DISTRIBUTION SHEET

To R.J. Nicklas	From A.P. Larrick Treatment Systems Plant Engineering	Page 1 of 1 Date December 22, 1994
Project Title/Work Order		EDT No. 127270 ECN No.

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
J.F. Berger	R1-43	X			
S.P. Biglin	R1-43	X			
T.M. Galoto	R1-43	X			
M.D. Guthrie	R1-43	X			
S.L. Hallsted	R1-43	X			
D.S. Haring	R1-43	X			
P.G. Johnson	R1-43	X			
A.P. Larrick	R1-43	X			
E.Q. Le	R1-43	X			
J.M. Light	B4-08	X			
R.J. Nicklas	R1-43	X			
R.M. Persin	R1-43	X			
R.E. Raymond	R2-54	X			
P.D. Rhodes	R1-43	X			
W.E. Ross	S5-07	X			
B.H. VonBargen	R1-43	X			
M.A. White	R1-43	X			
C. Zaccone	R1-43	X			
Central Files (2)	L8-04	X			
O.S.T.I. (2)	L8-07	X			
Station 3	S2-10	X			

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DEC 13 1994

ENGINEERING DATA TRANSMITTAL

1. EDT 127270

2. To: (Receiving Organization)

Treatment Systems Plant
Engineering

3. From: (Originating Organization)

Treatment Systems Plant
Engineering

5. Proj/Prog/Dept/Div: TWRS

6. Cog/Proj Engr: A. P. Larrick

8. Originator Remarks:

Original Distribution

4. Related EDT No:

7. Purchase Order No:

9. Equip/Component No:

10. System/Bldg/Facility:
242-A Evaporator

12. Major Assm Dwg No:

13. Permit/Permit Application No:

14. Required Response Date:

11. Receiver Remarks:

15. DATA TRANSMITTED

(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev No.	(E) Title or Description of Data Transmitted	(F) Impact Level	(G) Reason for Trans- mittal	(H) Originator Dispo- sition	(I) Receiv- er Dispo- sition
1	WHC-SD-WM-UM-029		0	242-A Evaporator Flowsheet Users Manual	N/A	1,2	1	1

16. KEY

Impact Level (F)	Reason for Transmittal (G)	Disposition (H) & (I)
1, 2, 3, or 4 see MRP 5.43 and EP-1.7	1. Approval 2. Release 3. Information 4. Review 5. Post-Review 6. Dist (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment 4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged

(G)	(H)	17. SIGNATURE/DISTRIBUTION (See Impact Level for required signatures)	(G)	(H)
Reason	Disp	(J) Name (K) Signature (L) Date (M) MSIN	Reason	Disp
1,2	1,2	Cog./Proj. Eng. <i>[Signature]</i> 12/13/94 RI-43		
4,2	1,2	Cog./Proj. Eng. Mgr. <i>[Signature]</i> 12/13/94 RI-43		
		QA		
		Safety		

18. Signature of EDT Originator <i>[Signature]</i> 12/13/94	19. Authorized Representative for Receiving Organization <i>[Signature]</i> 12/13/94	20. Cognizant/Project Engineer's Manager <i>[Signature]</i> 12/13/94	21. DOE APPROVAL (if required) Ltr No. ☐ Approved ☐ Approved w/comments ☐ Disapproved w/comments
--	---	---	---

RELEASE AUTHORIZATION

Document Number: WHC-SD-WM-UM-029, REV.0

Document Title: 242-A EVAPORATOR FLOWSHEET USERS MANUAL

Release Date: December 13, 1994

**This document was reviewed following the
procedures described in WHC-CM-3-4 and is:**

APPROVED FOR PUBLIC RELEASE

WHC Information Release Administration Specialist:

Kara M. Broz

December 13, 1994

TRADEMARK DISCLAIMER. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

This report has been reproduced from the best available copy. Available in paper copy and microfiche. Printed in the United States of America. Available to the U.S. Department of Energy and its contractors from:

U.S. Department of Energy
Office of Scientific and Technical Information (OSTI)
P.O. Box 62
Oak Ridge, TN 37831
Telephone: (615) 576-8401

Available to the public from:

U.S. Department of Commerce
National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161
Telephone: (703) 487-4650

SUPPORTING DOCUMENT

1. Total Pages 68

2. Title

242-A EVAPORATOR FLOWSHEET USERS MANUAL

3. Number

WHC-SD-WM-UM-029

4. Rev No.

0

5. Key Words

EVAPORATOR, PROCESS, MATERIAL BALANCE, FLOWSHEET

6. Author

Name: AP LARRICK

Signature

Organization/Charge Code TREATMENT
SYSTEMS PLANT ENGINEERING/71330APPROVED FOR
PUBLIC RELEASE

7. Abstract

This supporting document presents a description of the 242-A Evaporator flowsheet. Material balances are calculated for feed, slurry, and effluent streams based on input data for the feed stream.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

8.

RELEASE STAMP

OFFICIAL RELEASE	5
BY WHC	
DATE	DEC 13 1994
	<i>Ato 4</i>

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

242-A EVAPORATOR FLOWSHEET USERS MANUAL

A.P. LARRICK

TABLE OF CONTENTS

1.0 INTRODUCTION	1
2.0 DESCRIPTION OF FLOWSHEET	1
2.1 ASSUMPTIONS	1
2.2 MAJOR FEATURES OF THE SPREADSHEET	4
2.2.1. Main Spreadsheet	5
2.2.2. Constants, Formulae, and Conversion Factors	5
2.2.3. E-C-3 Vapor Generation Rate	6
2.2.4. Heat Loss for Water Leaks	6
2.2.5. Hydrogen Gas Generation Rate	6
2.2.6. Feed and Slurry Densities	6
2.2.7. "F" Constant Calculation	6
2.2.8. Radionuclide Data	7
2.2.9. Data Input Area/ Molecular Weights	7
2.2.10. Partition Coefficients and Activity Coefficients	7
2.2.11. Decontamination Factors	7
2.2.12. Historical Data	7
2.2.13. Summary of Results	8
2.2.14. Feed and Slurry Molar Concentration Calculations	8
2.3 CELL DESCRIPTIONS	8
2.3.1. Column A, Parameter Titles	8
2.3.2. Column B, Parameter Units	8
2.3.3. Column C, Feed Stream Values	8
2.3.3.1. Cell C9, Feed Flow	9
2.3.3.2. Cell C10, Batch Flow	9
2.3.3.3. Cell C11, Feed Temperature	9
2.3.3.4. Cell C12, Density	9
2.3.3.5. Cell C13, Vessel Vacuum	9
2.3.3.6. Cell C14, Vessel Vacuum	9
2.3.3.7. Cell C15, pH	9
2.3.3.8. Cell C16, TOC	10
2.3.3.8. Cell C17, TOC	10
2.3.3.9. Cell C18, TDS	10
2.3.3.10. Cell C19, TDS	10
2.3.3.11. Cell C20, Volume Flow	10
2.3.3.12. Cell C21, Mass Flow	10
2.3.3.13. Cell C22, Air Content	11
2.3.3.14. Cell C23, Air Mass Flow	11
2.3.3.15. Cells C24 and C25, Blank Cells	11
2.3.3.16. Cells C26 through C101, Radionuclide Concentrations	11
2.3.3.17. Cells C105 through C188, Inorganic Analyte Concentrations	12
2.3.3.18. Cells C190 through C377, Organic Analyte Concentrations	12

2.3.4	COLUMN D C-A-1 Slurry Stream Values	12
2.3.4.1	Cell D9, Slurry Flow	12
2.3.4.2	Cell D11, Temperature	12
2.3.4.3	Cell D12, Density	12
2.3.4.4	Cell D14, Vacuum	13
2.3.4.5	Cell D15, pH	13
2.3.4.6	Cell D16, TOC	13
2.3.4.6	Cell D17, TOC	13
2.3.4.7	Cell D24, Heat Content	17
2.3.4.8	Cells D26-D103, Radionuclide Concentrations	18
2.3.4.9	Cells D105-D188, Inorganic Analyte Concentrations	18
2.3.4.10	Cells D139 and D140, Hydrogen Concentration	18
2.3.5	Column E, Filtered Raw Water Values	20
2.3.5.1	Cells E8-E24, Physical Properties	20
2.3.5.2	Cells E26-E379, Composition Data	20
2.3.6	Column F, C-A-1 Vessel Vapor Stream Values	20
2.3.6.1	Cell F9, Total Flow	21
2.3.6.2	Cell F11, Temperature	21
2.3.6.3	Cell F12, Vapor Density	21
2.3.6.4	Cell F13, Absolute Pressure	21
2.3.6.5	Cell F14, Absolute Pressure	21
2.3.6.5	Cell F15, pH	21
2.3.6.6	Cells F16 and F17, TOC	21
2.3.6.7	Cells F18 and F19, TDS	22
2.3.6.8	Cells F20 and F21, H ₂ O	22
2.3.6.9	Cells F22 and F23, Air	22
2.3.6.10	Cell F24, Heat Content	23
2.3.6.11	Cells F26-F190, Composition Data	23
2.3.6.12	Cell F140, Hydrogen Generation	24
2.3.6.13	Cells F192-F379, Composition Data	24
2.3.7	Column G, E-C-1 Condensate Stream	25
2.3.7.1	Cells G1-G23, G25-G379, Properties and Compositions	25
2.3.7.2	Cell G24, Heat Content	25
2.3.8	Column H, E-C-1 Vapor Stream	25
2.3.7.1	Cells H1-H23, H25-H379, Properties and Compositions	25
2.3.8.2	Cell H24, Heat Content	25
2.3.9	Column I, E-C-2 Condensate Stream	26
2.3.9.1	Cells I1-I23, I25-I379, Properties and Compositions	26
2.3.9.2	Cell I24, Heat Content	26
2.3.10	Column J, E-C-2 Vapor Stream	26
2.3.10.1	Cells J1-J23, J25-J379, Properties and Compositions	26
2.3.10.2	Cell J24, Heat Content	26
2.3.11	Column K, E-C-3 Condensate Stream	27

2.3.11.1, Cells K1-K23, K25-K379, Properties and Compositions	27
2.3.11.2 Cell K24, Heat Content	27
2.3.12 Column L, Process Condensate	27
2.3.13 Column M, Process Condensate to LERF	27
2.3.14 Column N, Organic in C-100 Tank to 102-AW Tank	27
2.3.14 Column O, E-101 to Ion Exchange Stream	27
2.3.14.1 Cells O1-O23, O25-O379, Properties and Compositions	27
2.3.14.2 Cell O24, Heat Content	28
2.3.15, Column P, Ion Exchange Eluant to 102-AW Tank	28
2.3.16, Column Q, Stack Inlet Air	28
2.3.18 Column R, Air Stream to DU-C-1	29
2.3.18.1 Cell R9, Total Flow	29
2.3.18.2 Cell R11, Temperature	29
2.3.18.3 Cell R12, Vapor Density	29
2.3.18.4 Cells R13 and R14, Absolute Pressure	29
2.3.18.5 Cells R16-R19, TOC and TDS	29
2.3.18.6 Cells R20 and R21, Water Flow	29
2.3.18.7 Cells R22 and R23, Air Flow	30
2.3.18.8 Cell R24, Heat Content	30
2.3.18.9 Cells R26-R377, Composition Data	30
2.3.19 Column S, Air to F-C-5 Stream	30
2.3.20 Column T, Stack Exhaust Air	31
2.3.21 Column U, E-A-1 Reboiler Steam	31
2.3.21.1 Cell U11, Temperature	31
2.3.21.2 Cells U17, U19, U26-U108, Composition Data	31
2.3.21.3 Cell U24, Heat Content	31
2.3.22 Column V, E-A-1 Reboiler Steam Condensate	32
2.3.23 Column W, Raw Water to E-C-1	32
2.3.23.1 Cells W8-W23, Physical Properties	32
2.3.23.2 Cell W24, Heat Content	32
2.3.23.3 Cells W26-W379, Composition Data	32
2.3.24 Column X, Raw Water to E-C-2	32
2.3.25 Column Y, Raw Water to E-C-3	33
2.3.26 Column Z, Raw Water to B Pond	33
2.3.27 Column AA, J-EC1-1 Steam	33
2.3.27.1 Cell AA11, Temperature	33
2.3.27.2 Cells AA17, AA19, AA26-AA108, Composition Data	34
2.3.27.3 Cell AA24, Heat Content	34
2.3.28 Column AB, J-EC1-2 Steam	34
2.3.32 Column AF, P-B-1 Pump Seal Water	35
2.3.33 Column AG, P-B-2 Pump Seal Water	35
2.3.35 Column AI, Constants and Organic Partition Coefficients	35

2.3.35.1, Cells AI4-AN56, Table of Constants and Formulae	36
2.3.35.2 Cells AI190-AI377	38
2.3.36 Column AJ, E-C-1 Condenser Organic Partition Factors	41
2.3.37 Column AK, E-C-2 Organic Partition Factors	41
2.3.38 Column AL, E-C-3 Organic Partition Factors	41
2.3.39 Column AM, Anion Sums and Organic Partition Factors	42
2.3.39.3 Cell AM161, Heat Content	42
2.3.40 Column AN, Cation Sums and Water Content	43
2.3.41 Column AO, E-C-3 Vacuum	43
2.3.42 Column AP, Misc. Pressures and Slurry Anions	43
2.3.42.1 Cells AP10-AP21	43
2.3.43 Column AQ, Radionuclide Data, Hydrogen Generation and Cation Concentrations	43
2.3.43.1 Cells AQ23-AQ103, Radionuclide Data	43
2.3.43.2 Cells AQ112-AQ125	43
2.3.43.3 Cell AQ126, Hydrogen Generation	44
2.3.43.4 Cells AQ128-AQ129, Hydrogen Generation	44
2.3.43.5 Cells AQ138-AQ154, Slurry Cations	44
2.3.44 Column AR, Pressure and Radionuclide Data	44
2.3.44.1 Cells AR10-AR13, Pressure Data	44
2.3.44.2 Cells AR30-AR103, Radionuclide Energies	44
2.3.45 Column AS, Radionuclide Names	45
2.3.46 Column AT, Blank Column	45
2.3.48 Column AV, Blank Column	45
2.3.49-50 Columns AW and AX, Constituent Labels	45
2.3.51 Column AY, Data Entry Column	45
2.3.51.1 Cell AY20, Feed Water Volume	45
2.3.51.2 Cell AY21, Feed Water Mass Flow	45
2.3.52 Column AZ, Molecular Weights	46
2.3.53 Column BA, Ion Charges and Activity Coefficients	46
2.3.53.1 Cells BA105-BA187, Ion Charges	46
2.3.53.2 Cells BA190-BA376, Activity Coefficient	46
2.3.54 Column BB, C-A-1 Vapor Space Partition Coefficients	46
2.3.54.1 Cell BB16-BB187, Partition Coefficients	47
2.3.54.2 Cell BB141, Hydrogen Constants	47
2.3.54.3 Cells BB190-BB376, Vapor Pressure Constants	48
2.3.55 Column BC, E-C-1 Condensate Partition Coefficients	49
2.3.55.1 Cells BC16-BC187, Condensate	

