User's Guide for Waste Tank Corrosion Data Model Code

**D. B. Mackey
J. R. Divine**

December 1986

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

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 Battelle Memorial Institute, nor any of their employees, makes any warranty, expressed 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 of any agency thereof, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or Battelle Memorial Institute.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NTIS Price Codes
Microfiche A01

Printed Copy

Pages	Price Codes
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A010
226-250	A011
251-275	A012
276-300	A013

USER'S GUIDE FOR WASTE TANK
CORROSION DATA MODEL CODE

D. B. Mackey
J. R. Divine

December 1986

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

ACKNOWLEDGMENTS

The contribution of D. J. Bates and W. M. Bowen to the program and the report are gratefully acknowledged.

ABSTRACT

Corrosion tests were conducted on A-516 and A-537 carbon steel in simulated Double Shell Slurry, Future PUREX, and Hanford Facilities wastes. The corrosion rate data, gathered between 25 and 180°C, were statistically "modeled" for each waste; a fourth model was developed that utilized the combined data.

The report briefly describes the modeling procedure and details on how to access information through a computerized data system. Copies of the report and operating information may be obtained from the author (DB Mackey) at 509-376-9844 or FTS 444-9844.

CONTENTS

ACKNOWLEDGMENTS.	iii
ABSTRACT	v
TANK CORROSION MODEL PROGRAM	1
INTRODUCTION	1
Hypothesized Model Form	5
Data Analysis	6
INTERPRETING THE FITTED MODELS.	8
A COMPUTER PROGRAM FOR PREDICTING CORROSION RATES	11
INTRODUCTION	11
PROGRAM OPERATION	11
PROGRAM LIMITATIONS.	13
REFERENCES	14

TANK CORROSION MODEL PROGRAM

INTRODUCTION

Corrosion tests of tank construction material in support of construction and operation of double shell waste storage tanks at Hanford were initiated over the range of compositions and temperatures expected during waste storage. The major emphasis was placed on temperatures at or below 100°C because that was the primary operating range. However, tests up to at least 177°C were performed because that was the nominal design temperature at which corrosion rates were not to exceed one mil per year.

The experimental data were analyzed and used to generate "models." The models are statistical in nature with no attempt to describe the physical interaction.⁽¹⁾

This report briefly describes how the prediction models were set up and how to access the computer code used in conjunction with the corrosion rate prediction model. The models include the A-516 alloy steel used in the older single shell tanks as well as the A-537 alloy steel used currently on double shell tanks. Three types of wastes are modeled separately using different compositions and ranges of compositions to simulate Double Shell Slurry waste, Future PUREX waste, and Hanford Facilities waste, as shown in Tables 1 to 3. A fourth comprehensive model was developed using the combined corrosion data collected for each of the above types of waste.

This code was developed by the staff of Pacific Northwest Laboratory's (PNL) Statistics Section based on corrosion tests conducted for Rockwell Hanford and the U.S. Department of Energy High-Level Waste Program by the Corrosion Research and Engineering Section of PNL. The models were constructed based on a computer-aided designed regression experiment using a matrix of weight-loss data (converted to corrosion rates) generated as a function of a series of tank waste compositions.

The program and data are available on a Hewlett-Packard 100D minicomputer; a minimum knowledge of H-P's RTE 6/VM operating system is necessary to access the program. Presently a program called TNFIN is the only program available from a remote terminal, and its output is in tabular form.

TABLE 1. Double Shell Slurry Composition Range

	COMPOSITION Range (MOLARITY) <u>Low - High</u>
OH^-	0.5 - 10.0
NO_3^-	1.0 - 8.0
NO_2^-	0.2 - 10.0
AlO_2^-	0.0 - 5.0
CO_3^{--} (2 fixed values)	0.2 or 0.25
PO_4^{--}	0.0 - 2.0
EDTA/HEDTA	0.0 - 1.0
Citrate (3 fixed values)	0.0, 0.2, or 0.6
SO_4^{--}	0.05

