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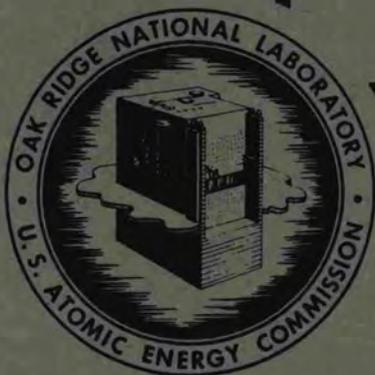
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ABSOLUTE DETERMINATION OF POWER
PRODUCED IN A NOMINALLY
ZERO POWER REACTOR
Stuart Snyder



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APPLIED NUCLEAR PHYSICS DIVISION

ABSOLUTE DETERMINATION OF POWER PRODUCED IN A
NOMINALLY ZERO POWER REACTOR

Stuart Snyder*

DATE ISSUED

MAY 15 1956

*Pratt and Whitney Aircraft

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ABSOLUTE DETERMINATION OF POWER PRODUCED IN A
NOMINALLY ZERO POWER REACTOR

Abstract

A method has been developed whereby the power produced in a low power reactor can be determined. Use is made of gamma-ray analysis of a sample of the fuel. The rate of decay of a fission product, as measured by the intensity of one of the gamma-rays produced during its decay, was used to determine the production rate of the fission product at the point in the reactor where the fuel element piece was located. This is related to the fission rate by the fission product abundance. Using catcher foils one obtains relative power traverses. From these the relative power distribution and the average relative power can be determined. The ratio of average relative power to relative power yields absolute power when normalized to the absolute fission rate at the measured position.

The measurement of power production in high power reactors is more or less easily accomplished by calorimetric means or by chemical assay of fission product production. For obvious reasons these techniques cannot be used to measure power production in a nominally zero power reactor. Reactors of the latter type are most commonly found in critical experiment facilities where fission rate distributions and power levels provide useful information in experimental reactor studies. In the method described below gamma-ray analysis is substituted for the less sensitive chemical analysis.

Using information about the nuclear properties of U-235 fission products,¹ it was decided that the fission product Ba¹⁴⁰ and its daughter La¹⁴⁰ would provide excellent indices of the fission rate. Ba¹⁴⁰ has a relative abundance in fission products of 6.3%. It has a half-life of 12.80 days, and the daughter product La¹⁴⁰ has a half-life of 40.2 hr. In addition, the 1.6-Mev gamma-ray emitted during the decay of La¹⁴⁰ is isolated and is more intense than any higher energy gamma-ray produced by fission products with half-lives comparable to or greater than that of Ba¹⁴⁰.

After a decay time of several days have elapsed, the only higher energy gamma-ray produced in quantity occurs at 2.5 Mev and is also produced during the La¹⁴⁰ decay. The 2.5-Mev gamma-ray is one-tenth as intense as the 1.6-Mev gamma-ray. However, the peak efficiency for

1. J. O. Blomeke, "Nuclear Properties of U-235 Fission Products," ORNL-1783 (Oct. 1955).

a 3 x 3 in. NaI(Tl) crystal decreases sufficiently with energy so that the apparent intensity ratio is 30 to 1. Thus the 1.6 Mev gamma-ray is sufficiently isolated to give an accurate measure of the decay rate of La^{140} .

During exposure there is a constant rate of production, k , of the parent per gram of fuel:

$$k = \alpha \int^u \Sigma_f(u) \phi(r, u) du dr \quad (1)$$

where α is the relative abundance of the fission product.

The relation between daughter concentration, exposure time, and time elapsed between the end of an exposure and the middle of the counting period is given by

$$N_2 = k \left[\frac{1}{\lambda_2 - \lambda_1} (1 - e^{-\lambda_1 t_e}) (e^{-\lambda_1 t} - e^{-\lambda_2 t}) + \frac{1}{\lambda_2} + \frac{1}{\lambda_2(\lambda_2 - \lambda_1)} e^{-\lambda_2 t_e} - \frac{1}{\lambda_2 - \lambda_1} e^{-\lambda_1 t_e} e^{-\lambda_2 t} \right] \quad (2)$$

$$N_2 = c(t, t_e)k \quad (3)$$

where

N_2 = daughter concentration,
 t_e = exposure time,
 t = time elapsed between the end of exposure and counting.

