Atlantic Richfield Hanford Company
Richland, Washington 99352

MASTER

ION EXCHANGE COMPUTER PROGRAM FOR
ZEOLON 900 CATION EXCHANGER

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ION EXCHANGE COMPUTER PROGRAM FOR ZEOLON 900 CATION EXCHANGER

INTRODUCTION

Recovery and purification of ^{137}Cs in B Plant has traditionally been accomplished with ion exchange processes. Two ion exchange columns are operated in the plant. A small 85-gallon column (T-38-5) uses Zeolon 900 resin for final purification of B Plant cesium product. The larger 2500-gallon column (T-18-2) currently recovers cesium from Purex sludge supernate (PSS) with an organic resin, Duolite ARC-359. After startup of the Purex plant, however, the proposed current acid waste (CAW) flowsheet⁽¹⁾ will include the use of T-18-2 with the inorganic exchanger, Zeolon 900.

Effective process control of ion exchange processes in B Plant has been limited by the lack of on-line process measurements, although gamma monitors help prevent excessive cesium waste losses. A partly "trial and error" approach to optimizing this batch process has been necessary in the past. A computer program which can model the interaction of process variables will benefit the optimization of ion exchange processes in B Plant. An accurate model of the proposed CAW flowsheet ion exchange process would be particularly useful. In this case, rapid changes and a wide range of feed conditions are possible. A computer model can also be useful for sensitivity analyses and for engineer training.

The computer program CIXZE (Cesium Ion Exchange with Zeolon Exchanger) was specifically developed for the Zeolon 900 exchanger for three reasons: (1) equilibrium data is available, (2) process experience from the existing cesium purification process is applicable, and (3) this type of exchanger will be used exclusively during B Plant CAW processing. The program is based on ion exchange engineering concepts describing the loading breakthrough (cation concentrations in the effluent as feed is passed through the column) and the shape of effluent concentration versus effluent volume curves during the scrub and elution cycles. A four-component system containing cesium, sodium, potassium, and rubidium is considered.

The reliability of the scrub and elution models will be determined by the quality of process, pilot plant, or laboratory data that is available. The scrub is the most difficult to model cycle of the ion exchange process and is critical in determining the final overall decontamination of impurities. The program is designed to be easily used and easily updated as process or other data is available. The most useful application, however, is to predict the loading of Zeolon 900 reasonably well. Cesium losses and final product composition can be predicted by the computer program as a function of the following variables: feed composition, feed volume loaded, scrub volume, eluent volume, resin volume.

SUMMARY

A computer program (CIXZE) has been developed to model Zeolon 900 ion exchange processes for study of the significant process variables. The program models the load, scrub, and elution cycle with four cations: cesium, sodium, potassium, and rubidium. Zeolon 900 equilibrium data is used in predicting the load, empirical data is taken into account in the scrub and elution models.

The program has been tested and adjusted with B Plant Cesium Purification process data. During the period of most stable operation in 1975, the relation between the loading variables was accurately predicted. The scrub indicated realistic changes during a sensitivity study. Many of the process measurements had to be extrapolated to obtain the desired data due to the high ^{137}Cs concentrations in the system limiting the reliability of process sampling.

The program was also tested with the proposed B Plant CAW process flowsheet (reference 1). A critical judgment at this time is the loading capacity of the large Zeolon 900 column (T-18-2) in the flowsheet. Unfortunately data on the loading of Zeolon 900 with other cations (in the CAW feed) is not available at this time. Program results were helpful in the flowsheet design, however, optimization of the program with the CAW ion exchange process will be completed in conjunction with the pilot plant demonstration.

DISCUSSION

Program Description

The program is organized as a batch process sequence (load-scrub-elution) and designed for use on a remote computer terminal. Written as a "conversational" program, the program prints all the necessary instructions for data input, including units. The user will need some familiarity with the ion exchange process, but not with the FORTRAN 4.5-extended language or the program logic. The program structure is simplified to aid future program revisions.