TABLE 2. Range of Composition of Future PUREX Waste

<u>Waste</u>	<u>OH^-</u>	<u>Al^{a}</u>	<u>NO^-</u>	<u>NO_2^-</u>	<u>CO_3^{--}</u>	<u>SO_4^{--}</u>	<u>Cit^{b}</u>	<u>F^-</u>	<u>K^+</u>
PUREX Sludge	.2-.8	-	.01-.05	.01-.05	.01-.05	s	-	1-1.5.	2-.5
Declad. Slurry	3.-8.	-	.2-.5	-	s	s	-	s(<1.)	2.-3
CAW (Opt. A)	3.-.8	-	.2-.5	-	s	s	-	.1-.2	-
CAW (Opt. B)	.001-.1	.5-1.	3.-s	1.-2.	-	s	1.-2.	.15-.3	-
CAW (Opt. C)	.5-1.	.5-.1	3.-s	1.-2.	s	s	-	.15-.3	-

TABLE 3. Hanford Facilities Waste Composition Range

OH^-	0.0001 - 2 M
NO_2^-	0 - 0.01
$\text{PO}_4^{=}$	0 - 5
$\text{SO}_4^{=}$	0 - 2.9

The three dimensional plots like the example shown in Figure 1 are based on the regression model. The plotting programs using the regression models currently are only available using the graphics terminals that are connected directly to the minicomputer.

For future use, the actual weight-loss data for the coupons are also stored on the computer utilizing H-P's "IMAGE" Database Management System. The design of the matrix for the tests, because of the number of possible input variables, produces a sparsely populated matrix of data. There has been no effort to date to graph the test results directly from the data base. As the system is expanded in the future, these data and other corrosion data may be used to form a more generalized corrosion data base.

The use of computer-aided design techniques for regression experiments is a significant advance over the more restrictive classical experimental designs (for example, factorial designs and special purpose response surface designs). The AODEXC computer program at PNL incorporates the methods described by Wynn⁽²⁾ and St. John and Draper⁽³⁾ for constructing optimal regression experimental designs. This is especially useful in designing corrosion experiments, where solubilities or other factors require the use of variable composition levels.

Because the range of concentrations of each chemical is continuous, the number of possible compositions is infinite. The classical factorial design approach would be to define three concentration levels (low, medium, and high concentrations) for each minor chemical. With five chemicals at three levels and three chemicals at two levels, the number of possible compositions is $3^5 \cdot 2^3 = 1944$. However, because a polynomial equation can be written to represent the data, it is not necessary to include all 1944 compositions in

FIGURE 1. Double Shell Slurry Predictor Model

the study. Also, practical considerations such as available facilities, manpower, time and budget dictated an upper limit of 40 compositions.

Hypothesized Model Form

For the construction of a computer-aided environmental design, a hypothesized prediction model with unknown parameters corresponding to "major" and "minor" chemicals is required. The major chemicals are those which are expected to influence the corrosion rate. The effective concentration levels of the major chemicals appear in the hypothesized model as linear (or first order) terms, quadratic (or second order) terms, and mixed quadratic terms (products of all possible pairs). The minor chemicals are expected to have little or no effect on the corrosion rate. The effective concentration levels of the minor chemicals appear in the hypothesized model only as linear terms.

The Future PUREX (FP) waste is used as an example of the design process. For the FP waste, there are five major chemicals and three minor chemicals. Thus, the hypothesized polynomial model for a specified composition is given by

$$y = a + \sum_{i=1}^8 b_i X_i + \sum_{i=1}^5 c_i X_i^2 + \sum_{i=1}^5 \sum_{j < i} d_{ij} X_i X_j + e,$$

where:

- y is the measured value of the corrosion indicator (e.g., corrosion rate in mils/year) for a specified composition,
- $X_1, X_2, \dots, X_5$ are the effective concentration levels of the major chemicals,
- X_6, X_7, X_8 are the effective concentration levels of the minor chemicals,
- $a, b_i, c_i,$ and d_{ij} are 24 unknown constants (parameters) that will be estimated from the experimental data,
- e is a random component due to the nonreproducibility of y when replicate experiments are performed using a specified composition. Details of this model and justification for its use have been given previously.⁽¹⁾

Data Analysis

Prior to actual model development, the data were transformed and coded based on observed corrosion rates (expressed as mils/year [mpy]) of the form

$$\ln mpy = \ln (mpy + 1.25)$$

The natural log transformation is a variance stabilizing procedure that was deemed necessary for this data due to an observed increase in corrosion variability with increased corrosion rates. The modeling procedure assumes that the variability in corrosion rates is approximately constant over all test conditions. The addition of 1.25 made all transformed values greater than zero.

