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COMPARISONS OF RESULTS OBTAINED WITH SEVERAL PROTON PENETRATION CODES - PART II

W. Wayne Scott and R. G. Alsmiller, Jr.

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W. Wayne Scott* and R. G. Alsmiller, Jr.

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Abstract

Comparisons of the results obtained for a hypothetical problem with four different proton penetration codes have previously been presented in ORNL-RSIC-17. In this report, similar comparisons obtained with two additional proton penetration codes, CHARGE written by J. R. Lilley and W. R. Yucker and ASTROS written by R. Wallace, P. G. Steward, and C. Sondhaus, which have been added to the code collection of the Radiation Shielding Information Center, are presented. The hypothetical problem considered is to find the dose as a function of depth in tissue when a typical solar-flare proton spectrum is incident on a semi-infinite slab of aluminum followed by tissue and to find the dose as a function of depth when monoenergetic protons are incident on a semi-infinite slab of tissue.

I. INTRODUCTION

In a previous report[1] (hereinafter referred to as 1), results obtained for a hypothetical problem with four proton penetration codes, which at that time were included in the code collection of the Radiation Shielding Information Center, were compared. Since the writing of that report, two additional proton penetration codes have been added to the code collection, and in this report comparisons similar to those given in 1 and using these additional codes are presented.

The codes considered in this report are NTC,[2] written by W. E. Kinney of the Neutron Physics Division of the Oak Ridge National Laboratory, CHARGE,[3] written by J. R. Lilley and W. R. Yucker of the Missile and Space Systems Division of Douglas Aircraft Company, and ASTROS,[4] written by R. Wallace, P. G. Steward, and C. Sondhaus of the University of California

Lawrence Radiation Laboratory.* The NTC code used here is the same as that used in 1, and in the one case when the hypothetical problem considered here is the same as that considered in 1, the calculated results with NTC are the same as in 1.

In section II the major differences between the codes are described. In section III the hypothetical problems are described, and in section IV the results are given and discussed.

II. GENERAL CODE DESCRIPTION

NTC and CHARGE calculate the primary and secondary particle doses behind multilayer shields due to a prescribed incident flux. ASTROS is more specialized and calculates the primary and secondary particle doses for monoenergetic protons incident on tissue. Since detailed descriptions of the codes and the data used in the codes are given in references 2-4, only a few general comments on the main differences between the codes will be given here.

NTC employs Monte Carlo methods and is unique among the codes being considered in that the angular distribution of the secondary particles produced by all elastic and nonelastic nuclear collisions is taken into account. CHARGE and ASTROS use the straightahead approximation in treating particle production from nuclear collisions and consider explicitly only first-generation secondary particles. Furthermore, ASTROS neglects entirely any contribution to the dose from neutrons.

*These codes are packaged for distribution by the Radiation Shielding Information Center as CCC-7/NTC, CCC-70/CHARGE, and CCC-43/ASTROS.

NTC uses data developed by Bertini[5] for particle production from high-energy nonelastic collisions while CHARGE and ASTROS rely on the data calculated by Metropolis *et al.*[6] The data of Bertini and Metropolis *et al.* are in reasonable agreement, but because only a few energies and elements were considered by Metropolis *et al.*, considerable extrapolation and interpolation were required to obtain the data which are actually used in CHARGE and ASTROS. Therefore, the particle-production data used in these codes may be quite different from those used in NTC.

III. RESULTS AND DISCUSSION

In order to compare the codes under several different circumstances and at the same time use existing NTC calculations, several slightly different hypothetical problems are considered.

The first problem considered is to find the dose as a function of depth in tissue when a typical solar-flare proton spectrum is normally incident on an infinite slab of aluminum 20 g/cm^2 thick followed by a tissue* slab 30 g/cm^2 thick. The flare spectrum is taken to be exponential in rigidity, that is, to be of the form

$$J_P(>E) = K \exp^{\frac{P(30)}{P_o}} \exp^{-\frac{P(E)}{P_o}}$$

$$P(E) = \frac{1}{e}[E(E + 2M_P)]^{\frac{1}{2}} ,$$

where K and P_o are parameters which must be specified. For the first problem considered, K and P_o are taken to be 10^9 protons/cm^2 and 100 MV, respectively, and because of limitations in NTC only incident protons between 50 and 400 MeV

*In CHARGE and ASTROS tissue is approximated by water.

are considered. The problem so defined is the same as that considered in 1 and the NTC results given here are the same as those given in 1.* The comparisons between the results given by CHARGE and NTC are shown in Figs. 1 to 4.

In Fig. 1 the primary proton doses are compared. A primary proton is defined to be an incident proton that has undergone neither elastic nor non-elastic nuclear collision. The primary proton doses are in reasonable agreement except at the aluminum-tissue interface where the CHARGE result is slightly higher than that given by NTC. The secondary proton doses and secondary neutron doses are compared in Figs. 2 and 3, respectively. In both figures the agreement is rather good at all tissue depths. In Fig. 4 the total doses, that is, the sum of the preceding three graphs, are shown.

The calculations presented in Figs. 1 to 4 are directly comparable to those presented in Figs. 1, 5, 9, and 13 of ref. 1. In general, the degree of agreement between CHARGE and NTC is comparable to the degree of agreement between LPSC and LPPC and NTC.

