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Memo

date: *May 31, 2013*

to: *RSC*

from: *D. Beavis*

subject: *Crab Cavity test in the SVTF*

Introduction

The SVTF blockhouse is being prepared to test a Crab cavity[1]. The cavity will be orientated with the electric field in the horizontal direction. The maximum voltage that electrons could accelerate across is 4MV. The shielding was inspected and the calculations conducted for 4 MeV electrons aimed at the side wall.

Estimate of x-rays Through the Sidewall Shielding

The small vertical blockhouse has heavy concrete walls that are 48 inches (122cm) thick. The cavity will be located close with an approximate distance of two meters to the exterior of the concrete wall. The dose rate for x-rays produced by 4 MeV electrons can be estimated[2] to be $2.5*10^3$ rads/hr at two meters for 200 Watts of power. The power supply has a maximum power of 200W and it is assumed that there is sufficient cooling to allow the cavity to operate with this heat load. The shielding attenuation can be estimated by using the TVLs given in Fig. 4.1 of footnote 2. Scaling light concrete to heavy concrete by the ratio of the densities results in an estimate of 4.41 TVLs for light concrete and 6.57 TVL for heavy concrete. **The dose rate outside the shielding is estimated to be 0.7 mrads/hr (100 mrads/hr for light concrete).** We expect a much lower value since the 200 Watts would not typically be entirely consumed by electons emissions across the 4MV.

An estimate of the dose rate outside the shielding was made using MCNPX[3]. The 4 MeV electrons were made to strike a copper target 2cm thick and 5 cm in radius. The statistics were too low for a direct result. The dose rate at 75 cm of penetration was extrapolated to from 75 cm

[1] S. Verdu-Andres and Q. Wu," Cold Test of DQWCC in SVTF", Updated May 29, 2013
[2] NCRP Report no. 144, Radiation Protection for Particle Accelerator Facilities, National Council on radiation Protection and Measurements, 2003
[3] MCNPX version 2.7C was used for the calculations in this report. D. B. Pelowitz et al., "MCNPX 2.7.C Extensions", LA-UR-10_00481, March 5, 2010.

to 122 cm of light concrete. The result was 120 mrads/hr in good agreement with the simple empirical method.

Concrete Seams

The cavity will be tested with the emission surfaces approximately 50cm or more below the horizontal seam in the concrete shielding that is formed by stacking the 54 inch high blocks. The seam is small but limited portions can be up to 5 mm high, although that dimension is not maintained uniformly through the shield wall. MCNPX was used to provide a estimate of the leakage outside of much larger gaps to provide an estimate of the potential dose rate. It should be noted that any leakage from the seam does not provide for a whole body dose.

The dose into the seams was modeled by having a pencil beam of 4 MeV electrons strike a copper disc. The copper disc was 2 cm thick, 5 cm in radius and 100 cm from a light concrete wall. The seam was modeled as an annulus with an inner radius of 50 cm and the outer radius was varied from 1 to four cm. The configuration used is shown in Figure 1.

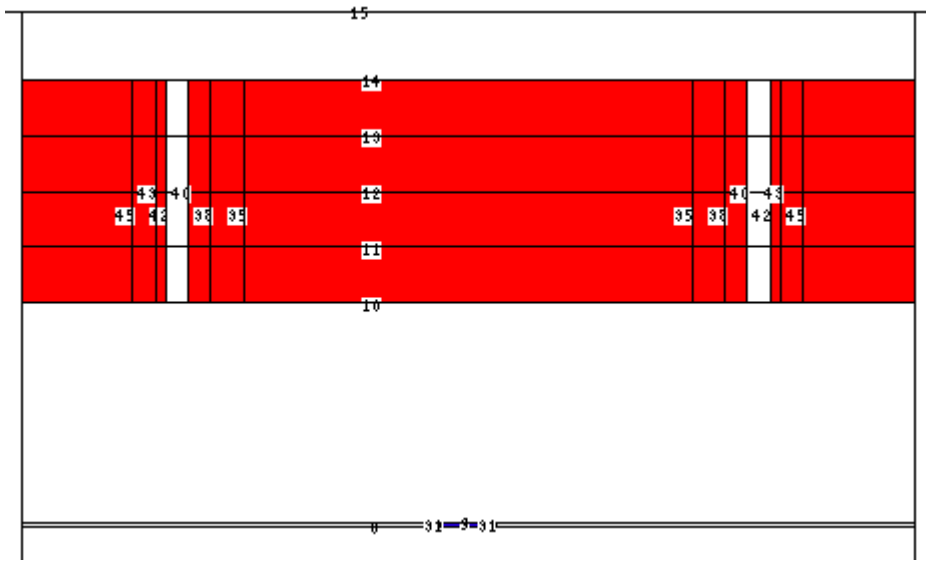

Figure 1: The gap has an inner radius of 50cm and an outer radius of 54cm. the target is centered and 100 cm from the light concrete wall.

