated a flowsheet to remediate tank SY-102. This DST is located in the 200 West Area and contains high-level radioactive waste (HLW). It is physically located next to tank SY-101, the highest priority safety-listed tank on the site. This report documents the results of the flowsheet demonstrations performed with simulated, but radioactive, wastes using an existing glovebox line at the Los Alamos Plutonium Facility. The tank waste was characterized using both a tank history approach and an exhaustive evaluation of the available core sample analyses. It also presents a limited conceptual design complete with a working material flow model (using Aspen Plus™ modeling software), a major equipment list, and cost estimates.

Project Scope

In general, as an overall TWRS program goal, remediation should be accomplished using an iterative and evolutionary approach. This means starting with tanks and waste that are well characterized and require a minimum of unit operations to process. These will then be used as test beds for demonstrating and optimizing the

techniques and equipment that will be common to remediating all the tanks. This includes, but may not be limited to, the equipment for mixing, slurring, and transporting the waste out of the tanks to the pretreatment facility. Of particular interest is the sludge removal equipment.

The Los Alamos SY-102 flowsheet proposal can support either the *Draft Reference Pretreatment System* or the *Extensive Pretreatment with Material Recycle (CLEAN)* options or a combination of both. With the current flowsheet, the removal efficiencies for transuranic (TRU) elements support the *Draft Reference Pretreatment plan*. The CLEAN option can also be supported with the addition of a Sr removal step and an increase in TRU element removal efficiency.

The project assumes that a large, centralized processing facility will not be available in the two to four year time frame given to remediate the tank. Therefore, the flowsheet and equipment are designed to use a combination of in-tank processing, existing facilities, and compact processing units (CPU). The volume in tank SY-102 on the Hanford Site will be recovered by treating the waste and preparing it for storage at an appropriate repository. The remediation plan assumes that there will be no *in situ* disposal of HLW and the recovery process will not further contaminate the site groundwater. Because the SY-102 flowsheet does not assume HWVP operation, it does not require additional separation steps to remove components that degrade glass performance. This minimizes the complexity of the flowsheet and allows greater flexibility in deploying the technology.

The first step to remediating any tank is an understanding, based on the best available data, of the waste characteristics and how the waste is distributed throughout the tank (by layering or other nonhomogeneous characteristics). Information can be obtained both through sampling and a reconstruction of the tank's history. Within the limitations of the waste characterization, the appropriate technology can then be chosen that can handle defined variations in key parameters and constituents. No matter how well the tank contents are mixed, a homogeneous feed stream probably cannot be achieved and therefore the flowsheet has to be robust enough to handle this variation. Additional separation steps have to be justified on the basis of their contribution to meeting the goal of safely, lawfully, and cost-effectively remediating the individual tanks. Minimizing

waste volumes, changing the waste classification, reducing the hazard and regulatory compliance are additional appropriate criteria.

A key component of this project is the design. The design uses either existing facilities which can be readily modified and repurposed or mobile/modular CPUs, instead of new and costly treatment facilities. New facilities will incur large investments for permitting, construction, and operation. Also, waste transfers and proper siting will be difficult.

To achieve these objectives, personnel at the Los Alamos Plutonium Facility are evaluating technology to remediate waste in the SY-102 double-shell tank. The mission of the LANL SY-102 Tank Waste Remediation Project is to process the entire contents of SY-102, including supernate and sludge, into forms that allow storage and final disposal in a safe, cost-effective, and environmentally sound manner. This will be achieved in general by separating the radioactive elements (actinides and fission products) from the stable elements to some pre-specified degree. The radioactive elements will be converted into a form suitable for long term disposal and the remainder will be placed into grout for internment on site. The most promising flowsheet was tested on a small scale with nonradioactive simulants and was then verified using simulated, but radioactive, wastes in an existing research and development (R & D) glovebox line.

The proposed flowsheet takes advantage of the moderate absorption of trivalent actinides and lanthanides on anion exchange resins from high nitrate/low acid solutions. This approach minimizes the overall volume and uses the Al, Fe, and Cr already present in the sludge as "salting agents" to enhance the recovery of Pu and Am. Because of the large reduction in waste volumes, the minimal amount of solids which must be handled, and the equipment simplification, most of the recent efforts at Los Alamos have been centered on testing this technique using a realistic tank waste simulant.

This approach has many benefits. Actual remediation of the site can begin and show real progress sooner than with an all-encompassing flowsheet designed to handle many different types of waste. This serves to demonstrate to the public that site problems are actually being addressed rather than just being studied and evaluated. This is possible because no new waste handling techniques or facilities need to be operating initially. All low-level radioactive waste (LLW) produced can be processed through the existing evaporation facility and the slurry placed into retrievable grout. A strength of this flowsheet

is that the TRU elements are in a form that can either be placed in a certified waste form and shipped to the Waste Isolation Pilot Plant (WIPP) or stored for eventual vitrification. The HLW fission product fraction will ultimately go to the HWVP, but early remediation can take place co-currently and in concert with its design and construction. In particular, phased treatment of salt cake and supernate allows for early availability of tank space, a demonstration of real progress in support of the Tri-Party Agreement, the initiation of pretreatment for disposal of the LLW, and the initiation of concentration of the HLW.

This approach eliminates the requirement to have an operating vitrification plant before beginning the tank remediation. The flowsheet is flexible and robust enough to handle waste which has large uncertainties in composition. The flowsheet includes general operations such as sludge washing, dissolution, separation of the radioactive from the nonradioactive constituents, and recycling of reagents where practical. The associated equipment includes industry standards such as dissolvers, filters, ion exchange columns, evaporators, tanks, and waste containers.

As defined in WHC-EP-0629, "Pretreatment Technology Plan", the SY-102 Remediation Project addresses the following needs and objectives.

- Removing the sludge and supernate from SY-102 provides tank space for further tank remediation activities. The major need is the timely remediation of the tank SY-101 which is a Safety Issue Resolution tank. This may be accomplished by moving a portion of the contents of SY-101 to SY-102 and diluting the contents of each to eliminate the safety hazard. This solves a high-priority safety issue quickly and allows the timely development of an effective organic treatment technology. This cannot be accomplished with the current inventory of TRU elements in SY-102.
- The SY-102 flowsheet minimizes the amount of high level waste that must be generated in remediating the tank.
- The low-level radioactive waste (LLW) produced will meet the current LLW waste form requirements.
- Even though the SY-102 project does not require the HWVP to be operational for technology demonstration, it produces a TRU waste form which can go directly to HWVP if necessary or be placed into a form for shipment and storage at WIPP.

- The flowsheet uses established technology and minimal reagent addition to ensure regulatory compliance and waste volume minimization.

The physical remediation of tank SY-102 will be a joint exercise between LANL and WHC. LANL will provide technical support and demonstrate the final flowsheet with actual waste on an appropriate scale. The following is a preliminary activity list with each responsible organization identified.

- Provide a complete material balance (LANL).
- Demonstrate a workable flowsheet (LANL).
- Prepare preliminary piping and instrumentation diagrams (P&IDs) (LANL).
- Prepare a preliminary equipment layout (WHC/LANL).
- Identify facility alternatives (WHC).
- Define decision criteria for alternative selection (WHC/LANL).
- Prepare detailed P&IDs (WHC/LANL).
- Design the process facility and/or facility modifications (WHC/LANL).
- Prepare the site/upgrade facilities (WHC/LANL).
- Acquire materials and equipment (WHC/LANL).
- Install equipment (WHC/LANL).
- Test equipment (WHC/LANL).
- Demonstrate "cold" operation (WHC/LANL).
- Operate the facility/remediate SY-102 (WHC/LANL).

There are several issues, both technical and operational, which must be addressed to assure the success of this, or any other, remediation project. They are summarized as follows.

- As a part of the selection criteria and design effort, identify and address site specific regulations or permitting requirements.
- Determine the final waste form requirements for LLW, TRU waste, and HLW.
- Determine the waste treatment capability and facility availability (for LLW in particular this refers to evaporators, grout facilities, and grout vaults).
- Determine the availability of liquid waste transportation (using rail cars, trucks, or transfer pipes) to the treatment facilities.

- Evaluate the applicability of any technology demonstrated to other SST or DST remediation efforts.
- Determine the impact of tank remediation on other operations ongoing within the 200W Area.
- Develop a legal definition of an "empty" tank so a remediation project has a predetermined closure or endpoint.

II. BACKGROUND

A. History and Project Justification

The Hanford Nuclear Reservation, shown in Fig. 1, is a 560-mi² site located in southeastern Washington state. In years past, it was an integral part of the nation's nuclear weapons complex as a site where plutonium was produced in nuclear reactors and recovered, along with uranium, in reprocessing facilities such as B-Plant, Redox, PUREX, and the Plutonium Finishing Plant (PFP). Tank Farm storage and evaporator facilities were constructed for the purpose of storing and concentrating radioactive wastes received from all site waste-generating plants whose radionuclide concentrations exceeded environmental release limits. The wastes were generated as a result of activities such as fuel reprocessing, waste fractionation, equipment decontamination, and analytical laboratory operations. The Tank Farm facilities received, aged (when appropriate), and evaporated the waste. The resulting salts were allowed to form salt cakes for interim storage in million-gallon, underground, carbon steel tanks (Cruse, et al., 1983).

Included in the Tank Farm facilities are 149 inactive underground single-shell tanks and 28 active double-shell tanks. In the past, selected SSTs underwent stabilization by removing the interstitial liquid using pumps while the remaining solids settled to the bottom. The current work at the Hanford Site includes remediating the waste in all these tanks. This involves removing the stored waste, both the supernate and the sludge, from the tanks and converting it into a form suitable for long term storage as either a grout for LLW or a borosilicate glass for HLW.

Responsibility for the Hanford Site has been given to DOE's Environmental Management division. There is currently no plutonium production mission and none is planned for the future. A Tri-Party Agreement has been negotiated between Washington State, the U.S. Environmental Protection Agency (EPA), and the DOE to

Fig. 1. Overview of the Hanford Nuclear Reservation

remediate the Site. Part of the remediation mission includes processing the liquids and solids stored in the underground storage tanks and placing them in a suitable waste form. There are, as yet, no demonstrated technologies for pretreatment of tank waste containing TRU elements. The current strategy is to place all of the radioactive materials into borosilicate glass with minimal pretreatment.

A current proposed minimum pretreatment method is to remove the Cs-137 from the alkaline supernates using an ion exchange process and "wash" the sludge to remove soluble salts. However, in order to maintain glass integrity and meet the vitrification plant feed specifications, several other components, such as Cr, Zr, Al, and PO_4 will have to be removed or diluted. Since there are currently no proven separation methods for removing these elements from the waste, the only alternative is to dilute the waste and thereby vastly increase the glass volume. This will significantly raise the overall site remediation cost. The proposed sludge washing step will increase the volume of LLW which must be placed in grout without significantly reducing the volume of material placed into glass.

The Los Alamos approach to pretreatment is based on the strong economic incentives to reduce the glass volume and the severe time restraints imposed as legal requirements in the Tri-Party Agreement. The Los Alamos strategy has been to focus on reasonably well-proven separation methods that will remove from the bulk of the waste the TRU elements (Pu and Am along with Th and U), the heat producers (Cs and Sr), and materials that could pose problems if placed into grout because of their leachability and environmental mobility (Tc). By removing these components from the bulk of the tank waste, the volume of HLW requiring disposal through vitrification or some other means will be significantly reduced. If vitrification is used for the HLW fraction, the integrity of the glass produced will be improved because the pretreatment process will also partition compounds such as Zr, Cr, Al and PO_3 into the LLW fraction which is disposed of in grout.

Another problem to be addressed by the remediation of a waste tank is the shortage of usable tank space in the 200 West Area. This severely limits operational flexibility and the ability to mitigate such high-priority safety issues as the gas generation in tank SY-101. Therefore, another element of the Los Alamos proposal is to achieve rapid disposal of the entire contents of a tank, both the sludge and the supernate. The resulting free tank space could

then be used for other purposes such as processing the tank SY-101 waste or providing more flexibility in PFP operations. This approach will also demonstrate a full-scale TRU element removal technology which could then be applied to other waste tanks on the Site.

B. Problem Definition

After a cursory review of several tank inventories, tank SY-102, a DST located in the 200 West Area, was selected for remediation. The tank has been used since its construction in the 2nd quarter of 1977 as the 242-S evaporator feed tank or to receive liquid wastes from numerous locations around the 200 West Area. During the evaporator operation phase between 1977 and 1981, basic solutions ($\text{pH} > 12$) generated during the SST salt well pumping program were sent to this tank and eventually concentrated using the 242-S evaporator. These wastes potentially contained soluble fission products as well as alkaline and alkaline earth elements. The wastes were probably low in actinides because of their low solubility in basic solutions. During the tank settling operation phase from 1981 to the present, the wastes received have been either decontamination solutions with some phosphate based cleaning agents or "neutralized" acid wastes ($\text{pH} > 12$) which contain hydroxide solids. The solids were allowed to settle to the bottom of the tank and the supernate was pumped off and sent to other selected DSTs. The wastes entering the tank during this period were analyzed for fissile content and pH to address criticality and corrosion concerns, respectively. Grab samples of the tank contents were taken periodically and core samples of the solids at the bottom of the tank were pulled in 1988 and 1990. Records of transfers into and out of the tank have been compiled and a level history developed by Agnew *et al.* at Los Alamos (Agnew, 1993). This history is graphically presented, including sampling dates, in Fig. 2.

Tank SY-102 is a right cylindrical vessel with a domed top, a nearly flat bottom, and an inner diameter of 75 ft. It currently contains 674,000 gal. of solids and liquids (Godfrey, 1992). Based on a sludge height of 38 in., 105,000 gal. of solids must be processed. The sludge washing studies of Swanson *et al.* (Swanson, 1993) suggest that approximately 9% of the sludge can be redissolved. Even after sludge washing, there would still remain 96,000 gal. of solids to be processed through the separations part of any flowsheet. The first step of any separation flowsheet is to get the sludge into solution, which can be accomplished by dissolution in nitric acid.

Fig. 2. Tank SY-102 Use and Level History

Table 1 presents a summary of the important cations in the sludge and totals the nitrate capacity both before and after the sludge washing technique is applied. Certain elements listed are assumed, as a conservative "worst-case," to be complexed with nitrate even though their most likely form in this solution is anionic (i.e. chromate, borate, etc.). All nitrate present in the dissolved sludge is assumed to be introduced from the nitric acid.

The recent Los Alamos review of the tank SY-102 activity (Agnew, 1993) indicates that the majority of the waste volume came from salt-well pumping operations, T Plant decontamination operations, and the PFP radioactive waste discharges and analytical operations. Because PFP operations are very similar to those at the Los Alamos Plutonium Facility and the T Plant solutions are low in TRU and other interfering elements, preparation of a SY-102 waste simulant to evaluate potential flowsheet options was possible. This also allowed testing of the flowsheet in a timely manner (on the order of several months) using existing equipment and facilities. This approach resulted in high confidence in the flowsheet and success in a full scale operation.

C. Flowsheet Options and Analysis

Several different remediation approaches for tank SY-102 were evaluated by Los Alamos personnel. They range from a "No Action" alternative to an actinide anion exchange flowsheet. The following provides a brief summary of each approach along with its advantages and disadvantages.

Option 1 - "No Action" – let the sludge and supernate stand in the tank.

This is not a viable option for legal and environmental reasons. The Hanford Site is directed by the Tri-Party Agreement signed in 1989 to follow a schedule and meet established milestones for conducting remediation of the Site. A part of the Agreement deals with the 177 underground solution storage tanks and the way they will be addressed. It does not allow for them to remain in their current state or for the solution within to be solidified *in situ*. In addition, although the tanks and the surrounding area are monitored constantly, leaks will eventually occur and solutions will be released to the environment. Finally, tank SY-102 still serves a useful purpose within the Tank Farms as a receiver and settling tank and could be used for additional activities, as previously mentioned, if it were emptied.

Option 2 – No actinide recovery; sludge and supernate mixed and solidified without further treatment.

This is not a viable option for waste handling reasons. If the supernate and sludge are slurried out of the tank together, the resulting mixture would be a TRU waste and would have to be packaged and handled accordingly. (Refer to Table 3 in the Performance Criteria section.) The 674,000 gals. of waste would have to be cemented or otherwise solidified. If this is done in 30-gal. lots within Department of Transportation (DOT) 17C Type A (55-gal. drum) containers, it would produce ~22,500

Table 1. Tank SY-102 Sludge Characteristics

Element	Element MW	Sludge (mole/L)	Valence	Total NO ₃ (moles)	Wt. Percent	Element Wt. (kg)	Mole Percent	Element Moles	Adjusted NO ₃ (moles)*
Ag	107.868	2.00E-03	1	792.30	0.08	85.46	0.02	792.30	792.30
Al	26.982	1.65E+00	3	1,960,942.50	16.28	17,636.72	17.94	653,647.50	588,282.75
As	74.922	1.00E-02	3	11,884.50	0.27	296.80	0.11	3,961.50	11,884.50
B	10.810	2.00E-02	3	23,769.00	0.08	85.65	0.22	7,923.00	23,769.00
Ca	40.080	1.60E-01	2	126,768.00	2.35	2,540.43	1.74	63,384.00	126,768.00
Cd	112.400	8.00E-03	2	6,338.40	0.33	356.22	0.09	3,169.20	6,338.40
Ce	140.120	7.00E-03	3	8,319.15	0.36	388.56	0.08	2,773.05	8,319.15
Cr	51.996	4.80E-01	3	570,456.00	9.13	9,887.14	5.22	190,152.00	570,456.00
Cs	132.905	1.70E-05	1	6.73	0.00	0.90	0.00	6.73	0.67
Cu	63.546	2.00E-02	2	15,846.00	0.46	503.47	0.22	7,923.00	15,846.00
Fe	55.846	4.50E-01	3	534,802.50	9.19	9,955.53	4.89	178,267.50	534,802.50
K	39.098	8.00E-02	1	31,692.00	1.14	1,239.09	0.87	31,692.00	316.92
Mg	24.305	7.00E-02	2	55,461.00	0.62	673.99	0.76	27,730.50	55,461.00
Mn	54.938	1.65E-01	2	130,729.50	3.32	3,591.01	1.79	65,364.75	130,729.50
Mo	95.940	1.00E-03	6	2,376.90	0.04	38.01	0.01	396.15	2,376.90
Na	22.989	6.00E+00	1	2,376,900.00	50.45	54,642.55	65.25	2,376,900.00	23,769.00
Nd	144.240	3.00E-03	3	3,565.35	0.16	171.42	0.03	1,188.45	3,565.35
Ni	58.710	1.00E-02	2	7,923.00	0.21	232.58	0.11	3,961.50	7,923.00
Pb	207.200	1.00E-02	2	7,923.00	0.76	820.82	0.11	3,961.50	7,923.00
Sb	121.750	3.00E-03	3	3,565.35	0.13	144.69	0.03	1,188.45	3,565.35
Sr	87.620	1.00E-03	2	792.30	0.03	34.71	0.01	396.15	792.30
Ti	47.900	3.00E-03	3	3,565.35	0.05	56.93	0.03	1,188.45	3,565.35
Tl	204.370	1.00E-02	3	11,884.50	0.75	809.61	0.11	3,961.50	11,884.50
V	50.941	1.00E-03	3	1,188.45	0.02	20.18	0.01	396.15	1,188.45
Zn	65.380	7.00E-03	2	5,546.10	0.17	181.30	0.08	2,773.05	5,546.10
Zr	91.220	4.00E-03	4	6,338.40	0.13	144.55	0.04	1,584.60	6,338.40
Am	241.000	3.70E-05	3	43.97	0.00	3.53	0.00	14.66	43.97
Np	237.000	8.40E-06	4	13.31	0.00	0.79	0.00	3.33	13.31
Pu	239.000	4.60E-04	4	728.92	0.04	43.55	0.01	182.23	728.92
Th	232.000	2.00E-02	4	31,692.00	1.70	1,838.14	0.22	7,923.00	31,692.00
U	238.000	2.00E-02	4	31,692.00	1.74	1,885.67	0.22	7,923.00	31,692.00
Totals		9.196		5,941,854.48	100.00	108,310.01	100.00	3,650,729.20	2,184,682.59

* After sludge wash

Tot sludge vol (L) = 396,150

Total vol (L) = 990,309

Adj tot vol (L) = 364,114

containers for shipment to the Waste Isolation Pilot Plant (WIPP) in New Mexico. No waste handling facility exists at the Hanford Site for this scale of TRU waste and the WIPP facility was not sized to accommodate this additional amount of TRU waste.

Option 3 – Decant the supernate and wash the sludge; solidify the remaining sludge without further treatment.

This is a potentially viable option. Based on the anionic content of the supernate, it is possible that it could be used directly to wash the sludge without adding additional solution and increasing the liquid waste volume. The supernate and the wash solution could be handled as a LLW. If necessary, Tc and Cs could be removed from the supernate using established and demonstrated anion and cation exchange techniques. The volume could be reduced through an evaporation process with the distillate being discharged to the environment and the bottoms being grouted and set in large concrete surface vaults. The remaining 96,000 gal. of washed sludge would be a TRU waste and would have to be packaged and handled accordingly. Again, the sludge would have to be cemented or otherwise solidified. If this is done as in Option 2 using DOT 17C Type A (55-gal. drum) containers, it would produce ~3,200 containers for shipment to the WIPP. This option is presented as a flow diagram in Fig. 3.

Option 4 – Decant the supernate, wash the sludge, dissolve the sludge heel in nitric acid and treat it using cation and anion exchange.

This is a viable option as it uses demonstrated, well-established technology to reduce the amount of TRU waste generated to a minimum. It effectively concentrates the actinides present in the waste to a manageable volume. This option is presented as a flow diagram in Fig. 4. The supporting calculations are presented in the project interim status report (Yarbro, et al., 1994).

After decanting the supernate and washing the sludge as in Option 3, the remaining sludge heel is dissolved in nitric acid. The solution is then passed through an anion exchange column on which the U, Pu and Th are selectively retained. The anion column is periodically eluted with dilute nitric acid and the U/Pu/Th in the eluate are precipitated by the addition of concentrated sodium hydroxide. The effluent solution is mixed with a reducing agent, such as hydroxylamine nitrate, to reduce the iron present from Fe(III)→Fe(II). This solution is then

Fig. 3. Sludge Washing Flowsheet

passed through a cation exchange column on which the Am and ~30% of the Fe will be sorbed. Batch contact studies using Dowex 50W-X4 cation exchange resin indicate that much of the Fe present will pass through the cation exchange column and not be sorbed if it is present as Fe(II). This increases the column capacity for the TRU element Am which is the target of this unit operation. The cation column is periodically eluted with nitric acid and the Am/Fe in the eluate are precipitated by the addition of concentrated sodium hydroxide. In this case, the Fe acts as a carrier for the Am and tends to produce a cleaner filtrate.

Several techniques have been developed in addition to Fe reduction to overcome the selectivity problems often experienced with cation exchange (Wheelwright, 1964 and Procter, 1974). In Wheelwright's work, a chromatographic process using a diethylenetriaminepentaacetic acid (DTPA) with a H⁺ barrier was developed. The typical feed to this process has Fe, Al, Cr, Ca and Th in large excess compared to the Am concentration. Much of the development work was completed using solutions that only had tracer Am with

Option 5 – Decant the supernate, wash the sludge, dissolve the sludge heel in nitric acid and treat it using anion exchange.

A refinement to the flowsheet presented as Option 4 is the elimination of the cation exchange step and the use of anion exchange to recover the Am and Pu from the dissolved sludge solution. This approach takes advantage of the moderate absorption of trivalent actinides and

lanthanides on anion exchange resins from high nitrate/low acid solutions. See Fig. 5 which presents Am and Pu distribution coefficients (K_D) from lithium nitrate solutions. Because of the large reduction in waste volumes, the minimal amount of solids which must be handled, and the equipment simplification, most of the recent efforts at Los Alamos have focused on testing this option using a radioactive acid-dissolved sludge simulant.

Fig. 5. Am and Pu K_D 's from LiNO_3 Solutions (Adar, et al., 1963)

This approach has been demonstrated before as part of the Oak Ridge National Laboratory (ORNL) Transplutonium Element Production Program. At ORNL during the 1960's and early 1970's, the High Flux Isotope Reactor (HFIR) was used to produce higher actinides from highly irradiated Pu-Al alloy targets. In order to recover the valuable isotopes, many different solvent extraction and ion exchange methods were developed for the recovery and purification process. One of the procedures developed uses a high nitrate/low acid solution to remove the Am-Cm fraction from Pu process waste streams (Lloyd, 1963). The flowsheet for this process is presented in Fig. 6. This method used standard anion exchange resin and standard fixed bed columns. Essen-

tially, the ORNL personnel were recovering Am and Cm from high Al and Fe solutions which also contained Sr, Cs, and other fission products. They demonstrated, on a pilot scale, over 99% recovery of the Am and Cm present (ORNL-3452). The demonstrated column capacities were on the order of 20g of metal/L of resin. The only problem identified during the pilot-scale runs was the post-precipitation of Al upon acid adjustment. However, for the proposed SY-102 flowsheet, the Al concentration is considerably lower and therefore post-precipitation will not be a problem. Other work has been done on lanthanide and trivalent actinide behavior in high nitrate/low acid solution by Danon (1958), Marcus (1959), and Adar et al., (1963).

