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THE CORROSION OF HANFORD FUEL ELEMENTS - METHOD FOR THE TREATMENT AND ANALYSES OF IN-PILE CORROSION DATA

By

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THE CORROSION OF HANFORD FUEL ELEMENTS -
METHOD FOR THE TREATMENT AND ANALYSES
OF IN-PILE CORROSION DATA

INTRODUCTION

The corrosion rates of slug jackets exposed in the Hanford piles are monitored to determine optimum operating conditions and to evaluate proposed changes in process specifications. Selected process tubes are charged with weighed slugs, and the coolant flow rate and temperature rise through the tubes are recorded until the slugs are discharged. The corrosion rates of these control slugs are computed from weight loss data after discharge. The data obtained in this manner are used to find the relationship between slug jacket corrosion rates and the various conditions of power and temperature that are encountered in the piles.

This report covers all of the corrosion data obtained to date for slugs that have been cooled with the currently specified process water, which is alum-coagulated and contains 2 ppm sodium dichromate as an inhibitor (see Appendix II for the water composition). All of the slugs were normal production pieces canned in 2-S aluminum.

HISTORICAL BACKGROUND

The first attempts to study slug jacket corrosion rates were concerned with correlating the corrosion rates with the ambient bulk water temperature. Very little success was realized in these efforts. In April, 1952, R. J. Shields reported the results of some work relating slug corrosion rates to surface temperatures that were corrected for the temperature rise across the heat-transfer water film.⁽¹⁾ His results were considerably more successful than any previous attempts, although they failed to account for a decrease in the corrosion rates in the rear end of the tube where there are high water temperatures, but low slug powers. His correlation also noted an apparent flow dependence

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of corrosion rates at a given surface temperature. Both of these results indicated that slug power may be an important variable. In April, 1954, S. Goldsmith came out with a new correlation that took into account both surface temperature and slug power. ⁽²⁾ While this correlation was much better than any previously published it still was unable to predict corrosion rates to better than a factor of about 2.2. ^(a) The correlation presented in this document differs from previous ones in that it takes into account the temperature rise across the corrosion product film on the slug surface. The agreement between calculated and observed corrosion rates is better than any previously obtained.

SUMMARY

A correlation between corrosion rates, slug surface temperature, slug power, and exposure time has been found that predicts corrosion rates within a band of $1.75^{\pm 1}$ with 95 per cent confidence in the region of practical interest. ^(b) This is much better than any correlation that has been published to date. The relationship is based on a means of calculating an effective rate-controlling temperature.

DISCUSSION OF DATA

Calculation of Corrosion Rates and Operating Variables

After pre-weighed slugs have been discharged from a corrosion control tube they are again weighed and the corrosion rates are calculated assuming uniform corrosion over the entire slug surface. In order to relate the individual slug corrosion rates to operating conditions, temperatures and powers must be computed at the location of the slug. Activity measurements, "weasel readings," are made on the slugs after

(a) With 95 per cent confidence.

(b) $\frac{\text{Actual Corrosion Rate}}{\text{Calculated Corrosion Rate}} \leq 1.75^{\pm 1}$

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they are discharged. The local slug power, P_s , is found by the relation,

$$P_s = \frac{\text{slug weasel reading}}{\sum_{\text{tube}} \text{slug weasel readings}} (\text{Tube power}). \quad (a)$$

The tube power, P_t , expressed in KW = $0.264 (F) (\Delta T_t)$, where F is the flow in gpm and ΔT_t is the temperature rise across the tube in degrees centigrade. (See Appendix I for nomenclature)

The local bulk water temperature, T_1 , is calculated from the slug powers by the relation:

$$T_1 = T_i + \frac{\sum_0^1 (P_s)_1 \Delta T_t}{P_t}$$

where T_i is the tube inlet temperature. The temperature at the surface of the slug, T_s , disregarding any film deposited on the slug, is calculated by the expression: $T_s = T_1 + \frac{P_s}{h}$ where h , the heat transfer coefficient, is evaluated by the method of Sieder and Tate as outlined by W. C. A. Woods. ⁽³⁾ For the Hanford slug geometry, $h = K_D (0.367 + 0.00639 T_1) F^{0.8}$; where K_D for 8" slugs is given in Table I.

TABLE I - CONSTANTS FOR CALCULATING h

<u>Pile</u>	<u>K_D for 8" slugs</u>
B, D, DR, F, H	0.1290
C	0.1020
KE, KW	0.0928

- (a) Actually for a natural uranium loading 6 per cent of the tube power is generated in the graphite. However, this small factor is normally considered insignificant when computing slug powers for use in corrosion calculations.

For Reynolds numbers less than 200,000 (as is the case for the experimental data considered in this report) h should be correct to within ± 20 per cent. (4) (a) This can introduce a maximum error of about 10 per cent in T_s for low values of T_1 , and will have less effect as T_1 increases.

The magnitude of the temperature drop across the film deposited on the slug will be considered later in this report.

Flow Laboratory Corrosion Rates

Flow laboratory corrosion tests are generally conducted by exposing slugs to preheated water in a mock-up of the pile slug and tube geometry. The advantages of such tests are that they are easy to perform, involve no radiation hazards, and can be closely controlled as to such variables as temperature and flow. The main disadvantage is that the corrosion rates are not directly comparable to in-pile rates apparently because of the absence of radiation and/or heat generation by the slugs. However, the flow laboratory data furnish a valuable starting point as they indicate the rate at which slugs should corrode in the absence of any effects of radiation and heat generation. When the corrosion rates of slugs exposed in the flow laboratory under identical conditions of temperature, flow, and exposure time are compared with each other it is found that the corrosion rates fall into a 95 per cent confidence band of about 1.4 ± 1 .

Scatter in the data is presumed to be caused by differences in the initial surface conditions of the slugs, variable rates of oxide build-up, etc. Therefore, the best correlation of corrosion rates with operating variables cannot be expected to predict the corrosion rates

(a) Estimated maximum deviation from the mean.

to better than about 1.4 ± 1 with 95 per cent confidence. This assumes that the operating conditions are known quite accurately. In the pile there are frequent fluctuations in flow, outlet temperature, and flux distribution. These all tend to increase the error in any in-pile corrosion rate correlation.

Laboratory Corrosion Rates as a Function of Temperature

The corrosion rate, CR, can be expressed as $CR = k_r (Al)^n (CH_2O)$ where: k_r is the specific rate constant, (Al) is the concentration of aluminum per unit area (constant) and (CH_2O) expresses the individual concentrations of the various corrosive agents in the water each raised to some power. For any given water quality it becomes apparent that $CR = k_r$ where k_r is the experimentally determined rate constant. ^(a)

According to the Arrhenius expression for the specific rate constant; $k_r = Ae^{-E_a/RT}$ where A is the so-called "frequency factor", E_a is the "activation energy", R is the universal gas constant, and T is the absolute temperature. Actually, according to transition state theory A is a function of temperature depending on the order of reaction. Under ordinary circumstances the temperature effect on A is over-shadowed by the exponential temperature term.

Figure 1 shows the flow laboratory corrosion rates as a function of $1/T$ for alum-coagulated water containing 2 ppm of sodium dichromate. Each point represents the average corrosion rate of an entire run at a given water temperature and exposure time. ⁽⁵⁾⁽⁶⁾⁽⁷⁾⁽⁸⁾⁽⁹⁾ Generally about 4 values are averaged to give one point. The line can be expressed by the equation $CR_o = 1.6 \times 10^8 e^{-7660/T}$ where CR_o is the flow laboratory corrosion rate in mils/mo, and T is the temperature in degrees Kelvin.

