Title

RADIATION ENVIRONMENT IN THE TUNNEL OF A HIGH-ENERGY PROTON ACCELERATOR AT ENERGIES NEAR 1 TEV

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Publication Date

1987-12-01

LBL-24640 c.2

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OCCUPATIONAL HEALTH DIVISION

To be presented at the Seventh Annual Congress of the International Radiation Protection Association, Sydney, Australia, April 10–17, 1988

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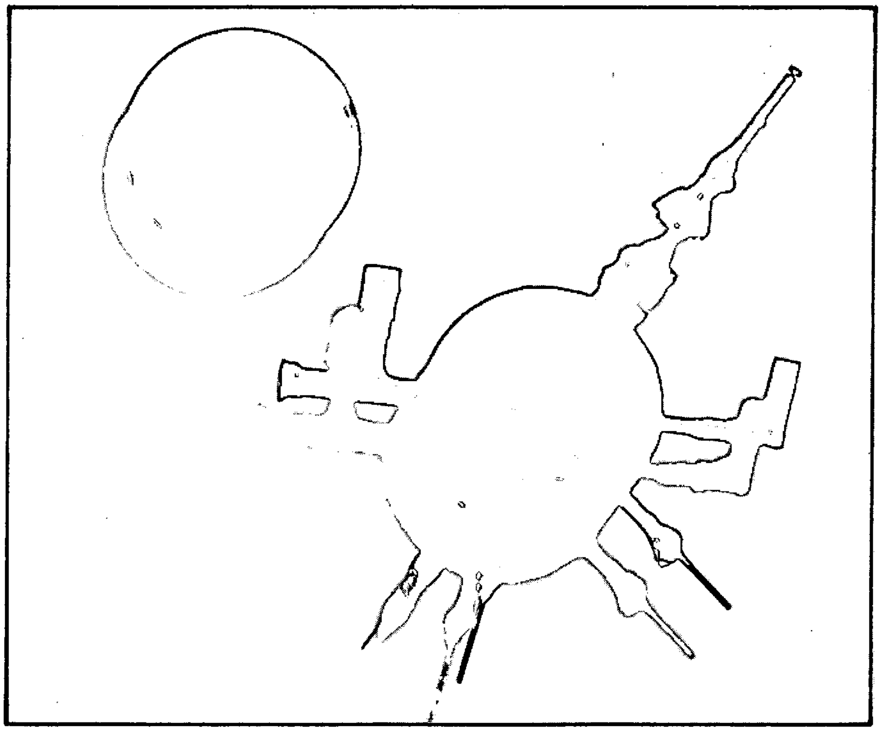
December 1987



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DISCLAIMER

RADIATION ENVIRONMENT IN THE TUNNEL OF A HIGH-ENERGY PROTON ACCELERATOR AT ENERGIES NEAR 1 TeV

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Neutron energy spectra, fluence distributions and rates in the FNAL Tevatron tunnel are summarized. This work has application to radiation damage to electronics and research equipment at high energy accelerators, as well as to radiological protection. Preliminary studies and related work are described elsewhere [1, 2, 3].

EXPERIMENTAL ARRANGEMENT

Figures 1 and 2 show the experimental arrangement in the A-17 region of the Tevatron tunnel. A room-temperature straight section (11.95 m) is shown which had a controlled N_2 leak in order to study neutron production as a function of beam-gas interaction rate during coasting beam conditions. Pressure was measured by a calibrated gauge near the leak and was controlled over the range 10^{-8} to 10^{-5} torr. The pressure in the adjoining cryogenic magnet chains, about 1×10^{-11} torr or less, was negligible by comparison. A "triangular" N_2 pressure distribution was assumed, *i.e.*, a linear decline in both directions from the leak, going to zero at the cryogenic interfaces. The interaction rate within the warm section was calculated to be 1.02×10^{-2} interactions per g cm^{-2} of N_2 and per passing proton, based on a total cross section for N of 238 mb.