The photon dose was tallied at 25 cm layers to the end of the wall which was 100cm thick. The dose was averaged over radial bins and is displayed in Figure 2. Fluence to dose conversion factors were used to convert the fluence to a dose. The statistics for small bins or where the dose is small are limited and the error estimates are not shown in the figure. For a crack at a radial distance of 50 cm from the cavity axis the dose rate at the crack is about 25% of the peak dose rate on the axis. The dose rate decreases about a factor of 10 for each 25 cm of light concrete, which is consistent with the empirical TVL data discussed above.

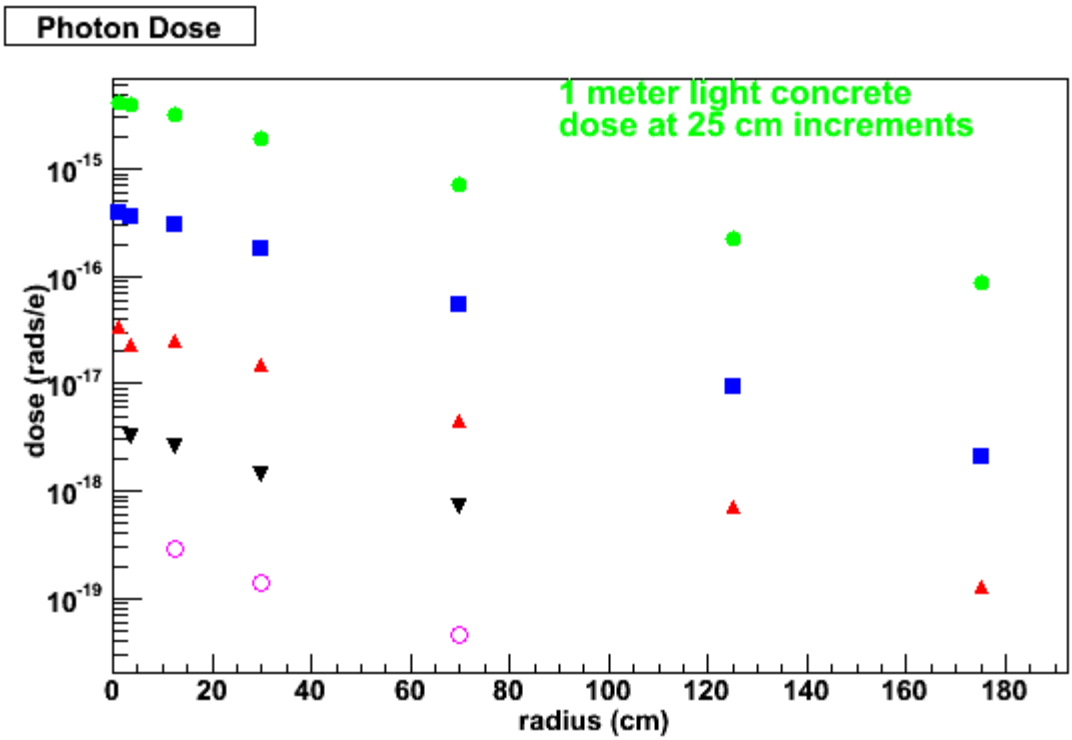

Figure 2: The photon dose in 25 cm increments in a 100cm thick light concrete wall. The dose is obtained by converting the fluence at the surfaces with fluence to dose conversion factors.

The gap size was changed and the model rerun to determine the effect of the gap size on the leakage radiation. The statistics become limited for surfaces 13 (75cm) and 14 (100cm). Figure 3 displays the photon dose at a depth of 75 cm for radii near and over the gap. The dose increases faster than linear based on the gap size. The dose has a tail on the outside radii which is a result of the continued directionality of the radiation and the decrease in effective shielding when the rays cross the gap. The 2cm gap has a dose rate which is three times higher than the expected level if no crack existed and the 4cm gap a factor of 6-7. The ratio of dose in the crack to the dose if there was not crack continues to rise as the depth increases.

