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TIME BEHAVIOR ANALYSIS OF THE PHOTONEUTRON
AND POLONIUM-BERYLLIUM SOURCES IN THE APPR-1

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Alco Products, Inc.
Post Office Box 414
Schenectady, New York

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Abstract

The time behavior of the strength of the Po-Be source to be used in the APPR-1 was investigated assuming that, besides the polonium decay, burnup of the polonium and beryllium is taking place. The results indicate that the initial source strength will be 3.8×10^7 neutrons per second and will decay exponentially with a half-life of about 138 days. The effect of the burnup was found to be small. A correction for change in polonium distribution due to elevated source temperature was indicated.

The strength of the photoneutron source was found for various times after shutdown assuming that it is irradiated by the gammas from fission products formed in the core during 1000 hours of operation at 10 megawatts. The number of neutrons formed per second was found to vary from about 8×10^7 to 3×10^7 in a period from 6 hours to 9 days after shutdown with 70% of the change occurring in the first 3 days.

An analysis for the case of the photoneutron source being irradiated only by the gamma photons coming from the activated shielding material shows that only a few thousand neutrons are formed per second.

Po-Be Source

The APPR-1 contains a Po-Be source containing 15 curies of polonium dispersed by volatilization over the surface of beryllium metal in the form of a pressed powder. The beryllium powder is contained in a cylindrical volume of one-half inch diameter and height inside of small welded, stainless steel can. On the basis that 90% of the available volume is occupied by beryllium and using the data of reference 1, the initial strength of this source is estimated to be 3.8×10^7 neutrons/second. The

neutron producing reactions are:

We assume that the source strength is proportional to the number of beryllium atoms present and the decay rate of the polonium.

$$h = \xi N \lambda P \dots \dots \dots (1)$$

where

h = source strength - neutrons/sec.

ξ = proportionality constant

N = number of beryllium atoms

λ = decay constant of polonium = $5.02 \times 10^{-3} \text{ days}^{-1}$

P = number of polonium atoms

We further define

ϕ_n = thermal neutron flux at source = $4 \times 10^{13} \frac{\text{neutrons}}{\text{cm}^2\text{-sec.}}$
from reactor

σ_N = thermal neutron capture crosssection for Be = .01 barn

σ_P = " " " " " " P_0 = unknown

t = time

the subscript "zero" indicates initial value

The equation for the number of polonium atoms as a function of time, assuming burnup and decay, is

$$P = P_0 \exp - [\lambda + \phi_n \sigma_P] t \dots \dots \dots (2)$$

The number of beryllium atoms at any time, assuming loss due to alpha capture and burnup, is:

$$N = N_0 \exp \left[\frac{\phi P_0 \lambda}{(\lambda + \phi_n \sigma_P)} \left\{ \exp [-(\lambda + \phi_n \sigma_P) t] - 1 \right\} - \phi_n \sigma_N t \right] \dots \dots (3)$$

Substituting into (1) and evaluating ξ in terms of initial conditions gives:

$$\eta = \eta_0 \exp \left[\frac{\eta_0}{N_0 (\lambda + \phi_n \sigma_P)} \left\{ \exp [-(\lambda + \phi_n \sigma_P) t] - 1 \right\} - \left\{ \lambda + (\sigma_P + \sigma_N) \phi_n \right\} t \right] \dots (4)$$

A consideration of the magnitudes of the variables shows that this equation may, with very little error, be reduced to

$$\eta = \eta_0 \exp [-(\lambda + \phi_n \sigma_P) t] \dots \dots \dots (5)$$

Using equation 5, the quantity η/η_0 is plotted in Figure 1 for the cases $\sigma_P = 0$ and $\sigma_P = 100$ barns. It is felt that the crosssection for polonium is probably in this range. Figure 2 shows the source strength decay using the estimated initial source strength of 3.8×10^7 .

