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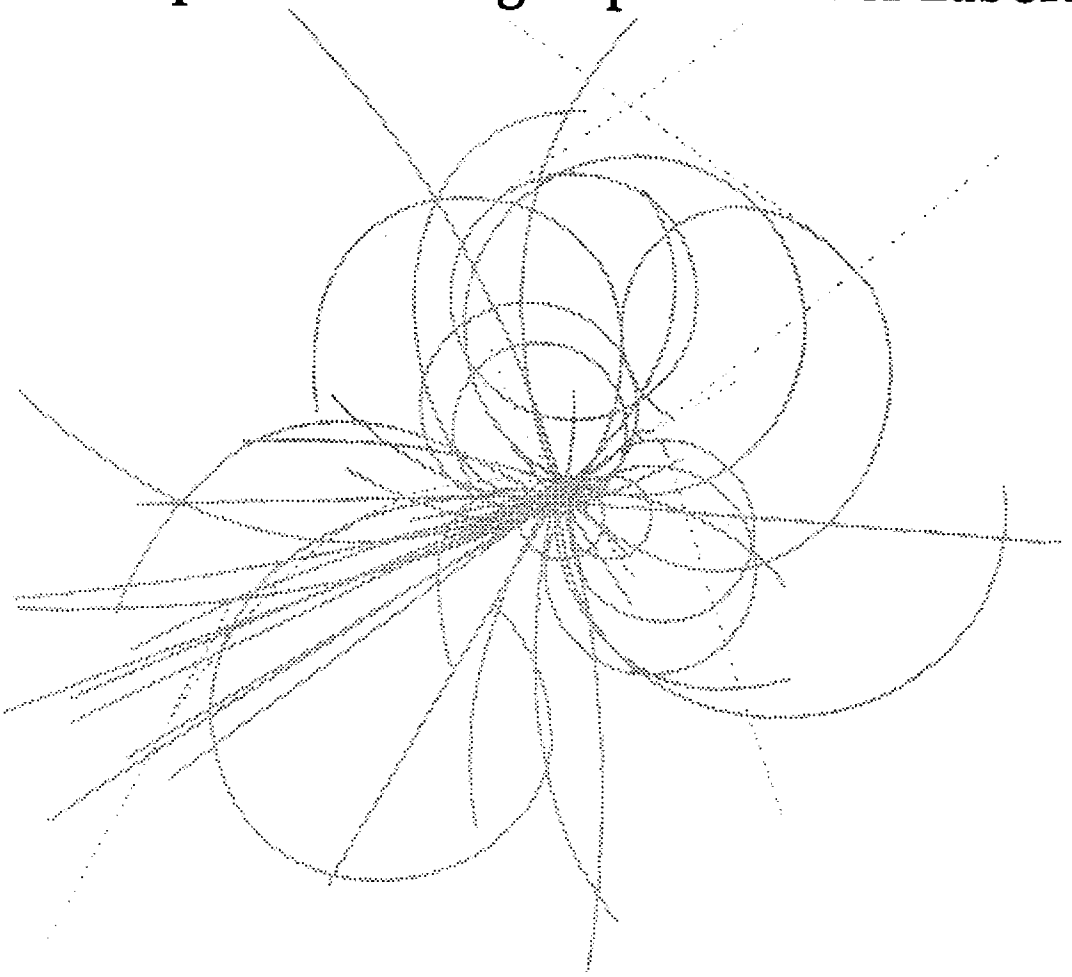

Erratum to SSC-SR-1033
Radiation Levels in the SSC Interaction Regions

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RADIATION LEVELS IN THE SSC INTERACTION REGIONS

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Abstract

Estimates for the maximum ionizing dose in electromagnetic showers induced by photons from primary π^0 decay are corrected downward by a factor of three. No other results are affected.

1. Introduction

Dan Green pointed out to us that his hand-calculated estimate of the maximum dose at electromagnetic cascade maximum was substantially lower than that given in SSC-SR-1033[1]. The problem was traced to Fig. 3 in Appendix 7, from which data for single-particle behavior were obtained. The left-hand scale of the figure is correct, but the right-hand scale is in error by a factor of about three because the scintillator plate thickness (3 mm) was forgotten. These results were copied to Fig. 3-1, and then used to generate data shown in Table 5-1, Fig. 5-6 and Fig. 5-8. Figure 5-8 has been widely shown and reproduced.

