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Experimental Results of Neutron Fluence Outside an Iron Shield in the Forward Direction

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Introduction

Analyses of both lateral shielding measurements and Monte Carlo calculations for beam stop geometry for incident hadrons at energies between 10 GeV and 10 TeV [Fasso et al. 1990] suggests that the dose equivalent can be represented by the expression

$$H = \frac{H_o(E)e^{-r/\lambda}}{r^2} \qquad (1)$$

where H_o is the source term, r is the radial distance to the point of interest in the shield, and λ is the effective interaction length, or absorption mean free path. However, unlike the lateral shielding case, there is no similiarly simple analytical expression that can be used to describe the on-axis longitudinal cascade development. In this study the results from the measurement in the forward direction of neutron fluence spectra (and the derived quantity dose equivalent) for 25 to 150 GeV pions incident on an iron beam stop as a function of thickness of iron are presented. The observed dependence of both fluence and dose equivalent on shield thickness and hadron energy was then quantified in terms of an expression in which a build up factor as well as an attenuation term was included. On the basis of this analysis the conversion factor from fluence to dose equivalent was also determined for these forward going neutrons. This work represents the first systematic study at an high energy accelerator of the depth dependence of neutron fluence in longitudinal shielding [Torres 1996].

Experimental Set Up and Measurements

The measurements were performed during the 1991-1992 fixed target run at Fermilab in the NWA enclosure at the NW beam line. The beam stop was constructed out of a series of iron slabs. A gap was left in the iron region to accomodate the detectors, and the movement of the individual iron slabs permitted measurements at different depths in iron. The iron was shielded on three sides by concrete blocks to help reduce background due to adjacent beam lines. The particles incident on this beam stop were negative pions with energies of 25 to 150 GeV. Neutron fluence spectra were obtained with a Bonner sphere spectrometer at 10 depths in iron from 40.6 cm to 264 cm in intervals of 20.3 cm in the forward direction.

The Bonner sphere spectrometer consisted of polyethylene spherical moderators with diameters of 5.1 (2"), 7.6 (3"), 12.7 (5"), 20.3 (8'), 25.4 (10"), and 30.5 (12") cm at the centers of which were placed 12.7 mm long by 12.7 mm diameter cylindrical ^{6}LiI(Eu) scintillators. These detectors respond to thermal neutrons via the ^{6}Li(n, a)^{3}H reaction (Q=4.78 MeV). A bare (unmoderated) ^{6}LiI crystal was also used. Most of the data was obtained with the all the spheres placed simultaneously into the neutron field as shown in Figure 1. The signal from each photomultiplier tube was transmitted through an amplifier to a multiplex-router, an ADC, and finally into a PC. Software developed by Canberra [1988] allowed the use of the computer as a multichannel analyzer. Neutron spectra were unfolded from measured sphere responses (normalized as indicated below) by use of the sphere response matrices of Sanna [1973] with the computer codes BUNKI [Lowry et al. 1984] and LOUHI [Routti et al. 1980].

The shape or profile of the neutron beam at the position of the detectors was determined by moving the 12.7 (5") cm diameter sphere to the locations of the other spheres at a number of iron thicknesses and pion energies. The beam profile was found to be independent of both incident energy and thickness in iron. The data from all spheres measured simultaneously at each energy and thickness were normalized to the neutron fluence at the beam position. Making measurements with all spheres simultaneously implicitly assumes that the spectral shape does not change with transverse position along the detector array in back of the iron shield. To check this, measurements were performed (at one pion energy and one iron thickness) by placing each detector at the same position (that of the 20.3 (8") cm diameter sphere), and comparing the results to that from a simultaneous measurement. The spectral shapes unfolded from the data were found to be essentially identical; any difference in spectral shape with position along the array must be small. Furthermore, measurements were also performed to check the effect of neutrons backscattered from the iron blocks situated in the back of the spherical detectors. It was concluded from these studies that such backscattering contributes little to the overall properties of the radiation field at the detector position.