(a) The term "water quality" is used throughout this report to designate a type of water prepared from Columbia River water by some given process and having certain definite characteristics, such as, pH, range of impurity concentrations inhibitor concentration, etc. (see Appendix II)

If the value for the gas constant, R , is inserted in the above equation the activation energy for the reaction is found to be 15 kcal/mole.

The curve in Figure 1 was plotted neglecting time as a variable. The flow laboratory data show that the corrosion rate increases initially with time and then decreases to some steady state value.⁽¹⁰⁾⁽¹¹⁾ The general shapes of the corrosion rate vs. time curves, as illustrated in Figure 2, have been established but their numerical values are not too well known.

FIGURE 2

EFFECT OF TIME ON FLOW LABORATORY CORROSION RATES

This time effect is presumably due to the corrosion product oxide film acting as a diffusion barrier.

Effects of Radiation and Heat Generation on Slug Corrosion Rates

An analysis of the data shows that at a constant slug surface temperature, T_s , the corrosion rate increases as the slug power, P_s increases. (All of the data are tabulated in Appendix IV.) This can be the result of two effects: first, the flux changes; and second, the temperature at the surface of the slug changes because the temperature drop across the corrosion product and deposition film on the slug is proportional to P_s . It has been demonstrated that the weight of film on a slug is almost directly proportional to the weight loss, due to corrosion, per unit area. ⁽⁵⁾⁽⁹⁾⁽¹²⁾ Hence, it can be assumed that the film is primarily corrosion product.

The following method of treating the in-pile corrosion data requires one basic assumption to be made. That is: the main effect of heat generation on corrosion rates is to elevate the rate-controlling temperature, T_c , above the water-film surface temperature, T_s . The amount by which the controlling temperature is elevated will be given by $\Delta T_f = (T_c - T_s) = \frac{P_s f}{h'}$ where ΔT_f is the temperature rise across the corrosion product film, f is the film thickness on the slug, and h' is the heat transfer coefficient for a given thickness of film. Now, if it is granted that $f \propto \text{weight loss} = (\text{CR} \times \text{time})$, then $\frac{\Delta T_f}{P_s}$ is some function of $(\text{CR} \times t)$.

If all extraneous effects on corrosion rate (such as radiation, flow, etc.) are neglected, the in-pile corrosion rate can be written as $\text{CR} = A e^{-E_a/R(T_c + 273)} = 1.6 \times 10^8 e^{-7660/(T_c + 273)}$. The number 273 appears in the exponent to convert T_c , expressed in degrees centigrade, to degrees Kelvin. When the in-pile corrosion rates are substituted into this equation T_c , and hence $\frac{\Delta T_f}{P_s}$ can be calculated and related to weight loss.

The value of ΔT_f calculated in this manner includes all other in-pile effects in addition to heat transfer that influence the corrosion rate. Thus, if there is a radiation contribution to corrosion this will be empirically included in this term. This calculation was made for all experimental corrosion rate points having $T_s \geq 60$ C. ^(a) When all of the data are compiled and transposed into a ΔT_f vs. weight loss plot, the graph in Figure 3 is obtained. The apparent convergence of all the lines to a maximum $\Delta T_f = 58$ degrees has a very interesting consequence. ^(b) This means that once the slug power and exposure time have increased to the point where ΔT_f becomes constant the maximum rate at which a slug can corrode in the pile is a function of T_s only. ^(c)

A plot of the maximum corrosion rates that have ever been observed with $T_s \geq 70$ C is shown in Figure 4. The apparent existence of an upper limit, above which no corrosion rates have been observed, seems to be strong support for this manner of treating the data.

-
- (a) The points having $T_s < 60$ C were disregarded in order to reduce the bulk of data to be handled. This left a total of about 540 experimental points to work with. These data are listed in Appendix IV.
- (b) No attempt will be made here to explain why the convergence occurs, but a partial list of factors that could contribute to this are listed below:
1. A non-exponential radiation contribution to corrosion rate would have a diminishing influence upon ΔT_f as the true heat transfer effect increased.
 2. The value of h' might increase as ΔT_f increases.
 3. The rate of Al diffusion through the film may well decrease as weight loss increases. This will lead to a lower calculated ΔT_f .
 4. The film thickness probably reaches some maximum mechanically stable thickness.
- (c) The maximum corrosion rate in mils/mo is given by $CR_{\max} = 1.6 \times 10^8 e^{-7660/T_s + 273 + 58}$.

DISCUSSION OF CORRELATION

The curves presented in Figures 1 and 3 are combined in Figure 5 to give a convenient plot for use in calculating corrosion rates expressed as mils/mo. To use this plot a guess must be made for the corrosion rate at the particular values of T_s , P_s , and t that are of interest. A value of ΔT_f can then be found that will correspond to the estimated corrosion rate. If this value of ΔT_f is added to T_s to obtain T_c a new value of the corrosion rate can be found. This can be used in the same manner to get a new approximation to the corrosion rate and so on until the value converges. The convergence is usually found to be quite rapid if a reasonable first guess is made for the corrosion rate. An example of this procedure is given in Appendix III.

A statistical analysis of the correlation presented in the previous sections shows that the predicted values of corrosion rate become more accurate as weight loss increases.⁽¹³⁾ The 95 per cent confidence limit, defined as the value of A where 95 per cent of the values of $\frac{(\text{CR})_{\text{observed}}}{(\text{CR})_{\text{calculated}}} \leq A \pm 1$, is shown in Table II expressed as a function of weight loss.

TABLE II

95% CONFIDENCE LIMITS FOR THE PRESENTED CORRELATION

Weight loss mg/cm ²	CR x t mils/mo x days	Mils penetration	95% limits A (a)	No. of observations, N	Bias, $\frac{\sum (CR)_{obs}}{\sum (CR)_{calc}} / N$
0 to 10	0 to 44	0 to 1.5	3.03	223	.92
10 to 20	44 to 87	1.5 to 2.9	2.35	93	.97
20 to 30	87 to 130	2.9 to 4.4	2.04	72	.96
30 to 40	130 to 175	4.4 to 5.8	1.72	53	.93
40 to 50	175 to 220	5.8 to 7.3	1.64	50	.97
50 to 60	220 to 260	7.3 to 8.7	1.47	22	1.03
60 and over	260 and over	8.7 and over	1.35	24	1.12
<hr/>					
<20	<87	<2.9	2.83	316	.93
>20	>87	>2.9	1.75	219	.98

(a) 95 per cent of the values of $\frac{(CR)_{observed}}{(CR)_{calculated}} \leq A \pm 1$

The greater scatter in the low weight loss region may well be inherent in the data, because it is in this region that corrosion rates are most dependent upon film thickness, and therefore, the region where such unpredictable things are abrasion removal of the film would be of the greatest importance. ^(b) The error in the correlation at high weight losses

(b) That is, if it is granted that the weight loss is proportional to the film thickness a change in film thickness causes a larger change in ΔT_f in the low weight loss region than in the high weight loss region. (See Figure 3)

is very close to that observed in predicting flow laboratory corrosion rates, and suggests that in this region the conversion factors from out-of-pile rates to in-pile rates may be more accurately known than the actual value of the out-of-pile rates.

When the derived curves are used to predict corrosion rates at high temperatures the extrapolation of the flow laboratory corrosion rates may well present the greatest single source of error. Any slight deviation of the flow laboratory curve in the experimental temperature range of between 60 and 100 C causes quite a large deviation at about 200 C. This is especially true when the corrosion rate is related to temperature on a reciprocal basis. In addition to this type of error there is the very real possibility that at some elevated temperature the corrosion mechanism changes completely, after which the proposed correlation loses all significance.

