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MUON FLUENCE MEASUREMENTS AT THE SITE BOUNDARY FOR 1985

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Introduction

Muon fluence (muons cm^{-2}) was measured downstream of the experimental area beamlines, just beyond the Fermilab site boundary at Route 38 (Roosevelt Road) in West Chicago. The main purpose of these measurements was to obtain an estimate of the yearly off-site radiation exposure to the general population due to accelerator-produced muons during the 1985 800 GeV run. Similar observations during the 1984 running period have been reported,[1] as have measurements[2] made at 350 and 400 GeV.

Measurements

The measurements were performed with the Mobile Environmental Radiation Lab (MERL), as described previously.[1,2] Muons were detected by a pair of 0.64 cm thick plastic scintillator paddles, with transverse dimensions of 20.32 cm by 20.32 cm, separated by 15 cm with a 2.54 cm thick aluminum plate placed in the gap. They were located in the vehicle at a height of about four feet above the ground. Standard electronic modules were used to record on scalers both singles and coincidence events from the two detectors. The scalers were gated on during both beam-on (a 23 sec beam spill period) and beam-off time periods in synchronization with the accelerator cycle.

Data were collected at Route 38, which is located at longitudinal distances of over 3000 m. from target locations for the various beams, along a line approximately normal to extensions of the beamlines. At each position along the scan detector counts were recorded for at least four beam pulses. Primary beam intensity information, as determined by secondary emission monitors (SEMs) located upstream of the target locations on the beamlines, were recorded for each beam pulse.

Results

Muon fluence based on singles counting rates is plotted in Fig. 1 as a function of lateral distance referenced to the center of the intersection of Town and Roosevelt Roads. The approximate positions at which extensions of the various secondary beamlines intersect Route 38 are indicated. The fluence is normalized to 10^{12} incident protons associated with the beamline indicated.

A comment should be made about the use of singles rates to determine muon fluence. Two scintillator paddles operated in coincidence serve to distinguish muons from other radiation, and in weak fields provides a more sensitive measure of their existence than do the singles rates from each paddle. However, under conditions in which there are no other components of the radiation field for which the plastic scintillator has a finite efficiency,[3] the singles rate itself provides a better measure of muon flux. This is because the coincidence rate depends upon the direction of the incident beam. It is only when the beam is incident along the normal to the surface that coincidence and singles rate should be equal. At the other extreme-muons incident isotropically from all directions-the coincidence efficiency is essentially given by the solid angle subtended at the first paddle by the second. Approximating the actual geometry by two coaxial parallel disks having the same surface area as the square paddles gives a greatly reduced coincidence efficiency of about 10% relative to singles.

In the present situation, as seen in Fig. 1, a significant muon fluence at paddle height appears to be associated only with the PW and MC beamlines. At the peaks of these distributions the ratio of coincidence-to-singles rates is about 0.3-0.4. This implies, in light of the above discussion, that although the muons are not incident uniformly from all directions, those that travel to this site boundary location have lost much of their original orientation parallel to the beamlines in which they originate.

Table 1 lists the average proton intensity for most of the operating beamlines during the period of these measurements. No muons associated with NC, ME, or PE beams were observed even though the beam intensity was equal to or greater than for PW and MC. While an understanding of the muon distributions requires an analysis based on the beamline and experimental layout, using, e.g., the HALO Monte Carlo code,[4] it is noted that the NC beamline is used for neutrino experiments and thus has been specifically designed to attenuate muon flux to small values. Further, the experiment on the ME line (E605) employed a massive magnet which deflected muons vertically thus reducing significantly the fluence at elevations corresponding to the operating height of MERL paddles.

The distribution of fluence as a function of lateral distance referenced to the extension of the PW beamline at Roosevelt Road is shown in Fig. 2. The results agree quite closely with the previous measurements[1] during the running of E615 in 1984. The histogram represents a HALO calculation[1] of the fluence based on the beam transport elements and experimental apparatus associated with E615. The calculated values at paddle height are lower than those measured over most of the lateral range, although HALO predicts muon fluence about an order of magnitude larger at an elevation of 200-250 feet above ground level.

Muon dose-equivalents associated with the measured fluence, normalized to 10^{18} protons, are shown by the right-hand ordinate in Fig. 1. The values are based on a fluence-to-dose-equivalent conversion factor[5] of 2.5 x 10^4 muons cm^{-2} $mrem^{-1}$ (or, equivalently, 40 fSv m^2 per muon). While 10^{18} protons represents a yearly value based on past experience, the actual number of protons delivered to the various targets during the 1985 running period was considerably less in most cases; the values for the different beamlines are listed in Table 1. Based on these proton intensities, the maximum yearly dose-equivalent at the site boundary was about 1.5 mrem for muons associated with MC, and 0.35 mrem at the peak of the PW distribution. The 10 mrem yearly limit set by the Fermilab Director would be approached by an increase in the MC average beam intensity that yields total accelerated beam larger by a factor of ~ 6. Neither the 500 mrem nor the more stringent 170 mrem DOE yearly limits are in jeopardy.

