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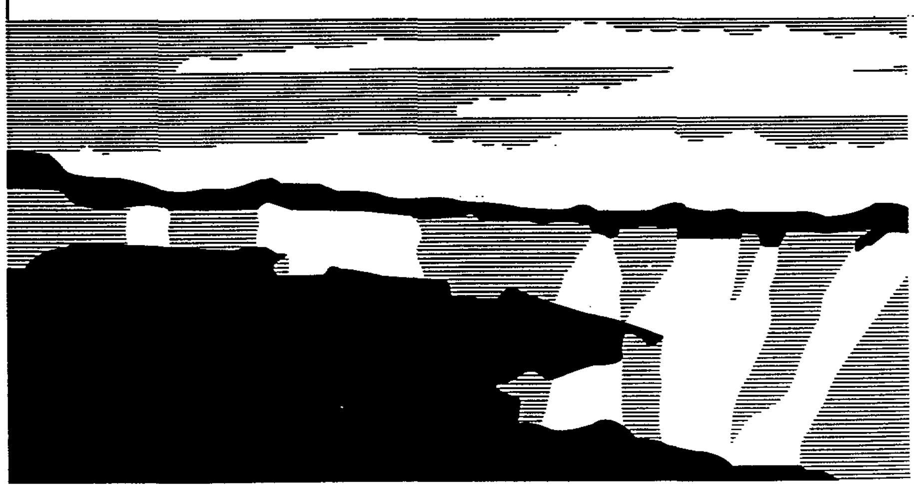

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DETERMINATION OF MIXED PROTON/NEUTRON FLUENCES IN THE LANSCE IRRADIATION ENVIRONMENT

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ABSTRACT

In support of the Accelerator Production of Tritium (APT) program, several materials were exposed to a high-energy proton and spallation neutron environments. Large differences in mechanical property changes in this environment are expected compared to the typical fusion or fission systems. To make proper dose correlations, it is important to accurately quantify the fluences. Activation foils consisting of a stack of disks of Co, Ni, Fe, Al, Nb and Cu were irradiated concurrent with mechanical testing samples in the Los Alamos Spallation Radiation Effects Facility (LASREF) at the Los Alamos Neutron Science Center, (LANSCE) facility. The irradiation consisted of an 800 MeV, 1 mA proton beam and a W target in the beam provided a source of spallation neutrons. The maximum proton fluence was around $3x10^{21}$ p/cm^2 and the maximum neutron fluence approximately $3x10^{20}$ n/cm^2. After irradiation, the foils were withdrawn and the radioactive isotopes analyzed using gamma spectroscopy. From initial estimates for the fluences and spectra derived from the Los Alamos High-Energy Transport (LAHET) Code System (LCS), comparisons to the measured levels of activation products were made. The Na-22 activation products in the Al foils were measured from different regions of the target in order to profile the spatial levels of the fluences. These tests gave empirical confirmation of the proton and neutron fluences of the irradiated samples throughout the target region.

I. INTRODUCTION

Activation measurements have been used for many years to measure neutron fluence and spectra [1]. With knowledge of the appropriate cross-sections, it is possible to use the production of radioactive isotopes to measure neutron flux in particular energy ranges. The present work uses the same technique and extends it to mixed proton/neutron environments. The target region of the LANSCE accelerator was configured to perform a materials irradiation to explore the changes in mechanical properties in high-energy proton and spallation neutron environments in support of the APT project [2]. The LANSCE accelerator delivers an 800 MeV, 1 mA proton beam and a W neutron source was used as a neutron production target. Configuration of the target inserts is shown in Fig. 1. The W neutron source is labeled 18A. The other components consist of containers for samples or other test materials. Samples were placed in various locations in and out of the beam to achieve a mix of irradiation conditions. The current analysis focuses on sample tubes in the 18C and 17A inserts which were in the proton beam downstream of the neutron source. The distribution of protons and neutrons across the tubes, and the fluences in those tubes, is being quantified. Packages of foils were placed in proximity to the samples inside of the tubes specifically to measure the fluences. Additional analysis will be done from modeling of the target region by the LAHET Code System (LCS) [3].

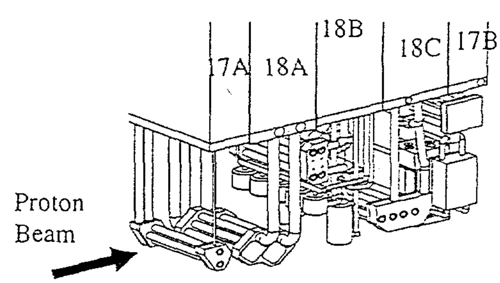

Figure 1. Configuration of the targets in the LANSCE accelerator.

