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Electron Energy Deposition in a Multilayered Carbon-Uranium-Carbon Configuration and in Semi-Infinite Uranium

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ELECTRON ENERGY DEPOSITION IN A MULTILAYERED
CARBON-URANIUM-CARBON CONFIGURATION
AND IN SEMI-INFINITE URANIUM

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ABSTRACT

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Absolute measurements of electron energy deposition profiles are reported here for electrons incident on the multilayer configuration of carbon-uranium-carbon. These measurements were for normally incident source electrons at an energy of 1.0 MeV. To complement these measurements, electron energy deposition profiles were also obtained for electrons incident on semi-infinite uranium as a function of energy and angle of incidence. The results are compared with the predictions of a coupled electron/photon Monte Carlo transport model. In general, the agreement between theory and experiment is good. This work was in support of the Reactor Safety Research Equation-of-State Program.

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INTRODUCTION

Previous measurements¹ in support of the pulsed electron beam experiments used to determine the vapor equation-of-state of materials in the Liquid-Metal Fast Breeder Reactor Program² have been made in low-Z/high-Z/low-Z three-layer configurations. In the case of Al-Au-Al, the agreement between theory and experiment is excellent, while in the case of C-Au-C and Be-Au-Be, significant discrepancies (in the low-Z material at the high-Z interface) are observed. In all cases, theory and experiment are in excellent agreement for deposition in the gold. At the time of these measurements, it was felt that the observed discrepancies might be a consequence of some inherent problem, either theoretical or experimental, with the low-Z materials. However, measurements of semi-infinite profiles for C and Be are in very good agreement with theory.¹

Based on these and earlier results, it was decided that additional measurements were needed. Of particular interest was the multilayer configuration C-U-C. Aside from the obvious importance of uranium as a fuel element, measurements of electron energy and charge albedos³ in uranium disagreed with theory by approximately 10 percent at 1.0 MeV. To complement the C-U-C measurement, electron energy deposition profiles were measured in uranium for normally incident source electrons at energies of 1.0, 0.5 and 0.3 MeV, and for 1.0 MeV source electrons incident at 60° from the normal. A brief description of the experimental method is given in the following section. Experimental results are then compared with the prediction of the one-dimensional, multimaterial coupled electron/photon Monte Carlo transport code, TIGER.⁴

Experimental Method

The apparatus consisted of an electron source, the experimental package, and the computer-based data collection and

analysis system. These have been described before^{1,3,5} so only a brief description will be given here.

The experimental package shown in Fig. 1 consisted of three layers, each containing a number of thin foils of the material appropriate to that layer. To measure the deposition profile in each layer, a thin calorimeter (of the same material as the layer involved) was placed at various positions within the layer. For the semi-infinite uranium profile measurements, a setup similar to the rear layer deposition in Fig. 1 was used, except the test material was entirely uranium.

The design of the calorimeters is described in detail in a previous publication.⁶ However, both carbon and uranium have high thermal emissivity so that thermal coupling of the calorimeters with the adjacent foils was excessive. To correct this situation, very thin aluminum (5×10^{-5} cm) heat shields were placed immediately before and after the calorimeters.

The data, consisting of the incident electron current (measured with a Faraday cup) and the calorimeter thermocouple voltage, were collected and processed by an on-line computer. For details of the method, see Ref. 5.

The calorimeters are normally calibrated by using a 100-kV positive ion accelerator to deposit energy at a well-defined rate. However, the aluminum heat shields used with these calorimeters presented a problem. The calibration of the carbon calorimeter is discussed in detail in Ref. 1. To check the performance of the carbon calorimeter, a point on the energy deposition profile in carbon was repeated and agreed with the previously reported value¹ to within 1.4 percent. The uranium calorimeter was calibrated as follows. First, using the positive ion accelerator the calorimeter was calibrated without the front heat shield and a calibration constant was determined. Then the second calibration constant was obtained with a thin aluminum foil in front which had a small hole to allow the ion beam to reach the calorimeter. Thus, two different constants were obtained. It was still necessary to demonstrate that the hole in the shield did not affect the calibration, since for electron

EXPERIMENTAL CONFIGURATION

Figure 1. Schematic of Experimental Apparatus for Measuring Electron Energy Deposition Profiles in Multilayer Configurations.

deposition the shield should not have this hole. This was accomplished by measuring the electron energy deposition at the surface of the uranium without a shield and again with the complete (no hole) heat shield. Using the first calibration constant for the no-shield case and the calibration constant obtained for the incomplete shield (with hole) for the second, agreement to within 1.2 percent (averaged over all energies) was obtained. Therefore we conclude that the hole in the shield does not significantly affect the calibration constant.