2. Scale correction

The calorimeters considered in Appendix 7 consist of 3 mm lead or uranium plates followed by 3 mm of liquid argon or scintillator. For Figs. 3 and 4 (pp. 128 and 129) the incident beam is normal to the plates. The left scale shows the average energy actually deposited in the sensitive region, in MeV per incident particle. In the case of scintillator, the density was 1.032 g cm^{-2}. To convert to Gy (J/kg), one must therefore multiply by

$$\frac{10^6\ \mathrm{eV/MeV} \times 1.6 \times 10^{-19}\ \mathrm{J/eV}}{0.3\ \mathrm{cm} \times 1.032\ \mathrm{g\ cm^{-3}} \times 10^{-3}\ \mathrm{g/kg}} = 5.17 \times 10^{-10}\ \mathrm{Gy\ cm^2}\ ,$$

or 5.17×10^{-10} Gy for an incident flux of 1 particle/cm^2. This establishes the correct right scale for Figs. 3 and 4; corrected figures are shown as Figs. 1 and 2 of this Erratum.

3. Changes to sections 3 and 5

The data for the uranium/scintillator case were copied directly to Fig. 3-1 (p. 22). With the corrected scale, the line shown in the figure is given by $3.2\times10^{-9}\,(E/1\ \mathrm{GeV})^{-0.93}$ Gy/(incident particle/cm^2). The corrected coefficient is 32% of the value given in the Report. The revised figure is included here as Fig. 3.

In the model assumed in the Report, the charged particle production rate was 7.5 per pseudorapidity interval over angles of interest. The π^0 rate was assumed to be half of this. The mean transverse momentum was taken as 0.60 GeV/c. Taking half of this mean for decay photons, we assumed 7.5 photons per pseudorapidity interval with mean momentum 0.30 GeV/c. Since $d\eta/d\Omega = (2\pi \sin^2\theta)^{-1}$ and $d\Omega/d(\text{area}) = 1/r^2$, the flux of photons is given by

$$\frac{7.5}{2\pi r^2 \sin^2\theta} \times \text{collision rate} .$$

The mean momentum at angle θ is (300 GeV)/ $\sin\theta$ = (300 GeV) $\cosh\eta$. Combining the above results for 10^{15} collisions/yr ("standard" SSC running conditions), we obtain

$$\dot{D} = \frac{31}{(r/200\ \text{cm})^2} \cosh^{2.93}\eta\ \text{Gy/yr}.$$

The coefficient is given as 97 in the text and appears as the intercepts at $\eta = 0$ for the electromagnetic dose shown in Figs. 5-6 and 5-8. Revised versions of Table 5-1*, Fig. 5-6 and Fig. 5-8 are attached (Figs. 4 and 5).

4. Stopping power correction

Consider a solid block of uranium or lead containing a thin layer of plastic scintillator. In a shower, the number of electrons crossing a surface in the metal *near the interface* will be the same as the number crossing the scintillator. However, an electron produces more ionization in the lower-Z scintillator that in the metal, so the ionizing dose is greater in the scintillator than in the adjacent metal. The correction factor is always greater than unity if the test volume has lower Z; an upper limit is given by the ratio of minimum ionization energy losses in the two materials. The ratio should actually be calculated by using restricted energy loss and correctly averaging over the electron energy spectra. For scintillator and either lead or uranium the ratio is about 1.7, for silicon 1.4 to 1.5, and for liquid argon about 1.4. To the extent that the signal is due to electrons, these factors should be applied in using the results shown in the revised Figs. 5-6 and 5-8. However, part of the signal is due to very short-range photoelectrons and Compton electrons. The photon-induced dose is very different in e.g. lead and scintillator. Numerical results are quite sensitive to EGS cutoff energies and other artifacts.

As it turns out, these effects seem to very nearly cancel in the material combinations under consideration. The stopping power enhancement for electrons in the lower-Z sensitive medium is about equal to the extra dose due to interacting photons in the high-Z absorber, with the net result that the left scale in Figs. 1 and 2 is very close to being the absorbed dose in either the sensitive material (argon or scintillator) or in the absorber (lead or uranium).

5. Changes for the SDC detector

The maximum electromagnetic dose in a cylindrical calorimeter has been given in the Solenoid Detector Collaboration's Expression of Interest and in other places. A revised

version is attached as Fig. 6. The numbers have simply been scaled down by a factor of three to correct for the scale error; no stopping power ratio factor has been included.

6. Independent check

An extensive series of EGS4[2] simulations were done recently in connection with the 1990 "Review of Particle Properties"[3]. Energy deposition profiles for 1 GeV and 100 GeV are shown in Figs. 7 and 8. Energy cutoffs were at 2.0 MeV for both electrons and photons. The factor $1/E_0$ normalizes the curves to unit area, and the energy deposition is per unit radiation length. The radiation length for uranium is 6.00 g cm^{-2}. The maximum comes at 0.13, so the maximum energy deposition is 0.13×1000 MeV/(6.00 g cm^{-2}) = 22 g^{-1}cm^2. In the absence of a stopping power correction, we would then expect 6.5 MeV energy deposit in 3 mm of plastic scintillator, and this is almost the number shown in Fig. 1.