The second problem for which comparisons between CHARGE and NTC have been made is the dose as a function of depth in the tissue when a solar-flare proton spectrum is isotropically incident on a slab of aluminum 20 g/cm^2 thick followed by a tissue slab 30 g/cm^2 thick. The shape of the flare spectrum is taken to be exponential in rigidity as before, but P_o is taken to be 80 MV and K is taken to be 2.388×10^9 $protons/cm^2$ so that the published NTC calculations of Irving *et al.*[8] could be used. In this case, as in the previous case, only incident protons below 400 MeV were considered, but unlike the previous case the low-energy protons, that is, the protons below 50 MeV, were considered. These low-energy protons do not get through the

*See also ref. 7.

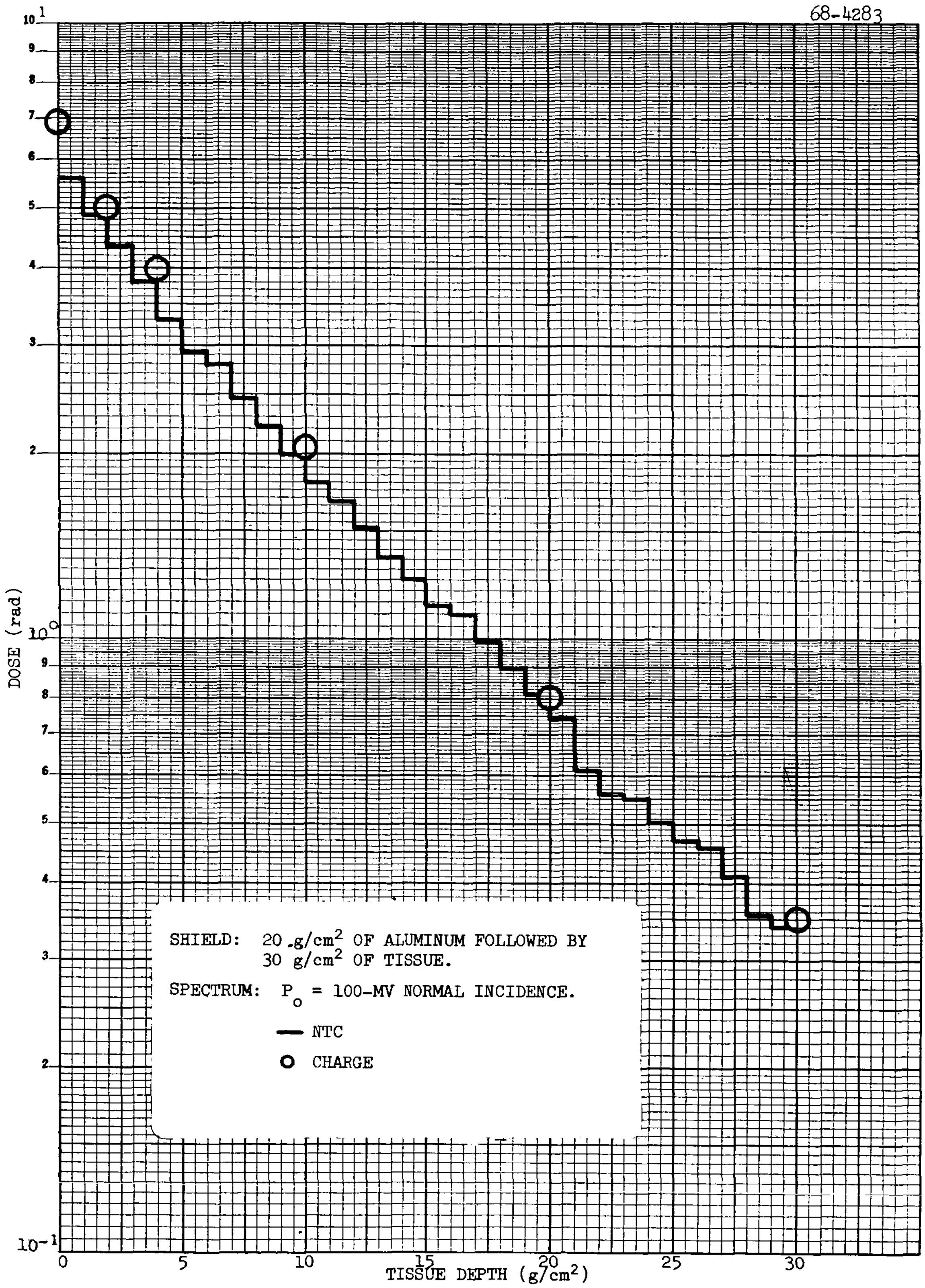

Fig. 1. Primary Proton Dose vs Depth in Tissue.

