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CERENKOV RADIATION GENERATED BY PERIODIC ELECTRON BUNCHES IN A FINITE AIR PATH

by

Lawrence A. Newton

December 1983

Thesis Advisor: F. R. Buskirk

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**Title:** Cerenkov Radiation Generated by Periodic Electron Bunches in a Finite Air Path

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**Report Date:** December 1983

**Abstract:**
Microwave Cerenkov radiation is measured for the case of bunched electron beams which exceed the velocity of light in a finite air path. The theoretical equation for prediction of the form of the power for Cerenkov radiation is tested experimentally for this case. Initial verification of the theory is observed.
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by Periodic Electron Bunches
in a Finite Air Path

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ABSTRACT

Microwave Cerenkov radiation is measured for the case of bunched electron beams which exceed the velocity of light in a finite air path. The theoretical equation for prediction of the form of the power for Cerenkov radiation is tested experimentally for this case. Initial verification of the theory is observed.
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I. INTRODUCTION

Since the speed of light is modified by the index of refraction in a dielectric, it is possible for relativistic electrons to have a velocity which actually exceeds that of light in the medium. In this circumstance a phenomenon known as Cerenkov radiation arises. This radiation appears in a cone, around the direction of motion of the electrons, defined by the Cerenkov angle.

\[ \theta_c = \cos^{-1} \left( \frac{c}{nv} \right) \]  \hspace{1cm} (eqn 1.1)

where \( c \) is the speed of light in a vacuum, \( n \) is the index of refraction, and \( v \) is the velocity of the electrons. This radiation is analogous to acoustic shock waves in air.

F. R. Buskirk and J. R. Neighbours [Ref. 1] calculated the power of Cerenkov radiation for the case where the electrons are bunched and the dielectric medium is of finite length. The experiments described in this thesis were designed to check those theoretical calculations.

Figure 1.1 depicts the pertinent physical relationships for this situation. See Table I for definitions of the variables. The first step in the theoretical derivation was to calculate the vector potential \( \mathbf{A} \) and the scalar potential, \( \phi \), at a field point \( \mathbf{r} \) resulting from an element of charge at a location within the electron bunch. A key factor in the analysis is that the current and charge densities which appear in the expressions for the potentials are periodic and may be expressed as Fourier series. Therefore, the potentials themselves may also be expressed as Fourier series, with Fourier coefficients representing the frequency components.
Figure 1.1 Cerenkov Radiation.
It is convenient to carry out the rest of the analysis in terms of the Fourier coefficients. The electric and magnetic field components are obtained from the potentials, and these, in turn, are used to find the frequency components of the average radiated power. An important assumption inherent in the procedure, which may directly affect experimental validity, is that the field point is assumed to be far from the source region. For details of the entire analysis, see [Ref. 2].

A principal result of [Ref. 2] is slightly recast in [Ref. 3] as the following expression for the power per unit solid angle at a given frequency,

\[ W(\nu, n) = \frac{\mu_c}{2} \nu^2 \nu_0^2 \sin^2 \theta |P_0'(k)|^2 I^2(u), \]  
\( \text{(eqn 1.2)} \)

with the parameters defined as follows:

\[ u = \frac{\nu L}{2} (\cos \theta_c - \cos \theta), \]  
\( \text{(eqn 1.3)} \)

\[ I(u) = \frac{\sin u}{u}, \]  
\( \text{(eqn 1.4)} \)

and

\[ P_0'(k) = \int \int \int d^3r e^{-ik \cdot r} P_0'(k), \]  
\( \text{(eqn 1.5)} \)

Refer to figure 1.1 and table I for clarification of these parameters.

The frequencies appearing in equation 1.2 are harmonics of the electron bunch frequency, which is a constant \( \nu_e \). Thus, writing \( \nu \) as \( j \nu_e \), and using a one-dimensional
TABLE I
Variable Definitions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( J )</td>
<td>current density</td>
</tr>
<tr>
<td>( l )</td>
<td>bunch spacing</td>
</tr>
<tr>
<td>( \nu_b )</td>
<td>bunch frequency</td>
</tr>
<tr>
<td>( v )</td>
<td>bunch velocity</td>
</tr>
<tr>
<td>( k )</td>
<td>power propagation direction</td>
</tr>
<tr>
<td>( \mathbf{n} )</td>
<td>unit vector in the ( k ) direction</td>
</tr>
<tr>
<td>( L )</td>
<td>length of finite emission region</td>
</tr>
<tr>
<td>( A )</td>
<td>vector potential</td>
</tr>
<tr>
<td>( \mathbf{r}_f )</td>
<td>position vector of field point</td>
</tr>
<tr>
<td>( \mathbf{r}_s )</td>
<td>position vector of source point</td>
</tr>
<tr>
<td>( \mathbf{\nu}_a )</td>
<td>Gaussian distribution of longitudinal bunch (charge) distribution</td>
</tr>
<tr>
<td>( b )</td>
<td>parameter for the charge distribution</td>
</tr>
<tr>
<td>( \mathbf{E} )</td>
<td>electric field vector</td>
</tr>
<tr>
<td>( \mathbf{B} )</td>
<td>magnetic field vector</td>
</tr>
</tbody>
</table>