The chemical compositions were coded by subtracting the approximate mid-range of the levels that occurred in the tests from each value and dividing by approximately one-half of the range. This helps protect against computer round-off error which can be a significant problem, especially with a data base of this size, the range of compositions that were used, and the use of polynomial models that require many multiplications. The resulting coded values are basically in the interval of -1 to 1. For the unified model, the actual codings for each composition are:

$$c0 = (\log_{10}(OH) + 1) / 3$$

$$c1 = (Al - 1.8) / 1.8$$

$$c2 = (NO_3 - 3.75) / 3.75$$

$$c3 = (NO_2 - 4) / 4$$

$$c4 = (Complex - .5) / .5$$

$$c5 = (F - .5) / .5$$

$$c6 = (CO_3 - .1) / .1$$

$$c7 = (PO_4 - 2.5) / 2.5$$

$$c8 = (SO_4 - 1.5) / 1.5$$

$$c9 = (Citrate - 1).$$

Exposure temperature and hours of exposure were also coded so that the values have minimum and maximum of approximately -1 and 1, respectively. The codings for the unified models are:

$$t1 = (\text{Temperature} - 100) / 75$$

$$h1 = (\text{Hours} - 5800) / 3000.$$

Because some chemical constituents did not appear in each waste type, it was not possible to use every cross product term in the model.

If a particular chemical constituent did not appear in the compositions for a particular waste type, it was given a value of zero prior to coding for all data of that waste type.

The initial polynomial model consisted of the following 372 terms:

- Intercept - 1 term
- Chemical Composition Terms - 30 terms:

Simple Linear Terms - $c_0 c_1 c_2 c_3 c_4 c_5 c_6 c_7 c_8 c_9$ - 10 terms

Pure Quadratic Terms - $c_0c_0 c_1c_1 c_2c_2 c_3c_3 c_4c_4 c_5c_5$ - 6 terms
(considered to be major constituents)

Cross Product Terms - $c_0c_1 c_0c_2 c_0c_3 c_0c_4 c_0c_5$ - 14 terms

$c_1c_2 c_1c_3 c_1c_4 c_1c_5$

$c_2c_3 c_2c_4 c_2c_5$

$c_3c_4 c_3c_5$

[Complex(c_4) and F(c_5) never occurred together]

- Temperature and Time Terms - 11 terms:

Simple Linear Terms - $t_1 h_1$ - 2 terms

Pure Quadratic Terms - $h_2 t_2 t_3$ - 3 terms

Cross Product Terms - $t_1h_1 t_2h_1 t_3h_1 t_1h_2 t_2h_2 t_2h_3$ - 6 terms

- Cross Products of Composition With Temperature and Time - 330 terms:

Each of the 30 chemical composition terms multiplied by each of the 11 temperature and time terms.

A model with so many terms in it can be expected to include some that do not add significant information and could be discarded without degrading the predictive capability of the equation; that is, a smaller subset of terms is probably adequate. To select an adequate subset of the terms, a stepwise regression procedure was used. The BMDP Statistical Software Program P2R - Stepwise Regression with the FSWAP option was used for this purpose. In this procedure, two options were set which control the program's progress. One is F-to-enter which defines the minimum F-statistic a term must have to enter into the model, while F-to-remove defines the minimum F-statistic a term must maintain to remain in the model. For these models, F-to-enter and F-to-remove, both were set at 1, which is approximately equal to a significance level of 0.25. The stepwise program then proceeds by selecting the term, not already in the model, that has the highest F-statistic and meets the F-to-enter criteria. Because many of the terms are correlated, adding a term to the model changes the F-statistic for each of the terms already in the model. The program then removes the term in the model with the lowest F-statistic if it does not meet the F-to-remove criteria; this is repeated until all "nonsignificant" terms are removed from the model. The program then repeats all of these steps until all terms that meet the criteria to enter the model have been entered.

