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Contribution of Backscattering to Radiation Fields in the Source Projector Facility

E. Marshall, K. Vaziri, F. Krueger, D. Cossairt*

Abstract

The Radiation Physics Source Projection Facility at Fermilab employs three collimated ^{137}Cs sources for different calibration purposes. This facility is used to calibrate many of the instruments used at Fermilab to measure both prompt and residual radiation fields due to accelerator operations. A study was done using three air ion chambers (2.5 ml, 80 ml, and 1000 ml) to measure field uniformity within the radiation cone and separately the contribution of backscatter. The field uniformity was measured by extracting the deviations of the gamma ray intensity from the inverse square law. Then by positioning the ion chambers at different location in the calibration cave, both inside and outside the effective radiation cone, the room scattered fraction has been extracted and compared to the calculations. It is found that the deviation from the inverse square law near the source is mainly due to scattering off the source collimator and at the far end is primarily due to scattering off the walls.

Introduction

A variety of portable instruments are used at Fermilab to measure both prompt and residual radiation fields due to accelerator operations. The vast majority are calibrated using the Radiation Physics Source Projector Facility† located on the Fermilab site. Because of its importance to the overall radiation protection program, it is imperative that the calibration fields generated with the facility be well understood.

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† Internal document. Krueger, F. and J. Larson. Fermilab ES&H Section Source Projector Facility Operating Procedures. April 1993.

To this end, several characterization studies have been conducted. One considered the contribution of electron secondary equilibrium on the irradiation field[‡] and another addressed the issue of backscattering along the center line to the end of the detector carriage track[||]. This paper describes a more comprehensive study undertaken to quantify the contribution of backscattering to radiation fields within the irradiation room of Fermilab's Source Projector Facility.

Experimental Apparatus

The Source Projector Facility is constructed of concrete and consists of an outer control room and an inner irradiation room. Two gamma-ray projectors are operated from the outer room. One of the projectors contains a nominal 3,700 GBq (100 Ci) ^{137}Cs source[¶]. The other is a dual projector containing two sources with nominal activities of 370 GBq (10 Ci) and 37 GBq (1 Ci) ^{137}Cs[#]. The source projectors are mounted on an elevated rolling stand in the outer room, with their radiation cones directed into the irradiation room through a port. The beam is collimated such that it has a full-width physical divergence of 30° for the largest ^{137}Cs source (~3,700 GBq) and 20° for the other sources. A positioning carriage which may be adjusted remotely is roller-mounted to the floor rails along the beam axis inside the inner room.

Three Far West Technology air ionization chambers[§] were used to measure field uniformity within the radiation cone and separately the contribution of backscatter. The ion chamber used was selected based on the electrical current expected, distance from the source, and the chamber effect

[‡] Internal document. Marshall, E. T., J. D. Cossairt, F. Krueger, and K. Vaziri. Determination of the Secondary Electron Equilibrium Using and Extrapolation Chamber. R. P. Note 120. January 1996.
[||] Internal document. Krueger, F. and S. Hawke. Calibration and On-Axis Characterization of the Source Projector Facility at the Radiation Physics Calibration Facility. R. P. Note 121. January 1996.
[¶] Model 28-10. J.L. Shepherd & Associates, 1010 Arroyo Ave., San Fernando, CA 91340-1822. (818)898-2391.
[#] Model 78-1M. J.L. Shepherd & Associates, 1010 Arroyo Ave., San Fernando, CA 91340-1822. (818)898-2391.
[§] Models IC17G, IC80, and IC1000. Far West Technology.

on the radiation field itself**. All three ion chambers were operated at a bias of -500 V. A Keithley Model 610C Electrometer†† was used to measure the charge and its output fed into a Keithley Model 617 Electrometer‡‡, used in the voltmeter mode for its data storage capabilities. The equipment was set-up in position the day before a measurement was to be taken to allow for acclimation and for any electrical transients due to cable stress to settle out.

The source was exposed and the instrumentation allowed to stabilize in the radiation field. The integrated voltage was recorded at preset time intervals. By correcting for leakage and the scale setting of the Keithley 610C Electrometer, the net charge was calculated and recorded.