Fig. 6. ORNL Am-Cm Recovery Flowsheet (Lloyd, 1963)

In the Option 5 flowsheet, the dissolved sludge solution is mixed with a reducing agent, such as ferrous sulfamate, to reduce the Pu(IV) to Pu(III). The solution is passed through a primary anion exchange column on which the Th and U preferentially load. Under the high nitrate/low acid conditions, Am forms an anionic complex which, along with the Pu(III), is retained on the resin. However, both the Am and Pu are readily displaced by the much larger concentration of Th and U. This displacement is assisted by the higher K_D s for Th and U as compared to Am and Pu. The Pu and Am continue on to a secondary anion exchange column where they are sorbed. When the primary column is fully saturated with Th and U, and nearly all of the Pu and Am have been displaced, the column is washed and then eluted with a

dilute acid solution. The Th and U in the eluate is discarded as LLW. The Pu and Am loaded on the secondary column is also eluted with a dilute acid solution. This eluate is then precipitated with concentrated NaOH to recover the Pu and Am as hydroxide complexes.

This approach would eliminate the accumulation of Th and Fe in the ion exchange steps and potentially yield a concentrated Pu/Am hydroxide cake. The resulting hydroxide cake could then be calcined to a stable oxide and made available for disposal at WIPP or placed in glass using the HWVP when it comes on line. Thus, nothing but liquid LLW would be generated while remediating the tank. This option is presented as a flow diagram in Fig. 7. The supporting calculations are presented in the project interim status report (Yarbro, et al., 1994).

Fig. 7. Anion Exchange Actinide Flowsheet

Summary of Flowsheet Options

A summary and comparison of the waste volumes generated by each option is presented in Table 2. It is apparent that the anion exchange process offers a tremendous potential for the tank SY-102 remediation by significantly reducing the amount of TRU waste produced over that using any of the other options.

A simplification of the Option 5 flowsheet was selected by Los Alamos as the baseline flowsheet used in all engineering evaluations. Due to waste disposal constraints, there appears to be no significant benefit to separating the Pu and Am from the larger quantities of U and Th even though it is possible to do so. If all the actinides can be recovered together and no partitioning is needed, only a single recovery step using an anion exchange resin column is required. The reductant stream introduced to reduce the Pu(IV) to Pu(III) is no longer required and Pu distribution coefficients on the resin are significantly increased. This flowsheet is presented in section V. Recommended Design.

III. DESIGN BASIS

A. Assumptions

The flowsheet presented in this report can remediate tank SY-102. Remediate is defined as completely emptying the tank of both solids (sludge and salt cake) as well as the liquid supernate. This would put the empty tank in a safe configuration for sealing off and long term stabilization or allow it to be reused to remediate other HLW tanks in the 200W Area.

The goal of the remediation effort is to produce a waste form that is suitable for disposal by the safest, most environmentally friendly, and most economical method. There is a fixed inventory of actinides and fission prod-

ucts in the tank which must be either reclaimed for additional use (recycled) or prepared for disposal. By segregating the actinides and fission products from the bulk of the waste, the tank's contents can be effectively managed.

Remediation of the tank can be accomplished using conventional demonstrated technologies and equipment. Separation processes will be used to remove the actinides (Th, U, Pu and Am) and select fission products (Cs, Sr, and Tc) from the bulk of the tank's contents. The resulting LLW can then be disposed of using the existing demonstrated techniques of evaporation and grouting. The actinide and fission product fractions can be disposed of using whatever technique (i.e. glass vitrification or engineered storage) is ultimately approved for the site. The HWVP does not need to be operational to proceed with this remediation effort.

The separations will be accomplished using well established and demonstrated technologies with the primary unit operation being ion exchange. The actinide removal portion of the flowsheet has been demonstrated on a laboratory scale using a simulant which contained all the actinides and non-radioactive isotopes of the fission products.

The entire flowsheet has been modeled using Aspen Plus™ process modeling software, the Hanford Site standard. Using this model, the processing equipment has been sized and scaled to process the tank's contents in approximately six months. This entails operating the process continuously during this period with an overall availability of 70%. A conceptual design and equipment layout was developed which requires a small module of ~1,200 ft² (and 24,000 ft³). This is roughly the size of the hot cell in the existing 242-S Evaporator Building located near the SY-102 tank.

Table 2. Waste Volumes Produced by Option/Flowsheet

Option	High-Level Waste (L) (borosilicate glass vitrification)	Transuranic Waste (MT)s (solidification, to WIPP)	Low-Level Waste (L) (evaporation and grout vault)	National Asset (kg) (engineered storage)
Option				
1	~	~	~	~
2	0	2,815	0	0
3	0	527	2,200,960	0
4	0	8.2	3,011,390	0
5	0	0	2,785,470	60

B. Performance Criteria

The goal of this flowsheet is to remove specific elements from the tank waste such that the remaining volume meets the Nuclear Regulatory Commission's (NRC) Class A LLW description and can be disposed of using NRC approved techniques. The performance criteria for the proposed flowsheet are thus established by the definitions of the various waste classes. Table 3 presents the current tank inventory of key nuclides and the NRC waste limits.

In Table 3 the requirements are identified which must be met if there is to be any advantage in separating the actinides and fission products from the bulk of the tank's contents. Since all the waste limits are presented in terms of concentrations, the entire initial contents of the tank will be used as a basis. Thus, process efficiencies will be evaluated in terms of overall impact on the entire tank contents.

First, the TRU content of the waste, primarily Pu-239 and Am-241, must be <100nCi/g for TRU waste and <10nCi/g for Class A LLW. In terms of removal efficiencies or decontamination factors, this is 98.2% or 55 and 99.8% or 553 respectively. Removing 99.8% of the Am

initially present will be the major challenge. Second, there are two fission products of concern, Cs-137 and Sr-90. For the Cs-137, the Class A LLW limit is 1 Ci/m³. In terms of removal efficiencies or decontamination factors, this is 97.1% or 34 which is probably achievable from the basic solution. For the Sr-90, the Class A LLW limit is 0.04 Ci/m³. In terms of removal efficiencies or decontamination factors, this is 99.7% or 388 which will present a major challenge. In addition, the Tc-99 will be removed from the waste because of its high mobility in most waste forms and because the technique is relatively straightforward. A summary of the required removal efficiencies is presented in Table 4.

Table 4. Required Removal Efficiencies

Nuclide	Removal Efficiency (%)	Decontamination Factor
Pu-239	98.2	55
Am-241	99.8	553
Cs-137	97.1	34
Sr-90	99.7	388

Table 3. Tank SY-102 Sludge and Supernate Waste Limits

Nuclide	Tk SY-102			TRU#	Waste Limits		
	Sludge Content (Ci/m ³)	Supernate Content (Ci/m ³)	Supernate Content (Ci/m ³)		Class C LLW (Ci/m ³)	Class B LLW (Ci/m ³)	Class A LLW (Ci/m ³)
C-14	3.00E-03	-	4.66E-04	-	8	0.8	0.8
Co-60	2.00E-01	-	3.10E-02	-	700	700	700
Ni-63	6.00E+00	-	9.31E-01	-	700	70	70
Sr-90	1.00E+02	-	1.55E+01	-	7000	150	0.04
Tc-99	3.00E-01	-	4.66E-02	-	3	0.3	0.3
I-129	4.00E-04	-	6.21E-05	-	0.08	0.008	0.008
Cs-137	2.00E+02	4.00E+00	3.44E+01	-	4600	44	1
	(nCi/g)*	(nCi/g)*	(nCi/g)**	(nCi/g)	(nCi/g)	(nCi/g)	(nCi/g)
Np-237	9.40E-01	-	1.98E-01	<100	<100	<10	<10
Pu-239	4.14E+03	1.81E-01	8.72E+02	<100	<100	<10	<10
Pu-240	1.51E+03	-	3.20E+02	<100	<100	<10	<10
Am-241	2.06E+04	-	4.34E+03	<100	<100	<10	<10
TRU Totals	2.63E+04	1.81E-01	5.53E+03	100	100	10	10

* Assumes sludge density = 1.5g/mL

** Assumes solution density = 1.03g/mL

Alpha-emitting transuranic nuclides with half-life greater than 20 yrs.

IV. DESIGN ANALYSIS

A. Tank Sludge Waste Composition Studies

The first step in developing a viable flowsheet to remediate tank SY-102 is to determine the tank sludge composition. Los Alamos focused on tank sludge because other projects, such as the Initial Pretreatment Project, are examining the recovery of tank supernate. Therefore, while data was gathered on the SY-102 supernate and is included in the material balances, most of the discussion presented is on the sludge composition determination which was the most difficult task. This is because tank SY-102 has been used since its construction in the mid-1970's as an evaporator feed tank or to receive liquid wastes from numerous locations around the 200 West Area. This has resulted in a very complex mixture of cationic and anionic species. All experimental work and design calculations were based on the information obtained from the four segments of the 1988 core sample. However, a thorough examination of all the available composition data has been compiled (Birnbaum, 1993).

These core samples were evaluated with regard to sludge density, plutonium content, and radiation dose rate. Four separate core segments were obtained, each of which should have been 19 in. long. The bottom core segment recovered was 4 in. shorter than expected. It was assumed that the missing 4 in. is from the bottom of the tank since the recovered sludge from the lowest portion of the bottom 19 in. segment is quite dense and hard. The core sampler may have become jammed at the bottom, preventing recovery of the last 4 in. of the sludge.

A color, density, and hardness demarcation exists in the bottom segment, 4 in. from the lowest portion of the segment recovered. It is assumed that this lowest 4 in. represents the "salt cake" in the tank, and if we include the missing 4 in. portion of the bottom segment, a total of 8 in. of "salt cake" could be left in the tank compared to the 38 in. reported in 1981 (Agnew, 1993). A portion of this information is presented in a schematic form in Figs. 8 and 9. The remainder of the sludge recovered, i.e., the upper 11 in. of the fourth core sample and the 19 in. of the third are primarily wastes from plutonium reprocessing in which iron hydroxide was used to precipitate the TRU elements.

Samples of the tank sludge and supernate from both the October 1988 and March 1990 core samples were analyzed at Hanford for nonradioactive cations and anions, fission products, and transuranics. This data is correlated

and presented as a comparison of sampling procedures in Fig. 10.

Los Alamos has determined useful elemental composition limits on the tank and generated a database which contains all the composition data currently available from core and grab samples taken from 1984 through 1990 (Birnbaum, 1993). These include solid and/or liquid analytical data reported by Bratzel (1984 and 1985), Process Chemistry (1989), Scheele and Peterson (1990), Kirkbride (1992), and Herting (1990). Analysis of this data to estimate the variance of the current liquid and solid tank waste composition is complicated by a variety of factors which play a critical role in its interpretation. These factors include, but are not limited to:

- possible presence of severe matrix interferences in the sample analyses;
- loss of 4 in. of the core taken on October 25, 1988;
- uncertainty as to the location of sampling points in the tank;
- uncertainty as to the homogeneity of the samples;
- uncertainty as to the effectiveness of the aqueous extraction procedure used for the anion analyses;
- limited analytical data for important elements, such as Th, that might affect proposed remediation schemes;
- limited analytical data for radioactive isotopes, such as Sr-90 and Tc-99, that might affect proposed remediation schemes;
- uncertainty as to the isotope distribution for radioactive elements such as plutonium; and
- no closing material balances performed to estimate sample analysis error.

In an ideal situation, the multiple analyses presented for the tank supernate and sludge would allow one to place confidence limits on the analytical data. However, in this case, since the analyses were performed on samples taken from different locations in the tank, each analysis represents a single picture of the tank waste composition both in physical location and time.

Of the items listed above, four would be expected to introduce large uncertainties into the understanding of the tank composition. The first consideration is that the missing 4-in. section of the fourth segment of the core, taken from the bottom of the tank, particularly impacts the amount of Cs-137 in the tank. The major change in the feed stream to the tank in 1981 is indicated by a division

Fig. 8. Tank SY-102 Core Data

SY-102 Riser
 segments #1 thru 4, Nov. 1988,
 12712-PCL90-050, 7 March 1990

Fig. 9. Cross Section View of Tank SY-102

Fig. 10. Analytical and Sampling Data Correlation for the '88 and '90 Cores (Birnbbaum, 1993)

in the October 1988 core 4 in. from the bottom. If the missing 4-in. segment comes from the bottom of that core sample, as expected from the method of taking the core, then the bottom layer, formed from evaporator sludge, is really 8 in. deep instead of 4 in. deep. Since the Cs-137 present in the tank is found primarily in this portion of the sludge, we would expect that the concentration of Cs-137 in the tank is actually twice that reported in the core analysis. Similar increases of other components from the bottom of the tank would also be expected. In contrast, if the missing core section is from the top of the fourth core segment, then we would expect the Cs-137 concentration to be 20% less than reported.

A second consideration is the horizontal homogeneity of the tank composition. If the sludge accumulated in horizontal layers over time, then the October 1988 core sample would accurately reflect the composition of the entire tank. If mixing occurred as the tank was filled and emptied, then the core sample reflects the tank composition in only one region of the tank. The grab samples taken over the years might be used to provide useful information regarding the horizontal homogeneity of the tank. Unfortunately, the depth at which the each grab sample was taken is uncertain. This results in significant uncertainties when attributing the variations in composition observed to either differences in depth, with respect to the core, or to differences in the composition of the layer at one depth but at different points in the tank.

Considering the size of the tank and the time frame over which the sludges were accumulated, it must be recognized that the nine sets of analytical data presently available represent an extremely limited sampling program which is incapable of determining the magnitude of any horizontal inhomogeneity in tank composition that may be present. Horizontal inhomogeneities are likely to result from pumping slurries into the tank and supernates out of the tank, since the sluicing action of the pump will tend to preferentially deposit or remove sludge from the region close to the riser used for the transfer. If different risers were used to carry out the transfers over the years, then horizontal inhomogeneities are expected to be present over a large portion of the tank. Temperature gradients between the tank contents already present and the incoming slurry can also induce significant horizontal inhomogeneities of form. In the absence of horizontal inhomogeneities, the analyses of grab samples taken 6 in. from the bottom of the tank in 1984 might be expected to closely match the analyses of the bottom and mixed

samples taken from the 1988 core. However, the differences in the sample analyses are due to a variety of factors, including mixing of the sludge layer between 1984 and 1988, inhomogeneities in the sludge, and errors in estimating sampling depths and analytical procedures.

A third consideration is the absence of isotopic distribution data and anion concentrations for many of the analyses reported. The radiochemical data depend on the isotopic mixture in the sample. For example, Scheele and Peterson report individual alpha activities for Pu-238, Pu-239, Pu-240 and Pu-241, whereas Weiss reports only the sum of Pu-239 and Pu-240 activities. Similar problems occur for other radiochemical measurements where there exists more than one isotope of an element. In many cases, analyses for Na, NO₃, and NO₂, the most abundant components of the sludge, were not reported. The data for anions is extremely limited. No anion analyses were reported by Scheele and Peterson for the 1988 core, whereas Herting reports some anion data but no radiochemical information on the same sample. The differences in the type and detail of analytical information available from various investigators makes comparison of the reports to confirm the reliability of the data inconclusive.

A final consideration is the question of what analytical controls were applied in the acquisition of the data. A memo from R.L. Weiss of the Office of Sample Management (Weiss, 1990) indicates that no matrix specific standards or spikes were run for the October 1988 core analyses carried out by the Process Chemistry Laboratories. No mention of analytical controls are reported for any of the other analyses on the tank SY-102 samples. The lack of matrix controls would introduce much greater uncertainty than that expected based on the particular analytical method selected. Errors in excess of 100% can easily occur.

In order to ensure proper flowsheet development and provide sufficient information for detailed design, a third core should be removed from tank SY-102 and analyzed. To improve the overall analysis approach, the following points should be considered.

- Preferably, the core should be taken from a point distant from the tank wall, the pump pits, and other risers in the tank previously used to transfer slurry into and out of the tank. This is because the region close to these risers may exhibit atypical layering of the sludge.

- All analyses should be obtained both with, and without, control spikes in order to estimate the extent of matrix interferences which are of major concern in such a complex mixture.
- The homogeneity of the core sample should be evaluated prior to carrying out duplicate analyses in order to estimate if the observed range is associated with analytical error or the inhomogeneity of the sample.
- Analyses for anions should be carried out on the acid digested sample in order to ensure detection of anions present in the sludge as insoluble salts.
- Analyses should be completed for all species (including complexants and other organics) that might interfere with ion exchange, solvent extraction, or vitrification methods that might be proposed as part of an overall remediation flowsheet.
- Analyses should be completed for all radioactive isotopes that might determine the final classification of the remediated LLW fraction as LLW Class A or B.
- The plutonium isotope distribution should be determined in order to address potential criticality concerns during the remediation process.
- Care should be taken to obtain a good material balance in the sample to ensure that those elements not analyzed do not make up a significant fraction of the sludge.
- Care should be taken to obtain a good radioactivity balance in the sample to ensure that those isotopes not analyzed do not comprise a significant fraction of the total alpha, beta and gamma activities of the sludge.

If another core sample is not a practical option, then priority should be given to reanalyzing the available cores according to the above guidelines to resolve some of the differences in the data. Also, it is important to test the proposed separation techniques with actual tank waste to ensure the feasibility of the flowsheet. It is especially important to identify any species that might interfere with standard ion exchange separation techniques or the other unit operations involved in the process.

It should be clear from the above points that any estimate of the tank SY-102 waste composition based on these previously reported analytical results of both core and grab samples is limited. Thus, wide range estimates for critical elements must be used as a basis for any flowsheet proposed.

B. Simulant Development

In spite of the analytical uncertainties, it seems clear that >99.97% of the Pu is in the solid phase (presumably as insoluble hydroxides) and the supernate is already a LLW. Unfortunately, the Pu concentration in the solids is such that if the tank contents were mixed and the solids uniformly suspended in a slurry, the entire volume would be a TRU waste. A comparison of the radioactive waste legal definitions and the tank contents is presented in the Performance Criteria section in Table 3. Thus, the solid phase requires further treatment to reduce the actinide content and concentrate the TRU elements.

A "sludge-washing" technique was developed and demonstrated at Battelle's Pacific Northwest Laboratory on small samples of tank sludge by Lumetta and Swanson (Lumetta and Swanson, 1992). It involves contacting the solids with a dilute sodium hydroxide solution to dissolve large fractions of the nonradioactive components. This approach was incorporated in the flowsheet development and thus the simulant recipe reflected this pretreatment step. Of the several techniques attempted, using 0.1M NaOH at 25°C allowed for the ready removal of 99% of the K and Na, and less than 10% of the Al. It also removed a portion of the Cl, PO₄, SO₄, and F anions initially present. However, they also tested other methods which only removed the Na, K, Cs and PO₄ present in the sludge. Because Al is important to the success of the proposed flowsheet, it was assumed that the sludge could be washed with the supernate by mixing the tank contents and not dissolve the Al, Fe, and Cr present. The resulting washed sludge could then be dissolved in nitric acid to make it available for further treatment. Therefore, the simulants used in the experimental studies were based on the assumption that only the alkali metals dissolve to any significant extent in the supernate/sludge wash and the remaining metal cations dissolve in the acid dissolution of the sludge.

Based on this information, a simulant recipe was originally developed by Marsh at Los Alamos and is presented in Table 5. The minimum amount of acid was used to get the components into solution. Thus, this simulant of the dissolved tank sludge has a low acid content (~0.1M) and a high nitrate content (~6.0M). It was used as the basis for the initial separation studies and flowsheet modeling. The Al concentration was increased to 1.2M in later simulants to account for the Al not removed from the sludge. Such changes are detailed in the Experimental Work Section which follows.

Table 5. Tank SY-102 Acid Dissolved Sludge Simulant Preparation Procedure (Marsh, 1993)

Basis: 1 L of simulant.

<u>Component</u>	<u>Compound</u>	<u>Moles</u>	<u>Grams</u>
Ca	$\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$	0.16	37.8
Cr	$\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$	0.40	160
Cu	$\text{Cu}(\text{NO}_3)_2 \cdot 2.5\text{H}_2\text{O}$	0.02	4.65
Fe	$\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$	0.45	181.8
K	KNO_3	0.008	0.81
Mg	$\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$	0.07	17.9
Mn	$\text{Mn}(\text{NO}_3)_2$	0.165	57ml of 52% soln
Na	NaNO_3	0.44	37.4
Ni	$\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$	0.01	2.91
Pb	$\text{Pb}(\text{NO}_3)_2$	0.014	4.63
Sr	$\text{Sr}(\text{NO}_3)_2$	0.001	0.22
Al	$\text{Al}(\text{NO}_3)_3$	0.506	230ml of 2.2M soln
Above salts dissolved in 200mL of 0.5M HNO_3 when heated in a hot water bath.			
Th	$\text{Th}(\text{NO}_3)_4 \cdot 5\text{H}_2\text{O}$	0.03	17.1
U	UO_2	0.03	8.1
UO_2 dissolved in 40mL of H_2O and 4mL of 15.6M HNO_3 added to the solution.			
Cl	HCl	0.015	1.3mL of 12M acid
PO_4	H_3PO_4	0.01	0.7mL of 14M acid
SO_4	H_2SO_4	0.01	0.6ml of 16M soln
Acids diluted in 40mL of H_2O then added to the solution while stirring.			
Si	$\text{Na}_2\text{SiO}_3 \cdot 9\text{H}_2\text{O}$	0.08	22.7
Silicate dissolved in 50mL of H_2O , HF and 50mL of 0.5M HNO_3 with heating in a hot water bath.			
F	HF	0.075	2.6ml of 28M soln
HF added to silicate solution, ppt. formed immediately but dispersed with stirring and heating in a hot water bath.			
Se	H_2SeO_3	0.03	3.87
Se dissolved in 50mL of H_2O .			
Am	AmO_3	3.7E-5	0.036 of 30% oxide
AmO_3 dissolved in 11mL of 15.6M HNO_3 then added to the solution while stirring.			
Pu	$\text{Pu}(\text{NO}_3)_4$	4.2E-4	0.003mL of 33g/L soln
The entire solution was cooled to room temperature and sufficient H_2O was added to bring the solution volume to 1.00L. Silica, which precipitated, was removed by filtration.			

C. Experimental Work

The following section is a summary of the experimental work performed at Los Alamos in support of the anion exchange flow sheet option presented earlier in this report. The first goal was to demonstrate the feasibility of using anion exchange for the selective removal of the actinides on a bench scale. The second goal was to use the data from these initial experiments to predict system performance and demonstrate the process on the pilot scale.

As mentioned previously, this approach is based on earlier studies performed at ORNL and Argonne National Laboratory (ANL) with high nitrate/low acid solutions (Adar, et al., 1962; Lloyd, 1963; and Lloyd and Leuze, 1961). These investigators found that trivalent actinides could be successfully retained on anion exchange resin under conditions of low acid and high nitrate concentrations. The apparent mechanism for this selectivity is the formation of anionic actinide-nitrate complexes that are readily retained by the resin.

Experiments were conducted to further investigate anion exchange for the removal of the major actinides present in the tank sludge, primarily Th, U, Pu and Am. Of these, Pu and Am must be removed with a high degree of selectivity in order to meet stringent Class A LLW criteria. Since the work of the earlier investigators suggests the retention of Am is the least favorable of the actinides present, most of our initial experiments focused on optimizing the removal of Am.

The experiments, conducted in existing R&D gloveboxes, were designed to determine if Am anion exchange is thermodynamically favorable under conditions of high nitrate/low acid and if the process can be realized in a flowing system under these conditions. Based on the results of these experiments, optimal processing parameters for a full scale operation can be calculated. This information can then be used to predict how the process will perform on the full scale.

Materials

The composition and method of preparation for the tank SY-102 acid dissolved sludge simulant used in the initial experiments are as presented previously in Table 5. Depending on the experiment involved, this recipe was varied to obtain the desired information. During the initial experiments it was discovered that certain species in the simulant had a very significant effect on the retention of Am. Because of this, the simulant recipe was varied

within the constraints imposed by the flow sheet in order to optimize the anion exchange of Am. The Resource Conservation and Recovery Act (RCRA) listed metals were replaced with non-RCRA listed metals (e.g. Fe^{3+} for Cr^{3+}) in most of the experiments to avoid the generation of mixed hazardous waste. Where appropriate, these variations are noted later in this section.

Most experiments were performed using Reillex HPQ, a macroporous polyvinylpyridine strong base anion exchange resin developed jointly by LANL and Reilly Industries, Inc. Originally developed for the recovery of plutonium from aqueous nitrate process streams, Reillex HPQ is characterized by excellent resistance to chemical attack and radiolytic degradation (Marsh, 1989; and Marsh, 1990). The resin, 40 to 70 mesh, was converted from its as-received chloride form to the nitrate form prior to use. Dowex 1x8-200, a polystyrene-divinylbenzene resin similar to that used in the ORNL studies, and Purolite A-520E, a polystyrene resin that appeared promising in other batch studies, were also tested.

Experimental

A summary of each experiment and the logic used to design subsequent experiments are presented in this section. Details of each experiment are presented in Appendix A.

In the first set of experiments simulant solutions containing Th, Pu, and Am were contacted with a batch of HPQ resin. The purpose of these experiments was to verify that Am removal from the simulant solution by anion exchange would be possible and of sufficient magnitude to suggest that a full scale process using this technology would be feasible.

The simulants used in both experiments contained 6M NO_3^- and 0.5M H^+ . The simulant used in the first experiment (#1) had the same composition as that shown in Table 5. The simulant used in the second experiment (#2) is the same as that used in experiment #1, except the RCRA listed cations were replaced with non-RCRA listed cations of the same valence. The experiments consisted of contacting 1g of resin with 10 ml of simulant for a period of 15 minutes. The solution was then analyzed for Pu and Am by radiochemistry.

Nearly all of the Pu and a significant amount of the Am was removed from the simulant by the HPQ resin. Distribution coefficients, defined as

$$K_d = \frac{\text{mg of solute / g of resin}}{\text{mg of solute / ml of solution}}$$

were calculated. In experiment #1 the K_D s for Pu and Am were 607 and 7.8, respectively. In experiment #2 the K_D s for Pu and Am were 1650 and 12.2, respectively. These results show that the retention of Am under the given conditions is thermodynamically favorable. As expected, the retention of Pu is much greater than that of Am. These encouraging results led us to pursue additional experiments using an ion exchange column.