NWA Results at Longitudinal Direction

Figure 2 shows some examples of neutron spectra unfolded by use of BUNKI for pions incident on 40.6 cm of iron. Neutron fluence per unit of log energy, or lethargy, is plotted as a function of energy. The spectra peak at energies in the hundreds of keV range, typical of neutron leakage through iron [Elwyn et al. 1986]. As seen, the spectral shape is roughly independent of incident beam energy. (There are some differences in shape at small neutron energies but the neutron fluence is in any case very small in this region). These results are similiar at other depths in iron as well. In all cases, there is little evidence of the existence of neutrons with energy greater than 10 MeV. This may be because of the poor response of Bonner spheres to such neutrons. However, a preliminary measurement that utilized ^{11}C activation also did not provide any definitive information on the neutron spectrum at energies above 20 MeV. The contribution from such neutrons to total fluence would have to be greater than about 10% to have been detected in those preliminary studies.

The data at all energies and depths in iron were unfolded by use of both the BUNKI and LOUHI codes, giving values of fluence and dose equivalent is close agreement with each other. Figures 3 and 4 show fluence and dose equivalent from BUNKI plotted as a function of iron thickness at each pion energy, and as a function of pion energy at each iron thickness, respectively. As seen, both fluence and dose equivalent increase with increasing energy at each thickness, and decrease as a function of thickness at each energy.

Discussions and Analysis of Longitudinal Results at NWA

Following a suggestion of Thomas et al. [1988], the observed dependence of both fluence and dose equivalent in the forward direction on shield thickness and energy was described by an expression :

$$R(E,z) = R_o(E,z)e^{-z/\lambda} \quad (2)$$

Here R represents either fluence or dose equivalent and R_o, the source term can be seperated into both depth and energy dependent factors: $R_o(E,z) = R_o(E)B(z)$. $B(z)$, a build up factor, can be represented approximately as an exponential, and the energy dependence $R_o(E)$ is assumed to be represented as a power law. Thus we write

$$R = R_o^{'}E^{m}e^{az}e^{-z/\lambda} \quad (3)$$

The results of the fitting, first the depth dependence, and then the dependence on energy, gives values for the quantities m, a, and λ. One obtains, finally, for both fluence and dose equivale

$$R = R_o^{'}E^{(0.83\pm0.08)}e^{0.028z}e^{-z/21.6} \quad (4)$$

where $e^{0.028z}$ represents the build up factor and $e^{-z/21.6}$ is the attenuation. $R_o^{'}$ the source term, is $(1.79\pm0.71)\times10^{-3}$ n-cm^{-2}-pion^{-1} for fluence and $(2.02\pm1.42)\times10^{-13}$ Sv-pion^{-1} for dose equivalent. The ratio of these two values gives a conversion factor between dose equivalent and fluence of $(1.13\pm0.91)\times10^{-10}$ Sv-cm^{-2}.

Measurements, not described here [Torres 1996], at one iron thickness and three pion energies in the lateral shielding direction were analyzed by use of Eqn. (1). The results were consistent with a value of λ, the effective interaction length in iron, of 21.6 cm, which is in agreement with that obtained in a least-squares analysis of the results from Monte Carlo calculations [Thomas et al. 1988]. The energy dependence was found to be consistent with a power law, E^m, with $m=0.86\pm0.02$, in good agreement with the "standard" value of 0.80 ± 0.10 quoted by Thomas et al.[1988]. The conversion factor obtained in the analysis was $(1.29\pm0.62)\times10^{-10}$ Sv-cm^2.

Conclusions

From the longitudinal shielding studies reported here, the attenuation mean free path is consistent with results for lateral shielding as long as a build up factor is included in the analysis. Alternatively, combining the two depth dependent factors in Eqn. (4), one finds an attenuation term with a generalized interaction length of 55.5 ± 7.7 cm, larger by a factor of 2.5 than the "standard" lateral shielding value. The energy dependence is essentially the same for both lateral and longitudinal shielding directions, and the exponent of E is consistent with the "standard" value of 0.8. Furthermore, when only neutrons are measured, the source strength, or conversion factor, for longitudinal shielding is the same, within the rather large errors, with that for the lateral case.

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References

Canberra Software, S-100-System 100 Version 2.0; 1988. Canberra Industries, Inc. Meridien, CT 06450 USA.

Elwyn, A.J, Cossairt, J.D. A Study of Neutron Leakage Trough an Fe Shield at an Accelerator. Health Phys. 51:723-735; 1986.

Fasso, A., Goebel, K., Hofert, M., Ranft, J., Stevenson, G.R. Shielding Against High Energy Radiation. Landolt-Bernstein Numarical Data and Functional Relationships in Science and Technology, Group I: Nuclear and Particle Physics, Springer-Verlag, Vol. 11;1990.