Measurements and Results

Beam uniformity

Since the instruments calibrated in the radiation field have finite extensions, the source construction may not necessarily be symmetrical, and the contribution of backscattering is proportional to the incident radiation intensity, the uniformity of the field generated by the three ^{137}Cs sources was investigated.

The two smaller ion chambers used for this measurement were mounted to a positioning stand. After making appropriate trigonometric corrections, measurements were taken along the cone formed by a 15 degree angle (7.5 degrees off-axis) at 0.5 m and 1 m from the source.

Measurements were taken over a period of several days. At the start of each day, a measurement of the on-axis point was taken using each source. The data were normalized to the average of these

** Krueger, F. Operation of Instrumentation Used for Gamma Ray Source Transfer Calibration and Facility Studies. R. P. Note 111. March 1995.
†† Model 610C, Keithley Instruments, Inc., 28775 Aurora Rd., Cleveland, OH 44139, (216)248-0400.
‡‡ Model 617, Keithley Instruments, Inc., 28775 Aurora Rd., Cleveland, OH 44139, (216)248-0400.

measurements. By employing this methodology, the effects of some day to day variations are minimized.

The measurement divided by the average of the on-axis measurements was then graphed versus its position. A review of the figures revealed that the beam generated by all three sources over this spatial region is very nearly uniform. Variations in the measurements, ranging between 0.5% and -4%, were probably due to slight positioning errors.

Chamber Gas Poisoning

The air ionization chambers used are not flow through chambers, instead they rely on existing ambient air currents for gas exchange. As such, chamber gas poisoning due to the radiation field itself may be a contributing factor under conditions of constant irradiation.

A test of this effect was set up using the largest ionization chamber and the 3,700 GBq (100 Ci) ^{137}Cs source. The Keithley 610C electrometer was set on the 100 X 10^{-10} coulomb range and the timer was set to trigger at 10 second intervals. Thirty measurements were taken over approximately 2 hours. The measurements were graphed and the plot indicated that there was a negligible effect due to this phenomenon.

Recombination losses

When using an ionization chamber, it may be necessary to compensate for recombination losses. Measurements were taken in a radiation field on the order of 5.5 mC kg^{-1} hr^{-1} (~21.5 R hr^{-1}) to determine if a correction would need to be made for recombination and the magnitude of the correction. A collection efficiency determined by Equation 1** of significantly different than 1.0 would required a correction.

$$A = \frac{4}{3} - \left(\frac{1}{3} X \frac{Q_1}{Q_2} \right) \qquad [1]$$

where Q_1 = charge collected at original bias

Q_2 = charge collected at half original bias

As the collection efficiency was calculated to be 0.999, no correction was needed to account for recombination losses.

Backscattering

An alternate method to estimate the backscatter was employed as no shield was available to attenuate the direct beam. Measurements of the exposure rate using the 3,700 GBq (100 Ci) ^{137}Cs source had been previously made. For those data obtained from within the direct radiation field, a correction for distance using the inverse square law was made. This value was then subtracted to yield the amount of backscatter. For those data obtained from outside the radiation field, the measured value provides an estimate of the backscatter at that position. The results are portrayed in Fig. 1.

The detector positioning carriage could not be used for the majority of the backscattering measurements (Positions 1-17 and 22). For these measurements, the largest ionization chamber was secured on a ring stand so that the center of the chamber was aligned with the center of the source. To minimize potential transient electrical effects, after movement of the chamber to a new location, the electronics were allowed to settle for approximately 1 hour before additional measurements were taken. To ensure that sufficient current was generated in the ionization chamber the 3,700 GBq (100 Ci) ^{137}Cs source was used. The measurements at Positions 18-21 were those obtained during the beam uniformity checks, using the intermediate volume ionization chamber and the detector positioning carriage.

The full-width physical divergence of the collimator cone for this particular projector is 30°. However, scattering off the collimator itself serves to increase the divergence of the cone. The boundaries of the effective collimator cone were determined by a series of measurements made prior to the backscattering measurements described here and are illustrated in Fig. 1 along with the exposure rates due to backscatter within the room.

This set of measurements was then compared to the previous measurements made during the Source Projector Facility calibration. Note that the previous measurements were made on-axis and the current measurements were made both on- and off-axis. This comparison is depicted in Fig. 2.