I wish to thank Ray Dagenais and Chuck Salsbury for their patient and extensive help with the taking of the data, and John Larson and Tom Anderson for their sometimes heroic efforts to keep the MERL telemetry system operational.

REFERENCES

1. Elwyn A.J. and Freeman W.S., 1984, Muon Fluence Measurements at 800 GeV, Fermi National Accelerator Laboratory, Batavia, IL. 60510, TM-1288.

2. Cossairt J.D., 1981, "Recent muon dose-equivalent measurements at Fermilab," Health Physics 45, 657.

3. The scintillator has an intrinsic efficiency of ∿ 7.5% for detection of neutrons of a few MeV. However, the neutron fluence at the Route 38 location, as measured with a precision $^{10}BF_3$ long counter, was found to be negligibly small during the present measurements.

4. Iselin Ch., 1974, HALO A Computer Program to Calculate Muon HALO, European Organization for Nuclear Research, Geneva, Switzerland, CERN Report #63-17.

5. Stevenson G.R., 1983, Dose and Dose Equivalent from Muons, European Organization for Nuclear Research, Geneva, Switzerland, TIS Divisional Report TIS-RP/099.

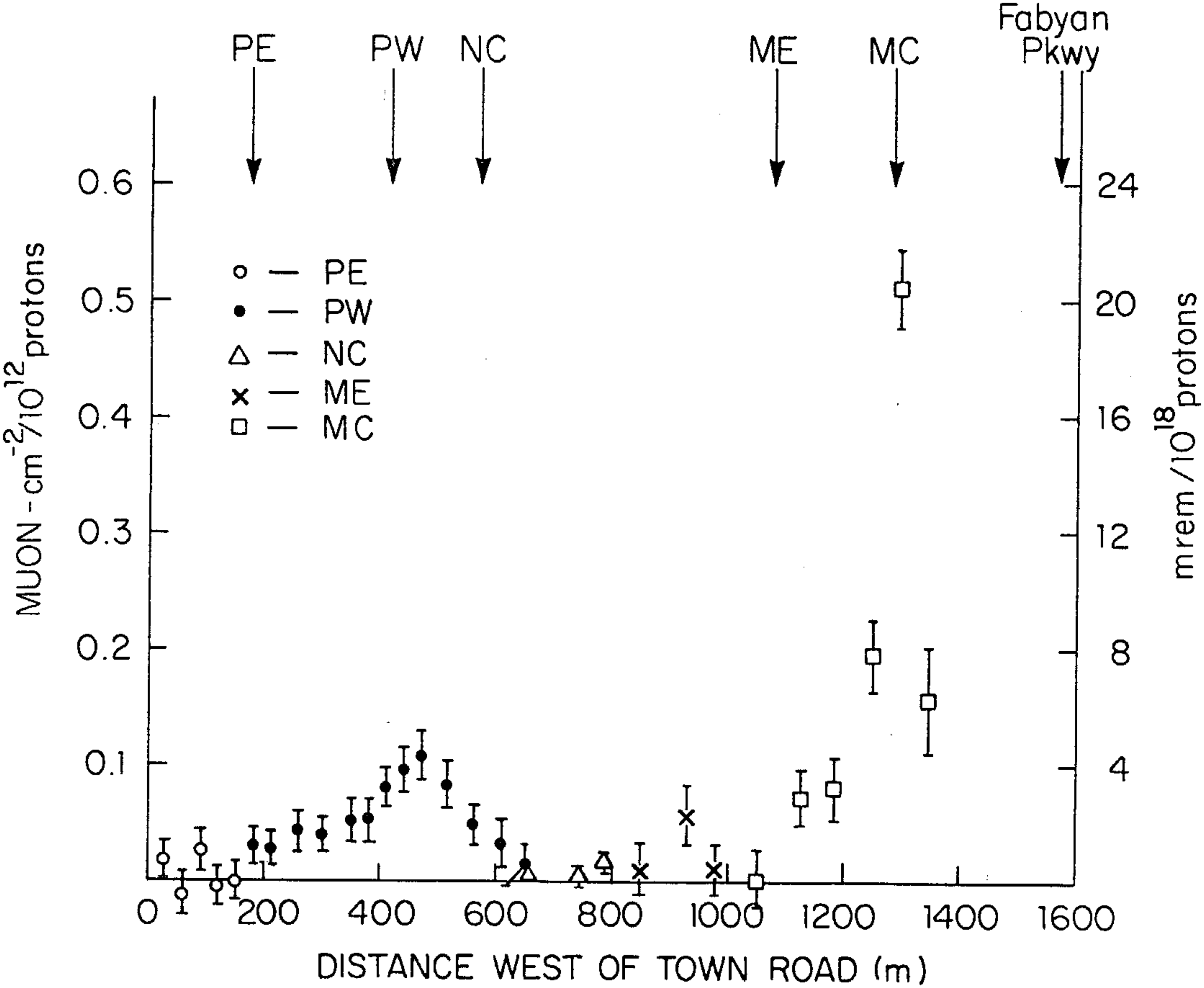
Table 1: Proton Intensities