II. PROCEDURE

A. Experimental Procedure

The activation foils were placed alongside mechanical test samples into water-cooled tubes in the target region of the LANSCE accelerator. These samples were then exposed to a high-energy proton beam with a Gaussian profile and with $2\sigma = 3$cm. The activation foils consisted of stacks of six, 3mm diameter disks of Cu, Co, Fe, Al, Nb and Ni. The disks were punched from sheets of material >99.98% purity. Upon completion of approximately six months of irradiation, the targets were removed and the activation foils counted to determine the levels of radioactive isotopes present. The counting was performed by the CST-11 group at LANL using counters specifically configured to handle the high-activity foils.

B. Calculation Procedure

The irradiation set-up was also modeled using the LCS code to estimate the fluences of protons and neutrons. A model was created of the target area in relation to the incoming proton beam and the LAHET code was run using $2x10^7$ particles. This provided sufficient statistics for an accurate profile of the proton and neutron fluence estimates across the tubes.

III. RESULTS/CALCULATIONS

The quantity of isotopes generated from the Al(n,x)Na-22 reaction was measured by gamma spectroscopy. Several foils were counted to provide data as a function of position in two separate tubes. The neutron activation cross section was used for both the protons and neutrons, as the proton cross section was not available. As most of the particles are protons at >200 MeV, where the cross sections are expected to be very similar [4], this is considered a reasonable approximation.

An overall cross section for the Na-22 production was calculated by adding the cross section for each energy weighted with the expected flux at that energy.

$$\Sigma_t = \frac{1}{\phi_t}\int \Sigma(E)\phi(E)dE \qquad (1)$$

Equation 1 expresses the relationship of overall cross section where Σ_t is the integrated cross section, φ_t is total flux, $\Sigma(E)$ and $\varphi(E)$ are energy dependent cross section and flux, respectively.

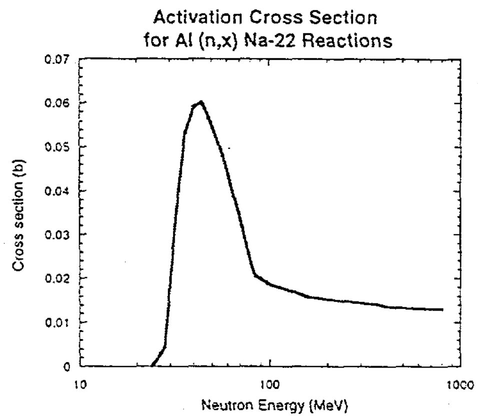

Figure 2. Activation cross section for Al (n,x) Na-22 reaction vs. neutron energy.

Fig. 2 shows the Na-22 cross section as a function of neutron energy. The overall average cross section using the proton and neutron spectra from the LCS calculations was determined to be 15.3 mb. The total integrated n/p fluences were calculated using this value and the Na-22 levels. Equation 2 relates the beam history and the half-life of Na-22 was used to calculate the production rate for the in-beam Al foil.

$$\alpha_0 = R_1\left(1-e^{-\lambda t_1}\right)\left(1-e^{-\lambda(t_2-t_1)}\right)e^{-\lambda(t_3-t_2)} + R_2\left(1-e^{-\lambda(t_3-t_2)}\right) \qquad (2)$$

Table 1 explains the variables and gives values for each. The approximate beam history for the irradiation is given in Fig. 3.

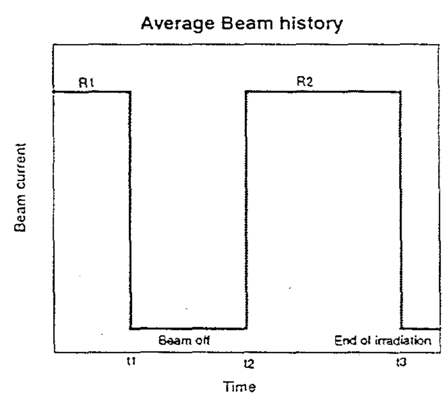

Figure 3. Beam history of irradiation at LANSCE accelerator.

The measured activity is given by α. R_1 and R_2 are Na-22 production rates for the two beam intervals, they are taken as proportional with $R_2 = 0.98R_1$ as the average beam current was slightly lower for the second irradiation period.