The following is a description of program operations in the sequence they are executed:

1. Input data for loading calculations includes column volume, feed composition, and feed volume.
2. Mass action quotients are calculated from Zeolon 900 equilibrium data.

3. Input slope (A) of cesium breakthrough on log-probability scale (A is a complex function of exchanger properties and operating conditions which is normally determined from process measurements or experience).
4. Cesium loading losses and the overall composition of the resin after the load are calculated.
5. Results of the loading calculations are printed and an option to repeat part of the calculations with different input variables can be executed.
6. Input scrub volume and option to enter new scrub effluent data can be executed (some data is preprogrammed).
7. Scrub calculations assume independent elution of impurities. Only the trailing edge of each elution curve (effluent concentration versus scrub volume) is computed, therefore process data from similar conditions is required to locate the curve as a function of total volume passed through the column.
8. Output from scrub calculations include printed summary of feed, load, and scrub results with the predicted final product purity.
9. Input for cesium elution requires volume and new cesium elution effluent data, if available (some data is preprogrammed).
10. Elution calculations are limited to determining the fraction of cesium removed. It is assumed that impurities are completely stripped during the first part of the elution, therefore the product purity (in terms of cation ratios) is determined in the scrub calculations.
11. Elution results are now printed.

It is anticipated that most uses of the program will include repetitive loading or scrub calculations with one or more parameters varied. Loops in the program can be executed by simply entering a "yes" or "no" after a question is printed. A number of options are available which either bypass a portion of the program or repeat a series of calculations. The flexibility of the built-in loop is shown in the schematic diagram (Figure 1).

A detailed description of the technical bases of the program equations is included in Appendix A. Appendix B is a glossary of variables as used in the program. Appendix C illustrates data input and printed results. Appendix D is a complete program listing.

Sensitivity Analysis and Comparison with Plant Data

In B Plant a final cesium purification process is performed before the cesium product is transferred to the encapsulation plant. The flowsheet for the initial campaign of this process is shown in Figure 2. One period of relatively stable operation, concluded in March 1975, was studied. Measured process performance was erratic during this period due to the difficulty in obtaining representative sample analyses of the extremely "hot" process streams (^{137}Cs concentrations exceeding 40,000 curies/gallon were encountered). However, the overall process was considered stable on the basis of measurements of a series of batches.

FIGURE 2

CESIUM PURIFICATION PROCESS FLOWSHEET -
HOT STARTUP TESTS (Completed May 1975)

Measured versus program calculated performance is shown in Table 1. The slope of the loading breakthrough curve was adjusted in the program to match the average batch size and cesium loading losses. From there, the program predicted (with reasonable accuracy compared to the measured data) the sensitive relationship between the loading losses and load volume. Final sodium (or potassium or rubidium) decontamination is a function of both scrub and load volumes, (i.e., the short load volume means proportionally more sodium is loaded, then the effectiveness of the scrub is dependent on the initial load of impurities). Three scrub volumes at a constant 400-gallon load are shown in the table as well as three load volumes with a 750-gallon scrub.

Future Program Development

Most future modifications to the program will specifically adapt the program to the CAW cesium recovery flowsheet. The performance of a large ion exchange column (T-18-2) with Zeolon 900 resin will be critical to the overall CAW process. As data becomes available, the program can also help with optimization of the cesium purification process. The following is a summary of important areas where CIXZE can be applied or improved:

- Work closely with CAW pilot plant studies to obtain pertinent data for an accurate ion exchange (T-18-2) model.
- A most important goal is to accurately model T-18-2 Zeolon 900 loading performance. Study the slope of the cesium breakthrough curve (A) as a function of column size, dimensions, feed rate, and composition.
- Examine Zeolon equilibrium data from lab studies and pilot plant for discrepancies.
- Pilot plant work may involve the study of scrub performance as function of scrub concentration - consistent empirical results can be added to the program.