In the next series of experiments, simulants containing Th, U, Pu, and Am were pumped through a bench scale ion exchange column containing HPQ resin. The purpose of these experiments was to determine how the anion exchange of Am behaves in a flowing system, what variables are important, and how the presence of other exchanging anions (Th, U, and Pu nitrate complexes) affect Am ion exchange.

The ion exchange column and supporting equipment used is shown in Fig. 11. The column is a 1.5 cm diameter by 14.5 cm high Pyrex tube with Kynar frits and valved fittings on each end. The corresponding total column bed volume is 25.6 cm³. A Lab Pump Jr. Model RHSY metering pump manufactured by Fluid Metering, Inc. was

used to pump solution through the column. A graduated reservoir connected to the pump inlet was used to deliver measured liquid volumes. The entire assembly was located inside a glovebox within the Plutonium Facility. Each run was made at room temperature with a 6M NO₃⁻, 0.5M H⁺ simulant. For these experiments the RCRA listed cations in the simulant were replaced with non-RCRA listed cations of the same valence.

Experiments #3, #4, and #5 were made at a volumetric flow rate of 1.13, 2.26, and 5.66 ml/min-cm², respectively. These flow rates correspond to 0.078, 0.156, and 0.39 column volumes per minute. Effluent samples were collected at specified intervals and analyzed for Am using an at-line gamma spectrometer. After each experiment any actinides remaining on the column were eluted with 0.5M HNO₃.

The effluent Am concentration profiles for experiments #3, #4, and #5 are shown in Fig. 12. It can be seen that Am breakthrough began almost immediately in each experiment, with the Am concentration approaching that of the feed after approximately 180 ml (7 column volumes) had been eluted. As expected from the results of the

Fig. 11. Single Column Anion Exchange Apparatus

Feed: 7.4 ppm Am with Th and Pu, 6M NO₃⁻, 0.5M H⁺

Fig. 12. Effect of Flowrate on Americium Retention

batch contact experiments, the Am was retained to some degree on the resin. This is evidenced by the gradual climb of the curve, rather than an immediate step increase, to the Am concentration of the feed, 7.4 ppm.

The Am concentration profiles shown in Fig. 12 also indicate that flow rate has a significant effect on the retention of Am. The first feature to note is that at lower flow rates more solution must be passed through the column before the onset of Am breakthrough. Although channeling can explain this phenomenon, the cause is probably due to slow ion exchange kinetics and/or equilibration between the Am nitrate anionic complex and the neutral and cationic Am complexes. Since HPQ is an anion resin, only the anionic Am complex will be retained.

The second feature to note is the overshoot in the effluent Am concentration relative to the feed concentration at effluent volumes beyond five column volumes. The overshoot itself is explained by the displacement of Am by Th and Pu. Such displacement is likely to occur since the distribution coefficients for Th and Pu are significantly greater than that for Am. In addition, Th is present in significantly higher concentrations than Am in the simulant feed. Also, the overshoot is highest at the lowest flow rate, suggesting more Am is being displaced. This is not unexpected since more Am is retained on the

column at lower flow rates, as evidenced by the delay in the onset of breakthrough. Therefore, more Am will be displaced at lower flow rates as Th and Pu continue to load on the column.

In experiment #6, the effluent Am concentration was allowed to overshoot and return to the feed concentration to better characterize the displacement of Am by Th and Pu. The lower flow rate of 0.078 column volumes per minute was used, with the same simulant recipe that was used in the previous three experiments. The effluent Am profile for experiment #6 is shown in Fig. 13. As expected, the Am concentration in the effluent approaches the Am concentration in the feed after the overshoot.

Since the results of this first series of column experiments indicated that Am was being displaced in the presence of Th and Pu, it was decided to investigate the loading of Am in the absence of the other actinides. The motivation for moving in this direction was that the anion exchange could be set up in two stages, where Th(IV) and U(VI) are removed on one column prior to removing Am(III) and Pu(III) on a second column. In a two column arrangement such as this, a reducing agent would be added prior to the first column to convert Pu(IV) to Pu(III). This would allow the Th to displace Pu from the first column to the second column.

Feed: 11.5 ppm Am with Th and Pu, 6M NO₃⁻, 0.5M H⁺

Fig. 13. Complete Americium Effluent Concentration Profile

The results of investigators at ORNL and ANL (Adar, 1962; and Lloyd, 1963) suggested that a lower acid concentration significantly improves the distribution coefficients for the trivalent actinides. Therefore, the effect of acid concentration was investigated in experiments #7 and #8. Experiment #7 was made with 0.5M H⁺ and experiment #8 was made with 0.1M H⁺. The lower flow rate of 0.078 column volumes per minute was used, and the simulant was prepared with only Al, Fe, and Na salts along with Am at ~20ppm. This simplified simulant was used to reduce the complexity of simulant preparation and still not compromise its effect on Am ion exchange. Additional NaNO₃ was added to bring the total NO₃⁻ concentration to 6M.

The resulting effluent Am concentration profiles are shown in Fig. 14. Although the onset of Am breakthrough for both runs is still just over one column volume, the rate at which the 0.5M H⁺ Am profile rises is significantly greater than that at the lower acid concentration. Extrapolation of the profiles to the inlet feed concentration and integration of the area above the profile and below the inlet feed concentration allows the resin capacity to be estimated. The capacities thus calculated for the 0.5M H⁺ and the 0.1M H⁺ runs are 25 and 450 mg/L of resin, respectively. This confirms the earlier investigators' findings that a lower acid concentration helps Am retention in a flowing ion exchange system.

Based on these results, it was decided to perform a series of batch contacts to investigate the effect of contact time, resin type, H⁺ and NO₃⁻ concentrations, and major cations on Am retention. Within the bounds imposed by the flow sheet, the results of these experiments would identify the most optimal conditions under which to perform the ion exchange step.

The effect of contact time was investigated in experiment #9. The simulant was made with Al, Fe, and Na nitrate salts resulting in a 0.1M H⁺, 3.0M NO₃⁻ solution along with Am at ~20 ppm. 1g of HPQ resin was contacted with 10 ml of simulant for 5, 15, and 30 minutes. The K_Ds calculated for these contact times were 1.0, 0.94, and 0.94, indicating that equilibration is rapid, occurring within five minutes.

In experiment #10 resin type was evaluated. Using the same quantities of resin and simulant as in experiment #9, three resins were tested: Dowex 1x8-200, Purolite A-520E, and HPQ, all of which are described in the materials section. The K_D calculated for the Dowex, Purolite, and HPQ resins were 0.77, 0.41, and 1.15, respectively. Based on these results, HPQ resin was chosen for further work.

In experiment #11, NO₃⁻ and H⁺ concentrations were varied to determine their effect on Am retention. A matrix of 0.1M/0.05M/0.01M H⁺ by 3M/4M/6M NO₃⁻ concentrations along with Am at ~20 ppm was tested, using the

Feed: 6M NO₃⁻, without Th and Pu

Fig. 14. Effect of Acid Concentration on Americium Retention

same amount of HPQ resin and simulant as before. In the range of concentrations tested, NO₃⁻ had a significant effect on Am retention, with the best performance observed at the highest NO₃⁻ concentration. Contrary to the results reported by the ORNL investigators, H⁺ concentrations between 0.1 and 0.01 had essentially no effect on Am retention. From these tests it became apparent that a high NO₃⁻ concentration is essential for acceptable Am anion exchange. In addition, considering the results of this experiment as well as experiments #7 and #8, acid concentration is not a significant factor as long as it is at or below 0.1M H⁺.

The effect of different cations was investigated in experiment #12. As in the previous three experiments, 1g of resin was contacted with 10 ml of simulant. In each case the simulant was prepared from a single, but different, nitrate salt to achieve a 6.8M NO₃⁻, 0.05M H⁺, ~20ppm Am solution. The cations tested were the major constituents in the tank sludge: Na⁺, Cr³⁺, Fe³⁺, Ca²⁺, Mn²⁺, and Al³⁺. A significant difference was observed in the amount Am retained on the resin in each case. The most Am was retained in the presence of Al³⁺, followed in descending order by Cr³⁺, Fe³⁺, Mn²⁺, Na⁺, and finally Ca²⁺. These results showed that a high trivalent cation concentration, in particular Al³⁺, is important for optimal Am retention.

A flow study was performed in experiment #13 using the ion exchange column from experiments #3-#8. Instead of one of the usual simulant variations, this experiment was performed with a nearly saturated solution of Al(NO₃)₃ (2.26M Al³⁺, 6.78M NO₃⁻, 0.05M H⁺, and ~20ppm Am). Although this solution does not represent the dissolved tank sludge, it was desired to see how much improvement in Am retention could be expected in a flow system, in effect, an upper bound on system performance. The 0.05M H⁺ was selected as a compromise to be below 0.1M H⁺.

The effluent Am concentration profile for experiment #13 is shown in Fig. 15. It can be seen that the Am concentration in the effluent did not reach 1.0% of the feed Am concentration until 440 ml, or 17 column volumes, had been passed through the column. This is better than the performance observed by the ORNL investigators, who also had feed solutions containing a high concentration of Al³⁺.

Experiment #14 was a repeat of experiment #13, except that the simulant feed was made to 1.28M Al in the presence of the other major cations. This feed composition represents the maximum achievable Al concentration if the sludge wash is performed such that nearly all of the Al remains in the sludge. The effluent Am concentration profile for this run is shown in Fig. 15. It can be seen that

Fig. 15. Effect of Aluminum Concentration on Americium Retention

the Am concentration in the effluent reaches the 1.0% level after approximately 170 ml, or 6.6 column volumes, have been passed through the column. While the retention of Am at the lower Al concentration is considerably less, it is still within acceptable limits for a successful recovery operation.

Experiment #15 was a repeat of experiment #14, except that the run was allowed to continue until the effluent Am concentration reached approximately 65% of the simulant Am concentration. By extrapolating the Am profile, it was possible to estimate the resin capacity as was done in experiments #7 and #8. The resulting capacity, 0.43 g Am/L of resin, was similar to that of experiment #8. This capacity was high enough to warrant further study.

A new column arrangement was used in experiment #16 in order to determine the Am concentration profile along the length of the ion exchange column. This information was necessary to predict column performance and optimize its design. The 1.5 cm diameter column was replaced with a five column arrangement as shown in Fig. 16. Each column was 1.0 cm in diameter by

Fig. 16. Five Column Anion Exchange Apparatus

15 cm in length. The columns were connected in series, resulting in an effective column length of 75 cm.

The simulant used in the previous two experiments (1.28M Al) was used in experiment #16. The flow rate was set at 1.0 ml/min to maintain the same linear velocity through the columns as before. Effluent samples were collected at the outlet of the last column and analyzed for Am using the gamma spectrometer. The experiment was terminated when the Am concentration in the effluent exceeded 1.0% of the feed Am concentration.

The resulting effluent Am concentration profile for experiment #16 is shown in Fig. 17. The Am concentration reached the 1.0% level after 1120 ml, or 19 column volumes, of simulant had been fed. Next, each column was isolated and the Am eluted with 0.05M HNO_3 . Sixty milliliters of eluant was sufficient to elute the Am from each column. The resulting Am loadings on each column are shown in Fig. 18. As suggested by the elution profiles from previous experiments, the results shown in Fig. 18

confirm that Am loads on the resin with a nonsharpening front.

Experiment #17 employed the same five column arrangement used in experiment #16. The other actinides (Th, U, and Pu) were added to the simulant to determine their effect on column performance. In addition, the RCRA listed metals as well as most other anions and cations present in smaller concentrations were added. The resulting effluent Am concentration profile for experiment #17 is shown in Fig. 19. The Am concentration reached the 1.0% level after 640 ml, or nearly 11 column volumes, of simulant had been fed. Each column was then eluted with 0.05M HNO_3 . The resulting Am loadings on each column are shown in Fig. 20. It can be seen that the largest amount of Am is present on the fifth column. These results are in agreement with our previous results and those of the ORNL investigators in that Am is displaced from the resin by the other actinides.

Fig. 17. Effluent Profile for Americium in Five Column System

Fig. 18. Americium Distribution on Ion Exchange Columns

Fig. 19. Effluent Profile for Americium with other Actinides Present

Fig. 20. Americium Distribution on Ion Exchange Columns with Other Actinides Present in Feed

The final goal of the experimental work was to establish the optimal flow rate through the resin bed to allow for proper scale up to the production sized equipment. Flow rate through an ion exchange column may be expressed as either a linear velocity [m/h or L/(h)(m²)] or a volume velocity [(L feed)/(L resin bed)(h)]. The approach involved determining the optimal flow rate through the resin bed to minimize the amount of resin required. There are two competing effects taking place as the flow rate of the feed is changed. Increasing the flow rate of the feed solution reduces the volume of resin required to be on stream to treat a set volume of feed by the following relationship (Schweitzer, 1979)

$$\text{Resin volume on stream (L resin)} = \frac{\text{solution to be treated (L feed / h)}}{\text{volume flow rate (L feed / L resin · h)}}$$

However, increasing the flow rate of the feed solution also reduces the resin capacity and thus increases the total amount of resin required to extract the actinides from a set volume of feed solution.

Experiment #18 consisted of a number of runs at various volume velocities in which the resin capacity was determined at the 1% Am breakthrough point. The simulant used was the same as in experiment #17 that

included all the actinides (Th, U, Pu, and Am), most of the anionic and cationic impurities, and the RCRA listed metals. Due to the physical and time constraints on the system, the resin bed depth could not be held constant in all runs, but the results were normalized with respect to the relative column volumes (resin bed volumes) of feed treated. The results are presented in Fig. 21 with the breakthrough capacities for Am determined at the various feed volume velocities.

With this data, an "on-line resin volume" was determined for comparison of the different feed volume velocities. The column capacity was normalized at 10 column volumes or bed volumes (BV). The rate of feed treatment was fixed at 1 gpm or 227.1 L/h. The following equation was used to calculate the resin volume on line.

The results are presented in Fig. 22 in which the "on-line resin volumes" are plotted against the various feed volume velocities. The minimum resin value fixed the optimal feed rate at 7.5 BV/h. This value was then used to size the actinide column for the full-scale processing equipment.

$$\text{Resin volume on line (L resin)} =$$

$$\frac{(\text{L feed / h} = 227.1)}{(\text{L feed / L resin · h})(\text{BV} / 10 \text{ BV})}$$

Fig 21. Column Capacity for Am vs. Feed Volume Velocities

Summary of Experimental Work

The use of anion exchange for the selective removal of actinides from dissolved SY-102 tank sludge was investigated. Using simulated solutions containing the actinides, batch contact and column flow experiments were performed on the bench scale to demonstrate and optimize the process. The effect of nitrate concentration, free acid concentration, specific cation concentrations, resin type, and flow rate were investigated. It was determined that the free acid concentration should be maintained at or below $0.1M$, that nitrate concentration should be kept as high as possible (preferably above $6M$), and the trivalent cation concentrations, in particular Al^{3+} , should be kept

as high as possible. Reillex HPQ resin was the best performer of the resins tested. The americium nitrate complex was observed to load in a nonsharpening front, and is displaced from the resin by the other more strongly bound nitrate complexes of thorium and plutonium. All actinides are easily eluted from the resin with a minimal amount of a low nitric acid solution ($0.5M$ or less). Finally, experiments were performed at various flow rates and resin bed volumes to optimize resin usage. It was found that ~ 7.5 bed volumes/hour is the optimal flow rate. This information was then used to size the anion exchange equipment for the full scale process.

Fig 22. Resin Volume vs. Feed Volume Velocities

D. Process Flow Diagram Development Using Aspen Plus™ Modeling Software

The Aspen Plus™ chemical process modeling and simulation package marketed by Aspen Technology, Inc. was used to model the tank SY-102 remediation flow sheet. A process flow diagram (PFD) and stream summary based on this model are given in Section V. Recommended Design. The output file in Appendix B has additional information on the simulation as well as hidden stream summary data.

As a "first pass", the modeling is primarily limited to defining stream flows through an overall material balance. In this first pass simulation, all streams are modeled as aqueous electrolyte liquids. The only chemical reaction

taking place is the that of H^+ and OH^- to make H_2O . Eakman and Golam from New Mexico State University compiled extensive thermodynamic data that can be used to assemble a more realistic simulation (Eakman and Golam, 1993). Time did not allow this information to be incorporated in this first pass modeling effort. However, it is available for use in future iterations of the model which may include additional reactions, material phases, and energy requirements.

Referring to the PFD and the stream summary, the composition of stream one is based on the current knowledge of tank contents. A split of 5:1 liquid:solid ratio is assumed in the tank. Again, for modeling purposes, both the liquid and solid portion of the tank are assumed to be

two aqueous liquid streams in this first iteration. The composition of the tank liquid/supernate is given in the stream summary portion of the Aspen output file, Appendix B, as stream 1SUPR. The composition of the tank solids/sludge is given in the stream summary as stream 1SLUD. These are combined to form stream one on the PFD, which represents the sludge washing step.

The composition of streams two and three are based on the sludge washing studies of Lumetta and Swanson (Lumetta and Swanson, 1992). As mentioned in the experimental section, a high Al content is essential for the actinide anion exchange unit operation. Although the sludge washing studies of Lumetta and Swanson suggest that as much as 70% of the Al may be dissolved out of the sludge, their results also show that Al dissolution is very dependent on time and temperature, and that the actual amount dissolved may vary considerably. It is therefore assumed that the sludge washing can be done such that 99% of the Al remains in the sludge. It is also assumed that 99% of the K and Na and 90% of the Cs is dissolved from the sludge and goes to the supernate.

As shown in the PFD, the washed sludge is dissolved in concentrated HNO_3 to yield a slightly acidic (0.05M H^+) product. The actinides are then removed by anion exchange, followed by Sr removal by ion exchange. The resulting stream (16) is combined with the supernate stream (27) after the Cs and Tc have been removed by cation and anion exchange, respectively. The actinide products from anion exchange are precipitated with NaOH, then calcined to an oxide. The caustic liquid from the precipitation is combined with streams 16 and 27.

Streams 15, 24, and 25 represent the removal of Sr, Cs, and Tc, respectively, by removal of the loaded resin. Since the model is set up with aqueous stream flows only, the flow rates for these streams are shown as zero on the PFD and stream summary. The density is also not given for these streams in the stream summary. The frequency and amount of backflush acid for the filter F-S-1 is not known a priori. Therefore, the flow rates for streams six and nine are listed as zero in the stream summary. Similarly, the heat loading required to dissolve the sludge in tank TK-S-1/2 is not known, so streams seven and eight are listed as zero.

Based on the input parameters specified, the combination of streams 16, 19, and 27 result in a solution caustic enough for direct cementation. However, due to uncertainties in the various feed compositions and splits, stream 28 is provided so that either HNO_3 or NaOH may be added as needed.

V. RECOMMENDED DESIGN

The following flowsheet with the associated preliminary equipment and cost estimates is based on the empirical results of the experimental work and the process modeling efforts. This preliminary design is presented for "order-of-magnitude" type comparison to other options currently being evaluated for remediation of the HLW tanks.

A. Process Flow Diagram/Material Balance

The flowsheet PFD and associated material balance were developed using the Aspen Plus™ process modeling package. They are presented as Figs. 23 and 24 and are available as LANL drawing 26Y-203029.

B. Equipment – Sizing and Physical Cost Estimate

The list of major pieces of equipment was developed based on the results of the Aspen Plus™ process modeling. Conservative estimates were made in sizing the various vessels. Conservative estimates were also made in the number of redundant vessels required to achieve the desired cycle times which is based on changing out the actinide ion exchange column once per eight-hour shift.

The sizing of the actinide column, which was the major separations process evaluated in this study, was performed using methods presented by Anderson in the *Handbook of Separation Techniques for Chemical Engineers* (Schweitzer, 1979). The maximum flow rate that gives satisfactory performance is determined in laboratory scale studies. This flowrate is then held constant in the scale-up process. Ion exchange data taken in 2.5-cm columns can be scaled up directly to any diameter column if the resin bed depth is kept constant. The most critical factor in this scale-up is that the feed be uniformly distributed over the resin surface and collected uniformly from across the bottom of the column (thus no channeling of solution occurs through the bed). Scaling up the height of the column will not change the shape of the effluent curve but will delay breakthrough. As a general rule-of-thumb, scaling up the column height by a factor of two is more likely to give an improvement in useful performance over laboratory scale columns than to reduce performance. The optimum flow rate determined at the laboratory scale should be maintained in the full-sized column. As long as the volume velocity is held constant, the cycle time and concentration profile do not change, regardless of column diameter. Only the volumes of liquid and resin change.

PRELIMINARY
NOT TO BE USED
FOR FABRICATION

1 BASIC SLURRY FEED	11 DISSOLVED SLUDGE FEED	21 ACTINIDE CALCIUM OFFGAS
2 BASIC SUPERNATE	12 0.05M NITRIC ACID ELUTION SOLUTION	22 ACTINIDE OXIDE
3 SLUDGE	13 ACTINIDE EFFLUENT	23 BASIC SOLUTION FEED
4 10M NITRIC ACID	14 ACTINIDE EFFLUENT	24 SPENT Ca RESIN
5 DISSOLVED SLUDGE	15 SPENT SR RESIN	25 Ca EFFLUENT
6 NITRIC ACID BACKFLUSH	16 ACTINIDE/SR EFFLUENT	26 SPENT Te RESIN
7 STEAM	17 10M SODIUM HYDROXIDE	27 Te EFFLUENT
8 STEAM CONDENSATE	18 ACTINIDE PPT SLURRY	28 16M NITRIC ACID OR 10M SODIUM HYDROXIDE
9 NITRIC ACID BACKFLUSH	19 ACTINIDE FILTRATE	29 GROUT PPT SLURRY
10 FILTERED DISSOLVED SLUDGE	20 ACTINIDE HYDROXIDE CAKE	

NOTE:

FLOW RATE (KG/HR)

ORIGINAL ISSUE			
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1	10/1/78	W. J. H. H.	W. J. H. H.
Los Alamos			
Los Alamos National Laboratory			
Los Alamos, New Mexico 87545			
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TITLES			
TWRS TK-102-SY			
REMEDIATION EQUIPMENT			
VOLUME - SHEET NUMBER			
1 OF 1			
SHEET NO.			
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PROJECT NO.			
26Y-203029			
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Fig. 23. Tank SY-102 Process Flow Diagram (26Y-203029 Shr 1)

The column may be intentionally oversized to give a capacity that fits a work-specific period.

For the full-scale actinide recovery anion exchange system, the column was sized based on the factors of optimum flow and the quantity of solution to be processed per unit time. In order to achieve the goal of remediating tank SY-102 in six months with a 70% efficiency factor, dissolved sludge must be processed through the actinide column at a rate of ~ 1 gpm or 227.1 L/h. Our experimental work indicated an optimal flow of 7.5 bed volumes (BV) per hour. The minimum volume of resin that must be on stream was determined by dividing the volume of the stream to be treated per unit time by the volume velocity.

This volume of resin was then increased to achieve a 50% loading with actinides in an eight-hour shift. The geometry of the actinide column was then determined by applying the above factors from Anderson. In particular, the resin bed depth was increased by a factor of five over that used in the laboratory scale studies. For all the other ion exchange columns, a less rigorous approach was used but volume velocities were maintained at or below the 7.5 BV/h rate.

The following list, presented as Table 6, presents the equipment identified by its Aspen designator and a brief summary of its characteristics.