However, in lieu of any better method of extrapolating corrosion rates, the curves will be considered correct over a large temperature range and the resulting extrapolations will be presented as being of general interest. In using these curves their limitations should be borne in mind.

Figures 6, 7 and 8 show predicted corrosion rates as a function of slug surface temperature and power at exposure times of 100, 150 and 200 days, respectively.

CONCLUSIONS

The correlation presented here will predict corrosion rates within a band of $1.75^{\pm 1}$ with 95 per cent certainty when the weight loss is $\geq 20 \text{ mg/cm}^2$. (a) This is better than any previously reported correlation, but points out the need for a better evaluation of out-of-pile rates and for such basic investigations as to the effects of heat transfer and radiation on corrosion rates.

DRD:ms

D. R. deHalas

(a) This is equivalent to ~3 mils penetration.

FIGURE 1

FLOW LABORATORY CORROSION RATES
IN ALUM TREATED WATER CONTAINING 2 ppm SODIUM DICHROMATE

FIGURE 3

ΔT_f AS A FUNCTION OF WEIGHT LOSS

FIGURE 4

MAXIMUM CORROSION RATES EVER OBSERVED AT EACH $T_s \geq 70^\circ\text{C}$

FIGURE 5

CURVES FOR COMPUTING IN - PILE CORROSION RATES

FIGURE 6
PREDICTED CORROSION RATES AT AN EXPOSURE TIME OF 100 DAYS

FIGURE 7

PREDICTED CORROSION RATES AT AN EXPOSURE TIME OF 150 DAYS

FIGURE 8

PREDICTED CORROSION RATES AT AN EXPOSURE TIME OF 200 DAYS

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- (12) Goldsmith, S., "Interim Report - Production Test Number 105-510-E - Determination of Pile Irradiation Effects on Corrosion of 2-S Aluminum," HW-27531, June 1, 1953.
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APPENDIX I

NOMENCLATURE AND CONVERSION FACTORS

A	Arrhenius "frequency factor"
CR	Corrosion rate, mils/mo
CR _o	Flow laboratory corrosion rate (out-of-pile), mils/mo
E _a	Activation energy in Arrhenius equation
F	Flow rate, gpm
h	Heat transfer coefficient for the water film, KW/8" slug/°C
h'	Heat transfer coefficient for given thickness of corrosion product film
k _D	Derived constant for calculating h
k _r , k _r '	Specific rate constants
P _s	8" slug power, KW
P _t	Tube power, KW
R	Gas constant (1.98 cal/°C/mole)
T	Absolute temperature, K
T _c	Corrosion rate controlling temperature, C
T _i	Tube inlet water temperature, C
T _l	Local bulk water temperature, C
T _o	Tube outlet water temperature, C
T _s	Slug surface temperature; no corrosion product film present, C
ΔT _f	Temperature rise across corrosion product film (T _c - T _s), C
ΔT _t	Temperature rise along tube (T _i - T _o), C
t	Exposure time, days

Corrosion Rates

$$1 \text{ mil/mo} = 0.229 \text{ mg/cm}^2/\text{day}$$

$$1 \text{ mg/cm}^2/\text{day} = 4.37 \text{ mils/mo}$$

Weight loss or Penetration

$$1 \text{ mil} = 25.4 \text{ mg/cm}^2$$

$$1 \text{ mg/cm}^2 = 0.146 \text{ mils}$$

APPENDIX II

AVERAGE COMPOSITION OF ALUM-COAGULATED PROCESS WATER^(e)

	Average	Maximum	Minimum
pH (a)	7.65	7.75	7.60
Methyl Orange Alkalinity (b)	54 ppm	63 ppm	46 ppm
Fe	0.010 ppm	0.020 ppm	0.001 ppm
Ca	21 ppm	26 ppm	17 ppm
Mg	4.7 ppm	5.7 ppm	4.1 ppm
Cu	0.007 ppm	0.30 ppm	<0.005 ppm
Al	0.07 ppm	0.13 ppm	0.01 ppm
Cl ⁻	1.5 ppm	2.4 ppm	0.8 ppm
SO ₄ ⁼	17 ppm	28 ppm	11 ppm
Na ₂ Cr ₂ O ₇ · 2H ₂ O (c)	1.8 ppm	2.2 ppm	1.5 ppm
Suspended Solids	---	<0.2 ppm	---
Specific Resistance (d)	6100 ohm-cm	7000 ohm-cm	4500 ohm-cm

(a) Measured at the ambient inlet water temperature (5C-18C)

(b) Expressed as ppm of CaCO₃

(c) Added as an inhibitor

(d) Measured at 25 C

(e) Taken at 100-D Area for 1953

APPENDIX III

EXAMPLE OF USING FIGURE 5 TO COMPUTE CORROSION RATES

Given: Slug Power, $P_s = 20$ KW

Surface Temperature, $T_s = 90$ C

Exposure Time, $t = 135$ days

Make a first guess at the corrosion rate; $CR = 2$ mils/mo; $CR \times t = 270$.

At a P_s of 20, ΔT_f is 53 C. $T_c = T_s + T_f = 143$ C.

At a T_c of 143 C the graph shows that $CR = 1.7$ mils/mo. Repeating the procedure gives:

$$\begin{aligned} CR \times t &= 230, \\ \Delta T_f &= 52, \\ T_c &= 142, \\ \text{and } CR &= 1.6 \text{ mils/mo} \end{aligned}$$

It can be seen that in this case the second guess gave essentially the final answer. If a close initial guess is made the corrosion rate can be found quite rapidly.

APPENDIX IVCORROSION DATA FOR pH 7.6 ALUM TREATED WATER
CONTAINING 2 ppm SODIUM DICHROMATE

The corrosion data used in the calculations presented in this document were obtained from the following sources:

<u>Production Test</u>	<u>Listed As</u>	<u>Title</u>
PT 105-503-E	503	The Use of Activated Silica as a Coagulation Aid for Aluminum Sulfate
PT 105-509-E	509	The Effects of Low pH Alum-Treated Water on Pile Operations
PT 105-513-E	513	100 Areas Process Water Quality Evaluation Tests
PT 105-519-E	519	Raising Permissible Outlet Water Temperatures at Selected Tubes at C Pile
PT 105-532-A	532	Irradiation of Enriched Uranium Slugs
PT 105-534-A	534	D Pile Operation with Maximum Panellit Pressure Monitor Protection
PT 105-549-A	549	Exposure Increases in High Power Tubes in C Pile
PT 105-9P	9	Corrosion of Slugs and Tubes

APPENDIX IV (contd.)

ABBREVIATIONS USED IN APPENDIX

Date	Charge Date
Exp.	Exposure Time (Days)
T _o	Average outlet temperature (c)
P _t	Average tube power (kw)
Size	Nominal Slug size (inches)
No.	Slug number from rear of charge
CR	Corrosion rate (mils/mo)
CR'	Corrosion rate (mg/cm ² /day)

All other abbreviations are the same as listed in Appendix I (Nomenclature).