TABLE I

COMPARISON OF B PLANT PROCESS DATA AND COMPUTER
PROGRAM RESULTS - PROCESS SENSITIVITY

<u>Process Variable</u>	<u>Measured Dependent Variable</u>	<u>Measured Value ± 15-20%</u>	<u>Calculated Value *</u>
Average load Volume 400 gallons	Loading Breakthrough % Losses	1.1	1.03
Load volume 380	% Losses	0.2	0.24
Load volume 440	% Losses	4.8	2.6
Load volume 390		0.35	0.64
Average scrub 750 gallons (with 400-gallon load)	Na/Cs Patio Product	0.03	0.03
Scrub 500 gallons 400-gallon load	"	0.15	0.15
Scrub 900 gallons 400-gallon load	"	0.013	0.009
350-gallon load 750-gallon scrub	Load losses 0 %	0.04	0.034
450-gallon load 750-gallon scrub	3.0%	0.03	0.027

* Data not available to determine slope of breakthrough A.
Value for "A" set at 2.5 in computer calculations for the
feed conditions used here.

REFERENCES

2. ARH-MA-103, (unclassified), compiled by D. W. Jeppson, "Technical Manual Waste Encapsulation and Storage Facility"
3. ISO-100, ^{DEL} [REDACTED], August 1967, edited by J. S. Buckingham, "Waste Management Technical Manual"
8. ARH-ST-145RD, (unclassified), February 1977, J. S. Buckingham - Paulett Bowling, "Removal of Radioactive Cesium from Purex Aqueous Solution"
9. ARH-SA-49, (unclassified), January 1970, J. S. Buckingham, "Laboratory Evaluation of Zeolitic Material for Removing Radioactive Cesium from Alkaline Waste Solutions"

APPENDIX A

THEORY - TECHNICAL BASIS FOR PROGRAM

Cesium Removal by Ion Exchange Processes

The chemistry of cation exchange reactions and the structure of zeolite ion exchange resins is covered in detail in reference 2 (page IV.19) and reference 3.

The concept of resin selectivity expressed as a mass action quotient is used in the computer program. A cation exchange reaction involving Cs^+ and Na^+ can be written as:

where X represents a structural unit of the resin. The mass action quotient is expressed as:

$$K_{\text{Na}}^{\text{Cs}} = \frac{(\text{CsX}) (\text{Na}^+)}{(\text{NaX}) (\text{Cs}^+)} \quad (2)$$

with the terms in concentration units. This approach is useful in the program because K as a function of solution composition is known (reference 2) and engineering loading concepts involving K are also used.

The performance of an ion exchange column can be defined by a breakthrough curve plotting the ratio of the effluent concentration to the feed concentration versus the feed throughput. The equilibrium for cesium loading on Zeolon is favorable, resulting in an early displacement of the ions initially on the bed and a self-sharpening boundary between the loaded and unloaded portions of the bed. The shape of cesium versus other cations boundary reaches steady-state quickly and determines the breakthrough curve. The cesium concentration ratio, c/Co , is usually plotted on a probability scale (to allow for a range of values between 0 and 1.0). The throughput volume (n = column volumes feed solution) is plotted on a logarithmic scale. These scales eliminate the sharp curvature obtained on linear scales. The equation for a straight line breakthrough curve on log-probability paper is:

$$C/\text{Co} = 1/2 [1 + \text{Pi} (A \ln n/\text{no})] \quad (3)$$

Pi = normal probability integral

no = column volumes feed as 50 percent breakthrough ($C/\text{Co} = .5$)

This type of breakthrough curve is obtained with a Zeolon 900 exchanger. The slope A is a complex function of process kinetics and operating conditions; it is not calculated in the computer program and must be given,

based on experience, to complete the loading calculations. A high value of $\underline{A}$ corresponds to more efficient cesium loading, or a feed with less impurities.

