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Power Deposition Measurements at the LAMPF Neutron Radiation Effects Facility

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POWER DEPOSITION MEASUREMENTS AT THE LAMPF NEUTRON RADIATION EFFECTS FACILITY

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ABSTRACT

A calorimeter has been used in the LAMPF A-6 neutron radiation effects area to measure the power deposition about 20 cm from the isotope production targets. The measured value is about $2 \text{ w/cm}^3/\text{mA}$, in reasonable agreement with previously calculated values.

I. INTRODUCTION

Recent efforts to characterize the irradiation environment at the LAMPF Radiation Effects Facility^{1,2} have included calculation of the power deposited in material located adjacent to the neutron sources.³ Measurement of this power deposition is important in checking the calculations and to the cooling of experiments located nearby. To measure the power produced, a calorimeter consisting of an inner copper cylinder supported on a stainless steel rod and surrounded by an outer shell of copper was constructed (Fig. 1). Two thermocouples were mounted on both the inner and outer cylinders and both cylinders were also equipped with electrical heaters to allow calibration of the calorimeter prior to use.

COPPER CALORIMETER

Fig. 1.

A cross-section of the calorimeter.

II. EXPERIMENTAL

The rate at which the temperature of the inner cylinder changes is given by:

$$mC \frac{\partial T_{in}}{\partial t} = pV - hA(T_{in} - T_{out}) - \epsilon\sigma A(T_{in}^4 - T_{out}^4), \quad (1)$$

where

m = mass of inner cylinder (g)

C = heat capacity (J/(g·K))

p = density of power generated (w/cm³)

V = inner cylinder volume (cm³)

h = heat transfer coefficient ($\text{w}/(\text{cm}^2 \cdot \text{K})$)

A = inner cylinder surface area (cm^2)

ϵ = inner cylinder emissivity

σ = Stefan-Boltzmann constant

T_{in} = inner cylinder temperature (K)

T_{out} = outer cylinder temperature (K)

An automated system measured temperatures every 45-50 s, thus allowing the inner and outer cylinder temperatures and the rate of change of the inner cylinder temperature to be determined. The power input can be directly computed if the coefficients $B1 = mC$, $B2 = hA$, and $B3 = \epsilon\sigma A$ are known. The mass, heat capacity, and area of the inner cylinder are known, while the heat transfer coefficient and emissivity must be estimated. The required coefficients were actually determined by supplying measured electrical power to the heaters attached to the inner and outer cylinders while the temperatures were recorded. This allowed us to solve for the three unknown coefficients, resulting in $B1 = 23.3 \text{ (J/K)}$, $B2 = .037 \text{ (w/K)}$, and $B3 = 9.31 \times 10^{-11} \text{ (w/K}^4\text{)}$. The measured coefficients were used in analyzing the experimental results.

The calorimeter was placed at the front end of radiation effects stringer #3 where it was approximately 20 cm below the proton beam line. The calorimeter's position along the beam line was such that it should have received a neutron flux within about 20% of the maximum value calculated.¹ The calorimeter was separated from the neutron/charged particle source by at least 0.3 cm of steel, comprising the stringer tube in which the calorimeter was installed. It is possible that an additional steel plate about 1-1.5 cm thick was, in fact, also shielding the calorimeter. The time and temperature readings were made as described in the calibration section; however, beam current readings could not be implemented due to equipment problems. Beam current readings were therefore taken from a one-day plot of the beam current vs time.

III. RESULTS AND DISCUSSION

The power input (in watts) to the calorimeter was calculated from Eq. (1) using the measured temperatures and times as input, together with the empirically determined coefficients listed. The results are shown in Fig. 2a. The beam current as a function of time is given in Fig. 2b. Figure 3 shows the power input divided by the beam current in milliamps. The fluctuating line was obtained by taking a moving average of three points for each of these quantities to average out the rapid fluctuations in the beam current. The straight line is a linear least squares fit to the fluctuating data, on the assumption that the power density per milliamp should be constant. The average value of the power density per milliamp is $2.1 \text{ watts/cm}^3/\text{mA}$. For the present conditions, a simple model of power deposition predicts power densities of about 1.8 to $2 \text{ w/cm}^3/\text{mA}$, depending on whether a 1 cm thick steel plate is or is not present just above the calorimeter. These calculated values are thus in good agreement with our measured values and lend confidence to the measured values.

Fig. 2a.

Power deposited in the calorimeter vs time.

Fig. 2b.

Proton beam current vs time.

Fig. 3.

Power density vs time. A three point moving average smooths the curve. The straight dashed line is the result of a least squares fit to the power density vs time.

The power density at the neutron irradiation effects area has been calculated in detail using the MCNP and HETC codes³ for several geometric arrangements of isotope production targets and shielding. The results show that for the position along the beam line where power deposition reaches a maximum, peak values of about 6.5 watts/cm³/mA are to be expected in stainless steel, with a rapid drop to about 0.8 watts/cm³/mA at a depth of 6 cm. There is also a large variation in the power deposited with position along the beam line, the peak power decreasing from 6.5 to 1.2 watts/cm³/mA, when one moves opposite the beam stop, about 50 cm downstream from the position of maximum power deposition. The simple model^{*} has been checked against this calculation and agrees to within 15%.

Further measurements of the heating are planned as part of neutron dosimetry measurements and will be performed at various locations along the beam line, as well as with varying shielding thicknesses.

* Information provided by Joey B. Donahue, Group MP-7, Los Alamos National Laboratory, January 1985.

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