Partition Coefficients	49
2.3.55.2 Cell BC141, Hydrogen Calculation Constant	50
2.3.55.3 Cells BC190-BC376, Second Vapor Pressure Constant	50
2.3.56 Column BD, 242-A Stack and Condensate Decontamination Factors	50
2.3.57 Column BE, Raw Water Data	50
2.3.58 Column BF, Steam Condensate Data	50
2.3.59 Column BG, Blank Column	51
2.3.60 Column BH, Blank Column	51
2.3.61 Column BI, Chemical and Radionuclide Identification	51
2.3.62 Column BJ, Specie Units	51
2.3.63 Column BK, DSSF Tank Composition	51
2.3.64 Column BL, DSS Tank Composition	51
2.3.65 Column BM, Tank AN-103 Analyses	51
2.3.66 Column BN, Tank AN-106 Analyses	52
2.3.67 Column BO, Tank AW-101 Analyses	52
2.3.68 Column BP, Raw Water Data	52
2.3.69 Column BQ, Blank Column	52
2.3.70 Column BR, Average Grout Feed Tank Composition	52
2.3.71 Column BS, Grout Feed Composition Standard Deviation	52
2.3.72 Column BT, Adjusted Feed to C-A-1	53
2.3.73 Column BU, Blank Column	53
2.3.74 Column BV, Blank Column	53
2.3.75 Column BW, Blank Column	53
2.3.76 Column BX, Parameter Identification	53
2.3.77 Column BY, Parameter Units	53
2.3.78 Column BZ, Feed Stream Composition	53
2.3.79 Column CA, Slurry Stream Composition	53
2.3.80 Column CB, Condensate to LERF Stream Composition	54
2.3.81 Column CC, Stack Gas Stream Composition	54
2.3.82 Column CD, Raw Water to B Pond Stream Composition	54
2.3.83 Column CE, E-A-1 Condenser Stream Composition	54
2.3.84 Column CF, Blank Column	54
2.3.85 Column CG, Feed Stream Molar Composition	54
2.3.86 Column CH, Slurry Stream Molar Composition	54
2.3.87 Column CI, Sums of Feed Stream Cations	54
2.3.88 Column CJ, Logarithm of Organic Activity Coefficient	55
2.3.88.1 Cell CJ185, Sums of Slurry Stream Cations	55
2.3.88.2 Cells CJ190-CJ376, Logarithm of the	

Activity Coefficient	55
2.3.89 Column CK, Organic Activity Coefficients . .	55
2.3.89.1 Cell CK185, Sum of Feed Stream Anions	55
2.3.89.2 Cells CK190-CK376, Organic Activity Coefficient	55
2.3.90 Column CL, Organic Specie Molecular Weights	56
2.3.90.1 Cell CL185, Sums of Slurry Stream Anions	56
2.3.90.2 Cells CL190-CL376, Organic Constituent Molecular Weights	56
3.0 OPERATION OF THE SPREADSHEET	57
3.1 PROTECTION FEATURES	57
3.2 DATA ENTRY	57
3.3 CONSTANT(S) REVISIONS	58
3.4 PRINTING	58
3.5 SPECIFIC OPERATIONS/CALCULATIONS	59
4.0 REFERENCES	59

1.0 INTRODUCTION

A flowsheet model of the 242-A Evaporator/Crystallizer was prepared by RB Bendixsen for use in the 242-A FSAR (Lavender, J.C., 1992). This flowsheet was written using a Lotus 123 spreadsheet. A brief description of the flowsheet was presented in the FSAR and at an American Nuclear Society Meeting (Bendixsen, R.B., 1991); a more complete description is presented in this document along with instructions for its use. Several modifications were made to the flowsheet and the descriptions of these modifications are included in this updated document.

Figure 1 presents a schematic of the 242-A Evaporator showing all major streams. The flowsheet models each of these streams, giving flows, stream properties, temperatures, and compositions. Each stream in Figure 1 is identified with a number and this number, along with a stream title, is used in the spreadsheet model to identify the respective streams. The spreadsheet is written so that changes in the variable parameters such as stream flows or feed composition can be easily input or changed resulting in immediate recalculation of all stream data and immediate readjustment to new values. Constants used in the calculations, such as activity and partition constants, are conveniently located in the spreadsheet, and can be changed easily when data support new values for constants. Also, the equations in the spreadsheet can be changed, if desired, to accommodate changes in the plant or new assumptions about the stream flow relationships.

The FSAR, Chapter 6, includes complete descriptions of the normal operating source terms and the equipment within the Evaporator facility. Engineering and process instrumentation details and flow diagrams also are included in the FSAR. The reader is referred to the FSAR for these details.

2.0 DESCRIPTION OF FLOWSHEET

2.1 ASSUMPTIONS

The flowsheet and flowsheet stream compositions were developed using the following assumptions, as reproduced from the FSAR.

- Gas- and liquid-phase concentrations for radionuclide and inorganic compounds can be calculated using partition coefficients based on sample analysis data (Bendixsen 1990; and DOE-RL 1990). Where sample analysis data were not available, conservative partition coefficients were used to determine the gas- and liquid-phase concentrations.
- Gas- and liquid-phase concentrations for organic

Figure 1
Process Flowsheet for a Double-Shell Slurry
Feed Evaporator Run

compounds are calculated using activity coefficients and the pure component vapor pressure of the organic compounds. The activity coefficients can be adjusted for the Evaporator process using feed stream data and condensate stream data. Where feed and condensate stream organic data were not available, conservative activity coefficients were calculated using published activity coefficient equations (Pierotti et al. 1959). Activity coefficients and pure component vapor pressure values are used to calculate vapor- and liquid-phase concentrations because the vapor pressure of organic compounds varies with temperature. Activity coefficients were used for organic compounds because the partition coefficients do not provide a good estimate of the vapor- and liquid-phase concentrations.

- Use of activity and partition coefficients assumes that the gas- and liquid-phase concentrations are at equilibrium conditions. This is a good assumption because the Evaporator process operates for long periods of time with only slight variations in both feed and slurry flow rates.
- Evaporator vessel C-A-1 is modeled as a well-mixed reactor. This is based on the rapidly recirculating flow rate of ~61,000 L/min (~16,000 gal/min) for a normal operating volume of 85,000 to 95,000 L (22,500 to 25,000 gal). Typical feed rates are 340 to 530 L/min (90 to 140 gal/min), typical slurry rates are 160 to 420 L/min (43 to 110 gal/min), and typical process condensate rates are 75 to 225 L/min (20 to 60 gal/min). The feed and slurry rates are <1.0% of the recirculation rate, making the vessel contents a well-mixed solution. A well-mixed solution supports the assumption that vessel C-A-1 is a well-mixed reactor.
- The vapor phase is assumed to be primarily water vapor with slight concentrations of radionuclides, inorganic compounds, and organic compounds. This allows for a simplification of the formulas used to calculate the gas-phase concentrations. Analysis of the condensate stream shows that this assumption is valid because a majority of the concentrations are in microcuries per liter and parts per billion.
- There are five areas in the Evaporator facility that require using partition and activity coefficients to calculate gas- and liquid-phase concentrations. These are the following:
 - Evaporator vessel, C-A-1
 - Primary condenser, E-C-1

- Inter-condenser, E-C-2
 - After condenser, E-C-3
 - Condensate tank, TK-C-100.
-
- The feed stream composition to the Evaporator used in the FSAR is a corrected average of sample data from tanks TK-AN-103, TK-AN-106, and TK-AW-101 (Hendrickson 1990). The same feed stream composition is used in this document to illustrate use of the spreadsheet. Samples from the tanks and samples of slurry flow to the tanks represent DSS and DSSF concentrations produced by the Evaporator facility. The feed stream concentrations were adjusted in order for the slurry flow (stream 2) to match the sample data of these three tanks. In this manner, the flowsheet is a model of current operating practices and procedures.
 - Hydrogen concentrations in feed, product, and effluent streams are based on calculated hydrogen generation rates and the solubility of hydrogen in aqueous solutions. Hydrogen generation rates are based on the radionuclide concentrations in the vessel and the hydrogen generation values $[G(H_2)]$ for gamma, beta, and alpha decay radiation (Denaco and Jayson 1972). Solubility of hydrogen in aqueous solutions depends on solution temperature and the partial pressure of hydrogen in the gas phase (Perry 1973a). Hydrogen generation values were calculated for both the feed tank and the C-A-1 vessel. Hydrogen concentrations throughout the process were calculated using hydrogen partial pressure and solubility relationships.
 - Intermediate campaigns of more dilute wastes will have lower concentrations of radionuclides and most hazardous wastes in the effluents, product, and feed flows. The flowsheet is close to the upper boundary for future Evaporator operations. Each Evaporator campaign is unique because the concentrations of both radionuclides and hazardous materials come from so many sources.

2.2 MAJOR FEATURES OF THE SPREADSHEET

In standard spreadsheet fashion, the flowsheet is set up with a system of columns and rows. The columns are identified with alpha designations beginning with "A" for the first column and proceeding through column "CL". The rows are identified numerically starting with "1" and proceeding through "388". In addition, descriptions of the type of information contained in each column and row are placed at the tops of the columns and at the beginning of each row. The column descriptions usually correspond with the streams identified

in Figure 1 and the row descriptions usually correspond with the properties or compositions in each of these streams. Some exceptions to this general description occur away from the main spreadsheet where data are entered, stored or calculated.

The spread sheet has been divided into sections where common functions are performed. These are:

2.2.1. Main Spreadsheet

The main spreadsheet is located in Columns A through AH and extends from Row 1 down to Row 388. The first column identifies the physical property or analyte for each of the streams in the model. The second column identifies the units of temperature, pressure, concentration, etc. used for each property or analyte. Columns C through AH each correspond to a stream identified in Figure 1 and contain the specific value for each property or analyte composition in each of the streams as listed in Column A. The values for the feed are input by the spreadsheet user and all other stream composition values are calculated using the feed values and the operating parameters as input by the user as constants.

Rows 7 through 24 contain the major properties of each stream, such as form (liquid, vapor), pressure, temperature, flow, density, total dissolved solids and water content, and air content. Rows 26 through 104 contain the radionuclide concentrations in each stream, Rows 105 through 189 contain the inorganic analyte concentrations in each stream, and Rows 190 through 388 contain the organic analyte concentrations in each stream. Each radionuclide and analyte concentration is given in terms of a concentration (e.g., Uci/ml, mg/L) and in terms of a total amount per unit time (e.g., Uci/min, mg/min).

When new data are entered into the spreadsheet, as described later, the properties and compositions in each stream are recalculated on the basis that all streams are at equilibrium with each other. The spreadsheet contains rows identifying many analytes that may not be present; their inclusion has been made based on their known use on site, but not necessarily having been detected in the double shell waste storage tanks, or as possible degradation products of compounds known to exist. It is easier for the user of the spreadsheet to leave the feed column concentration for these analytes blank than to constantly add or delete analytes to the spread sheet each time the spreadsheet is used for a new feed composition. This also permits "what-if" calculations to be made for constituents not actually present without major changes to the spreadsheet.

2.2.2. Constants, Formulae, and Conversion Factors

Columns AI through AM between Rows 1 and 56 contain a grouping of constants, formulae and conversion factors used in the spreadsheet. The constants are mostly parametric constants associated with 242-A Evaporator equipment operation; these include such items as stream flows, pressures, vacuum settings, temperatures, etc. The spreadsheet uses these values in performing the calculations in the main spreadsheet section. Changes are made by altering the data in Column AI. The formulae are given for such items as calculating water density, pressure conversions, etc. The constants are included because many of the constants used in individual cell calculations in the main spreadsheet are not commonly used and by listing here the user of the spreadsheet can save much valuable time in determining the source and units of a particular constant.

2.2.3. E-C-3 Vapor Generation Rate

The calculations to determine the quantities of vapors exiting the E-C-3 Condenser to the stack are conducted in Columns AK and AL between Rows 60 and 70.

2.2.4. Heat Loss for Water Leaks

The calculation of heat loss, in Joules, for water leaks in the E-C-1 Condenser is made in Column AM, Rows 160 and 161.

2.2.5. Hydrogen Gas Generation Rate

Columns AO through AR between Rows 112 and 129 contain formulae for calculating the hydrogen generation rate due to radiolysis in the feed and slurry streams.

2.2.6. Feed and Slurry Densities

Column AM, in Rows 157 and 158, contains a formula for calculating the feed stream density based on chemical composition of the stream.

2.2.7. "F" Constant Calculation

Column AI, between Rows 189 and 376, contains a formula for calculating a factor representing the ratio of each organic analyte concentration in the vapor to that in the liquid in the C-A-1 vessel. Similar calculations are made in columns AJ through AM for other equipment locations in the Evaporator building. The description of the calculation, which is complex, is given in the section dealing with the contents of individual cells. The variables in the formula include the analyte activity coefficient, vapor pressure, molecular weight, and total moles. Also included are the vessel operating temperature and pressure.

2.2.8. Radionuclide Data

Columns AQ through AS between Rows 23 and 103 contain data on each radionuclide (i.e., half lives and energies), used in the hydrogen generation calculations.

2.2.9. Data Input Area/ Molecular Weights

Column AY contains the cells for inputting new feed concentration data into the flowsheet. These data are transferred by the spread sheet to Column C where they are used to initiate the stream composition calculations. Column AZ contains the molecular weights for each inorganic analyte. Column BA, down to Row 188, contains the ion charge for the inorganic analytes. Column CL, between rows 190 and 376, contains the molecular weights for the organic analytes.

2.2.10. Partition Coefficients and Activity Coefficients.

Column BA, between Rows 190 and 376 contains calculated values for the activity coefficient (γ) used in the organic analyte "F" factor calculations. The calculations for the activity coefficients are made in Columns CJ and CK, between Rows 190 and 376 using an empirical equation. Columns BB and BC, from Row 1 down to Row 187 contain the vapor space and condensate partition coefficients for the inorganic and radionuclide analytes. When the vapor pressures are not listed in the Perry Handbook (Perry, 1973), they are calculated using an empirical equation. Between Rows 190 and 376, these columns contain constants for an empirical Vapor Pressure Correlation that are used in calculating the organic analyte vapor pressures. See Section 2.1 for assumptions concerning the partition coefficient and activity coefficient data and calculations.

2.2.11. Decontamination Factors

Columns BD contains calculated decontamination factors consisting of the analyte concentration listed in Column D (Slurry composition) divided by the analyte concentration listed in Column T (Stack Air composition).

2.2.12. Historical Data

Columns BE and BF contain historical radionuclide and inorganic analyte composition data for the evaporator raw water cooling stream and the evaporator steam condensate. Columns BH through BT contain historical feed data for the compositions of the wastes in various tanks, an average of the data for the values for three of the tanks, the standard deviation of the values, and an adjusted feed composition to the evaporator vessel, C-A-1. These data were

used in the flow sheet model development for the feed values; the outputs of the model can be checked or compared with past data using these data whenever the user makes changes to the model.

2.2.13. Summary of Results

Columns BX through CE contain a condensed summary of the calculated results for selected flowsheet streams. The results are for the feed, slurry, condensate, stack air, and raw water streams. This listing makes it easy for the user to view the major stream compositions side by side or to print a hard copy of the results.

2.2.14. Feed and Slurry Molar Concentration Calculations

Columns CG and CH, between Rows 105 and 188, calculate the mole concentrations of the feed and slurry streams using the parts per million data in Columns C and D. The data are summed in Cells CG189 and CH189. The sums include the dissolved ions only; the mole concentration of water is calculated in Cell CG21.

The total cations and anions for both the feed and slurry streams, in units of M/L, are summed on Columns CI-CL, at Rows 183-185.

The data are converted to millimole/L for anions and cations in the feed and slurry solutions in Columns AM to AR between Rows 138 and 154. The sum of the anions in the feed stream, in units of millimole/L is also contained in Column AM at Rows 175 and 176.

2.3 CELL DESCRIPTIONS

The organization of this cell description section generally is a discussion starting with Column A and proceeding down this column describing individual cells in each row, as appropriate, then repeating the process for Column B and succeeding columns.

2.3.1. Column A, Parameter Titles

Each individual cell in this column is simply a title identifying the parameter being calculated or input in Columns C through AH. No further description of individual cells will be given.

2.3.2. Column B, Parameter Units

Each individual cell in this column is simply a title identifying the units in which the parameter in Column A is presented. No further description of individual cells will be given.