Figure 4 displays the dose in the crack as a function of depth in the crack. The 1 cm crack has a dose of $3.7*10^{-19}$ rads/electron at 100cm which was the light concrete thickness used in the simulation. Based on the curve it would be expected that the 1cm gap would have at least a factor of two less dose if the simulation had been extended to 122 cm (48 inches) which is the actual thickness of the heavy concrete wall. 200 Watts of power if consumed by driving electrons across a 4MV gap would correspond to $1.12*10^{18}$ electron per hour. Thus a 1 cm crack in a four foot light concrete wall would have a possible exit dose rate of 200 mrads/hr for the gap. This is expected to be conservative. If we assume linear scaling by gap thickness a dose of 100 mrads/hr would exist to a 5 mm uniform gap.

The SVTF block walls are 48 inches of heavy concrete. It would be expected that the dose rate would be smaller by at least the ratio of the attenuation lengths for light to heavt concrete which is a factor of 0.7. Therefore, a reasonable estimate for a 5mm high crack would be 70 mrads/hr. This should be compared to the 0.7 mrads/hr expected through the uniform concrete at the peak.

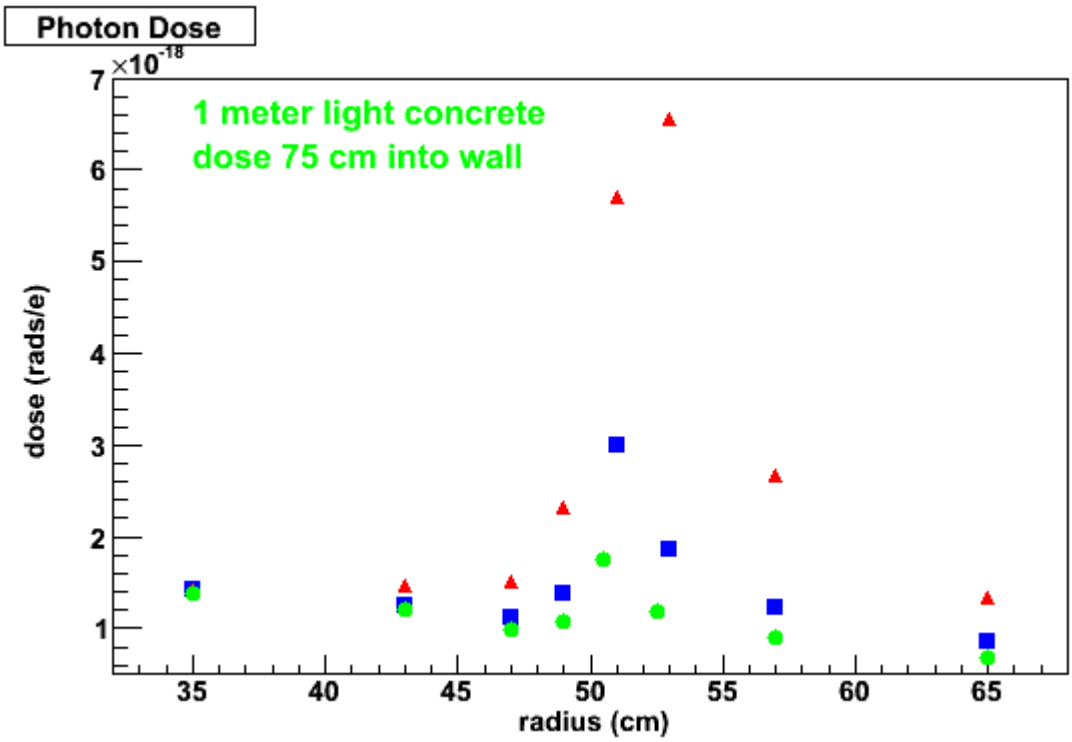

Figure 3: The photon dose as a function of radius at a depth of 75 cm into a 100cm thick light concrete wall. The points are for gaps of 1cm (green), 2cm (blue), and 4cm (red).

