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A NEUTRON SOURCE DESIGN WHICH ELIMINATES RADIOCHEMISTRY FROM THE PROCESS OF PRODUCTION

by

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Abstract

Neutron sources involving the alpha particle bombardment of fluorine, boron, and beryllium are discussed with a view to eliminating the necessity of separating the alpha emitter, polonium, from the material irradiated in the production pile. The case of fluorine is treated in some detail and compared with a more conventional source.

Introduction

The usual neutron source is small in physical size, since the polonium is used in purified form.[1] For some applications, the small size of these sources is a distinct advantage, as in calibration work. The application of neutron sources to drive exponential piles and sigma piles does not appear to place a stringent restriction on the dimensions of the source. Assuming that this is true, various possibilities are open for exploration. It is also apparent that the separation of polonium from the bismuth which is irradiated in the production piles is at least inconvenient and somewhat expensive. Since the sources must be replaced periodically (polonium has a half life of 138 days) this inconvenience and expense is repetitive for a continuing program. Hence, it is of interest to develop a source which does not require this separation.

Discussion

Neutron sources may be prepared by mixing the light element which serves as the target for the alpha particles with the bismuth and exposing the mixture to neutron bombardment in the production pile. After discharge, the slugs should produce neutrons at a calculable rate due to the bombardment of the light element by the polonium alpha particles. After the source has decayed below a usable level, it could possibly be reactivated by recharging it in a production pile. This would eliminate all the steps involving polonium chemistry.

The yield of target materials when bombarded with polonium alpha particles is 70 neutrons per 10^6 alpha particles for beryllium on a thick target basis, 22 for boron, and 12 for fluorine.[2] The high neutron capture cross section of boron makes it an undesirable material. The utilization of beryllium would require the use of an intermetallic compound of bismuth and beryllium, which does not appear to exist, or an alloy of the two metals. Either situation would give the homogeneous mixing required for the efficient use of the polonium produced in the slug. Production of an alloy might require the use of powder metallurgy techniques, which involves some hazards because of the toxicity of beryllium. Using the method given in TID-5087, the yield of such a target, assuming very homogeneous mixing, has been calculated and is reported in Table I.

TABLE I

Neutron Yield in Neutrons per 10^6 Alpha Particles of a Target Composed of Bismuth and Beryllium

Atomic Ratio of Beryllium to Bismuth	Neutrons per 10^6 Alpha Particles
1	12
2	20
3	26
6	38
8	43
10	47
Pure Beryllium	70

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Fluorine has been considered as the target element. A suitable compound, BiF_3, does exist, having a density of 5.32.[3] The yield from this target is calculated to be 5.7 neutrons per 10^6 alpha particles. This is unfavorable when compared to beryllium. Since the density of BiF_3 is known, it is possible to calculate the size of the source necessary to be of use at Hanford. Such calculations cannot be made for the bismuth-beryllium proposal until the density of the material is known.

The yield of polonium in a column of bismuth metal may be predicted by using the following expression:[4]

$$\text{Curies per column} = x\, y\, E\, \overline{\Delta T}\, \overline{F}\, Q$$

In the above expression, x and y are the correction factors for the length of the bismuth column and the surrounding metal columns respectively, E is the weighted average pile efficiency, $\overline{\Delta T}$ the average temperature rise in °C of surrounding uranium columns, $\overline{F}$ the average water flow in gpm in the surrounding uranium columns and Q is a function of exposure and decay time and conversion constants. Using appropriate conversion constants the expression may be written in terms of tube power in watts. A correction must be made in the expression because the atomic concentration of bismuth is only 42.6% of that of the pure metal. The expression is then converted to give neutrons per second for the charge in the tube by using the yield given above.

$$\text{Neutrons per second per tube} = x\, y\, E\, Q\,(\text{average power in watts of adjacent tubes})\; 342.0$$

In HW-25477, an example is given of a column of 57 pure bismuth slugs, for which E = 0.9, x = 1.0, y = 1.04 and the average adjacent tube power has 157 kw. The total neutron emission per second at the time of discharge, and 30 days following discharge has been determined for a column of BiF_3 irradiated under similar conditions by obtaining the appropriate values of Q from HW-25477. These values are reported in Table II. Table III is similar, except that the adjacent tube power has been assumed to be 500 kw.

TABLE II

Neutron Emission of 57 BiF_3 Slugs at the Time of Discharge and after 30 Days Decay as a Function of Pile Irradiation Time at 157 Kilowatt Adjacent Tube Power

Exposure Time in Days	Source Strength at Discharge in Neutrons/Second	Source Strength 30 Days after Discharge in Neutrons/Second	Curies of Po at Discharge (42.6% of Normal Column)
30	0.92×10^7	1.05×10^7	44
60	1.96	1.90	93
90	2.86	2.71	135
120	3.66	3.41	173
150	4.37	3.96	206
180	4.91	4.46	233
210	5.52	4.86	261
240	6.02	5.27	285

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TABLE III

Neutron Emission of 57 Slugs at Time of Discharge and after 30 Days of Decay as a Function of Pile Irradiation Time at 500 KW Average Adjacent Tube Power

Exposure Time in Days	Source Strength at Discharge in Neutrons/Second	Source Strength 30 Days after Discharge in Neutrons/Second	Curies of Po at Discharge (42.6% of Normal Column)
30	2.93×10^7	3.34×10^7	140
60	6.24	6.04	295
90	9.10	8.62	430
120	11.6	10.8	552
150	13.9	12.6	655
180	15.6	14.2	740
210	17.5	15.4	829
240	19.1	16.7	907

Comparison of the values in the above tables with the specifications of polonium boron source PB-304 are of interest. That source contained 306.7 curies of polonium and emitted 1.6×10^8 neutrons/second.[5] 800 curies of polonium would be required to produce the same number of neutrons with a BiF_3 neutron source. The lengthy exposure time indicated in Table III could be shortened by using more tubes, i.e. more slugs, or irradiating the 57 slugs in the central portion of two or more tubes, which would also make for greater uniformity.

As has been indicated, the use of beryllium in the place of fluorine, or in addition to fluorine, would increase the efficiency of this type of source, perhaps by a factor of 5.0. J. E. Minor has suggested mixing BeF_2 with the BiF_3 in order to increase the efficiency. If the atomic concentration of bismuth was not decreased appreciably, this suggestion would have much merit. As with the beryllium-bismuth alloy, no calculations can be made until the density and composition of such material is known. If such information is obtained, a much more favorable comparison with conventional sources, such as the one mentioned above, may be expected.

Footnotes

1 GEH-20411, Neutron Source PB-304 (OGT-11585), V. V. Hendrix

2 TID-5087

3 International Critical Tables

4 HW-25477, Method of Predicting Polonium Yields, G. C. Fullmer, W. A. Cummings, A. W. Halliday

5 GEH-20411

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