FURTHER EVALUATION OF NEUTRON SKYSHINE DOSE IN VICINITY OF THE K1200 SUPERCONDUCTING CYCLOTRON OF THE NSCL USING BUBBLE DOSIMETERS

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Abstract

The air-scattered radiation (Skyshine) is commonly a primary contributor to the public radiation exposure at distant locations form a high-energy particle accelerator facility. We have reported the results of the first series of measurement of skyshine from neutrons, using superheated bubble dosimeters. We have continued our measurements of skyshine, produced during "typical" operational condition at the National Superconducting Cyclotron Laboratory (NSCL). The measurements were carried out using the BD-100R Bubble Dosimeters with sensitivities of 470 nSv and 220 nSv per bubble at 20 ^{o}C, with an accuracy of ± 20% when calibrated using the ^{241}AmBe neutron spectrum. The dosimeters were placed at 25 and 50 meters from a point on the shielding roof of the NSCL's Analysis Hall, and 75, 100, and 115 meters from this point but about one to two meters above the floor of the NSCL facility at these distances. The skyshine neutron dose equivalents were measured for the $^{4}He^{2+}$, $^{13}C^{+4}$, and $^{20}Ne^{6+}$ beams at the energy of 140 MeV/A, 100 MeV/A and 100MeV/A respectively.

1 INTRODUCTION

During the operation of a high-energy particle accelerator, the secondary neutrons produced at targets and beam stops may leak out into the atmosphere after penetrating an inadequately shielded roof. They may be drifted to a long distance from the source, after undergoing multiple scattering in the atmosphere. This phenomenon is known as skyshine [1, 2, 3]. The National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University presently runs two superconducting cyclotrons (K500 and K1200) capable of accelerating ion species ranging from $^{2}H^{1+}$ to ^{238}U. The skyshine was produced by the neutrons during K1200 operations, which leaked through 26 cm thick local iron "shielding" of the dipole magnet (analyser) and the 1.37m thick concrete roof (Figure 1).

The neutron bubble dosimeters were placed at 25 and 50 meters from the expected source (reference point) of the skyshine, *i.e.*, the spot at the roof surface directly above the neutron-producing target situated in the NSCL's Analysis Hall and 75, 100 and 115 meters from this reference point on the ground floor of the NSCL facility. The “zero-distance” reference point (A) is on the roof shielding above the first of a pair of dipoles in the A1200 analysis system, the expected source of the neutron skyshine (Figure 1). In 1997 the first measurement of the neutron skyshine at the National Superconducting Cyclotron Laboratory (NSCL) using superheated bubble dosimeters [3] was carried out. We have further continued our measurements of skyshine, produced during "typical" operations at the NSCL. These additional data should also prove useful for anticipating the neutron doses when coupled-cyclotron operations commence. This report highlights the results of the recent neutron skyshine measurement experiments at the NSCL using BD-100R Bubble Dosimeters.

2 METHODS AND MATERIALS

2.1 Neutron Skyshine Calculation

Neutron Skyshine fluence ϕ *[cm^{-2}]* from high energy particle accelerators are described by the following equation [2]:

$$\phi = \frac{a \times Q}{4\pi r^2} e^{-r/\lambda}(1 - e^{-r/\mu}) \qquad (1)$$

where

a = empirical build up parameter = 2.8
μ [m] = effective interaction length of neutrons in air
Q [cm^{2}] = neutron fluence (source strength)
r [m] = distance from the source
λ [m] = effective build up relaxation parameter

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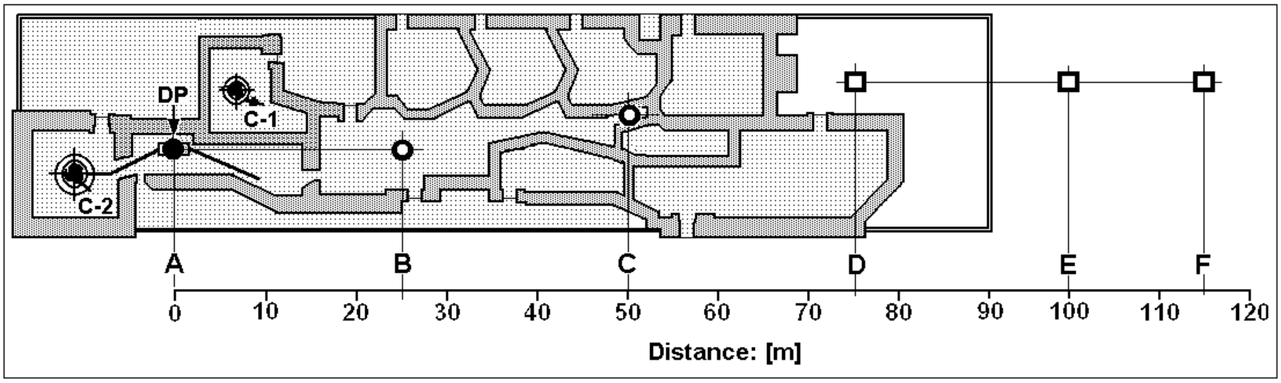

Figure 1: The foot print diagram (plan view) of the NSCL facility showing the various shielded experimental vaults and the positions of the K500 (C1) and K1200 (C2) cyclotrons and the first dipole pair (DP). The locations of the bubble dosimeters "B", "C", "D", "E" and "F" and the reference point "A" are also indicated. However, for the sake of clarity the beam transport lines and associated experimental devices are not included in this figure. The figure is further explained in the main text.