The meaning of the cutoffs in an energy deposition calculation is that the energy is deposited at a point whenever a particle's energy falls below the relevant cutoff. The results are thus not sensitive to cutoffs if the range of the particles is small compared to distances being considered.

7. Discussion

(a) Comparison of electromagnetic to hadronic dose

We have assumed that the electromagnetic component (photons from π^0 decay) carries half as much energy as the hadronic component at a given angle. The radiation length in lead is 6.37 g cm^{-2}, and the nuclear interaction length is 194 g cm^{-2}. It takes about 20 X_0 to contain 99% of a 1 GeV EM shower, and about 6 λ_I to catch 99% of a hadronic shower. The relative size of the EM and hadronic maximum doses should then be about

$$\frac{1}{2}\frac{194}{6.37}\frac{6}{10} = 9.1$$

In Fig. 5-8, the ratio is 14; as compared with the revised ratio of 4.7. We have always been concerned that the ratio was too big, although the uncertainties because of the containment region ratio are large.

(b) Rules of thumb

The only real measure of ionizing dose is energy deposition. Rules involving "electron number" must be tuned. Most are based on Rossi's Approximation B[4, 5], and results obtained with this approximation differ from modern simulations by factors of two in either direction, depending upon atomic number.

Any rule which quotes a fixed number of electrons per incident GeV[6] or a fixed energy fraction at maximum is of necessity wrong: showers lengthen with increasing energy, albeit slowly. As an illustration, compare Figs. 6 and 7. In going from incident electron energies of 1 GeV to 100 GeV on uranium, the value at maximum changes from 0.13 to 0.09 as the full width at half-maximum moves from 7 to 11 radiation lengths. It is because of this that the slope of the fit in Fig. 3 is 0.93 rather than unity.

Table 5-1

Coefficients of functions of the form $A\langle p_\perp\rangle^\alpha \cosh^{\alpha'}\eta$ shown in the figures of this Section. α is the slope of the momentum power law fitted to whatever single-particle response is being considered. α' is the same as α if the dose or fluence is a function of pseudorapidity and greater by two if it is a function of solid angle or area. A is the product of the rapidity plateau height (taken as 7.5), the amplitude of the single-particle response, and (if required) the number of collisions per year. $\langle p_\perp\rangle$ is in units of GeV/c.

Figure	A	Units	$\langle p_\perp\rangle$	α	α'	Remarks
5-2	19.5	per evt	0.3	0.70	0.70	$E_\gamma > 1.0$ MeV
	34.5	per evt	0.3	0.68	0.68	$E_\gamma > 0.1$ MeV
5-3	18.8	per evt	0.6	0.5	0.5	
5-4	5.4×10^{11}	$cm^{-2}yr^{-1}$	0.6	0.67	2.67	$r = 200$ cm
	5.4×10^{7}	$cm^{-2}yr^{-1}$	0.6	0.67	2.67	$r = 20$ m
5-6	96.*	Gy yr^{-1}	0.3	0.93	2.93	$r = 200$ cm
5-8	11.3	Gy yr^{-1}	0.6	0.89	2.89	$r = 200$ cm

*Corrected.

References

1. "Report of the Task Force on Radiation Levels in the SSC Interaction Regions," ed. by D. E. Groom, SSC Central Design Group Report SSC-SR-1033 (June 1988).
2. W. R. Nelson, H. Hirayama, and D. W. O. Rogers, "The EGS4 Code System," SLAC-265, Stanford Linear Accelerator Center (Dec. 1985).
3. *With the Particle Data Group.* J. J. Hernández *et al.*, "Review of Particle Properties," Physics Letters **B239** (to be published, July 1990).
4. B. Rossi, *High Energy Particles*, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1952.
5. *Experimental Techniques in High Energy Physics*, ed. by T. Ferbel (Addision-Wesley, Menlo Park CA 1987).
6. K. Kleinknecht, *Detectors for Particle Radiation*, Cambridge (1986).