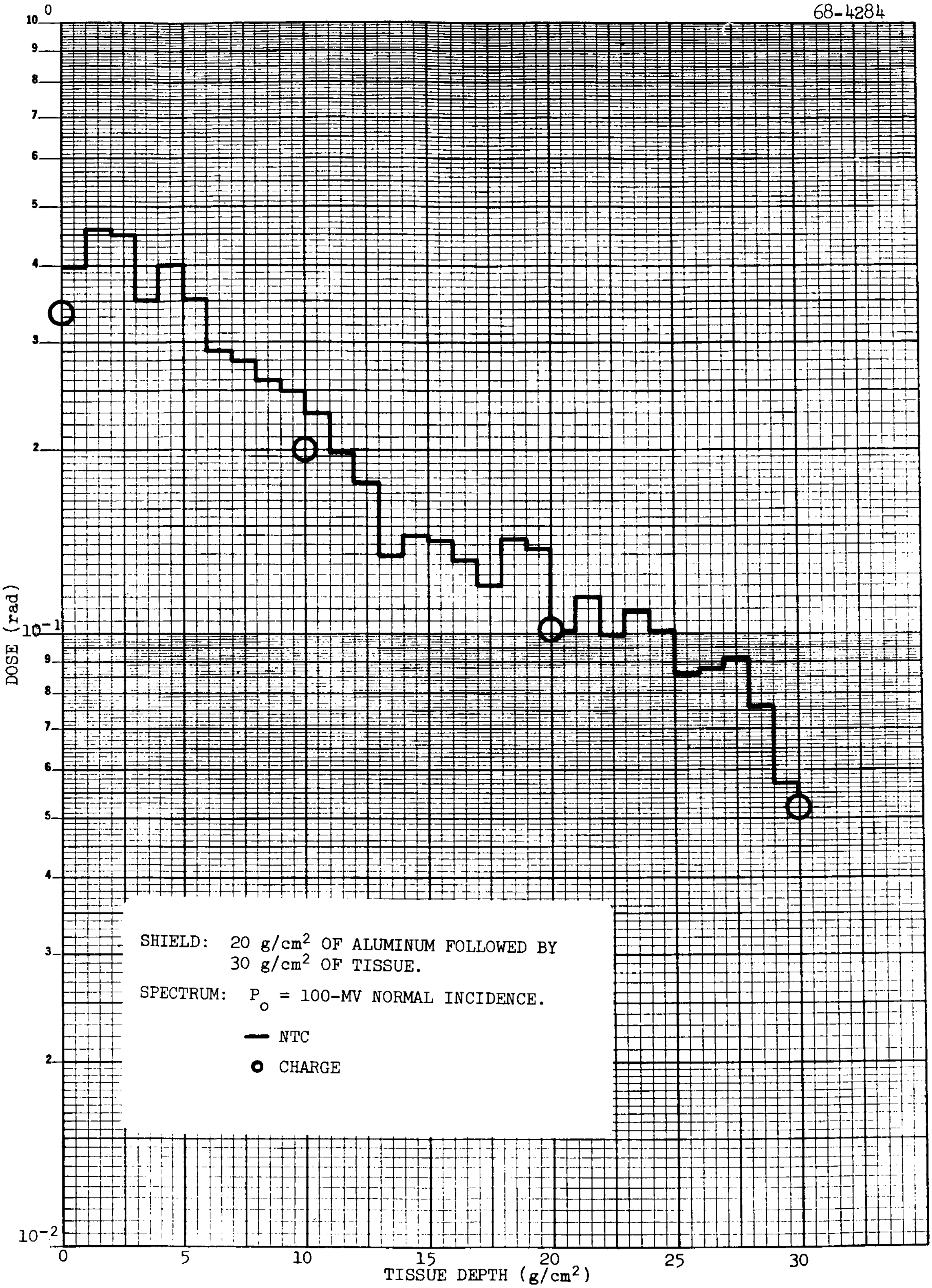

Fig. 2. Secondary Proton Dose vs Depth in Tissue.