As rough check of the measured backscattered fraction, Chilton's [Chilton, Shultis and Faw 1984] differential albedo factors were calculated. The albedo calculation in this method is based on Compton scattering of the photons. For each position of the detector, the backscattering contributions from all five surfaces of the room exposed to the photons was calculated. However, Chilton's calculations are based on a model of a source and a detector in front of a scattering surface. The source being located in a recess in the wall, behind a collimator, alters the situation. For example, positions 12-15 are in the shadow of the radiation cone, and will not be exposed to the direct radiation. As such, the reflection factors were not calculated for these locations. Since the other four surfaces were shadowed by the cone, only the back wall contribution was calculated for points 19 and 20. For positions 6-9, 16, 17, and 22, the contribution of the side walls were not included, since more than half of the other surfaces, except the back wall, were shadowed by the collimator cone. For the five points closest to the back wall, the contributions from all the surfaces were included in the calculations. The results of these calculations are given in the parentheses, under the measured value, in Fig. 1. The results of the calculations are at worse different by a factor of two. The effects of the positioning table/carriage and a storage shelf in the room are obviously not taken into account in this simple model. As a next step a Monte Carlo modeling of this room will be attempted.

Discussion/Conclusions

In addition to those mentioned here, two other phenomena, temporal variation and the effects of air being a non-ideal gas on the ion chamber measurements, were investigated as part of this study. In summary, the effects of these phenomena (temporal variation, chamber gas poisoning, beam uniformity, and air not being an ideal gas) upon the data obtained are insignificant when measurement errors are considered.

The contribution of backscatter from the walls and other equipment in the room was studied. Although previous measurements had been conducted, these were limited to the areas of the room accessible using the detector positioning carriage. The current measurements confirmed minimal backscattering within the region of the irradiation room in which instrument calibrations are conducted. These data also quantified the backscatter throughout the rest of the irradiation room. As expected, the closer to the walls of the room, the greater the contribution of backscatter to the exposure rate is.

This study was one part of the characterization of the Source Projector Facility. Investigation of these properties of the collimated beam and its operation did provide useful information about equipment response and facility controls which will be useful for future measurements.

References

Chilton, B. A., Shultis, J. K., Faw, R. E. Principles of radiation shielding. Tenth printing, New Jersey: Prentice-Hall, Inc.; 1984.

Acknowledgments

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Figure Captions:

