Application of a Simple Analytical Model to Estimate Effectiveness of Radiation Shielding for Neutrons

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Abstract

Neutron dose equivalent rates have been measured for 800-MeV proton beam spills at the Los Alamos Meson Physics Facility. Neutron detectors were used to measure the neutron dose levels at a number of locations for each beam-spill test, and neutron energy spectra were measured for several beam-spill tests. Estimates of expected levels for various detector locations were made using a simple analytical model developed for 800-MeV proton beam spills. A comparison of measurements and model estimates indicates that the model is reasonably accurate in estimating the neutron dose equivalent rate for simple shielding geometries. The model fails for more complicated shielding geometries, where indirect contributions to the dose equivalent rate can dominate.

I. INTRODUCTION

The assessment of radiation shielding for the Los Alamos Meson Physics Facility (LAMPF) and the Los Alamos Neutron Scattering Center (LANSCE) required a quick and simple method of estimating neutron dose equivalent rates (DER) for 800-MeV proton beam spills. An analytical model has been developed for this purpose. During the 1992 operating cycle, neutron DER measurements were performed in the switchyard area of LAMPF and at LANSCE. These results have been used to gauge the accuracy of the model to estimate the neutron DER (accuracy within a factor of 2-3 is desired). The analytical model is discussed, the 1992 beam-spill measurements performed are described, and a comparison with the model estimates is made.

II. ANALYTICAL MODEL FOR ESTIMATING NEUTRON DOSE EQUIVALENT RATES

The analytical model used to estimate the neutron DER is a combination of a Moyer Model [1,2] for lateral production angles and extended for 800-MeV proton beams and a Monte Carlo based formula for forward production angles [3]. The model has the following functional form:

$$D = \frac{H_o}{r^2}\exp(-\beta\theta)\exp\left(-\sum_i \frac{r_i}{\lambda_i}\right)$$

where D is the neutron dose equivalent rate, H_o is the source term, r is the distance from spill to observation point, β is the angular relaxation parameter, θ is the production angle between the incident beam direction and the ray from spill to observation point, r_i and λ_i are the path length through and attenuation length for material i, respectively. The model parameters are listed in Table 1, which includes the attenuation lengths for concrete (2.42 g/cc), magnetite concrete (3.64 g/cc), natural iron (7.87 g/cc), and tuff (1.6 g/cc). For production angles of 30°≤θ≤60°, DER estimates are made with both sets of parameters defining a range of possible values.

Table 1.
Analytical Model Parameters for Estimating Neutron Dose Equivalent Rates for 800-MeV Proton Beam Spills.

Parameter	0°≤θ≤30°	60°≤θ≤120°
H_o (mrem•m^2)/(hr•µA)	856 x 10^6	296 x 10^6
β (rad^{-1})	2.14	2.3
λ concrete (m)	0.58	0.50
λ mag. concrete (m)	0.43	0.40-0.43
λ tuff (m)	0.77	0.66
λ nat. iron (m)	0.35	0.20

III. 1992 BEAM-SPILL MEASUREMENTS

A. Description of Beam-spill Measurements and Detector Locations

Beam-spill measurements were performed in the switchyard area of LAMPF and at LANSCE. The switchyard measurements were performed in Line D, the transfer line from the linac to the Proton Storage Ring that supplies beam to LANSCE. Measurements were made for two spill points in the Line D 89° bend, and for four spill points at LANSCE. Measurements for two detector/spill point combinations in the switchyard area and 25 detector/spill point combinations at LANSCE were compared to model estimates.

The neutron dose equivalent rates (mrem/hr) for various beam-spill tests were measured using HPI Pulsed Neutron Detectors Model 2080, referred to as Albatrosses. For each spill test, Albatross readings were taken after three time intervals; usually three, six, and nine minutes. This allowed each detector to come into equilibrium and established that it was consistent over time. The DER measurements for each spill test were then normalized by the beam current to the units mrem/(hr•µA).

B. Corrections to the Neutron DER Measurements

Albatrosses have a very low efficiency for detecting the contribution to the DER from neutrons with $E_n \geq 20$ MeV. Therefore, an estimate of the DER that was not measured by the Albatrosses must be made and a correction factor applied to the data. Neutron energy spectrum measurements were performed for two beam spill and detector locations in 1992. These, and previous spectrum measurements, indicate that the DER contribution from neutrons with $E_n \geq 20$ MeV is (34-

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65)% of the total, for a correction factor of $f \approx 1.5$-3.0. A value of $f \approx 1.5$ corresponds to a detector location where the indirect contribution to the DER is large, while a value of $f \approx 3$ corresponds to detector locations where the indirect contribution is negligible. Since not every detector location has a corresponding spectrum measurement, a correction factor of $f = 2.25$ has been applied and the neutron DER measurements are believed accurate to within a factor of 2 [4].