Lowry, K.A., Johnson, T.L. Modification to Iterative Recurssion Unfolding Algorithms and Computer Codes to Find More Appropriate Neutron Spectra. U.S. Naval Research Laboratory, Report NRL-5340, Washigton, D.C.; 1984.

Routti, J.T., Sandeberg, J.V. General Purpose Unfolding LOUHI78 with Linear and Non-Linear Regularization. Comp. Phy. Commun. 21:119-144;1980.

Sanna, R.S. Thirty One Group Response Matrices for the Multisphere Neutron Spectrometer over the Energy Range Thermal to 400 MeV. USAEC, HASL-267; 1973.

Thomas, R.H., Stevenson, G.R. Radiological Safety Aspects of the Operation of Proton Accelerators. Technical Report Series No 283, IAEA, Vienna;1988.

Torres, M.M.C., Neutron Radiation Fields Outside Shielding at the Fermilab Tevatron, Ph.D Dissertation, University of Michigan, Unpublished; 1996.

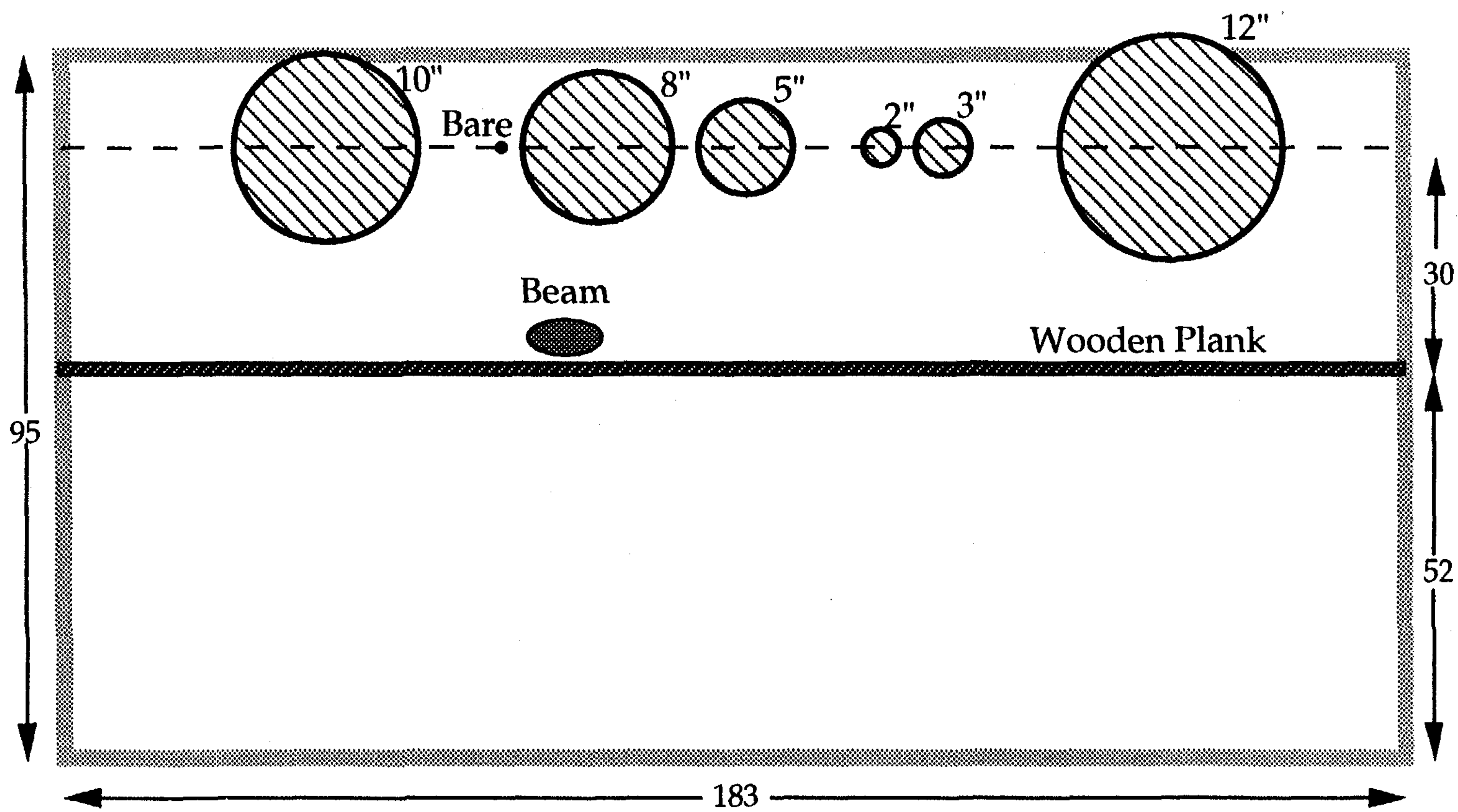

Figure 1. Bonner Sphere Layout. Shown is the layout of the Bonner sphere spectrometer used at NWA. The pion beam is traveling into the page. The extent of the iron plate shielding is indicated by the gray outline. The positions of the spheres, beam and the wooden plank support structure are shown. The dimensions indicated are in centimeters. The origin of the coordinate system is at the center of the beam position.

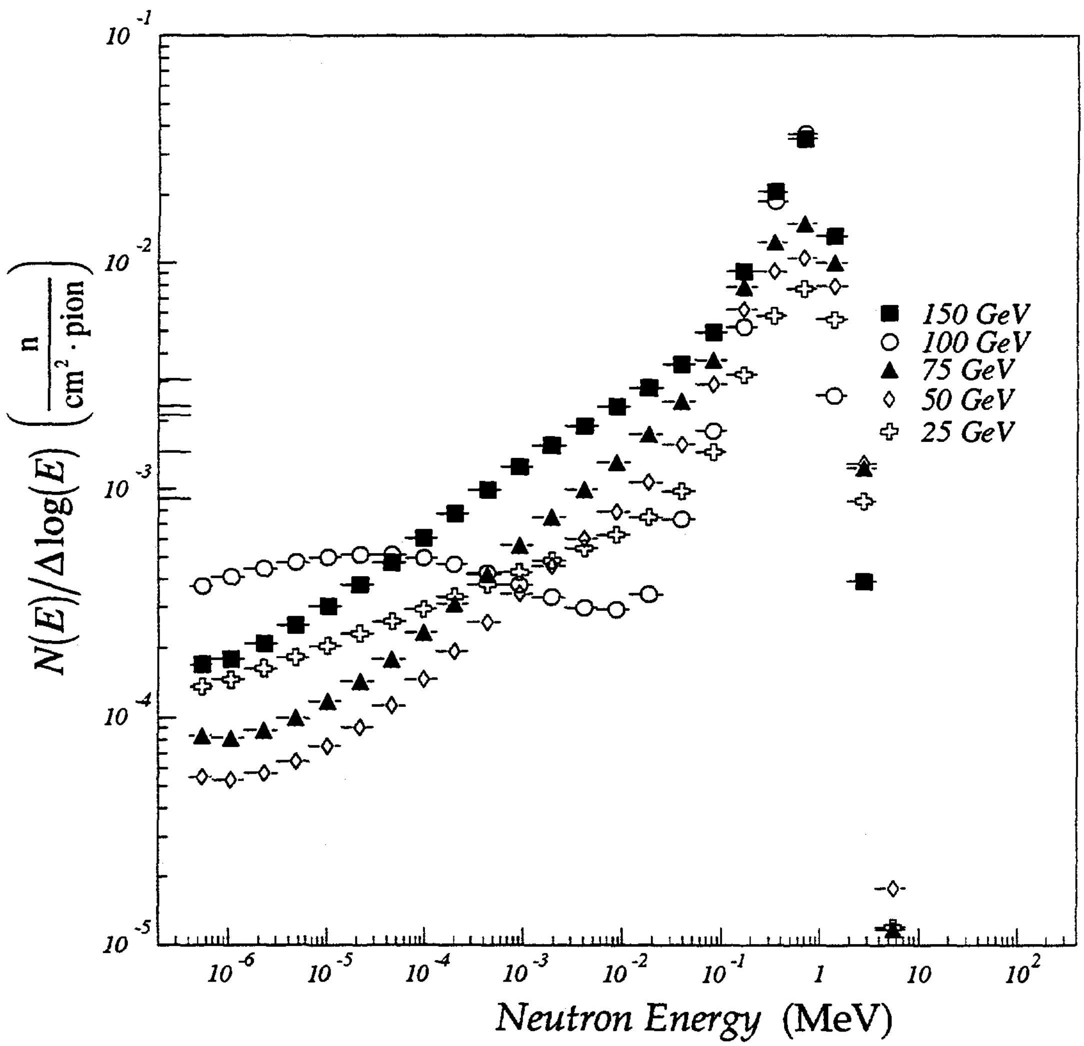

Figure 2. Unfolded Neutron Spectra For Incident Pions on 40.6 cm of Iron. Shown are the neutron spectra obtained using BUNKI for pions at 5 different energies incident on 40.6 cm (16 in, 2.4 λ) of iron. For each energy, the fluence per unit lethargy per pion is plotted as a function of neutron energy.