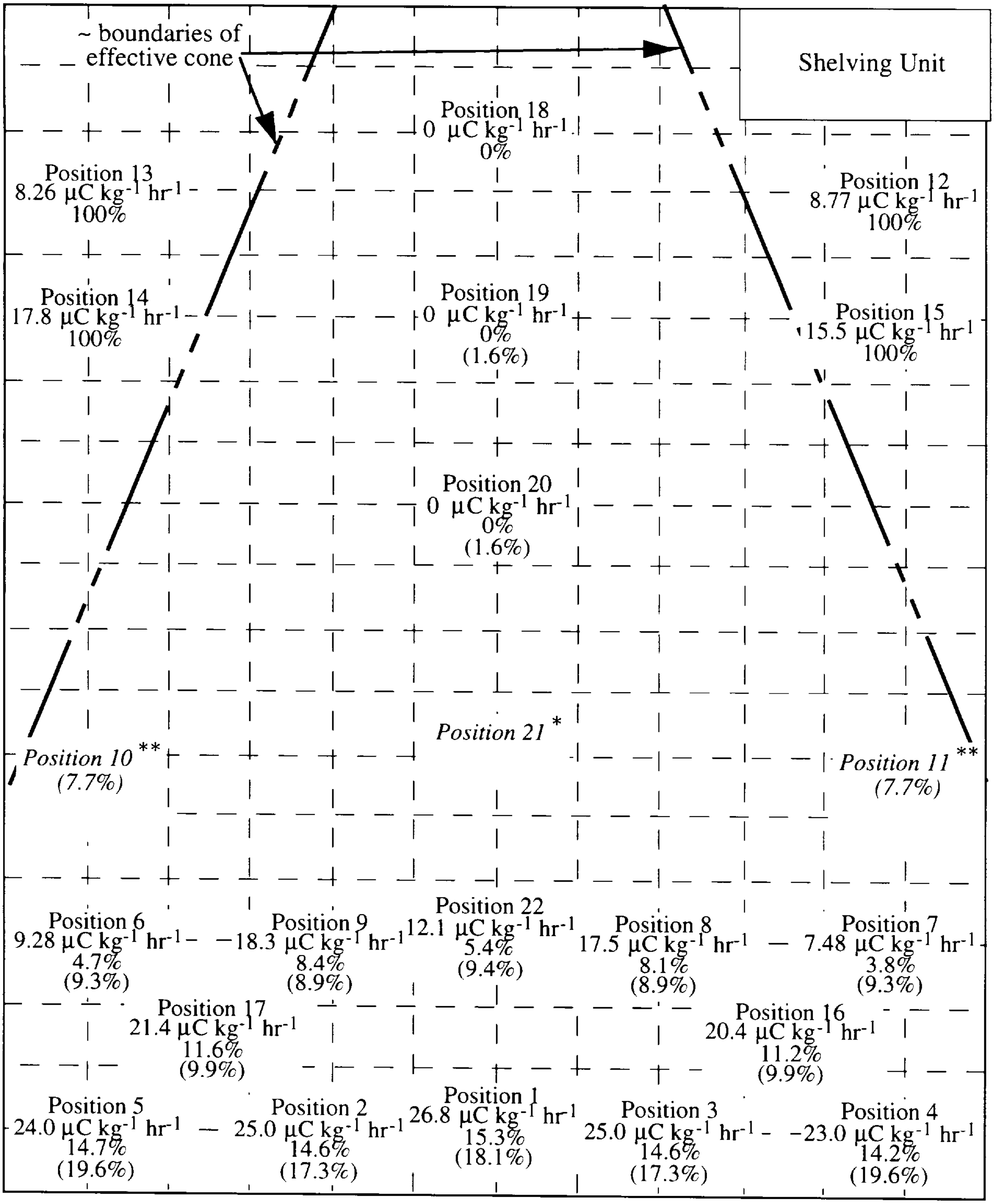
Fig. 1: Exposure Rates Due to Backscattering. The percentages reported are the percent of the measured exposure rate due to backscattering. The values in parenthesis are predicted backscattering contributions.

