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SIMPLIFIED PLUTONIUM CONVERSION EXPRESSION

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SIMPLIFIED PLUTONIUM CONVERSION EXPRESSION

Introduction

The purpose of this study was to find an accurate, simplified expression relating plutonium conversion to exposure which could be substituted for the lengthy sub-routine used to calculate conversions in the Process Optimization Program⁽¹⁾. In this program the conversion sub-routine, which is based on the program used to generate official values⁽²⁾, is used in an iterative manner such that many conversions are calculated in the computer's search for a single optimum point. A simplification of this sub-routine would reduce computer time (and hence, cost) for routine optimization runs.

Summary

The plutonium conversion-exposure relationship

$$y = ae^{-bM} + cM^2$$

where: y = conversion, grams Pu/MWD
e = exponential
M = exposure, MWD/Ton
a, b, c = arbitrary constants

was fitted to the data in HW-50300-B and found to fit very well in the ranges of normal exposure. Conversions calculated by this expression were found to deviate from accepted values by a maximum of about 0.07% for natural metal (interval $300 < M < 1000$) and 0.1% for enriched metal (interval $100 < M < 1500$). On the basis

(1) HW-64654, Turner, RL and CF Poor, "Process Optimization 709 Program," 4/6/60, (Secret).

(2) HW-50300-B, Hoba, DW, "Plutonium Conversion Tables," 11/1/60, (Secret).

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of this investigation, the above expression was felt to be sufficiently accurate for most purposes and has since been put into the Process Optimization Program.

Arbitrary constants a, b, and c for various reactor loadings are listed in Table I and the accuracy of each expression is also shown.

Other exponential forms were tried but none proved as satisfactory as the above expression.

TABLE I

Empirical Constants for $y = ae^{-bM} + cM^2$ and Accuracy of Formula for Various Tube Loadings

Fuel Type	Total Pieces/ Tube	Total Mixers/ Tube	Mixer Slug Spacing From Rear	Reactor	a	b x 10 ⁴	c x 10 ⁸	Max. % ⁽³⁾ Deviation
O-II-N	32	1	6-1-25	H,DR	0.96562	2.21526	3.0993	0.063 ⁽⁴⁾
O-II-N	34	1	6-1-27	D,F	0.96591	2.33073	3.4766	0.052 ⁽⁴⁾
O-II-N	34	1	7-1-26	B	0.96602	2.33970	3.5175	0.049 ⁽⁴⁾
O-II-E	34	1	6-1-27	D,DR	0.79459	1.50763	1.5103	0.102 ⁽⁵⁾
O-II-E	34	0	---	B,F,H	0.79179	1.49672	1.4864	0.097 ⁽⁵⁾
C-II-N	32	1	6-1-25	C	0.96523	2.17833	2.9984	0.065 ⁽⁴⁾
C-II-E	35	1	14-1-20	C	0.79503	1.48928	1.4795	0.102 ⁽⁵⁾
K-III-N	38	0	---	K	1.05020	2.18429	2.9705	0.067 ⁽⁴⁾
K-III-E	46	0	---	K	0.85305	1.46279	1.4056	0.078 ⁽⁵⁾

Discussion

Sample curves of per cent deviation from accepted values for conversions calculated by the expression

$$y = ae^{-bM} + cM^2 \quad (1)$$

are shown on Figure 1. No claims are made that an expression of the above form is the best possible fit for the tabulated data; however, the expression

$$y = ae^{-bM^c} \quad (2)$$

was tried for c = 0.5 and 1.0, and neither was found to fit as well as equation (1). (See Figure 2.) By a process of simple iteration, equation (2) was found to fit rather well when c = 0.83 (see Figure 3), but this form was discarded as

(3) Percent deviation from accepted values (BW-50300-B).

(4) Within interval $300 < M < 1000$.

(5) Within interval $100 < M < 1500$.

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Figure 1. Percent Deviation from Accepted Values of Conversion for K Reactors Calculated by

$$Y = ae^{-bM} + cM^2$$

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Figure 2. Comparison of Various Exponential Conversion Expressions for K-III-E.

Figure 3. Percent Deviation from Accepted Values of Conversion for K-III-E Calculated by $Y = ae-bM^c$ for Various Values of " c "

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Figure 4. Comparison of Exponential Conversion Expressions for K-III-E.