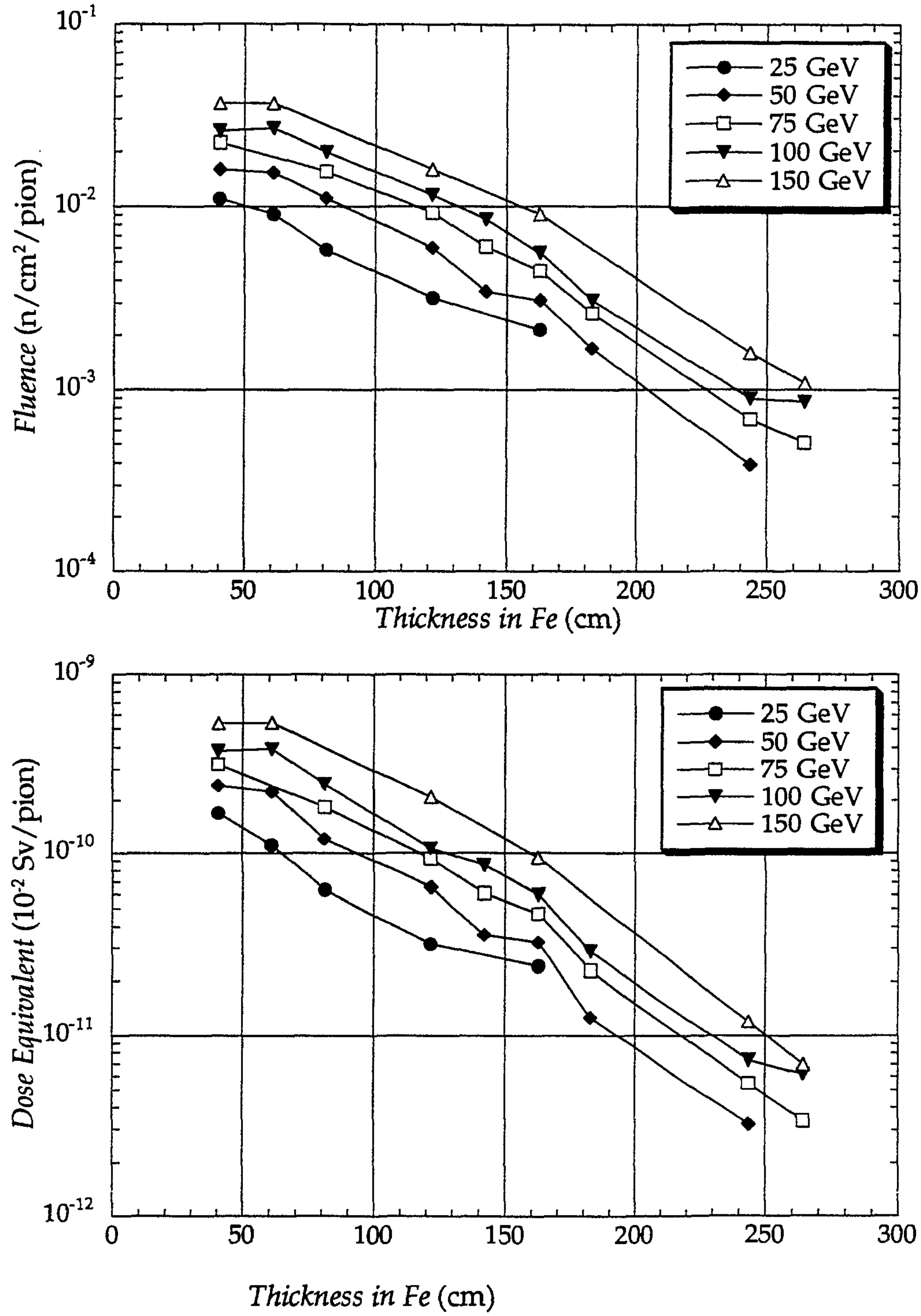

Figure 3. Fluence and Dose Equivalent vs. Thickness of Iron. Shown are fluence and dose equivalent plotted as a function of thickness in the longitudinal direction for incident pions at five energies. The fluence and dose equivalent decrease as a function of thickness at a specific energy.