Tube Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
1090 C	8-03-53	150	60.1	48.2	636	597	9	8
<u>No.</u>	<u>T_l-</u>	<u>P_s-</u>	<u>T_s-</u>	<u>CR_i</u>	<u>CR</u>			
1	60.1	2.5	61.6	.024	.103			
3	58.3	8.9	63.6	.045	.195			
5	56.1	14.0	64.5	.070	.301			
7	53.1	18.8	64.9	.069	.295			
9	49.5	22.9	64.0	.128	.550			
11	45.2	27.7	63.6	.123	.529			
13	40.5	30.0	61.5	.080	.344			

Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
2071	C	6-13- 3	50	93.3	30.0	619	259	519	4

No.	T ₁	P _s	T _s	CR ₁	CR
1	92.2	8.6	96.8	.087	.374
3	90.9	10.6	97.7	.084	.361
5	89.0	14.4	96.9	.142	.611
7	86.8	17.6	96.6	.119	.512
9	84.5	18.2	94.7	.161	.692
11	81.9	20.2	93.6	.137	.589
13	79.3	20.2	91.1	.205	.882
15	76.6	21.8	89.7	.118	.507
17	73.7	22.4	87.4	.244	1.049
19	70.9	21.8	84.6	.153	.658
21	68.2	21.4	81.8	.156	.671
23	65.4	21.8	79.9	.178	.765
25	62.6	22.4	77.6	.154	.662
27	59.5	24.6	76.4	.118	.507
29	56.5	23.4	72.9	.080	.344
31	53.6	22.4	69.9	.066	.284
33	50.5	22.4	67.3	.027	.116
35	47.9	23.0	65.4	.029	.125
37	45.1	21.8	62.3	.021	.090

Tube	Area	Date	Exp.	T _O	F	P _t	Level	PT#	Size
2071	C	8-05-53	111	99.1	33.0	725	645	519	4

<u>No.</u>	<u>T_l</u>	<u>P_s</u>	<u>T_s</u>	<u>CR_l</u>	<u>CR</u>
4	96.4	12.0	102.1	.211	.905
8	92.0	18.6	101.1	.512	2.203
12	86.5	24.0	98.7	.392	1.685
16	79.9	28.8	95.4	.310	1.331
20	73.1	30.0	90.0	.242	1.040
24	66.4	29.0	83.7	.172	.741
28	60.1	27.0	77.0	.109	.468
32	53.1	30.6	73.5	.110	.475
36	46.4	29.4	67.1	.055	.235
40	40.1	27.0	60.7	.040	.170

Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
2071	C	12-12-53	103	93.4	32.0	730	600	519	4

No.	T ₁	P _s	T _s	CR ₁	CR
1	93.0	7.4	96.7	.074	.318
2	92.4	10.2	97.5	.115	.495
3	91.8	11.6	97.7	.172	.740
4	91.0	13.2	97.7	.208	.894
5	90.1	14.6	97.6	.240	1.032
6	89.2	16.0	97.4	.329	1.415
7	88.1	17.6	97.3	.326	1.402
8	87.1	19.0	97.1	.387	1.664
9	85.9	19.0	95.9	.393	1.690
10	84.7	20.4	95.6	.465	2.000
11	83.4	22.0	95.2	.443	1.905
12	82.1	22.0	94.1	.431	1.853
13	80.7	23.4	93.6	.419	1.802
14	79.3	24.8	93.1	.420	1.806
15	77.7	24.8	91.6	.432	1.858
16	76.2	26.2	91.1	.431	1.853
17	74.6	27.8	90.6	.403	1.733
18	73.0	27.8	89.2	.389	1.673
19	71.2	29.2	88.4	.421	1.810
20	69.5	29.2	86.9	.374	1.608
21	67.7	29.2	85.3	.328	1.410
22	65.9	30.6	84.8	.336	1.445
23	64.1	30.6	83.2	.387	1.664
24	62.2	30.6	81.6	.270	1.161
25	60.4	30.6	80.0	.236	1.015
26	58.6	30.6	78.5	.257	1.105
27	56.7	32.2	78.2	.193	.830
29	53.6	32.2	75.1	.101	.434
30	51.1	32.2	73.5	.122	.525
31	49.1	32.2	72.1	.731	3.143
32	47.3	32.2	70.6	.053	.227

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Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
2072	C	11-18-52	153	60.6	38.3	538	595	9	8
No.	$\frac{T}{l}$ -	$\frac{P}{s}$ -	$\frac{T}{s}$ -	$\frac{CR}{l}$	$\frac{CR}{t}$				
1	60.6	6.6	66.0	.022	.095				
3	59.2	10.9	67.0	.038	.163				
5	56.4	14.9	67.0	.045	.194				
7	53.7	17.4	67.0	.049	.211				
9	50.1	18.3	64.0	.062	.267				
11	46.4	18.6	61.0	.038	.163

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Tube	Area	Date	Exp.	T _O	F	P _t	Level	PT#	Size
2073	C	11-18-52	153	60.6	39.5	555	595	9	8
No.									
		<u>T_l</u>	<u>P_s</u>	<u>T_s</u>	<u>CR'</u>	<u>CR</u>			
1		60.6	6.7	66.0	.025	.108			
3		59.0	11.1	67.0	.034	.146			
5		57.0	15.7	68.0	.060	.258			
7		53.0	17.5	66.0	.054	.232			
9		50.0	18.9	64.0	.046	.198			
11		46.5	18.9	61.0	.035	.151

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Tube	Area	Date	Exp.	T _O	F	P _t	Level	PT#	Size
2076	C	11-18-52	153	61.8	39.5	570	595	9	Ø
	<u>No.</u>	<u>T_l-</u>	<u>P_s-</u>	<u>T_s-</u>	<u>CR_i</u>	<u>CR_r</u>			
	1	62.0	7.0	67.0	.023	.099			
	3	60.0	12.2	68.0					
	5	57.5	15.9	69.0	.056	.241			
	7	54.0	18.0	67.0	.062	.267			
	9	51.0	20.3	66.0	.064	.275			
	11	47.0	19.9	62.0	.036	.155			

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Tube Area	Date	Exp.	T _O	F	P _t	Level	PT#	Size
2083 C	8-03-53	167	78.3	40.5	700	837	549	8
No.	$\frac{T}{s}-$	$\frac{P}{s}-$	$\frac{T}{s}-$	$\frac{CR}{s}$	$\frac{CR}{s}$			
1	76.6	9.1	82.0	.087	.374			
3	74.1	12.9	81.7	.112	.482			
5	71.0	17.2	81.8	.093	.400			
7	67.0	21.0	80.1	.148	.636			
9	62.6	23.5	78.3	.145	.624			
11	57.9	24.9	74.5	.139	.598			
13	52.8	27.7	72.6	.125	.538			
15	47.3	28.7	69.4	.167	.718			
17	41.7	30.1	66.8	.101	.434			
19	36.1	30.1	61.2	.023	.099			

Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
2168	C	6-13-53	50	87.7	30.0	575	235	519	4

No.	T _l	P _s	T _s	CR'	CR
1	86.6	8.0	91.0	.070	.301
3	85.4	9.6	90.8	.141	.606
5	83.7	12.8	91.0	.172	.740
7	82.0	12.8	89.4	.143	.615
9	79.8	15.6	88.9	.132	.568
11	77.5	16.6	87.3	.108	.464
13	75.1	17.6	85.7	.133	.572
15	72.6	18.8	84.2	.122	.525
17	69.9	19.2	81.8	.142	.611
19	67.2	20.4	80.3	.093	.400
21	64.4	20.8	78.1	.095	.409
23	61.6	20.8	75.7	.069	.297
25	58.7	21.4	73.4	.057	.245
27	55.8	21.4	70.9	.042	.181
29	53.0	20.8	68.1	.034	.146
31	50.3	20.4	65.3	.031	.133
33	47.6	20.4	63.1	.026	.112
35	44.8	20.4	60.7	.021	.090