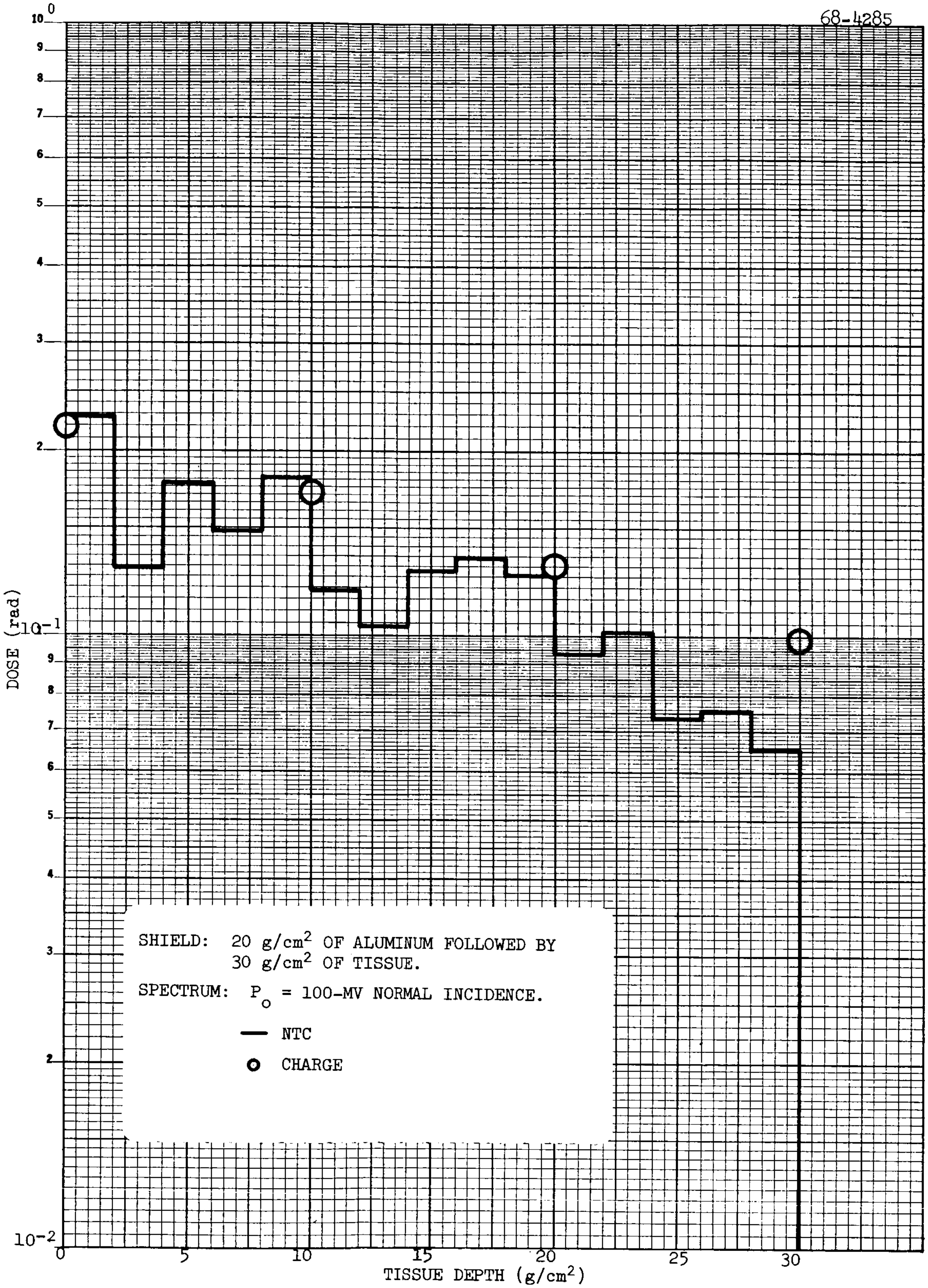

Fig. 3. Secondary Neutron Dose vs Depth in Tissue.

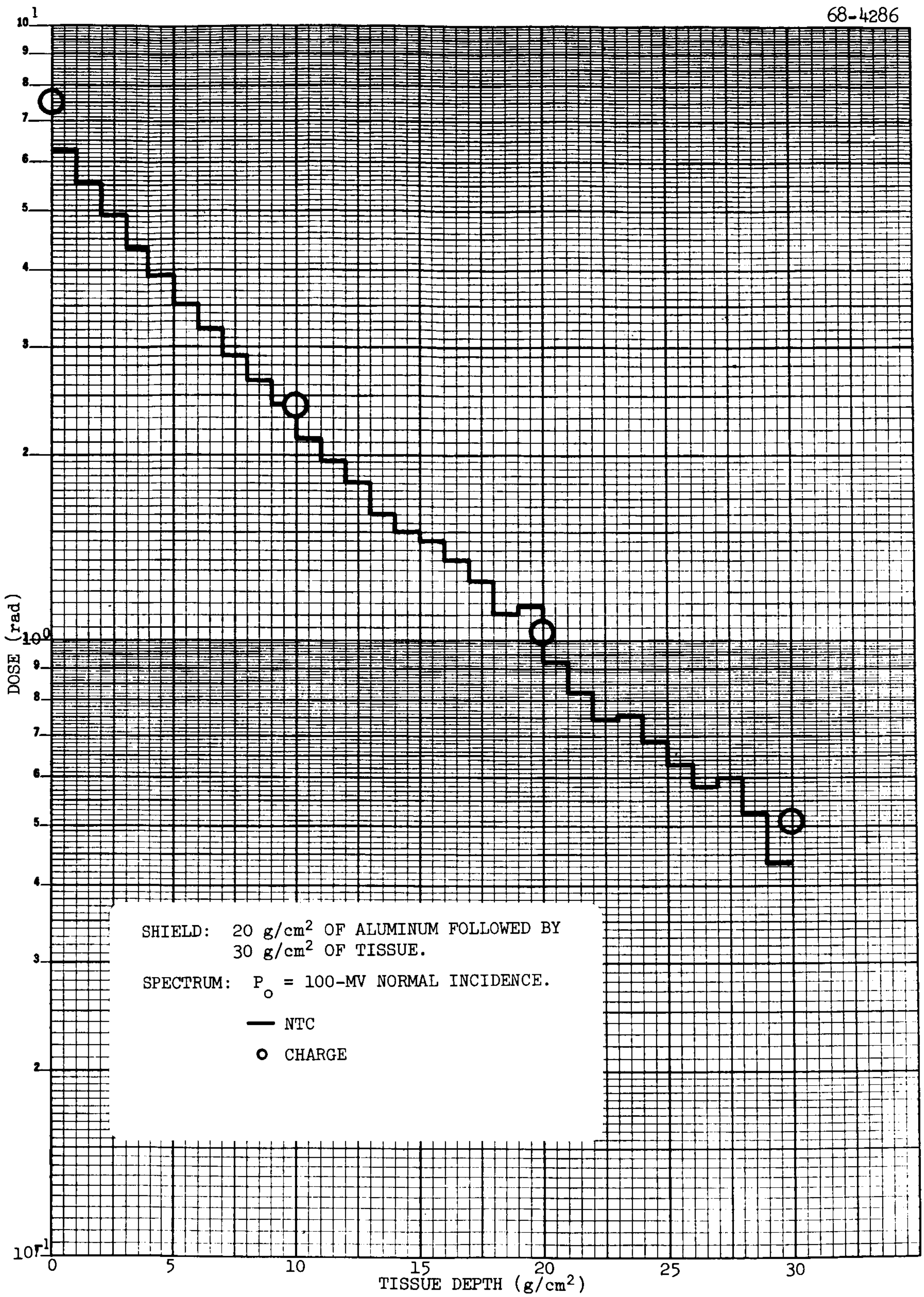

Fig. 4. Total Dose vs Depth in Tissue.

aluminum and therefore contribute to the dose only by producing secondary neutrons. The contribution to the dose of these secondary neutrons produced by low-energy incident protons was found by Irving *et al.* to be small, but it is included here.