Results and Discussion

The results of the present measurement of the electron energy deposition profile for the multilayered configuration, C-U-C, are shown in Fig. 2. Electron energy deposition is plotted as a function of the accumulated fraction of the continuous-slowing-down-approximation (CSDA) range for normally incident 1.0 MeV source electrons. The values of the CSDA range used were 0.5508 gm/cm^2 and 0.8098 gm/cm^2 for carbon and uranium, respectively. The estimated uncertainty in the measured data is about 3 percent. Also shown in Fig. 2 in histogram form is the prediction of the coupled electron/photon Monte Carlo code, TIGER.⁴ The estimated statistical standard errors in the code results are generally less than 2 percent, except at very large depths.

Agreement between theoretical and experimental deposition profiles is generally good. However, when comparing with theoretical and experimental profiles for C-Au-C, there are discrepancies. In the C-Au-C case, the agreement between experimental and theoretical profiles is excellent in the gold, while the agreement is not good in the carbon near the low-Z/high-Z interfaces. The experimental deposition profile is 10 percent higher than the theoretical profile in the front carbon near the interface, while the experimental carbon profile is 10 percent lower than predicted in the rear carbon near the interface. In the C-U-C deposition measurements, the agreement in the uranium

Figure 2. Electron Energy Deposition Profiles in the Multilayer Configuration, C-U-C, for Normally Incident 1.0 MeV Electrons. (Solid circles are experimental values and histograms are results of calculations with the TIGER code.)

is only fair, with the experimental value being as much as 7 percent higher in the uranium near the front low-Z/high-Z interface. However, the agreement between theory and experiment in the carbon is much better, with the experimental value being only 2 percent higher in the carbon near the front low-Z/high-Z interface and 4 percent lower in the carbon near the rear high-Z/low-Z interface. Note that these are both within the combined uncertainties of experiment and theory. These differences in the comparisons for the two multilayer configurations are not understood at this time.

Electron energy deposition profiles in carbon have been reported earlier¹ and were found to be in close agreement with the theory. Thus, to complete the data set and for comparison with theory, electron energy deposition profiles were measured in uranium for normally incident source electrons at energies of 1.0, 0.5 and 0.3 MeV, and for 1.0-MeV electrons at an incident angle of 60 degrees.

The results of these measurements are shown in Figs. 3 through 6 as solid circles. The estimated uncertainty in these measurements is 3 percent. The open circles represent the theoretical values. The average deposition in the calorimeter is plotted against the total thickness of the front foils, expressed in units of fractional calorimeter thickness. This permits a more direct comparison and is especially desirable in those cases where a significant variation in the differential energy deposition over the calorimeter thickness is expected. The smooth curves were drawn as average data curves so that the experimental profiles could be integrated to obtain the total energy deposited for comparison with theoretical and previous measurements³ using a total-stopping calorimeter (thickness greater than the CSDA range). The integration was performed by constructing a histogram with an increment of 1 calorimeter thickness and summing the areas⁵ under the histogram. As previously noted, the results of the total-stopping calorimeter measurements and theoretical values differed by approximately 10 percent. The results obtained by integrating the differential

Figure 3. Electron Energy Deposition Profile in Semi-Infinite Uranium for 1.0 MeV Electrons at Normal Incidence. Solid circles are experimental values and open circles are results of a calculation with the TIGER code. Smooth curves represent data averaging for integration purposes.

Figure 4. Electron Energy Deposition Profile in Semi-Infinite Uranium for 0.5 Electrons at Normal Incidence. Solid circles are experimental values and open circles are the results of a calculation with the TIGER code. Smooth curves represent data averaging for integration purposes.

Figure 5. Electron Energy Deposition Profile in Semi-Infinite Uranium for 0.3 MeV Electrons at Normal Incidence. Solid circles are experimental values and open circles are results of a calculation with the TIGER code. Smooth curves represent data averaging for integration purposes.

Figure 6. Electron Energy Deposition Profile in Semi-Infinite Uranium for 1.0 MeV Electrons at Incident Angles of 60°. Solid circles are experimental values and open circles are results of a calculation with the TIGER code. Smooth curves represent data averaging for integration purposes.

measurements fall between the theoretical and total-stopping calorimeter measurements in all cases. The results of the three determinations of total energy deposited are shown in Table I. The percent difference between the two experimental determinations is 5 percent for the 1.0 and 0.5 MeV data, and 9 percent for the 0.3 MeV data. The experimental determinations agree within the total estimated uncertainty, except at 0.3 MeV where the agreement is slightly outside this range. It is disturbing, however, that all of the values from the differential measurements are higher than the total-stopping calorimeter measurements. The reason for this is unknown.

The differences between theory and experiment in the two carbon/high-Z/carbon multilayered configuration are of concern. Until they can be resolved, care should be taken in the interpretation of the predictions of the condensed history electron/photon Monte Carlo codes for multimaterial configurations.

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TABLE I

Total Energy Deposited

Electron Energy (MeV)	Angle of Incidence (degrees)	Theoretical Value (MeV)	Differential Measurement (MeV)	Total Stopping Calorimeter (MeV)
1.0	0	0.602	0.584	0.555
1.0	60	0.427	0.413	0.394
0.5	0	0.288	0.277	0.263
0.3	0	0.170	0.165	0.151

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