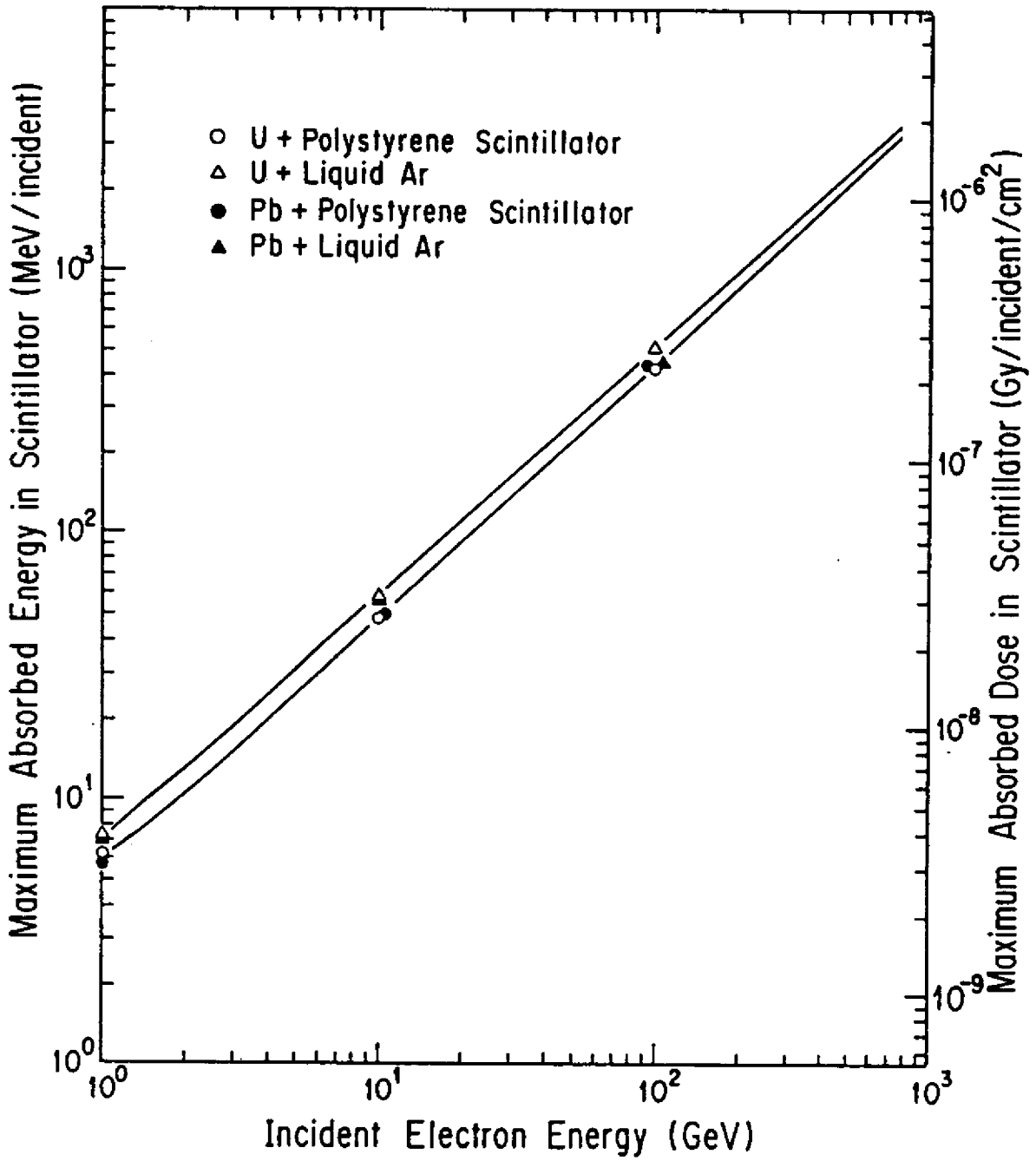

FIG. A7-3 *Revised.* Maximum absorbed energy and maximum absorbed dose for the normal incident parallel beam in the active material for the various combinations as the function of the incident electron energy.

FIG. 1. Revised Fig. 3 from Appendix 7 in SSC-SR-1033, with the right scale changed as described in the text. The left scale refers to energy deposition in 3 mm of scintillator or argon.