The decay rate of the daughter, $\lambda_2 N_2$, can be determined experimentally provided the concentration, N_2 , does not change appreciably during the counting period. It can be shown that for short exposures the concentration of the daughter reaches a maximum 82 hr after the end of exposure. This is a broad maximum and the concentration varies less than 1% during an interval of a day about the maximum. Furthermore, the small decay constant of the parent makes the concentration a slowly varying function of time. Thus long counting times can be tolerated where power levels are quite low.

From Eq. (3)

$$\lambda_2 N_2 = \lambda_2 c(t, t_e)k \quad (4)$$

where $\lambda_2 N_2$ is obtained experimentally. Solving Eq. (4) for k we can then obtain the fission rate and thus the power production rate.

In the reactor studied, the fuel elements were 4-mil-thick metallic sheets of uranium in which the U-235 isotopic content was about 90%. A 3/8-in.-dia piece of one of these elements was selected for study. The element, which had no previous exposure, was placed at one of the more reactive fuel positions, and the power level was increased with a constant period to some arbitrary final level which was maintained during an effective exposure time of 4.2 hr.² In future runs the foil diameter can be increased to 3/4 in. and the exposure time standardized to 1 hr.

After 175 hr had elapsed, the gamma-ray spectrum from the 3/8-in.-dia foil was measured with a 3 x 3 in. NaI(Tl) crystal and a 20-channel analyzer. The differential pulse height distribution is shown in Fig. 1. At an elapsed time of 178.67 hr, the pulse height distribution, due to the 1.6-Mev gamma-ray, was examined on an expanded scale.

The area under the peak is proportional to the number of disintegrations which occurred during the counting period. The area is determined after background counts and counts due to Compton-scattered gamma-rays have been subtracted from the curve. The curve must have the form of the Gaussian error function

$$y = y_0 e^{-h^2x^2} \quad (5)$$

Taking the log of both sides of Eq. (5) one obtains h^2 and y_0 as shown in Fig. 2. But

$$\lambda_2 N_2 \propto A = \int_{-\infty}^{+\infty} y dx = y_0 \int e^{-h^2x^2} dx \quad (6)$$

Thus
$$A = \frac{y_0 \sqrt{\pi}}{h} \quad (7)$$

The fission rate is obtained by adjusting the peak efficiency of the crystal for 1.6-Mev gamma-rays, the solid angle subtended by the crystal, attenuation in the polystyrene absorber, the relative intensity of the 1.6-Mev gamma-ray in La^{140} decay, the relative abundance of Ba^{140} in the fission products, and the weight of the section of the fuel element. The fission rate for this experiment was 5.8×10^7 fissions per second per gram of fuel element at the point where the section was located. The ratio of average relative power to relative power at the point under consideration was 0.265 and the average fission rate was 1.54×10^7 fissions per gram of fuel; hence, the power level during the 4.2-hr exposure was 16.6 watts.

In addition to this low power run with a solid fuel reactor, a sample of fuel which had been exposed at a high power level for an