Table 6. Equipment Characteristics

Item	
Designator	Characteristics
241-SY-102	<p>Description: Subterranean carbon steel tank lined with concrete, right cylinder with a domed top and a flat bottom</p> <p>Capacity: 1.1×10^6 gallons = 147,000 ft³</p> <p>Size: Diameter = 75 ft, height = 35 ft</p> <p>Contents: (As of 12/92) 2,551,000 L of slurry, with 396,000 L of sludge and 2,155,000 L of liquid</p>
P-S-1	<p>Description: Recirculation pump to wash and suspend the sludge as a slurry using an internal spray nozzle</p> <p>Capacity: 106,000 L/hr or 1,800 L/min</p> <p>Basis: Turn over of the tank contents once per 24 hour period</p>
C-S-1	<p>Description: Centrifuge to separate solids from liquids in slurry</p> <p>Capacity: 1,000 L/hr</p> <p>Basis: Provide feed to Sludge Dissolver at 120 L/hr (0.6 m bowl diameter)</p> <p>Size: Estimated at 1.5 m X 1.5 m X 2.0 m</p>
TK-S-1/2	<p>Description: Two sludge dissolvers using heated/stirred tanks to dissolve sludge in a batch mode, one vessel receiving feed from the centrifuge and the other dissolving and transferring feed</p> <p>Capacity: 2,500 L</p> <p>Basis: Provide a dissolved acidic feed to the actinide column feed tank</p> <p>Size: Cylindrical D = 1.25 m, H = 2.0 m</p>
AMU-TK-1	<p>Description: Aqueous make-up tank for concentrated nitric acid to feed TK-S-1/2</p> <p>Capacity: 1,000 L</p> <p>Basis: Provide 700 L nitric acid per 8 hr shift</p> <p>Size: Cylindrical D = 0.8 m, H = 1.0 m</p>
P-S-2	<p>Description: Solution pump to drive dissolved acidic feed through the slurry filter and into the feed tank</p> <p>Capacity: 400 L/hr</p> <p>Basis: Provide feed to sludge dissolver at 227 L/hr</p>

Table 6. Equipment Characteristics (con't)

Item	
Designator	Characteristics
F-S-1	Description: Slurry filter to remove residual sludge solids from the acidic feed Capacity: 400 L/hr Basis: Filters flushed with nitric acid back into a sludge dissolver tank
TK-F-1	Description: Feed tank Capacity: 2,500 L Basis: Tank receiving feed from sludge dissolver and feeding the Actinide column Size: Cylindrical D = 1.25 m, H = 2.0 m
P-F-1	Description: Feed pump to drive dissolved acidic feed through the Polish Filters and on through the Actinide and Strontium columns Capacity: 400 L/hr Basis: Maintain established volume velocities through the resin beds
F-P-1	Description: Polish Filter to remove solids from the acidic feed to protect the resin beds Capacity: 400 L/hr Basis: Fine filters which can be backflushed with acid into the sludge dissolver
IX-A-1/2/3	Description: Three Actinide anion exchange columns for removal of Th, U, Pu and Am (loaded with Reillex HPQ resin) Capacity: 227 L/hr on 500 L resin Basis: One column on line, one column being eluted, one column in standby Size: Cylindrical D = 0.4 m, H = 4.0 m
AMU-TK-2	Description: Aqueous make-up tank for dilute nitric acid to elute IX-A-1/2/3 Capacity: 1,500 L Basis: Provide 1,000 L solution per 8 hr shift Size: Cylindrical D = 0.8 m, H = 1.5 m
IX-S-1/2	Description: Two Strontium ion exchange columns for removal of Sr from acid solution (loaded with Sr Spec resin) Capacity: 227 L/hr on 125L Basis: One column on line, one column in standby Size: Cylindrical D = 0.4 m, H = 1.0 m
TK-P-1/2	Description: Two Actinide precipitators Capacity: 2,500 L Basis: One tank receiving effluent from the Actinide Column, the other precipitating actinide hydroxides and feeding the Actinide Slurry Filter Size: Cylindrical D = 1.25 m, H = 2.0 m
P-A-1	Description: Actinide slurry pump to feed the slurry filter Capacity: 250 L/hr Basis: 100 L/hr ppt. and 130 L/hr filtrate

Table 6. Equipment Characteristics (con't)

Item	
Designator	Characteristics
F-A-1	<p>Description: Actinide slurry filter to remove actinide hydroxide precipitate from solution with the filtrate going on to the grout neutralization tank and the cake on to the Actinide rotary calciner</p> <p>Capacity: 250 L/hr</p> <p>Basis: Drum filter sized to remove hydroxide cake in a continuous manner (2.8m² of filter)</p> <p>Size: Estimated at 1.0 m X 0.5 m X 1.0 m</p>
RC-A-1	<p>Description: Actinide rotary calciner to convert the actinide hydroxide cake to oxide</p> <p>Capacity: 2 L/hr</p> <p>Basis: Calciner sized to convert the hydroxide cake to oxide in a continuous manner</p> <p>Size: Estimated at 2.5 m X 0.5 m X 1.0 m</p>
TK-F-2	<p>Description: Feed tank</p> <p>Capacity: 10,000 L</p> <p>Basis: Tank receiving feed from the centrifuge and feeding the Cesium and Technetium columns</p> <p>Size: Cylindrical D =2 m, H =3.0 m</p>
P-F-2	<p>Description: Feed pump to drive basic feed through the Polish Filters and on through the Cesium and Technetium columns</p> <p>Capacity: 1,000 L/hr</p> <p>Basis: Maintain established volume velocities through the resin beds</p>
F-P-2	<p>Description: Polish Filter to remove solids from the basic feed to protect the resin beds</p> <p>Capacity: 1,000 L/hr</p> <p>Basis: Fine filters which can be backflushed with acid into the sludge dissolver</p>
IX-C-1	<p>Description: Cesium ion exchange columns for removal of Cs from basic solution</p> <p>Capacity: 781 L/hr, loading capacity limited by thermal loading</p> <p>Basis: One column on line, resin changed when breakthrough achieved</p> <p>Size: Cylindrical D = 0.75 m, H = 2.0 m</p>
IX-T-1	<p>Description: Technetium anion exchange columns for removal of Tc from basic solution</p> <p>Capacity: 781 L/hr</p> <p>Basis: One column on line, resin changed when breakthrough achieved</p> <p>Size: Cylindrical D = 0.75 m, H = 1.0 m</p>
TK-G-1/2	<p>Description: Two grout neutralization tanks</p> <p>Capacity: 15,000 L</p> <p>Basis: One tank receiving effluent from the Strontium and Technetium columns as well as the Actinide slurry filtrate, the other neutralizing the waste in preparation for grouting.</p> <p>Size: Cylindrical D = 2.2 m, H = 4.0 m</p>

Table 6. Equipment Characteristics (con't)

Item	
Designator	Characteristics
AMU-TK-3	Description: Aqueous make-up tank for sodium hydroxide to feed TK-P-1 and TK-G-1/2.
	Capacity: 1,000 L
	Basis:
	Size: Cylindrical D = 0.8 m, H = 1.0 m
P-G-1	Description: Grout slurry pump to transfer neutralized solutions to the grout facilities
	Capacity: 1,500 L/hr
	Basis: Empty tank to transfer vehicle and subsequent LLW storage area in a timely manner

The major pieces of equipment, primarily the large process vessels, were laid out to estimate the size of the building required to house them. The layout did not include pumps, filters or associated piping but did provide for 1 m. aisle space between the vessels. All the equipment was also kept on a single floor level and not "stacked," although this approach could significantly reduce the equipment footprint and thus the size and cost of the building. The equipment layout correlates to a rough material flow pattern. This approach provided a building shell encompassing 606 m³ (~24,000 ft³) with an equipment footprint of 101 m² (~1,200 ft²). It is presented as Fig. 25 and is available as LANL drawing 26Y-203029.

The following costing exercise was an attempt to provide an estimate of the total plant direct cost (TPDC) or the physical cost of the process equipment. This includes the initial capital cost as well as installation costs. Clearly, the location of the equipment, whether in a new building designed specifically to house it or in a remodeled existing building such as the 242-S evaporator building, will have a large impact on both the cost and schedule of the project. In this exercise, a relatively expensive new building and a major addition to an existing facility as an auxiliary cost were used to provide this value. No attempt was made to include engineering or construction labor costs as these would be specific to the Hanford Site.

Physical cost estimates for the major equipment items were made primarily using nomographs available in several plant design texts (Peters and Timmerhaus, 1980; and Valle-Riestra, 1983). The materials of construction were

selected as 304 and 316 series stainless steels. All costs are initially reported in January 1979 dollars and are brought to a May 1993 present value using the Chemical Engineering Plant Cost Index for equipment. This is a factor of $357.0/229.8 = 1.554$ (with 1957-59 = 100). Resin costs, which are not included, are typically 10-20\$/lb. for the standard cation and anion exchange resins proposed for use. Specialty resins, such as the Sr Spec, currently cost ~5\$/g but may become more cost effective as larger amounts are requested.

Table 7. presents the major equipment physical costs which are broken out by equipment type. The total cost in 1979 dollars is \$418,200.

The method of Direct Fixed Capital (Valle-Riestra, 1983) was used to provide an estimate of the TPDC or physical cost based on the total equipment cost (EC) determined in Table 7 above. The results are presented in Table 8 with a final estimate of \$2,336,100 in present value dollars.

The engineering and construction costs must be factored onto this physical cost and these will be unique to the Hanford Site. Valle-Riestra suggests that they should be no more than 25-40% of the TPDC, even for high labor jobs. The costs associated with decontamination and decommissioning (D&D) should also be factored in to the construction costs "up front" for a complete comparison to other options. This is a cost that has traditionally been overlooked, but as exemplified in the many existing facilities on the site at the end of their useful lifetimes, it is clearly significant. Not properly addressing D&D factors in the initial design can entail significant additional costs at the end of a project.

Table 7. Equipment Physical Costs

Item	Cost (\$, 1979)
Calciner	
RC-A-1	<u>40,000</u>
	40,000
Columns (with distributors and frits, excluding resin)	
IX-A-1	10,400
IX-A-2	10,400
IX-A-3	10,400
IX-C-1	13,100
IX-S-1	6,100
IX-S-2	6,100
IX-T-1	<u>6,600</u>
	63,100
Filters	
C-S-1	30,000
F-A-1	36,000
F-P-1	2,000
F-P-2	1,700
F-S-1	<u>1,100</u>
	70,800
Pumps (SS reciprocating)	
P-A-1	5,000
P-F-1	5,700
P-F-2	6,800
P-G-1	7,800
P-S-1	55,000
P-S-2	<u>5,700</u>
	86,000
Tanks (316 SS including agitator and drive motor)	
AMU-TK-1	7,800
AMU-TK-2	8,700
AMU-TK-3	7,800
TK-F-1	11,000
TK-F-2	23,000
TK-G-1	28,000
TK-G-2	28,000
TK-P-1	11,000
TK-P-2	11,000
TK-S-1	11,000
TK-S-2	<u>11,000</u>
	<u>158,300</u>
Equipment Cost (EC)	\$418,200

C. Process Control Strategy

A fully automated process can be implemented using a combination of computer-based supervisory control and data acquisition (SCADA) software and programmable logic controllers (PLC). This is industrially proven technology that is relatively inexpensive to implement and is available commercially from a large number of vendors.

Direct sequential control logic can be programmed into a PLC using ladder-logic for real-time system response. The SCADA system allows for graphical operator interfacing, real-time data display, trending, archiving, reporting and alarming. In general, computer graphics that represent the process display current conditions and operating options. In addition, current process parameters can be downloaded into the PLC via a recipe loader in order to effectively target a variety of feed streams or to quickly incorporate experimental results. Single loop controllers can be implemented for the control of flow rates, liquid levels, and pressures.

Typical equipment would include an Allen-Bradley PLC-5 processor in conjunction with adequate chassis-mounted analog and discrete input/output hardware. Optional Data Highway communications media and additional processor can be incorporated for maximum reliability through hot backup. Ethernet communications can allow for additional computers for both multiple operator workstations, engineering workstations and SCADA backup. Commercial operator training and ISO certification for system components is also available.

Commercial sensors and transmitters for flow, level, pressure, and temperature will be implemented. Commercial spectrometers that use high-purity germanium crystal detectors will be customized to determine the state of the ion exchange separation by monitoring gamma signal intensities at the outflow of the resin column.

Typical computer equipment would include a 80486-based IBM-PC compatible with SVGA graphics, industrial trackball input device, sealed operator keyboard, and industrial alarm speaker. Redundant panel controls are also recommended for system start-up, testing, and maintenance.

Table 8. Total Plant Direct Cost (TPDC)

1. Equipment purchased cost (PC) (bare cost in PV dollars)	$1.554 \times \text{EC} = \text{PC}$ $(1.554)(418,200) = 649,900$
2. Installation	$43\% \text{ PC} =$ $(0.43)(649,900) = 279,400$
3. Process piping (solid-fluid)	$43\% \text{ PC} =$ $(0.43)(649,900) = 279,400$
4. Instrumentation (computer auto control)	$40\% \text{ PC} =$ $(0.40)(649,900) = 260,000$
5. Insulation (low temp. process)	$8\% \text{ PC} =$ $(0.08)(649,900) = 52,000$
6. Electrical facilities	$11\% \text{ PC} =$ $(0.11)(649,900) = 71,500$
7. Buildings (fluid and solids process)	$60\% \text{ PC} =$ $(0.60)(649,900) = 389,900$
8. Yard improvements	$16\% \text{ PC} =$ $(0.16)(649,900) = 104,000$
9. Auxiliary facilities (major addition)	$50\% \text{ PC} =$ <u>$(0.40)(649,900) = 250,000$</u>
Sum = TPDC	<u><u>\$2,336,100</u></u>

VI. FUTURE WORK (TECHNICAL TASK PLAN)

This section is presented in the format of a Technical Task Plan. It can be used as a stand-alone document in project or budgetary reviews.

A. Task Summary

The Hanford Site needs additional tank space to allow pretreatment activities to begin. Because of the high cost of building new tanks, priority should be given to providing additional tank space without new construction. Two types of wastes, PFP and Double-Shelled Slurry Filtrate (DSSF) could potentially be processed quickly to provide additional tank space. Currently, DSSF can be processed by using cesium ion exchange recovery followed by grouting. Unfortunately, these tanks are in the 200 East

Area and are not easily accessible for remediation operations in the 200 West Area. Tank SY-102 offers the opportunity to provide tank space in the 200 West Area in a relatively short time. This is important because tank SY-101 is in the 200 West Area and is the Site's highest safety priority. However, no established flowsheet exists for PFP waste recovery. Because PFP waste is a major portion of the tank SY-102 inventory and PFP operations are very similar to Los Alamos Plutonium Facility operations, it is possible to closely simulate tank SY-102 waste and develop a flowsheet for remediation. A potential advantage is that once a flowsheet is developed, it may be possible to use existing buildings or CPU to carry out this process without building large and expensive new facilities. This will vastly reduce costs and the time involved for tank waste processing and disposal.

B. Objectives

The goal is to develop and test a robust flowsheet to recover actinides and metals that could potentially interfere with either the glass or grouting process from neutralized PFP tank waste. The flowsheet will produce a low-level (<100 nCi/g) liquid waste and a small amount of TRU (>100 nCi/g) solid waste. The LLW waste will be compatible with retrievable grout, the TRU waste can either be placed into grout for shipment to WIPP or stored for vitrification, and the HLW fission product component will be stored for vitrification.

C. Approach

Develop a flowsheet tailored to the individual tank (or similar groups of tanks):

- use established and demonstrated technologies;
- streamline and simplify the flowsheet wherever possible to meet or exceed the objective; and
- demonstrate the flowsheet using surrogates and actual waste on the laboratory, bench, and pilot scales.

Remediate tanks and dispose of the waste to an appropriate repository:

- begin with the "simpler" tanks and wastes, then advance or evolve to more complex situations using the expanding experience base; and
- use existing facilities, structures, or mobile/modular CPUs to house the treatment equipment.

Specific Program Element supported by this project as defined in WHC-EP-0577:

- blending to support 101-SY hazard reduction;
- sludge wash to remove soluble components;
- solid-liquid separation;
- cesium removal from basic solutions;
- strontium removal from acid solutions (if required for LLW Class A);
- technetium removal from basic solutions;
- sludge dissolution;
- TRU removal; and
- chemical recycle.

D. Benefits

Tank space required for future tank waste remediation efforts, and particularly tank SY-101, can be provided by recovering the SY-102 tank. This process is straightforward and can be implemented using existing facilities or CPUs. The process does not require that the HWVP be operational to be implemented.

E. Budget Summary

	<u>FY 94</u>	<u>FY 95</u>	<u>FY 96</u>
Operating (\$K)	450	TBD	TBD
Capital (\$K)	20	TBD	TBD
TOTAL (\$K)	470	TBD	TBD

F. Task/Milestone Summary

<u>Task</u>	<u>Start</u>	<u>End</u>
Complete CDR	9/1/93	10/8/93
25 Liter Flowsheet Demonstration	11/1/93	11/19/93
Complete ASPEN Model	8/1/93	2/15/93
Report on Site Recommendation	1/5/93	4/1/93
Final Summary Report	2/15/93	6/15/93

This task schedule assumes funding available in late October 1993.

G. Overall Project Implementation Schedule

This implementation schedule, presented in Fig. 26, is provided only to illustrate the potential times and probable tasks involved in construction and operation of the tank SY-102 remediation project. Actual times and tasks will require the input of WHC personnel and funding levels.

Fig. 26. Tank SY-102 Implementation Schedule

VII. SUMMARY AND CONCLUSIONS

The high-salt, low acid flowsheet is feasible for remediation of the SY-102 tank at the Hanford Site. It produces relatively low waste volumes, can be accomplished with conventional chemical processing equipment, and takes advantage of the components of the waste to increase the efficiency of the TRU recovery. The construction costs are reasonable and competitive with the costs of building new tanks. If existing buildings or CPUs are used, the D&D costs will also be minimized. The Title I design can be started within the next fiscal year without a large amount of additional experimental work. However, tests with actual waste are desirable to finish flowsheet verification.

VIII. ACKNOWLEDGEMENTS

We appreciate the technical recommendations and support from Ron Orme, Blaine Barton, Chris Winkler, and Dan Reberger of Westinghouse Hanford Company and Gregg Lumetta and John Swanson of Pacific Northwest Laboratories. Also, we appreciate the timely programmatic support from John Peschong and Steve Birnum of DOE-Richland.

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APPENDIX A

EXPERIMENTAL DETAILS

EXPERIMENT #1

Experiment Type: batch contact

Equipment: 1 oz. plastic bottles, glass wool for filtration, shaker for mixing

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: same composition as that given in Table 5

Calculations:

$$K_D = \frac{\text{mg of solute} / \text{g of resin}}{\text{mg of solute} / \text{ml of solution}} = \frac{10 (\text{PPM Am start} - \text{PPM Am end})}{\text{PPM Am end}}$$

Procedure: 1g of Reillex HPQ resin contacted with 10ml of simulant, shaken for 15 minutes, then filtered. Resulting solution and initial simulant analyzed for Pu and Am by radiochemistry.

Results:	<u>Americium</u>	<u>Plutonium</u>
Simulant feed:	0.246 ppm	1270 ppm
Sol'n after contact:	0.138 ppm	20.6 ppm
K_D	7.8	607

Evaluation of Results: Americium is retained by the resin to some extent; it is thermodynamically favorable. Plutonium is retained to a much greater extent.

EXPERIMENT #2

Experiment Type: batch contact

Equipment: 1 oz. plastic bottles, glass wool for filtration, shaker for mixing

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: same composition as that given in Table 5, except the RCRA listed cations Cr^{3+} and Pb^{2+} were replaced with additional Fe^{3+} and Ca^{2+} , respectively

Calculations:

$$K_D = \frac{\text{mg of solute} / \text{g of resin}}{\text{mg of solute} / \text{ml of solution}} = \frac{10 (\text{PPM Am start} - \text{PPM Am end})}{\text{PPM Am end}}$$

Procedure: 1g of Reillex HPQ resin contacted with 10ml of simulant, shaken for 15 minutes, then filtered. Resulting solution and initial simulant analyzed for Pu and Am by radiochemistry.

Results:	<u>Americium</u>	<u>Plutonium</u>
Simulant feed:	0.257 ppm	1040 ppm
Sol'n after contact:	0.116 ppm	6.28 ppm
K_D	12.2	1650

Evaluation of Results: As in Experiment #1, Americium is retained by the resin to some extent and plutonium is retained to a much greater extent. The resin performance is better in the absence of the RCRA metals, therefore any final testing need to be performed with those metals present.

EXPERIMENT #3

Experiment Type: flow experiment using single 1.5 cm diameter ion exchange column

Equipment: Lab Pump Jr. Model RHSY metering pump from Fluid Metering, Inc.

Graduated feed reservoir with valved outlet

1.5 cm diameter X 15 cm long Pyrex ion exchange column, with valved fittings on each end, packed with resin (see Fig. 11)

At-line gamma spectrometer set to measure the Am 59 keV peak

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: same composition as that used in Experiment #2, except more Am was added (to 7.4 ppm) to allow better detection with the gamma scanner.

0.5M HNO_3 for removal of actinides from the column

Calculations: None

Procedure: Run simulant through ion exchange column at 2 ml/min, collect a 5ml sample of effluent every 20ml. Analyze for Am using the gamma spectrometer. When the Am concentration in the effluent reaches that of the feed, stop the run. Remove the Am from the column using 0.5M HNO_3 .

Results: See plot of effluent Am concentration vs. volume eluted (Fig. 12).

Evaluation of Results: Americium is retained to some extent on the resin, however, it has a nonsharpening front. Am is displaced from the resin by more strongly bound Th, Pu, or U nitrate complexes.

EXPERIMENT #4

Experiment Type: flow experiment using single 1.5 cm diameter ion exchange column

Equipment: Lab Pump Jr. Model RHSY metering pump from Fluid Metering, Inc.

Graduated feed reservoir with valved outlet

1.5 cm diameter X 15 cm long Pyrex ion exchange column, with valved fittings on each end, packed with resin (see Fig. 11)

At-line gamma spectrometer set to measure the Am 59 keV peak

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: same composition as that used in Experiment #2, except more Am was added (to 7.4 ppm) to allow better detection with the gamma spectrometer.

0.5M HNO_3 for removal of actinides from the column

Calculations: None

Procedure: Run simulant through ion exchange column at 4 ml/min, collect a 5ml sample of effluent every 20ml. Analyze for Am using gamma spectrometer. When the Am concentration in the effluent reaches that of the feed, stop the run. Remove the Am from the column using 0.5M HNO_3 .

Results: See plot of effluent Am concentration vs. volume eluted (Fig. 12).

Evaluation of Results: Flow rate does have a significant effect on the effluent Am concentration profile. The Am concentration rises earlier in the elution, but does not overshoot the feed concentration as high as it does at the lower flow rate.

EXPERIMENT #5

Experiment Type: flow experiment using single 1.5 cm diameter ion exchange column

Equipment: Lab Pump Jr. Model RHSY metering pump from Fluid Metering, Inc.

Graduated feed reservoir with valved outlet

1.5 cm diameter X 15 cm long Pyrex ion exchange column, with valved fittings on each end, packed with resin (see Fig. 11)

At-line gamma spectrometer set to measure the Am 59 keV peak

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: same composition as that used in Experiment #2, except more Am was added (to 7.4 ppm) to allow better detection with the gamma spectrometer.

0.5M HNO_3 for removal of actinides from the column

Calculations: None

Procedure: Run simulant through ion exchange column at 10 ml/min, collect a 5ml sample of effluent every 20ml. Analyze for Am using gamma spectrometer. When the Am concentration in the effluent reaches that of the feed, stop the run. Remove the Am from the column using 0.5M HNO_3 .

Results: See plot of effluent Am concentration vs. volume eluted (Fig. 12).

Evaluation of Results: Effect of increased flow rate observed in Experiment #4 even more pronounced. See Experimental section in main body of report for detailed description.

EXPERIMENT #6

Experiment Type: flow experiment using single 1.5 cm diameter ion exchange column

Equipment: Lab Pump Jr. Model RHSY metering pump from Fluid Metering, Inc.

Graduated feed reservoir with valved outlet

1.5 cm diameter X 15 cm long Pyrex ion exchange column, with valved fittings on each end, packed with resin (see Fig. 11)

At-line gamma spectrometer set to measure the Am 59 keV peak

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: same composition as that used in Experiments #3, 4, &5, except the Am concentration was increased to 11.5ppm

0.5M HNO₃ for removal of actinides from the column

Calculations: None

Procedure: Run simulant through ion exchange column at 2 ml/min, collect a 5ml sample of effluent every 20ml. Analyze for Am using gamma spectrometer. When the Am concentration in the effluent approaches that of the feed after the overshoot, stop the run. Remove the Am from the column using 0.5M HNO₃.

Results: See plot of effluent Am concentration vs. volume eluted (Fig. 13).

Evaluation of Results: As anticipated, the Am concentration in the effluent approaches that of the feed asymptotically after the overshoot. This confirms the loading of Am on the resin and its subsequent replacement by the other actinides.

EXPERIMENT #7

Experiment Type: flow experiment using single 1.5 cm diameter ion exchange column

Equipment: Lab Pump Jr. Model RHSY metering pump from Fluid Metering, Inc.

Graduated feed reservoir with valved outlet

1.5 cm diameter X 15 cm long Pyrex ion exchange column, with valved fittings on each end, packed with resin (see Fig. 11)

At-line gamma spectrometer set to measure the Am 59 keV peak

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: *simplified recipe of the following composition:*

<u>Component</u>	<u>mol/L</u>
Al ³⁺	0.510
Fe ³⁺	0.450
Na ⁺	2.62
H ⁺	0.50
NO ₃ ⁻	6.0
Am ³⁺	5.6ppm

0.5M HNO₃ for removal of actinides from the column

Calculations: None

Procedure: Run simulant through ion exchange column at 2 ml/min, collect a 5ml sample of effluent every 20ml. Analyze for Am using gamma spectrometer. When the Am concentration in the effluent is at least half that of the feed, stop the run. Remove the Am from the column using 0.5M HNO₃.

Results: See plot of effluent Am concentration vs. volume eluted (Fig. 14).

Evaluation of Results: The beginning of the Am profile is similar to that observed when all the components were added to the simulant (Fig. 13). Therefore, a simplified simulant provides a reasonable approximation to the full composition simulant for many of the preliminary experiments.

EXPERIMENT #8

Experiment Type: flow experiment using single 1.5 cm diameter ion exchange column

Equipment: Lab Pump Jr. Model RHSY metering pump from Fluid Metering, Inc.

Graduated feed reservoir with valved outlet

1.5 cm diameter X 15 cm long Pyrex ion exchange column, with valved fittings on each end, packed with resin (see Fig. 11)

At-line gamma spectrometer set to measure the Am 59 keV peak

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: simplified recipe of the following composition with the acid concentration reduced to 0.1M H⁺:

<u>Component</u>	<u>mol/L</u>
Al ³⁺	0.510
Fe ³⁺	0.450
Na ⁺	3.02
H ⁺	0.10
NO ₃ ⁻	6.0
Am ³⁺	52.7ppm

0.5M HNO₃ for removal of actinides from the column

Calculations: None

Procedure: Run simulant through ion exchange column at 2 ml/min, collect a 5ml sample of effluent every 20ml. Analyze for Am using gamma spectrometer. When the Am concentration in the effluent is at least half that of the feed, stop the run. Remove the Am from the column using 0.5M HNO₃.

Results: See plot of effluent Am concentration vs. volume eluted (Fig. 14).

Evaluation of Results: Acid concentration has a significant effect on the retention of Americium by the resin. The onset of Am breakthrough for both runs is just over one column volume. The rate at which the Am profile for this run rises is significantly less than that of Experiment #7 (0.5M H⁺). By extrapolation and integration of the profile, the resin capacity is estimated to be 450 mg/L of resin, much higher than that of Experiment #7 (25 mg/L). A lower acid concentration significantly improves Am retention by the resin.