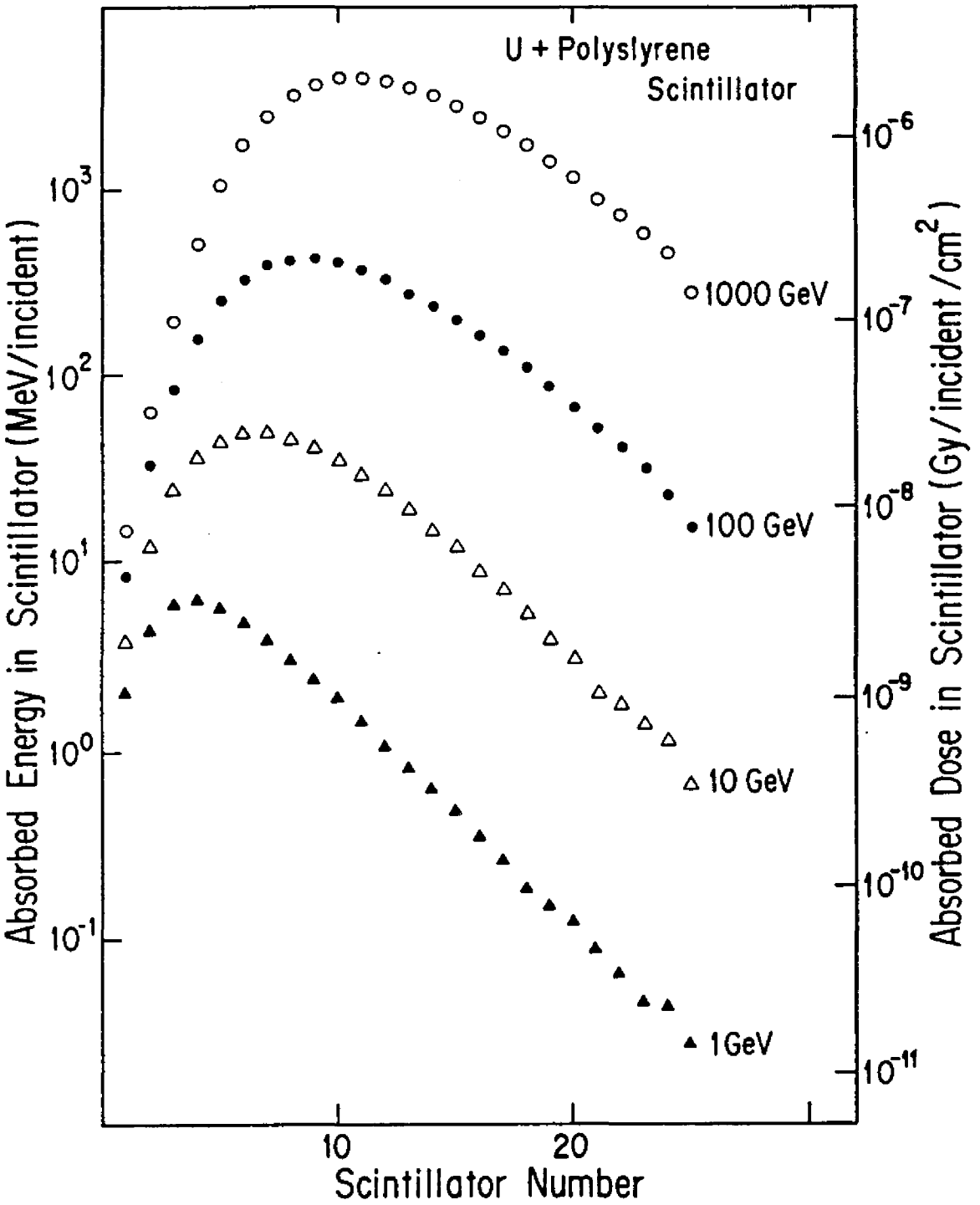

FIG. A7-4 *Revised.* Distribution of absorbed energy and absorbed dose for the normal incident parallel beam in the scintillator for the different incident energy.

FIG. 2. Revised Fig. 4 from Appendix 7 in SSC-SR-1033, with the right scale changed as described in the text. The left scale refers to energy deposition in 3 mm of scintillator or argon.