The SVTF is located in a Radiation Area. The orientation of the cavity for this first test has the axis for high field emissions pointed at the labyrinth shield wall on one side and an area that is fenced off on the opposite end. The labyrinth has two layers of concrete and greater distance than used in the simulations.

The simulations were conducted with an annulus rather than a straight line. The differences in geometry could impact the results. The surface area that contributes to the exit dose is restricted in a circular geometry due to the internal shield at the smaller radius. However, the same impact may exist for integration along a straight crack since the radiation tends to maintain direction. The dose drop off in the crack does not follow the typical decrease seen in penetration formulas since most of the scattered radiation must be emitted along the surface. Using a penetration analysis[4] does not predict the substantial decrease in the early segment of the crack as demonstrated in the MCNPX analysis. This may be an indication that a straight crack has inside surfaces that are limited similar to the circular geometry. More analysis should be conducted and a criteria for crack dimensions developed for the x-ray sources.

[4] A.H. Sullivan, A guide to Radiation and radioactivity Levels Near High Energy Particle Accelerators, Nuclear Technology Publishing, 1992.

It is concluded that with the present cavity orientation, the experience with field emissions, and the present simple analysis that the crab cavity is safe to operate in the SVTF. The experiment will work with the RCTs to ensure that radiation surveys are conducted both for the solid shielding and along the seams in the concrete. The experiment will request radiation surveys if increases in field emissions above previous levels are suspected. The Liaison Physicist will review the final surveys with the RCD Facility Representative and the RSC Chair after the four day test is complete or if any unexpected radiation levels are measured.

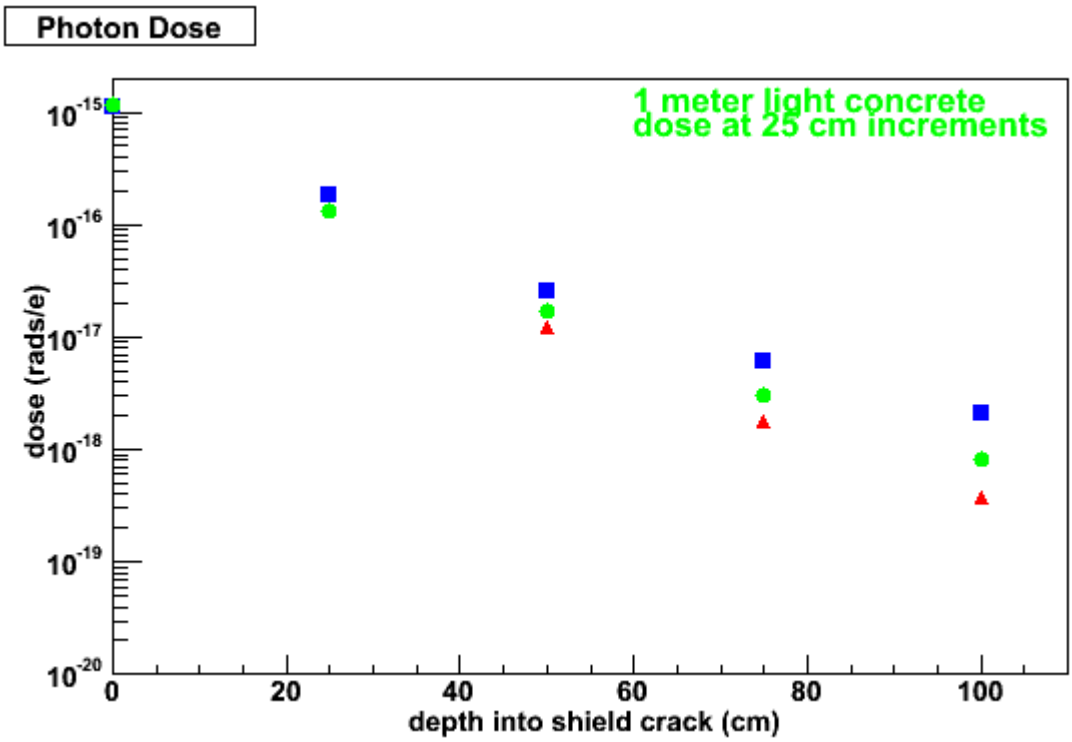

Figure 4: The dose per electron along concrete seams 1, 2, and 4 cm high as a function of depth into the light concrete shield.

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