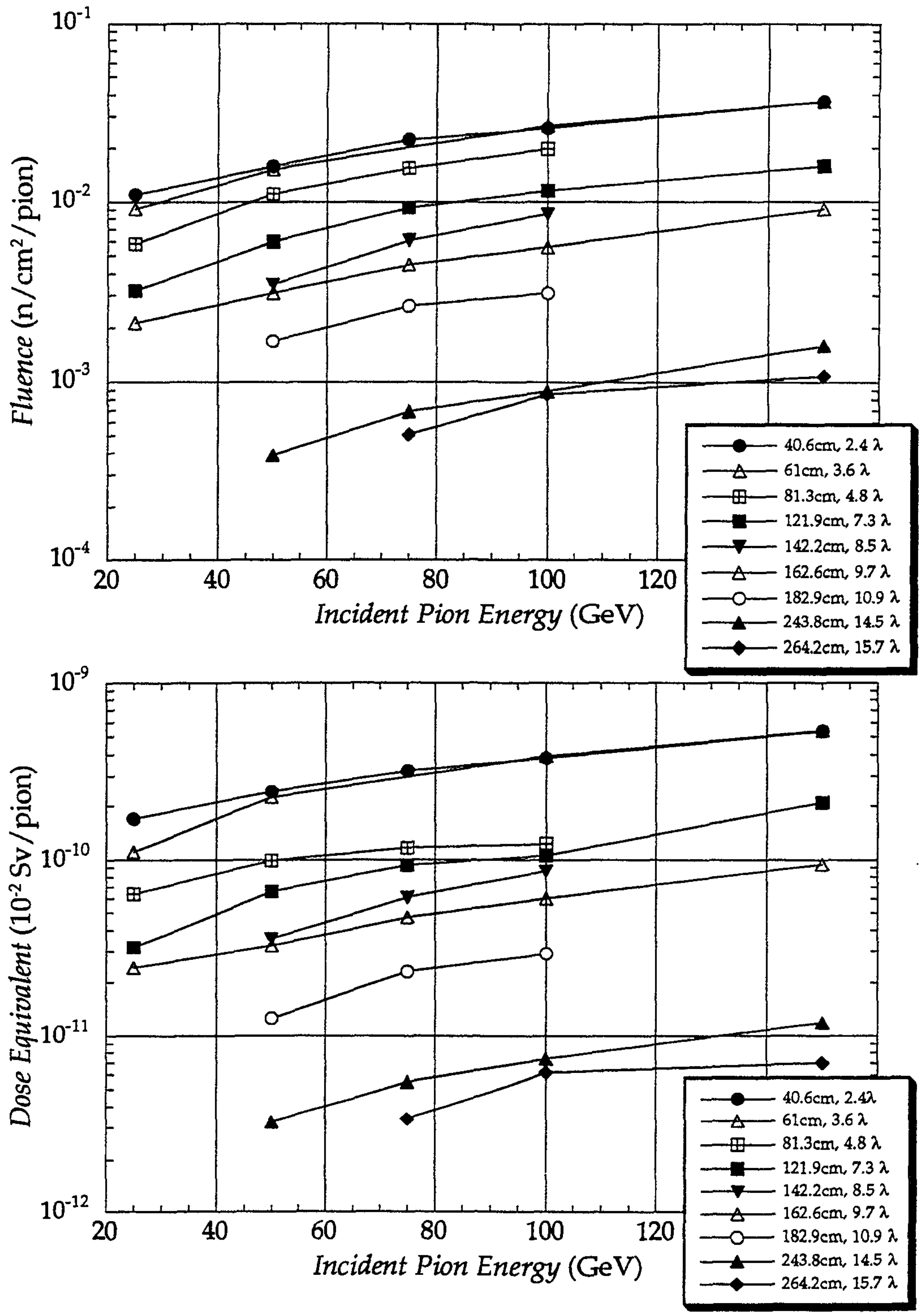

Figure 4. Fluence and Dose Equivalent vs. Incident Pion Energy. Shown are fluence and dose equivalent plotted as a function of incident pion energy in the longitudinal direction The fluence and dose equivalent increase as a function of incident energy at a specific thickness.