Table 1. Equation Variables

Variable		Value
α_0	Activity at shut-down	Measured
R_1	Prod. Rate, interval 1	
R_2	Prod. Rate, interval 2	R_2=0.98R_1
λ	Decay constant	0.266 1/y
t_1	Time of initial shut-off	0.172 y
t_2	Time restart of beam	0.556 y
t_3	Time at final shut-off	0.895 y

The production rate was used along with the reaction cross-section to determine the average proton beam intensity.

$$I = \frac{R_1}{\Sigma_t} \quad (3)$$

The beam intensity, I, was multiplied by the total irradiation time of 1.616×10^7 s, to calculate the sum total number of protons and neutrons from the irradiation. The experimentally determined values for the leading tube, tube 21, of 18C are shown in Fig. 4. The comparison with the integrated fluence from the LCS calculations is also shown. The results show good agreement for total fluence and distribution across the tube.

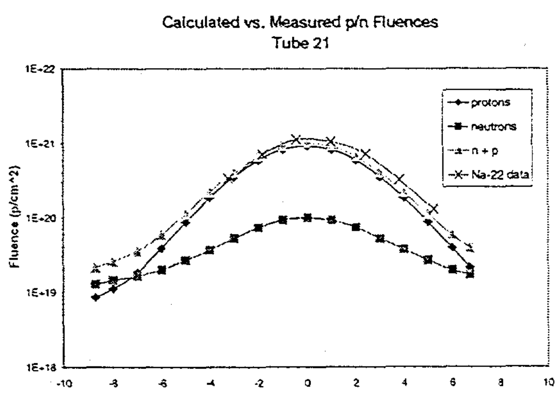

Figure 4. Total proton and neutron fluences as a function of position for Tube 21 from the 18C insert. The proton beam is centered at zero.

Calculations for the leading tube, tube 1, of the 17A insert were also performed. The results are shown in Fig 5. A comparison of the Na-22 activation data to the total p/n fluences calculated by LCS shows very good agreement, both in the peak and distribution of the fluence.

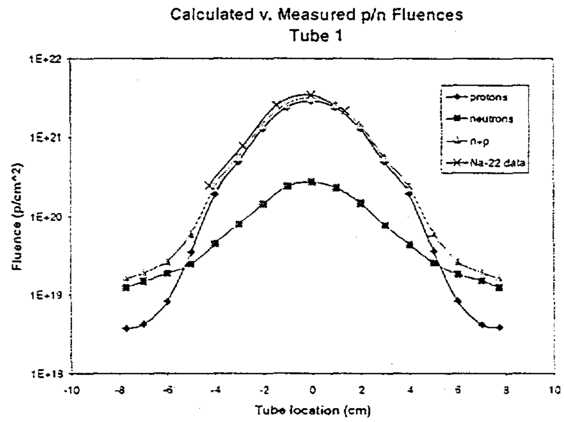

Figure 5. Total proton and neutron fluences as a function of position for Tube 1 from the 17A insert. The proton beam is centered at zero.

Until more detailed analysis is completed, the LCS model is the only source of information on the breakdown between protons and neutrons as a function of energy. The energy spectra of each for the center of the tube and the periphery are given in Fig. 6. The contributions to the fluences are dominated by the protons >200 MeV, particularly in the center of the beam with the neutron contributions more significant at the ends of the tubes (outside of the proton beam).

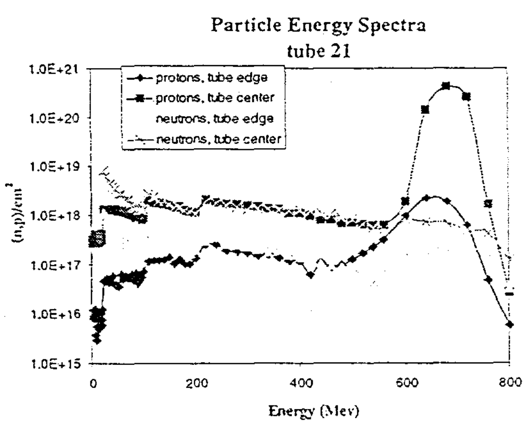

Figure 6. Energy spectra for protons and neutrons for center and periphery of a sample tube.

IV. SUMMARY AND CONCLUSIONS.

The results of LCS calculations combined with measured activation products have been used to provide estimates of mixed p/n fluences for interpretation of the effects of irradiation on mechanical properties of various metal alloys. Good agreement was seen between the calculated fluences and the activation measurements of Na-22 from the Al activation foils. The leading tube, tube 1, of the 17A insert saw a maximum combined fluence of protons and neutrons of around 3×10^{21} 1/cm^2. The combined fluence on tube 21 of the 18C insert received $\sim1\times10^{21}$ 1/cm^2. The distribution of fluence across the tubes also matched well with calculations.

A more complete analysis will be performed when tabulated energy-dependent activation cross-sections are available for the proton reactions.

ACKNOWLEDGMENTS

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