The comparisons between CHARGE and NTC are shown in Figs. 5 and 6. In Fig. 5 the doses from primary protons are compared, while in Fig. 6 the doses from all secondary particles are compared. The primary proton doses are not in complete agreement and the secondary particle doses are in serious disagreement. The reason for this difference is not known.

The third problem and the first case for which all three codes, NTC, CHARGE, and ASTROS, are compared is to find the dose as a function of depth when 200-MeV protons are normally incident on a slab of tissue 30 g/cm^2 thick. The NTC calculations for this case are taken from the work of Zerby and Kinney.[9] Comparisons of both the primary and secondary doses are shown in Fig. 7. The primary doses obtained with all three codes are in very good agreement at all tissue depths. The secondary doses are in good agreement at the small tissue depths, but there are significant deviations at the larger depths.

Calculations with CHARGE and NTC have also been carried out for the case of 200-MeV protons isotropically incident on a tissue slab 30 g/cm^2 thick. The primary and secondary particle doses for this case are compared in Fig. 8. The NTC results are again taken from the work of Zerby and Kinney.[9] It is to be noted that the NTC results plotted in Fig. 8 are a factor of two smaller than those given by Zerby and Kinney since in Fig. 8 the results are given per unit incident flux rather than per unit incident current. There is a significant difference between both the primary and

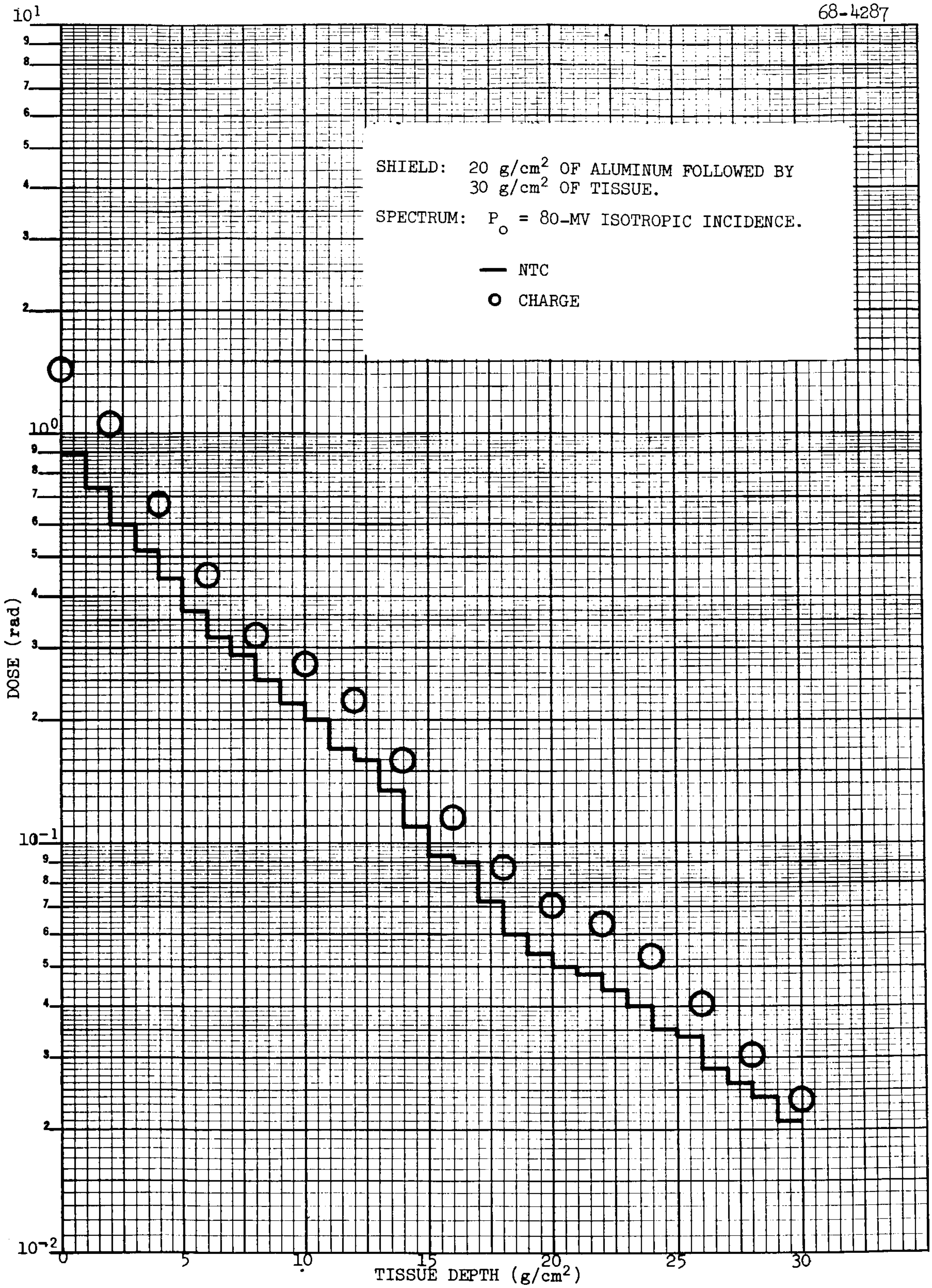

Fig. 5. Primary Proton Dose vs Depth in Tissue.

