Stopping Powers and Differential Ranges for ^{79}Br and ^{127}I in UF_4†

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Stopping powers and differential ranges for ^{79}Br and ^{127}I ions in UF_4 have been measured in the energy range 20–100 MeV. A single empirical formula is given which represents the data for both ions in various elemental solids as well as in the compound UF_4. Application of the results to other compounds is suggested.

I. INTRODUCTION

A KNOWLEDGE of the differential energy loss by fission fragments in various solid materials is of interest in several fields of applied nuclear energy. For example, as shown by Miley,[1] the calculated efficiency of the fission electric cell, a direct radiation-electrical energy conversion device, depends on a precise knowledge of the energy spectrum of the fission fragments that escape from the fuel plate. In addition, the determination of reaction efficiencies in some chemonuclear experiments depends on the amount of energy deposited by fission fragments in the fuel plate.[2]

Relations frequently used to give the fragment energy at a particular point in its path require that the total range be known.[1,3,4] In the work reported here, differential energy loss values were obtained in the range 15–100 MeV for ^{79}Br and ^{127}I ions in polycrystalline UF_4. An empirical formula was found that predicts the present observations as well as those of earlier measurements in elemental solids.[5] The results allow extrapolation to other absorbers of known composition and to other ions of known mass and atomic number.

II. EXPERIMENTAL PROCEDURE

Multicomponent beams of ^{79}Br and ^{127}I from the Oak Ridge Tandem Accelerator with incident energies ranging from 15–100 MeV were passed through a thin film of polycrystalline UF_4. Shifts in pulse heights in a solid-state detector between an open beam run and an absorber run indicated the amount of energy lost in the absorber foil. The procedures for obtaining these beams and techniques for analyzing the data have been amply described elsewhere,[6–8] and will not be repeated here.

Several absorber foils were prepared by vacuum deposition on 70 $\mu g/cm^2$ carbon backings. Foil thicknesses were measured by α-particle dE/dx measurements using the stopping-power equations given by Whaling[9] with α particles from ^{241}Am, and by α counting of the absorber foils themselves. The isotopic concentration of the uranium was determined from the relative count rates of α particles from ^{234}U and ^{238}U. The two methods gave results that were in statistical agreement with less than 10% error. Energy spectra of the ion beam showed no crystal channel effects and the foils were therefore assumed to be polycrystalline.

III. RESULTS

Peak shifts in the ion energy spectra corresponding to as much as 8 MeV, after corrections for loss in the carbon backing,[5] were observed at the highest energy. The thickness of the foil used in these runs was (316 ± 30) $\mu g/cm^2$. Variations in the measured energy losses among the various runs was $\pm5\%$ or less. The energy loss divided by the foil thickness for both ^{79}Br and ^{127}I is shown in Fig. 1. The errors in the final determinations of the values for the individual points in Fig. 1 are considered to be less than $\pm15\%$.

The differential range is given by[10]

$$R(E)-R(E_0)=\int_{E_0}^{E}\left(\frac{dE'}{dx}\right)^{-1}dE'. \quad (1)$$

This integration was performed on the data obtained in the present experiment as well as data from earlier ex-

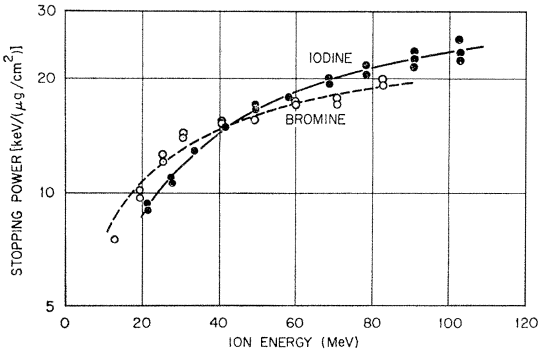

FIG. 1. Stopping power of UF_4 for ^{79}Br and ^{127}I.

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[1] George H. Miley, Nucl. Sci. Eng. **24**, 322 (1966).
[2] M. Steinberg, Nucleonics **21**, 151 (1963).
[3] J. N. Anno, Ph.D. thesis, The Ohio State University, 1965 (unpublished).
[4] Steve Kahn, Randall Harman, and Vernon Forgue, Nucl. Sci. Eng. **23**, 8 (1965).
[5] C. D. Moak and M. D. Brown, Phys. Rev. **149**, 244 (1966).
[6] C. D. Moak, J. H. Neiler, H. W. Schmitt, F. J. Walter, and G. F. Wells, Rev. Sci. Instr. **34**, 853 (1963).
[7] C. D. Moak, Nucl. Instr. Methods **28**, 155 (1964).
[8] S. Datz, T. S. Noggle, and C. D. Moak, Nucl. Instr. Methods **38**, 221 (1965).
[9] W. Whaling, in *Handbuch der Physik*, edited by S. Flügge (Springer-Verlag, Berlin, 1958), Vol. 34, p. 193.
[10] L. C. Northcliffe, Ann. Rev. Nucl. Sci. **13**, 67 (1963).

