EVALUATION OF RADIATION EXPOSURE AROUND END STATIONS AT JLAB
JLAB Technical Note JLAB-TN-08-034
P. Degtiarenko
Radiation Control Department
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606
(August 4, 2008)

Conservative estimates of typical yearly average personal radiation dose exposures that may be observed at the ground level around the high beam power experimental end stations Hall A and Hall C at JLab are obtained based on model calculations for typical expected experimental parameters. Historical measurements for the last ten years of operations, as well as specially conducted measurements during high-dose test runs in the Halls are used to corroborate the calculations and determine the maximum credible accumulated radiation doses that could be expected in the area.

I. EVALUATION METHODS AND RESULTS

The design of the high beam power end stations at JLab was based on the necessity to build large semi-underground experimental areas, capable to host large movable experimental equipment, and at the same time providing radiation protection to the personnel outside the end stations, to the general population beyond the facility boundaries, and to the environment. The solution was to use spherical-section concrete and berm roofs covering the Halls and supported only around the perimeter of the Hall. The roof thickness was selected to provide the radiation protection for a typical experimental running conditions in the Halls, corresponding to the average “equivalent thick target beam loss” [1] of 50 W in the experimental target area in the Hall. To provide mechanical stability of the construction, and to help shield the radiation flux from the targets, the concrete walls above ground were surrounded by the relatively thick berm as shown in Fig. 1 for Hall A end station, and in Fig. 2 for Hall C. The plots are taken from current GEANT [2] models that are used presently in radiation background calculations. The combined thickness of the walls and the berm at the sides of the Halls is large. Using the parameterization published in [3] and substituting parameters of the equivalent thick target beam loss, thickness of the shielding, and the distance from the target, the estimates of the corresponding dose rates at the ground outside the Halls were obtained. There is practically no direct radiation coming from the target through the wall and berm to a person standing at the beginning of the berm slope. The estimate there shows values orders of magnitude smaller than the level of natural radiation background in the area, of the order of 10 microrem (0.1 µSv) per hour.

At the top edge of the berm, where the Access Control fences are placed, the direct thickness of the shielding is much smaller as can be seen in the plots, and the level of the direct radiation is estimated to be about 3.7 µRem/h.

The thicknesses of the domes themselves are necessary much smaller than walls. Accordingly, the dose rates expected and measured experimentally there, are much larger, and can reach several millirem per hour in typical experimental runs. Therefore, the domes are the main radiation sources outside and around the Halls. The calculations of the radiation fields produced around the Halls are complicated, and involve relatively detailed modeling of the target and the beamline setup, materials and dimensions of major construction elements such as walls and roofs of the halls, and modeling of the surrounding environment.
In the special study [4] we showed that the major contribution to the radiation dose around the JLab end stations is coming from the energetic neutrons produced in the experimental targets, penetrating through the roofs, and then scattering and producing energetic particle cascades in the air (so-called neutron skyshine). Fig. 3 shows an example of the calculations showing the map of the expected dose rates around the Hall C during a typical high power experiment using a typical Deuterium target. The main goal of these calculations was to evaluate and to better understand the dose at the boundary of CEBAF site, and to establish a method to control the environmental radiation. The strict administrative limits imposed on the boundary dose accumulation (less than 10 millirem per year) forced us to introduce the so-called Radiation Budgeting process in which the expected boundary dose accumulation is estimated for each planned new experiment at CEBAF, and shielding and scheduling measures are taken to limit the contributions of particular high impact experiments to the boundary dose. The “Budget Expenditures” are controlled by the measurements of the neutron boundary dose rates continuously. Semiannual accounts are published internally at JLab [5]. History of the boundary dose budget predictions and measurements is shown in Fig. 4.

FIG. 2. Same as in Fig. 1, but for the GEANT model of the Hall C end station at JLab.