Tube 2168	Area C	Date 8-03-53	Exp. 146	T _O 94.7	F 38.0	P _t 826	Level 685	PT# 519	Size 4
No.	$\frac{T}{s}$	$\frac{P}{s}$	$\frac{T}{s}$	$\frac{CR}{t}$	$\frac{CR}{t}$				
1	92.1	11.0	97.0	.220	.946				
4	88.2	17.2	96.0	.368	1.582				
8	83.6	20.4	93.5	.393	1.690				
12	78.3	22.6	89.3	.444	1.909				
16	72.2	24.6	85.2	.309	1.329				
20	66.6	26.0	80.3	.241	1.036				
24	60.5	27.0	75.5	.171	.735				
28	54.0	28.0	70.1	.149	.641				
32	47.4	28.8	65.8	.083	.357				
36	40.8	28.8	60.2	.075	.323				

Tube Area Date Exp T_o F P_t Level PT# Size
2172 C 11-18-52 153 62.0 39.5 570 595 9 8

<u>No.</u>	<u>T_l</u>	<u>P_s</u>	<u>T_s</u>	<u>CR_i</u>	<u>CR</u>
1	62.0	8.3	68.0	.022	.095
3	60.0	12.4	69.0	.041	.176
5	58.0	15.2	69.0	.054	.232
7	55.0	16.6	67.0	.062	.267
9	51.0	18.0	64.0	.084	.361
11	48.0	19.4	63.0	.049	.211

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Tube Area
2174 C

Exp.
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PT# Size
532 4

No.	$\frac{P}{s}$	$\frac{T}{s}$	$\frac{CR^1}{}$	$\frac{CR}{}$
11	14.6	74.9	.092	.396
12	14.6	74.6	.075	.323
13	14.8	74.2	.045	.194
14	15.0	73.9	.049	.211
15	15.2	73.4	.049	.211
16	15.2	72.9	.046	.198
17	15.4	72.3	.035	.151
18	15.6	71.7	.029	.125
19	16.0	71.0	.025	.108
20	16.2	70.5	.024	.103

Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
2270	C	6-14-53	116	98.3	31.7	680	630	519	4

No.	T _l	P _s	T _s	CR _l	CR
1	97.3	8.8	101.5	.150	.645
3	96.1	11.4	101.6	.129	.554
5	94.3	14.2	101.3	.374	1.608
9	89.9	19.6	99.9	.416	1.789
11	87.2	22.4	98.7	.470	2.019
13	84.2	24.6	97.1	.408	1.753
15	81.1	25.8	95.0	.387	1.662
17	78.0	26.6	92.6	.306	1.316
19	74.6	27.8	90.2	.285	1.225
21	71.2	28.6	87.6	.254	1.094
23	67.5	29.2	84.9	.273	1.176
25	64.0	32.0	83.5	.858	3.691
27	60.6	28.6	78.5	.205	.882
29	56.6	27.2	74.3	.193	.830
31	54.0	26.6	71.8	.167	.718
33	51.1	25.2	68.4	.161	.690
35	48.2	24.6	65.5	.106	.455
37	45.3	23.8	62.5	.085	.365
39	42.4	24.6	60.8	.036	.156

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Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
2276	C	6-13-53	50	98.6	30.0	661	263	519	4

No.	T ₁	P _s	T _s	CR'	CR
1	97.4	9.4	102.1	.098	.421
3	96.0	10.8	101.7	.125	.538
5	94.3	14.4	101.9	.180	.774
7	92.0	17.0	101.1	.219	.942
11	87.0	21.0	98.6	.209	.899
13	84.2	22.4	96.9	.265	1.140
15	81.2	24.0	95.0	.275	1.183
17	78.1	24.4	92.5	.265	1.140
19	75.1	24.4	90.0	.219	.942
21	71.7	26.6	88.3	.271	1.165
23	68.7	24.0	84.1	.216	.929
25	65.6	24.6	81.8	.177	.761
27	62.1	27.8	80.9	.191	.821
29	58.5	27.8	77.8	.140	.602
31	55.2	26.4	73.8	.152	.654
33	52.0	25.4	70.7	.073	.314
35	48.9	24.8	67.7	.067	.288
37	45.6	25.8	65.4	.032	.138
39	42.5	24.4	62.2	.030	.129
41	39.2	26.4	61.2	.035	.151

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Tube	Area	Date	Exp.	T _O	F	P _t	Level	PT#	Size
2276	C	8-05-53	111	102.3	33.0	756	670	519	4
<hr/>									
No.	$\frac{T_1}{T_2}$		$\frac{P}{S}$	$\frac{T}{S}$	$\frac{CR_1}{CR_2}$				
4	99.4		12.4	105.0	.597	2.566			
8	94.6		21.2	105.2	.732	3.147			
12	88.9		24.6	101.2	.610	2.623			
16	82.7		26.8	96.1	.412	1.772			
20	76.1		28.8	92.1	.311	1.337			
24	69.4		29.4	85.7	.249	1.069			
28	62.5		29.4	80.9	.228	.979			
32	55.7		29.4	74.1	.157	.675			
36	48.8		30.2	70.4	.116	.501			
40	41.5		31.4	63.1	.086	.369			

Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
2276	C	12-12-53	103	97.8	32.0	766	614	519	4

No.	T _l	P _s	T _s	CR _l	CR
1	97.3	7.6	101.1	.097	.418
2	96.7	9.2	101.3	.194	.834
3	96.1	10.8	101.5	.193	.830
4	95.3	12.2	101.4	.188	.808
5	94.5	13.8	101.4	.231	.993
6	93.6	15.4	101.3	.261	1.122
7	92.7	15.4	100.5	.323	1.389
8	91.7	16.8	100.2	.314	1.350
9	90.6	18.4	100.0	.364	1.565
10	89.5	18.4	99.0	.405	1.742
11	88.4	20.0	98.8	.425	1.828
12	87.2	20.0	97.6	.493	2.120
13	85.9	21.4	97.2	.491	2.111
14	84.5	23.0	96.7	.580	2.494
15	83.3	23.0	95.7	.575	2.473
16	81.8	23.0	94.3	.539	2.318
17	80.4	24.6	93.9	.491	2.111
18	78.9	24.6	92.6	.467	2.008
19	77.4	26.0	92.0	.449	1.931
20	75.8	26.0	90.6	.448	1.926
21	74.2	27.6	90.1	.392	1.686
22	72.6	27.6	88.6	.353	1.518
23	70.9	29.2	88.1	.391	1.681
24	69.2	29.2	86.6	.354	1.522
25	67.5	29.2	85.1	.313	1.346
26	65.6	30.6	84.5	.311	1.337
27	63.7	30.6	82.8	.261	1.122
28	61.8	32.2	82.2	.285	1.226
29	59.9	32.2	80.5	.232	.998
30	58.0	32.2	79.2	.208	.894
31	56.0	33.8	78.5	.117	.503
32	54.0	33.8	76.8	.158	.679

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Tube	Area	Date	Exp.	T ₀	F	P _t	Level	PT#	Size
2381	C	10-20-53	117	86.8	40.5	732	686	9	4
	No.	T ₁	P _s	T _s	CR ₁	CR			
4		84.0	15.0	90.8	.124	.534			
8		80.0	21.2	89.6	.085	.367			
12		75.2	25.6	86.8	.133	.573			
16		69.8	29.2	84.4	.082	.353			
20		63.9	31.4	80.3	.075	.323			
24		58.0	31.4	75.1	.050	.215			
28		52.4	29.6	69.4	.055	.235			
32		46.7	30.4	65.0	.027	.115			
36		41.0	30.4	60.5	.015	.065			