2.3.3. Column C, Feed Stream Values

2.3.3.1. Cell C9, Feed Flow

Cell C9 copies the total feed flow to the evaporator in units of liters/min from Cell AY9. Cell AY9 converts the flow from Cell AL15 from gal/min to liters/min. The flow in Cell AL15 is input by the spreadsheet user and remains a constant until changed by the user.

2.3.3.2 Cell C10, Batch Flow

Blank cell for the feed stream, as the feed is dynamic parameter, not a batch parameter.

2.3.3.3 Cell C11, Feed Temperature

Cell C11 copies the feed stream temperature from Cell AY11. At Cell AY11 the temperature is input by the spreadsheet user and remains a constant until changed by the user.

2.3.3.4 Cell C12, Density

Cell C12 copies the feed stream density from Cell AY12, which in turn copies the density from Cell AM158. The density is calculated in Cell AM158 from the equation (Reynolds and Herting, 1984):

$$\text{Density} = 1.017 + 0.0587[\text{AlO}_2] - 0.01943[\text{OH}] - 0.000505[\text{Temp}] + 0.0459[\text{AlO}_2 + \text{OH} + \text{NO}_3 + \text{NO}_2] - 0.000883[\text{NO}_3][\text{NO}_2]$$

where the temperature is copied from Cell AY11, where it is input by the spreadsheet user, and the anion concentrations are molar values calculated in Cells CG105, CG141, CG155, and CG157 for aluminate, hydroxide, nitrate and nitrite, respectively. The molar values for the anions in the CG cells are calculated from the data inputted by the spreadsheet user in Column AY in units of mg/L and the molecular weights stored in Column AZ.

2.3.3.5 Cell C13, Vessel Vacuum

Cell C13 copies the Evaporator C-A-1 vessel vacuum from Cell AL18. At Cell AL18 the vacuum is input by the spreadsheet user in units of Torr and remains a constant until changed by the user. A Torr unit is equivalent to mm mercury vacuum.

2.3.3.6 Cell C14, Vessel Vacuum

Cell C14 converts the vacuum in Cell C13 from Torr to Pascals by multiplying by the constant 133.23 Pa/torr.

2.3.3.7 Cell C15, pH

Cell C15 copies the feed stream pH from Cell AY15. At Cell AY15 the

pH value is input by the spreadsheet user where it remains a constant.

2.3.3.8 Cell C16, TOC

Cell C16 copies the feed stream Total Organic Carbon (TOC) value from Cell AY16. At Cell AY 16 the TOC value is input by the spreadsheet user in units of milligram/liter where it remains a constant.

2.3.3.8 Cell C17, TOC

Cell C17 calculates the TOC in terms of milligrams/minute by multiplying the value in Cell C16 (mg/L) by the flow in Cell C9 (L/min).

2.3.3.9 Cell C18, TDS

Cell C18 copies the feed stream Total Dissolved Solids (TDS) value from Cell AY18. At Cell AY18 the TDS value is input by the spreadsheet user in units of milligram/liter where it remains a constant.

2.3.3.10 Cell C19, TDS

Cell C19 calculates the TDS in terms of milligrams/minute by multiplying the value in Cell C18 (mg/L) by the flow in Cell C9 (L/min).

2.3.3.11 Cell C20, Volume Flow

Cell C20 copies the feed stream water volume flow in L/min from Cell AY20. Cell AY 20 calculates the volume flow from the mass flow in Cell AY21 by correcting for the density as a function of temperature in accordance with the equation:

$$\text{L/min} = [\text{Cell AY21, water flow, kg/min}] / [(-0.0003184)(\text{Cell AY11, temperature, C}) + 1.0048118]$$

This equation is a regression equation calculated using a standard scientific calculator from density versus temperature data in the Perry Chemical Engineers Handbook (Perry, 1973).

2.3.3.12 Cell C21, Mass Flow

Cell C21 copies the feed stream water mass flow in kg/min from Cell AY21. Cell AY21 calculates the mass fraction water flow in the total feed mass flow in accordance with the following equation:

$$\text{kg/min} = [(\text{Cell AY9, feed flow, L/min})(\text{Cell AY12, feed stream$$

density, g/cc)(1000 cc/L) - (Cell AY189, total inorganic concentration in the feed stream, mg/L)(Cell AY9, feed stream flow, L/min)/1000 mg/g]/1000 g/kg

Cell AY189 is the sum of the inorganic analyte concentrations in Cells AY105-AY188 in mg/L. These are the same concentrations as in Column C. The organic and radionuclide analytes are ignored in this summation as they are usually a very small fraction of the total mass.

2.3.3.13 Cell C22, Air Content

Cell C22 copies the feed stream air content value from Cell AY22. At Cell AY22 the air content value is input by the spreadsheet user in units of liter/minute where it remains a constant. There normally is not a value entered in the cell in Column C Row 22 but values are entered in other columns in this row where air concentrations or mass flows are of interest.

2.3.3.14 Cell C23, Air Mass Flow

Cell C23 calculates the air mass flow from the volume flow in Cell C22 at STP in accordance with the following equation:

$$\text{kg/min} = [(\text{Cell C22, air flow, L/min})(29 \text{ g/mole air})]/[(1000 \text{ g/Kg})(22.4 \text{ L/mole air})]$$

2.3.3.15 Cells C24 and C25, Blank Cells

These cells are blank.

2.3.3.16 Cells C26 through C101, Radionuclide Concentrations

Cells C26 through C103 contain the radionuclide concentration data for the feed solution. Two consecutive rows are utilized for each radionuclide. The first contains the radionuclide concentration in microcuries/milliliter and the second calculates the radionuclide transportation rate in microcurie/minute from the first row. The concentration data in the first row for each radionuclide are copied from the corresponding row in Column AY. The data are input by the spreadsheet user in Column AY where they remain as constants. The data in the second row for each radionuclide are calculated as follows using Cell C27 as an example:

$$\text{uCi/min} = (\text{Cell 26, radionuclide concentration, uCi/ml})(\text{Cell C9, feed stream flow, L/min})(1000 \text{ ml/L})$$

2.3.3.17 Cells C105 through C188, Inorganic Analyte

Concentrations

Cells C103 through C186 are similar to those in the above paragraph but for the inorganic analytes. The difference is that the concentrations in the first row for each analyte are in mg/L and in the second row in mg/min. The calculation in the second row is similar to in the above paragraph except the conversion factor of 1000 ml/L is not necessary.

2.3.3.18 Cells C190 through C377, Organic Analyte Concentrations

Cells C188 through C375 are the same as in the above paragraph but for the organic analytes.

2.3.4 COLUMN D C-A-1 Slurry Stream Values

2.3.4.1 Cell D9, Slurry Flow

Cell D9 calculates the total slurry flow in liter/minute using the formula:

$$\text{Slurry Flow} = (\text{Feed Flow, L/min})(1 - \text{Waste Volume Reduction Factor}/100)$$

The waste reduction factor is input by the spreadsheet user into Cell AL17, where it remains as a constant.

2.3.4.2 Cell D11, Temperature

Cell D11 calculates the temperature in the C-A-1 vessel from the boiling point equation using the slurry composition data (Allison, 1985, page 10):

$$\text{Temperature, } ^\circ\text{C} = 236.0 + 19.5\ln(\text{Pressure, Torr}) + 0.136(\text{Sum of the cation analytes, moles})^2 - 0.000848(\text{Sum of the cation analytes, moles})^3 - 273.15 \text{ } ^\circ\text{K}$$

The sum of the cations, in moles, is given in Cell CJ183 and the pressure is input by the spreadsheet user into Cell AL18, where it remains a constant. Each of these values is copied to the equation in Cell D11.

2.3.4.3 Cell D12, Density

Cell D12 calculates the density of the slurry (which is assumed to be the same as the contents of the waste solution within the C-A-1 vessel) using the same equation as given above for Cell C12. The composition data are obtained from the analyte compositions in Column D, the slurry composition. Note that a slight difference

exists between Cell C12 and D12 because the analyte compositions required in this equation are in moles; the constant 1000 millimole/mole is used in Cell D12 to convert the composition data to the correct units.

2.3.4.4 Cell D14, Vacuum

Same as Cell C14.

2.3.4.5 Cell D15, pH

This cell contains a constant, the slurry pH, and is input by the spreadsheet user.

2.3.4.6 Cell D16, TOC

Cell D16 converts the slurry Total Organic Carbon (TOC) value in Cell D17 (in milligrams/minute) into units of milligrams/L by dividing by the flow in Cell D9, L/min.

2.3.4.6 Cell D17, TOC

Cell D17 calculates the TOC value for the slurry stream, in units of mg/min, from the equation:

$$TOC, \text{mg/min} = \frac{TOC_F + TOC_{RW} + TOC_{PB1} + TOC_{PB2}}{1 + \frac{F_V * F_P}{F_S - F_{PB2}}} \quad (\text{Eq. 1})$$

Where:

- TOC_F = Total Organic Carbon concentration in feed stream, mg/min
- TOC_{RW} = TOC concentration in the raw water spray stream to the C-A-1 Vessel demister pads, mg/min
- TOC_{PB1} = TOC concentration in the PB-1 pump seal in-leakage water, mg/min
- TOC_{PB2} = TOC concentration in the PB-2 pump seal in-leakage water, mg/min
- F_V = Vapor flow from the C-A-1 vessel, L/min
- F_S = Feed stream flow into the C-A-1 vessel, L/min
- F_{PB2} = PB-2 pump seal in-leakage water flow, L/min
- F_p = The Organic Partition Coefficient. The ratio of the mg/L of a constituent in the vapor phase to the mg/L of the constituent in the liquid phase

While the following discussion treats the TOC (total organic carbon) value in Cell D17 being calculated as an organic analyte in order to show the derivation of the equations, it is actually

calculated as an inorganic constituent in this particular cell and a K_p value is used rather than an F_p value. This is because TOC is a summation of all the organics and an F_p cannot be calculated. The K_p is obtained from TOC sample data just as for the inorganic constituents.

Cell D17 is the first of many that use a material balance around the C-A-1 Vessel to calculate the concentrations of specific components. The derivation of this equation is shown as follows:

The basic flow balance around the C-A-1 Vessel is shown in Figure 2. To simplify the derivation, first consider the simplified flow balance shown in Figure 3 where a_1 represents the quantity of any constituent in units of mg/min entering the evaporator in the feed stream, b_1 represents the quantity of the same constituent in units of mg/min in the vapor leaving the evaporator, and c_1 represents the quantity in the slurry stream leaving the evaporator.

Figure 2
FLOWSHEET MATERIAL BALANCE

Figure 3

Then:

$$a_1 = b_1 + c_1 \quad (\text{Eq. 2})$$

$$a_1 = (c_1)(1 + b_1/c_1) \quad (\text{Eq. 3})$$

$$c_1 = a_1 / (1 + b_1/c_1) \quad (\text{Eq. 4})$$

The Organic Partition Coefficient, F_p , is defined as the ratio of the concentration of a constituent in the vapor phase to the concentration in the liquid phase:

$$F_p = \frac{b_2, \text{ mg/L in the vapor}}{c_2, \text{ mg/L in the liquid}} \quad (\text{Eq. 5})$$

Further, the ratio b_1/c_1 may also be expressed as:

$$\frac{b_1 \text{ mg per min in vapor}}{c_1 \text{ mg per min in liquid}} = \frac{(b_3 \text{ L vapor/min}) * (F_p \text{ mg/L vapor})}{c_3 \text{ L liquid/min} \text{ mg/L liquid}} \quad (\text{Eq. 6})$$

Substituting Eq. 6 into Eq. 4 gives:

$$c_1 = a_1 / (1 + (b_3 * F_p) / c_3) \quad (\text{Eq. 7})$$

Equation 7 is a simplified form of Equation 1. In order to modify equation 7 to the form shown in equation 1 first note that a_1 is the sum of the three streams entering the evaporator vessel, i.e., the evaporator feed stream, the pad spray stream, and the PB-1 pump seal water in-leakage stream. The slurry flow is measured downstream of the PB-2 pump seal water in-leakage stream, so this in-leakage must be subtracted from the c_3 flow rate as the in-leakage is not in equilibrium with the vapor phase. The flow in Cell D9 is defined as (Cell C9) (1 - Weight Reduction Factor) which is the total of the slurry plus PB-2 Seal in-leakage. Finally, if the user is interested in the concentration of an analyte entering the slurry tank after the stream leaves the evaporator the contribution of this component in the PB-2 seal water in-leakage stream must be added as shown by the term TOC_{PB2} in equation 1.

For the inorganic constituents an inverse of the Organic Partition Coefficient, identified as K_p , is used in the spreadsheet for the Partition Coefficient. The inorganic Partition Coefficient is defined as the concentration of an analyte in the liquid divided by the concentration in the vapor, or c_2/b_2 .

Relationships for the concentrations of organics in the vapor phase and for the inorganics and radionuclides are derived similarly to the derivation leading to equation 7. These are shown in the following table:

Equilibrium Equations

Organic Analytes

$$c_1 = a_1 / (1 + (b_3 * F_p) / c_3) \\ (\text{slurry}) \quad (\text{Equation 7})$$

$$b_1 = a_1 / (1 + c_3 / (b_3 * F_p)) \\ (\text{vapor}) \quad (\text{Equation 9})$$

Inorganic and Radionuclide Analytes

$$c_1 = a_1 / (1 + b_3 / (c_3 * K_p)) \\ (\text{slurry}) \quad (\text{Equation 8})$$

$$b_1 = a_1 / (1 + (c_3 * K_p) / b_3) \\ (\text{vapor}) \quad (\text{Equation 10})$$

The use of these equations is applicable for calculating the equilibrium concentrations in the evaporator vessel, the three condensers and the condensate collection tank. The organic and inorganic partition coefficients provide the means to estimate liquid and vapor equilibrium concentrations in each of the five equipment items.

Samples of solution and the vapor space above the solutions in

underground storage tanks provided the initial vapor and liquid phase compositions for radionuclide and inorganic specie (Bendixsen, 1991). The solution concentrations divided by the vapor concentration yields an estimate of the partition coefficient for the specie. Operating data and literature information (Eguchi et al. 1973) suggest a lower partition coefficient for condensate than for the higher salt solution in the vacuum evaporator vessel. The partition coefficients for the salt solution come directly from the sample data. Partition coefficients for the condensate flow come from correlating sample data of condensate receiver tanks with gaseous effluent data. Where sample data are lacking, conservative partition coefficient values of 1.0×10^7 for salt solutions and 1.0×10^5 for condensate were used. While the partition coefficient data were inputted by Bendixsen from the above sources, they are to be updated and refined by the users of the spreadsheet as additional information becomes available from future evaporator operating runs.

While the partition coefficients for the inorganic constituents are obtained from sample data and literature data, the partition coefficients for the organic constituents are calculated from the organic constituent activity coefficients and vapor pressures. This is because the organic partition coefficient varies considerably with changes in these parameters. Activity coefficients based on empirical equations estimate deviations from ideal behavior for organic compounds in dilute mixtures (Pierotti et al., 1959). The organic vapor pressure equations use partial pressure data of the organic compounds. The organic vapor pressure equation is an exponential temperature dependent equation of the form:

$$P = e^{(A \cdot T + B)},$$

where P = pressure in mm Hg, and T = temperature in $^{\circ}\text{C}$. Calculating the A and B constants requires linear regression of natural logarithms of organic pressure-temperature data for the operating temperature range. Together, the activity coefficient and the organic vapor pressure equation estimate the equilibrium concentrations of the organic species in gas and liquid phases, using activity coefficients and the partial pressure equation. Details of these calculations and derivation of the equations used are contained in the discussion of F_p under the description of Cell AI190.