EXPERIMENT #9

Experiment Type: batch contact

Equipment: 1 oz. plastic bottles, glass wool for filtration, shaker for mixing

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant:

<u>Component</u>	<u>mol/L</u>
Al ³⁺	0.31
Fe ³⁺	0.27
Na ⁺	1.18
H ⁺	0.10
NO ₃ ⁻	3.0
Am ³⁺	12.8 ppm

Calculations:

$$K_D = \frac{\text{mg of solute / g of resin}}{\text{mg of solute / ml of solution}} = \frac{10 (\text{PPM Am start} - \text{PPM Am end})}{\text{PPM Am end}}$$

Procedure: Prepare three samples each of 1g of Reillex HPQ resin contacted with 10ml of simulant. Shake one for 5 min, the next for 15 min, and the last for 30 min. Filter each after the contact time is up. Use gamma spectrometer to determine Am content.

Results:	Time (min):	5	15	30
	[Am] (ppm):	11.6	11.7	11.7
	K _D	1.0	0.94	0.94

Evaluation of Results: The resin and Am in solution come to equilibrium rather quick (5 min or less) at the higher [H⁺]/ lower [NO₃⁻] used. It is expected to be at least that rapid at higher [NO₃⁻], lower [H⁺].

EXPERIMENT #10

Experiment Type: batch contact

Equipment: 1 oz. plastic bottles, glass wool for filtration, shaker for mixing

Reagents: Reillex HPQ resin, Purolite A-520E resin, and Dowex 1x8-200 resin, all 40-70 mesh, converted to nitrate form

Simulant:

<u>Component</u>	<u>mol/L</u>
Al ³⁺	0.31
Fe ³⁺	0.27
Na ⁺	1.18
H ⁺	0.10
NO ₃ ⁻	3.0
Am ³⁺	12.8 ppm

Calculations:

$$K_D = \frac{\text{mg of solute / g of resin}}{\text{mg of solute / ml of solution}} = \frac{10 (\text{PPM Am start} - \text{PPM Am end})}{\text{PPM Am end}}$$

Procedure: Prepare three-1g samples of each resin and contact with 10ml of simulant. Shake one for 5 min, the next for 15 min, and the last for 30 min. For the HPQ, do only the 5 min contact. Filter each after the contact time is up. Use gamma scanner to determine Am content.

Results: Am concentration in solution after contact (ppm):

<u>Time(min)</u>	<u>Dowex</u>	<u>Purolite</u>	<u>HPQ</u>
5	11.7	12.1	11.3
15	11.6	11.6	
30	11.5	12.1	

K_D for the contacts:

<u>Time(min)</u>	<u>Dowex</u>	<u>Purolite</u>	<u>HPQ</u>
5	0.77	0.41	1.15
15	0.86	0.86	
30	0.96	0.41	

Evaluation of Results: The distribution coefficient for HPQ matched very well with the value from Experiment #9, which was performed under the same conditions ($K_D=1.0$). HPQ was the best performer (highest K_D). Purolite was not as good as Dowex at 5 and 30 minute contact times. Purolite showed no consistent trend with time. Dowex does appear to be time dependent, with the best K_D at 30 min.

EXPERIMENT #11

Experiment Type: batch contact

Equipment: 1 oz. plastic bottles, glass wool for filtration, shaker for mixing

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: nine different recipes of varying $[\text{NO}_3^-]$ and $[\text{H}^+]$ as given in the following table (concentrations in mol/L, except Am given in ppm)

<u>Sim</u>	<u>[H⁺]</u>	<u>[NO₃⁻]</u>	<u>[Fe³⁺]</u>	<u>[Al³⁺]</u>	<u>[Na⁺]</u>	<u>[Am]</u>
1	0.1	3.0	0.27	0.31	1.16	15.3
2	0.05	3.0	0.27	0.31	1.21	13.8
3	0.01	3.0	0.27	0.31	1.25	14.8
4	0.1	4.0	0.36	0.41	1.59	14.7
5	0.05	4.0	0.36	0.41	1.64	14.6
6	0.01	4.0	0.36	0.41	1.68	15.6
7	0.1	6.0	0.54	0.61	2.45	14.5
8	0.05	6.0	0.54	0.61	2.50	14.6
9	0.01	6.0	0.54	0.61	2.54	15.1

Calculations:

$$K_D = \frac{\text{mg of solute} / \text{g of resin}}{\text{mg of solute} / \text{ml of solution}} = \frac{10 (\text{PPM Am start} - \text{PPM Am end})}{\text{PPM Am end}}$$

Procedure: Contact 1g samples of HPQ resin with 10ml of each simulant listed above. Shake 15 minutes then filter. Use gamma spectrometer to determine Am content.

Results:	Sim #	[Am]f	K_D
	1	14.0	0.93
	2	12.6	0.95
	3	13.6	0.88
	4	12.1	2.1
	5	12.1	2.1
	6	12.1	2.9
	7	7.97	8.2
	8	8.05	8.1
	9	8.27	8.3

Evaluation of Results: For the range of $[H^+]$ and $[NO_3^-]$ looked at, $[NO_3^-]$ has a significant effect on Am retention, whereas $[H^+]$ has little to no effect on Am retention. See Figs. A1 and A2.

Fig. A1. Effect of NO_3^- Concentration on Am Retention

Fig. A2. Effect of H^+ Concentration on Am Retention

EXPERIMENT #12

Experiment Type: batch contact

Equipment: 1 oz. plastic bottles, glass wool for filtration, shaker for mixing

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: Six different recipes, each with a single different cation, but all with $[NO_3^-] = 6.78M$ and $[H^+] = 0.05M$ as given in the following table

Simulant	M	[M](mol/L)	[Am](ppm)
1	Na ⁺	6.64	16.57
2	Ca ²⁺	3.32	15.84
3	Mn ²⁺	3.32	14.06
4	Cr ³⁺	2.21	15.57
5	Fe ³⁺	2.21	14.97
6	Al ³⁺	2.21	16.15

Calculations:

$$K_D = \frac{\text{mg of solute} / \text{g of resin}}{\text{mg of solute} / \text{ml of solution}} = \frac{10 (\text{PPM Am start} - \text{PPM Am end})}{\text{PPM Am end}}$$

Procedure: Contact 1g samples of HPQ resin with 10ml of each simulant listed above. Shake 15 minutes then filter. Use gamma scanner to determine Am content.

Results:	<u>Sim #</u>	<u>M</u>	<u>[Am]/f</u>	<u>K_D</u>
	1	Na ⁺	6.81	14.3
	2	Ca ²⁺	9.23	7.2
	3	Mn ²⁺	3.44	30.9
	4	Cr ³⁺	2.29	58.0
	5	Fe ³⁺	3.07	38.8
	6	Al ³⁺	1.63	89.1

Evaluation of Results: Specific cations have a significant effect on Am retention. All +3 cations result in greater Am uptake than the +2 and +1 cations. Aluminum is by far the best.

EXPERIMENT #13

Experiment Type: flow experiment using single 1.5 cm diameter ion exchange column

Equipment: Lab Pump Jr. Model RHSY metering pump from Fluid Metering, Inc.

Graduated feed reservoir with valved outlet

1.5 cm diameter X 15 cm long Pyrex ion exchange column, with valved fittings on each end, packed with resin (see Fig. 11)

At-line gamma spectrometer set to measure the Am 59 keV peak

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: Al(NO₃)₃ solution with 2.26M Al³⁺, 6.78M NO₃⁻, 0.05M H⁺, and 14.3 ppm Am

0.05M HNO₃ for removal of actinides from the column

Calculations: None

Procedure: Run simulant through ion exchange column at 2 ml/min, collect a 5ml sample of effluent every 20ml. Analyze for Am using gamma spectrometer. When the Am concentration in the effluent exceeds 1% of that of the feed, stop the run. Remove the Am from the column using 0.05M HNO₃.

Results: See plot of effluent Am concentration vs. volume eluted (Fig. 15). The Am concentration in the effluent did not reach 1% of the feed Am concentration until 440 ml, or 17 column volumes, had been passed through the column.

Evaluation of Results: Al³⁺ significantly improves the retention of Am on the HPQ resin. Therefore the ion exchange feed should have as much Al as possible.

EXPERIMENT #14

Experiment Type: flow experiment using single 1.5 cm diameter ion exchange column

Equipment: Lab Pump Jr. Model RHSY metering pump from Fluid Metering, Inc.

Graduated feed reservoir with valved outlet

1.5 cm diameter X 15 cm long Pyrex ion exchange column, with valved fittings on each end, packed with resin (see Fig. 11)

At-line gamma spectrometer set to measure the Am 59 keV peak

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: maximized Al of the following composition as determined from calculations (see below). Fe is substituted for Cr:

<u>Component</u>	<u>mol/L</u>
Al ³⁺	1.286
Fe ³⁺	0.725
Mn ²⁺	0.133
Ca ²⁺	0.128
H ⁺	0.05
NO ₃ ⁻	7.67
Am ³⁺	17.0 ppm

0.05M HNO₃ for removal of actinides from the column

Calculations: Determine the maximum Al concentration achievable in the TK SY-102 dissolved sludge. From Table 1, [Al³⁺]=1.65 M. Total NO₃⁻ = 5,941,854 moles. The sludge volume is 396,150L. Max. NO₃⁻ concentration achievable is ~7M.

$$5,941,854 \text{ moles} / (7 \text{ M}) = 848,836 \text{ L}$$

Element	Sludge M	Total moles	Diss. Sludge Conc M
Al	1.65	653,648	0.770
Ca	0.16	63,384	0.075
Cr	0.48	190,152	0.224
Fe	0.45	178,268	0.210
Mn	0.17	67,346	0.079
Na	6.00	2,376,900	2.800

If 99% of Na and K are selectively removed, the total NO₃⁻ is reduced by 2,384,506 moles

Total NO₃⁻ = 3,558,141 moles, and 3,558,141 / 7M = 508,306 L

Element	Diss. Sludge Conc M
Al	1.286
Ca	0.128
Cr	0.374
Fe	0.351
Mn	0.133

Sludge dissolution volume by acid addition. No correction for sludge washing volume.

Sludge = 396,150 L

All nitrate supplied by HNO₃, providing 5,941,854 moles.

$$5,941,854 \text{ moles} / (15.6 \text{ M}) = 380,888 \text{ L HNO}_3$$

Assume no volume reduction on mixing. Then the sludge volume is $V_s = 396,150\text{L} + 380,888\text{L} = 777,038\text{L}$

Acid required to reach 0.05M excess: $V_a = (0.05)(777,038)/15.55 = 2499 \text{ L}$

$$[\text{H}^+] = (2499\text{L})(15.6\text{M})/(777,038 + 2499\text{L}) = 0.05\text{M}$$

$$[\text{NO}_3^-] = (383,438\text{L})(15.6\text{M})/(777,038 + 2499\text{L}) = 7.67\text{M}$$

Procedure: Run simulant through ion exchange column at 2 ml/min, collect a 5ml sample of effluent every 20ml. Analyze for Am using gamma spectrometer. When the Am concentration in the effluent exceeds 1% of that of the feed, stop the run. Remove the Am from the column using 0.05M HNO₃.

Results: See plot of effluent Am concentration vs. volume eluted (Fig. 15). Am in the effluent reaches the 1.0% level after approximately 170 ml, or 6.6 column volumes, have been passed through the column.

Evaluation of Results: Retention of Am is somewhat reduced from the higher [Al³⁺] run, but is still satisfactory.

EXPERIMENT #15

Experiment Type: flow experiment using single 1.5 cm diameter ion exchange column

Equipment: Lab Pump Jr. Model RSHY metering pump from Fluid Metering, Inc.

Graduated feed reservoir with valved outlet

1.5 cm diameter X 15 cm long Pyrex ion exchange column, with valved fittings on each end, packed with resin (see Fig. 11)

At-line gamma spectrometer set to measure the Am 59 keV peak

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: same as that used in experiment #14 (see below):

<u>Component</u>	<u>mol/L</u>
Al ³⁺	1.286
Fe ³⁺	0.725
Mn ²⁺	0.133
Ca ²⁺	0.128
H ⁺	0.05
NO ₃ ⁻	7.67
Am ³⁺	14.9 ppm

0.05M HNO₃ for removal of actinides from the column

Calculations: none

Procedure: Run simulant through ion exchange column at 2 ml/min, collect a 5ml sample of effluent every 20ml. Analyze for Am using gamma spectrometer. When the Am concentration in the effluent exceeds 50% of that of the feed, stop the run. Remove the Am from the column using 0.05M HNO₃.

Results: See plot of effluent Am concentration vs. volume eluted (Fig. 15). Extrapolation of the effluent Am concentration profile and integration of the area above the curve and below the feed concentration results in an effective resin capacity of 0.43 g Am/L resin.

Evaluation of Results: The resin capacity is sufficiently high. The capacity is close to the value estimated in experiment #8.

EXPERIMENT #16

Experiment Type: flow experiment using five 1.0 cm diameter ion exchange columns connected in series.

Equipment: Lab Pump Jr. Model RHSY metering pump from Fluid Metering, Inc.

Graduated feed reservoir with valved outlet

Five 1.0 cm diameter X 15 cm long Pyrex ion exchange columns packed with HPQ resin (see Fig. 16)

At-line gamma spectrometer set to measure the Am 59 keV peak

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: same as that used in experiment #14 (see below):

<u>Component</u>	<u>mol/L</u>
Al ³⁺	1.286
Fe ³⁺	0.725
Mn ²⁺	0.133
Ca ²⁺	0.128
H ⁺	0.05
NO ₃ ⁻	7.67
Am ³⁺	14.4 ppm

0.05M HNO₃ for removal of actinides from the columns

Calculations: none

Procedure: Run simulant through ion exchange columns at 1 ml/min, collect a 5ml sample of effluent every 40ml. Analyze for Am using gamma spectrometer. When the Am concentration in the effluent exceeds 1% of that of the feed, stop the run. Remove the Am from each column separately using 0.05M HNO₃.

Results: See plot of effluent Am concentration vs. volume eluted (Fig. 17). The Am concentration in the effluent reached 1% of the feed concentration after 1120 ml, or 19 column volumes, of simulant was passed through the columns. The Am loading on each column after eluting with 0.05M HNO₃ is given in Fig. 18. Sixty ml of eluant was sufficient to elute the Am from each column.

Evaluation of Results: The column loadings confirm that Am loads in a nonsharpening front. The first two columns are near the expected maximum loadings of ~0.5 g Am / Liter of resin.

EXPERIMENT #17

Experiment Type: flow experiment using five 1.0 cm diameter ion exchange columns connected in series.

Equipment: Lab Pump Jr. Model RHSY metering pump from Fluid Metering, Inc.

Graduated feed reservoir with valved outlet

Five 1.0 cm diameter X 15 cm long Pyrex ion exchange columns packed with HPQ resin (see Fig. 16)

At-line gamma spectrometer set to measure the Am 59 keV peak

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: Simulant with other major actinides, anions and cations:

<u>Component</u>	<u>mol/L</u>	<u>Component</u>	<u>mol/L</u>
Al ³⁺	1.286	Pu ⁴⁺	3.59E-04
Ca ²⁺	0.125	Th ⁴⁺	0.0156
Fe ³⁺	0.351	U ⁴⁺	0.0156
Cr ³⁺	0.374	H ⁺	0.05
Na ⁺	0.047	NO ₃ ⁻	7.67
Mn ²⁺	0.129	F ⁻	0.075
Sr ²⁺	7.79E-04	SO ₄ ²⁻	0.01
Am ³⁺	16.6 ppm		

0.05M HNO₃ for removal of actinides from the columns

Calculations: none

Procedure: Run simulant through ion exchange columns at 1 ml/min, collect a 5ml sample of effluent every 40ml. Analyze for Am using gamma spectrometer. When the Am concentration in the effluent exceeds 1% of that of the feed, stop the run. Remove the Am from each column separately using 0.05M HNO₃.

Results: See plot of effluent Am concentration vs. volume eluted (Fig. 19). The Am concentration in the effluent reached 1% of the feed concentration after 640 ml, or nearly 11 column volumes, of simulant was passed through the columns. The Am loading on each column after eluting with 0.05M HNO₃ is given in Fig. 20. Sixty ml of eluant was sufficient to elute the Am from each column.

Evaluation of Results: The column loadings confirm that Am is displaced by the other actinides. With the other actinides, cations and anions present, Am loads sufficiently to make this a viable process.

EXPERIMENT #18

Experiment Type: flow experiment/volume velocity optimization

Equipment: Lab Pump Jr. Model RHSY metering pump from Fluid Metering, Inc.

Graduated feed reservoir with valved outlet

1.0 cm diameter X 15 cm long Pyrex ion exchange columns packed with HPQ resin (see Fig. 16)

At-line gamma spectrometer set to measure the Am 59 keV peak

Reagents: Reillex HPQ resin, 40-70 mesh, converted to nitrate form

Simulant: same as that used in experiment #17

0.05M HNO_3 for removal of actinides from the columns

Calculations:

The resin volume required to be on stream is given by the following relationship (Schweitzer, 1979):

$$\text{Resin volume on stream (L resin)} = \frac{\text{solution to be treated (L feed / h)}}{\text{volume flow rate (L feed / L resin \cdot h)}}$$

and the resin volume on line from the normalized data is given by:

$$\text{Resin volume on line (L resin)} = \frac{(\text{L feed / h} = 227.1)}{(\text{L feed / L resin} \cdot \text{h})(\text{BV} / 10 \text{ BV})}$$

where BV = bed volumes, or column volumes.

Procedure: Run simulant through different lengths of 1 cm diameter ion exchange columns at flow rates from 1 ml/min to 4 ml/min. These correspond to volume velocities from 1 to 10 L feed/L resin-hr. Analyze for Am using gamma spectrometer. When the Am concentration in the effluent exceeds 1% of that of the feed, stop the run. Remove the Am from each column separately using 0.05M HNO_3 .

Results: See plot of effluent Am concentration vs. relative column volumes eluted (Fig. 21). The Am concentration in the effluent reached 1% of the feed concentration at various bed volumes, depending on the volume velocity used. Using the second equation in the calculations section, the calculated on line resin volumes were plotted against the various feed volume velocities (Fig. 22). The minimum resin value is at ~7.5 BV/hr.

Evaluation of Results: The optimal feed rate of 7.5 BV/hr should be used to size the actinide column for the full scale equipment.

APPENDIX B

ASPEN PLUS™ SY-102 REMEDIATION FLOWSHEET

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SOFTWARE CLAUSES OR OTHER SIMILAR REGULATIONS OF OTHER GOVERNMENTAL
AGENCIES WHICH DESIGNATE SOFTWARE AND DOCUMENTATION AS PROPRIETARY.

*** INPUT ECHO(ES) ***

>>CURRENT RUN

ORIGINAL RUN
10:47:10 A.M.
INPUT FILE: SY102A.inp
OUTPUT PDF: SY102A VERSION: 1
LOCATED IN: C:\MMWORK\SY102A
PDF SIZE: FILE (PSIZE)=99999 RECORDS. IN-CORE = 400 RECORDS.

SEPTEMBER 20, 1993
MONDAY

```
1 ;
2 ;Input file created by ModelManager Rel. 3.3-6 on Mon Sep 20 10:46:58
3 ;Directory C:\MMWORK Runid SY102A
4 ;
5
6
7
8 TITLE '102SY REMEDIATION FLOWSHEET'
9
10 IN-UNITS MET VOLUME-FLOW='L/HR' ENTHALPY-FLO='KCAL/HR' &
11 HEAT-TRANS-C='KCAL/HR-SQM-K' TEMPERATURE=C DELTA-T=C &
12 HEAD=METER HEAT=KCAL FLUX='L/SQM-HR' MOLE-CONC='MOL/L'
13
14 DEF-STREAMS CONV ALL
15
16 STREAM-REPOR BPS-REPORT=YES
17
18 DATABANKS AQUEOUS / DIPPRPCD / BPS
19
20 PROP-SOURCES AQUEOUS / DIPPRPCD / BPS
21
22 COMPONENTS
23 H2O H2O H2O /
24 NA+ NA+ NA+ /
25 CS+ CS+ CS+ /
26 CA+2 CA+2 CA+2 /
27 SR+2 SR+2 SR+2 /
28 MN+2 MN+2 MN+2 /
29 FE+3 FE+3 FE+3 /
30 CR+3 CR+3 CR+3 /
31 ZR+4 * ZR+4 /
32 MO+6 * MO+6 /
33 AM+3 * AM+3 /
34 NP+4 * NP+4 /
35 PU+4 * PU+4 /
36 TH+4 * TH+4 /
37 U+4 * U+4 /
38 AL+3 AL+3 AL+3 /
39 H+ H+ H+ /
```

```

40      OH- OH- OH- /
41      CL- CL- CL- /
42      CO3-2 CO3-2 CO3-2 /
43      F- F- F- /
44      NO3- NO3- NO3- /
45      NO2- NO2- NO2- /
46      PO4-3 PO4-3 PO4-3 /
47      SO4-2 SO4-2 SO4-2 /
48      TCO4- * TCO4-

```

50 FLOWSHEET

```

51      BLOCK C-S IN=1 OUT=3 2
52      BLOCK TK-SF IN=3 4 OUT=11
53      BLOCK IX-A IN=11 12 OUT=14 13
54      BLOCK IX-S IN=14 OUT=16 15
55      BLOCK IX-C IN=2 OUT=25 24
56      BLOCK IX-T IN=25 OUT=27 26
57      BLOCK TK-P IN=13 17 OUT=18
58      BLOCK F-A IN=18 OUT=20 19
59      BLOCK TK-G IN=16 27 19 OUT=29
60      BLOCK B56 IN=1SUPR 1SLUD OUT=1

```

62 PROPERTIES SYSOP15

64 PROP-DATA CHARGE

```

65      IN-UNITS MET VOLUME-FLOW='L/HR' ENTHALPY-FLO='KCAL/HR' &
66      HEAT-TRANS-C='KCAL/HR-SQM-K' TEMPERATURE=C DELTA-T=C &
67      HEAD=METER HEAT=KCAL FLUX='L/SQM-HR' MOLE-CONC='MOL/L'
68      PROP-LIST CHARGE
69      PVAL ZR+4 4.0
70      PVAL MO+6 6.0
71      PVAL AM+3 3.0
72      PVAL NP+4 4.0
73      PVAL PU+4 4.0
74      PVAL TH+4 4.0
75      PVAL U+4 4.0
76      PVAL TCO4- -1.0

```

78 PROP-DATA DGFORM

```

79      IN-UNITS MET VOLUME-FLOW='L/HR' ENTHALPY-FLO='KCAL/HR' &
80      HEAT-TRANS-C='KCAL/HR-SQM-K' TEMPERATURE=C DELTA-T=C &
81      HEAD=METER MOLE-ENTHALP='J/KMOL' HEAT=KCAL FLUX='L/SQM-HR' &
82      MOLE-CONC='MOL/L'
83      PROP-LIST DGFORM
84      PVAL ZR+4 0.0
85      PVAL MO+6 22506000.0
86      PVAL AM+3 0.0
87      PVAL NP+4 0.0
88      PVAL PU+4 0.0
89      PVAL TH+4 0.0
90      PVAL U+4 0.0
91      PVAL TCO4- 0.0

```

93 PROP-DATA DHFORM

```

94      IN-UNITS MET VOLUME-FLOW='L/HR' ENTHALPY-FLO='KCAL/HR' &
95      HEAT-TRANS-C='KCAL/HR-SQM-K' TEMPERATURE=C DELTA-T=C &
96      HEAD=METER MOLE-ENTHALP='J/KMOL' HEAT=KCAL FLUX='L/SQM-HR' &
97      MOLE-CONC='MOL/L'
98      PROP-LIST DHFORM
99      PVAL ZR+4 6934100.0

