RADIATION PHYSICS NOTE 90

SOURCE TERM FROM THE RESULTS OF T777

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MARCH 1991

In an experiment[1] performed to study the radiation environment in the Tevatron tunnel, T777, a beam particle interacts with a residual N atom in the "warm" straight section at A17. A cascade develops in the magnets downstream of A17. Neutron fluence rates as a function of gas pressure from a controlled N_2 leak were measured along the tunnel wall at a distance of 2 m from the beam line by use of a number of identical 12.7 cm diameter spherical moderators surrounding a ^{6}LiI scintillator. At each location the neutron counting rate as a function of N_2 pressure was fit to a linear relation. An example of such a measurement is shown in Fig. 1. The slopes and intercepts from each fit for each location were converted to neutron fluence rates per 900 GeV proton passing the A17 section. These quantities are plotted in Fig. 2. The slopes data are related to primary interactions with the N_2 molecules in the "warm" section. The intercepts data are related to primary interactions on other materials in the vicinity (not N_2).

Integrating the longitudinal slope distribution[1] in Fig. 2, and extrapolating back to the beam line from the detectors on the assumption that the neutrons are produced by a line source of radiation (i.e., 1/r-dependency), gives a source term of 50 neutrons per 900 GeV passing proton per g/cm^2 of N_2 target. From Monte Carlo simulations of these measurements performed at ORNL by Gabriel, et al.,[2] about 80% of the flux measured at 2 m from the beam is due to albedo neutrons.* Correction for this albedo contribution gives a direct source term of 10 neutrons per passing 900 GeV proton per g/cm^2 of N_2 target.

The yield of neutrons from a nuclear target struck by protons is proportional to the production cross section per nucleon times the target thickness in g/cm^2. Measurements[3] of inclusive neutron production at 400 GeV indicate that the cross section per nucleon on Be, Cu, and Pb are approximately equal. Therefore, generalizing the above result to a proton beam striking any nuclear target of mass A of thickness t (g/cm^2) in a beam enclosure leads to a source term for direct neutrons of

$$10 \times t \text{ n/p at 900 GeV.}$$

*The albedo distribution is broader than the distribution of direct neutrons and is very likely due to the experimental N_2 source being distributed over nearly 11 m of "warm" section.

For a one interaction length Fe "target", t =131.9 g/cm^2, the result is 1319 n/p at 900 GeV. The prescription of Rameika[4] to determine the source strength at the mouth of a labyrinth due to a beam loss opposite or nearly opposite is smaller by almost a factor of 6. (But see below.)

The spectrum of the neutrons at the tunnel wall 2 m from the beam line was also measured[1] in the T777 experiment. A Bonner sphere spectrometer consisting of seven polyethylene spherical moderators surrounding ^{6}LiI scintillators plus a "bare" scintillator was used, and the neutron counting rate in each sphere was determined as a function of N_2 pressure, as described above. The slopes from fluence versus pressure plots were used as input to the LOUHI unfolding program, and the neutron spectrum obtained. Of relevance to the present remarks, the features of the spectrum are the existence of a prominent peak at a few hundred keV (about 400 keV), a fairly large "thermal" energy peak (albedo neutrons), and the almost complete lack of any neutron fluence above 2 MeV (about 1% of the total fluence).

In Ref. 4 Rameika suggests a value of 3×10^7 for the conversion of neutron fluence into dose equivalent (rem) at the mouth of a labyrinth, appropriate to 1 MeV neutrons. If, on the other hand, more representative neutron energies are on the order of a few hundred keV, this factor should be closer[5] 6×10^7 neutrons/cm^2 per rem, a factor of two larger.

Moore[6] has compared the results of Ref. 4 with measurements[7] at 300 GeV made in 1973 in a typical Fermilab labyrinth. Good absolute agreement with the Rameika prescription was found for the 2nd and 3rd leg attenuation. In the first leg, however, the calculations are lower than the data by factors of 3-4.

Moore's[7] 300 GeV measurement of 0.8×10^4 rem for 4.5×10^{14} protons, or 1.78×10^{-11} rem per proton, at the mouth of a labyrinth due to a "point" source of neutrons a distance r=6.7 feet = 204 cm away, can be used with the 900 GeV result from T777 of 10 n/p per g/cm^2 of target thickness to determine both the source term constant k and the exponent of energy scaling n for an assumed source term of form $k \times E^n$. If the loss is on a one interaction length magnet and if 6×10^7 n/cm^2 per rem converts neutron fluence to dose equivalent as suggested above, then from Ref. 7,

$$k \times 300^n = 1.78 \times 10^{-11} \times 3.15 \times 10^{13} = 560.2. \qquad (1)$$

From T777,

$$k \times 900^n = 10 \times 131.9 = 1319. \qquad (2)$$

Solving for n and k from (1) and (2) gives

$$n = 0.8 \text{ and } k = 5.78.$$

A source strength, $5.78 \times 10^{0.8}$, is therefore consistent with results at both 300 GeV and 900 GeV, on the assumption of a beam loss on a one interaction length Fe target. Note that the result is in agreement with the energy scaling assumed by Rameika.[4] It is further noted that if the Rameika prescription is modified to

$$\text{Dose (rem)} = \frac{5.78 \times E^{0.8} \times N_p}{4\pi R^2 \times 6 \times 10^7} \approx \frac{E^{0.8} \times N_p}{4\pi R^2 \times 10^7},$$

then the comparison discussed in Ref. 6 becomes quite good in the first leg, but somewhat worse in absolute value in the 2nd and 3rd legs, although of course the dependence on distance is unchanged.

References

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