2.3.4.7 Cell D24, Heat Content

Cell D24 contains an equation for calculating the increase in heat content, in units of Joules/min, for the slurry stream in relationship to the feed stream. The equation is:

$$\text{Joules/min} = (C_p, \text{Joules/kg-}^{\circ}\text{C})(1000 \text{ cc/L})(1/1000 \text{ g/Kg})(\text{Cell}$$

D9, L/min) (Cell D11-Cell C11, °C)

Where the heat capacity, $C_p = (\text{Cell CH189}) * (-7.9168) + 3391$, is derived as follows:

The Chemical Engineer's Handbook (Perry, 1973b) contains data relating specific heats of solution for NaOH and NaCl as a function of mole percent. The data for NaOH were converted to units of Joules/Kg-°C and then a correlation was developed for C_p as shown above. The datum from Cell CH189 is the molar sum of the individual constituents in the slurry stream, or total moles. The equation is assumed to be valid for the composite solution as the data from the handbook are very similar for both NaOH and NaCl.

2.3.4.8 Cells D26-D103, Radionuclide Concentrations

Cells D26-D103 contain the concentrations of the radionuclides in the slurry stream. These concentrations are calculated from the inorganic Partition Coefficient, K_p , and the equation

$$c_1 = a_1 / (1 + b_3 / (c_3 * K_p))$$

as described in Section 2.3.4.6 for Cell D17.

2.3.4.9 Cells D105-D188, Inorganic Analyte Concentrations

Cells D105-D188 contain the concentrations of the inorganic analytes in the slurry stream. These are calculated as described above for the radionuclide analytes. The exception is for hydrogen in Cells D139 and D140, which is calculated differently as described below.

2.3.4.10 Cells D139 and D140, Hydrogen Concentration

Cells D139 and D140 calculate the hydrogen concentration in the slurry stream.

The flowsheet for 242-A uses the following methods to calculate hydrogen concentrations in the feed, slurry, and other flows in the process.

Assumptions:

- a) Hydrogen generation rates $G(H_2)$ are as follows (Denaro, 1972):

Alpha	1.57 molecules H_2 /100 eV disintegration
Beta	0.6 molecules H_2 /100 eV disintegration
Gamma	0.45 molecules H_2 /100 eV disintegration

- b) Volume in the C-A-1 Evaporator Pot is 25,000 gallons.
Normal operating level in the evaporator supports this assumption.
- c) Volume in the 102-AW feed tank is 500,000 gallons.
Tank capacity is 1.0 million gallons.
- d) Henry's Law applies for Hydrogen concentrations in solutions (Perry, 1973a):

$$p = Hx$$
 where x = mole fraction solute in liquid phase
 p = partial pressure of solute in gas phase
 H = proportionality constant, atmospheres of solute pressure/unit concentration in liquid

Using the above assumptions, the spread sheet formulae calculate and total the disintegration energies and radionuclide concentrations for alpha, beta and gamma radiation for all of the isotopes. The units for this summation are:

$$\frac{\mu\text{Ci MeV molecules H}_2}{\text{ml disintegration 100eV}}$$

These units come from multiplying radionuclide concentration ($\mu\text{Ci/ml}$) times the disintegration energy (MeV/disintegration) times the $G(\text{H}_2)$ value (molecules $\text{H}_2/100\text{eV}$).

A constant was calculated converting the above values to Hydrogen generating rates in mg/min. This constant has a value of $7.37\text{E}-08$ (disintegrations $100\text{eV ml mg/min MeV L } \mu\text{Ci molecules H}_2$) and comes from multiplying ($3.7\text{E}+10$ disintegrations/Ci sec) times (60 sec/min) times ($1.0\text{E}+04$ [100eV]/MeV) times (1000 ml/L) times (Ci/ $1.0\text{E}+06 \mu\text{Ci}$) times (mole $\text{H}_2/0.6024\text{E}+24$ molecules) times (2000 mg $\text{H}_2/\text{mole H}_2$).

An equation developed from Perry's Chemical Engineers' Handbook (Perry, 1973a) relates Hydrogen concentration in the gas phase versus the liquid phase for different temperatures. This equation is: $H (1.0\text{E}-04) = .82541 \ln(T) + 4.45419$ where T is solution temperature in degrees centigrade. The units for H are atmospheres/(moles $\text{H}_2/\text{moles liquid}$).

Another constant developed for the equations ties the H value from Perry's (Perry, 1973a) to the distribution equations developed for the evaporator pot, condensers and the condensate collection tank. This constant comes from multiplying vacuum (Pascals) times 22.4 (l/mole) times salt moles (moles/L) times temperature correction ($273+^\circ\text{C}/273$ divided by H times 10,000 times 101325

(Pascals/atmosphere).

The hydrogen generation in the C-A-1 Vessel is first calculated in Cell AQ126 as follows:

$$H_2, \text{ mg/min} = (\text{Vessel volume, gal}) * 3.785 \text{ L/gal} * (1.57 \text{ molecule } H_2 / 100 \text{ ev} * \Sigma\alpha + 0.6 \text{ molecule } H_2 * \Sigma\beta + 0.45 \text{ molecule } H_2 * \Sigma\gamma) * 7.37 \times 10^{-8}$$

Where $\Sigma\alpha$ is the summation of each alpha emitter concentration times energy: $\Sigma\alpha = (\text{uCi/ml} * \text{Mev/dis})_1$, etc.

The quantity of hydrogen generated within the vessel is added to the quantity of hydrogen coming into the vessel in the feed stream and the amount remaining in the slurry is calculated in Cell D140 using an equation similar to that described for Cells D26-D103.

Typical Hydrogen generation rates calculated are 30 mg/min for the feed tank and 2.2 mg/min for the C-A-1 vessel, based on the tank and feed composition data base used in the 242-A Evaporator FSAR.

Values for various evaporator stream flows are:

<u>Description</u>	<u>Units</u>	<u>Feed</u>	<u>Slurry</u>	<u>C-A-1 Vapor</u>
H ₂	mg/L	1.3E-04	1.6E-09	9.3E-07
H ₂	mg/min	4.4E-02	3.9E-07	2.2E+00

2.3.5 Column E, Filtered Raw Water Values

2.3.5.1 Cells E8-E24, Physical Properties

The physical property data for the variables (temperature, flow, pH, etc.) discussed for the feed and slurry streams are similarly presented for the filtered raw water stream in Column E, Rows 8-24. The data are entered as constants by the spreadsheet user directly into Column E, or into Columns AL (for Row 21) or Column BE where they are copied into the respective rows in Column E.

2.3.5.2 Cells E26-E379, Composition Data

The composition data for the filtered raw water for radionuclides, inorganic analytes, and organic analytes are entered by the spreadsheet user as constants into Column BE and are copied into Column E for use in spreadsheet calculations. The radionuclide, inorganic, and organic concentration data are an average of several raw water samples (Loll 1990a).

2.3.6 Column F, C-A-1 Vessel Vapor Stream Values

2.3.6.1 Cell F9, Total Flow

The total vapor flow in L/min is given in this cell. The flow is the sum of the water vapor flow from Cell F20, the air flow from Cell F22, and the hydrogen gas flow from Cell F142.

2.3.6.2 Cell F11, Temperature

The vapor temperature is copied from Cell D11, the slurry temperature. Both temperatures will be the same.

2.3.6.3 Cell F12, Vapor Density

Cell F12 calculates the vapor density, assuming all the vapor is water, for the vapors exiting the C-A-1 vessel. The calculation uses the ideal gas equation:

$$\text{g/cc} = ((\text{Cell F13, torr}/760 \text{ atm/torr}) * 18 \text{ g/mole}) / ((82.1 \text{ cc-atm/}^\circ\text{K-mole}) * (273 + \text{Cell F11, }^\circ\text{C}))$$

This equation is derived as follows:

Density, g/cc = m/V where m is grams and V is volume, cc.

From the ideal gas law, $V = nRT/P$ where n is moles or m/MW, MW is molecular weight, and R is the gas constant 82.1. Combining equations, density, d is:

$$d = m / ((m/MW)RT/P) = P * MW / RT$$

2.3.6.4 Cell F13, Absolute Pressure

The absolute pressure is copied from Cell AL18, where it is entered as a constant by the spreadsheet user in units of Torr. This is the operating pressure for the evaporator.

2.3.6.5 Cell F14, Absolute Pressure

The absolute pressure in units of Pascals is calculated from Cell F13 by multiplying by the constant 133.23 Pa/Torr.

2.3.6.5 Cell F15, pH

This cell contains a location for the user to enter the pH, but is normally not used because the pH is normally a liquid phase value.

2.3.6.6 Cells F16 and F17, TOC

The Total Organic Carbon calculations are similar to those in Cells D16 and D17; see these cells for methodology. Note that the

material balance equations are for the vapor phase, not the liquid phase (see Equations 7-10 in Cell D17).

2.3.6.7 Cells F18 and F19, TDS

The Total Dissolved Solids calculations are similar to those in Cells D18 and D19; see these cells for methodology. Note that the material balance equations are for the vapor phase, not the liquid phase as described in D17.

2.3.6.8 Cells F20 and F21, H₂O

Cell F21 calculates the quantity of water vapor, in kg/min, exiting the C-A-1 vessel by adding and subtracting the entering and exiting stream quantities:

$$\text{kg/min} = \text{Cell C21}(\text{feed}) - \text{Cell D21}(\text{slurry}) + \text{Cell E21}(\text{pad spray raw water}) + \text{Cell AF21}(\text{P-B-1 pump seal water}) + \text{Cell AG21}(\text{P-B-2 pump seal water}) + .0038(\text{Kg water/Kg air}) * \text{Cell F23}(\text{Kg/min air})$$

The value for the constant, 0.0038, comes from the exponential portion of the equation in Cell J21, where the water content of the air stream is calculated from an empirical correlation of water content versus temperature:

$$\text{Water, Kg/min} = (\text{Air Flow, Kg/min}) * \exp (.0638 * ^\circ\text{C} - 5.51967)$$

Cell F20 converts the value from Cell F21 into vapor flow in units of liter/min at the C-A-1 vessel operating conditions using the following equation based on ideal gas law relationships:

$$\text{L/min} = ((\text{Cell F21 kg/min}) (1000 \text{ g/kg}) (22.4 \text{ L/mole}) (T_2, ^\circ\text{K}) (P_1 \text{ atm} * 101321 \text{ Pa/atm})) / (18 \text{ g/mole}) (T_1, ^\circ\text{K}) (P_2 \text{ Pascals})$$

This equation is derived as follows:

$$\begin{aligned} \text{L/min at operating conditions} &= (\text{L/min at STP}) (T_2/T_1) (P_1/P_2) \\ \text{where L/min at STP} &= \\ &(\text{Cell F21, Kg/min}) * (1000 \text{ g/Kg}) * (22.4 \text{ L/mole}) / (18 \text{ g/mole}) \end{aligned}$$

2.3.6.9 Cells F22 and F23, Air

Cell F23 calculates the quantity of air exiting the C-A-1 vessel that was introduced as instrument air using input from Cell AL23 where the instrument air flow, in units of cubic feet/min, is entered by the spreadsheet user as a constant. The calculation is:

$$\text{kg/min} = (\text{Cell AL23, cfm}) (28.316 \text{ L/ft}^3) (.029 \text{ kg/mole}) / 22.4 \text{ L/mole}$$

Cell F22 converts the value from Cell F23 into L/min at the vessel operating conditions using the same equation as does cell F20 except the molecular weight of air, 29 g/mole, is substituted for the molecular weight of water.

2.3.6.10 Cell F24, Heat Content

Cell F24 calculates the increase in heat content, in Joules/minute, of the vapor stream leaving the evaporator vessel using the feed stream as the base point. The equation is Joules/min = Heat to raise the liquid temperature from the feed temperature to the evaporator temperature + Heat required to evaporate the liquid to steam + Heat required to raise the air temperature to the vapor temperature.

The first term, heat required to raise the liquid temperature = $4186.8 * (\text{Cell D11, slurry temp } ^\circ\text{C} - \text{Cell C11, feed temp, } ^\circ\text{C}) * (\text{Cell F21, water mass flow, Kg/min})$

Where the liquid heat capacity, C_p , = $1\text{BTU/lb-F} \times 1055 \text{ Joules/Btu} \times 1 \text{ lb/.4536 Kg} \times 1.8 \text{ F/}^\circ\text{C} = 4186.8$

The second term, heat required to evaporate the liquid to steam, = $((-2408.4 * \text{Cell D11, temperature, } ^\circ\text{C}) + 2503300) * \text{Cell F21, water mass flow, Kg/min}$

Where the first term is the latent heat of vaporization, h , calculated at the temperature of the steam from a regression analysis of data over the range of temperatures expected in the evaporator as shown:

<u>$^\circ\text{F}$</u>	<u>h, BTU/lb</u>	<u>h, Joules/Kg</u>
110	1031.32	2.3959 E6
120	1025.63	2.3856 E6
130	1010.84	2.3721 E6
140	1019.11	2.3588 E6

The regression coefficients are $A = -2408.4$ and $B = 2503300$ and the equation for h is $h = -2408.4 * ^\circ\text{C} + 2503300$

The third term, heat required to heat the air = $(1004.8) * (\text{Cell F23, air mass flow, Kg/min}) * (\text{Cell D11, evaporator temperature} - 10)$

Where the air heat capacity, C_p , = $.45\text{BTU/lb-F} \times 1055 \text{ Joules/Btu} \times 1 \text{ lb/.4536 Kg} \times 1.8 \text{ F/}^\circ\text{C} = 1884$

The value of 10 in the delta temperature term is the average air temperature of the inlet air.

2.3.6.11 Cells F26-F190, Composition Data

Cells F26-F190 are used to calculate the radionuclide and inorganic analyte compositions in the vapor phase. These cells are similar to Cells D26-D190 except the material balance equation is Equation 10 described in Section 2.3.4.6 rather than Equation 8:

$$b_1 = a_1 / (1 + (c_3 * K_p) / b_3)$$

2.3.6.12 Cell F140, Hydrogen Generation

An exception to the above paragraph is that the hydrogen mass flow rate is calculated with a modified equation in Cell F140. A description of how the formula used for this calculation was derived is given in the description of Cell D139. The equation is similar to Equation 9 in Section 2.3.4.6 with the following modifications:

$$b_1 = a_1 / (1 + c_3 / (b_3 * F_p))$$

Where:

a_1 is the hydrogen generation rate within the evaporator vessel (Cell AQ126) plus the hydrogen contained in the feed stream (Cell C140)

c_3 is slurry flow

b_3 is the vapor flow, and

F_p is a modified partition coefficient with terms including the total moles salt in the slurry (Cell CH189), a factor H relating hydrogen distribution between the gas and liquid phases, and several constants to get the units correct. See Cell D139 for a complete description.

While this equation is both eloquent and involved, it may be observed that the value for b_1 is essentially the value of the hydrogen generation rate from Cell AQ128.

2.3.6.13 Cells F192-F379, Composition Data

Cells F192-F379 are used to calculate the organic analyte compositions in the vapor phase. These cells are similar to Cells D192-D380 except the material balance equation is Equation 9 described in Section 2.3.4.6 rather than Equation 7:

$$b_1 = a_1 / (1 + c_3 / (b_3 * F_p))$$

2.3.7 Column G, E-C-1 Condensate Stream

2.3.7.1 Cells G1-G23, G25-G379, Properties and Compositions

The data for these cells are calculated from the data from Columns C, D, and F, and from constants input by the spreadsheet user. The equations are all similar to those described previously for Columns C, D, and F.

2.3.7.2 Cell G24, Heat Content

Cell G24 calculates the heat content of the condensate stream in the E-C-1 condenser as follows:

$$\begin{aligned} \text{Joules/min} = & (\text{Condensate Flow} - \text{Tube leak flow,} \\ & \text{kg/min}) (C_p(\text{vapor}) * \Delta T + C_p(\text{liquid}) * \Delta T) + h * (\text{Condensate Flow} - \\ & \text{Tube leak flow, kg/min}) - (\text{Tube leak flow, kg/min}) \\ & (C_p(\text{liquid}) * \Delta T) \end{aligned}$$

Where $C_p(\text{vapor}) = 0.45 \text{ BTU/lb-}^\circ\text{F} = 1884 \text{ Joules/Kg-}^\circ\text{C}$,

$C_p(\text{liquid}) = 1 \text{ BTU/lb-}^\circ\text{F} = 4186.8 \text{ Joules/Kg-}^\circ\text{C}$, and h = the latent heat of condensation as described in Cell F24.