This procedure was applied separately to each of the alloys. For example, for the A-537 data, a model with 75 terms was chosen with an R^2 value of 0.56 (R^2 is the percent of the variability in the observed corrosion rates accounted for by the selected model). Similar techniques were applied to the individual waste types to generate specific models for each.⁽¹⁾

The equation generated for the A-537 alloy is given in Table 4. Equations for other models are similar but have more or fewer terms than this.

INTERPRETING THE FITTED MODELS

Several precautionary statements need to be made about attempts to interpret the values of coefficients for terms in the models. First, most of the boundaries of the experimental region are determined by limitations on the "nominal" levels of the ten anions in a chemical solution. That is, because of solubilities and saturation, some of the anions which may be added

TABLE 4. Prediction Equation for the Unified Model for A-537

$$\ln(\text{mpy}+1.25) =$$

0.43205	+ 0.55970 * c1
- 0.34198 * c3	+ 0.18315 * c4
+ 0.24974 * c5	+ 0.11096 * c7
- 0.12772 * c9	+ 0.30340 * t1
+ 0.63840 * c0c0	- 0.67956 * c0c1
+ 0.20703 * c0c2	+ 1.31491 * c0c3
- 0.34562 * c0c5	+ 0.12923 * c1c1
- 0.03165 * c1c2	- 0.16298 * c1c3
+ 0.08573 * c1c4	+ 0.13896 * c1c5
- 0.33832 * c2c2	+ 0.31082 * c2c3
+ 0.28202 * c3c3	+ 0.07159 * c3c4
+ 0.05832 * c3c5	+ 0.11298 * c4c4
- 0.08185 * c5c5	- 0.43004 * t1c0
+ 0.11316 * t1c8	+ 0.69320 * t1c0c0
- 0.10608 * t1c0c3	- 0.06173 * t1c1c4
- 0.07806 * t1c2c3	- 0.13423 * t1c3c3
- 0.69605 * t2c0	+ 0.42856 * t2c3
- 0.42572 * t2c7	+ 0.22014 * t2c8
+ 0.07859 * t2c9	+ 0.16308 * t2c0c0
- 0.29343 * t2c0c2	- 1.00524 * t2c0c3
- 0.11869 * t2c0c5	+ 0.25478 * t2c1c3
- 0.10346 * t2c2c3	- 0.13387 * t2c3c3
+ 0.19910 * t2c5c5	- 0.08787 * t3c1
+ 0.17871 * t3c7	+ 0.09917 * t3c9
- 0.26151 * t3c0c3	- 0.13895 * t3c0c4
- 0.22433 * t3c0c5	+ 0.21617 * t3c2c2
+ 0.14096 * t3c3c3	- 0.12292 * t3c3c4
+ 0.01768 * h1c6	- 0.11417 * h1c0c0
+ 0.04434 * h1c2c2	- 0.03892 * h1c3c3
- 0.05244 * h2c6	- 0.08303 * h2c0c0
- 0.09040 * h2c0c4	+ 0.04020 * h2c1c5
- 0.08524 * h2c4c4	+ 0.03395 * h2c5c5
- 0.25629 * t1h1c0c0	+ 0.03848 * t1h1c1c4
- 0.01958 * t1h1c1c5	+ 0.04262 * t1h1c3c4
- 0.11474 * t2h1c0c0	- 0.02753 * t3h1c1c1
- 0.08666 * t1h2c5	- 0.05076 * t2h2c1c2
+ 0.10346 * t3h2c5	- 0.15302 * t3h2c0c0
+ 0.19643 * t3h2c0c3	- 0.26171 * t3h2c0c4

to a solution at their highest levels may be effective at much lower levels due to the presence of other components at high or low levels. These relationships were taken into account in designing the experiments for each one of the waste types and the chemical compositions which are included in each experiment are specified in terms of the "nominal" levels of the anions. Second, all terms appear as coded values and not as raw values. Third, and most important, the reader should be aware of the correlations among the terms in the predictor equations and the effect this has on interpretation. Although the fitted models provided in this report will produce reasonably good predictions of corrosion rates in their respective experimental regions, the values of the individual estimated coefficients should not be used to infer the effect or importance of the corresponding terms relative to the corrosion rate. The primary use of these models is for predicting corrosion rates and not for corrosion process modeling.