Gaussian distribution to describe the longitudinal bunch dimension, a relatively simple Čerenkov radiation power function is given by equation 1.6 (equations 9 and 10 of [Ref. 3]). This is the expression which was used to compare theoretical to experimental results.

\[
p_j(\theta) = \frac{2\nu_0^2 \rho^2 q^2}{c} \left( \frac{L^2}{4} \right) \sin^2 \theta \left( \frac{\sin u}{u} \right)^2 \exp\left( \frac{-k^2 b^2}{2} \right), \text{(eqn 1.6)}
\]
Note that the radiation function varies with the square of the harmonic number, the length $L$ of the emission region, and the angle at which the radiation is being observed. Note also the interference factor, similar to what might be experienced with optical radiation, and the way in which the bunch dimension, $b$, appears in the expression. The length of the emission region and the angle appear not only directly, but also through the factor $u$ (see equation 1.3).

The results of this simple equation are quite interesting. Due to the finite size of the emission region, radiation no longer appears only at the Cerenkov angle, but throughout a range of angles determined by the $(\sin u)/u$ factor. Figure 1.2 shows how the radiation is spread for three different sizes of emission region. For a given harmonic, smaller emission regions cause greater spread, or diffraction, of the radiation. The power is distributed to varying degrees among the different harmonics also, as depicted by figure 1.3. Higher harmonics have larger peak powers, and are peaked at a smaller angle than are lower harmonics.

For this experiment, the microwave portion of the spectrum was investigated, and the dielectric medium for the electron path was chosen to be air. The electrons were accelerated to relativistic velocities by the Naval Postgraduate School LINAC, which produces electrons with energies of approximately 100 Mev. For the theoretical calculations, a Fortran program (see appendix A) was used to calculate the power as a function of angle from equation 1.6. Variants of this program (appendices B and C) were used to superimpose data points over the theoretical curves.

The experimental apparatus and procedures are described in detail in the next chapter.
Figure 1.2  Third Harmonic for $L = 0.7, 0.9, 1.5$ meters.
Figure 1.3  Harmonics 3, 5, 7 for L = 1.0 meters.
II. EXPERIMENT

A. BASIC EXPERIMENTAL DESIGN

The purpose of this experiment was to measure the power from Cerenkov radiation as a function of angle, in order to compare it with theoretical curves such as those depicted in figures 1.2 and 1.3. The basic design for this experiment is shown in figure 2.1. Photographs of the experimental apparatus are presented in Appendix D. The electron bunches exit the Linac aperture and emit Cerenkov radiation until they reach the aluminum mirror. This mirror allows the electrons to pass and proceed into the beam dump, while the microwave radiation of interest is reflected into the detector area. The mirror therefore performs the function, required by theory, that the radiation be emitted over a finite distance. The detector is mounted on a pivot arm, which is placed such that the detector is always pointed at the virtual center of the emission region. The pivot arm also fixes the distance from the center of the emission region to the detector, so that the distance over which the radiation travels is eliminated as a variable.

With this experimental setup, the basic experimental procedure was to sweep the detector over the angular range of interest using a small motor in the detector mount. The signal picked up by the detector was transmitted to the observer station, where it was fed into an amplifier and then into both an oscilloscope and a pulse height analyzer. The oscilloscope allowed a gross measure of power, while the frequency distribution measured by the pulse height analyzer gave a more precise value. The end result of this procedure was tabular data in the form of signal versus angle.
This brief overview of the experimental design is amplified in the next section with a more detailed look at various elements of the experimental apparatus.

B. EXPERIMENTAL APPARATUS

In this section, the components of the experimental apparatus will be examined, in order to provide a precise understanding of the experiment. The various components of the signal train will be reviewed in order, from the originating device (LINAC) to the final detection and analysis component.
1. LINAC

The salient features of the LINAC are listed in table II. These parameters are the same as those calculated by A. Saglas in prior thesis work with the LINAC at the Naval Postgraduate School [Ref. 4]. These parameters also meet those chosen in [Ref. 3] which gives the theoretical curves for Cerenkov radiation. The LINAC provided fairly consistent signals for the experiments which are reported here. However, the signal eventually developed instabilities which precluded further experiments. That is, it became impossible to distinguish between signal variation due to the LINAC and that due to variation in the angle of detection. It may be that some of the experimental deviation from theory can be adequately explained by the variability of the LINAC itself.