2.3.8 Column H, E-C-1 Vapor Stream

2.3.8.1 Cells H1-H23, H25-H379, Properties and Compositions

The data for these cells are calculated from the data from Columns C, D, and F, and from constants input by the spreadsheet user. The equations are all similar to those described previously for Columns C, D, and F.

2.3.8.2 Cell H24, Heat Content

Cell H24 calculates the heat content of the vapor stream according to the equation:

$$\begin{aligned} \text{Joules/min} = & (C_p(\text{air}) * [(\text{Air flow, Kg/min}) (\Delta T) + (\text{Water in air} \\ & \text{in-leaks, Kg/min}) (\Delta T)] + (C_p(\text{water vapor}) * [(\text{Water Vapor flow,} \\ & \text{Kg/min}) (\Delta T) \end{aligned}$$

Where:

$$C_p(\text{air}) = 1004.8 \text{ Joules/Kg-}^\circ\text{C}$$

$$(C_p(\text{water vapor}) = 1884 \text{ Joules/Kg-}^\circ\text{C}$$

and airflow is inputted from Cell F23, water in air in-leakage from Cell AC23, and water vapor flow from Cell H21. Temperatures are inputted from Row 11 in their respective columns.

2.3.9 Column I, E-C-2 Condensate Stream

2.3.9.1, Cells I1-I23, I25-I379, Properties and Compositions

The data in these cells are input and calculated similarly to that described for Column G.

2.3.9.2, Cell I24, Heat Content

Cell I24 calculates the heat transferred to the condensate by subtracting from the heat in the steam from Cell AA24 the heat of condensation and adjusting by adding the heat change in the liquid according to the equation:

$$\begin{aligned} \text{Joule/min} = & (\text{Cell AA24, Joule/min}) - [((-2408.4) * (\text{Cell AA11, } ^\circ\text{C}) \\ & + 2503300) * (\text{Cell J21-Cell H21, Kg/min})] + \\ & C_p(\text{water}) * \Delta T * (\text{Cell AA21-Cell J21} + \text{Cell H21, Kg/min}) \end{aligned}$$

Where the term $(-2408.4) * (\text{Cell AA11, } ^\circ\text{C}) + 2503300$ is the term for h , BTU/lb, described in Cell F24 and $C_p(\text{water})$ is 4186.8 Joules/Kg- $^\circ\text{C}$.

2.3.10 Column J, E-C-2 Vapor Stream

2.3.10.1, Cells J1-J23, J25-J379, Properties and Compositions

The data in these cells are input and calculated similarly to that described for Column H.

2.3.10.2 Cell J24, Heat Content

Cell J24 calculates the heat content of the E-C-2 vapor from the equation:

$$\begin{aligned} \text{Joule/min} = & (C_p(\text{air}) \text{ Joule/Kg-}^\circ\text{C}) * (\text{air flow, Kg/min}) * \Delta T + \\ & (C_p(\text{water vapor}) \text{ Joule/Kg-}^\circ\text{C}) * (\text{air flow, Kg/min}) * \Delta T \\ & + (h, \text{ Joules/Kg}) * (\text{Vapor flow, Kg/min}) \end{aligned}$$

Where: ($C_p(\text{air})$ = 1004.8 Joules/Kg-°C, ($C_p(\text{water vapor})$ = 1884 Joules/Kg-°C, and h is as described in Cell D24

2.3.11 Column K, E-C-3 Condensate Stream

2.3.11.1, Cells K1-K23, K25-K379, Properties and Compositions

The data in these cells are input and calculated similarly to that described for Column G.

2.3.11.2 Cell K24, Heat Content

Cell K24 calculates the heat content of the E-C-3 condensate in a manner similar to that described in Cell I24. See Cell I24 description.

2.3.12 Column L, Process Condensate

The constants for this column are input by the spreadsheet user similarly to previous columns and the composition calculations are the sum of the properties and compositions for the E-C-1, -2, and -3 condensate streams in Columns G, I, and K.

2.3.13 Column M, Process Condensate to LERF

The constants for this column are input by the spreadsheet user similarly to previous columns and the composition is the same as the composition for the Process Condensate stream in Column L.

2.3.14 Column N, Organic in C-100 Tank to 102-AW Tank

This column is normally not used in the spreadsheet and is set up as a batch operation. Should it be necessary to overflow the C-100 Tank to remove organic phase floating on the water surface, data could be entered in this column. The data would be entered as constants by the spreadsheet user. Surrogate data are entered in the current model in Cells N11-N15 for temperature, density, pressure, and pH.

2.3.14 Column O, E-101 to Ion Exchange Stream

2.3.14.1 Cells O1-O23, O25-O379, Properties and Compositions

The rows for properties and composition of the eluant stream used to regenerate the ion exchange resin are reserved for data concerning the eluant. The flowsheet model currently does not contain data in this column because an eluant is no longer used for

routine operation.

2.3.14.2 Cell O24, Heat Content

Cell O24 calculates the heat content of the sodium nitrate eluant to the ion exchange column according to the equation:

$$\text{Joule/min} = C_p * m * \Delta T$$

Where C_p for 1 M sodium nitrate used for the regeneration is 3977.5 Joule/Kg-°C,

m is the mass flow, Kg/min input as a batch flow by the spreadsheet user into Cell AL29 and adjusted by the small increase that would occur due to raw water in-leakage from the condenser tubes during regeneration by multiplying by the ratio $1/(1 - (\text{Cell AL20}/100))$. Cell AL20 contains the value for in-leakage.

and ΔT is the difference in Tank E-101 temperature and the raw water temperature.

2.3.15, Column P, Ion Exchange Eluant to 102-AW Tank

See comments for Column O; not a routine operation. The spent eluant would be routed to the 102-AW waste tank.

2.3.16, Column Q, Stack Inlet Air

The properties of the air bled into the ventilation exhaust stack through Filter F-C-7 upstream of the Deentrainment Pad DU-C-1 are given in this column. The formulas for calculating the properties in Row Q9-Q22 are essentially the same as those described in Column F. Cell Q23 contains an air material balance to calculate the mass air flow, Kg/min according to the equation:

$$\text{Air, Kg/min} = \text{Cell R23} - \text{Cell J23} - \text{Cell AB23} - \text{Cell AH23}$$

Where Cell R23, the airflow to H-C-1, is calculated the same as in Cell F23. The flow for H-C-1 is input by the spreadsheet user into Cell AL14 using operating data for FE-AS-5, flow to H-C-1. Flow normally runs 650-700 cfm. During one instance when Stream 15 was valved off, flow remained at 600-650 cfm, indicating that air came in through C-100 Tank, Stream 32, via the vent from Steam Condensate Tank C-103. C-103 has a lid open to air, so much inleakage can occur here.

Cell J23 is the air from E-C-2 inter condenser = Cell H23 (air from E-C-1) + Cell AA23 (air entrapped in steam in jet ejector J-EC1-1).

Cell AB23 is the air entrapped in steam in jet ejector J-EC2-

1, and

Cell AH23 is airflow from C-100 Tank vent, Stream 32. Datum is input from Cell AL36 where it is entered as a constant by the spreadsheet user.

2.3.18 Column R, Air Stream to DU-C-1

Column R describes the properties of the air entering and exiting the stack deentrainment pad, DU-C-1.

2.3.18.1 Cell R9, Total Flow

See Cell Q9 and F9 for description.

2.3.18.2 Cell R11, Temperature

The temperature is calculated using the formula:

$T, ^\circ\text{C} = (\text{Cell AL43} - 32) / 1.8$ $^\circ\text{C}/^\circ\text{F}$ where Cell AL43, in the table of constants, contains the stack temperature at the HC-1 inlet in $^\circ\text{F}$.

2.3.18.3 Cell R12, Vapor Density

See Cell F12 for description.

2.3.18.4 Cells R13 and R14, Absolute Pressure

The absolute pressure is calculated in Cell R13 using the formula:

$P, \text{Torr} = (1 \text{ atm})(760 \text{ Torr/atm}) - (\text{Cell AO42, inches vacuum})(1.8683 \text{ Torr/in vac})$

Where cell AO42 contains the E-C-3 vacuum in inches. Data are input by the user using operating data (PI-DUC1-3).

The value in Cell R13 is converted to Pascal units in Cell R14.

2.3.18.5 Cells R16-R19, TOC and TDS

The values for TOC and TDS are calculated similar to as described in Cell D17, using Equation 10 and adjusting the flows to reflect the material balance around the system.

2.3.18.6 Cells R20 and R21, Water Flow

These cells calculate the water content of the air similarly to that in Cells Q20 and Q21 except that a different correlation is

used for the water content of the air:

Cell R21, water, kg/min = [Cell J23(water in J-C-2 vapor)]*[0.0167387*Cell K11(E-C-3 condensate temperature, C) - 0.8713] + Cell Q21(water in stack air) + Cell AH21(water in C-100 air flow)

Since this correlation produces a significantly different value for water content, future users of the spread sheet should determine which correlation is the most valid. Note that Cell AK66 has this correlation but it is J23(.0167387*K11-.18713) whereas the last constant in Cell R21 is .8713. This may be the answer.

2.3.18.7 Cells R22 and R23, Air Flow

See Cell Q23 for description.

2.3.18.8 Cell R24, Heat Content

Cell R24 calculates the heat content of the air in a manner similar to that described in Cell J24. See Cell J24 description.

2.3.18.9 Cells R26-R377, Composition Data

These cells calculate the radionuclide and inorganic constituent concentrations using Equation 10 described in Cell D17 and the organic constituent concentrations using Equation 9 described in Cell D17.

The hydrogen concentration in Cell R140 is the sum of the hydrogen in the three streams making up the stack air flow, the vapor coming from the E-C-3 After Condenser, the vapor coming from the C-100 Tank, and the air bleeding in through the F-C-1 filter (which has zero hydrogen content). The hydrogen from the E-C-3 After Condenser is calculated in Cells AL60-AL70, and the hydrogen from the C-100 Tank in Cell AH140.

2.3.19 Column S, Air to F-C-5 Stream

The descriptions for the air stream entering the F-C-5 High-Efficiency filter are similar to the descriptions given in Column R except:

The pressure in Cell S13 is the sum of the pressure in Cell R13 plus the differential pressures across H-C-1 and DUC-1. The constant 1.8683 is a conversion factor from inches of water to Torr.

Cell S24 calculates the heat content of the air in a manner similar

to that described in Cell J24. See Cell J24 description.

2.3.20 Column T, Stack Exhaust Air

The descriptions for the air stream exiting the F-C-5 High-Efficiency filter are similar to the descriptions given in Column S except:

The concentrations for the TDS in Cell T19, and the radionuclide and inorganic constituents in Cells T26-T188 are decreased from the inlet concentrations in Column S by the decontamination factor achieved in passing through the high-efficiency filter. This decontamination factor is entered into Cell AL88 by the spreadsheet user.

2.3.21 Column U, E-A-1 Reboiler Steam

Column U contains the properties for the steam entering the E-A-1 Reboiler. The calculations are similar to previously described calculations with the following exceptions:

2.3.21.1 Cell U11, Temperature

The steam temperature is calculated from a regression analysis equation developed around the pressures expected and uses the pressure from Cell U14:

$$\text{Temperature, } ^\circ\text{C} = (\text{Cell U14}) * 0.0002068 + 80.083$$

The pressure in Cell U14 is copied from Cell AR12, which in turn converts the pressure input by the spreadsheet user in Cell AP12 (in units of psig) into units of Pascals.

2.3.21.2 Cells U17, U19, U26-U108, Composition Data

The composition data are copied from corresponding cells in Column V. The data in column V are copied from Column BF, where they are input by the spreadsheet user. The concentrations of radionuclide and inorganic compounds are values from and average of samples of the steam condensate (Loll 1990b).

2.3.21.3 Cell U24, Heat Content

The equation in Cell U24 calculates the heat balance around E-A-1 as follows:

$$\text{Joules/min} = ((\text{Steam flow, lb/min})(2326 \text{ Joules-lb/BTU-kg})) * (\text{enthalpy steam} - \text{enthalpy water})$$

Where enthalpy steam is a correlation for enthalpy around the temperatures expected in E-A-1: $h = .65069 \cdot ^\circ\text{C} + 1085.45$ and enthalpy water is a correlation : $h = 1.7973 \cdot ^\circ\text{C} + 0.1054406$

Values for steam flow, steam temperature, and water temperature are inputted from Cells U21, U11, and V11, respectively.

2.3.22 Column V, E-A-1 Reboiler Steam Condensate

The data for Column V are copied from Column BF. The data in Column BF are entered by the spreadsheet user as constants. Calculations are similar to those previously described.

2.3.23 Column W, Raw Water to E-C-1

2.3.23.1 Cells W8-W23, Physical Properties

The physical property data for the variables (temperature, flow, pH, etc.) previously discussed for the filtered raw water stream in Column E, Cells E8-E24 are similar to the data for Column W. The data are entered as constants by the spreadsheet user directly into Column W, or into Columns AL (for Cells 9 and 20), Column AP (for Cell 14) or Column BE where they are copied into the respective rows in Column W.

2.3.23.2 Cell W24, Heat Content

The equation in Cell W24 calculates the heat balance for raw water to E-C-1 as follows:

$$\text{Joules/min} = (\text{Joules/min condensate} + \text{Joules/min vapor}) (1 - \text{Cell AL24}/100)$$

Where the condensate and vapor data are inputted from Cells H24 and G24, respectively, and Cell AL24 is the percent heat loss to the room.

2.3.23.3 Cells W26-W379, Composition Data

The composition data for the filtered raw water for radionuclides, inorganic analytes, and organic analytes are entered by the spreadsheet user as constants into Column BE and are copied into Column W for use in spreadsheet calculations.

2.3.24 Column X, Raw Water to E-C-2

The raw water to E-C-2 is a parallel stream to the raw water to E-C-1, thus the properties and composition data described in Column W are the same for Column X except for Cell X24, Heat Content. The

equation in Cell X24 calculates the heat balance for raw water to E-C-2 as follows:

$$\text{Joules/min} = \text{Joules/min condensate} - \text{Joules/min vapor}$$

Where the condensate and vapor values are inputted from Cells I24 and J24, respectively.

2.3.25 Column Y, Raw Water to E-C-3

The E-C-2 and E-C-3 raw water cooling is connected in series, therefore the property and composition data are the same except for the increase in heat content which is calculated in Cell Y24, Heat Content. The equation in Cell Y24 calculates the heat balance for raw water to E-C-3 as follows:

$$\text{Joules/min} = \text{Joules/min condensate} - \text{Joules/min vapor}$$

Where the condensate and vapor values are inputted from Cells K24 and R24, respectively.

2.3.26 Column Z, Raw Water to B Pond

The properties and composition for Stream No. 24, the raw water to B Pond are given in Column Z. This stream is the combination of the raw water coolant streams from the E-C-1 and E-C-3 condensers. The data are the same for these streams as described under Columns W and X, except for the composition data and the heat content data. The composition data are the sum of the data for the two source streams less the amount of each analyte removed via leakage in the E-C-1 condenser. The equation in Cell Y24 calculates the heat balance for raw water to B Pond as follows:

$$\text{Joules/min} = \text{Water mass flow} * (\text{Outlet temperature} - \text{Inlet Temperature}) * 4186.8 \text{ Joules/Kg-}^{\circ}\text{C}$$

Where water mass flow, and temperatures are inputted from Cells Z21, Z11 and W11, respectively. The conversion factor, 4186.8 is the specific heat of water (equivalent to 1 BTU/lb- $^{\circ}\text{F}$).