The area under the breakthrough curve determines the first desirable process variable, cesium loading waste losses.

$$\text{Waste Loss Fraction} = \text{WLF} = \frac{1}{n} \int_0^n C/Co \, dn \quad (4)$$

The value of WLF is determined graphically in reference 2, and as a function of n/n_0 and $\underline{A}$ in the computer program. The equations will not be fully derived here but the two used to determine n/n_0 are:

$$n_L = n_0 e^{1/2 A^2} \quad (5)$$

$$n_L = Q \, qp/Co \quad (6)$$

where n_L = number of column volumes to fully load the bed

n_0 = column volumes loading to 50 percent breakthrough

Q = maximum exchange capacity of the exchanger, millequivalents (meq)/gm

Co = concentration of absorbing ion (Cs) in feed, meq/ml

p = bulk density of resin, g/ml

q = equivalent fraction of the absorbing ion (Cs) on the exchanger, in equilibrium with the load.

The first n_L equation is a simplification from the use of log-probability scales. The equilibrium fraction of cesium on the resin, q , is determined from equilibrium data where mass action quotients as a function of feed composition for the resin are known. The following equation is used, assuming a 4-component system with Cs^+ and Na^+ , K^+ , and Rb^+ impurities.

$$q = \frac{1}{1 + \frac{(Na^+)}{K_{Na}^{Cs} (Cs^+)} + \frac{(K^+)}{K_K^{Cs} (Cs^+)} + \frac{(Rb^+)}{K_{Rb}^{Cs} (Cs^+)}} \quad (7)$$

The concentrations are feed concentrations. The use of these equations in the computer program is described in a later section.

Elution of Impurities and Product (Cs)

Two distinct ion exchange cycles following loading are the scrub and cesium elution. The scrub is a careful elution of impurities with $(\text{NH}_4)_2\text{CO}_3$, replacing impurity cations with NH_4^+ , which is terminated before a significant amount of cesium is displaced. The cesium elution is a total replacement of the remaining cations. An unfavorable equilibrium exists between these cations and the Zeolon exchange producing a nonsharpening boundary between loaded and eluted portions of the bed. The elution curve (effluent concentration versus volume of effluent) for both the elution of impurities (scrub) and cesium elution is bell-shaped with a long trailing edge. The trailing edge is represented by the equation:

$$\log C_2/C_1 = -K(n_2 - n_1) \quad (8)$$

where C_2 = effluent concentration after n_2 volumes

C_1 = effluent concentration after n_1 volumes

K = a constant dependent on the equilibrium constant and exchange kinetics of the system.

The differences in Na, K, Rb, and Cs equilibrium with the resin allow the impurities to be effectively eluted during a weak $(\text{NH}_4)_2\text{CO}_3$ scrub with minor cesium losses, then a complete elution of product with strong $(\text{NH}_4)_2\text{CO}_3$. A more useful equation representing the amount of product (or impurity) ion left on the ion exchange bed after n_1 volumes of elution is found by integrating equation (8) from $n = n_1$ to $n = \infty$.

$$\frac{Y}{V} = \frac{C_1}{2.3K} \quad (9)$$

where Y/V = the total equivalents of the ion left on the bed per liter.

C_1 = concentration of ion in effluent solution after n_1 column volumes of eluent have been passed through

K = the constant determined in equation (8).

To utilize these equations in the computer model it should be noted that the shape of the elution curve with respect to each cation (the value of K) may be fairly consistent over a range of feed and loading conditions with Zeolon. However, an actual process data point (C_3 at n_3 column volumes) is required to determine the final decontamination factors with a scrub of n_1 volumes or the portion of cesium eluted after an n_1 volume cesium elution.

Bases of CIXZE Calculations

This section will be presented in the same sequence as the computer program calculations.

Load

When the loading section of the program is executed the feed composition (cation to cesium mole ratios), cesium concentration, and feed volume are entered. Mass action quotients, K_{Na}^{Cs} , K_K^{Cs} , K_{Rb}^{Cs} , are calculated from equilibrium data shown in figure 3 (from reference 2). From equations (6) and (7) n_i is calculated, the volume of feed solution of this composition required to totally load the resin bed. The load volume at 50 percent breakthrough, n_0 , is calculated from equation (5).