2. Air Path

The air path was chosen to be 1.0 meter in length, which was convenient for the dimensions of the LINAC end station. The characteristic index of refraction for air was taken to be 1.000268, which is the same as that given for

<table>
<thead>
<tr>
<th>TABLE II</th>
<th>LINAC Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch Frequency:</td>
<td>2.855 GHz</td>
</tr>
<tr>
<td>Bunch Velocity:</td>
<td>2.997886E08 m/s</td>
</tr>
<tr>
<td>Bunch Size Parameter:</td>
<td>0.24 cm</td>
</tr>
<tr>
<td>Electron Energy:</td>
<td>100 Mev</td>
</tr>
<tr>
<td>Bunch Spacing:</td>
<td>10.5 cm</td>
</tr>
</tbody>
</table>


air in [Ref. 3]. This gives a speed of light in air of 2.997127E08 meters per second, which is less than the velocity of 100 MeV electrons (see Table II).

3. **Mirror**

A polished aluminum mirror 50 centimeters in length was used to fix the path length. The mirror performed the dual function of allowing the electron bunches to pass and proceed into the beam dump, while causing the microwave Cerenkov radiation to be reflected into the detection area. The electron bunches continued to emit Cerenkov radiation after passing through the mirror. It was assumed that this radiation did not reach the detection area, due to the inherent weakness of the signal, and due to the distance and multiple reflections it would have to travel through in order to reach the detection area.

The mirror was tilted 10 degrees, causing the reflection axis to be offset 20 degrees from the beam axis. Therefore, the actual length of the emission region varied between approximately 95 and 105 centimeters. Measurements were made over a range of from 0 to 15 degrees. The mirror was long enough to reflect most, but not all, of the radiation at 15 degrees. See figure 2.1 for details of the geometry of the experiment.

4. **End Station Detection Apparatus**

The detection apparatus was mounted at the end of a pivot arm of fixed length. The pivot point was located at the center of the virtual image projected by the mirror, in order for the detector to always be pointed at the virtual center of the emission region. Theory assumed that the emission region would be a short distance, small compared to the detector distance \( r' \) (field point). Focusing the detector on the center of the emission region was done to
approximate theory as closely as possible. The pivot arm also kept the detector at a fixed distance from the (virtual) center of the emission region. Therefore, the distance of travel of the measured radiation was approximately the same for all angles, so that variation in distance would have minimal effect on the signal variation.

a. Antenna

A small antenna, with a lateral dimension of 2.8 centimeters, served as the forward end of the detection apparatus. This antenna served two functions. First, it was small enough that, with the given length of the pivot arm, the antenna subtended an arc length of approximately 1 degree. Therefore, an experimental measurement resolution of 1 degree was obtained. Further, this antenna had a very wide beam width. The antenna profiles for the electric and magnetic fields are given in figures 2.2 and 2.3. Using the half-power points as cutoffs, the beam width is found to be greater than 60 degrees for both the E and H fields, and thus for the power as well. At a distance equal to the average of that between the antenna and the mirror, approximately 130 centimeters, the beamwidth covers an arc length of 68 centimeters, which is larger than the length of the mirror.

Therefore, radiation arriving at the antenna and originating from any part of the emission region would be collected by the antenna. This again approximates the theoretical condition that the emission region be a point source, since the antenna “sees” the entire emission region at every angle of interest.

In summary, the antenna’s narrow dimensions have provided spatial resolution, while its wide beamwidth has approximated a theoretical requirement.
Figure 2.2 Antenna Beam Profile for the Electric Field.
Figure 2.3 Antenna Beam Profile for the Magnetic Field.

20
b. Filters

In previous experiments reported in [Ref. 4] a section of X-band waveguide was included between the antenna and the crystal detector. This waveguide serves as a partial filter of the microwave radiation, since it does not pass the fundamental frequency (2.86 GHz) nor the second harmonic (5.71 GHz). Use of the X-band waveguide as a filter was included as one of the variants in this experiment. Additionally, filters were available which were able to select the third and the fourth harmonics of the bunch frequency. These filters were designed and built by K. Alexander and S. Hamel [Ref. 5]. The band-pass characteristics for these filters are shown in figures 2.4 and 2.5.

c. Detector

The final component in the detection apparatus was the detector itself, an HP X-band X424A crystal detector. The detector was used without the square-law load. Therefore, the response varied linearly with the input (Cerenkov) signal.

5. Cable

In the work done by A. Saglam [Ref. 4] the experimental area (end station of the LINAC) was described as very noisy due to the electromagnetic energy radiated by the LINAC klystrons. This problem was effectively solved in this experiment by using doubly-shielded cable to transmit the detected signal to the observer station.