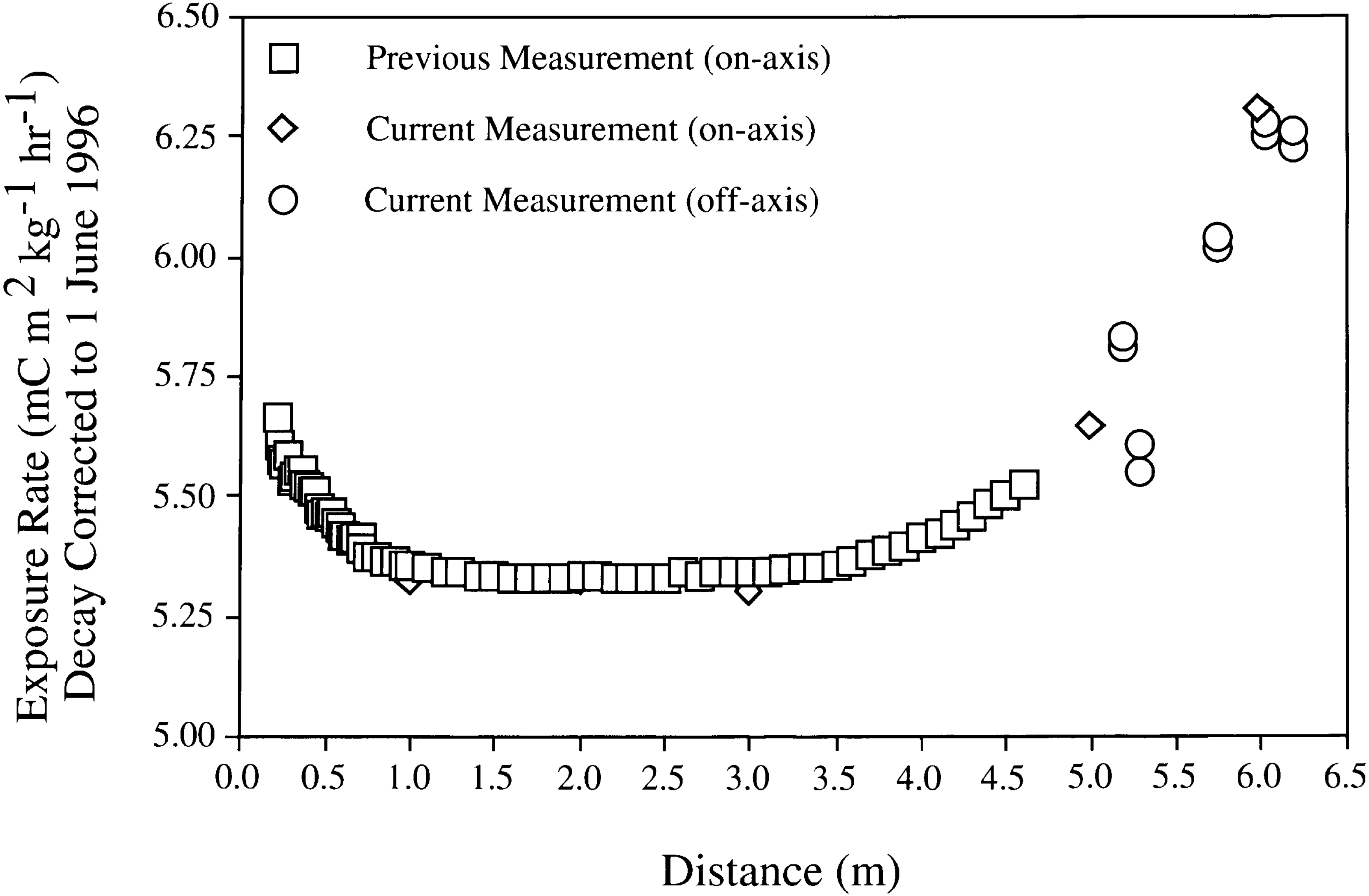
Notes to Fig. 1:

* Data at Position 21 was flawed and omitted from the study.

** These data lie on the edges of the effective cone and therefore, may be partially shadowed by the collimator. The backscatter fraction was not calculated.

Fig. 2: Comparison of This Study to Previous Measurements Made During Facility Calibration.


~ boundaries of
effective cone
Shelving Unit
Position 18
0 μC kg-1 hr-1
0%
Position 13
8.26 μC kg-1 hr-1
100%
Position 12
8.77 μC kg-1 hr-1
100%
Position 14
17.8 μC kg-1 hr-1
100%
Position 19
0 μC kg-1 hr-1
0%
(1.6%)
Position 15
15.5 μC kg-1 hr-1
100%
Position 20
0 μC kg-1 hr-1
0%
(1.6%)
Position 21 *
Position 10 **
(7.7%)
Position 11 **
(7.7%)
Position 22
12.1 μC kg-1 hr-1
5.4%
(9.4%)
Position 6
9.28 μC kg-1 hr-1
4.7%
(9.3%)
Position 9
18.3 μC kg-1 hr-1
8.4%
(8.9%)
Position 8
17.5 μC kg-1 hr-1
8.1%
(8.9%)
Position 7
7.48 μC kg-1 hr-1
3.8%
(9.3%)
Position 17
21.4 μC kg-1 hr-1
11.6%
(9.9%)
Position 16
20.4 μC kg-1 hr-1
11.2%
(9.9%)
Position 5
24.0 μC kg-1 hr-1
14.7%
(19.6%)
Position 2
25.0 μC kg-1 hr-1
14.6%
(17.3%)
Position 1
26.8 μC kg-1 hr-1
15.3%
(18.1%)
Position 3
25.0 μC kg-1 hr-1
14.6%
(17.3%)
Position 4
23.0 μC kg-1 hr-1
14.2%
(19.6%)



Previous Measurement (on-axis)
Current Measurement (on-axis)
Current Measurement (off-axis)
Exposure Rate (mC m 2 kg-1 hr-1)
Decay Corrected to 1 June 1996
Distance (m)
6.50
6.25
6.00
5.75
5.50
5.25
5.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5