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FIGURE 1

RELATIVE SOURCE STRENGTH VS TIME

σ_p = neutron crosssection for Po^{210} - BARNES

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It is stated in reference 1 that if any source is heated above 150°C, the decay cannot be expected to follow that of polonium. This is due to a redistribution of the polonium. Under prolonged heating, it is expected that the source strength will at first change rapidly while the polonium is redistributing itself, then, when the polonium reaches some equilibrium distribution, the source strength decay will follow that of the polonium. In the APPR-1, the source is expected to be in a region where the temperature is about 210°C, hence one can expect an initial decline in source strength after startup. On the basis of data given in reference 1 on the change of efficiency of a standard source as a function of the time the source was held at 850°C, we estimate that our source will drop to about 40% of its original efficiency in 600 days at 210°C and not change much thereafter. Source strength curves corrected for change in efficiency appear in Figure 2.

Photoneutron Source Strength

The photoneutron source in the APPR-1 consists of a beryllium block, 3" x 3" x .5", packaged in a 1/8" stainless steel box and located on the skirt, half way up the active core. The reaction giving the neutrons is the photodisintegration process:

A curve of the crosssection of this reaction as a function of energy appears in Figure 3. Reference 2 was consulted for the number and energy of photons emitted by fission products or their progeny which have energy above the threshold. Eight gammas were found. One nucleus listed as giving a 1.65 Mev gamma (La^{140}), was omitted since it appears that recent work places the energy of this photon as nearer 1.60 Mev. (See reference 3).

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FIGURE 3
PHOTODISINTEGRATION* CROSS-SECTION OF Be^9

* GUTH AND MULLINS — "THEORY OF THE
PHOTO AND ELECTRO-DISINTEGRATION OF Be^9 "
PHYSICAL REVIEW 76, 234, (1949)

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FIGURE 4

NUMBER OF PHOTONEUTRONS PRODUCED PER
SECOND AS A FUNCTION OF TIME AFTER
SHUTDOWN ASSUMING 1000 HOURS OF PREVIOUS
OPERATION AT 10 MEGAWATTS

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The method of calculating the γ flux at the source position, considering that the distribution of the fission products in the core is not uniform, is similar to that used in reference 4. In this analysis, the actual core is replaced by 3 solid cylinders of different radius but of the same height as the actual core. The power level, and hence the fission product density, in each cylinder is adjusted according to the volume of the cylinder and the average power level in the portion of the core it is supposed to represent. The largest cylinder has the same diameter as the actual core. The flux at the source due to each cylinder is calculated separately using the formulas of reference 5, and the results are added. In the calculations it is assumed that the smaller cylinders are shielded by inactive core material out to the source position. Gamma ray absorption coefficients at different energies are calculated for the core using the curves of reference 5 and assuming that the core is composed of 80% water, 19.6% iron and .4% uranium.

The neutron source strength at any time is calculated from

$$h = N \sum_{i=1}^8 \phi_i \sigma_i$$

where h = number of photoneutrons produced per second

N = total number of Be^9 atoms

ϕ_i = γ flux at the i th energy and at a particular time.

σ_i = crosssection at the i th energy

The time behavior enters the problem through ϕ_i which depends on the density of fission products which in turn depend on the time of operation previous to shutdown and the power level. In this study, an operating period of 1000 hours at 10 megawatts was assumed. Reference 2 gave fission product decay curves from which densities at various times could be calculated. The results are shown in Figure 4.

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An analysis was made of the photoneutron source level due to irradiation of the beryllium block by gamma photons from activated shielding material. The one reaction found which gave a photon of energy above the threshold was

Using the data for stainless steel from references 6 and 7 and the thermal neutron fluxes for the APPR-1 reported in reference 7, we calculated the photoneutron level due to irradiation by the thermal shield. The results indicated an exponentially decaying level of 2.6×10^3 neutrons per second after 1 day of shutdown. The contribution of the other shields is expected to be very small because of shielding by the inner shields.

CONCLUSIONS

During the entire core life of the APPR-1, one may expect the overall source level to remain at approximately its initial value because, even though the polonium beryllium source has decayed from a level of about 4×10^7 to 4×10^5 neutrons/second in 2 years, the photoneutron source level will reach the order of 10^7 neutrons per second in about 1 month after startup and remain at this level.

If all the spent fuel elements are removed, however, the source level will fall to that of the polonium-beryllium source. This is because the gamma flux due to activated iron in the shielding material produces negligible photoneutrons in the beryllium block.

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Calculation of Residual Activity in APPR-1 Reactor Components
After Shutdown.

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Author - J. H. Rosolowski

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