A COMPUTER PROGRAM FOR PREDICTING CORROSION RATES

INTRODUCTION

The fitted models developed for predicting corrosion rates have been incorporated into an interactive computer program which is the subject of this report. The program requests the user to state the alloy, waste type, exposure time, temperature, and the chemical constituents appropriate to the selected waste type. It then utilizes the fitted models to predict the average corrosion rate, in mpy, that would be expected to occur under the specific conditions. The program also computes an estimate of the standard deviation of the predicted value. The program uses these results to compute upper confidence limits for the true average corrosion rate for that set of conditions at the 90, 95, and 99% confidence levels. It also computes upper 90/90, 95/90 and 99/90 tolerance limits for the average corrosion rates expected to occur in repeated experiments under this set of conditions. For example, an upper 95/90 tolerance limit indicates that we are 95% confident that 90% of average corrosion rates observed under this set of conditions will fall below the limit. The FORTRAN code for the program is not presented in this report but is available from the authors either on tape or as a hard-copy listing.

PROGRAM OPERATION

Logging in remotely requires a terminal or another computer using a terminal emulator program and a suitable modem. The H-P computers use the Enquire/Acknowledge handshake protocol rather than the more common DEC usage of Xon/Xoff (DC1/DC3) protocol. When you dial the number for the H-P computer, the computer will adjust its baud rate to yours (300 or 1200 baud), and when the connection is complete, if you press any key, the computer will respond with a log-in prompt.

Logging in on an H-P computer system is similar to logging into any multiuser system. After establishing a connection, the system prompts with a

"PLEASE LOG ON" prompt and the user types in his ID using the following format:

XXXX.ZZZZ

where:

XXXX is the user account name and zzzz is a group descriptor.

The computer phone number, account name, group descriptor, and password may be obtained from the first author on 376-9844.

If the ID is valid, the system will prompt "PASSWORD?" and read the user's password without echoing the password back to the user's terminal. An example of a valid log-in would be as follows:

PLEASE LOG-ON: User, General (return)

PASSWORD? xyz (return)

(xyz would not appear on the screen for security reasons.)

With a successful log-in, the system will print some log-in information followed by a welcome message with any current messages of importance to the user. The Tank Model Corrosion Program "TNFIN" will be automatically started and will display the following menu:

ENTER WHICH WASTE MODEL TO USE

1--DOUBLE SHELL SLURRY

2--FUTURE PUREX

3--CUSTOMER WASTE

4--ALL OF THEM TOGETHER (COMBINED MODEL).

Enter number of desired waste model (followed by return key) to start the program.

The program will now prompt you for the input variables (alloy, time, temperature) and chemical concentrations. After completing the input, the program will print out a list of the variables. There will be a delay of up to several minutes while the computer solves the mathematical model and displays the complete output.

At this time the program prompts:

IS THERE ANOTHER RUN TO BE PERFORMED? Y/N.

If the answer is "Y" the program will start over with the request for new inputs. If the answer is "N" the program will end but you will still be logged onto the computer. Your current line will start with a ":" followed by a blinking cursor, and, if you press any key, the computer will display the following message:

WAITING FOR INPUT

: (blinking cursor)

If, at this time, you type

EX, RP,,KI (return)

you will be logged off the system and some pertinent information about your session will be displayed. You will remain connected to the H-P system modem until you hang up your modem.

If you are in a hurry you can hang up your modem and the system will automatically log you off.

PROGRAM LIMITATIONS

This program employs very limited error trapping, and it is very easy to abort the program. When this happens the program can be restarted by typing the program name (TNFIN) when there is a system prompt displayed on the screen, (:), a colon followed by a blinking cursor. Sometimes while the program is running and waiting for an input, if a key is struck twice the computer system will respond with a (S=50 COMMAND ?) prompt, which is a system break-mode query and you can normally recover by pressing the return key.