```



```

100      PVAL MO+6 22468000.0
101      PVAL AM+3 0.0
102      PVAL NP+4 0.0
103      PVAL PU+4 0.0
104      PVAL TH+4 7021000.0
105      PVAL U+4 0.0
106      PVAL TCO4- 0.0
107
108      PROP-DATA MW
109          IN-UNITS MET VOLUME-FLOW='L/HR' ENTHALPY-FLO='KCAL/HR' &
110              HEAT-TRANS-C='KCAL/HR-SQM-K' TEMPERATURE=C DELTA-T=C &
111              HEAD=METER HEAT=KCAL FLUX='L/SQM-HR' MOLE-CONC='MOL/L'
112      PROP-LIST MW
113      PVAL ZR+4 91.220
114      PVAL MO+6 95.940
115      PVAL AM+3 241.0
116      PVAL NP+4 237.0
117      PVAL PU+4 239.0
118      PVAL TH+4 232.0
119      PVAL U+4 238.0
120      PVAL TCO4- 163.0
121
122      PROP-DATA OMEGA
123          IN-UNITS MET VOLUME-FLOW='L/HR' ENTHALPY-FLO='KCAL/HR' &
124              HEAT-TRANS-C='KCAL/HR-SQM-K' TEMPERATURE=C DELTA-T=C &
125              HEAD=METER HEAT=KCAL FLUX='L/SQM-HR' MOLE-CONC='MOL/L'
126      PROP-LIST OMEGA
127      PVAL ZR+4 0.296
128      PVAL MO+6 0.296
129      PVAL AM+3 0.296
130      PVAL NP+4 0.296
131      PVAL PU+4 0.296
132      PVAL TH+4 0.296
133      PVAL U+4 0.296
134      PVAL TCO4- 0.296
135
136      PROP-DATA PC
137          IN-UNITS MET VOLUME-FLOW='L/HR' ENTHALPY-FLO='KCAL/HR' &
138              HEAT-TRANS-C='KCAL/HR-SQM-K' PRESSURE='N/SQM' TEMPERATURE=C &
139              DELTA-T=C HEAD=METER HEAT=KCAL FLUX='L/SQM-HR' &
140              MOLE-CONC='MOL/L'
141      PROP-LIST PC
142      PVAL ZR+4 2968820.0
143      PVAL MO+6 2968820.0
144      PVAL AM+3 2968820.0
145      PVAL NP+4 2968820.0
146      PVAL PU+4 2968820.0
147      PVAL TH+4 2968820.0
148      PVAL U+4 2968820.0
149      PVAL TCO4- 2968820.0
150
151      PROP-DATA TB
152          IN-UNITS MET VOLUME-FLOW='L/HR' ENTHALPY-FLO='KCAL/HR' &
153              HEAT-TRANS-C='KCAL/HR-SQM-K' TEMPERATURE=K DELTA-T=C &
154              HEAD=METER HEAT=KCAL FLUX='L/SQM-HR' MOLE-CONC='MOL/L'
155      PROP-LIST TB
156      PVAL ZR+4 341.9
157      PVAL MO+6 341.9
158      PVAL AM+3 341.9
159      PVAL NP+4 341.9

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160      PVAL PU+4 341.9
161      PVAL TH+4 341.9
162      PVAL U+4 341.9
163      PVAL TCO4- 341.9
164
165      PROP-DATA TC
166      IN-UNITS MET VOLUME-FLOW='L/HR' ENTHALPY-FLO='KCAL/HR' &
167      HEAT-TRANS-C='KCAL/HR-SQM-K' TEMPERATURE=K DELTA-T=C &
168      HEAD=METER HEAT=KCAL FLUX='L/SQM-HR' MOLE-CONC='MOL/L'
169      PROP-LIST TC
170      PVAL ZR+4 507.4
171      PVAL MO+6 507.4
172      PVAL AM+3 507.4
173      PVAL NP+4 507.4
174      PVAL PU+4 507.4
175      PVAL TH+4 507.4
176      PVAL U+4 507.4
177      PVAL TCO4- 507.4
178
179      PROP-DATA VC
180      IN-UNITS MET VOLUME-FLOW='L/HR' ENTHALPY-FLO='KCAL/HR' &
181      HEAT-TRANS-C='KCAL/HR-SQM-K' TEMPERATURE=C DELTA-T=C &
182      HEAD=METER MOLE-VOLUME='CUM/KMOL' HEAT=KCAL &
183      FLUX='L/SQM-HR' MOLE-CONC='MOL/L'
184      PROP-LIST VC
185      PVAL ZR+4 .369445
186      PVAL MO+6 .369445
187      PVAL AM+3 .369445
188      PVAL NP+4 .369445
189      PVAL PU+4 .369445
190      PVAL TH+4 .369445
191      PVAL U+4 .369445
192      PVAL TCO4- .369445
193
194      PROP-DATA ZC
195      IN-UNITS MET VOLUME-FLOW='L/HR' ENTHALPY-FLO='KCAL/HR' &
196      HEAT-TRANS-C='KCAL/HR-SQM-K' TEMPERATURE=C DELTA-T=C &
197      HEAD=METER HEAT=KCAL FLUX='L/SQM-HR' MOLE-CONC='MOL/L'
198      PROP-LIST ZC
199      PVAL ZR+4 0.260
200      PVAL MO+6 0.260
201      PVAL AM+3 0.260
202      PVAL NP+4 0.260
203      PVAL PU+4 0.260
204      PVAL TH+4 0.260
205      PVAL U+4 0.260
206      PVAL TCO4- 0.260
207
208      PROP-DATA PLXANT
209      IN-UNITS MET VOLUME-FLOW='L/HR' ENTHALPY-FLO='KCAL/HR' &
210      HEAT-TRANS-C='KCAL/HR-SQM-K' PRESSURE='N/SQM' TEMPERATURE=K &
211      DELTA-T=C HEAD=METER HEAT=KCAL FLUX='L/SQM-HR' &
212      MOLE-CONC='MOL/L'
213      PROP-LIST PLXANT
214      PVAL ZR+4 -1.0E28 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 2000.0
215      PVAL MO+6 -1.0E28 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 2000.0
216      PVAL AM+3 -1.0E28 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 2000.0
217      PVAL NP+4 -1.0E28 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 2000.0
218      PVAL PU+4 -1.0E28 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 2000.0
219      PVAL TH+4 -1.0E28 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 2000.0

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220      PVAL U+4 -1.0E28 0.0 0.0 0.0 0.0 0.0 0.0 0.0 2000.0
221      PVAL TCO4- -1.0E28 0.0 0.0 0.0 0.0 0.0 0.0 0.0 2000.0
222
223  PROP-DATA SY102
224      IN-UNITS MET VOLUME-FLOW='L/HR' ENTHALPY-FLO='KCAL/HR' &
225      HEAT-TRANS-C='KCAL/HR-SQM-K' TEMPERATURE=C DELTA-T=C &
226      HEAD=METER HEAT=KCAL FLUX='L/SQM-HR' MOLE-CONC='MOL/L'
227  PROP-LIST WATSOL
228      PVAL ZR+4 -5.30 -500.0 0.0 0.0 1000.0
229      PVAL MO+6 -5.30 -500.0 0.0 0.0 1000.0
230      PVAL AM+3 -5.30 -500.0 0.0 0.0 1000.0
231      PVAL NP+4 -5.30 -500.0 0.0 0.0 1000.0
232      PVAL PU+4 -5.30 -500.0 0.0 0.0 1000.0
233      PVAL TH+4 -5.30 -500.0 0.0 0.0 1000.0
234      PVAL U+4 -5.30 -500.0 0.0 0.0 1000.0
235      PVAL TCO4- -5.30 -500.0 0.0 0.0 1000.0
236
237  STREAM 1SLUD
238      SUBSTREAM CONV TEMP=298.15 <K> PRES=1.00 &
239      VOLUME-FLOW=2.50 <L/MIN> SOLVENT=H2O NPHASE=1 PHASE=L
240      MOLE-CONC NA+ 6.082 / CS+ 1.70E-05 / CA+2 0.230 / SR+2 &
241      0.001 / MN+2 0.220 / FE+3 0.507 / CR+3 0.480 / &
242      ZR+4 0.004 / MO+6 0.001 / AM+3 3.70E-05 / NP+4 &
243      8.40E-06 / PU+4 4.60E-04 / TH+4 0.020 / U+4 0.020 / &
244      AL+3 1.650 / OH- 15.11 / CL- 0.150 / CO3-2 0.600 / &
245      F- 0.300 / NO3- 3.000 / NO2- 0.800 / PO4-3 0.600 / &
246      SO4-2 0.100 / TCO4- 0.00018
247
248  STREAM 1SUPR
249      SUBSTREAM CONV TEMP=298.15 <K> PRES=1.00 &
250      VOLUME-FLOW=12.50 <L/MIN> SOLVENT=H2O NPHASE=1 PHASE=L
251      MOLE-CONC NA+ 0.92 / AL+3 0.050 / OH- 1.12 / CL- &
252      0.020 / CO3-2 0.050 / F- 0.040 / NO3- 0.400 / &
253      NO2- 0.050 / PO4-3 0.005 / SO4-2 0.008 / TCO4- 0.0
254
255  STREAM 4
256      SUBSTREAM CONV TEMP=298.15 <K> PRES=1.00 &
257      VOLUME-FLOW=1.45728 <L/MIN> SOLVENT=H2O NPHASE=1 PHASE=L
258      MOLE-CONC H+ 15.6 / NO3- 15.6
259
260  STREAM 12
261      SUBSTREAM CONV TEMP=298.15 <K> PRES=1.00 VOLUME-FLOW=125 &
262      SOLVENT=H2O NPHASE=1 PHASE=L
263      MOLE-CONC H+ 0.05 / NO3- 0.05
264
265  STREAM 17
266      SUBSTREAM CONV TEMP=298.15 <K> PRES=1.00 VOLUME-FLOW=4.3492 &
267      SOLVENT=H2O NPHASE=1 PHASE=L
268      MOLE-CONC NA+ 10.0 / OH- 10.0
269
270  BLOCK B56 MIXER
271      PARAM PRES=1.00 NPHASE=1 PHASE=L
272
273  BLOCK C-S SEP
274      FRAC STREAM=3 SUBSTREAM=CONV COMPS=H2O NA+ CS+ CA+2 &
275      SR+2 MN+2 FE+3 CR+3 ZR+4 MO+6 AM+3 NP+4 PU+4 TH+4 &
276      U+4 AL+3 OH- CL- CO3-2 F- NO3- NO2- PO4-3 SO4-2 &
277      TCO4- FRACS=0.16091 0.00569 0.10000 1.00 1.00 1.00 &
278      1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.85974 &
279      0.43543 0.0 .70588 0.60 0.0 0.0 0.0 0.0 0.71429 0.0

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280
281 BLOCK F-A SEP
282     FRAC STREAM=20 SUBSTREAM=CONV COMPS=NA+ CS+ AM+3 NP+4 &
283     PU+4 TH+4 U+4 CL- CO3-2 F- NO3- NO2- PO4-3 SO4-2 &
284     FRACS=0.0 0.0 0.999 0.999 0.999 0.999 0.999 0.0 0.0 &
285     0.0 0.0 0.0 0.0 0.0
286     MOLE-FLOW STREAM=20 SUBSTREAM=CONV COMPS=OH- FLOWS= &
287     0.024274
288
289 BLOCK IX-A SEP
290     FRAC STREAM=14 SUBSTREAM=CONV COMPS=H2O NA+ CS+ CA+2 &
291     SR+2 MN+2 FE+3 CR+3 ZR+4 MO+6 AM+3 NP+4 PU+4 TH+4 &
292     U+4 AL+3 H+ CL- CO3-2 F- NO3- NO2- PO4-3 SO4-2 &
293     FRACS=0.621 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 &
294     1.00 0.001 0.0 0.0 0.0 0.0 1.00 0.6449 1.00 1.00 &
295     1.00 0.99544 1.00 1.00 1.00
296
297 BLOCK IX-C SEP
298     FRAC STREAM=25 SUBSTREAM=CONV COMPS=H2O NA+ CS+ AL+3 &
299     OH- CL- CO3-2 F- NO3- NO2- PO4-3 SO4-2 TCO4- FRACS= &
300     1.00 1.00 0.001 1.00 1.00 1.00 1.00 1.00 1.00 1.00 &
301     1.00 1.00 1.00
302
303 BLOCK IX-S SEP
304     FRAC STREAM=16 SUBSTREAM=CONV COMPS=H2O NA+ CS+ CA+2 &
305     SR+2 MN+2 FE+3 CR+3 ZR+4 MO+6 AM+3 AL+3 H+ CL- &
306     CO3-2 F- NO3- NO2- PO4-3 SO4-2 FRACS=1.00 1.00 1.00 &
307     1.00 0.001 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 &
308     1.00 1.00 1.00 1.00 1.00 1.00 1.00
309
310 BLOCK IX-T SEP
311     FRAC STREAM=27 SUBSTREAM=CONV COMPS=H2O NA+ CS+ AL+3 &
312     OH- CL- CO3-2 F- NO3- NO2- PO4-3 SO4-2 TCO4- FRACS= &
313     1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 &
314     1.00 1.00 0.001
315
316 BLOCK TK-G RSTOIC
317     PARAM TEMP=298.15 <K> PRES=1.00 NPHASE=1 PHASE=L
318     STOIC 1 CONV H+ -1.0 / OH- -1.0 / H2O 1.0
319     CONV 1 CONV H+ 1.00
320
321 BLOCK TK-P RSTOIC
322     PARAM TEMP=298.15 <K> PRES=1.00 NPHASE=1 PHASE=L
323     STOIC 1 CONV H+ -1.0 / OH- -1.0 / H2O 1.0
324     CONV 1 CONV H+ 1.00
325
326 BLOCK TK-SF RSTOIC
327     PARAM TEMP=298.15 <K> PRES=1.00 NPHASE=1 PHASE=L
328     STOIC 1 CONV H+ -1.0 / OH- -1.0 / H2O 1.0
329     CONV 1 CONV OH- 1.00
330 ;
331 ;
332 ;
333 ;
334 ;

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*** INPUT TRANSLATOR MESSAGES ***

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCLIMS.4)
PARAMETER CHARGE/ELEMENT 1 (DATA SET 1)
UPPER BOUND VIOLATED FOR COMPONENT MO+6
VALUE = 6.0000 , UPPER BOUND = 5.0000

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.1)
PARAMETER PLXANT (DATA SET 1) FOR COMPONENT ZR+4:
UNREASONABLE VAPOR PRESSURE CALCULATED AT NORMAL BOILING POINT.
VALUE SHOULD BE WITHIN 10% OF 1D5 N/SQM. PLEASE CHECK YOUR INPUT
FOR THE ANTOINE PARAMETERS.

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.1)
PARAMETER PLXANT (DATA SET 1) FOR COMPONENT MO+6:
UNREASONABLE VAPOR PRESSURE CALCULATED AT NORMAL BOILING POINT.
VALUE SHOULD BE WITHIN 10% OF 1D5 N/SQM. PLEASE CHECK YOUR INPUT
FOR THE ANTOINE PARAMETERS.

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.1)
PARAMETER PLXANT (DATA SET 1) FOR COMPONENT AM+3:
UNREASONABLE VAPOR PRESSURE CALCULATED AT NORMAL BOILING POINT.
VALUE SHOULD BE WITHIN 10% OF 1D5 N/SQM. PLEASE CHECK YOUR INPUT
FOR THE ANTOINE PARAMETERS.

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.1)
PARAMETER PLXANT (DATA SET 1) FOR COMPONENT NP+4:
UNREASONABLE VAPOR PRESSURE CALCULATED AT NORMAL BOILING POINT.
VALUE SHOULD BE WITHIN 10% OF 1D5 N/SQM. PLEASE CHECK YOUR INPUT
FOR THE ANTOINE PARAMETERS.

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.1)
PARAMETER PLXANT (DATA SET 1) FOR COMPONENT PU+4:
UNREASONABLE VAPOR PRESSURE CALCULATED AT NORMAL BOILING POINT.
VALUE SHOULD BE WITHIN 10% OF 1D5 N/SQM. PLEASE CHECK YOUR INPUT
FOR THE ANTOINE PARAMETERS.

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.1)
PARAMETER PLXANT (DATA SET 1) FOR COMPONENT TH+4:
UNREASONABLE VAPOR PRESSURE CALCULATED AT NORMAL BOILING POINT.
VALUE SHOULD BE WITHIN 10% OF 1D5 N/SQM. PLEASE CHECK YOUR INPUT
FOR THE ANTOINE PARAMETERS.

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.1)
PARAMETER PLXANT (DATA SET 1) FOR COMPONENT U+4:
UNREASONABLE VAPOR PRESSURE CALCULATED AT NORMAL BOILING POINT.
VALUE SHOULD BE WITHIN 10% OF 1D5 N/SQM. PLEASE CHECK YOUR INPUT
FOR THE ANTOINE PARAMETERS.

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.1)

PARAMETER PLXANT (DATA SET 1) FOR COMPONENT TCO4-:
UNREASONABLE VAPOR PRESSURE CALCULATED AT NORMAL BOILING POINT.
VALUE SHOULD BE WITHIN 10% OF 1D5 N/SQM. PLEASE CHECK YOUR INPUT
FOR THE ANTOINE PARAMETERS.

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.4)
PARAMETER CPIG (DATA SET 1) FOR COMPONENT ZR+4:
UNREASONABLE HEAT CAPACITY CALCULATED AT TEMPERATURE LOWER BOUND,
VALUE = -4412.9 J/KMOL-K. VALUE SHOULD BE GREATER THAN
MINIMUM ALLOWABLE VALUE = 8314.3 J/KMOL-K. PLEASE CHECK
YOUR INPUT FOR THE CPIG PARAMETERS.

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.4)
PARAMETER CPIG (DATA SET 1) FOR COMPONENT MO+6:
UNREASONABLE HEAT CAPACITY CALCULATED AT TEMPERATURE LOWER BOUND,
VALUE = -4412.9 J/KMOL-K. VALUE SHOULD BE GREATER THAN
MINIMUM ALLOWABLE VALUE = 8314.3 J/KMOL-K. PLEASE CHECK
YOUR INPUT FOR THE CPIG PARAMETERS.

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.4)
PARAMETER CPIG (DATA SET 1) FOR COMPONENT AM+3:
UNREASONABLE HEAT CAPACITY CALCULATED AT TEMPERATURE LOWER BOUND,
VALUE = -4412.9 J/KMOL-K. VALUE SHOULD BE GREATER THAN
MINIMUM ALLOWABLE VALUE = 8314.3 J/KMOL-K. PLEASE CHECK
YOUR INPUT FOR THE CPIG PARAMETERS.

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.4)
PARAMETER CPIG (DATA SET 1) FOR COMPONENT NP+4:
UNREASONABLE HEAT CAPACITY CALCULATED AT TEMPERATURE LOWER BOUND,
VALUE = -4412.9 J/KMOL-K. VALUE SHOULD BE GREATER THAN
MINIMUM ALLOWABLE VALUE = 8314.3 J/KMOL-K. PLEASE CHECK
YOUR INPUT FOR THE CPIG PARAMETERS.

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.4)
PARAMETER CPIG (DATA SET 1) FOR COMPONENT PU+4:
UNREASONABLE HEAT CAPACITY CALCULATED AT TEMPERATURE LOWER BOUND,
VALUE = -4412.9 J/KMOL-K. VALUE SHOULD BE GREATER THAN
MINIMUM ALLOWABLE VALUE = 8314.3 J/KMOL-K. PLEASE CHECK
YOUR INPUT FOR THE CPIG PARAMETERS.

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.4)
PARAMETER CPIG (DATA SET 1) FOR COMPONENT TH+4:
UNREASONABLE HEAT CAPACITY CALCULATED AT TEMPERATURE LOWER BOUND,
VALUE = -4412.9 J/KMOL-K. VALUE SHOULD BE GREATER THAN
MINIMUM ALLOWABLE VALUE = 8314.3 J/KMOL-K. PLEASE CHECK
YOUR INPUT FOR THE CPIG PARAMETERS.

- * WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.4)
PARAMETER CPIG (DATA SET 1) FOR COMPONENT U+4:
UNREASONABLE HEAT CAPACITY CALCULATED AT TEMPERATURE LOWER BOUND,
VALUE = -4412.9 J/KMOL-K. VALUE SHOULD BE GREATER THAN
MINIMUM ALLOWABLE VALUE = 8314.3 J/KMOL-K. PLEASE CHECK
YOUR INPUT FOR THE CPIG PARAMETERS.

* WARNING IN PHYSICAL PROPERTY SYSTEM WHILE RETRIEVING AND CHECKING
PARAMETER VALUES (LCCHCK.4)
PARAMETER CPIG (DATA SET 1) FOR COMPONENT TCO4-:
UNREASONABLE HEAT CAPACITY CALCULATED AT TEMPERATURE LOWER BOUND,
VALUE = -4412.9 J/KMOL-K. VALUE SHOULD BE GREATER THAN
MINIMUM ALLOWABLE VALUE = 8314.3 J/KMOL-K. PLEASE CHECK
YOUR INPUT FOR THE CPIG PARAMETERS.

*** FLOWSHEET ANALYSIS MESSAGES ***

FLOWSHEET CONNECTIVITY BY STREAMS

STREAM	SOURCE	DEST	STREAM	SOURCE	DEST
4	----	TK-SF	12	----	IX-A
17	----	TK-P	1SLUD	----	B56
1SUPR	----	B56	3	C-S	TK-SF
2	C-S	IX-C	11	TK-SF	IX-A
14	IX-A	IX-S	13	IX-A	TK-P
16	IX-S	TK-G	15	IX-S	----
25	IX-C	IX-T	24	IX-C	----
27	IX-T	TK-G	26	IX-T	----
18	TK-P	F-A	20	F-A	----
19	F-A	TK-G	29	TK-G	----
1	B56	C-S			

FLOWSHEET CONNECTIVITY BY BLOCKS

BLOCK	INLETS	OUTLETS
C-S	1	3 2
TK-SF	3 4	11
IX-A	11 12	14 13
IX-S	14	16 15
IX-C	2	25 24
IX-T	25	27 26
TK-P	13 17	18
F-A	18	20 19
TK-G	16 27 19	29
B56	1SUPR 1SLUD	1

COMPUTATION ORDER FOR THE FLOWSHEET IS:
B56 C-S IX-C IX-T TK-SF IX-A TK-P F-A IX-S TK-G

INFORMATION DURING PROGRAM GENERATION (OLDMOD.3)
MAX PARAMETER EXCEEDED: OLD NISTW = 25
NEW NISTW = 26
NUMBER OF CONVENTIONAL COMPONENTS IS TOO SMALL
THEREFORE, THE MODULE CANNOT BE USED
MODULE SY102A WILL BE GENERATED 09/20/93 10:47:10:01
LOCATED IN:C:\MMWORK\SY102A
IN-CORE-PLEX SIZE = 213 RECORDS, WORK SIZE = 995 INTEGER WORDS

*** SUMMARY OF ERRORS ***

	PHYSICAL PROPERTY	SYSTEM	SIMULATION
TERMINAL ERRORS	0	0	0
SEVERE ERRORS	0	0	0
ERRORS	0	0	0
WARNINGS	17	0	0

SIMULATION PROGRAM MAY BE EXECUTED

* ASPEN PLUS INPUT TRANSLATOR ENDS EXECUTION *

*** CALCULATION TRACE ***

102SY REMEDIATION FLOWSHEET

SIMULATION CALCULATIONS BEGIN

ENTHALPY CALCULATION FOR INLET STREAM 1SUPR OF BLOCK B56
 KODE = 2 NO. TEMP ITER = 1 TEMP = 298.15
 KPHASE = 2 KODE = 2 T = 298.15 P = 0.10133E+06 Q = 0.00000E+

ENTHALPY CALCULATION FOR INLET STREAM 1SLUD OF BLOCK B56
 KODE = 2 NO. TEMP ITER = 1 TEMP = 298.15
 KPHASE = 2 KODE = 2 T = 298.15 P = 0.10133E+06 Q = 0.00000E+

UOS BLOCK B56 MODEL: MIXER
 KODE = 1 NO. TEMP ITER = 4 TEMP = 300.60
 KPHASE = 2 KODE = 1 T = 300.60 P = 0.10133E+06 Q = 0.00000E+

UOS BLOCK C-S MODEL: SEP
 ---FLASH OUTLET STREAM 3 :
 KODE = 2 NTRIAL = 2 T = 300.6 P = 0.1013E+06 V = 0.0000E+00
 ---FLASH OUTLET STREAM 2 :
 KODE = 2 NTRIAL = 2 T = 300.6 P = 0.1013E+06 V = 0.0000E+00

UOS BLOCK IX-C MODEL: SEP
 ---FLASH OUTLET STREAM 25 :
 KODE = 2 NTRIAL = 2 T = 300.6 P = 0.1013E+06 V = 0.0000E+00
 ---FLASH OUTLET STREAM 24 :
 KODE = 2 NTRIAL = 2 T = 300.6 P = 0.1013E+06 V = 0.0000E+00

UOS BLOCK IX-T MODEL: SEP
 ---FLASH OUTLET STREAM 27 :
 KODE = 2 NTRIAL = 2 T = 300.6 P = 0.1013E+06 V = 0.0000E+00
 ---FLASH OUTLET STREAM 26 :
 KODE = 2 NTRIAL = 2 T = 300.6 P = 0.1013E+06 V = 0.0000E+00

ENTHALPY CALCULATION FOR INLET STREAM 4 OF BLOCK TK-SF
 KODE = 2 NO. TEMP ITER = 1 TEMP = 298.15
 KPHASE = 2 KODE = 2 T = 298.15 P = 0.10133E+06 Q = 0.00000E+

UOS BLOCK TK-SF MODEL: RSTOIC
 KODE = 2 NO. TEMP ITER = 1 TEMP = 298.15
 KPHASE = 2 KODE = 2 T = 298.15 P = 0.10133E+06 Q = -22151.

ENTHALPY CALCULATION FOR INLET STREAM 12 OF BLOCK IX-A
 KODE = 2 NO. TEMP ITER = 1 TEMP = 298.15
 KPHASE = 2 KODE = 2 T = 298.15 P = 0.10133E+06 Q = 0.00000E+

UOS BLOCK IX-A MODEL: SEP
 ---FLASH FEED STREAM TO CALCULATE TEMPERATURE:
 NO. TEMP ITER = 4 TEMP = 298.51