To complete the cesium waste loss calculation the expected slope of the breakthrough curve A is now entered. From Figure 4 (reference 2) which is a graphical solution of equations (3) and (4), the waste loss fraction is calculated as a function of n/n_0 and A .

After printing the loading calculations results, the program loops allow the option of repeating the calculations with a new feed volume, new A , or all new feed conditions. The loading calculations also determine the composition of the resin bed after loading with a Cs material balance (Cs actually loaded) and a variation of equation (7):

$$(M^+)_{\text{Resin after Load}} = \frac{9 \times (M^+/Cs^+) \text{ feed}}{K_{Cs}^M} \quad (10)$$

Figure 3
MASS ACTION QUOTIENTS as a FUNCTION
of SOLUTION COMPOSITION

Figure 4
CUMULATIVE PERCENT BREAKTHROUGH LOSS
as a FUNCTION of A and the THROUGHPUT RATIO, n/n_0

Scrub Calculations

Data input to initiate scrub calculations are the k values used in equation (8), or the constant will be calculated if effluent concentration versus volume data is known. The most recent values of K_{Na} , K_{Rb} , K_K are already programmed (and do not need to be entered into each calculation). One actual data point is entered (effluent concentration versus volume throughput), on the trailing edge of a typical elution curve for each component, and the intended scrub volume. With equation (8) the effluent concentration of the component and the end of the scrub is calculated. Equation (9) then provides the concentration of each cation left on the bed.

A check is now made, in the program, to determine if these cation concentrations are realistic (i.e. - less than the cations initially on the bed at the end of the load) and a message printed that the scrub data is invalid, if necessary. Printed scrub cycle results include the final product cation ratios as no decontamination is accomplished in the Cs elution, and the elution calculations will not be executed every time. Similar program loops, as in the load section, give the option to repeat some of the calculations without rerunning the entire program.

Cesium Elution

Cesium elution calculations are identical to the scrub calculations. A value of K_{Cs} is available in the program or a new value can be calculated with effluent concentration versus volume data. An actual data point and the eluent volume is required to complete the calculations. The fraction of cesium left on the resin and the average eluate (product) cesium concentration is computed. The elution calculations are of limited value but serve to complete the model of the entire ion exchange process cycle.

APPENDIX B

GLOSSARY OF ION EXCHANGE VARIABLES USED

VARIABLE	AS CODED IN CIXZE	EXPLANATION
Na/Cs	FNACS	Feed composition mole ratios
K/Cs	FKCS	
Rb/Cs	FRBCS	
Cs	FCSM	Feed Cs concentration (<u>M</u>)
F VOL.	F VG	Feed volume (gallons)
n	FN	Feed volume (column volumes)
Cs	CSNAK	Mass action quotients
K _{Na}		
	CSKK	
	CSRBK	
N ₁	FNL	Feed volume 100 percent load (col. volumes)
n ₀	FN0	Feed vol. 50 percent breakthrough
n/n ₀	FNFN0	Feed volume ratio
A	A	Slope of breakthrough curve (log-prob.)
Q	Q	Maximum exchange capacity resin
P	D	Bulk density of resin, gm/ml
Co	FCSM	Feed Cs concentration (<u>M</u>)
9	QQ	Fraction of Cs on exchanger in equilibrium with feed solution
WLF	WLF05 - WLF 100	Loading waste loss fraction percent - coding in program corresponds to A value
Cs	ZCS	Resin composition at the end of the load (Molarities)
K	ZK	
RB	ZRB	
	DFLNA	Loading decontamination factors
	DFLK	
	DFLRB	
KNa	SKNA	Scrub elution constants
Kk	SKK	
K _{RB}	SKRB	
N _{a1} , N _{a2}	SNA1, SNA2	Effluent concentrations, scrub
K ₁ , K ₂	SK1, SK2	
RB1, RB2	SRB1, SRB2	Effluent volumes, scrub
n, n	SNA11	
	SNA12	
	SKN1	
	SKN2	
	SRB11	
	SRB12	
S Vol	SVG	Scrub volume gallons
S Loss	SWLF	Scrub waste losses, percent
CS	SCSE	Resin composition at end of scrub
Na	SNAE	
K	SKE	
Rb	SRBE	