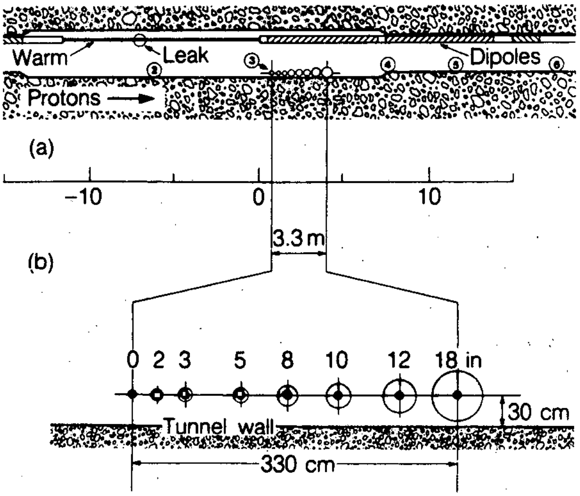

Fig. 1. Plan view of experimental setup in the tunnel near A-17. (a) overall view; (b) spectrometer geometry.

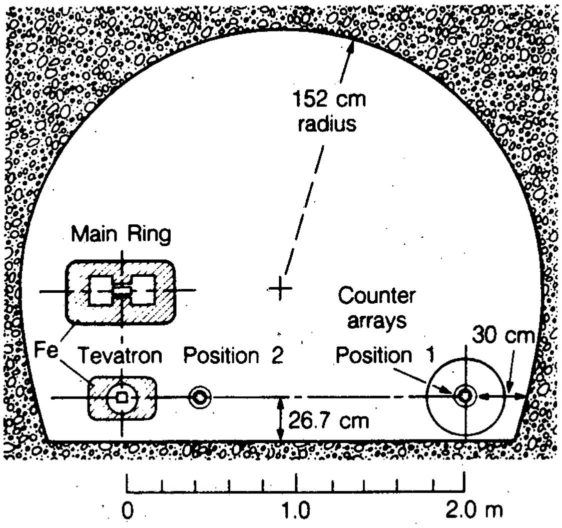

Fig. 2. Tunnel cross section near A-17.

A Bonner multisphere neutron spectrometer [4] was used, consisting of eight LiI(Eu) scintillation crystals (12.7 mm diam × 12.7 mm high), enriched to 99% ^{6}Li, and surrounded by spherical polyethylene neutron moderators ranging in diameter from 0 to 45.72 cm. These detectors were coupled through photomultiplier tubes to an 8-input 4096-channel analyzer. For spectral unfolding, the response functions of Sanna were used [5] in the program LOUHI [6]. For some runs the eight detectors were fitted with identical 12.7-cm spheres to study the longitudinal distribution of neutron fluence.

The Tevatron and Main Ring (MR) share a common tunnel (Fig. 2) [7]. Because the MR produced elevated radiation backgrounds, detectors were gated off during MR operation which accelerated protons from 8 to 150 GeV. A standard current toroid served as beam monitor.

Preliminary measurements were made in 1985 at a different location (A-48; not shown here), a low-loss region (small β) representing "quiet" coasting-beam conditions of accelerator operation. Here, the spectrometer was deployed 14.2 - 17.6 m downstream of a 4-m long warm section containing a nominal pressure of 2×10^{-8} torr. Measurements were made during Tevatron operation at 150 and 800 GeV, and during MR operation (only) at 150 GeV.