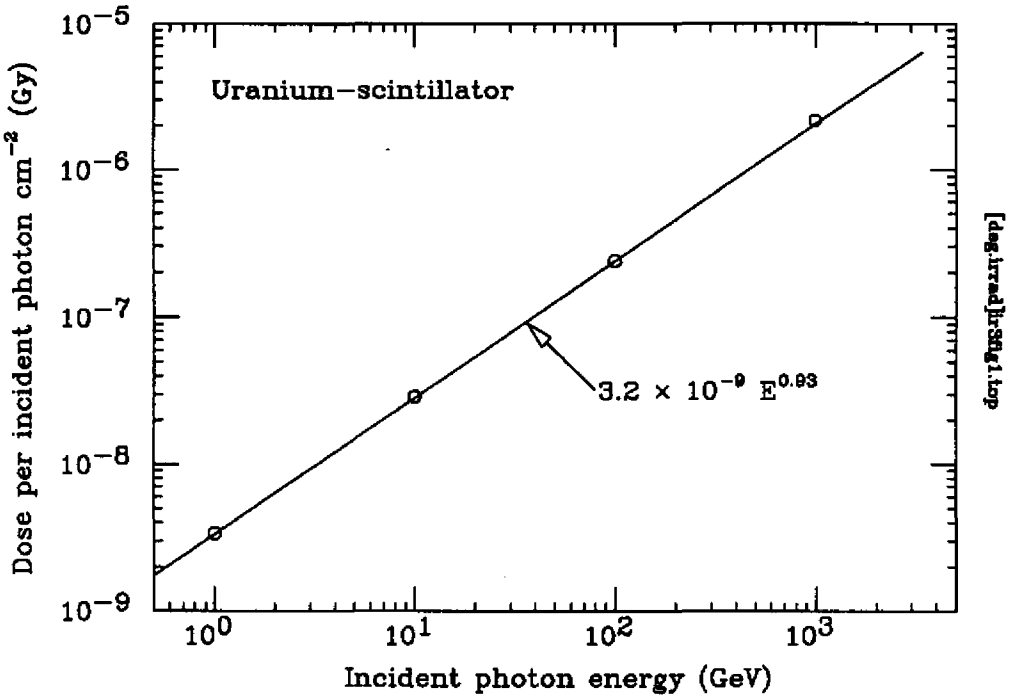

FIG. 3-1 *Revised.* The maximum electromagnetic dose in Gy per incident photon cm^{-2} in the metal plates or scintillator of a uranium/scintillator calorimeter vs. incident photon energy.

FIG. 3. Revised Fig. 3-1 from SSC-SR-1033.

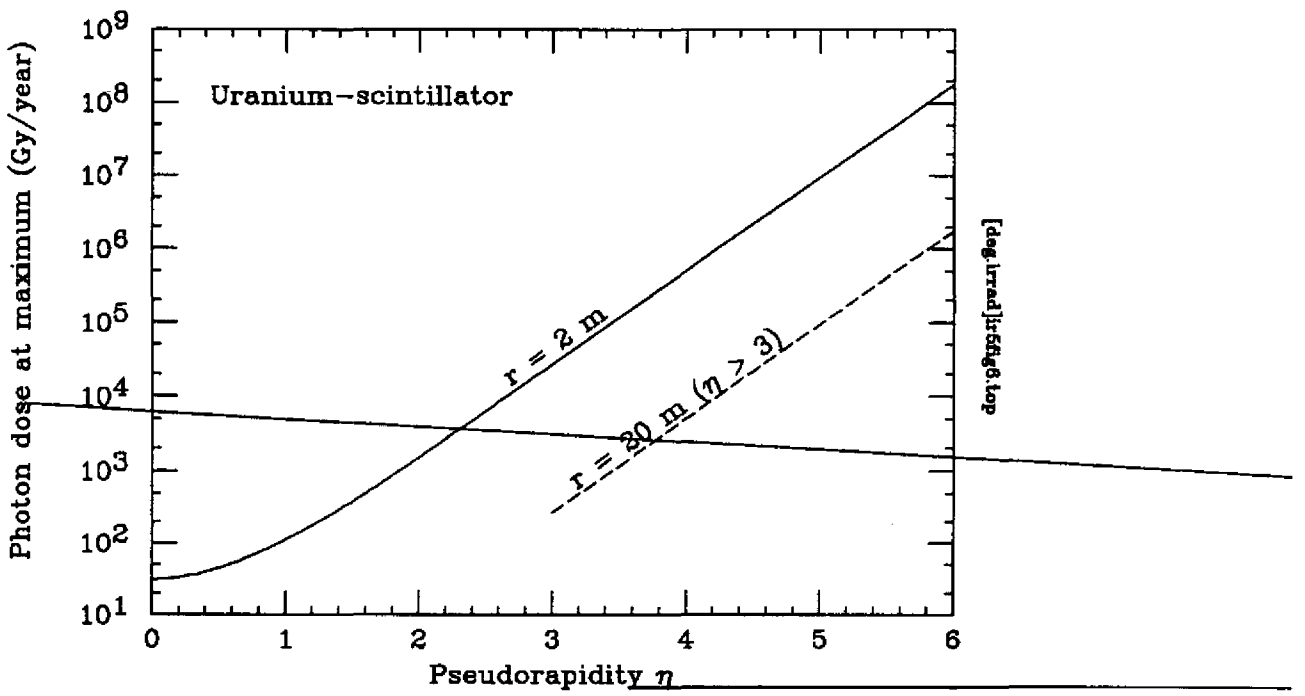

FIG. 5-6 *Revised.* The maximum dose from incident photons. The solid curve assumes the maximum occurs at 200 cm. The other curve is calculated for 20 m, typical of forward detectors.

FIG. 4. Revised Fig. 5-6 from SSC-SR-1033.