APPENDIX B

(continued)

VARIABLE	AS CODED IN CIXZE	EXPLANATION
NaDF	DFONA	Overall Decontamination factors
KDF	DFOK	
Rb DF	DFORB	
KCs	EKCS	Cesium elution constant
E Vol.	EVG	Elution volume
CS ₃	ECS	Effluent concentration, elution
N ₃	ECSN	Effluent volume
CS E	ECSE	Resin Concentration, end of elution
% Eluted	PE	Percent Cs eluted
Cs P	PC	Eluate product concentration

APPENDIX C

EXAMPLE DATA INPUT AND OUTPUT

..RUN FTH,F=CINZE24

PROGRAM CINZE DOES ION EXCHANGE CALCULATIONS FOR.....
LOADING, SCRUB, AND ELUTION BASED ON ZEOLON EQU.....
DATA AND DATA AVAILABLE FOR THE SYSTEM THE PROG.....
IS APPLIED TO CONSULT PROGRAM FOR DETAILS OF..

THE EQUATIONS USED, LOAD, SCRUB, AND ELUTION ARE
TREATED INDEPENDENTLY BUT RESULTS OF LOAD ARE
REQUIRED TO DO SCRUB CALCULATIONS, AND SCRUB MUST.....
BE DONE BEFORE ELUTION. FOR THE LOAD, SOME
DATA HAS BEEN PREPROGRAMMED TO CHANGE ANY OF THE.....
FOLLOWING PUNCH RETURN, AND TYPE CHANGE (NO SPACES).....

MAXIMUM EXCHANGE CAPACITY (MEQ/GM) = 1.9.....
RESIN DENSITY (BULK DFG) = 0.8.....
RESIN VOLUME (GAL) = 2400.

2.093 CP SECONDS COMPILATION TIME
CHANGE

ENTER THE THREE NEW NUMBERS
1.9,0.8,85

ENTER THE FOLLOWING FEED DATA (UNITS):.....
NA CI, K CI, RB CI (MOLE RATIOS)....
CI (MOLARITY), FEED VOL (GAL)
.62, .089, .037, .11, 400

ENTER VALUE FOR A, THE SLOPE OF THE BREAKTHRU
CURVE ON LOG-PROB. SCALE (A=0.5, 1., 1.5, 2., 2.5,
3., 4., 5., 6., 8., 10., NO OTHER A'S ALLOWED)....
2.5

FEED COMPOSITION:..NA/CS.....K/CS... RB/CICI (M)
..... 6.20E-01..8.90E-02..3.70E-02..1.10E-01..

LOAD VOLUME:..400..GALLONS...A=.2.5..LOADING LOGS (ES):..1.47.....
DO YOU WANT TO RECALCULATE WITH NEW FEED..
VOLUME ONLY ? NO

DO YOU WANT ME TO RECALCULATE WITH NEW A..??..NO

DO YOU WANT ME TO RECALCULATE WITH NEW FEED COND.....NO

COMPLETE RESULTS OF LOADING CALCULATIONS.

EXCHANGER : RESIN TYPE..CAPACITY (MEQ/GM)..DENSITY..VOLUME (GAL)..
ZEOLON 900.....1.90.....80.....85.0.....

FEED COMPOSITION:..NA/CS...K/CS... RB/CI...CI (M)..
..... 6.20E-01..8.90E-02..3.70E-02..1.10E-01..

LOAD VOLUME:..400..GALLONS.

SLOPE OF BREAKTHROUGH CURVE (A)=.2.5..LOGS (ES)..1.47.....