REFERENCES

1. Divine, J. R., W. M. Bowen, D. B. Mackey, D. J. Bates, and K. H. Pool. 1985. Prediction Equations for Corrosion Rates of A-537 and A-516 Steels in Double Shell Slurry, Future PUREX and Hanford Facilities Wastes. PNL-5488. Pacific Northwest Laboratory, Richland, Washington.
2. Wynn, H. P. 1970. "The Sequential Generation of D-Optimum Experimental Designs." Annals of Mathematical Statistics 41:1655-1664.
3. St. John, R. C., and N. R. Draper. 1975. "D-Optimality for Regression Designs: A Review." Technometrics 17:15-23.

DISTRIBUTION

<u>No. of Copies</u>		<u>No. of Copies</u>	
	<u>OFFSITE</u>		A. T. Clark Division of Fuel Material Safety Nuclear Regulatory Commission Washington, DC 20555
30	DOE Technical Information Center		
5	Geologic Repository Division DOE Office of Civilian Radioactive Waste Management Forrestal Building Washington, DC 20585 ATTN: J. W. Bennett, RW-20 C. R. Cooley, RW-4 M. W. Frei B. C. Rusche, RW-1 R. Stein, RW-23		W. J. Dircks Office of the Executive Director for Operations Mail Station 6209 Nuclear Regulatory Commission Washington, DC 20555
3	DOE Office of Defense Waste & Transportation Management GTN Washington, DC 20545 ATTN: G. H. Daly, DP-123 J. E. Lytle, DP-12 T. C. Chee, DP-123 R. B. Hindman, DP-12	2	Environmental Protection Agency Office of Radiation Programs 401 M Street, S.W. Washington, DC 20460 ATTN: D. Egan G. L. Sjoblom
7	DOE Office of Terminal Waste Disposal & Remedial Action GTN Washington, DC 20545 ATTN: J. E. Baublitz, NE-24 J. A. Coleman, NE-25 T. W. McIntosh, NE-25 D. J. McGoff, NE-23 W. R. Voigt, NE-20 H. F. Walter, NE-25 Z. B. Zorn, NE-25	3	DOE Albuquerque Operations Office P.O. Box 5400 Albuquerque, NM 87185 ATTN: K. A. Carlson M. H. McFadden J. McGough
	M. J. Bell Division of Nuclear Materials Safety & Safeguards Mail Station 881-SS Nuclear Regulatory Commission Washington, DC 20555		W. H. Hannum DOE West Valley Operations Office P.O. Box 191 West Valley, NY 14171
		2	DOE Idaho Operations Office 550 Second Street Idaho Falls, ID 83401 ATTN: J. D. Hamric J. B. Whitsett M. J. Barainca
			L. Lanni DOE San Francisco Operations 1333 Broadway Oakland, CA 94612

No. of
Copies

No. of
Copies

M. R. Jugan DOE Oak Ridge Operations Office P.O. Box E Oak Ridge, TN 37830	4	Battelle Memorial Institute Project Management Division 505 King Avenue Columbus, OH 43201 ATTN: W. A. Carbeiner/ S. H. Basham J. F. Kircher W. J. Madia B. Rawles
S. A. Mann DOE Chicago Operations Office 9800 South Cass Avenue Argonne, IL 60439		
J. O. Neff DOE National Waste Program Office 505 King Avenue Columbus, OH 43201		F. Holzer Lawrence Livermore National Laboratory University of California P.O. Box 808 Livermore, CA 94550
W. Cornman Savannah River Laboratory Aiken, SC 29801		D. T. Oakley, MS 671 Los Alamos Scientific Laboratory P.O. Box 1663 Los Alamos, NM 87544
G. K. Oertel DOE Savannah River Operations Office P.O. Box A Aiken, SC 29801		T. H. Row Oak Ridge National Laboratory P.O. Box X Oak Ridge, TN 37830
D. L. Vieth DOE Nevada Operations Office P.O. Box 14100 Las Vegas, NV 89114		R. T. Jubin Consolidated Fuel Reprocessing Program Oak Ridge National Laboratory P.O. Box X Oak Ridge, TN 37830
2 Argonne National Laboratory 9700 South Cass Avenue Argonne, IL 60439 ATTN: C. S. Abrams/J. H. Kittel M. J. Steindler/ L. E. Trevorow	3	Oak Ridge National Laboratory P.O. Box Y Oak Ridge, TN 37830 ATTN: J. O. Blomeke W. D. Burch L. A. Dole
W. Newcomb Battelle Memorial Institute Office of Crystalline Repository Development 9800 South Cass Avenue Argonne, IL 60439		