NEUTRON FIELD IN THE TUNNEL

Fluence rates as functions of gas pressure were measured along the tunnel over the range $-19 \leq z \leq 35$ m using identical 12.7-cm moderators surrounding each LiI scintillator. Figure 3 shows an example of a linear fit relating the counting rate to the gas pressure in the warm straight section for a 900-GeV proton beam. The slopes and intercepts from such fits for each location were converted to fluence rates per proton *passing* the measurement point and are plotted separately to show the distribution along z in Fig. 4. It is evident that the slope data (Figs. 3, 4a) are related to primary interactions within the warm section. There are variations (S. D. $\approx$ 20%) which are not understood between the measurement sets shown (Fig. 4a). The longitudinal distribution of intercepts (Fig. 4b) was found to be very similar in shape to that of the slopes, but the variance is much larger.

Representative neutron spectra made using the Bonner spectrometer under five different conditions are shown in Fig. 5. The remarkable features of these spectra are: (a) the prominent peak in all distributions that lies in the few-hundred keV region; (b) the relatively few high-energy neutrons (about 10% and 1% of fluence above 2 and 50 MeV, respectively); and (c) the average quality factor in the range $\overline{Q} = 6.9 - 7.6$.

With the spectrometer deployed as in Fig. 1 during 900-GeV operation, the *slopes* from fluence-vs pressure plots (Fig. 3) were used as input data to LOUHI. This procedure gives the spectrum of neutrons *unambiguously* produced in cascades initiated by primary interactions of protons on N_2 of the warm section. The prominent peak is centered at about 360 keV. The spectrum derived from *intercepts* of the same plots is related to primary interactions on materials in the vicinity other than introduced N_2. The peak is centered at about 75 keV and can be compared with spectra obtained downstream of A-48 (1985) at a gas pressure such that interactions in the warm section should not dominate. The spectra shown are for 150 and 800 GeV Tevatron operation and for MR-only operation at 150 GeV. The peaks are centered at 280, 135 and 240 keV, respec-

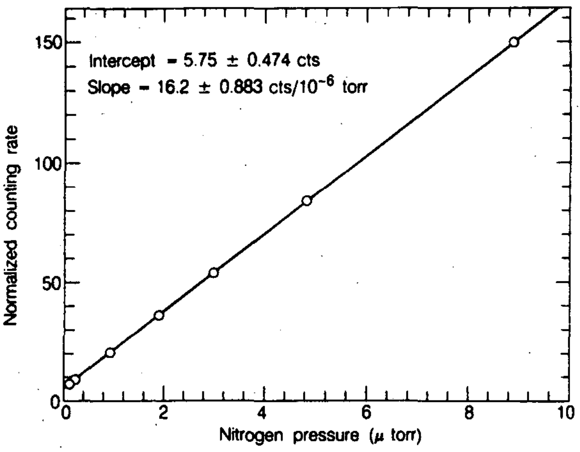

Fig. 3. Example of neutron fluence at 2m plotted *vs* N_2 pressure in warm section A-17 for 900-GeV protons.