2. E. L. Zimmerman, "A Graphite Moderated Critical Assembly," Y-881 Appendix A (Dec. 7, 1952).

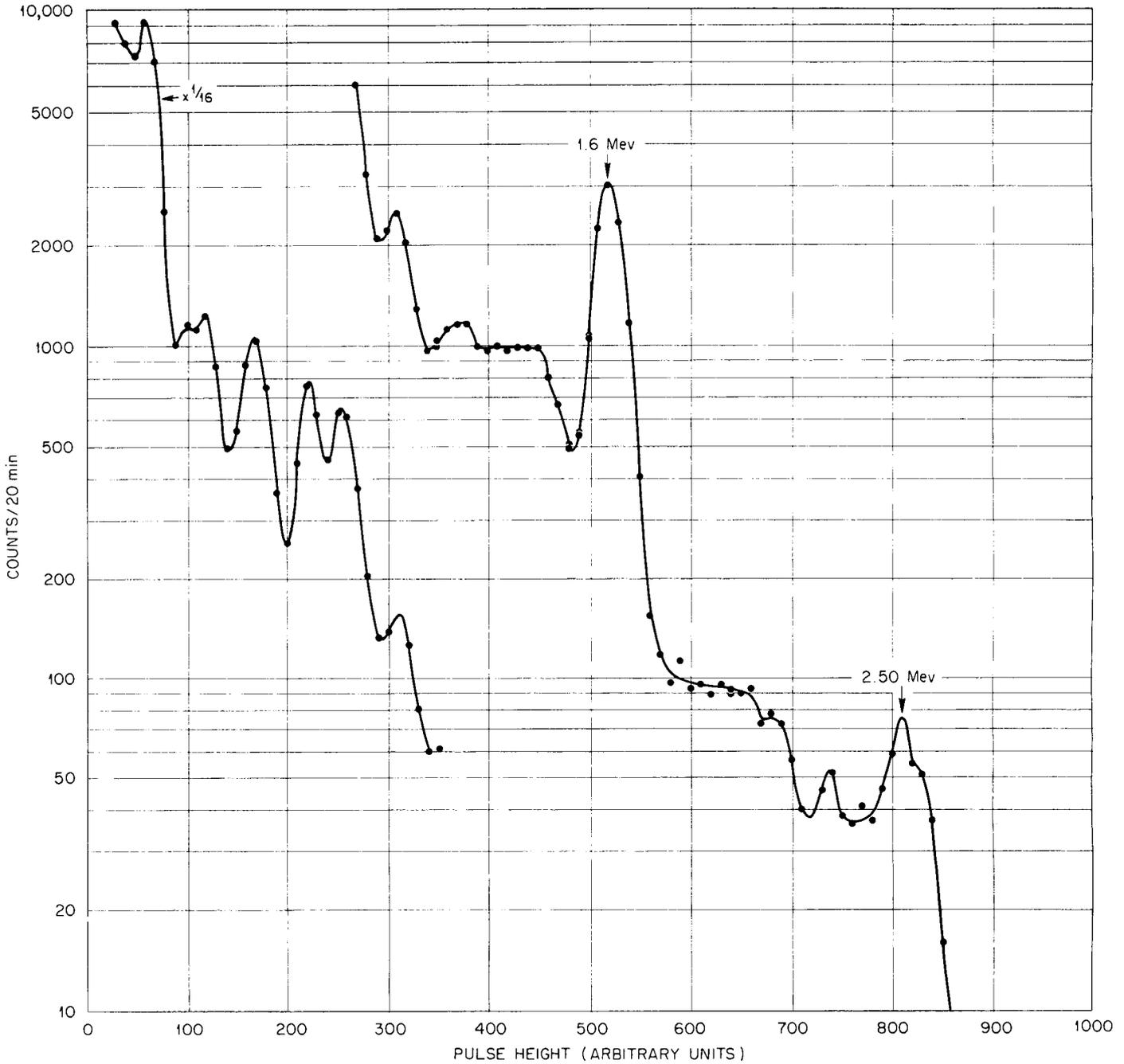


Fig.1. Gamma-Ray Pulse Height Spectrum from Exposed Fuel Element Section .