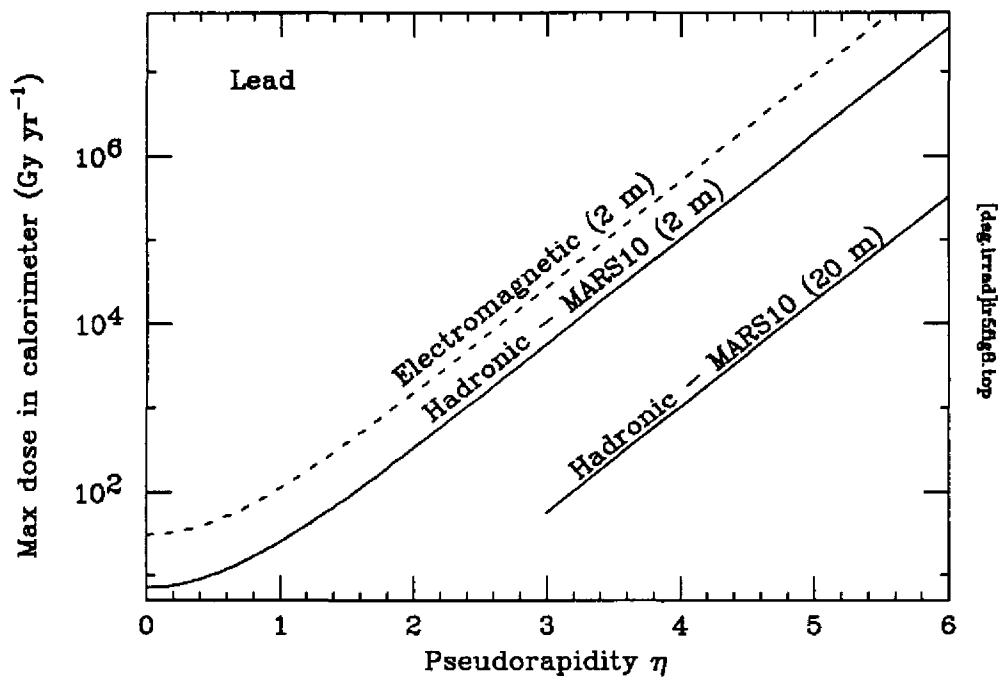

FIG. 5-8 *Revised.* The maximum hadronic dose as a function of pseudorapidity for a lead sphere, assuming that the maximum dose occurs at the indicated radius. The electromagnetic maximum dose (U/scint.) is copied from Fig. 5-6 for comparison purposes.

FIG. 5. Revised Fig. 5-8 from SSC-SR-1033./smallskip

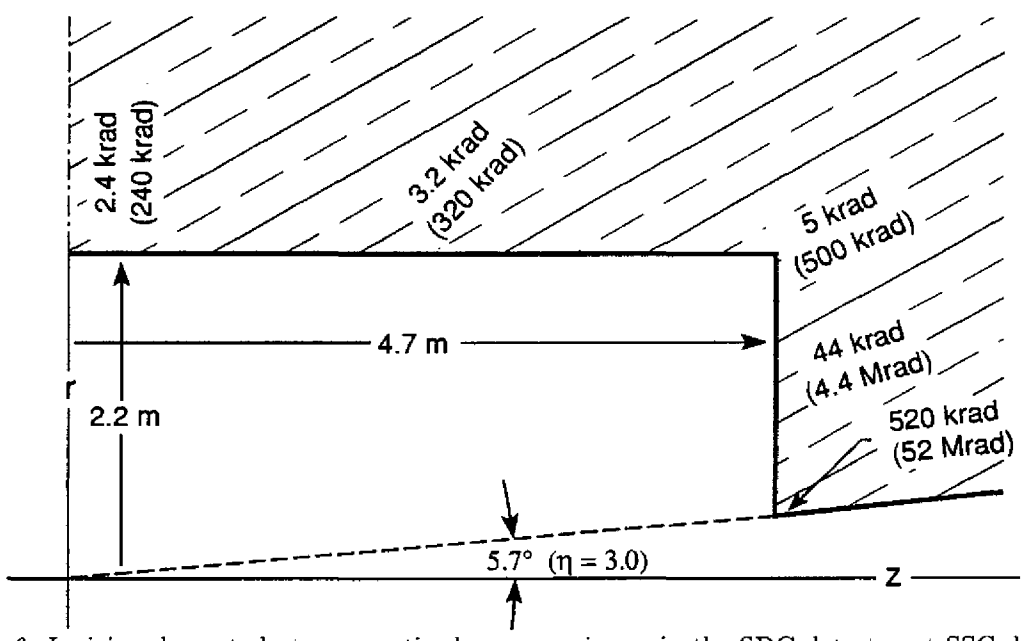

FIG. 6. Ionizing dose at electromagnetic shower maximum in the SDC detector at SSC design luminosity for one year and (in parenthesis) at $\mathcal{L} = 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for 10 years. The doses have been corrected downward by a factor of three from those given in the SDC EoI.