LOADING DECONTAMINATION FACTORS:..NA.../46.3...K....1.2...RB...1.6..

EXAMPLE DATA INPUT AND OUTPUT

DO YOU WANT TO RUN SCRUB CALCULATIONS ??? YES

CESIUM SCRUB LOSS WILL NOT BE CALCULATED
 IN PROGRAM BUT IS NEEDED TO CORRECT PRODUCT...
 CALCULATIONS (CS MATERIAL BALANCE) ..
 SCRUB LOSS (PERCENT) 3

ELUTION OF IMPURITIES DURING THE SCRUB CAN BE...
 DESCRIBED BY THIS EQUATION :

$KM = -\log_{10} (M2 + \frac{K}{M1}) / (M2 - M1)$
 WHERE: M2, M1 = COLUMN VOLUMES SCRUBBED AT
 EFFLUENT CONCENTRATIONS M2, M1
 THE CONSTANTS KMA, KK, KRB DESCRIBE THE
 SLOPE OF THIS CURVE. IF YOU LACK BETTER
 DATA THESE VALUES ARE ASSUMED :

KMA = .87
 KK = .17
 KRB = .25
 DO YOU WISH TO CALCULATE OR ENTER NEW
 VALUES ?? NO

(ACTUAL) SCRUB EFFLUENT DATA IS REQUIRED TO
 LOCATE MA (K, RB) ELUTION CURVE
 TO COMPLETE SCRUB CALCULATIONS I NEED (ACTUAL)
 SCRUB DATA (ONE DATA POINT FOR EACH COMPONENT)
 ENTER: MA3, M3 (MA), K3, M3 (K), RB3, M3 (RB)
 1.12, 7, .0041, 7, .0032, 7

ENTER SCRUB VOLUME (GALLONS) : 750

PRODUCT COMPOSITION BASED ON LOADING OF
 SUMMARY OF LOADING AND SCRUB RESULTS
 FEED COMPOSITION: MA/CS K/CS RB/CS CS (M) ...
 6.20E-01 .. 8.90E-02 .. 3.70E-02 .. 1.10E-01 ..

LOAD ME: ... 400. GALL. ... A = 2.5. LOADING LOSSES (%): ... 1.47.

ELUTION ITY: ... MA/CS K/CS RB/CS ..
 2.93E-02 .. 1.04E-02 .. 3.94E-03

OVERALL DECONTAMINATION FACTORS: ... MA K RB
 21.15 8.57 9.40

LOAD VOLUME : ... 400. GALLONS ... SCRUB VOLUME : ... 750. GALLONS

 DO YOU WANT TO REPEAT SCRUB CALC. ?? NO

EXAMPLE DATA INPUT AND OUTPUT

DO YOU WANT TO RUN ELUTION CALCULATIONS??...YES

CESIUM ELUTION IS DESCRIBED BY THIS EQUATION:..

$KDSE = -\log_{10}(CS2/CS1) / (M2-M1)$

UNLESS YOU HAVE A BETTER VALUE OR WISH TO.....

RECALCULATE, PROGRAM ASSUMES:.....

$KDSE = 0.008$...

DO YOU WISH TO CALCULATE OR ENTER NEW KDSE?....NO

TO COMPLETE CS ELUTION CALCULATIONS I NEED....

ACTUAL ELUTION DATA ENTER: CS3,M3..

.001,12

ENTER ELUENT VOLUME TO BE USED (GALLONS):.....1500

ELUTION RESULTS:.....

.....

PERCENT CS ELUTED:..90.10....AVE CS CONC. PRODUCT:..2.53E-02.....

DO YOU WANT TO REPEAT ELUTION WITH.

NEW VOLUME ONLY..???????.NO

DO YOU WANT TO REPEAT ENTIRE ELUTION CALC.??..NO

DO YOU WANT TO REPEAT LOAD CALCULATIONS.?.....NO

DO YOU WANT TO REPEAT SCRUB.?.....NO

WHY DO YOU WANT TO STOP NOW WHEN YOU'RE.....