6. Observer Station

The analyzing equipment consisted of an ORTEC 450 Research Amplifier, a TEKTRONIX 7904A Oscilloscope, and a TRACER NORTHERN TN-7200 Pulse Height Analyzer (PHA). The
Figure 2.4 Filter Band-pass for the Third Harmonic.
Figure 2.5  Filter Bandpass for the Fourth Harmonic.
critical piece of equipment for experimental purposes was
the PHA. This instrument divided the detection range into a
predetermined number of channels (e.g., 1024) and then
recorded graphically the frequency with which each signal
channel was detected. This allowed the observer to deal
with a certain degree of variability in the signal, by
choosing the observed value to be the peak of the frequency
distribution. The frequency distributions observed ranged
from very sharp spikes at the lower signal levels to typi-
cally broader peaks at higher signal levels. The PHA
display also provided an measure of LINAC stability. If the
frequency distribution of the detected signal was extremely
broad or if multiple peaks were formed while detection angle
remained constant, machine instabilities were indicated.

This concludes the discussion of the experimental
apparatus. Comparison of experimental results to theoret-
ical curves is presented in the next chapter.
III. RESULTS

A. METHOD OF DATA REDUCTION

As explained in Chapter 2, the raw data from the experiment was in the form of signal (power) versus angle. Since the signal was processed through a series of elements (filter, detector, amplifier, PHA), a measurement of the absolute power was not available. Therefore, it was necessary to normalize these measurements in order to make comparisons with the theoretical curves. The method of normalization chosen was the matching of peaks. For a given experiment, the experimental points were examined to determine which one had the peak value. This value was then adjusted such that it exactly matched (in magnitude) the peak value of the appropriate theoretical curve. All other experimental points for that experiment were then adjusted by the same factor, so that the experimental points maintained the same relative magnitudes.

B. DATA

The results presented here are characteristic for the experiments which were performed. Each figure shows the theoretical curve for the harmonics assumed to be present for a given filter, with the experimental points overlaid and normalized to the peak value of the theoretical curve. Tabular data for figures 3.1 through 3.5 are presented in Appendix E. Figure 3.1 and 3.2 compare the theoretical curves for harmonics three and four to the radiation measured with the appropriate filters inserted before the detector. Figure 3.3 compares the theoretical curve for the sum of harmonics three through seven with the radiation...
measured with an X-band waveguide inserted before the detector.

These results appear to be good enough to indicate an initial verification of the theory. Results were best for the fourth harmonic (figure 3.2), with very close agreement between theory and experimental points. The experimental results for the third harmonic (figure 3.1) are shifted somewhat to the left of theory, while the results for the sum of harmonics (figure 3.3) are shifted to the right.

One predicted effect which is clearly evident despite the shifting is the relative spread of the Cerenkov angle for different harmonics. The third harmonic is predicted to spread the radiation over a broader range of angles than does the fourth harmonic, and this is verified by the experimental results.

There are several possible explanations for the deviations from theory which are shown here. For example, certain assumptions necessary for theoretical simplicity may not hold in the experimental situation. It may be that the charge distribution of the electron bunches is not Gaussian, or that a lateral parameter should be included in the Gaussian to account for divergence of the beam over the air path. Another factor possibly affecting the results was the mirror tilt, which caused the air path length to be longer than one meter on one side of the beam, and shorter on the other.

Another factor which must affect the results to some degree is simply the experimental geometry. For a number of reasons, theory calls for the field point distances to be much greater than the source point distances. That is, the path length should be small in relation to the distance to the point at which the fields are measured. However, the dimensions of the LINAC end station prohibit this, so that at angles larger than just a few degrees, there is ambiguity
Figure 3.1 Harmonic=3 : L=1.0 m: Filter = 3rd.
Figure 3.2  Harmonic=4 : L = 1.0 m : Filter=4th.
Figure 3.3  Harmonics= 3-7 : L = 1.0 m : Filter = Waveguide.
regarding exactly which angle is being measured. For small observation angles, the air path does look like a point, but as the angles become larger there are increasing differences between the angle as measured from the beginning of the air path and the angle as measured from the end of the air path. At large angles (greater than five degrees) the angle as measured from the center of the air path is substantially smaller than that measured from the end of the path. Since the radiation originating from the end of the path is stronger (it has traveled a smaller distance to the detector), and since this radiation originates at an angle larger than that which is being measured, the radiation at the measured angle is actually overstated. This may be the cause of the shift to higher angles observed in figure 3.3.