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Tube Area Date Exp. T_O F P_t Level PT# Size
2481 C 10-20-53 90 85.9 40.5 722 557 9 4

No.	T _l	P _s	T _s	CR _l	CR
4	83.4	13.4	89.5	.064	.274
8	79.9	18.4	88.3	.082	.354
12	75.3	25.0	86.7	.065	.281
16	70.0	28.2	84.1	.066	.284
20	64.2	31.2	80.5	.068	.292
24	58.3	31.2	75.3	.081	.346
28	52.2	33.0	71.2	.077	.329
32	46.2	31.8	65.6	.043	.184

Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
2572	C	6-14-53	116	98.3	31.7	680	608	519	4

No.	T _l -	P _s -	T _s -	CR'	CR
1	98.3	10.2	102.2	.431	1.853
3	95.7	11.6	101.6	.568	2.442
5	93.9	15.0	101.6	.593	2.550
7	91.8	17.6	100.9	.790	3.397
9	89.4	19.8	99.8	.713	3.066
11	86.8	21.8	98.3	.763	3.281
13	83.9	24.4	97.2	.604	2.597
15	80.8	25.8	95.1	.519	2.232
17	77.0	27.2	92.6	.501	2.154
19	74.2	27.8	90.4	.408	1.754
21	70.8	28.6	87.8	.369	1.587
23	67.3	28.6	85.0	.331	1.423
25	64.0	27.8	81.6	.283	1.217
27	60.7	27.2	78.4	.241	1.036
29	57.5	27.2	75.6	.223	.959
31	54.3	26.6	72.5	.256	1.101
33	51.1	26.6	69.8	.192	.826
35	48.0	25.8	66.7	.126	.542
37	44.9	25.8	64.1	.105	.452
39	41.9	25.2	61.3	.067	.288

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Tube	Area	Date	Exp.	T _O	F	P _t	Level	PT#	Size
2572	C	10-20-53	94	97.3	35.0	814	395	519	8
	<u>No.</u>	<u>T_l-</u>	<u>P_s-</u>	<u>T_s-</u>	<u>CR_i</u>	<u>CR</u>			
	1	95.4	9.0	100.7	.010	.043			
	3	92.2	14.7	99.0	.441	1.896			
	5	87.9	19.5	97.7	.536	2.305			
	17	47.4	35.8	70.9	.133	.572			
	19	39.7	35.8	65.4	.047	.202			

Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
2578	C	8-03-53	150	85.1	40.5	725	810	549	8
No.		$\frac{T_1}{-}$	$\frac{P}{S-}$	$\frac{T}{S-}$	$\frac{CR_1}{-}$	$\frac{CR}{-}$			
1		83.8	7.0	87.2	.181	.778			
3		81.2	13.9	89.4	.291	1.251			
5		77.6	19.4	89.0	.367	1.578			
7		73.0	24.4	88.3	.335	1.441			
9		68.2	26.3	85.7	.282	1.213			
11		63.2	31.3	80.7	.244	1.049			
13		57.4	31.3	79.4	.232	.998			
15		51.2	33.3	76.8	.211	.907			
17		45.0	33.3	70.6	.192	.826			
19		38.8	33.3	66.6	.158	.679			
21		32.9	31.3	61.4	.098	.421			

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Tube Area Date Exp. T_O F P_t Level PT# Size
2579 C 8-03-53 140 84.1 45.0 847 810 549 8

No.	$\frac{T}{s}$	$\frac{P}{s}$	$\frac{T}{s}$	$\frac{CR_i}{CR}$	$\frac{CR_i}{CR}$
1	83.5	3.8	88.5	.114	.490
3	80.7	16.1	89.3	.197	.847
5	79.2	21.2	90.4	.242	1.041
7	72.8	26.3	87.4	.261	1.122
9	69.6	31.0	86.3	.238	1.023
11	61.8	34.8	83.6	.190	.817
13	55.6	36.9	78.7	.173	.744

Tube	Area	Date	Exp.	T _o	P	P _t	Level	PT#	Size
2670	C	6-13-53	50	93.2	30.0	618	231	519	4

No.	T ₁	P _s	T _s	CR'	CR
1	92.3	7.4	96.2	.082	.353
3	91.1	9.2	96.0	.079	.340
5	89.3	13.6	96.7	.231	.993
7	87.5	14.2	95.3	.218	.937
9	85.4	16.0	94.4	.265	1.140
11	83.2	18.0	93.5	.159	.684
13	80.7	19.8	92.1	.207	.890
15	78.2	20.4	90.2	.131	.563
17	75.3	21.6	88.3	.202	.869
19	72.5	22.2	86.2	.073	.314
21	69.6	23.4	84.4	.124	.533
23	66.6	24.2	82.3	.052	.224
25	63.4	24.8	79.9	.044	.189
27	60.3	24.8	77.1	.046	.198
29	57.0	24.8	74.2	.027	.116
31	54.0	24.8	71.7	.034	.146
33	51.0	24.2	68.8	.029	.125
35	48.0	24.2	66.3	.032	.138
37	45.0	24.2	63.9	.019	.082
39	41.9	24.2	61.4	.017	.073

Tube	Area	Date	Exp.	T _O	F	P _t	Level	PT#	Size
2670	C	8-05- 3	111	99.6	33.0	725	645	519	4

No.	T _l	P _s	T _s	CR'	CR
4	96.7	12.8	102.5	.285	1.225
8	92.4	18.4	101.6	.417	1.794
12	87.2	23.0	98.7	.386	1.660
16	81.2	26.0	92.6	.313	1.345
20	74.9	28.2	90.6	.215	.926
24	67.9	29.6	84.3	.183	.788
28	60.9	29.6	79.4	.165	.710
32	54.3	29.6	72.8	.111	.477
36	47.8	28.2	67.9	.085	.363
40	41.8	26.8	60.9	.066	.284

Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
2670	C	12-12-53	91	102.2	35.0	786	555	519	4

No.	T ₁ -	P _s -	T _s -	CR ¹	CR
1	101.8	6.2	105.3	.199	.854
2	101.1	9.4	106.5	.480	2.064
3	100.4	12.6	107.6	.446	1.918
4	99.6	14.2	107.8	.553	2.378
5	98.7	15.8	107.8	.460	1.978
6	97.6	17.2	107.4	.517	2.223
7	96.5	18.8	107.2	.784	3.371
8	95.3	18.8	106.0	.889	3.823
9	94.1	20.4	105.8	.628	2.700
10	93.8	22.0	105.4	.736	3.165
11	91.5	22.0	104.1	.789	3.393
12	90.1	23.6	104.8	.836	3.595
13	88.5	25.2	104.4	.741	3.186
14	86.9	26.8	103.8	.789	3.393
15	85.3	26.8	102.2	.495	2.129
16	83.7	28.2	101.5	.614	2.640
17	81.9	28.2	99.8	.737	3.169
18	80.1	28.2	98.2	.772	3.320
19	78.4	28.2	96.7	.479	2.060
20	76.7	28.2	95.3	.631	2.713
21	75.0	28.2	93.9	.538	2.313
22	73.1	28.2	92.4	.389	1.673
23	71.4	28.2	90.7	.486	2.090
24	69.6	29.8	90.6	.494	2.124
25	67.8	29.8	90.1	.443	1.905
26	66.0	31.4	88.7	.443	1.905

