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FRINGE ISOTOPE PRODUCTION

AUTHOR

W. L. BUNCH.

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FRINGE ISOTOPE PRODUCTION

INTRODUCTION

The purpose of this work has been to determine the production rate of tritium in fringe Li-Al alloy columns with the degree of precision necessary for economic analyses of such reactor loadings (1,2). These results are provided for use in such an analysis.

SUMMARY

This experiment indicates the production rate of tritium in the outermost fringe tubes to be:

$$T = 0.0216 M_E = 0.175 M_t \quad \text{grams Ti for Li⁶ enriched} = 0.0213084 \text{ g. MWD}$$

where T = grams of tritium per full length (67 pieces) charge of Li-Al alloy material

M_E = MWD/Adjacent Ton of E Metal

M_t = MWD/Adjacent Tube of E Metal

The above values should apply for fringe loads utilizing greater or smaller quantities of E metal; that is, for isotope production loadings which are over or under-compensated from a reactivity standpoint. In the actual test load it was calculated that one gram of tritium and 13.5 grams of Pu were made for each 21.3 grams of U-235 burned up. During the same time interval the displaced uranium loading would have generated 24.3 grams of Pu and burned up 29.9 grams of U-235.

The factor which seems to limit the accuracy with which these data can be interpreted is the ratio of the activity of the cobalt pieces. This limitation is not due to the accuracy of the experimental determination of the ratios but due to the variation in the ratios which appears to exist. It can be seen that the ratio decreases from the bottom of the test load to the top and that the ratio decreases downstream (and presumably upstream) from the loading centerline. If the cause of this systematic variation can be found a correction might be applied. In the present analysis it was assumed that any large scale reactor loading would be subject to the same type of variations and that the average value from the test would approximate the average value for the larger loading.

DESCRIPTION OF TEST

Isotope production rates in materials placed within a reactor are governed by the neutron flux in which the material resides. In the case of fissionable materials (or paired columns containing significant fissionable material) the neutron flux can be evaluated by the heat generation rate in the tube. In full length isotope production columns it is necessary to determine the flux by some other method. The radioactivity of cobalt samples irradiated in the tubes has been used in this experiment to relate the flux level in the fringe mint columns to the flux level (as indicated by heat generation rate) of the adjacent E metal columns.

Cobalt has a long half-life (5.2 years) compared to the length of the irradiation (approximately one-half year); hence, the radioactivity of the cobalt pieces is directly proportional to the integrated exposure. The cobalt-aluminum mixture which was used in the test was designed to absorb neutrons at the same rate as either E metal or mint material. Therefore the volume average flux in an isolated cobalt-aluminum piece should be representative of the volume average flux in the E metal or mint piece which it displaced. The flux in the experimental E column and the fringe mint column is related to the radioactivity of the cobalt-aluminum pieces by the equation:

$$(1) \quad \phi_p = \frac{A_p \phi_e}{A_e}$$

where ϕ is the flux in neutrons per square centimeter per second and A is the cobalt slug activity in arbitrary units; the subscripts p and e mean poison (mint material) and experimental enrichment (E metal) respectively.

The flux in the E column is related to the heat produced in the process tube by the relation:

$$(2) \quad \phi_e = \frac{M_e \int_{tube} dx}{c(1+\delta) H_f \sigma_f \int_{\Delta t} f(t) dt \int_{tube} b(x) dx}$$

where M_e = MWD/Ton

c = 8.899×10^{-20} (MWD per Mev)(cc of E metal per Ton of E metal)
 $(1+\delta)$ = 1.064, where δ = fast fissions per thermal fission
 H_f = 200 Mev per fission

σ_f = 0.26 cm^{-1} , thermal fission cross section for E metal

$f(t)$ = the time function describing power level changes

$b(x)$ = the front-to-rear flux distribution

Tritium production in the fringe column is given by the relation:

$$(3) \quad T = \frac{g \sigma_a \phi_p \int_{\Delta t} f(t) dt \int_{tube} b(x) dx}{\int_{tube} dx}$$

where T = grams of tritium per full length column of mint slugs

g = 3.053×10^{-20} (grams of tritium per atom)(cc of Li-Al alloy per column of mint pieces)

σ_a = 0.511 cm^{-1} (Li-Al alloy absorption cross section for tritium formation)