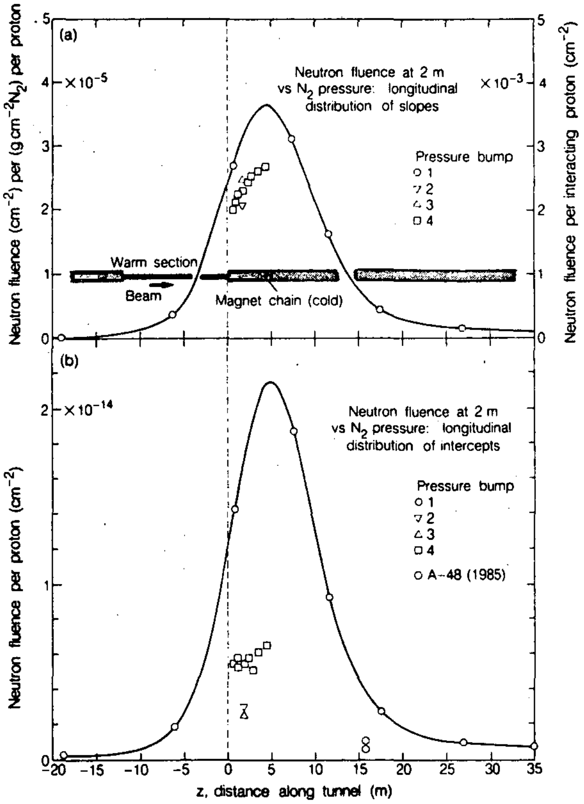

Fig. 4. Neutron fluence at 2m from beam line: (a) Per *passing* 900-GeV proton and unit N_2 target thickness (left ordinate) or per *interacting* proton (right ordinate), as derived from slopes of fluence-pressure plots; (b) per *passing* proton, as derived from intercepts of fluence-pressure plots.

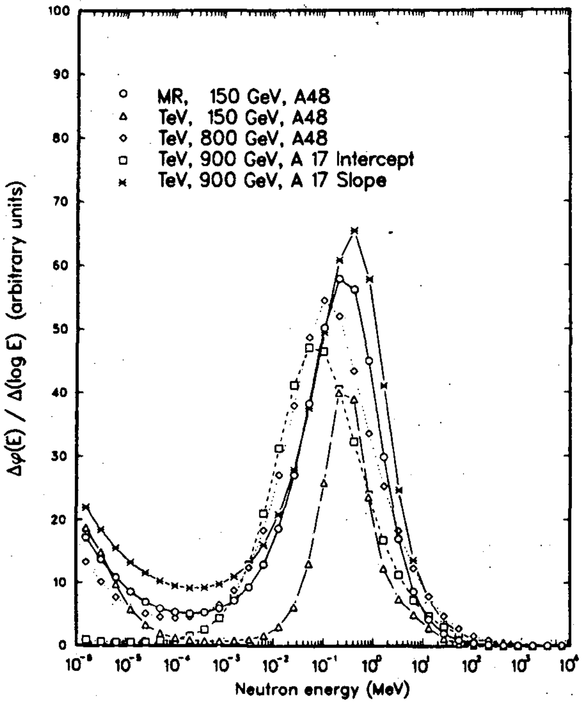

Fig. 5. Unfolded fluence spectrum at 2m from beam line for four types of Tevatron run and one Main-Ring run.

tively. We do not fully understand the differences between peaks but point out that the primary interactions that do not occur on N_2 most likely occur either on H_2 or He in cryogenic sections or with machine materials.

Monte-Carlo simulations performed by Gabriel et al. (not shown here) are in good agreement with the spectrum of Fig. 5 derived from slopes [3]. They furthermore indicate that about 80% of the neutrons at 200 cm from the beam line are albedo neutrons, *i.e.* , scattered from tunnel walls. This was tested experimentally by repeating certain runs at 39 cm from the beam line (Position 2, Fig. 2). The result was consistent with the expected radial distribution for the direct fluence, assuming that the albedo fluence is uniform across the tunnel section.

Integration over the "slope" z-distribution of Fig. 4a and correcting for the albedo fluence gives a value 10 neutrons produced per 900-GeV proton passing A-17 and per g cm^{-2} of N_2 target. A similar calculation based on an integration over the intercept z-distribution (Fig. 4b) gives 5×10^{-9} neutrons produced per passing 900-GeV proton. We caution the reader that this latter value is not well understood, is subject to the vagueries of machine operation and will likely vary widely from place to place around a given accelerator ring.

The above observations suggest a common "filter" for the neutrons, regardless of the nature of the original interactions which produce the parent cascade. Prominent parts of the filter must be the iron magnet yokes as well as the concrete tunnel lining. The neutron field dominates the tunnel radiation field in terms of absorbed dose to tissue. Because of their capability of producing lattice defects and transmutations, neutrons of energy $E_n \geq 150$ keV are the most important potential cause of radiation damage to solid state electronic devices in accelerator tunnel environments similar to those studied [1].

This work was partially supported by the U. S. Department of Energy under Contract No. DE-AC03-76SF00098 with the University of California.

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