2.3.27 Column AA, J-EC1-1 Steam

Column AA contains the properties for the steam entering the J-EC1-1 Steam Jet Ejector used to pull a vacuum on the Primary Condenser. The calculations are similar to previously described calculations with the following exceptions:

2.3.27.1 Cell AA11, Temperature

The steam temperature is calculated from a regression analysis equation developed around the pressures expected and uses the pressure from Cell AA14:

$$\text{Temperature, } ^\circ\text{C} = (\text{Cell AA14}) * 5.07 \text{ E-5} + 129.12139$$

The pressure in Cell AA14 is copied from Cell AM5, which in turn converts the pressure input by the spreadsheet user in Cell AL5 (in units of psig) into units of Pascals.

2.3.27.2 Cells AA17, AA19, AA26-AA108, Composition Data

The composition data are copied from Column BF, where they are input by the spreadsheet user.

2.3.27.3 Cell AA24, Heat Content

Cell AA24 calculates the heat transferred for steam passing through EC1 by subtracting the enthalpy of water from steam according to the equation:

$$\text{Joules/min} = (\text{Cell AA21, steam, Kg/min}) * (2326 \text{ Joule-lb/BTU-Kg}) * [(.40054 * ^\circ\text{C} + 1121.26) - (1.7973 * ^\circ\text{C} + .1054)]$$

Where $.40054 * ^\circ\text{C} + 1121.26$ is a regression analysis correlation of BTU/lb values for steam taken from Table 3-276 in Perry's Handbook (Perry, 1973) and $1.7973 * ^\circ\text{C} + .1054$ is a correlation for water around the operating temperature, in BTU/lb.

2.3.28 Column AB, J-EC1-2 Steam

Column AB contains the properties for the steam entering the J-EC1-2 Steam Jet Ejector used to pull a vacuum on the Inter Condenser. The calculations are similar to previously described calculations for Column AA.

2.3.29 Column AC, Air Inleakage to E-C-1, Stream 27

Air is added to control the vacuum in the C-A-1 Evaporator Vessel. The properties of this air, and the cell descriptions, are similar to those given in Column R, Stream 16 with the following exception:

The flow rate is input as data into Cell AL9 by the spreadsheet user and is used in Cell AC 23 to calculate mass flow.

2.3.30 Column AD, Spare

Column AD is a spare column; it was used in a previous generation of the spreadsheet for the vessel vent steam heater, a piece of equipment no longer used.

2.3.31 Column AE, Spare

Same as Column AD

2.3.32 Column AF, P-B-1 Pump Seal Water

The properties and composition of the P-B-1 Pump Seal water, which is filtered raw water, are the same as described in Columns W, X, Y, and Z, raw water to the condensers. The radionuclide, inorganic, and organic concentration data are an average of several raw water samples (Loll 1990a). A small portion of this water leaks through the pump seals at a leak rate input by the spreadsheet user into Cell AL19 where is used in Cell AF20.

2.3.33 Column AG, P-B-2 Pump Seal Water

The properties and composition of the P-B-2 Pump Seal water, which is filtered raw water, are the same as described in Columns W, X, Y, and Z, raw water to the condensers. The radionuclide, inorganic, and organic concentration data are an average of several raw water samples (Loll 1990a). A small portion of this water leaks through the pump seals at a leak rate input by the spreadsheet user into Cell AL21 where is used in Cell AG20.

2.3.34 Column AH, Tank C-100 Air Flow, Stream

The air that bleeds into the stack from Tank C-100 is modeled in Column AH. The properties are similar to those previously described in Columns J, Q, and R. The value for the air flow is input by the spreadsheet user into Cell AL36 in units of cubic feet per minute; this value is used in Cell AH23 where it is converted to mass flow. A description of the value for entering into Cell AL36 is given in the description of Column Q.

The radionuclide, inorganic, and organic components for this stream are in equilibrium with Stream 10. As with E-C-1, E-C-2, and E-C-3, the pure water partition coefficients and activity coefficients are used to calculate the equilibrium concentrations in the gas and liquid flows. The vapor temperature is assumed to be the same as the water temperature in Tank TK-C-100.

2.3.35 Column AI, Constants and Organic Partition Coefficients

2.3.35.1, Cells AI4-AN56, Table of Constants and

Formulae

A variety of constants for various process operating conditions such as flow rates, temperatures, vacuum, and pressures are input by the spreadsheet user into the Table of Constants beginning at Cell AI4. A descriptor for each constant makes it evident what the constant parameter and units are. A listing of these constants is given in Table 2.3.35A. Beginning at Cell AI49, a small table of conversion factors that are used in the spreadsheet are documented. Many of the factors are not used in routine engineering practice so their documentation at this location provides the spreadsheet user a handy reference for identifying constants that may not be familiar to the user. A listing of these conversion factors is given in Table 2.3.35B.

Table 2.3.35A
Table of Constants and Formulae

Water density = $-.0003184*(oC)+1.0048118$			
Steam pressure =	9.0e+01	psig =	7.2e+05 Pascals
Steam Temp. = $.0000507*Pa+129.12139$			Centigrade
J-EC1-1 Steam Flow Rate		6.8e+02	lb/hr
J-EC2-1 Steam FLOW Rate		7.5e+02	lb/hr
Air to control C-A-1 vacuum		2.5e+01	scfm
RW to E-C-1		3.5e+03	gpm
RW to E-C-2		8.0e+01	gpm
Steam to E-A-1		2.7e+04	lb/hr
Steam to H-C-1		0.0	lb/hr
Air to H-C-1 (FE AS-5)		6.5e+02	scfm
Feed flow to C-A-1		9.0e+01	gpm
Filtered RW (PAD SPRAY)		1.0e+03	lb/hr
Waste Volume Reduction		3.0e+01	%
C-A-1 Vacuum		5.0e+01	Torr
P-B-1 Seal water flow rate		1.5e-01	gpm

E-C-1 Water leakage rate		1.0e-02	gpm
P-B-2 Seal water flow rate		1.0e-01	gpm
PB-2 Pump Press.		5.0e+01	
E-C-1 Pressure drop		2.0e+01	Torr
Inst. Air into C-A-1		1.0e+00	CFM
Percent heat losses to room		1.0e+01	Percent
E-C-2 Pressure		8.0e-01	psia
E-C-3 Vacuum		1.0e+01	in. of H2O
F-C-1 Filter efficiency		9.5e+01	Percent
F-C-5 Filter efficiency		9.9e+01	Percent
E-101 Batch Size		3.4e+03	Gal
E-101 Temperature		7.0e+01	C
E-101 NaNO3 Molarity		1.0e+00	Moles/L
H-C-1 Differential Pressure		3.0e+00	in. H2O
F-C-5 Differential Pressure		4.0e+00	in. H2O
90Sr IX adsorbing eff.		9.5e+01	Percent
134Cs, 137Cs IX eff.		9.5e+01	Percent
Gas Flow, C-100 to Stack		6.0e+02	SCFM
Water Vap. Pressure Coeff.		5.7e-02	-1.4e+01
Alpha Hydrogen (G)		1.6e+00	Molecules/ 100-eV
Beta Hydrogen (G)		6.0e-01	Molecules/ 100-eV
Gamma Hydrogen (G)		4.5e-01	Molecules/ 100-eV
C-A-1 Volume		2.5e+04	Gal

Stack Vacuum at DU-C-1 Inlet (PI-DUC1-1)	1.2 16.32	Inches Mercury = Inches Water
Stack Temp. at HC1-1 Inlet	85	Degrees Fahrenheit
DU-C-1 Differential Pressure	3	Inches Water
Water boiling temp (oC)=18.42337*ln(pressure,Torr)-33.700954		
Water vapor density= m/V= P*M.W./RT, where n=m/M.W. = g/cc = (Torr/760 atm) (18g/mole) / ((82.1cc-atm/oK-mole) (273.15+oC))		

Table 2.3.35B
Table of Little Known Conversion Factors

1 mole gas = 22.4 Liters
1 atmosphere = 101325 Pascals
1 torr = 133.23 Pascals
1 torr = 1mm Hg
1 cu. ft. = 28.316 Liter
1 psi = 6894 Pascals

2.3.35.2 Cells AI190-AI377, Organic Partition Factors

The Organic Partition Factors, F_p , are calculated in Cells AI188-AI377 for each organic constituent. The partition factor, F_p , is the ratio of the concentration of an organic in the vapor phase to the concentration in the liquid phase at equilibrium as defined in the description of Cell D17. F_p is calculated in Cell AI190 according to the formula:

$$F_p = \frac{(\gamma) (P^{\circ}_i) (273)}{P}$$

$$(273 + T)(760)(22.4)(\text{moles/L water} + \text{moles/L salt}) \quad (\text{Eq. 1})$$

Where γ = the activity coefficient for a specific organic constituent, calculated in Cell BA190
 P_i^0 = The vapor pressure of the organic constituent, Calculated from constants located in Cells BB190 and BC190
 and 273 = The standard condition temperature, °K
 T = The operating temperature, °C obtained from Cell F11
 760 = The standard pressure, mm Hg
 22.4 = The volume of one liter gas at STP
 moles/L water = calculated in Cell AN190 by subtracting the g/L of salts from the total g/l of solution (obtained from the density in Cell D12) and dividing by the molecular weight of water, 18 g/mole
 moles/L salt = the molar sum of the individual salt constituents, from Cell CH 189

Equation 1 for the Partition Coefficient is derived as follow:

From Dalton's Law: $Y_i = P_i/P_t$ (Eq. 2)

Where Y_i = the mole fraction of component i in the vapor phase
 P_i = the vapor partial pressure of component i,
 and P_t = the total or operating pressure of the system

From Raoult's Law: $P_i = X_i * P_i^0$ for an ideal gas
 $= \gamma * X_i * P_i^0$ for a non ideal gas (Eq. 3)

Where X_i = the mole fraction of component i in the liquid phase

Combining Equations 2 and 3:

$$\gamma = \frac{Y_i * P_t}{X_i * P_i^0} \quad (\text{Eq. 4})$$

The molar concentration of component i in the vapor is:

$$\text{moles} = \frac{(\text{Conc. in mg/L})(1 \text{ g}/1000 \text{ mg})}{\text{Molecular Weight of i}} \quad (\text{Eq. 5})$$

The total moles in one liter of vapor is:

$$\text{moles} = \frac{1 \text{ Liter gas}}{(22.4 \text{ moles/L}) (760 \text{ torr}/P_t) ((273 + T)/273)} \quad (\text{Eq. 6})$$

The mole fraction of i in the vapor phase is:

$$Y_i = \text{Equation 5/Equation 6} \quad (\text{Eq. 7})$$

The molar concentration of component i in the liquid phase is:

$$\text{moles} = \frac{(\text{Conc. in mg/L}) (1 \text{ g}/1000 \text{ mg})}{\text{Molecular Weight of i}} \quad (\text{Eq. 8})$$

The total moles in one liter of liquid is:

$$\text{moles} = \text{moles of water} + \text{moles of salts} \quad (\text{Eq. 9})$$

$$\text{moles water} = \frac{((\text{Slurry Density from Cell D12, g/cc,} \times 1000 \text{ cc/L}) - \text{Total grams/L salts from Cell D189))}{18}$$

$$\text{moles of salts} = \text{The sum of the individual molar concentrations, from Cell CH189}$$

The mole fraction of i in the liquid phase is:

$$X_i = \text{Equation 8/Equation 9} \quad (\text{Eq. 10})$$

Let the concentration (mg/L in vapor) in Equation 5 be represented by the letter "G" and the concentration (mg/L in liquid) in Equation 8 be represented by the letter "L", then the ratio G/L is the same as the definition of F_p :

$$F_p = G/L$$

Next, divide Equation 7 by Equation 10:

$$\begin{aligned} Y_i/X_i &= \frac{(G/1000/MW) (22.4) (760/P_t) ((273+T)/273) (\text{Total Moles})}{L/(1000) (MW)} \\ &= \gamma P_i^\circ / P_t \quad (\text{From Equation 4}) \end{aligned}$$

Rearranging and canceling terms:

$$F_p = G/L = \frac{(\gamma) (P_i^\circ) (273)}{(273 + T) (760) (22.4) (\text{moles/L water} + \text{moles/L salt})}$$

Which is Equation 1.

The vapor pressure of each organic analyte, P_i° , in units of

Torr, is calculated from the equation:

$$P_i^o = \exp(A * (273 + T) + B) \quad (\text{Eq. 11})$$

Where:

A = A constant, which is entered by the spreadsheet user into Cell BB190 for use in Eq. 11
 B = A constant, which is entered by the spreadsheet user into Cell BC190, and
 T = Temperature, °C, obtained from Cell F11, or
 K = Temperature, °K, used only for acetone, difluorodichloromethane, and vinyl Chloride. All the other organics use only °C in this correlation.

See the description of the constants in Cells BB190-BB376 for the origin of these constants.

2.3.36 Column AJ, E-C-1 Condenser Organic Partition Factors

The organic partition factors, F_p , for the E-C-1 Condenser are calculated in Cells AJ190-AJ377 similar to as described for Cells AI190-AI377. The major differences are that the E-C-1 temperature is used and, since there are only trace quantities of salts present, only the moles of water (55.56) is used.

2.3.37 Column AK, E-C-2 Organic Partition Factors

Cell AK 5 is the steam pressure in psig entered by the spreadsheet user and is converted to Pascals in Cell AM 5, which in turn is used in Cells AA14 and AB14. Cells AK60 to AL70 contain an equation to calculate the hydrogen content in the E-C-3 Condenser vapor. The equation is the equilibrium equation calculating the hydrogen distribution between the liquid and vapor phases that is used in Cells F140 and J140 and discussed in detail in the description of Cell F140. The calculated value is used in Cell R140 where the hydrogen exiting the stack is calculated.

The organic partition factors for the E-C-2 Condenser are calculated in Cells AK190-AK377 the same as described for Cells AJ190-AJ377.

2.3.38 Column AL, E-C-3 Organic Partition Factors

Cell AL9 contains the value for air inleakage to control vacuum in the evaporator vessel, and is used in Cell AC23. Cell AL43

contains the estimated air temperature and is used in Columns R and AC.

The organic partition factors for the E-C-3 Condenser are calculated in Cells AL190-AL377 the same as described for Cells AJ190-AJ377.

2.3.39 Column AM, Anion Sums and Organic Partition Factors

2.3.39.1 Cells AM138-AM154, Anion Concentration Sum

Cells AM138-AM154 convert the value of the total of the anion constituents in the feed stream, obtained from Cell CK185 in units of moles/liter, to units of millimoles/liter.

2.3.23.2 Cell AM158, Feed Solution Density

Cell AM158 calculates the feed solution density using the following equation (Reynolds and Herting, 1984, p.24):

$$1.017 + 0.0587*(AlO_2^-) - 0.01943*(OH^-) - 0.000505*(Temperature) + 0.0459*(SIG) - 0.00088267*(NO_2^-)*(NO_3^-)$$

where the concentrations for the ions are obtained from Column CG and SIG is the sum of the concentrations of AlO_2^- , OH^- , NO_2^- , and NO_3^- .

2.3.39.3 Cell AM161, Heat Content

Cell AM161 calculates the heat content in Joules/min of the E-C-1 leaks:

$$\text{Joules/min} = (C_p)(\text{Cell A20, gal/min})(3.785 \text{ L/gal})(\text{Cell G11-Cell W11, } ^\circ\text{C})$$

Where the first term, $C_p = 1 \text{ BTU/lb-}^\circ\text{F} = 4186.8 \text{ Joules/Kg-}^\circ\text{C}$

The second term is the mass flow, Kg/min, and the third term is the stream temperature rise, $^\circ\text{C}$.