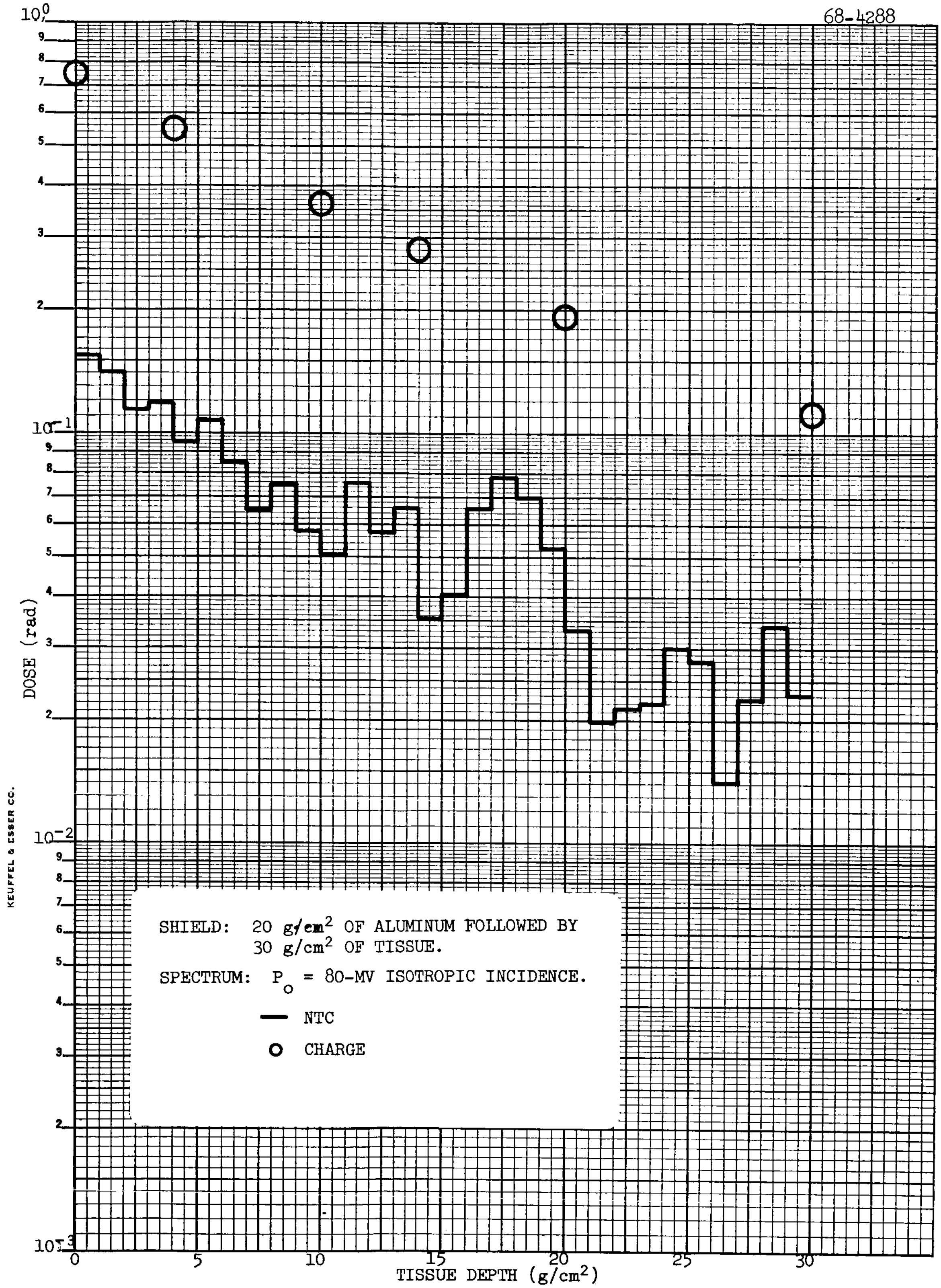

Fig. 6. Total Secondary Particle Dose vs Tissue Depth.