Combining equations (1), (2), (3):

$$T = \frac{g \sigma_a A_p M_e}{c \sigma_f A_e (1+\delta) H_f} = K' M_e$$

To relate the fringe tritium production to the E metal production rate in the adjacent columns (the experimental columns were located in the third lattice unit) the exposure of this column must also be considered. The ratio of the fluxes in the experimental and adjacent E column are the same as the ratio of the exposures. The relation then becomes:

$$(4) \quad T = \frac{g \sigma_a A_p M_e}{c \sigma_f A_e M_E (1+\delta) H_f} \quad M_E = K M_E$$

where M_E is the exposure of the adjacent E metal columns. (Note: the ratio $\frac{M_e}{M_E}$, which is equal to the product of the ratios M_e/M_E and A_p/A_e , was estimated to be approximately 0.7 from extrapolation of tube power data early in the test. The final data yield a value of 0.69 for this ratio). The value of K which is obtained from the experimental data and the previously listed constants and cross sections is 0.0216 grams of tritium per tube of mint per MW/AT of E with an estimated accuracy of $\pm$ two percent. Using this value it is calculated that one gram of tritium is produced in a tube for each 46.3 MWD/AT of E metal. Utilizing the flux distribution in the test zone (1) it was calculated that one gram of tritium and 13.5 grams of Pu were made for each 21.3 grams of U-235 burned up.

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The displaced natural uranium would have produced 24.3 grams of Pu and burned up 29.9 grams of U-235 during a similar time interval. It is apparent that an insufficient amount of E metal was used to maintain heat generation in the test region even though an adequate reactivity match was achieved. Radial enrichment could be used in conjunction with fringe isotope production to maintain heat generation in the region.

The front-to-rear flux traverse of the E metal columns is shown in Figure I where the data from the four tubes are averaged together. This averaging was necessary because the metal was not segregated during discharge. A cosine curve has been drawn which describes the upstream portion of the data rather well; it is impossible to obtain a good bit of the downstream data with a simple cosine. The mint pieces were weaseled also, but the data were found to scatter quite badly. The scatter is undoubtedly due to non-homogeneous impurities in the material and has been noted previously. It was assumed that the front-to-rear distribution in the mint was the same as in the adjacent E metal. This should be a good assumption because of the close proximity of the material and the absence of perturbing effects such as control rods or off-centered flattening columns. However, it was disturbing to find that the flux ratios were not constant along the column.

Table I presents a summary of the weasel data which were obtained from the cobalt pieces. These data were obtained using the under water air column located in the KW basin, a facility originally utilized for Project Bluenose work. Numerous readings were taken of each individual piece and were found to be consistent even though the pieces were rotated or moved; there appears to be no question about the reproducibility of the readings.

TABLE I
COBALT SLUG DATA

Pc. No.	Tube No. A	Tube No. B	Rel. Radioactivity A (e col)	Rel. Radioactivity B (p col)	A_p/A_e Ratio of Activities	A_p/A_e Corrected* Ratios	Test Pile Results A	Test Pile Results B
1	1894	1896	.902	.525	.582	.550	13.416	13.556
2	2094	2096	.703	.338	.481	.481	13.614	13.625
3	2294	2296	.915	.472	.516	.516	13.698	13.802
4	2594	2596	.710	.322	.454	.454	13.929	14.089
Average						0.500		

* Corrected ratios include a small correction for end effects of the pieces located adjacent to natural uranium. Loading scheme in the reactor is as follows: A series were in E metal columns, B series in mint columns. Pieces numbered 1 and 3 were centered in the metal charge, pieces number 2 and 4 were located one quarter of the way from the downstream end of the active charge.

Also included in Table I are the Hanford Test Pile reactivity results. These indicate that the composition of the test pieces was rather consistent insofar as cobalt content is concerned, since most of the reactivity effect is due to the cobalt. The pieces also matched the reactivity effect of mint whose slug dih averages about 14.

Over four hundred determinations of the tube powers of the adjacent E metal columns and the experimental E columns were obtained during the test period to evaluate the exposure ratios of these tubes (M_e/M_g). With an estimated accuracy of approximately $\pm$ four percent on the individual determinations, the resulting ratio is calculated to be within $\pm$ 0.2 percent. The ratio (M_e/M_g) was 1.377.

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The large spread in the ratios of the activity of the cobalt pieces limits the accuracy of any analysis based upon this experiment. A better method of obtaining production data obviously is to process the material; unfortunately, a rather large uncertainty exists even in that case.

W. L. Bunch

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Research & Engineering Operation
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Work performed with
Operational Physics Operation
Research & Engineering Operation
IRRADIATION PROCESSING DEPARTMENT

1. HW-51723, "Interim Report, Operational Physics Aspects of Production Test IP-14-AC, Use of E Metal in Shield Protection," W. L. Bunch, dated 9-18-57.
2. HW-53345, "Supplement B, Production Test IP-14-AC, Use of E Metal in Shield Protection," W. L. Bunch, L. W. Lang, dated 10-25-57.

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Relative Flux as a Function of Distance From Metal Centerline-

Cosine $\frac{17x}{800}$ shown for Comparison

Figure I

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