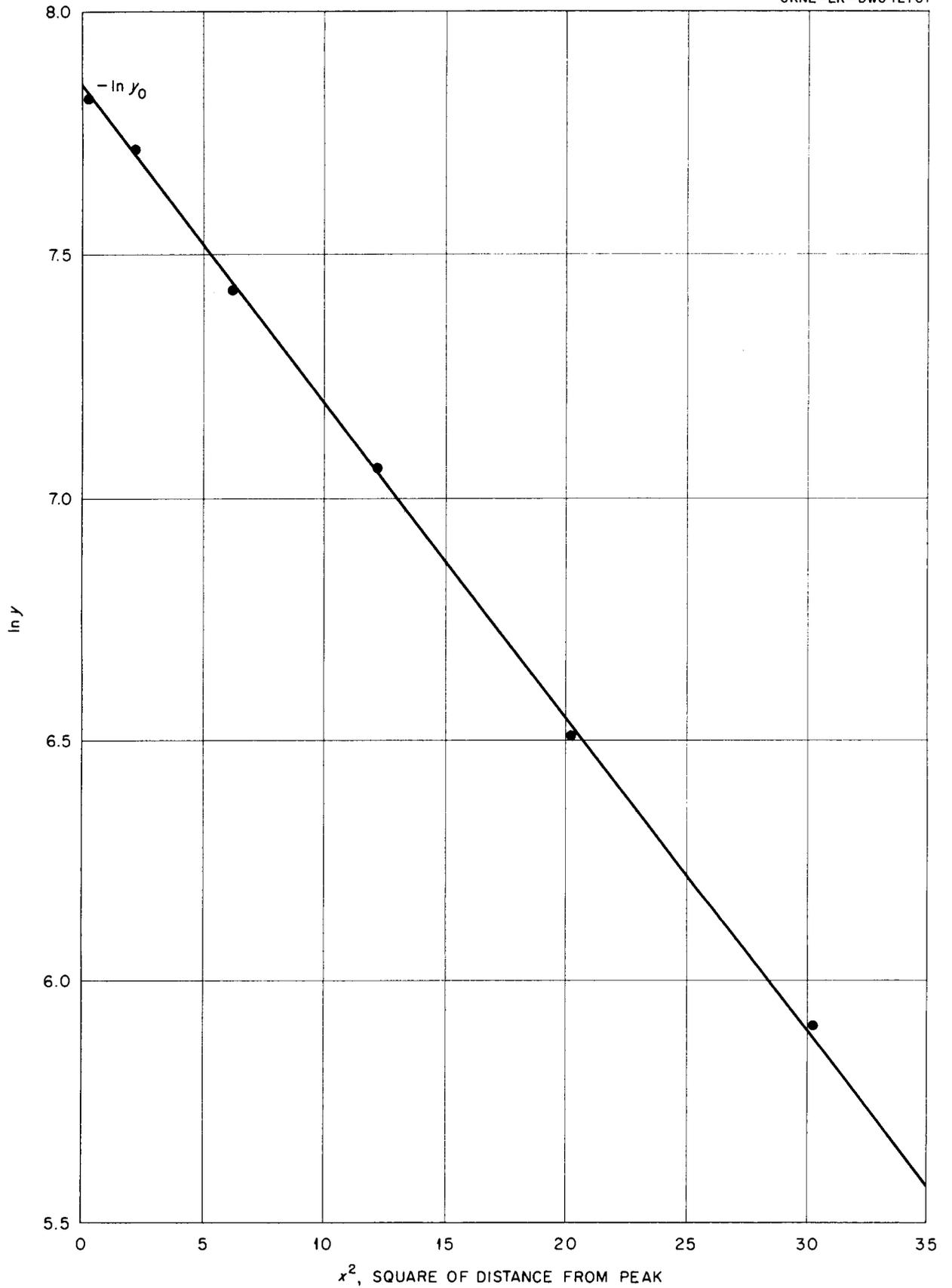


Fig. 2. $\ln y = \ln y_0 - h^2 x^2$

indeterminate period was taken from a homogeneous aqueous fuel reactor. Since time-integrated power was high it was possible to perform a chemical analysis for fission products as well as a gamma-ray analysis. The result in fissions per milliliter from a chemical analysis of Ba¹⁴⁰ was 2.6×10^{12} while the result from gamma-ray analysis was 2.8×10^{12} fissions per milliliter.