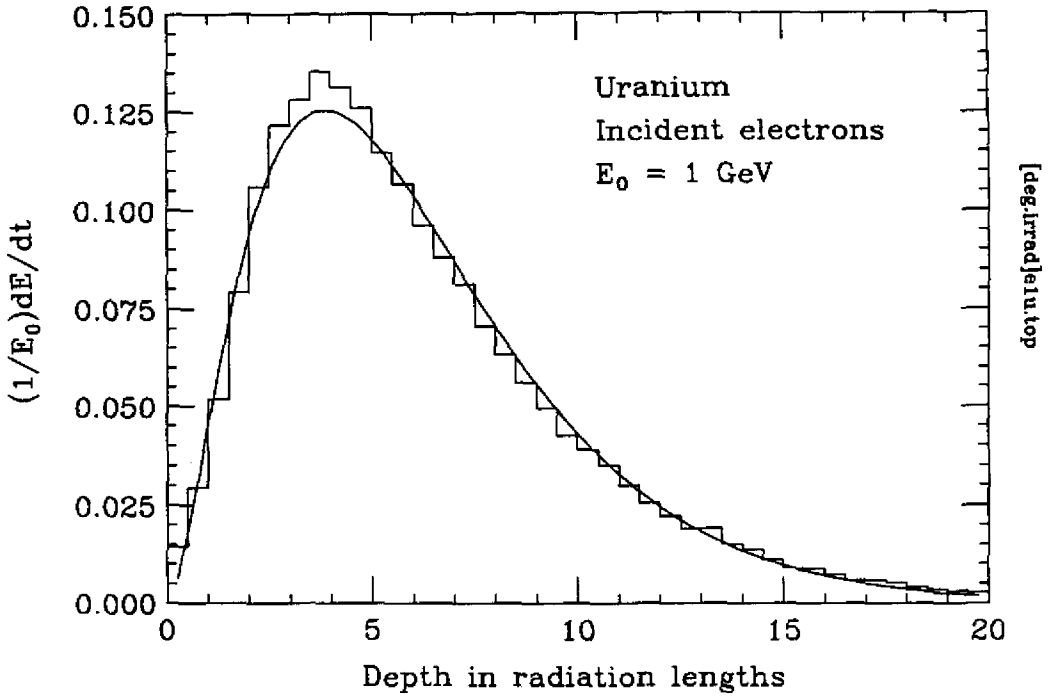

FIG. 7. Energy deposition per unit radiation length in lead for a 1 GeV incident electron, normalized to unit area.

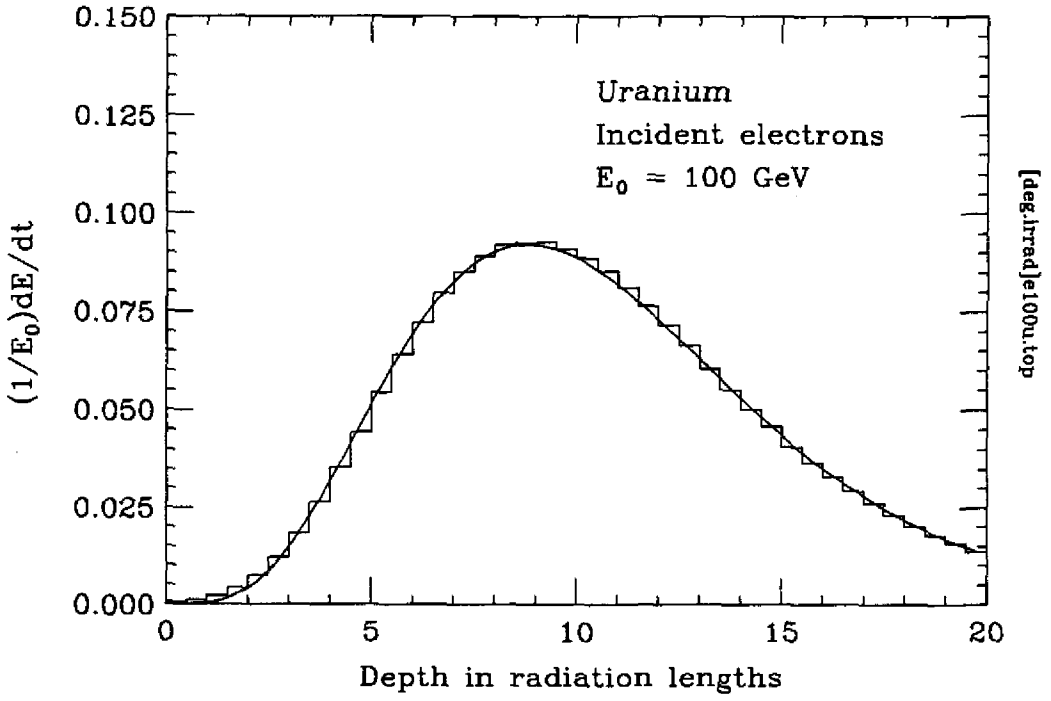

FIG. 8. Energy deposition per unit radiation length in lead for a 100 GeV incident electron, normalized to unit area.