Finally, the frequency range over which the filters are valid must be considered. The X-band filters and waveguide used in this experiment are designed for use with radiation in the frequency range 8.2 to 12.4 GHz. Radiation within this band will only propagate in the dominant TE mode in X-band waveguide. Note that this encompasses only the third (8.57 GHz) and the fourth (11.42 GHz) harmonics of the LINAC bunch frequency. When radiation outside this frequency band is fed into the waveguide (as with the fifth and higher harmonics of the bunch frequency which are expected in Cerenkov radiation), modes other than the dominant may be excited in the waveguide. As indicated by [Ref. 6], the effects of coupling multiple modes into and out of a waveguide are complex, and the normal single probe configuration for detecting signal energy in the dominant mode cannot be reliably used in this situation. Since frequencies outside the X-band operating range were expected to be present in this experiment, modes higher than the dominant may have been excited, thereby causing inaccuracies in the measurement of power by the signal detector.
A comparison was made to test for the possibility that frequencies outside the X-band operating range were not being accurately measured by the single probe detector. Figure 3.3 compares the theoretical sum of harmonics 3-7 with the data measurements from the X-band waveguide, using no filter in the waveguide. Adding higher harmonics to the sum, although theoretically correct, would cause a larger discrepancy between theory and experiment, since higher harmonics are shifted towards smaller angles. Assuming the worst case, that harmonics five and above excite modes in the waveguide which are somehow not correctly coupled and detected, implies the possibility that only harmonics three and four are being measured when X-band waveguide is used as a filter. Figure 3.4, showing the data gathered with the waveguide filter normalized against the sum of harmonics three and four, appears to fit the data better, in that the width of the theoretical curve is more closely approximated by the experimental points than in figure 3.3. This lends some credence to the supposition that the detector does not respond well to harmonics higher than the fourth.

A second comparison was made to investigate the possibility that the filters which were used to isolate the third and fourth harmonics were also passing higher resonant frequencies. Such higher frequencies would be close to multiples of the frequency which the filter was designed to pass. For example, figure 3.1 compares the data gathered with the filter for the third harmonic to the theoretical curve for the third harmonic. Figure 3.5 compares the same data to the theoretical sum of the third and sixth harmonics. Note that a somewhat better fit of the data at the smaller angles is obtained in figure 3.5, indicating that the filter may be passing higher resonant frequencies, which in this case are measured by the detector, despite the effects of higher modes which may have been excited.
Figure 3.4 Harmonics = 3 + 4 : L=1.0 m : Filter = Waveguide.
Figure 3.5 Harmonics = 3 + 6 : L=1.0 m : Filter = 3rd.
C. CONCLUSIONS

The results presented here demonstrate initial confirmation of the theory. Although it is difficult to improve the geometry of the experiment, definite improvements can be made in the measurement of the microwave radiation. Instead of using waveguide filters and a crystal detector (the use of which leads to measurement ambiguities for harmonics greater than the fourth), a tunable YIG filter coupled to a spectrum analyzer of appropriate sensitivity should be used. This will enable the observer to isolate harmonics for measurement without ambiguity, as well as allowing the measurement of absolute (vice relative) power.
APPENDIX A

FORTRAN PROGRAM FOR CALCULATING CERENKOV RADIATION CURVES

This is an interactive program which calculates and plots Cerenkov radiation curves for the case of a finite path length. Up to five different harmonics of the electron bunch frequency and five different lengths of emission path may be selected for presentation. The program also allows for adjustment of all basic parameters and constants of the Cerenkov power equation. A different curve will be plotted for each distinct combination of path length and harmonic.
THIS PROGRAM CALCULATES AND PLOTS CERENKOV RADIATION CURVES. UP TO CEROCC10
FIVE HARMONICS AND FIVE LENGTHS OF EMISSION REGION MAY BE CHOSEN.
A DIFFERENT CURVE WILL BE PLOTTED FOR EACH DISTINCT COMBINATION OF CEROCC30
LENGTH AND HARMONIC.

REAL N, MU, KAY, MO, NUO, IF, B, C, GAMMA, BETA, V, CCSTC,
* CC, U, F, CO, N, MU, NUO, Q, E, MO, B
DIMENSION W(1000), THEATA(1000), HARM(5), CELL (5)

C

C INITIALIZE CONSTANTS
DATA IC/CO /1/E/N ;/IMU/*MU * ;/INU/*NUO * ;
* 10*/Q ;/IE/E ;/IMO/*MO * ;/IB*B ;/IV*Y ;/INO/*N /
NPCINT = 101
THEATAF = 20.0
PI = 3.14159265359
DGTrEC = 0.01745329525199
RDTCG = 57.29977951308

C

C *** INITIALIZE PROGRAM CONSTANTS
CO = 2.997925E0
N = 1.000268E0
MU = 1.256E-6
NUC = 2.852E9
Q = 1.94E-12
E = 1.6E-11
MO = 5.10953E-31
B = -0024E0