2.3.39.4 Cells AM175-AM176, Anion Concentration Sum

Cells AM175-AM176 repeat the calculation of summing the anion concentrations, in units of moles/liter, in the feed stream that are calculated in Cell CK185. Cells AM175-AM176 use the individual constituent concentrations in Cells C107-C188, while Cell CK185 uses the concentrations in Cells CG107-CG108. The

answers should be the same.

2.3.39.5 Cells AM190-AM377, Organic Partition Factors

The organic partition factors for Tank C-100 are calculated in Cells AM190-AM377 the same as described for Cells AJ190-AJ377.

2.3.40 Column AN, Cation Sums and Water Content

Cells AN138-AN154 convert the value of the total of the cation constituents in the feed stream, obtained from Cell CI185 in units of moles/liter, to units of millimoles/liter.

Cell AN190 calculates the moles/L water in the C-A-1 Evaporator Vessel by subtracting the g/L of salts (Cell D189) from the total g/l of solution (obtained from the density in Cell D12) and dividing by the molecular weight of water, 18 g/mole. The calculated value is used in Cell AI190.

2.3.41 Column AO, E-C-3 Vacuum

Cell AO42 contains the E-C-3 vacuum in inches. Data are input by the user using operating data (PI-DUC1-3).

2.3.42 Column AP, Misc. Pressures and Slurry Anions

2.3.42.1 Cells AP10-AP21, Miscellaneous Pressures

Cells AP10-AP21 contain pressures, in psig, to be used for various stream calculations such as for the raw water streams to the condensers. Data are input by the spreadsheet user and are copied to Columns W, X, Y, and Z where they are used for stream property data. The data are also converted to pascal units in Cells AR10-AR13.

2.3.42.2 Cells AP138-AP154, Slurry Anions

Cells AP138-AP154 convert the value of the total of the anion constituents in the slurry stream, obtained from Cell CL185 in units of moles/liter, to units of millimoles/liter.

2.3.43 Column AQ, Radionuclide Data, Hydrogen Generation and Cation Concentrations

2.3.43.1 Cells AQ23-AQ103, Radionuclide Data

Cells AQ23-AQ103 contain the half lives of the radionuclides in units of years.

2.3.43.2 Cells AQ112-AQ125

Cells AQ112-AQ125 sum the quantity, (uCi/ml)(MeV), for the radionuclide beta emitters, alpha emitters, and gamma emitters. The value for uCi/ml is obtained from the slurry concentrations in Column D and the value for MeV is obtained from the table in Column AR. The sums are used in Cell AQ126 to calculate the hydrogen generation rate in the C-A-1 vessel.

2.3.43.3 Cell AQ126, Hydrogen Generation

The hydrogen generation rate, in mg/min, within the C-A-1 vessel is calculated in this cell. The sum of the alpha, beta, and gamma emitter concentrations is multiplied by their respective G values, the result added, and this sum in turn is multiplied by the C-A-1 volume in liters and a constant, $7.4E-8$. The G values are stored as constants in Cells AL38, AL39, and AL40. A description of the derivation of the equation and the constant is given in the description of Cell D139.

2.3.43.4 Cells AQ128-AQ129, Hydrogen Generation

Cells AQ128-AQ129 convert the hydrogen generation rate calculated in Cell AQ126 to the hydrogen generation rate in the TK-AW-102 feed tank by multiplying by the volume ratios of the two vessels and the waste concentration factor. The value is used in Cell C139.

2.3.43.5 Cells AQ138-AQ154, Slurry Cations

Cells AQ138-AQ154 convert the value of the total of the cation constituents in the slurry stream, obtained from Cell CJ185 in units of moles/liter, to units of millimoles/liter.

2.3.44 Column AR, Pressure and Radionuclide Data

2.3.44.1 Cells AR10-AR13, Pressure Data

Cells AR10-AR13 contain absolute pressures, in pascals, to be used for various stream calculations such as the steam pressure in Column U. Data are input by the spreadsheet user into Cells AP10-AP13 in units of psig and are converted to pascal units in Cells AR10-AR13 by adding 14.7 and multiplying by the conversion factor 6894.8 Pa/psia.

2.3.44.2 Cells AR30-AR103, Radionuclide Energies

Cells AR30-AR103 contain the energies of the major beta/alpha emission and the major gamma emission for each radionuclide. These are used to calculate the hydrogen generation rates in Cells AQ112-AQ129.

2.3.45 Column AS, Radionuclide Names

Column AS, Cells AS30-AS103, repeats the radionuclide names for ease in scanning the half life and energies in Columns AQ and AR.

2.3.46 Column AT, Blank Column

2.3.47 Column AU, Blank Column

2.3.48 Column AV, Blank Column

2.3.49-50 Columns AW and AX, Constituent Labels

The constituent labels consisting of constituent names and concentration units from Columns A and B are repeated in Columns AW and AX for use with Column AY.

2.3.51 Column AY, Data Entry Column

2.3.51.1 Cell AY20, Feed Water Volume

Cell AY20 calculates the volume of the water in the feed solution from the mass flow of water in Cell AY21. The volume flow is corrected for temperature using a regression equation calculated from the known properties of water published in handbooks. The regression analysis is made on a standard hand calculator and takes the form:

$$H_2O, L/min = \frac{CellAY21}{-.003184 * temp, ^\circ C + 1.0048}$$

2.3.51.2 Cell AY21, Feed Water Mass Flow

Cell AY21 calculates the amount of water in the feed solution according to the equation:

$$H_2O, kg/min = \frac{(F, L/min) * (D, g/cc) * (1000 cc/L) - (I, mg/L) * \left(\frac{F, L/min}{1000 g/mg} \right)}{1000 g/kg}$$

Where

F = Feed solution flow

D = Feed solution density

I = Sum of inorganic constituent concentrations

2.3.51.3 Cells AY26-AY388, Typical Concentrations

Typical concentrations of the radionuclide, inorganic and organic constituents are entered into these cells by the spreadsheet user for use in initiating spreadsheet calculations. The values are copied by the spreadsheet to Column C for use in the calculations.

2.3.52 Column AZ, Molecular Weights

Column AZ contains the molecular weights of the inorganic analytes in Cells AZ105-AZ187.

2.3.53 Column BA, Ion Charges and Activity Coefficients

2.3.53.1 Cells BA105-BA187, Ion Charges

Cells BA105-BA187 contain the ion charges of the inorganic analytes.

2.3.53.2 Cells BA190-BA376, Activity Coefficients

The value of the activity constant for each organic analyte is calculated in Cells CJ190-CJ376 and CK190-CK376 using an empirical formula from the literature (Pierotti, 1959):

$$\log \gamma = A_{1,2} + B_2 * \frac{n_1}{n_2} + C_1 * \frac{1}{n_1} + D * (n_1 - n_2)^2 + F_2 * \frac{1}{n_2} \quad (\text{Eq. 1})$$

These values are then copied to Cells BA190-BA376 for use in calculating the organic Partition Coefficients in Cells AI190-AI376.

As an example, substituting in the correct constants for acetone, Equation 1 becomes:

$$\log \gamma = -1.475 + .622 * (3) + 0.5 * (1/2 - 1/2)^2 \quad (\text{Eq. 2})$$

and $\gamma = 7.78$

A complete listing of the constants is given in appendix A.

2.3.54 Column BB, C-A-1 Vapor Space Partition Coefficients

2.3.54.1 Cell BB16-BB187, Partition Coefficients

Cells BB16-BB187 contain the C-A-1 Vapor space partition coefficients, K_p , for TOC, TDS, the radionuclides, and the inorganic analytes. The values are used in Column D and F calculations. The values have been set to 1×10^7 for everything except TOC, H-3, Sr-90, Ru-106, Sn-113, I-129, Cs-134, Cs-135, Cs-137, Pu-238, Pu-239, Pu-240, Pu-241, Am-241, Am-243, AlO_2^- , NH_4^+ , Cl^- , Cr^{+++} , F^- , H_2 , Pb, NO_3^- , NO_2^- , K^+ , Na^+ , and SO_4^{--} .

Samples of solution and the vapor space above the solution in underground storage tanks provided the initial vapor and liquid phase compositions for radionuclide and inorganic species (Bendixsen, 1991). The solution concentration divided by the vapor concentration yields an estimate of the partition coefficient for the species. Operating data and literature information suggest a lower partition coefficient for condensate than for the higher salt solution in the vacuum evaporator vessel. The partition coefficients for the condensate flow come from correlating sample data of condensate receiver tanks with gaseous effluent data (Bendixsen, 1991). Where sample data are lacking, conservative partition coefficient values of 1×10^7 for salt solutions and 1×10^5 for condensate were used (Bendixsen, 1991).

The ammonia distribution value was obtained somewhat differently as follows. On page 6-8 of the original 242-A Evaporator SAR (SD-WM-SAR-023), it was stated that 90% of the ammonia in the feed is converted to gas with the remaining going out with the slurry. The ammonia in the gas phase is condensed in the E-C-1 Condenser and goes into the process condensate stream while about 1% of the feed value is not condensed and is released out the stack. The spreadsheet partition coefficient was adjusted until the spreadsheet calculated the above distribution. Subsequent data from Evaporator Run 94-2 shows that 3% to 9% of the feed stream concentration exits out the stack, so that the spreadsheet values are not completely accurate. For ammonia in particular, it may be necessary to incorporate a more complex calculated coefficient with variables such as concentration, solubility, and temperatures incorporated to replace the single constant now used.

Once the actual evaporator operating data become available, the spreadsheet user needs to update the values in these cells to match actual operating equipment and process conditions.

2.3.54.2 Cell BB141, Hydrogen Constants

The value in this cell is the first of two constants, (0.82541), used in the calculation described in Cell D137 for relating the

hydrogen concentration distribution between the liquid and vapor phases. It is not a true distribution constant, but is used to calculate a pseudo constant in Cell F142. The second constant used in this calculation, 4.45419, is in Cell BC141.

2.3.54.3 Cells BB190-BB376, Vapor Pressure Constants

The vapor pressure of each organic analyte is calculated from the equation:

$$P_i^{\circ} = \exp(A * (273 + T) + B) \quad (\text{Eq. 1})$$

Where:

- A = A constant for each organic analyte, which is entered by the spreadsheet user into Cells BB188-BB376
- B = A constant for each organic analyte, which is entered by the spreadsheet user into Cells BC188-BC376, and
- T = Temperature, °C, obtained from Cell F11, or
- K = Temperature, °K, used only for acetone, difluorodichloromethane, and vinyl Chloride. All the other organics use only °C in this correlation. Water also uses °K.

The equation is a standard regression analysis equation incorporated into engineering calculators (An HP-15C was used for this spreadsheet). The user enters known vapor pressure data over a range of interest and the constants are calculated. The user can then use the constants and Equation 1 to calculate the vapor pressure at any point within the valid range. The constants for each organic analyte have been calculated by R.B. Bendixsen from known vapor pressure/temperature data over the temperature range expected in the 242-A Evaporator (30 to 50 C) and entered into Cells BB190-BB376 for the first constant and Cells BC190-BC376 for the second constant. When Bendixsen could not find vapor pressures for a given organic analyte, he used an organic of similar molecular weight and structure as a substitute to estimate the pure component vapor pressure equation.

An example is shown below for water. The appropriate data for temperature and vapor pressure are obtained from the Perry's Chemical Engineering Handbook (Perry, 1973) as follows:

Temperature, C	Temperature, K	Vapor Pressure, mm Hg
22.1	295.22	20
34	307.12	40

41.5

324.62

60

The regression constants are then calculated as 0.056777 and -13.7611. They are entered into Equation 1 to calculate pressure as:

$$\text{mmHg} = \exp(0.056777 * (K) - 13.7611)$$

Checking this equation at 41.5 C, yields an answer of P = 60.5, which is very close to the published handbook value.

Another example, for Benzene, uses °C rather than °K:

Temperature, C	Temperature, K	Vapor Pressure, mm Hg
15.4	N/A	60
26.1	N/A	100
42.2	N/A	200

A = 0.04478 and B = 3.417. Substituting into the above equation:

$$\text{mmHg} = \exp(0.04478 * (C) + 3.417)$$

Checking at 15.4 C, yields and answer of P = 61.8

The regression analysis equation used for the pressure calculation, as described above, is of the form $P = \exp(Ax + B)$. Some checking of the equation immediately above shows fair correlation. However, other examples checked, such as acetone, did not show such good correlation. It would be in the interest in improving the spreadsheet in the future to convert the vapor pressure calculation to a correlation of the form $P = Ax + Bx^2 + Cx^3 + D$ or $P = A * x^B$ to obtain a better fit. The latter correlation for acetone resulted in an equation $P = (8.1473 \times 10^{-30}) (T^{12.702})$ which provided a linear fit over the entire range. Perhaps a more standard approach would be to use the Antoine Equation as presented in Section 10-31 of Lange's Handbook of Chemistry (Dean, 1973). The Antoine Equation is of the form $\log_{10} P = A - B/(C + ^\circ C)$ and when this equation is not applicable, an equation of the form $\log_{10} P = -52.23B/^\circ C + C$ is used. The constants for both equations are in the handbook.

2.3.55 Column BC, E-C-1 Condensate Partition Coefficients

2.3.55.1 Cells BC16-BC187, Condensate Partition Coefficients

Cells BC16-BC187 contain the E-C-1 vapor space coefficients. See Cells BB16-BB187 for descriptions. The values are used in Column G and H calculations. As in Column BB, these constants need to be adjusted once operating data become available.

2.3.55.2 Cell BC141, Hydrogen Calculation

Constant

The value in this cell is the second of two constants, 4.45419, used in the calculation described in Cell D141 for relating the hydrogen concentration distribution between the liquid and vapor phases. It is not a true distribution constant, but is used to calculate a pseudo constant in Cell F142. The first constant used in this calculation, 0.82541, is in Cell BB141.

2.3.55.3 Cells BC190-BC376, Second Vapor Pressure Constant

See the above description for Column BB for the First Vapor Pressure Constant. The second constant from the regression analysis, B, is entered into these cells.

2.3.56 Column BD, 242-A Stack and Condensate Decontamination Factors

The cells in Column BD calculate the decontamination factor for each analyte and radionuclide by dividing the concentration in the slurry by either it's concentration in the stack air or by it's concentration in the evaporator condensate in alternating cells.

2.3.57 Column BE, Raw Water Data

The composition data for the filtered raw water for radionuclides, inorganic analytes, and organic analytes are entered by the spreadsheet user into Column BE and are copied into Columns E, W, X, and Y for use in spreadsheet calculations. The radionuclide, inorganic, and organic concentration data currently entered are an average of several raw water samples (Loll 1990a).

2.3.58 Column BF, Steam Condensate Data

The composition data for the steam condensate water for radionuclides, inorganic analytes, and organic analytes are entered by the spreadsheet user into Column BF and are used in Columns U, V, AA, and AB for use in spreadsheet calculations for steam; this assumes the steam has the same mass quantity of each analytes as does the condensate. The concentrations of

radionuclide and inorganic compounds are values from an average of samples of the steam condensate (Loll 1990b).

2.3.59 Column BG, Blank Column

2.3.60 Column BH, Blank Column

2.3.61 Column BI, Chemical and Radionuclide Identification

Column BI is the first of a block of columns containing data from analyses of the contents of several DSTs. Column BI contains the names of the nuclide and chemical species.

2.3.62 Column BJ, Specie Units

Column BJ contains the units for the chemical and radionuclide species concentration values listed in Columns BK-BT.

2.3.63 Column BK, DSSF Tank Composition

Column BK contains an analysis of a DST containing Double Shell Slurry Feed as reported in Document WHC-SD-WM-PSE-008. This analysis is not used in the spreadsheet, but is there for reference.