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Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
2679	C	6-13-53	50	96.1	30.0	641	231	519	4

No.	T _l -	P _s -	T _s -	CR'	CR
1	95.2	7.0	98.8	.119	.512
3	94.2	8.4	98.6	.100	.430
5	92.5	12.8	99.3	.092	.396
7	90.6	15.4	98.9	.084	.361
9	88.3	18.0	98.2	.100	.430
11	85.8	19.8	96.9	.097	.417
13	83.2	21.2	95.2	.099	.426
15	80.4	22.4	93.4	.086	.370
17	77.5	22.4	90.7	.098	.421
19	74.5	23.0	88.4	.072	.310
21	71.6	23.8	86.5	.061	.262
23	68.6	23.8	83.7	.072	.310
25	65.6	23.8	81.1	.080	.344
27	62.5	24.4	78.8	.050	.215
29	59.4	24.4	76.1	.053	.228
31	56.4	24.4	73.6	.034	.146
33	53.4	24.4	71.1	.040	.172
35	50.3	24.4	68.5	.034	.146
37	47.2	24.4	66.0	.031	.133
39	44.1	24.4	63.2	.025	.108
41	41.1	24.4	60.8	.024	.103

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Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
2679	C	8-05-53	111	100.2	33.0	737	635	519	4

<u>No.</u>	<u>T₁</u>	<u>P_s</u>	<u>T_s</u>	<u>CR'</u>	<u>CR</u>
4	97.0	14.0	103.6	.687	2.954
8	92.3	19.8	102.0	.754	3.242
16	80.5	26.8	94.8	.484	2.081
20	74.0	28.8	90.2	.307	1.320
24	67.3	29.0	84.4	.256	1.101
28	60.7	28.8	78.7	.224	.963
32	54.3	27.6	72.5	.222	.955
36	47.8	28.4	67.5	.153	.658
40	41.1	29.0	62.7	.114	.490

Tube	Area	Date	Exp.	T _O	F	P _t	Level	PT#	Size
2679	C	12-12-53	71	95.8	34.0	799	442	519	4

No.	T ₁	P _S	T _S	CR ₁	CR
1	95.5	6.2	99.2	.085	.366
2	95.0	8.2	99.9	.105	.452
3	94.5	9.2	100.0	.120	.516
4	93.8	11.4	100.6	.201	.864
5	93.2	11.4	100.1	.182	.783
6	92.4	13.4	100.5	.241	1.036
7	91.7	14.4	100.5	.258	1.109
8	90.8	16.4	100.8	.308	1.324
9	89.9	16.4	100.0	.159	.684
10	88.8	17.6	99.8	.356	1.531
11	87.7	19.6	99.9	.354	1.522
12	86.6	20.6	96.6	.410	1.763
13	85.4	20.6	95.8	.265	1.140
14	84.1	22.6	95.6	.646	2.778
15	82.8	24.8	95.6	.448	1.926
16	81.3	25.8	94.7	.462	1.987
17	79.8	27.8	94.4	.424	1.823
18	78.1	28.8	93.4	.396	1.703
19	76.5	28.8	92.0	.441	1.896
20	74.8	31.0	91.6	.475	2.043
21	73.1	31.0	90.3	.356	1.531
22	71.4	31.0	89.8	.345	1.484
23	69.7	31.0	87.3	.367	1.578
24	67.9	31.0	85.7	.342	1.471
25	66.3	31.0	84.3	.129	.555
26	64.5	31.0	82.7	.300	1.290
29	59.3	31.0	78.4	.180	.774
31	55.9	31.0	75.5	.132	.568
32	54.2	31.0	74.3	.150	.645

Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
2870	C	6-13-53	50	88.3	30.0	580	215	519	4

No.	T ₁	P _s	T _s	CR'	CR
1	87.4	7.6	91.6	.081	.348
3	85.8	12.6	92.0	.081	.348
5	84.2	12.8	91.4	.101	.434
7	82.3	15.0	90.9	.074	.318
9	80.3	16.2	89.7	.065	.280
11	78.0	17.4	88.2	.098	.421
13	75.6	19.2	87.0	.061	.262
15	73.0	20.4	85.4	.069	.297
17	70.3	21.4	83.7	.057	.245
19	67.6	22.0	81.7	.058	.249
21	64.8	22.0	79.3	.056	.241
23	62.0	22.0	76.7	.049	.211
25	59.2	22.0	74.3	.035	.151
27	56.3	22.0	71.8	.050	.215
29	53.6	22.0	69.3	.023	.099
33	48.0	22.0	64.7	.016	.069
35	45.2	22.0	62.1	.015	.065

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Tube Area	Date	Exp.	T _O	F	P _t	Level	PT#	Size
2870 C	8-03-53	143	97.4	33.0	738	710	519	4
No.	T _l -	P _s -	T _s -	CR _i	CR			
4	94.3	13.4	100.7	.644	2.769			
8	90.4	17.8	99.2	.637	2.739			
12	85.3	22.2	96.8	.419	1.802			
16	79.2	26.2	93.2	.325	1.398			
20	73.1	26.2	87.9	.269	1.157			
28	59.0	30.8	78.4	.148	.636			
32	51.9	30.8	72.7	.105	.452			
36	45.9	30.8	67.5	.068	.292			

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Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
2873	C	8-03-53	165	80.8	40.5	727	890	549	8
No.		<u>T_l</u>	<u>P_s</u>	<u>T_s</u>	<u>CR_i</u>	<u>CR</u>			
1		79.4	7.6	83.9	.061	.262			
3		76.5	15.3	85.5	.076	.327			
5		72.6	20.4	85.4	.187	.804			
7		68.1	24.4	83.4	.204	.877			
9		63.5	24.4	79.8	.197	.847			
11		58.7	25.5	75.7	.206	.886			
13		53.2	29.5	74.3	.146	.628			
15		48.0	28.0	69.5	.086	.370			
17		43.4	24.4	62.2	.048	.206			
19		37.8	26.9	60.2	.022	.095			

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Tube	Area	Date	Exp.	T _O	F	P _t	Level	PT#	Size
2975	C	6-14-53	116	97.6	31.7	675	557	519	4

No.	T ₁	P _s	T _s	CR'	CR
1	97.6	9.4	101.1	.309	1.329
3	95.0	12.2	101.2	.254	1.092
5	93.2	15.8	101.3	.299	1.286
7	91.0	18.2	100.5	.325	1.398
9	88.5	20.2	99.1	.348	1.496
11	85.9	22.2	97.8	.350	1.505
13	83.0	24.4	96.4	.333	1.432
15	80.0	25.0	94.0	.306	1.316
17	76.8	26.4	92.0	.256	1.101
19	73.5	27.6	89.7	.240	1.032
21	70.1	28.4	87.2	.211	.907
23	66.8	28.4	84.3	.188	.808
25	63.4	28.4	81.4	.177	.761
27	60.1	27.6	81.4	.137	.589
29	57.0	26.4	74.6	.090	.387
31	54.0	25.0	71.1	.063	.271
33	51.4	22.2	67.0	.029	.125
35	49.4	15.8	60.7	.019	.082
37	47.0	19.6	63.8	.018	.077
39	44.2	23.6	62.1	.020	.086
41	41.2	25.0	60.4	.023	.099