IV. COMPARISON OF MODEL ESTIMATES WITH MEASUREMENTS

A. Comparison for the LAMPF Switchyard Area

The LAMPF switchyard area has an overburden of tuff, with two penetrations, the personal access maze and the truck access. The truck access is filled with large concrete shielding blocks whose total length is ≈6.8 meters. A tungsten block was inserted between two bending magnets midpoint in the 89° bend and the upstream bending magnet was turned off, simulating a spill in one of the magnets. Two Albatrosses were located 6.3 meters along, and on top of, the concrete shielding blocks in the truck access. There was a total distance of (12-12.5) meters between spill and observation point, with a total of (6.4-7.2) meters of concrete shielding. Approximately 70% of the beam interacted within the magnets and tungsten block, with an equivalent natural iron path length of 0.1-0.2 m, and the remainder continued forward and struck the concrete shielding blocks. The production angle ranged from 12° to 29°. The [estimated: measured] values for the neutron DER for the two Albatross locations are [76:120] and [19:63]. The estimates are within a factor of 2-3 of the measured values, and are acceptable given the complexity introduced from the beam interacting at two locations.

B. Comparison for LANSCE

The LANSCE spill measurements include cases in which the DER is expected to be dominated by direct contributions as well as cases dominated by indirect contributions from scattered neutrons. The LANSCE experimental area is composed of adjacent two-story buildings. The beam enters on the upper floor (Service Area) of the first building and is bent 90° downwards into the neutron production target. The lower floor is Experimental Room 1 (ER1) and contains the neutron production target surrounded by a bulk shield with the horizontal neutron beam lines fanning out radially. As shown in Figure 1, steel shielding was added in the forward beam direction on the upper level. The second building is Experimental Room 2 (ER2). The spill points and detector locations are illustrated in Figure 1, and the corresponding model estimates and measured neutron DER are tabulated in Table 2.

The model accurately estimated the neutron DER for a number of spill and Albatross locations (**bold type**), but was unsuccessful for others. First, let us consider the three Albatross locations A-C in ER2. Albatross A was located 6.8 m above the floor of ER2, while Albatrosses B & C were 2.4 m above the floor, all directly along the beam's line-of-sight. The model grossly underestimated the measured DER for Spills 1-3 for Albatross B and Spills 2-3 for Albatross C. This is because the model only estimates the direct line-of-sight contribution to the DER. The additional steel shielding, as well as the large amount of tuff, in the forward direction substantially reduces the direct contribution to the DER at locations B & C, so that scattering of low-energy neutrons from larger production angles and other indirect contributions dominate. To illustrate this point, consider the ratio of the difference between measured and estimated values for Albatrosses B & C to the measured values for Albatross A, where the indirect contribution to the DER is negligible. The

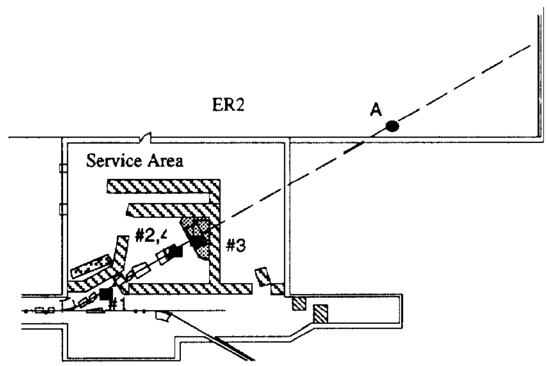

Figure 1.a. Plan view of the Service Area and the upper level of ER2.

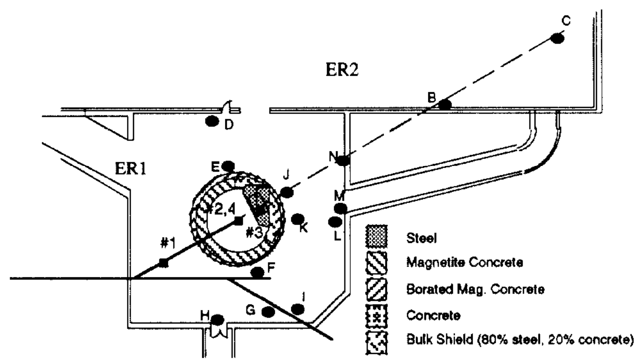

Figure 1.b. Plan view of ER1 and ER2.