For many accelerator laboratories, μ was found to be 56 meters.

The neutron skyshine dose equivalent at the r from the source H(r) was calculated as:

$$H(r) = k\phi \qquad (2)$$

where

k [μSvm^2] = fluence to dose equivalent conversion factor

The effective build up relaxation parameter (λ) and fluence to dose conversion factor (k) used in the skyshine calculation depend on neutron energy.

2.2 Skyshine Dose Measurement

A spherical neutron detector (model: NRD, manufacturer: Eberline Co, USA) was placed on the roof, above the stopped beam in the dipole magnet. This "zero-distance" point is on the roof shielding above the first pair of dipoles in the A1200 analysis system, the expected source of the neutron skyshine. The detector was used to integrate the total dose at this point. Measurements using Bonner-spheres were also made at this point. The sphere diameters were 2, 3, 5, 8, 10, and 12 inches. Additionally, data were collected using the Bonner-sphere system's bare detector, this detector covered by cadmium, and using a polyethylene cylinder that approximates an 18-inch diameter sphere [3]. Data were taken for three primary beams, 140A MeV ^{4}He, 100A MeV ^{13}C, and 100A MeV ^{20}Ne. The related experimental methods are described in details elsewhere [3, 4].

The neutron skyshine doses were recorded using the passive superheated bubble dosimeter [5] manufactured by the Bubble Technologies Industries, Canada [6]. Each dosimeter (model: BD-100R) Each has a sensitivity of 22 or 47 bubbles per millirem at 20 ^{o}C, with an accuracy of ± 20% when calibrated using the ^{241}AmBe neutron spectrum. The dosimeters were placed at 25 and 50 meters from a point on the roof of the NSCL's Analysis Hall, and 75, 100, and 115 meters from this point but about one to two meters above the floor of the NSCL facility at these distance (Figure 1). The results are summarised in Table 1. In Figure 2 the measured neutron doses are shown as a function of distance from the reference point and compared with calculated values using equation 1.

Table 1: Summary of the skyshine dose measurement at the NSCL using BD-100R superheated bubble dosimeters. The neutron dose equivalent H(r), corresponding exposure time T and the distance of the measurement point r for the three common accelerated ion species are shown. The experimental uncertainty for the neutron dose equivalent estimation using the BD-100R dosimeters was ± 20%.

	Ion Species: 100MeV/A ^{20}Ne^{6+}		**Ion Species: 100MeV/A ^{13}C^{4+}**		**Ion Species: 140MeV/A ^{4}He^{2+}**	
r [m]	**H(r) [μSv]**	**T [h]**	**H(r) [μSv]**	**T [h]**	**H(r) [μSv]**	**T [h]**
0	3760	175	5360	138	10313	131
25	19.0	175	29.0	138	69.3	131
50	14.1	175	11.5	138	25.4	131
75	1.6	175	2.1	138	2.3	131
100	1.5	175	1.2	138	2.2	131
115	0.5	175	2.3	138	2.9	131

The data for each beam and each point were simply averaged in our analysis. We adjusted the "source strength" Q and the "effective build-up relaxation length" λ to fit the overall trend of the averaged data set. We obtain $Q = 5.18 \times 10^{2}$ [$mSvm^{-2}$] and λ = 64.3 meters. For a spectrum having a dependence on neutron energy of 1/E with an endpoint of about 10 MeV, one might expect λ to be 200m [7]. Given our smaller value of λ = 64.3 meters, the spectra we measured are quite soft, with many low energy neutrons contributing. This is consistent with the measured average energy of 5 MeV.

3 SUMMARY AND CONCLUSION

Personnel doses from penetrating radiation at accelerators originate in part from line-of-sight penetration of shielding. However, air-scattered radiation, "skyshine", from radiation penetrating a "thin" shielding roof may also contribute to the dose. One of the standard equations describing skyshine is shown to work adequately for data taken at the NSCL. These data should also prove useful anticipating doses when coupled-cyclotron operations commence. This allows predictions to be made for neutron radiation levels at site boundaries.

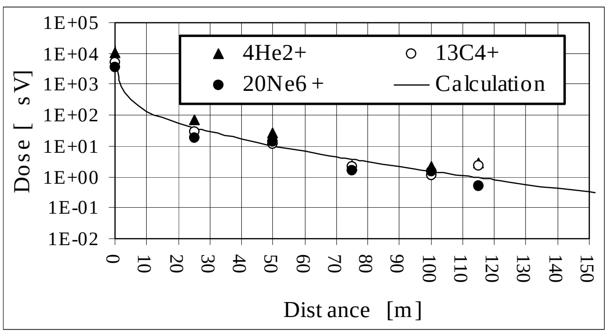

Figure 2: Showing the variation of neutron skyshine dose equivalent at the NSCL facility with the distance from the reference point.

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