 KODE = 1 NTRIAL = 2 T = 298.5 P = 0.1013E+06 V = 0.0000E+00
 ---FLASH OUTLET STREAM 14 :
 KODE = 2 NTRIAL = 2 T = 298.5 P = 0.1013E+06 V = 0.0000E+00
 ---FLASH OUTLET STREAM 13 :
 KODE = 2 NTRIAL = 2 T = 298.5 P = 0.1013E+06 V = 0.0000E+00

ENTHALPY CALCULATION FOR INLET STREAM 17 OF BLOCK TK-P

KODE = 2 NO. TEMP ITER = 1 TEMP = 298.15
KPHASE = 2 KODE = 2 T = 298.15 P = 0.10133E+06 Q = 0.00000E+

UOS BLOCK TK-P MODEL: RSTOIC
KODE = 2 NO. TEMP ITER = 1 TEMP = 298.15
KPHASE = 2 KODE = 2 T = 298.15 P = 0.10133E+06 Q = -202.53

UOS BLOCK F-A MODEL: SEP
---FLASH OUTLET STREAM 20 :
KODE = 2 NTRIAL = 2 T = 298.2 P = 0.1013E+06 V = 0.0000E+00
---FLASH OUTLET STREAM 19 :
KODE = 2 NTRIAL = 2 T = 298.2 P = 0.1013E+06 V = 0.0000E+00

UOS BLOCK IX-S MODEL: SEP
---FLASH OUTLET STREAM 16 :
KODE = 2 NTRIAL = 2 T = 298.5 P = 0.1013E+06 V = 0.0000E+00
---FLASH OUTLET STREAM 15 :
KODE = 2 NTRIAL = 2 T = 298.5 P = 0.1013E+06 V = 0.0000E+00

UOS BLOCK TK-G MODEL: RSTOIC
KODE = 2 NO. TEMP ITER = 1 TEMP = 298.15
KPHASE = 2 KODE = 2 T = 298.15 P = 0.10133E+06 Q = -3639.5

SIMULATION CALCULATIONS COMPLETED

PDF UPDATED

REPORT WRITER ENTERED

REPORT GENERATED

NO ERRORS OR WARNINGS GENERATED

* ASPEN PLUS SIMULATION PROGRAM ENDS EXECUTION *

* THE FOLLOWING TYPES OF NUMERIC COPROCESSOR ERRORS HAVE *
* OCCURRED DURING THE COURSE OF SIMULATION CALCULATIONS. *
* INVALID OPERATION *
* DIVIDE BY ZERO *

TM

SEPTEMBER 20, 1993
MONDAY
10:48:31 A.M.

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ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL 09/20/93
102SY REMEDIATION FLOWSHEET
RUN CONTROL SECTION

RUN CONTROL INFORMATION

THIS COPY OF ASPEN PLUS LICENSED TO NASA LOS ALAMOS NATIONAL LABS

TYPE OF RUN: NEW

INPUT FILE NAME: SY102A.inp

OUTPUT PROBLEM DATA FILE NAME: SY102A VERSION NO. 1
LOCATED IN: C:\MMWORK\SY102A

PDF SIZE USED FOR INPUT TRANSLATION:
NUMBER OF FILE RECORDS (PSIZE) = 99999
NUMBER OF IN-CORE RECORDS = 400
PSIZE NEEDED FOR SIMULATION = 231

CALLING PROGRAM NAME: SY102A
LOCATED IN: C:\MMWORK\SY102A

SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

BLOCK STATUS

*
* ALL UNIT OPERATION BLOCKS WERE COMPLETED NORMALLY
*

09/20/93

FLOWSHEET CONNECTIVITY BY STREAMS

STREAM	SOURCE	DEST	STREAM	SOURCE	DEST
4	----	TK-SF	12	----	IX-A
17	----	TK-P	1SLUD	----	B56
1SUPR	----	B56	3	C-S	TK-SF
2	C-S	IX-C	11	TK-SF	IX-A
14	IX-A	IX-S	13	IX-A	TK-P
16	IX-S	TK-G	15	IX-S	----
25	IX-C	IX-T	24	IX-C	----
27	IX-T	TK-G	26	IX-T	----
18	TK-P	F-A	20	F-A	----
19	F-A	TK-G	29	TK-G	----
1	B56	C-S			

FLOWSHEET CONNECTIVITY BY BLOCKS

BLOCK	INLETS	OUTLETS
C-S	1	3 2
TK-SF	3 4	11
IX-A	11 12	14 13
IX-S	14	16 15
IX-C	2	25 24
IX-T	25	27 26
TK-P	13 17	18
F-A	18	20 19
TK-G	16 27 19	29
B56	1SUPR 1SLUD	1

COMPUTATIONAL SEQUENCE

SEQUENCE USED WAS:

B56 C-S IX-C IX-T TK-SF IX-A TK-P F-A IX-S TK-G

OVERALL FLOWSHEET BALANCE

OVERALL FLOWSHEET BALANCE (CONTINUED)

	*** MASS AND ENERGY BALANCE ***		***	RELATIVE DIFF.
	IN	OUT		
CONVENTIONAL COMPONENTS			GENERATION	
(KMOL/HR)				
H2O	58.6763	60.0466	1.37026	0.362392E-15
NA+	1.64579	1.64579	0.000000E+00	0.000000E+00
CS+	0.255000E-05	0.255000E-05	0.000000E+00	0.000000E+00
CA+2	0.345000E-01	0.345000E-01	0.000000E+00	0.000000E+00
SR+2	0.150000E-03	0.150000E-03	0.000000E+00	0.180700E-15
MN+2	0.330000E-01	0.330000E-01	0.000000E+00	0.000000E+00
FE+3	0.760500E-01	0.760500E-01	0.000000E+00	0.000000E+00
CR+3	0.720000E-01	0.720000E-01	0.000000E+00	0.000000E+00
ZR+4	0.600000E-03	0.600000E-03	0.000000E+00	0.000000E+00
MO+6	0.150000E-03	0.150000E-03	0.000000E+00	0.000000E+00
AM+3	0.555000E-05	0.555000E-05	0.000000E+00	0.000000E+00
NP+4	0.126000E-05	0.126000E-05	0.000000E+00	0.000000E+00
PU+4	0.690000E-04	0.690000E-04	0.000000E+00	0.000000E+00
TH+4	0.300000E-02	0.300000E-02	0.000000E+00	0.000000E+00
U+4	0.300000E-02	0.300000E-02	0.000000E+00	0.000000E+00
AL+3	0.285000	0.285000	0.000000E+00	0.000000E+00
H+	1.37026	0.000000E+00	-1.37026	0.000000E+00
OH-	3.14999	1.77973	-1.37026	-0.704905E-16
CL-	0.375000E-01	0.375000E-01	0.000000E+00	0.000000E+00
CO3-2	0.127500	0.127500	0.000000E+00	0.000000E+00
F-	0.750000E-01	0.750000E-01	0.000000E+00	0.000000E+00
NO3-	2.12026	2.12026	0.000000E+00	0.000000E+00
NO2-	0.157500	0.157500	0.000000E+00	0.000000E+00
PO4-3	0.937500E-01	0.937500E-01	0.000000E+00	0.000000E+00
SO4-2	0.210000E-01	0.210000E-01	0.000000E+00	0.000000E+00
TCO4-	0.270000E-04	0.270000E-04	0.000000E+00	0.000000E+00
TOTAL BALANCE				
MOLE (KMOL/HR)	67.9824	66.6121	-1.37026	-0.653241E-17
MASS (KG/HR)	1330.29	1330.29		0.103005E-06
ENTHALPY (KCAL/HR)	-0.448826E+07	-0.450653E+07		0.405410E-02

COMPONENTS

ID	TYPE	FORMULA	NAME OR ALIAS	REPORT NAME
H2O	C	H2O	H2O	H2O
NA+	C	NA+	NA+	NA+
CS+	C	CS+	CS+	CS+
CA+2	C	CA+2	CA+2	CA+2
SR+2	C	SR+2	SR+2	SR+2
MN+2	C	MN+2	MN+2	MN+2
FE+3	C	FE+3	FE+3	FE+3
CR+3	C	CR+3	CR+3	CR+3
ZR+4	C	MISSING	MISSING	ZR+4
MO+6	C	MISSING	MISSING	MO+6
AM+3	C	MISSING	MISSING	AM+3
NP+4	C	MISSING	MISSING	NP+4
PU+4	C	MISSING	MISSING	PU+4
TH+4	C	MISSING	MISSING	TH+4
U+4	C	MISSING	MISSING	U+4
AL+3	C	AL+3	AL+3	AL+3
H+	C	H+	H+	H+
OH-	C	OH-	OH-	OH-
CL-	C	CL-	CL-	CL-
CO3-2	C	CO3-2	CO3-2	CO3-2
F-	C	F-	F-	F-
NO3-	C	NO3-	NO3-	NO3-
NO2-	C	NO2-	NO2-	NO2-
PO4-3	C	PO4-3	PO4-3	PO4-3
SO4-2	C	SO4-2	SO4-2	SO4-2
TCO4-	C	MISSING	MISSING	TCO4-

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL 09/20/93
 102SY REMEDIATION FLOWSHEET
 U-O-S BLOCK SECTION

BLOCK: B56 MODEL: MIXER

 INLET STREAMS: 1SUPR 1SLUD
 OUTLET STREAM: 1
 PROPERTY OPTION SET: SYSOP15 ELECTROLYTE NRTL / REDLICH-KWONG-SOAVE

	*** MASS AND ENERGY BALANCE ***		
	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	55.9480	55.9480	0.000000E+00
MASS(KG/HR)	1076.34	1076.34	-0.211246E-15
ENTHALPY(KCAL/HR)	-0.378848E+07	-0.378848E+07	0.000000E+00

*** INPUT DATA ***
 ONE PHASE FLASH SPECIFIED PHASE IS LIQUID
 MAXIMUM NO. ITERATIONS 30
 CONVERGENCE TOLERANCE 0.000100000
 OUTLET PRESSURE ATM 1.00000

BLOCK: C-S MODEL: SEP

 INLET STREAM: 1
 OUTLET STREAMS: 3 2
 PROPERTY OPTION SET: SYSOP15 ELECTROLYTE NRTL / REDLICH-KWONG-SOAVE

	*** MASS AND ENERGY BALANCE ***		
	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	55.9480	55.9480	0.127001E-15
MASS(KG/HR)	1076.34	1076.34	-0.211246E-15
ENTHALPY(KCAL/HR)	-0.378848E+07	-0.378562E+07	-0.754379E-03

*** INPUT DATA ***
 FLASH SPECS FOR STREAM 3
 TWO PHASE TP FLASH
 PRESSURE DROP ATM 0.0
 MAXIMUM NO. ITERATIONS 30
 CONVERGENCE TOLERANCE 0.000100000

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL
102SY REMEDIATION FLOWSHEET
U-O-S BLOCK SECTION

09/20/93

BLOCK: C-S MODEL: SEP (CONTINUED)

FLASH SPECS FOR STREAM 2
TWO PHASE TP FLASH
PRESSURE DROP ATM
MAXIMUM NO. ITERATIONS
CONVERGENCE TOLERANCE

0.0
30
0.000100000

FRACTION OF FEED
SUBSTREAM= CONV
STREAM= 3

CPT= H2O
NA+
CS+
CA+2
SR+2
MN+2
FE+3
CR+3
ZR+4
MO+6
AM+3
NP+4
PU+4
TH+4
U+4
AL+3
OH-
CL-
CO3-2
F-
NO3-
NO2-
PO4-3
SO4-2
TCO4-

FRACTION=

0.16091
0.0056900
0.100000
1.00000
1.00000
1.00000
1.00000
1.00000
1.00000
1.00000
1.00000
1.00000
1.00000
1.00000
0.85974
0.43543
0.0
0.70588
0.60000
0.0
0.0
0.0
0.0
0.71429
0.0

*** RESULTS ***

COMPONENT = H2O

STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	0.16091
2	CONV	0.83909

COMPONENT = NA+

STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	0.0056900
2	CONV	0.99431

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL
102SY REMEDIATION FLOWSHEET
U-O-S BLOCK SECTION

09/20/93

BLOCK: C-S MODEL: SEP (CONTINUED)

COMPONENT = CS+		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	0.100000
2	CONV	0.900000

COMPONENT = CA+2		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	1.000000

COMPONENT = SR+2		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	1.000000

COMPONENT = MN+2		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	1.000000

COMPONENT = FE+3		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	1.000000

COMPONENT = CR+3		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	1.000000

COMPONENT = ZR+4		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	1.000000

COMPONENT = MO+6		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	1.000000

COMPONENT = AM+3		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	1.000000

COMPONENT = NP+4		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	1.000000

COMPONENT = PU+4		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	1.000000

COMPONENT = TH+4		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	1.000000

COMPONENT = U+4		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	1.000000

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BLOCK: C-S MODEL: SEP (CONTINUED)

COMPONENT = AL+3		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	0.85974
2	CONV	0.14026

COMPONENT = OH-		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	0.43543
2	CONV	0.56457

COMPONENT = CL-		
STREAM	SUBSTREAM	SPLIT FRACTION
2	CONV	1.00000

COMPONENT = CO3-2		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	0.70588
2	CONV	0.29412

COMPONENT = F-		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	0.60000
2	CONV	0.40000

COMPONENT = NO3-		
STREAM	SUBSTREAM	SPLIT FRACTION
2	CONV	1.00000

COMPONENT = NO2-		
STREAM	SUBSTREAM	SPLIT FRACTION
2	CONV	1.00000

COMPONENT = PO4-3		
STREAM	SUBSTREAM	SPLIT FRACTION
2	CONV	1.00000

COMPONENT = SO4-2		
STREAM	SUBSTREAM	SPLIT FRACTION
3	CONV	0.71429
2	CONV	0.28571

COMPONENT = TCO4-		
STREAM	SUBSTREAM	SPLIT FRACTION
2	CONV	1.00000

BLOCK: F-A MODEL: SEP

INLET STREAM:	18	
OUTLET STREAMS:	20	19
PROPERTY OPTION SET:	SYSOP15	ELECTROLYTE NRTL / REDLICH-KWONG-SOAVE

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL
 102SY REMEDIATION FLOWSHEET
 U-O-S BLOCK SECTION

09/20/93

BLOCK: F-A MODEL: SEP (CONTINUED)

	*** MASS AND ENERGY BALANCE ***		RELATIVE DIFF.
TOTAL BALANCE	IN	OUT	
MOLE (KMOL/HR)	7.26727	7.26727	0.000000E+00
MASS (KG/HR)	132.694	132.694	-0.214189E-15
ENTHALPY (KCAL/HR)	-494612.	-493506.	-0.223412E-02

*** INPUT DATA ***

FLASH SPECS FOR STREAM 20
 TWO PHASE TP FLASH
 PRESSURE DROP ATM 0.0
 MAXIMUM NO. ITERATIONS 30
 CONVERGENCE TOLERANCE 0.000100000

FLASH SPECS FOR STREAM 19
 TWO PHASE TP FLASH
 PRESSURE DROP ATM 0.0
 MAXIMUM NO. ITERATIONS 30
 CONVERGENCE TOLERANCE 0.000100000

FRACTION OF FEED
 SUBSTREAM= CONV
 STREAM= 20

CPT=	NA+	FRACTION=
	CS+	0.0
	AM+3	0.0
	NP+4	0.99900
	PU+4	0.99900
	TH+4	0.99900
	U+4	0.99900
	CL-	0.0
	CO3-2	0.0
	F-	0.0
	NO3-	0.0
	NO2-	0.0
	PO4-3	0.0
	SO4-2	0.0

MOLE-FLOW (KMOL/HR)
 SUBSTREAM= CONV
 STREAM= 20

CPT=	OH-	FLOW=
		0.024274

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL
 102SY REMEDIATION FLOWSHEET
 U-O-S BLOCK SECTION

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BLOCK: F-A MODEL: SEP (CONTINUED)

*** RESULTS ***

COMPONENT = H2O		
STREAM	SUBSTREAM	SPLIT FRACTION
19	CONV	1.00000
COMPONENT = NA+		
STREAM	SUBSTREAM	SPLIT FRACTION
19	CONV	1.00000
COMPONENT = AM+3		
STREAM	SUBSTREAM	SPLIT FRACTION
20	CONV	0.99900
19	CONV	0.00100000
COMPONENT = NP+4		
STREAM	SUBSTREAM	SPLIT FRACTION
20	CONV	0.99900
19	CONV	0.00100000
COMPONENT = PU+4		
STREAM	SUBSTREAM	SPLIT FRACTION
20	CONV	0.99900
19	CONV	0.00100000
COMPONENT = TH+4		
STREAM	SUBSTREAM	SPLIT FRACTION
20	CONV	0.99900
19	CONV	0.00100000
COMPONENT = U+4		
STREAM	SUBSTREAM	SPLIT FRACTION
20	CONV	0.99900
19	CONV	0.00100000
COMPONENT = OH-		
STREAM	SUBSTREAM	SPLIT FRACTION
20	CONV	0.65179
19	CONV	0.34821
COMPONENT = NO3-		
STREAM	SUBSTREAM	SPLIT FRACTION
19	CONV	1.00000

BLOCK: IX-A MODEL: SEP

INLET STREAMS:	11	12
OUTLET STREAMS:	14	13
PROPERTY OPTION SET:	SYSOP15	ELECTROLYTE NRTL / REDLICH-KWONG-SOAVE

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL 09/20/93
 102SY REMEDIATION FLOWSHEET
 U-O-S BLOCK SECTION

BLOCK: IX-A MODEL: SEP (CONTINUED)

	*** MASS AND ENERGY BALANCE ***		
	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE (KMOL/HR)	20.2943	20.2943	-0.175060E-15
MASS (KG/HR)	441.511	441.511	-0.128748E-15
ENTHALPY (KCAL/HR)	-0.137741E+07	-0.137731E+07	-0.715359E-04

*** INPUT DATA ***

INLET PRESSURE: MINIMUM OF INLET STREAM PRESSURES

FLASH SPECS FOR STREAM 14
 TWO PHASE TP FLASH
 PRESSURE DROP ATM
 MAXIMUM NO. ITERATIONS
 CONVERGENCE TOLERANCE

0.0
 30
 0.000100000

FLASH SPECS FOR STREAM 13
 TWO PHASE TP FLASH
 PRESSURE DROP ATM
 MAXIMUM NO. ITERATIONS
 CONVERGENCE TOLERANCE

0.0
 30
 0.000100000

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BLOCK: IX-A MODEL: SEP (CONTINUED)

FRACTION OF FEED
 SUBSTREAM= CONV
 STREAM= 14

CPT= H2O	FRACTION=	0.62100
NA+		1.00000
CS+		1.00000
CA+2		1.00000
SR+2		1.00000
MN+2		1.00000
FE+3		1.00000
CR+3		1.00000
ZR+4		1.00000
MO+6		1.00000
AM+3		0.00100000
NP+4		0.0
PU+4		0.0
TH+4		0.0
U+4		0.0
AL+3		1.00000
H+		0.64490
CL-		1.00000
CO3-2		1.00000
F-		1.00000
NO3-		0.99544
NO2-		1.00000
PO4-3		1.00000
SO4-2		1.00000

*** RESULTS ***

COMPONENT = H2O		
STREAM	SUBSTREAM	SPLIT FRACTION
14	CONV	0.62100
13	CONV	0.37900

COMPONENT = NA+		
STREAM	SUBSTREAM	SPLIT FRACTION
14	CONV	1.00000

COMPONENT = CS+		
STREAM	SUBSTREAM	SPLIT FRACTION
14	CONV	1.00000

COMPONENT = CA+2		
STREAM	SUBSTREAM	SPLIT FRACTION
14	CONV	1.00000

COMPONENT = SR+2		
STREAM	SUBSTREAM	SPLIT FRACTION
14	CONV	1.00000

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BLOCK: IX-A MODEL: SEP (CONTINUED)

COMPONENT = MN+2		
STREAM	SUBSTREAM	SPLIT FRACTION
14	CONV	1.00000
COMPONENT = FE+3		
STREAM	SUBSTREAM	SPLIT FRACTION
14	CONV	1.00000
COMPONENT = CR+3		
STREAM	SUBSTREAM	SPLIT FRACTION
14	CONV	1.00000
COMPONENT = ZR+4		
STREAM	SUBSTREAM	SPLIT FRACTION
14	CONV	1.00000
COMPONENT = MO+6		
STREAM	SUBSTREAM	SPLIT FRACTION
14	CONV	1.00000
COMPONENT = AM+3		
STREAM	SUBSTREAM	SPLIT FRACTION
14	CONV	0.00100000
13	CONV	0.99900
COMPONENT = NP+4		
STREAM	SUBSTREAM	SPLIT FRACTION
13	CONV	1.00000
COMPONENT = PU+4		
STREAM	SUBSTREAM	SPLIT FRACTION
13	CONV	1.00000
COMPONENT = TH+4		
STREAM	SUBSTREAM	SPLIT FRACTION
13	CONV	1.00000
COMPONENT = U+4		
STREAM	SUBSTREAM	SPLIT FRACTION
13	CONV	1.00000
COMPONENT = AL+3		
STREAM	SUBSTREAM	SPLIT FRACTION
14	CONV	1.00000
COMPONENT = H+		
STREAM	SUBSTREAM	SPLIT FRACTION
14	CONV	0.64490
13	CONV	0.35510
COMPONENT = CO3-2		
STREAM	SUBSTREAM	SPLIT FRACTION
14	CONV	1.00000

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL
 102SY REMEDIATION FLOWSHEET
 U-O-S BLOCK SECTION

09/20/93

BLOCK: IX-A MODEL: SEP (CONTINUED)

COMPONENT = F-
 STREAM SUBSTREAM SPLIT FRACTION
 14 CONV 1.00000

COMPONENT = NO3-
 STREAM SUBSTREAM SPLIT FRACTION
 14 CONV 0.99544
 13 CONV 0.0045600

COMPONENT = SO4-2
 STREAM SUBSTREAM SPLIT FRACTION
 14 CONV 1.00000

BLOCK: IX-C MODEL: SEP

 INLET STREAM: 2
 OUTLET STREAMS: 25 24
 PROPERTY OPTION SET: SYSOP15 ELECTROLYTE NRTL / REDLICH-KWONG-SOAVE

	*** MASS AND ENERGY BALANCE ***		RELATIVE DIFF.
	IN	OUT	
TOTAL BALANCE			
MOLE(KMOL/HR)	46.0085	46.0085	0.000000E+00
MASS(KG/HR)	882.720	882.720	0.128792E-15
ENTHALPY(KCAL/HR)	-0.310582E+07	-0.310582E+07	-0.430386E-07

*** INPUT DATA ***

FLASH SPECS FOR STREAM 25
 TWO PHASE TP FLASH
 PRESSURE DROP ATM 0.0
 MAXIMUM NO. ITERATIONS 30
 CONVERGENCE TOLERANCE 0.000100000

FLASH SPECS FOR STREAM 24
 TWO PHASE TP FLASH
 PRESSURE DROP ATM 0.0
 MAXIMUM NO. ITERATIONS 30
 CONVERGENCE TOLERANCE 0.000100000

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL
 102SY REMEDIATION FLOWSHEET
 U-O-S BLOCK SECTION

09/20/93

BLOCK: IX-C MODEL: SEP (CONTINUED)

FRACTION OF FEED

SUBSTREAM= CONV

STREAM= 25

CPT= H2O	FRACTION=	1.00000
NA+		1.00000
CS+		0.00100000
AL+3		1.00000
OH-		1.00000
CL-		1.00000
CO3-2		1.00000
F-		1.00000
NO3-		1.00000
NO2-		1.00000
PO4-3		1.00000
SO4-2		1.00000
TCO4-		1.00000

*** RESULTS ***

COMPONENT = H2O

STREAM	SUBSTREAM	SPLIT FRACTION
25	CONV	1.00000

COMPONENT = NA+

STREAM	SUBSTREAM	SPLIT FRACTION
25	CONV	1.00000

COMPONENT = CS+

STREAM	SUBSTREAM	SPLIT FRACTION
25	CONV	0.00100000
24	CONV	0.99900

COMPONENT = AL+3

STREAM	SUBSTREAM	SPLIT FRACTION
25	CONV	1.00000

COMPONENT = OH-

STREAM	SUBSTREAM	SPLIT FRACTION
25	CONV	1.00000

COMPONENT = CL-

STREAM	SUBSTREAM	SPLIT FRACTION
25	CONV	1.00000

COMPONENT = CO3-2

STREAM	SUBSTREAM	SPLIT FRACTION
25	CONV	1.00000

COMPONENT = F-

STREAM	SUBSTREAM	SPLIT FRACTION
25	CONV	1.00000

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL 09/20/93
 102SY REMEDIATION FLOWSHEET
 U-O-S BLOCK SECTION

BLOCK: IX-C MODEL: SEP (CONTINUED)

COMPONENT = NO3-
 STREAM SUBSTREAM SPLIT FRACTION
 25 CONV 1.00000

COMPONENT = NO2-
 STREAM SUBSTREAM SPLIT FRACTION
 25 CONV 1.00000

COMPONENT = PO4-3
 STREAM SUBSTREAM SPLIT FRACTION
 25 CONV 1.00000

COMPONENT = SO4-2
 STREAM SUBSTREAM SPLIT FRACTION
 25 CONV 1.00000

COMPONENT = TCO4-
 STREAM SUBSTREAM SPLIT FRACTION
 25 CONV 1.00000

BLOCK: IX-S MODEL: SEP

 INLET STREAM: 14
 OUTLET STREAMS: 16 15
 PROPERTY OPTION SET: SYSOP15 ELECTROLYTE NRTL / REDLICH-KWONG-SOAVE

	*** MASS AND ENERGY BALANCE ***		
	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE (KMOL/HR)	13.3477	13.3477	0.000000E+00
MASS (KG/HR)	314.878	314.878	-0.541575E-15
ENTHALPY (KCAL/HR)	-904094.	-904076.	-0.201773E-04

*** INPUT DATA ***

FLASH SPECS FOR STREAM 16
 TWO PHASE TP FLASH
 PRESSURE DROP ATM 0.0
 MAXIMUM NO. ITERATIONS 30
 CONVERGENCE TOLERANCE 0.000100000

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL
 102SY REMEDIATION FLOWSHEET
 U-O-S BLOCK SECTION

09/20/93

BLOCK: IX-S MODEL: SEP (CONTINUED)

FLASH SPECS FOR STREAM 15
 TWO PHASE TP FLASH
 PRESSURE DROP ATM
 MAXIMUM NO. ITERATIONS
 CONVERGENCE TOLERANCE

0.0
 30
 0.000100000

FRACTION OF FEED
 SUBSTREAM= CONV
 STREAM= 16

CPT= H2O	FRACTION=	1.00000
NA+		1.00000
CS+		1.00000
CA+2		1.00000
SR+2		0.00100000
MN+2		1.00000
FE+3		1.00000
CR+3		1.00000
ZR+4		1.00000
MO+6		1.00000
AM+3		1.00000
AL+3		1.00000
H+		1.00000
CL-		1.00000
CO3-2		1.00000
F-		1.00000
NO3-		1.00000
NO2-		1.00000
PO4-3		1.00000
SO4-2		1.00000

*** RESULTS ***

COMPONENT = H2O		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

COMPONENT = NA+		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

COMPONENT = CS+		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

COMPONENT = CA+2		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

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BLOCK: IX-S MODEL: SEP (CONTINUED)

COMPONENT = SR+2		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	0.00100000
15	CONV	0.99900

COMPONENT = MN+2		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

COMPONENT = FE+3		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

COMPONENT = CR+3		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

COMPONENT = ZR+4		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

COMPONENT = MO+6		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

COMPONENT = AM+3		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

COMPONENT = AL+3		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

COMPONENT = H+		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

COMPONENT = CO3-2		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

COMPONENT = F-		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

COMPONENT = NO3-		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

COMPONENT = SO4-2		
STREAM	SUBSTREAM	SPLIT FRACTION
16	CONV	1.00000

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL
 102SY REMEDIATION FLOWSHEET
 U-O-S BLOCK SECTION

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BLOCK: IX-T MODEL: SEP

 INLET STREAM: 25
 OUTLET STREAMS: 27 26
 PROPERTY OPTION SET: SYSOP15 ELECTROLYTE NRTL / REDLICH-KWONG-SOAVE

	*** MASS AND ENERGY BALANCE ***		
	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	46.0085	46.0085	0.000000E+00
MASS(KG/HR)	882.719	882.719	0.000000E+00
ENTHALPY(KCAL/HR)	-0.310582E+07	-0.310582E+07	0.624227E-07

*** INPUT DATA ***

FLASH SPECS FOR STREAM 27
 TWO PHASE TP FLASH
 PRESSURE DROP ATM 0.0
 MAXIMUM NO. ITERATIONS 30
 CONVERGENCE TOLERANCE 0.000100000

FLASH SPECS FOR STREAM 26
 TWO PHASE TP FLASH
 PRESSURE DROP ATM 0.0
 MAXIMUM NO. ITERATIONS 30
 CONVERGENCE TOLERANCE 0.000100000

FRACTION OF FEED
 SUBSTREAM= CONV
 STREAM= 27

CPT=	FRACTION=
H2O	1.00000
NA+	1.00000
CS+	1.00000
AL+3	1.00000
OH-	1.00000
CL-	1.00000
CO3-2	1.00000
F-	1.00000
NO3-	1.00000
NO2-	1.00000
PO4-3	1.00000
SO4-2	1.00000
TCO4-	0.00100000

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BLOCK: IX-T MODEL: SEP (CONTINUED)

*** RESULTS ***

COMPONENT = H2O		
STREAM	SUBSTREAM	SPLIT FRACTION
27	CONV	1.00000

COMPONENT = NA+		
STREAM	SUBSTREAM	SPLIT FRACTION
27	CONV	1.00000

COMPONENT = CS+		
STREAM	SUBSTREAM	SPLIT FRACTION
27	CONV	1.00000

COMPONENT = AL+3		
STREAM	SUBSTREAM	SPLIT FRACTION
27	CONV	1.00000

COMPONENT = OH-		
STREAM	SUBSTREAM	SPLIT FRACTION
27	CONV	1.00000

COMPONENT = CL-		
STREAM	SUBSTREAM	SPLIT FRACTION
27	CONV	1.00000

COMPONENT = CO3-2		
STREAM	SUBSTREAM	SPLIT FRACTION
27	CONV	1.00000

COMPONENT = F-		
STREAM	SUBSTREAM	SPLIT FRACTION
27	CONV	1.00000

COMPONENT = NO3-		
STREAM	SUBSTREAM	SPLIT FRACTION
27	CONV	1.00000

COMPONENT = NO2-		
STREAM	SUBSTREAM	SPLIT FRACTION
27	CONV	1.00000

COMPONENT = PO4-3		
STREAM	SUBSTREAM	SPLIT FRACTION
27	CONV	1.00000

COMPONENT = SO4-2		
STREAM	SUBSTREAM	SPLIT FRACTION
27	CONV	1.00000

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL 09/20/93
 102SY REMEDIATION FLOWSHEET
 U-O-S BLOCK SECTION

BLOCK: IX-T MODEL: SEP (CONTINUED)

COMPONENT = TCO4-
 STREAM SUBSTREAM SPLIT FRACTION
 27 CONV 0.00100000
 26 CONV 0.99900

BLOCK: TK-G MODEL: RSTOIC

 INLET STREAMS: 16 27 19
 OUTLET STREAM: 29
 PROPERTY OPTION SET: SYSOP15 ELECTROLYTE NRTL / REDLICH-KWONG-SOAVE

	*** MASS AND ENERGY BALANCE ***		
	IN	OUT	GENERATION RELATIVE DIFF.
TOTAL BALANCE			
MOLE (KMOL/HR)	66.5930	66.5816	-0.113507E-01 -0.546522E-16
MASS (KG/HR)	1328.44	1328.44	0.854445E-09
ENTHALPY (KCAL/HR)	-0.450318E+07	-0.450631E+07	0.694466E-03

*** INPUT DATA ***

SIMULTANEOUS REACTIONS
 STOICHIOMETRY MATRIX:

REACTION # 1:
 SUBSTREAM MIXED :
 H2O 1.00 H+ -1.00 OH- -1.00

REACTION CONVERSION SPECS: NUMBER= 1
 REACTION # 1:
 SUBSTREAM:MIXED KEY COMP:H+ CONV FRAC: 1.000

ONE PHASE TP FLASH SPECIFIED PHASE IS LIQUID
 SPECIFIED TEMPERATURE C 25.0000
 SPECIFIED PRESSURE ATM 1.00000
 MAXIMUM NO. ITERATIONS 30
 CONVERGENCE TOLERANCE 0.000100000

*** RESULTS ***
 OUTLET TEMPERATURE C 25.000
 OUTLET PRESSURE ATM 1.0000
 HEAT DUTY KCAL/HR -3129.5

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL 09/20/93
 102SY REMEDIATION FLOWSHEET
 U-O-S BLOCK SECTION

BLOCK: TK-P MODEL: RSTOIC

 INLET STREAMS: 13 17
 OUTLET STREAM: 18
 PROPERTY OPTION SET: SYSOP15 ELECTROLYTE NRTL / REDLICH-KWONG-SOAVE

	***	MASS AND ENERGY BALANCE	***	
		IN	OUT	GENERATION RELATIVE DIFF.
TOTAL BALANCE				
MOLE(KMOL/HR)	7.27352		7.26727	-0.625004E-02 0.426197E-15
MASS(KG/HR)	132.694		132.694	0.471010E-08
ENTHALPY(KCAL/HR)	-494437.		-494612.	0.352091E-03

*** INPUT DATA ***

SIMULTANEOUS REACTIONS
 STOICHIOMETRY MATRIX:

REACTION # 1:
 SUBSTREAM MIXED :
 H2O 1.00 H+ -1.00 OH- -1.00

REACTION CONVERSION SPECS: NUMBER= 1
 REACTION # 1:
 SUBSTREAM:MIXED KEY COMP:H+ CONV FRAC: 1.000

ONE PHASE TP FLASH SPECIFIED PHASE IS LIQUID	
SPECIFIED TEMPERATURE C	25.0000
SPECIFIED PRESSURE ATM	1.00000
MAXIMUM NO. ITERATIONS	30
CONVERGENCE TOLERANCE	0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	C	25.000
OUTLET PRESSURE	ATM	1.0000
HEAT DUTY	KCAL/HR	-174.15

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL 09/20/93
 102SY REMEDIATION FLOWSHEET
 U-O-S BLOCK SECTION

BLOCK: TK-SF MODEL: RSTOIC

 INLET STREAMS: 3 4
 OUTLET STREAM: 11
 PROPERTY OPTION SET: SYSOP15 ELECTROLYTE NRTL / REDLICH-KWONG-SOAVE

	*** MASS AND ENERGY BALANCE	***		
	IN	OUT	GENERATION	RELATIVE DIFF.
TOTAL BALANCE				
MOLE (KMOL/HR)	14.7258	13.3731	-1.35266	-0.165865E-15
MASS (KG/HR)	316.656	316.656		0.427172E-06
ENTHALPY (KCAL/HR)	-886415.	-905461.		0.210346E-01

*** INPUT DATA ***

SIMULTANEOUS REACTIONS
 STOICHIOMETRY MATRIX:

REACTION # 1:
 SUBSTREAM MIXED :
 H2O 1.00 H+ -1.00 OH- -1.00

REACTION CONVERSION SPECS: NUMBER= 1
 REACTION # 1:
 SUBSTREAM:MIXED KEY COMP:OH- CONV FRAC: 1.000

ONE	PHASE	TP	FLASH	SPECIFIED PHASE IS	LIQUID
SPECIFIED TEMPERATURE	C				25.0000
SPECIFIED PRESSURE	ATM				1.00000
MAXIMUM NO. ITERATIONS					30
CONVERGENCE TOLERANCE					0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	C	25.000
OUTLET PRESSURE	ATM	1.0000
HEAT DUTY	KCAL/HR	-19046.

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1 11 12 13 14

STREAM ID	1	11	12	13	14
FROM :	B56	TK-SF	----	IX-A	IX-A
TO :	C-S	IX-A	IX-A	TK-P	IX-S
CLASS:	CONV	CONV	CONV	CONV	CONV
SUBSTREAM: CONV					
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID
COMPONENTS: KMOL/HR					
H2O	49.4693	11.3711	6.9086	6.9280	11.3517
NA+	1.6023	9.1171-03	0.0	0.0	9.1171-03
CS+	2.5500-06	2.5500-07	0.0	0.0	2.5500-07
CA+2	3.4500-02	3.4500-02	0.0	0.0	3.4500-02
SR+2	1.5000-04	1.5000-04	0.0	0.0	1.5000-04
MN+2	3.3000-02	3.3000-02	0.0	0.0	3.3000-02
FE+3	7.6050-02	7.6050-02	0.0	0.0	7.6050-02
CR+3	7.2000-02	7.2000-02	0.0	0.0	7.2000-02
ZR+4	6.0000-04	6.0000-04	0.0	0.0	6.0000-04
MO+6	1.5000-04	1.5000-04	0.0	0.0	1.5000-04
AM+3	5.5500-06	5.5500-06	0.0	5.5445-06	5.5500-09
NP+4	1.2600-06	1.2600-06	0.0	1.2600-06	0.0
PU+4	6.9000-05	6.9000-05	0.0	6.9000-05	0.0
TH+4	3.0000-03	3.0000-03	0.0	3.0000-03	0.0
U+4	3.0000-03	3.0000-03	0.0	3.0000-03	0.0
AL+3	0.2850	0.2450	0.0	0.0	0.2450
H+	0.0	1.1351-02	6.2500-03	6.2500-03	1.1351-02
OH-	3.1065	0.0	0.0	0.0	0.0
CL-	3.7500-02	0.0	0.0	0.0	0.0
CO3-2	0.1275	9.0000-02	0.0	0.0	9.0000-02
F-	7.5000-02	4.5000-02	0.0	0.0	4.5000-02
NO3-	0.7500	1.3640	6.2500-03	6.2484-03	1.3640
NO2-	0.1575	0.0	0.0	0.0	0.0
PO4-3	9.3750-02	0.0	0.0	0.0	0.0
SO4-2	2.1000-02	1.5000-02	0.0	0.0	1.5000-02
TCO4-	2.7000-05	0.0	0.0	0.0	0.0
TOTAL FLOW:					
KMOL/HR	55.9480	13.3731	6.9211	6.9466	13.3476
KG/HR	1076.3437	316.6556	124.8549	126.6322	314.8783
L/HR	897.1045	226.9470	125.0000	125.4761	225.5807
STATE VARIABLES:					
TEMP C	27.4477	25.0000	25.0000	25.3646	25.3646
PRES ATM	1.0000	1.0000	1.0000	1.0000	1.0000
VFRAC	0.0	0.0	0.0	0.0	0.0
LFRAC	1.0000	1.0000	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
CAL/MOL	-6.7713+04	-6.7706+04	-6.8188+04	-6.8121+04	-6.7733+04
CAL/GM	-3519.7150	-2859.4084	-3779.9165	-3736.8788	-2871.2080
KCAL/HR	-3.7885+06	-9.0546+05	-4.7195+05	-4.7322+05	-9.0409+05
ENTROPY:					
CAL/MOL-K	-38.6557	-41.8448	-38.9499	-38.8710	-41.8759
CAL/GM-K	-2.0093	-1.7672	-2.1591	-2.1323	-1.7751
DENSITY:					
MOL/CC	6.2365-02	5.8926-02	5.5369-02	5.5362-02	5.9170-02
GM/CC	1.1998	1.3952	0.9988	1.0092	1.3958

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL 09/20/93
102SY REMEDIATION FLOWSHEET
STREAM SECTION

1 11 12 13 14 (CONTINUED)

STREAM ID	1	11	12	13	14
AVG MW	19.2382	23.6784	18.0396	18.2294	23.5905

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15 16 17 18 19

STREAM ID	15	16	17	18	19
FROM :	IX-S	IX-S	----	TK-P	F-A
TO :	----	TK-G	TK-P	F-A	TK-G
CLASS:	CONV	CONV	CONV	CONV	CONV
SUBSTREAM: CONV					
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID
COMPONENTS: KMOL/HR					
H2O	0.0	11.3517	0.2399	7.1742	7.1742
NA+	0.0	9.1171-03	4.3492-02	4.3492-02	4.3492-02
CS+	0.0	2.5500-07	0.0	0.0	0.0
CA+2	0.0	3.4500-02	0.0	0.0	0.0
SR+2	1.4985-04	1.5000-07	0.0	0.0	0.0
MN+2	0.0	3.3000-02	0.0	0.0	0.0
FE+3	0.0	7.6050-02	0.0	0.0	0.0
CR+3	0.0	7.2000-02	0.0	0.0	0.0
ZR+4	0.0	6.0000-04	0.0	0.0	0.0
MO+6	0.0	1.5000-04	0.0	0.0	0.0
AM+3	0.0	5.5500-09	0.0	5.5445-06	5.5445-09
NP+4	0.0	0.0	0.0	1.2600-06	1.2600-09
PU+4	0.0	0.0	0.0	6.9000-05	6.9000-08
TH+4	0.0	0.0	0.0	3.0000-03	3.0000-06
U+4	0.0	0.0	0.0	3.0000-03	3.0000-06
AL+3	0.0	0.2450	0.0	0.0	0.0
H+	0.0	1.1351-02	0.0	0.0	0.0
OH-	0.0	0.0	4.3492-02	3.7242-02	1.2968-02
CL-	0.0	0.0	0.0	0.0	0.0
CO3-2	0.0	9.0000-02	0.0	0.0	0.0
F-	0.0	4.5000-02	0.0	0.0	0.0
NO3-	0.0	1.3640	0.0	6.2484-03	6.2484-03
NO2-	0.0	0.0	0.0	0.0	0.0
PO4-3	0.0	0.0	0.0	0.0	0.0
SO4-2	0.0	1.5000-02	0.0	0.0	0.0
TCO4-	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
KMOL/HR	1.4985-04	13.3475	0.3269	7.2672	7.2369
KG/HR	1.3130-02	314.8652	6.0621	132.6944	130.8548
L/HR	MISSING	225.5789	4.3492	130.0139	129.7372
STATE VARIABLES:					
TEMP C	25.3646	25.3646	25.0000	25.0000	25.0000
PRES ATM	1.0000	1.0000	1.0000	1.0000	1.0000
VFRAC	0.0	0.0	0.0	0.0	0.0
LFRAC	1.0000	1.0000	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
CAL/MOL	-7457.5640	-6.7733+04	-6.4911+04	-6.8059+04	-6.8161+04
CAL/GM	-85.1125	-2871.2662	-3500.5480	-3727.3944	-3769.6568
KCAL/HR	-1.1175	-9.0407+05	-2.1221+04	-4.9461+05	-4.9329+05
ENTROPY:					
CAL/MOL-K	-24.9822	-41.8771	-34.2290	-38.6369	-38.6452
CAL/GM-K	-0.2851	-1.7752	-1.8459	-2.1160	-2.1372
DENSITY:					
MOL/CC	MISSING	5.9170-02	7.5169-02	5.5896-02	5.5781-02
GM/CC	MISSING	1.3958	1.3938	1.0206	1.0086

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL 09/20/93
102SY REMEDIATION FLOWSHEET
STREAM SECTION

15 16 17 18 19 (CONTINUED)

STREAM ID	15	16	17	18	19
AVG MW	87.6200	23.5897	18.5429	18.2591	18.0815

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1SLUD 1SUPR 2 20 24

STREAM ID	1SLUD	1SUPR	2	20	24
FROM :	----	----	C-S	F-A	IX-C
TO :	B56	B56	IX-C	----	----
CLASS:	CONV	CONV	CONV	CONV	CONV
SUBSTREAM: CONV					
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID
COMPONENTS: KMOL/HR					
H2O	8.2932	41.1761	41.5092	0.0	0.0
NA+	0.9123	0.6900	1.5931	0.0	0.0
CS+	2.5500-06	0.0	2.2950-06	0.0	2.2927-06
CA+2	3.4500-02	0.0	0.0	0.0	0.0
SR+2	1.5000-04	0.0	0.0	0.0	0.0
MN+2	3.3000-02	0.0	0.0	0.0	0.0
FE+3	7.6050-02	0.0	0.0	0.0	0.0
CR+3	7.2000-02	0.0	0.0	0.0	0.0
ZR+4	6.0000-04	0.0	0.0	0.0	0.0
MO+6	1.5000-04	0.0	0.0	0.0	0.0
AM+3	5.5500-06	0.0	0.0	5.5389-06	0.0
NP+4	1.2600-06	0.0	0.0	1.2587-06	0.0
PU+4	6.9000-05	0.0	0.0	6.8931-05	0.0
TH+4	3.0000-03	0.0	0.0	2.9970-03	0.0
U+4	3.0000-03	0.0	0.0	2.9970-03	0.0
AL+3	0.2475	3.7500-02	3.9974-02	0.0	0.0
H+	0.0	0.0	0.0	0.0	0.0
OH-	2.2665	0.8400	1.7538	2.4274-02	0.0
CL-	2.2500-02	1.5000-02	3.7500-02	0.0	0.0
CO3-2	9.0000-02	3.7500-02	3.7500-02	0.0	0.0
F-	4.5000-02	3.0000-02	3.0000-02	0.0	0.0
NO3-	0.4500	0.3000	0.7500	0.0	0.0
NO2-	0.1200	3.7500-02	0.1575	0.0	0.0
PO4-3	9.0000-02	3.7500-03	9.3750-02	0.0	0.0
SO4-2	1.5000-02	6.0000-03	5.9999-03	0.0	0.0
TCO4-	2.7000-05	0.0	2.7000-05	0.0	0.0
TOTAL FLOW:					
KMOL/HR	12.7745	43.1734	46.0085	3.0344-02	2.2927-06
KG/HR	278.7704	797.5732	882.7197	1.8395	3.0471-04
L/HR	150.0000	750.0000	782.9640	0.5314	MISSING
STATE VARIABLES:					
TEMP C	25.0000	25.0000	27.4477	25.0000	27.4477
PRES ATM	1.0000	1.0000	1.0000	1.0000	1.0000
VFRAC	0.0	0.0	0.0	0.0	0.0
LFRAC	1.0000	1.0000	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
CAL/MOL	-6.7287+04	-6.7840+04	-6.7504+04	-7297.0469	-7427.8797
CAL/GM	-3083.3874	-3672.2217	-3518.4172	-120.3671	-55.8884
KCAL/HR	-8.5957+05	-2.9289+06	-3.1058+06	-221.4227	-1.7030-02
ENTROPY:					
CAL/MOL-K	-39.1716	-38.6310	-38.4671	-24.4744	-24.7103
CAL/GM-K	-1.7950	-2.0911	-2.0049	-0.4037	-0.1859
DENSITY:					
MOL/CC	8.5164-02	5.7565-02	5.8762-02	5.7101-02	MISSING
GM/CC	1.8584	1.0634	1.1274	3.4616	MISSING

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL 09/20/93
102SY REMEDIATION FLOWSHEET
STREAM SECTION

1SLUD 1SUPR 2 20 24 (CONTINUED)

STREAM ID	1SLUD	1SUPR	2	20	24
AVG MW	21.8222	18.4737	19.1859	60.6232	132.9054

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25 26 27 29 3

STREAM ID	25	26	27	29	3
FROM :	IX-C	IX-T	IX-T	TK-G	C-S
TO :	IX-T	----	TK-G	----	TK-SF
CLASS:	CONV	CONV	CONV	CONV	CONV
SUBSTREAM: CONV					
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID
COMPONENTS: KMOL/HR					
H2O	41.5092	0.0	41.5092	60.0465	7.9601
NA+	1.5931	0.0	1.5931	1.6457	9.1171-03
CS+	2.2950-09	0.0	2.2950-09	2.5730-07	2.5500-07
CA+2	0.0	0.0	0.0	3.4500-02	3.4500-02
SR+2	0.0	0.0	0.0	1.5000-07	1.5000-04
MN+2	0.0	0.0	0.0	3.3000-02	3.3000-02
FE+3	0.0	0.0	0.0	7.6050-02	7.6050-02
CR+3	0.0	0.0	0.0	7.2000-02	7.2000-02
ZR+4	0.0	0.0	0.0	6.0000-04	6.0000-04
MO+6	0.0	0.0	0.0	1.5000-04	1.5000-04
AM+3	0.0	0.0	0.0	1.1094-08	5.5500-06
NP+4	0.0	0.0	0.0	1.2600-09	1.2600-06
PU+4	0.0	0.0	0.0	6.9000-08	6.9000-05
TH+4	0.0	0.0	0.0	3.0000-06	3.0000-03
U+4	0.0	0.0	0.0	3.0000-06	3.0000-03
AL+3	3.9974-02	0.0	3.9974-02	0.2850	0.2450
H+	0.0	0.0	0.0	0.0	0.0
OH-	1.7538	0.0	1.7538	1.7554	1.3526
CL-	3.7500-02	0.0	3.7500-02	3.7500-02	0.0
CO3-2	3.7500-02	0.0	3.7500-02	0.1275	9.0000-02
F-	3.0000-02	0.0	3.0000-02	7.5000-02	4.5000-02
NO3-	0.7500	0.0	0.7500	2.1202	0.0
NO2-	0.1575	0.0	0.1575	0.1575	0.0
PO4-3	9.3750-02	0.0	9.3750-02	9.3750-02	0.0
SO4-2	5.9999-03	0.0	5.9999-03	2.1000-02	1.5000-02
TCO4-	2.7000-05	2.6973-05	2.7000-08	2.7000-08	0.0
TOTAL FLOW:					
KMOL/HR	46.0085	2.6973-05	46.0085	66.5816	9.9394
KG/HR	882.7194	4.3966-03	882.7150	1328.4351	193.6240
L/HR	782.9639	MISSING	782.9613	1131.5315	120.3495
STATE VARIABLES:					
TEMP C	27.4477	27.4477	27.4477	25.0000	27.4477
PRES ATM	1.0000	1.0000	1.0000	1.0000	1.0000
VFRAC	0.0	0.0	0.0	0.0	0.0
LFRAC	1.0000	1.0000	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
CAL/MOL	-6.7504+04	-7442.6116	-6.7504+04	-6.7680+04	-6.8393+04
CAL/GM	-3518.4182	-45.6601	-3518.4357	-3392.1456	-3510.8718
KCAL/HR	-3.1058+06	-0.2007	-3.1058+06	-4.5063+06	-6.7980+05
ENTROPY:					
CAL/MOL-K	-38.4671	-24.7593	-38.4672	-39.1271	-40.3125
CAL/GM-K	-2.0049	-0.1519	-2.0049	-1.9610	-2.0694
DENSITY:					
MOL/CC	5.8762-02	MISSING	5.8762-02	5.8842-02	8.2588-02
GM/CC	1.1274	MISSING	1.1274	1.1740	1.6088

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL 09/20/93
102SY REMEDIATION FLOWSHEET
STREAM SECTION

25 26 27 29 3 (CONTINUED)

STREAM ID	25	26	27	29	3
AVG MW	19.1859	163.0000	19.1859	19.9519	19.4803

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4
 -

STREAM ID	4
FROM :	----
TO :	TK-SF
CLASS:	CONV
SUBSTREAM:	CONV
PHASE:	LIQUID
COMPONENTS: KMOL/HR	
H2O	2.0583
NA+	0.0
CS+	0.0
CA+2	0.0
SR+2	0.0
MN+2	0.0
FE+3	0.0
CR+3	0.0
ZR+4	0.0
MO+6	0.0
AM+3	0.0
NP+4	0.0
PU+4	0.0
TH+4	0.0
U+4	0.0
AL+3	0.0
H+	1.3640
OH-	0.0
CL-	0.0
CO3-2	0.0
F-	0.0
NO3-	1.3640
NO2-	0.0
PO4-3	0.0
SO4-2	0.0
TCO4-	0.0
TOTAL FLOW:	
KMOL/HR	4.7863
KG/HR	123.0317
L/HR	87.4368
STATE VARIABLES:	
TEMP C	25.0000
PRES ATM	1.0000
VFRAC	0.0
LFRAC	1.0000
SFRAC	0.0
ENTHALPY:	
CAL/MOL	-4.3167+04
CAL/GM	-1679.3470
KCAL/HR	-2.0662+05
ENTROPY:	
CAL/MOL-K	-39.6836
CAL/GM-K	-1.5438
DENSITY:	
MOL/CC	5.4741-02
GM/CC	1.4070

ASPEN PLUS VER: DOS-386 REL: 8.5-6 INST: LANL
102SY REMEDIATION FLOWSHEET
STREAM SECTION

09/20/93

4 (CONTINUED)

STREAM ID	4
AVG MW	25.7047

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