Dose map around Hall C roof

FIG. 3. A schematic map of Hall C and the surrounding CEBAF site is shown. The coordinates: the $z$-axis is parallel to the direction of the electron beam entering the hall as indicated by the arrow; the $x-z$ plane is parallel to the ground surface; the $y$-axis is vertical. The hall is shown in the center of the figure as a white circle. The corner of the CEBAF site boundary nearest to the hall is shown by the two arrows. The $x-z$ coordinate distribution of neutrons exiting the hall roof is illustrated by a scatter-plot on top of the hall circle. The neutron skyshine and direct dose rate distribution around the hall is shown as a color (density) plot with lines of equal dose rate plotted as white contours. The logarithmic color scale for the dose rate is shown as the right scale in the figure; one step in color and the distance between neighboring lines of equal dose rate correspond to a factor of 2 in dose rate. The dose rate in $\mu$Sv/hour is indicated on the labels attached to the white contours.

FIG. 4. Yearly boundary dose accumulation due to CEBAF operations for the period starting in 1996 through the end of 2007. Open circles show the measured dose accumulated during each calendar year. Error bars indicate 30% estimated systematic error of the measured value. Thick solid lines show accumulation of the dose as a function of time in the corresponding year. Thin-line gaps between thick portions of the lines indicate that only integral dose measurement data were available. No differential data is given for 1996. Thin solid lines ending with open squares show the integral estimated boundary dose produced by all experiments planned to run in the corresponding year. Every estimate is made before the actual run time. Dash-dotted line illustrates the design goal not to exceed 10 mrem yearly dose accumulation at the boundary.
Every year during CEBAF operations we observed the boundary dose accumulation which was noticeable, but low enough to satisfy the administrative goal not to exceed 10 millirem per year. In the evaluation of the dose fields around the end stations, therefore, we may use both the assumption that the yearly dose accumulation at the boundary will not exceed 10 millirem, and the typical dose distribution map as shown in Fig. 3. From Fig.3 we may draw a conclusion that the dose rates in the vicinity of Hall C are estimated as approximately factor 5 larger than at the boundary. Taking into account the variability of the dose distributions depending on targets and energy, we may conservatively assume that the maximum yearly dose accumulation next to Hall C will be no larger than ten times the accumulation on the boundary, that is, 100 millirem per year. The corresponding dose map hasn't been calculated for Hall A. Hall A is characterized by a relatively larger roof size, smaller roof thickness, and larger distance from JLab boundary. Several test experiments were run in Hall A yielding relatively large instant dose rates outside the Hall such that the accumulated doses could be reliably measured. The results of one such experiment are shown in Fig. 5. Max. dose accumulation was measured to be 15 microrem at the boundary, 270 microrem at the parking lot adjacent to Hall A, and 70 millirem on top of Hall A roof.

FIG. 5. JLab site schematic map with indications of places and values of accumulated dose measurement during a test run in Hall A in which relatively high dose rates outside the Hall were generated.

We expect that corresponding dose accumulation at the ground level next to the start of Hall A berm slope would be no more than a factor 2-5 larger than at the parking lot. Thus, conservatively we may assume that the dose around Hall A at the ground level is not expected to be more than a factor of 100 larger than the dose at the boundary. As the yearly boundary dose accumulation is regulated administratively to be lower than 10 millirem per year, the dose accumulation around Hall A at the ground level is limited to 1000 millirem. The dose accumulation to a worker spending 2000 hours in a year at that location (which is unrealistically conservative) will therefore be limited to about 200 millirem per year.

II. CONCLUSIONS

In conclusion, conservative estimates of typical yearly average personal radiation dose exposures that may be observed at the ground level around the high beam power experimental end stations Hall A and Hall C at JLab are obtained based on model calculations for typical expected experimental parameters. Historical measurements for the last ten years of operations, as well as specially conducted measurements during high-dose test runs in the Halls indicate that the conservatively evaluated yearly accumulation of radiation dose to a worker spending 2000 hours in a year in a vicinity of high beam power experimental Halls A and C at CEBAF site will not exceed 200 millirem.