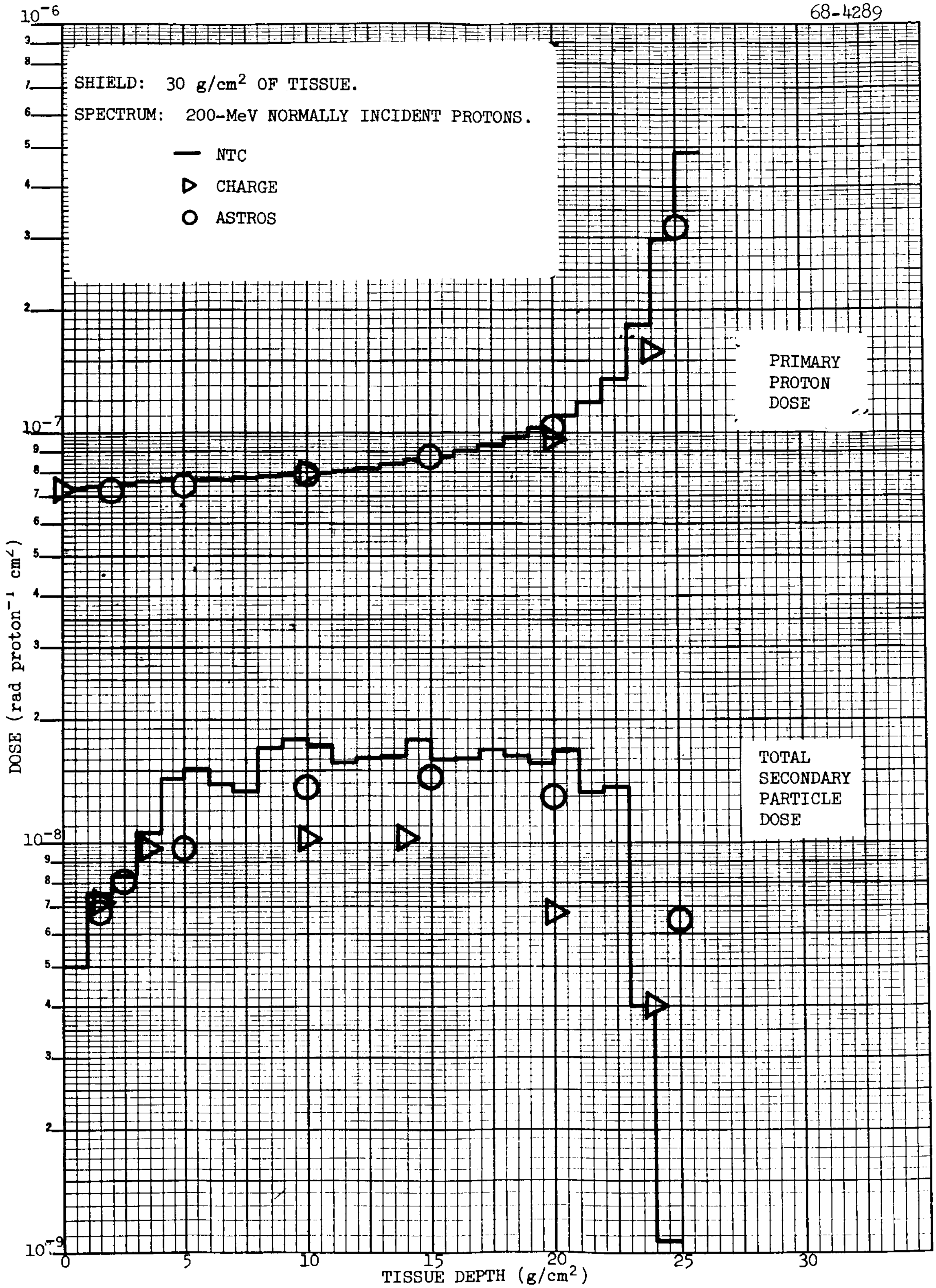

Fig. 7. Dose vs Depth in Tissue.