C

C *** ARE PROGRAM CONSTANTS OK?
10 WRITE(6,902) CO,N,MU,NUO,Q,E,MO,B
REAL(5,501) IANS
IF (IANS.EQ.0) GC TO 40
C

C *** NO, PROGRAM CONSTANTS NEED TO BE CHANGED
WRITE(6,902)
REAL(5,503) IANS

C

C IF(IANS.NE.100) GO TO 11
WRITE(6,904) IANS
READ(5,*) CO
CC TC 10
C

C IF(IANS.NE.100) GO TO 12
WRITE (6,904) IANS
READ (5,*) N
CC TC 10
C

C IF(IANS.NE.IMU) GO TO 13
WRITE(6,904) IANS
READ (5,*) MU
CC TC 10

C  13 IF(IANS.NE.INUO) GO TO 14
WRITE (6,904) IANS
READ (5,*) NUO
GO TO 10
C  14 IF(IANS.NE.10) GO TO 15
WRITE (6,904) IANS
READ (5,*) C
GO TO 10
C  15 IF(IANS.NE.1E) GO TO 16
WRITE (6,904) IANS
READ (5,*) E
GO TO 10
C  16 IF(IANS.NE.1N) GO TO 17
WRITE (6,904) IANS
READ (5,*) NO
GO TO 10
C  17 IF(IANS.NE.18) GO TO 18
WRITE (6,904) IANS
READ (5,*) B
GO TO 10
C  18 *** ERRCR
WRITE (6,910)
GO TO 10
C  40 WRITE(6,505)
READ(5,*) HARM(1), HARM(2), HARM(3), HARM(4), HARM(5)
WRITE(6,506)
READ(5,*) CELL(1), CELL(2), CELL(3), CELL(4), CELL(5)
C  CALL TEK610
C  CALL PETKAL
C  CALL PETPLT(72,6)
C  CALL VESETG(0,0,0)
CALL CPPR3
C  CALL NCERDR
CALL PACE(8.5,11.0)
C  THE LOCATION OF THE ORIGIN:
CALL PHYSOR(1.0,1.0)
THE AREA IN INCHES BY INCHES:
CALL AREA2D(17.0, 10.0)

WHATEVER LABELS DESIRED ON X AND Y AXIS:
CALL XNAME ("ANGLE", 100)
CALL YNAME ("POWER/STERADIAN (WATTS)", 100)
CALL YAXANG(10)

WHATEVER HEADING DESIRED FOR GRAPH:
CALL HEADIN("THIS IS A HEADING", 100, 1, 2, 2)
CALL HEADD("HEADING ON NEXT LINE", 100, 1, 2, 2)

RANGE AND INCREMENTS OF X AND RANGE AND INCREMENTS OF Y
CALL GRAP(10.0, 5.0, 15.0, 0.0, 0.01, 0.15)

NEED SPLINE FOR SMOOTH FIT (OTHERWISE GET LINEAR FIT)
CALL SPLINE

DO 70 J = 1, 5
   IF (FARNIJ).EQ.0) GC TO 70

   IF (CELL(J).EQ.0) GO TO 70

   *** BEGIN CALCULATIONS
   C = CO * N
   GAMMA = E / (MO*CO*CO)
   BETA = (1.0 - 1.0 / (GAMMA*GAMMA)) ** 0.5
   V = BETA * CO
   COSTC = C / V
   CI = MU*C*NUC*NUO*Q*C / (8.0*F1*F1)
   KAY = 2.0*PI*HARM(J)*NUO / C

   WRITE(50,*) KAY, COSTC, HARM(J), CELL(K)