No. of
Copies

- 5 Sandia Laboratories
P.O. Box 5800
Albuquerque, NM 87185
ATTN: D. R. Anderson
J. F. Ney
R. W. Lynch
W. Weart
Technical Library
- B. R. Wheeler
Westinghouse Idaho Nuclear
Co., Inc.
P.O. Box 4000
Idaho Falls, ID 83401
- 6 E. I. du Pont de Nemours
Company
Savannah River Laboratory
Aiken, SC 29801
ATTN: M. D. Boersma
J. G. Glasscock
E. J. Hennelly
J. R. Knight
M. J. Plodinec
C. T. Randall
- E. A. Jennrich
EG&G Idaho
P.O. Box 1625
Idaho Falls, ID 83415
- V. Ricks
EG&G
1580 Sawtill
P.O. Box 1680
Idaho Falls, ID 83415
- K. V. Gilbert/P. G. Hagen
Rockwell International
Rocky Flats Plant
P.O. Box 464
Golden, CO 80401
- G. W. Meyers
Atomics International Division
Rockwell International
8900 DeSoto Avenue
Canoga Park, CA 91304

No. of
Copies

- T. H. Pigford
Department of Nuclear
Engineering
University of California
Berkeley, CA 94720
- M. E. Spaeth
Science Applications, Inc.
2769 South Highland
Las Vegas, NV 89109
- J. F. Strahl
Weston
2301 Research Boulevard
Third Floor
Rockville, MD 20850
- R. Williams
Electric Power Research
Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94304
- 5 West Valley Nuclear Services
Company
P.O. Box 191
West Valley, NY 14171
ATTN: C. C. Chapman
J. C. Cwynar
J. L. Knabenschuh
J. E. Krauss
J. M. Pope
- J. W. Bartlett
The Analytic Sciences
Corporation
6 Jacob Way
Reading, MA 01867
- W. A. Freeby/J. L. Jardine
Bechtel National, Inc.
P.O. Box 3965
San Francisco, CA 94119

No. of
Copies

Librarian
Westinghouse Electric
Corporation
Technical Library
P.O. Box 40039
Albuquerque, NM 87196

L. L. Hench
Department of Materials Science
& Engineering
University of Florida
Gainesville, FL 32611

J. L. Larocca, Chairman
Energy Research & Development
Authority
Empire State Plaza
Albany, NY 12223

R. G. Post
College of Engineering
University of Arizona
Tucson, AZ 85721

ONSITE

10 DOE Richland Operations Office

J. H. Anttonen
E. A. Bracken
G. J. Bracken
R. D. Izatt
N. T. Karagianes
M. J. Plahuta
J. L. Rhoades
M. W. Shupe
J. O. White
C. E. Collantes

10 Rockwell Hanford Operations

A. J. Diliberto
R. N. Gurley
H. E. McGuire
R. D. Prosser
I. E. Reep
J. C. Womack

No. of
Copies

Rockwell Hanford Operations
(Continued)

T. B. Venziano
D. D. Wodrich
R. D. Wojtasek
File Copy

UNC United Nuclear Industries

T. E. Dabrowski/W. J. Kyriazis

Westinghouse Hanford Company

R. E. Lerch

21 Pacific Northwest Laboratory

J. R. Divine
M. S. Hanson
P. E. Hart
W. W. Laity
D. B. Mackey (10)
Technical Information (5)
Publishing Coordination (2)