periments,[5] using a cutoff energy E_0 of 10 MeV. The results for ^{79}Br and ^{127}I are plotted against velocity in Figs. 2 and 3, respectively. Clearly, the differential ranges are of the form

$$R(v)=Kv-\Delta, \quad (2)$$

where v is the ion velocity and K and Δ depend on the ion and absorbing material. This is the velocity dependence predicted by Lindhard *et al.*[11] for heavy ions in this velocity region. The constant Δ contains a part of the total range over which nuclear stopping dominates and Eq. (2) simply expresses this part of the range as a constant.

Some authors[12,13] have suggested that the coefficient K in Eq. (2) contains the factor $A/\sqrt{Z}$, where A is the

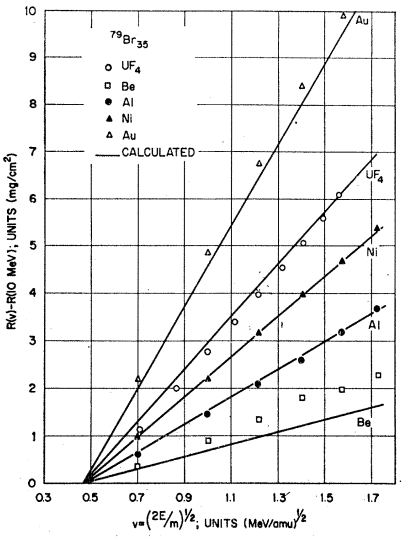

FIG 2. Differential range of ^{79}Br in various solids.

mass and Z is the atomic number of the stopping material. It was found that the experimental data in Figs. 2 and 3 could be represented to within less than 10% error by the following formula:

$$R(v)-R(10\text{ MeV}) = AZ^{-1/2}(0.0685Z_1^{1/2}v-0.182)\text{ mg/cm}^2, \quad (3)$$

where A and Z are as stated above, Z_1 is the atomic number of the ion, and $v=(2E/m)^{1/2}$ is the velocity of the ion in units of $(\text{MeV/amu})^{1/2}$. This function is plotted in Figs. 2 and 3 (solid lines). The data for Be do not agree with Eq. (3) as well as the data for the other elements. There is reason to expect that the film used

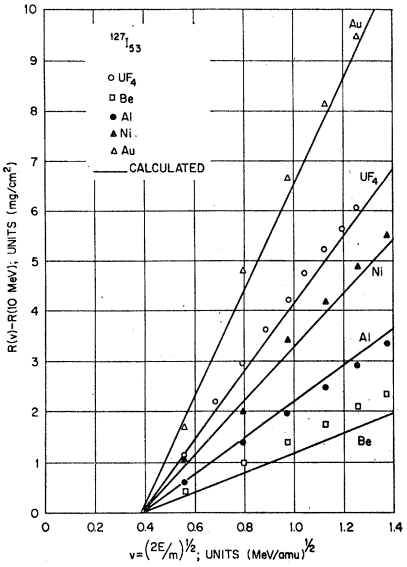

FIG. 3. Differential range of ^{127}I in various solids.

in those experiments[5] was oxidized. This would decrease the stopping power, therefore increasing the differential range, thus accounting for the discrepancy.

In generalizing Eq. (3) to include compounds, a method suggested by Domeij *et al.*[14] was used. The result is, in mg/cm^2,

$$R(v)-R(10\text{ MeV})=M(0.0685Z_1^{1/2}v-0.182)/(aZ_a^{1/2}+bZ_b^{1/2}+\cdots), \quad (4)$$

where M is the molecular weight of the compound and a, b, $\cdots$, are the number of atoms of each specie in the molecule, and Z_a, Z_b, $\cdots$, are the corresponding atomic numbers. Agreement of Eq. (4) with the UF_4 data is equally good.

It should be noted that the uranium compound used in this experiment is very similar to UO_2 and UO_3, the compounds normally used as sources of fission fragments from ^{235}U. Application of Eq. (4) to these compounds should yield results as accurate as in the present case.

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[11] J. Lindhard, M. Scharff, and H. E. Shiøtt, Kgl. Danske Videnskab. Selskab, Mat. Fys. Medd. **33**, No. 14 (1963).
[12] E. Segre and C. Wiegand, Phys. Rev. **70**, 808 (1946).
[13] P. W. Frank, Bettis Technical Report No. WAPD-BT-30, 1964, pp. 47–52 (unpublished).
[14] B. Domeij, F. Brown, J. A. Davies, and M. McCargo, Can. J. Phys. **42**, 1624 (1964).