   *** CALCULATE FUNCTIONAL VALUES
   RASF = THEITA * DOTRD
   XFCINT = FLOAT(NPOINT-1)
   CC 80 I=1,NPCINT
   RATIO = FCAT(I-1) / XPOINT
   ANGLE = RATIC * RADF
   THETA(I) = RATIO * THEITA
   F = 1/(EXP(0.25 * B*KAY*COS(ANGLE)) * R*KAY*COS(ANGLE))
   U = (KAY * CELL(K) * (CSTC-CSTC*S(ANGLE))) / 2
   IF = SIN(U) / U
   W(I) = CI * (F*KAY*CELL(K)*S(ANGLE)*IF) ** 2
WRITE(50,*) W(I),THETA(I),F,IF
C
80 CONTINUE
C& CALL CURVE FOR EACH CURVE DESIRED (0 IN LAST PARAMETER
C& INDICATES CG NOT DISPLAY DATA POINTS, 1 MEANS DISPLAY
C& EVERY DATA POINT)
C& CALL CLFVE (THETA, W, NPOINT, 0)
C& CALL CLFVE (X, Y, N, 0)
C& CALL CLFVE (X, YY, N, 0)
C& CONTINUE
C
75 CONTINUE
C
70 CONTINUE
C& CALL ENDPL
C& ** USER WANT ANOTHER RUN?
C& WRITE(6,508)
C& REAL(5,901) IANS
C& IF(IANS.EQ.14) GO TO 10
C& CALL DECPL
C& CONTINUE
C& STOP
C
900 FORMAT(1/, " PROGRAM CONSTANTS CURRENTLY HAVE VALUES AS FOLLOWS: ", /
C& * 5X, CC = SPEED OF LIGHT IN VACUUM = E14, /
C& * 5X, A = AIR REFRACTIVE INDEX = E14, /
C& * 5X, K = PERMEABILITY OF AIR = E14, /
C& * 5X, A0 = BUNCH FREQUENCY = E14, /
C& * 5X, E = ELECTRON CHARGE = E14, /
C& * 5X, E = ELECTRON ENERGY = E14, /
C& * 5X, P = ELECTRON REST MASS = E14, /
C& * 5X, B = BUNCH SIZE PARAMETER = E14, /
C& DO YOU WANT TO CHANGE ANY OF THESE VALUES? ( Y OR N )
C& * 

901 FORMAT(A1)
902 FORMAT(1/, " ENTER CONSTANT TO BE CHANGED: ")
903 FORMAT(A1)
904 FORMAT(A1, " ENTER NEW VALUE FOR ',A1,":")
905 FORMAT(1/, " ENTER VALUES FOR HARM (HARMONIC OF BUNCH FREQUENCY) : ")
906 FORMAT(1/, " ENTER VALUES FOR CELL (LENGTH OF EMISSION REGION) : ")
907 FORMAT(1/, " WANT ANOTHER RUN? ( ENTER Y OR N )")
908 FORMAT(1/, " THE VARIABLE SELECTED IS NOT IN THE LIST - TRY AGAIN")
910 FORMAT(1/, " END")
END
APPENDIX B
FORTRAN PROGRAM - CERENKOV CURVES WITH DATA POINTS