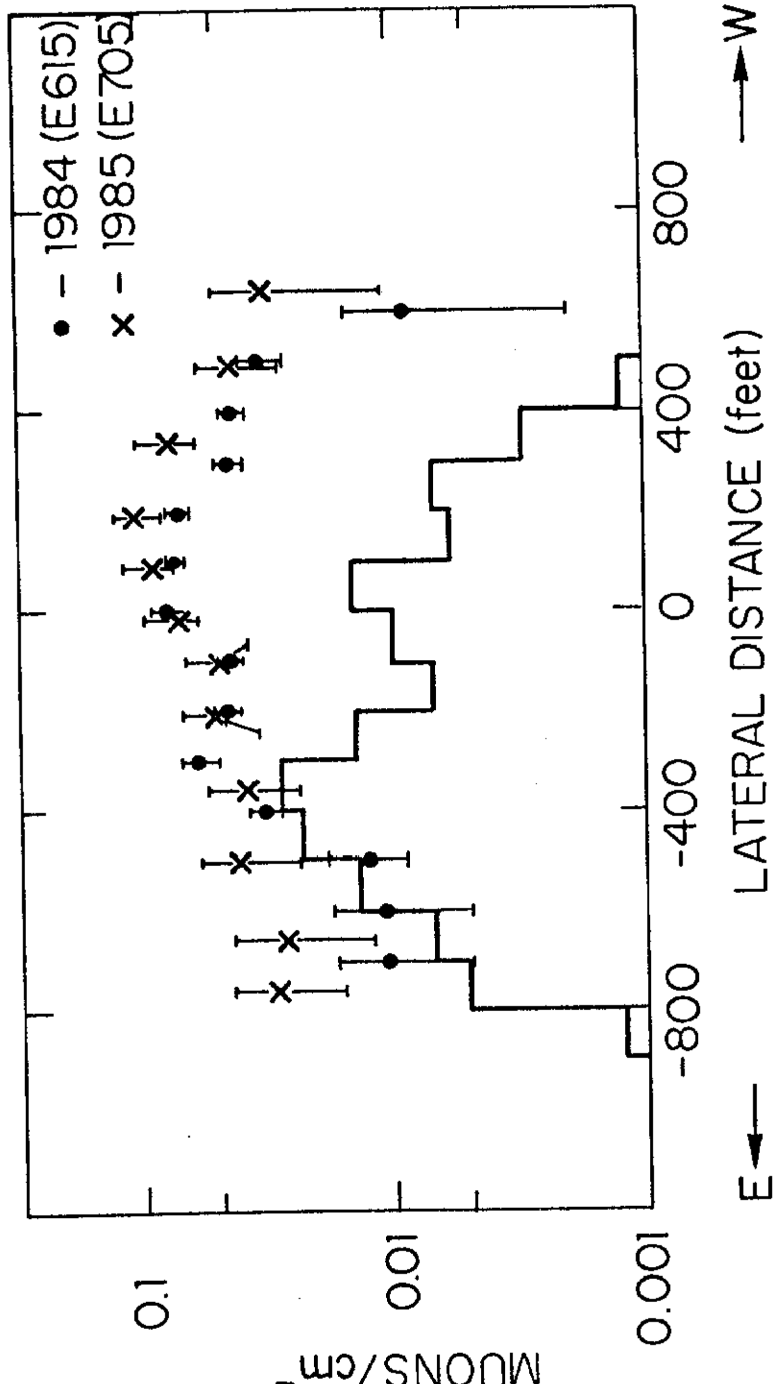
Beamline	Average Beam Intensity during Present Measurements ($x10^{12}$/pulse)	Total Delivered Beam during 1985 ($x10^{17}$)
PEAST	1.60	1.73
PCENTER	0.31	0.29
PWEST	1.84	0.79
NEAST	0.12	1.35
NCENTER	5.07	6.37
MEAST	1.31	1.73
MCENTER	1.24	0.75

FIGURES

1. Muon fluence per 10^{12} incident protons and dose-equivalent per 10^{18} protons as a function of the distance West of the intersection of Town and Roosevelt Roads. Muon intensity is normalized to the protons associated with the beamlines indicated by the symbols in the legend.

2. The lateral distribution of muon fluence per 10^{12} incident protons referenced to the intersection of the extension of the PW secondary beamline with Roosevelt Road. The histogram represents a HALO calculation (see ref. 1).


PE
PW
NC
ME
MC
Fabyan Pkwy
0.6
0.5
0.4
0.3
0.2
0.1
MUON - cm^{-2}/10^{12}protons
24
20
16
12
8
4
mrem / 10^{18}protons
○ — PE
● — PW
△ — NC
× — ME
□ — MC
0
200
400
600
800
1000
1200
1400
1600
DISTANCE WEST OF TOWN ROAD (m)



• - 1984 (E615)
× - 1985 (E705)
MUONS/cm²
0.1
0.01
0.001
-800
-400
0
400
800
LATERAL DISTANCE (feet)
E
W