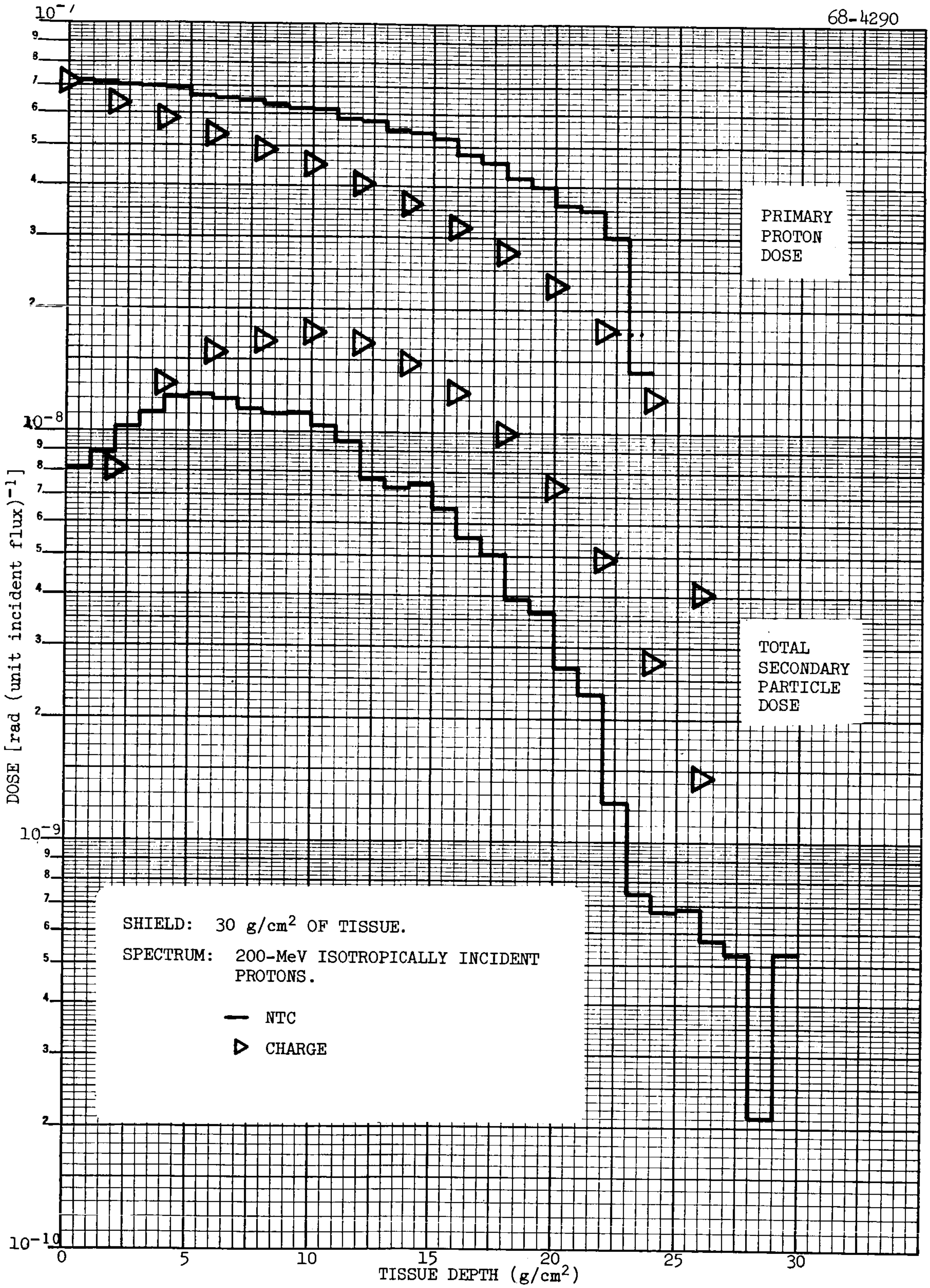

Fig. 8. Dose vs Depth in Tissue.

secondary particle doses in this case. In general, the agreement between NTC and CHARGE is much better for the case of normal incidence than for the case of isotropic incidence.

Finally, in Fig. 9 CHARGE and ASTROS are compared for the case of 730-MeV protons normally incident on a very thick (300 g/cm^2) slab of tissue. For this high-energy case the primary proton and secondary proton doses are in reasonable agreement at all tissue depths considered. A secondary neutron dose from ASTROS is not shown because the secondary neutrons are neglected in this code. Beyond the range of the primary protons ($\sim$200 g/cm^2), neither CHARGE nor ASTROS gives a secondary proton contribution because both codes consider only first-generation secondary particles.

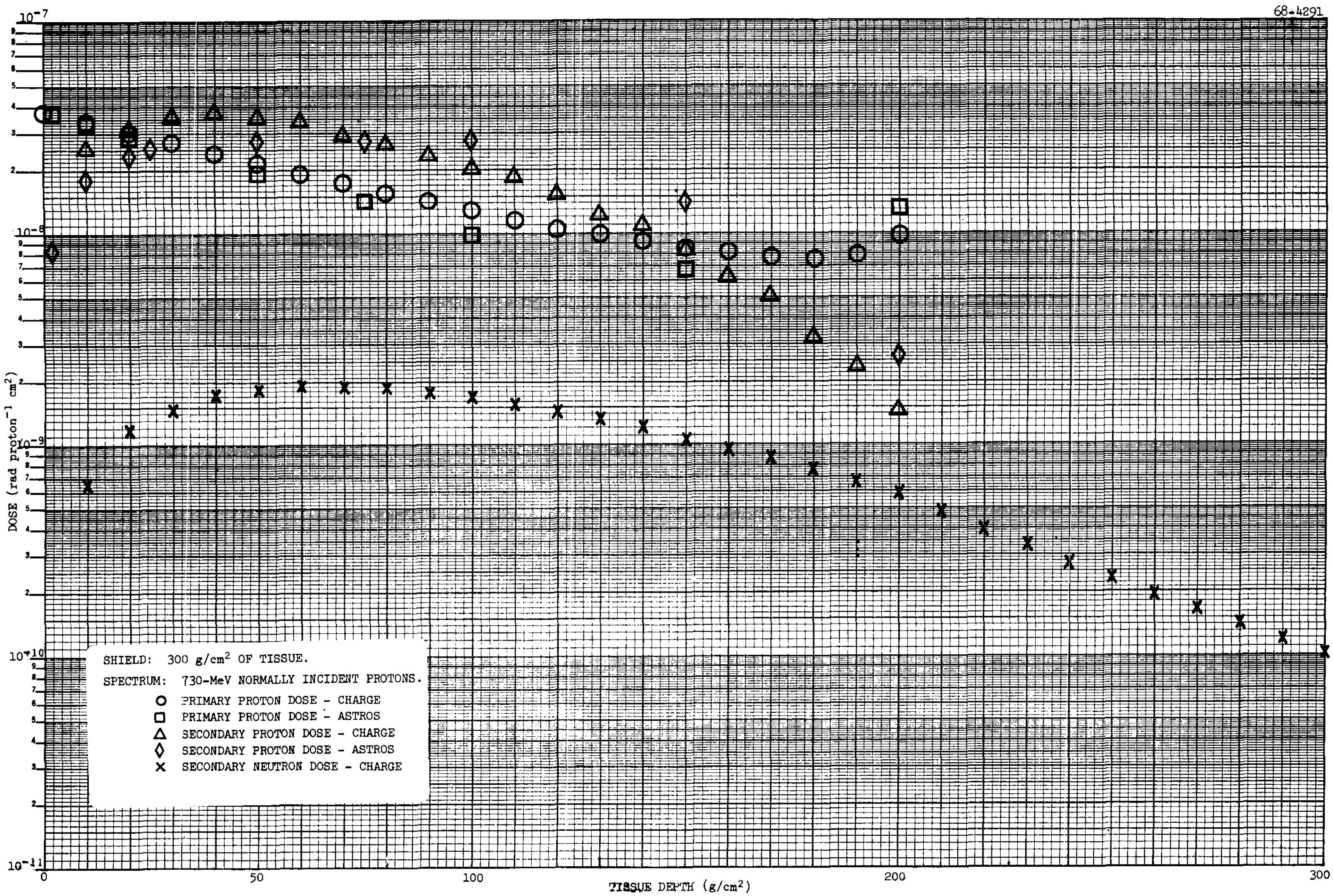

Fig. 9. Dose vs Depth in Tissue.

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