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Tube Area	Date	Exp.	T _o	F	P _t	Level	Size
0984 D		206	69.0	26.3	378	620	8
No.	$\frac{T_1}{-}$	$\frac{P}{s-}$	$\frac{T}{s-}$	$\frac{CR^1}{-}$	$\frac{CR}{-}$		
1	68.0	3.4	70.5	.038	.163		
3	66.0	5.7	70.2	.065	.280		
5	64.0	9.1	70.8	.216	.929		
7	61.1	13.0	69.7	.089	.383		
9	57.6	13.0	67.8	.088	.378		
11	53.7	14.7	65.7	.064	.275		

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Tube 1177	Area D	Exp. 157	T _o 74.0	F 28.2	P _t 447	Level 560	PT# 534	Size 4
No.	T ₁	P _s	T _s	CR _i	CR			
1	74.0	5.2	77.3	.082	.353			
3	72.4	6.6	76.7	.097	.417			
5	70.0	11.0	77.2	.188	.808			
7	66.7	13.6	75.9	.099	.426			
9	62.6	15.6	73.6	.083	.357			
11	58.2	17.6	71.0	.076	.327			
13	53.4	17.6	66.7	.038	.163			
15	48.5	18.2	63.0	.035	.151			

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Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
1178	D	7-13-53	189	85.2	27.0	500	687	534	8
No.		T ₁	P _s	T _s	CR _i	CR _t			
1		84.0	5.3	87.0	.092	.394			
3		83.0	7.0	86.0	.155	.667			
5		79.0	10.8	86.0	.270	1.161			
7		75.0	14.5	84.0	.244	1.049			
9		70.0	16.3	81.0	.200	.860			
11		65.0	17.8	78.0	.248	1.066			
13		59.0	19.8	74.0	.186	.800			
15		53.0	21.5	70.0	.158	.679			
17		47.0	21.5	65.0	.122	.525			
19		41.0	23.5	62.0	.070	.301			

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Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
1577	D	8-19-53	159	86.1	28.0	556	700	534	8
No.		T _l	P _s	T _s	CR _i	CR			
1		85.5	2.2	86.6	.072	.308			
3		83.6	7.0	87.0	.104	.446			
5		80.5	11.4	86.2	.160	.688			
7		76.8	13.9	84.9	.187	.803			
11		66.2	20.6	77.2	.149	.642			
13		59.7	23.1	72.5	.121	.519			
15		53.1	25.3	67.8	.105	.450			

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Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
2473	D	9-19-53	151	84.0	26.3	513	600	534	8

No.	T ₁	P _s	T _s	CR ⁱ	CR
1	82.0	5.4	86.0	.289	1.243
3	80.0	9.8	86.0	.165	.710
5	76.0	13.6	85.0	.207	.890
7	71.0	16.9	83.0	.232	.998
9	65.0	19.0	79.0	.208	.894
11	60.0	20.3	75.0	.176	.757
13	54.0	20.8	69.0	.147	.632
15	48.0	19.5	64.0	.071	.305

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Tube Area	Exp.	T _o	F	P _t	Level	Size
2575 D	157	74.0	26.5	421	530	8
No.	P _s	T _s	CR _i	CR		
1	5.1	77.4	.127	.546		
3	7.6	77.5	.174	.748		
5	11.0	77.7	.166	.714		
7	12.2	75.4	.189	.813		
9	14.3	74.9	.060	.258		
11	14.8	71.7	.093	.400		
13	14.8	67.8	.034	.146		
15	16.9	65.8	.019	.082		
17	16.9	62.0	.122	.525		
		T _l				
		74.0				
		72.3				
		70.1				
		66.7				
		62.9				
		58.7				
		54.4				
		49.9				
		45.3				

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Tube	Area	Date	Exp.	T _o	F	P _t	Level	PT#	Size
3571	D	3-29-53	70	67.0	29.0	432	265	509	4

No.	T ₁	P _s	T _s	CR ₁	CR
1	67.4	5.0	70.8	.024	.105
2	67.1	6.0	71.1	.031	.131
3	67.0	6.6	71.5	.031	.135
4	66.6	7.6	71.7	.033	.141
5	66.2	8.2	71.8	.037	.157
6	65.8	9.0	72.0	.035	.148
7	65.2	9.8	71.9	.028	.121
8	64.7	10.6	71.9	.043	.186
9	64.1	11.2	71.8	.041	.177
10	63.5	12.2	71.9	.069	.296
11	62.7	12.6	71.4	.071	.306
12	62.0	13.2	71.2	.076	.327
13	61.1	13.8	70.8	.085	.367
14	60.1	14.4	70.3	.097	.415
15	59.2	14.8	69.8	.074	.318
16	58.2	15.4	69.3	.100	.432
17	57.6	15.8	69.0	.122	.526
18	56.0	16.4	67.9	.068	.294
19	54.8	16.8	67.2	.056	.243
20	53.6	17.2	66.4	.074	.317
21	52.6	17.6	65.8	.054	.233
22	51.2	18.0	64.8	.058	.250
23	49.9	18.2	63.8	.054	.230
24	48.6	18.4	63.0	.044	.189
25	47.3	18.6	62.0	.040	.172
26	45.9	18.8	60.9	.044	.187
27	44.6	19.0	60.0	.043	.186

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Tube Area	Exp.	T _O	F	P _t	Level	PT#	Size
0960 DR	270	64.1	24.5	328	703	513	8
No.	$\frac{P}{S}$	$\frac{T}{S}$	CR _i	CR			
1	3.0	66.4	.011	.046			
3	6.5	68.1	.015	.065			
5	7.0	66.4	.020	.084			
7	11.5	67.4	.028	.120			
9	8.0	61.4	.030	.131			
11	12.0	61.8	.027	.115			

Tube Area	Exp.	T _o	F	P _t	Level	PT#	Size
2662 DR	109	60.9	26.7	352	310	9	8
No.	T ₁	P _S	T _B	CR _t	CR		
1	60.9	3.6	63.6	.017	.071		
3	59.7	6.8	64.8	.025	.107		
5	57.7	8.7	64.3	.052	.224		
7	55.2	10.2	63.1	.032	.138		
9	52.2	10.4	60.5	.025	.108		

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Tube	Area	Exp.	T _o	F	P _t	Level	PT#	Size
2690	DR	109	56.8	26.5	321	280	9	8

<u>No.</u>	<u>T_l</u>	<u>P_s</u>	<u>T_s</u>	<u>CR'</u>	<u>CR</u>
3	55.5	6.1	60.3	.017	.074
5	53.6	8.0	60.0	.014	.060

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Tube	Area	Exp.	T _o	F	P _t	Level	PT#	Size
4063	DR	164	59.7	25.5	286	355	513	8

<u>No.</u>	<u>T₁</u>	<u>P_s</u>	<u>T_s</u>	<u>CR_i</u>	<u>CR</u>
1	59.2	3.3	61.8	.010	.044
3	57.7	5.5	62.1	.012	.051
5	55.7	7.5	61.8	.015	.064
7	53.0	9.3	60.7	.021	.092

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Tube	Area	Exp.	T _o	F	P _t	Level	PT#	Size
1162	F	73	57.1	22.6	310	175	503	4

No.	T ₁	P _s	T _s	CR'	CR
5	56.7	4.6	61.0	.015	.065
9	55.2	6.8	61.0	.018	.077
13	52.8	8.8	61.0	.022	.095

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ABSTRACT

A method of calculating corrosion rates of aluminum-clad fuel elements from surface temperature, local power, and exposure time is presented. It is indicated that the main difference between in-pile and out-of-pile corrosion rates is a consequence of increased aluminum surface temperatures resulting from the heat transfer through the corrosion product film on the fuel element. A procedure for calculating this temperature rise is given.

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