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being too difficult to evaluate in relation to any accuracy gained over equation (1), (see Figure 4).

Equation (1) has been programmed and is currently being used as the conversion sub-routine in the Process Optimization Program. It is felt that for most applications its accuracy will be adequate; however, the former program, with the lengthy conversion sub-routine, is available and can be used should the need arise.

Determination of the arbitrary constants for equation (1) was done in essentially two steps:

1. Transforming the tabulated data from grams Pu/ton U to grams Pu/MWD, by dividing conversion by exposure.

$$\frac{g}{T} \div \frac{MWD}{T} = \frac{g}{MWD} = y$$

2. Changing the basic expression to linear form by taking the natural log of both sides

$$y = ae^{-bM} + cM^2$$

$$\ln y = \ln(ae^{-bM} + cM^2) = \ln a + \ln(e^{-bM} + cM^2)$$

$$\ln y = \ln a - bM + cM^2$$

and solving the resulting expression by conventional methods.

For convenience and to maintain the desired accuracy, if these calculations are to be done by hand, converting the natural log terms to $\log_{10}$ may be desirable.

$$2.302585 \log_{10} y = 2.302585 \log_{10} a - bM + cM^2$$

Sufficient accuracy can be maintained by using seven-place log tables. A sample calculation, which may be used as a guide in evaluating constants for new reactor loadings, is shown in the appendix.

Arbitrary constants a, b, and c were determined for the common current central power zone charges. When the desired conversion data was not available in HW-50300-B, it was generated by the same computer program as was used for HW-50300-B. The total conversion was not printed out directly for loadings which included a mixer slug. For this type loading, conversions for the mixer slug are calculated separately by the program, and it was necessary to calculate total charge conversions at various exposures by hand. This was done in the following manner:

conversion for total charge $\frac{g \text{ Pu}}{T}$

$$= \frac{n_1 w_1 g_1 + n_2 w_2 g_2}{n_1 w_1 + n_2 w_2}$$

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where: n = number of slugs in charge
 w = slug weight, pounds
 g = conversion, $\frac{gPu}{T}$
1 denotes regular slug
2 denotes mixer slug

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APPENDIX

Sample calculation showing determination of arbitrary constants for $y = ae^{-bM} + cM^2$.

Given:	<u>Exposure (MWD/T)</u>	<u>Conversion (g PU/T)</u>
	400	322.55
	800	612.56
	1200	876.42
	$y_1 = 322.55/400 = 0.80638$	$\log y_1 = 0.9065397-1 = 0.0934603$
	$y_2 = 612.56/800 = 0.76570$	$\log y_2 = 0.8840586-1 = 0.1159414$
	$y_3 = 876.42/1200 = 0.73035$	$\log y_3 = 0.8635310-1 = 0.1364690$

$$2.302585 \log y_1 = -0.2152003 = \ln a - 400b + 1.6 \times 10^5 c \quad (1)$$

$$2.302585 \log y_2 = -0.2669649 = \ln a - 800b + 6.4 \times 10^5 c \quad (2)$$

$$2.302585 \log y_3 = -0.3142315 = \ln a - 1200b + 14.4 \times 10^5 c \quad (3)$$

$$0.0517646 = 400b - 4.8 \times 10^5 c \quad (2) - (1) \quad (4)$$

$$0.0472666 = 400b - 8.0 \times 10^5 c \quad (3) - (2) \quad (5)$$

$$0.0044980 = 3.2 \times 10^5 c \quad (5) - (4) \quad (6)$$

solving (6) for "c"

$$c = \frac{0.0044980}{3.2 \times 10^5} = 1.4056 \times 10^{-8}$$

substituting for "c" into (4) and solving for "b"

$$b = \frac{0.0517646 + 4.8 \times 10^5 (1.4056 \times 10^{-8})}{400} = 1.46279 \times 10^{-4}$$

substituting for "b" and "c" into (1) and solving for "ln a"

$$\ln a = -0.2152003 + 400(1.46279 \times 10^{-4}) - 1.6 \times 10^5 (1.4056 \times 10^{-8}) = -0.1589377$$

$$\log a = -0.1589377/2.302585 = -0.0690258 = 0.9309742-1$$

$$a = 0.85305$$

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