TO MUCH FUN.??????.....

END

[illegible][illegible]

APPENDIX D

COMPLETE PROGRAM LISTING

	11	10	9	8	7
G	100	PROGRAM LINE 22 INPUT/OUTPUT			
	110	PROGRAM LINE 23. ZEDION AND EQUILIBRIUM DATA AND ENGINEERING			
	120	CONCEPTS PRESENTED IN AHH-MH-14, AND ENH-E-40, IN THIS ION			
	130	EXCHANGE MODEL. FLOW-SHEET INCLUDES LONDS, LRSUS, AND US ELUTION			
	140	WITH NO REVERSE FOR 4 COMPONENT SYSTEM (H ₂ O, H ₂ SO ₄ , ION,			
	150	PRESENTED INDEPENDENTLY. SOME E-MFLES OF REVERSIBLES USED IN THE			
	160	PROGRAM INCLUDES			
	170	1. ION-EXCHANGE ACTION QUOTIENT FROM EQUIL. LOADING DATA			
	180	2. H ₂ O LOSE OF LOADING BREAKTHROUGH CURVE ON LOS-FRDS. LAME			
	190	3. LONDS RATE LOSS FACTOR			
F	200	4. LONDS IN ION ELUTION (LRSUS) ELUTION			
	210	5. LONDS VOLUME ELUTED TO REMAIN HMI			
	220	6. ION CONCENTRATION IN EFFLUENT AT HMI VOLUMES			
	230	7. FRACTION OF PRODUCT ELUTION			
	240	8. CONCENTRATION OF ION IN EFFLUENT AFTER LONDS			
	250	9. ION CONCENTRATION ON EXCHANGE AFTER LRSUS			
	260	10. ION CONCENTRATION ON EXCHANGE AFTER LRSUS			
	270	11. ION CONCENTRATION ON EXCHANGE AFTER ELUTION			
	280	12. PERCENT ION ELUTED			
	290	13. PERCENT PRODUCT CONCENTRATION (LRS)			
E	300	PRINT ** PROGRAM LINE 200. ION EXCHANGE CALCULATION. FOR			
	310	PRINT ** LOADING, LRSUS, AND ELUTION BASED ON ZEDION EQU.			
	320	PRINT ** DATA HAS BEEN PREPARED. TO CHANGE ANY OF THE			
	330	PRINT ** THE ELUTIONS, USED, LONDS, LRSUS, AND ELUTION ARE			
	340	PRINT ** TREATED INDEPENDENTLY, BUT RESULT OF LONDS ARE			
	350	PRINT ** REQUIRED TO DO LRSUS CALCULATION, AND LRSUS MUST			
	360	PRINT ** BE DONE BEFORE LRSUS ELUTION. FOR THE LONDS, SOME			
	370	PRINT ** DATA HAS BEEN PREPARED. TO CHANGE ANY OF THE			
	380	PRINT ** FOLLOWING FOUR RETURN, AND TYPE CHANGE AND FIVE			
	390	PRINT ** *****			
D	400	PRINT ** ON ION EXCHANGE, APPROXIMATELY 1.0			
	410	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	420	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	430	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	440	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	450	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	460	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	470	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	480	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	490	PRINT ** ELUTION DENSITY, ZEDION 1.000			
C	500	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	510	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	520	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	530	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	540	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	550	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	560	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	570	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	580	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	590	PRINT ** ELUTION DENSITY, ZEDION 1.000			
B	600	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	610	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	620	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	630	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	640	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	650	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	660	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	670	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	680	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	690	PRINT ** ELUTION DENSITY, ZEDION 1.000			
A	700	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	710	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	720	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	730	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	740	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	750	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	760	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	770	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	780	PRINT ** ELUTION DENSITY, ZEDION 1.000			
	790	PRINT ** ELUTION DENSITY, ZEDION 1.000			