2.3.64 Column BL, DSS Tank Composition

Column BL contains an analysis of a DST containing Double Shell Slurry as reported in Document 65959-87-720Starr. This analysis is not used in the spreadsheet, but is there for reference.

2.3.65 Column BM, Tank AN-103 Analyses

Column BM contains the composition of the chemicals and radionuclides in DST AN-103 as reported in Document WHC-SD-WM-TI-355 (Hendrickson, 1990). This tank was one of three tanks characterized for feed for the first Grout campaign. The other two tanks characterized for the grout campaign were AN-106 and AW-101; their compositions are given in columns BN and BO. The data are not the adjusted grout source term data given in Section 2 of Hendrickson, 1990, but are obtained from the raw data on pages 33-35 of the referenced document and adjusted for this spreadsheet by multiplying by the density (1.6 g/ml for Tank AN-103, 1.2 g/ml for Tank AN-106) to get into units of mg/L. The data for the three tanks are averaged in Column BR and the standard deviation calculated in Column BS for each specie. Since the contents of these tanks is either DSS or DSSF, they were considered typical of the slurry stream from the evaporator and were used in the FSAR for illustration of the spreadsheet. These

values are the same values that the original spreadsheet contains in Column D for the slurry stream as described and documented in the FSAR (Lavender, 1992). These tank analyses are to be retained in the spreadsheet for reference should the user wish to compare runs before and after spreadsheet modifications or for other reasons. It should be noted that the spreadsheet has been updated and corrected in several locations so that the calculated values using these tank analyses will not always agree with the previous values reported in the FSAR.

The final data manipulation on these tank analyses is done in Column BT where the slurry values are "adjusted" to be used as values for the spreadsheet feed stream composition. These data are then either copied to Column AY or C for initiation of the spreadsheet calculations. The adjusting was accomplished by multiplying the values in Column BR by 0.7 to arrive at what the feed composition should have been for a 30% volume reduction. These feed compositions were then adjusted in until the spreadsheet produced answers for the slurry composition in Column D matching the slurry values in Column BR. These were then used for the example calculations in the FSAR (Lavender, 1990, p.6A-4). This discussion is more of a historical nature than for future calculations since actual feed analyses are to be used in the future.

2.3.66 Column BN, Tank AN-106 Analyses

Column BN contains the second of the three grout feed tank analyses. See Column BM for description.

2.3.67 Column BO, Tank AW-101 Analyses

Column BO contains the third of the three grout feed tank analyses. See Column BM for description.

2.3.68 Column BP, Raw Water Data

Column BP repeats from Column BD the composition data for the raw water.

2.3.69 Column BQ, Blank Column

2.3.70 Column BR, Average Grout Feed Tank Composition

Column BR contains the average composition of the three feed tank compositions listed in Columns BM, BN, and BO. See Column BM for description.

2.3.71 Column BS, Grout Feed Composition Standard Deviation

Column BS contains the standard deviation of the compositions of the three grout feed tanks listed in Columns BM, BN, and BO. See Column BM for description.

2.3.72 Column BT, Adjusted Feed to C-A-1

Column BT contains an artificial feed composition based on the grout feed composition in Column BR that would produce an evaporator slurry matching the grout feed composition. See Column BM for description.

2.3.73 Column BU, Blank Column

2.3.74 Column BV, Blank Column

2.3.75 Column BW, Blank Column

2.3.76 Column BX, Parameter Identification

Column BW is the first column of a block of columns that conveniently relocates the key information of the overall material balance for the evaporator (feed, slurry, condensate, stack gas, raw water effluent and E-A-1 condenser streams) so that the spreadsheet user can print the values of these streams in one block. Column BW contains the identification (name) of each parameter in the columns.

2.3.77 Column BY, Parameter Units

Column BY contains the units for the parameter listed in Column BX.

2.3.78 Column BZ, Feed Stream Composition

Column BZ repeats the feed stream composition information from Column C. In order for the spreadsheet user to put current Column C information into Column BZ, the following Lotus 123+ operations must be done:

- (1) Unprotect the area in Column BZ to which the data are to be transferred using the /Range, Unprotect commands and use the down arrow or page down keys to mark the range desired.
- (2) At Column C, use the /Range, Value commands and use the down arrow or page down keys to mark the range desired. Go to Column BZ and enter the data. This will put the data in numeric format suitable for printing while if the Copy command was used the formula would be copied giving the wrong information.

2.3.79 Column CA, Slurry Stream Composition

Column CA repeats the slurry stream composition information from

Column D. See Column BZ for instructions on how to enter the data into this column.

2.3.80 Column CB, Condensate to LRF Stream Composition

Column CB repeats the Condensate to LRF stream composition information from Column M. See Column BZ for instructions on how to enter the data into this column.

2.3.81 Column CC, Stack Gas Stream Composition

Column CC repeats the Stack Gas stream composition information from Column T. See Column BZ for instructions on how to enter the data into this column.

2.3.82 Column CD, Raw Water to B Pond Stream

Column CD repeats the Raw Water to B Pond stream composition information from Column Z. See Column BZ for instructions on how to enter the data into this column.

2.3.83 Column CE, E-A-1 Condenser Stream Composition

Column CE repeats the E-A-1 Condenser stream composition information from Column G. See Column BZ for instructions on how to enter the data into this column.

2.3.84 Column CF, Blank Column

2.3.85 Column CG, Feed Stream Molar Composition

Column CG calculates the composition of the feed stream in units of moles/liter for each inorganic analyte using the equation:

$$\text{mole/L} = (\text{mg/L}) / 1000 / \text{molecular weight}$$

where the concentration in mg/L is obtained from column AY and the molecular weight from column AZ. The values are summed in Cell CG189.

2.3.86 Column CH, Slurry Stream Molar Composition

Column CH is the same as Column CG, except the slurry stream is used. The values are summed in Cell CH189.

2.3.87 Column CI, Sums of Feed Stream Cations

Cell CI185 sums the total cations in the feed stream, in units of moles/liter, from the individual constituents in cells CG105-CG188. The value is used in cells AN138-AN151.

2.3.88 Column CJ, Logarithm of Organic Activity Coefficient

2.3.88.1 Cell CJ185, Sums of Slurry Stream Cations

Cell CJ185 sums the total cations in the slurry stream, in units of moles/liter, from the individual constituents in Cells CH105-CH188. The value is used in Cells AQ138-AQ151.

2.3.88.2 Cells CJ190-CJ376, Logarithm of the Activity Coefficient

The value of the logarithm of the activity constant for each organic analyte is calculated in Cells CJ190-CJ376 using an empirical formula from the literature (Pierotti, 1959):

$$\log \gamma = A_{1,2} + B_2 * \frac{n_1}{n_2} + C_1 * \frac{1}{n_1} + D * (n_1 - n_2)^2 + F_2 * \frac{1}{n_2} \quad (\text{Eq. 1})$$

These values are first converted from logarithm of the activity coefficient to the coefficient value in Cells CK190-CK376, then copied to Cells BA190-BA376 for use in calculating the organic Partition Coefficients in Cells AI190-AI376.

As an example, substituting in the correct constants for acetone, Equation 1 becomes:

$$\log \gamma = -1.475 + .622 * (3) + 0.5 * (1/2 - 1/2)^2 \quad (\text{Eq. 2})$$

and $\gamma = 7.78$

2.3.89 Column CK, Organic Activity Coefficients

2.3.89.1 Cell CK185, Sum of Feed Stream Anions

Cell CK185 sums the total anions in the feed stream, in units of moles/liter, from the individual constituents in Cells CG105-CG188. The value is used in Cells AM138-AM151.

2.3.89.2 Cells CK190-CK376, Organic Activity Coefficient

Cells CK190-CK376 calculate the values of the activity

coefficients for the organic constituents by taking the antilog of the values for the logarithm of the activity coefficients in Column CJ using the equation $\gamma = 10^{\text{Log}\gamma}$. These values are used in Cells BA190-BA376 for calculating the partition coefficients.

2.3.90 Column CL, Organic Specie Molecular Weights

2.3.90.1 Cell CL185, Sums of Slurry Stream Anions

Cell CL185 sums the total anions in the slurry stream, in units of moles/liter, from the individual constituents in Cells CH105-CH188. The value is used in Cells AP138-AP151.

2.3.90.2 Cells CL190-CL376, Organic Constituent Molecular Weights

Cells CL190-CL376 contain the molecular weights of the organic constituents for use in calculating the activity coefficients.

3.0 OPERATION OF THE SPREADSHEET

3.1 PROTECTION FEATURES

Two protection features are employed with the spreadsheet in order to preserve inadvertent erasure of the file or contents. The first protection feature is a DOS protection - the file has been converted to a "Read only" file using the DOS attributes command. This allows the file, which is named FSARREV3.WK3, to be copied or read into memory but it cannot be deleted or changed and then saved in replacement of the existing file. If these operations are desired, the file, while in DOS, needs to have the "R" removed from its attribute designation. This can be done with an editing utility, such as Directory Magic or PCTools, which reveals the attributes or it can be done from DOS. When a directory command is performed in DOS, the screen does not give the information about the attributes. Typing "attrib" does give this information however. To remove the "R" using DOS, type "attrib -R [path, filename] where path is the drive and directory in which the file resides, and the filename is FSARREV3.WK3.

The second protection feature resides within the Lotus spreadsheet. The Lotus version in which the spreadsheet currently is used is 123 Version 3.1Plus. Descriptions of the spreadsheet operation in this document will thus be those of Version 3+. Other spreadsheets can be used, such as Quattro Pro or Excel, but some commands may differ. Most other spreadsheets will load in the Lotus spreadsheet directly but some older versions may require that the import command be invoked to load. The protection feature prevents the user from making changes within individual cells. This feature is invoked or revoked by using the Lotus command "Range, Protect (or Unprotect)", and selecting the cells for which the protection is to be added or removed.

The protection feature in Lotus Version 3+ may also be invoked by using the Lotus commands "Worksheet, Global, Protect". Both of these Lotus protection features may be invoked.

It is suggested that the user of the spreadsheet maintain a protected copy and a working copy. Should the working copy inadvertently be wiped out or in some manner it hangs up, the user always has the protected copy to start over with.

3.2 DATA ENTRY

The data are conveniently entered into the spreadsheet by placing the new data into the cells in Column AY. The parameter name and the units for each parameter are in the two columns to the left of the data entry column for reference; these are the same as in

Columns A and B. The radionuclide data are entered in units of uCi/ml, the inorganic constituents in units of mg/L, and the organic constituents in units of mg/L. The spreadsheet will then transfer these data to Column C upon invoking the Calculate command (F9) and update all the calculations in the spreadsheet to reflect the new data.

If the flow data, temperature data, pressure data, etc. are to be changed, these changes are also done in Column AY at Rows 7 through 23.

If the user is combining data from several sources as the feed term, it is suggested that the labels in Columns AW and AX be copied to an area outside the existing spreadsheet, i.e., to the right of Column CL, and any data entry and manipulation, such as averaging, be done there. These combined data can then be simply copied to Column AY for incorporation into the spreadsheet.

3.3 CONSTANT(S) REVISIONS

Most of the constants that pertain to the evaporator operation are located in Column AL. These are seldom changed, but can be readily changed if evaporator operating conditions are modified.

The chemical constants are located in various locations. Radionuclide constants are located in Columns AQ, AR, and AS; there should be little need to change these constants. The partition coefficients for the radionuclides and inorganic analytes are given in Columns BB and BC. One of the initial tasks of the spreadsheet user will be to compare the data for these constants in the original spreadsheet versions and update them once actual data from evaporator operation become available. The constants from which the organic analyte activity coefficients are calculated are also given in Columns BB and BC. These constants are taken from Chemistry Handbooks and are fairly reliable but should also be checked against actual operating data during spreadsheet validation. As with the evaporation operating constants, the chemical constants can be readily changed after removing the cell protection feature.

3.4 PRINTING

Printing is readily performed using the conventional Lotus 123 printing conventions. The user first needs to make sure he has loaded the proper drivers for his particular printer, and has selected the correct ports (Print, Printer, Options, Advanced, Device). From the Command Line menu, enter Print, Select Printer to instruct the output to go to the printer, select the Range on the spreadsheet for printing, then select Go. The use of compressed print allows the user to place more columns on the printout which makes reading more convenient since the

spreadsheet is so wide. This is invoked by entering the commands Print, Printer, Options, Setup then entering the \015 code. For most cases, only the summary columns, Columns BX through CE, should be printed.

3.5 SPECIFIC OPERATIONS/CALCULATIONS

The Lotus spreadsheet allows the user to select either automatic recalculation of all values whenever a data entry is made or manual operation. The flowsheet model is set for manual recalculation. This is because for most cases the user will be changing several data values or constants at a time and if automatic recalculation is used the time it takes to recalculate each entry is so long that it becomes maddening before the job is completed. With manual recalculation, several entries may be made and when the data entry job is finished, the user hits the F8 key for manual recalculation and has to wait only once.

4.0 REFERENCES

Allison, J.M., 1985, Computer Prediction of Evaporator Operation, SD-WM-ADO-004, Rockwell Hanford Operations, Richland, Washington

Bendixsen, R.B., 1990, 702-A Ventilation System Flowsheet, WHC-SD-WM-TA-020, Westinghouse Hanford Company, Richland, Washington

Bendixsen, R.B., 1991, 242-A Evaporator/Crystallizer Flowsheet, WHC-SA-1390-FP
Westinghouse Hanford Company, Richland, Washington

Dean, John A., 1973, Lange's Handbook of Chemistry, Eleventh Edition, McGraw-Hill Book Company, New York, NY

Denaro, A.R., and G.G. Jayson, 1972, Fundamentals of Radiation Chemistry, p. 130, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan

DOE-RL, 1990, 242-A Evaporator Dangerous Waste Permit Application, DOE/RL-90-42, Rev 0, Appendix 3E, U.S. Department of Energy-Richland Operations Office, Richland, Washington

Eguchi, W., et al., 1973, Dependency of Partition Equilibrium of Iodine Between Air and Aqueous solution Containing Sodium Hydroxide Upon Temperature and Concentration, Journal of Chemical Engineering of Japan, Vol. 6, No. 5, 1973, pp. 389-396

Hendrickson, D.W., 1990, Methods and Data for Use in Determining Source Terms for the Grout Disposal Program, WHC-SD-WM-TI-355, Rev. 1, Westinghouse Hanford Company, Richland, Washington

Lavender, J.C., 1992, 242-A Evaporator/Crystallizer Safety Analysis Report, WHC-SD-WM-SAR-023 REV 1, Westinghouse Hanford Company, Richland, Washington

Loll, C.M., 1990a, 242-A Evaporator Cooling Water Stream-Specific Report, WHC-EP-0342-21, Addendum 21, Westinghouse Hanford Company, Richland, Washington

Loll, C.M., 1990b, 242-A Evaporator Steam Condensate Stream-Specific Report, WHC-EP-0342-26, Addendum 26, Westinghouse Hanford Company, Richland, Washington

Perry, C.H., and C.H Chilton, 1973, Chemical Engineers Handbook, 5th Edition, p. 3-97, McGraw-Hill Book Company, New York, New York

Perry, C.H., and C.H Chilton, 1973a, Chemical Engineers Handbook, 5th Edition, pp. 3-96,-97, McGraw-Hill Book Company, New York, New York

Perry, C.H., and C.H Chilton, 1973b, Chemical Engineers Handbook, 5th Edition, p. 3-135, McGraw-Hill Book Company, New York, New York

Pierotti, G.J., et al., 1959, Activity Coefficients and Molecular Structure, Industrial and Engineering Chemistry, Volume 51, No. 1, pp. 95-102.

Reynolds, D.A., and D.L. Herting, 1984, Solubilities of Sodium Nitrate, Sodium Nitrite, and Sodium Aluminate in Simulated Nuclear Waste, RHO-RE-ST-14 P, Rockwell International, Richland, Washington