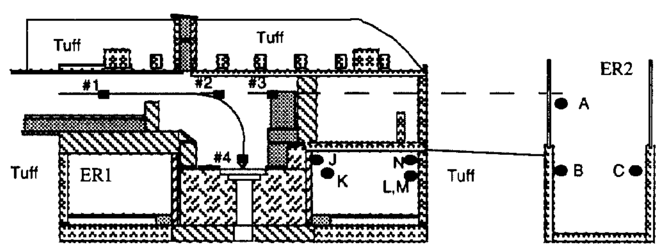

Figure 1.c. Vertical elevation view of the Service Area, ER1, and ER2.

Table 2.
Comparison of the Measured DER with the Model Estimate for the 1992 Beam-Spill Tests at LANSCE.

Albatross	Spill #	Production Angle (°)	Measured DER	Estimated DER
A	1	**3.2**	**13**	**---**
	2	**3.8**	**331**	**409**
	3	**4.6**	**522**	**706**
	4	**97**	**0.0**	**0.0**
B	1	11	1.6	0.0
	2	13	54	0.0
	3	16	84	0.01
	4	**86**	**0.0**	**0.0**
C	1	**9.5**	**6.1**	**6.9**
	2	10	109	2.9
	3	12	163	9.7
	4	**88**	**0.4**	**0.0**
D	4	**87**	**124**	**295**
E	4	**88**	**783**	**1067**
F	4	**88**	**859**	**1067**
G	4	**87**	**144**	**295**
H	4	**85**	**173**	**272**
I	4	**84**	**110**	**117**
J	1	24	44	2.4
	2	37	713	15
	3	62	456	0.0
	4	75	6.1	0.04
K*	1	---	82	---
	2	---	1582	---
	3	---	498	---
	4	---	8.2	---
L*	1	---	50	---
	2	---	1074	---
	3	---	506	---
	4	---	9.0	---
M*	1	---	46	---
	2	---	946	---
	3	---	605	---
	4	---	3.8	---
N	1	16	16	0.4
	2	21	457	26
	3	29	683	40
	4	85	1.1	0.01

* Included for informational purposes only.

difference between measured and estimated DER is used in order to remove the direct contribution from the total. The ratio values for Albatross B to A are 0.125, 0.163 and 0.161 (mean=0.150). The ratio values for Albatross C to A are 0.329 and 0.293 (mean=0.311). These values are relatively constant and independent of spill location indicating that detector locations B and C will see an indirect contribution equal to 15% and 31% of the total DER at location A for all spill points. The large discrepancy between measurement and calculation indicates that indirect contributions can dominate the total DER, particularly for locations where the expected direct line-of-sight contribution is small.

This is further illustrated by the comparison between measurement and model estimate for Albatross locations in ER1. No calculations have been performed for K, L, & M; these measurements are included for information purposes only. The analytical model was successful in estimating the DER for D, E, F, G, H & I and Spill 4. where the estimated DER was large. The model was unsuccessful for detector locations J & N. As stated previously, these two locations are directly shielded by the additional steel shielding. The other nine locations are mostly shielded by magnetite concrete only. The discrepancy between measured and estimated DER is considerably larger than was observed in ER2. This is most probably due to ER1 being a much smaller enclosed area, a large fraction of the room is occupied by equipment and shielding for the 12 neutron beam lines, and the room is enclosed on three sides by tuff. The backscattering of low-energy neutrons may play a greater role in this case.

V. SUMMARY

The analytical model was successful in estimating the neutron DER for those spill/observation point combinations where the shielding geometry was relatively simple. The model accurately estimated the DER for forward angles in the Line D switchyard and the ER2 crane area, at lateral angles at LANSCE where the shielding geometry was simple and/or where the estimated direct DER was dominant. The model was unsuccessful at forward and lateral angles for more complicated shielding geometries, particularly where the estimated direct contribution was small.

A simple analytical model can be used to estimate the neutron DER for many spill/observation point combinations allowing the user to perform a large number of calculations relatively quickly. However, the model must be applied discerningly and with a great deal of caution; the shielding geometry must be well understood so that it can be determined that indirect contributions to the DER are negligible.

VI. REFERENCES

[1] G. Stevenson and R. Thomas, "Determination of Transverse Shielding for Proton Accelerators Using the Moyer Model," Health Physics **43**, 13 (1982).

[2] J. McCaslin, W. Swanson, and R. Thomas, "Moyer Model Approximations for Point and Extended Beam Losses," Nucl. Instrum. Methods **A256**, 418 (1987).

[3] C. Wilkinson *et al.*, "Monte Carlo Based Formula For Radiation Shielding Assessment in the Forward Direction," these proceedings.

[4] S. Frankle, "Neutron Energy Spectrum Measurements with Bonner Spheres and Neutron Dose Equivalent Rate Measurements Using Albatrosses," PSR Technical Note 93-005, LA-UR number to be assigned.