This is an interactive program which calculates and plots several Cerenkov radiation curves as well as a single set of experimentally observed data points. Up to five different harmonics of the bunch frequency and five different lengths of the emission path may be chosen for presentation. A different curve will be plotted for each distinct combination of path length and harmonic. The program also allows adjustment of all basic parameters and constants of the Cerenkov power equation. The program then prompts for 20 data measurements of power (one per degree) which will be superimposed over the curves.
C THIS PROGRAM CALCULATES AND PLOTS CERENKOV RADIATION CURVES FOR
C UP TO FIVE DIFFERENT HARMONICS AND FIVE DIFFERENT LENGTHS OF
C EMISSION REGION. A DIFFERENT CURVE WILL BE CALCULATED FOR EACH
C DISTINCT COMBINATION OF LENGTH AND HARMONIC. THE PROGRAM THEN ASKS
C FOR 20 DATA POINTS (ONE PER DEGREE) TO BE SUPERIMPOSED OVER THE
C CURVES.
C
C REAL N, MU, KAY, MO, NUO, IF,B,C,GAMMA,DETA,COSTC,
*C INU,F,CO,N,MU,NUG,G,E,MOR
*C DIMENSION W(L1000),THETA(L1000),HARM(5),CELL(5),THETA(20),
*C
C INITIALIZE CONSTANTS
DATA IGG/CO//IN/N///IMU/MU ///INUC/NUO/,
*C IC/0 ///IE/E ///IMO/0 ///IB/E ///IV/Y///INO/N///
NPCINT = 101
THETA = 20.0
PI = 3.14159265359
DGHIO = 0.0174532925199
RDT influencers = 97.29577551308
C
C ** INITIALIZE PROGRAM CONSTANTS
CO = 2.997925E08
N = 1.000288800
MU = 1.256E-6
NUO = 2.85E09
Q = 1.94E-12
E = 1.6E-11
MO = 5.10533E-31
B = .04024E00
C
C ** ARE PROGRAM CONSTANTS OK?
10 WRITE(6,900) CO,N,MO,NUO,Q,E,MOR,
REAL(5,901) IANS
IF (IANS.EQ.INC) GC TO 40
C ** NO PROGRAM CONSTANTS NEED TO BE CHANGED
WRITE(6,902)
REAL(5,903) IANS
C
IF(IANS.NE.CO) GC TO 11
WRITE(6,504) IANS
READ(5,4) CO
GC TO 10
C
IF(IANS.NE.IN) GC TO 12
WRITE(6,904) IANS
READ(5,4) N
GC TO 10
C
C 12 IF (IANS .NE. IMU) GO TO 13
    WRITE (6,904) IANS
    READ (5,*) MU
    GC TC 10
C 13 IF (IANS .NE. INUO) GO TO 14
    WRITE (6,904) IANS
    READ (5,*) NUO
    GC TC 10
C 14 IF (IANS .NE. IG) GO TO 15
    WRITE (6,904) IANS
    READ (5,*) G
    GC TC 10
C 15 IF (IANS .NE. IE) GO TO 16
    WRITE (6,904) IANS
    READ (5,*) E
    GC TC 10
C 16 IF (IANS .NE. IMO) GO TO 17
    WRITE (6,904) IANS
    READ (5,*) PO
    GC TC 10
C 17 IF (IANS .NE. IB) GO TO 18
    WRITE (6,904) IANS
    READ (5,*) B
    GC TC 10
C 18 *** ERROR
    WRITE (6,910)
    GC TO 10
C 40 WRITE (6,905)
    READ (5,*) HARM(1), HARM(2), HARM(3), HARM(4), HARM(5)
    WRITE (6,906)
    READ (5,*) CELL(1), CELL(2), CELL(3), CELL(4), CELL(5)
C 41 WRITE (6,907)
    DO 41 I = 1, 20
       READ (5,*) POWER(I)
       CONTINUE
C 42 DO 42 I = 1, 20
       THETA(I) = 1
       CONTINUE
CALL TEK618
CALL PTEKAL
CALL PRPL1T(72,6)
CALL VRSTEC(0,0,0)
CALL CCFRS
CALL NCERDR
CALL PAGE(8.5,11.0)
THE LOCATION OF THE ORIGIN:
CALL PSYSOR(1.0,1.0)
THE AREA IN INCHES BY INCHES:
CALL AREA2D(7.0,10.0)
WHATEVER LABELS DESIRED ON X AND Y AXIS:
CALL XNAME("ANGLE $",100)
CALL YAXANG(3)
CALL YNAME("POWER/STERADIAN (WATTS) ",100)
WHATEVER HEADING DESIRED FOR GRAPH:
CALL HEADING("THIS IS A HEADING$",100,1.2.2)
CALL HEADING("HEADING ON NEXT LINE$",100,1.2.2)
RANGE AND INCREMENTS OF X AND RANGE AND INCREMENTS OF Y
CALL GRAP(0.0,5.0,15.0,0.0,.01,0.15)
NEED SPLINE FOR SMOOTH FIT (OTHERWISE GET LINEAR FIT)
CALL SPLINE
DO 70 J = 1,5
  IF (HARHIJ.EQ.0) GC TO 70
  DO 50 K = 1,5
     IF (CELL(K).EQ.0) GO TO 70
50    CONTINUE
*** BEGIN CALCULATIONS
  C = CO / N
  GAMMA = E / (MO*CO*CQ)
  BETA = (1.0 - 1.0 / (GAMMA*GAMMA)) ** 0.5
  V = BETA * CO
  CSTC = C / V
  C1 = NU*C4*NUC*NUO*Q*Q / (8.0*FI*FI)
  KAY = 2.0*PI*HARHIJ*NUO / C
WRITE(50,*) KAY,CSTC,HARHIJ,CELL(K)
**CALCULATE FUNCTIONAL VALUES**

```plaintext
RAEF = THEETA * DGTORD
XPOIN = FLOAT(NPCINT-1)
DC 80 I=1,NPCINT
    RATIO = FCAT(I-1) / XPOIN
    ANGLE = RATIO * RAD
    THEETA(I) = RATIO * THEETA
    F = 1/(EXP(0.25 * B*KAY*COS(ANGLE) * B*KAY*COS(ANGLE))
    U = (KAY * CELI(K)) * (COSTC-COS(ANGLE)) / 2
    IF = SIN(U) / U
    W(I) = CI * (F*KAY*CELI(K)*SIN(ANGLE)*IF)**2
```

---

**CONTINUE**

**CALL CURVE FOR EACH CURVE DESIRED (0 IN LAST PARAMETER**

**INDICATES NO DISPLAY DATA POINTS, 1 MEANS DISPLAY**

**EVERY DATA POINT**

**CALL CURVE (THETA, W,NPOINT,0)**

**CALL CLFVE (X,Y,N,0)**

**CALL CLFVE (X,Y,Y,N,0)**

---

**CONTINUE**

**CALL CURVE (THEPTA,POWER,20,-1)**

**CALL EACPL(C)**

**USER WANTS ANOTHER RUN?**

**WRITE(6,508)**

**REAL(5,901) IANS**

**IF(IANS,EQ.1) GC TC 10**

**CALL DCKEPL**

---

**CONTINUE**

**STCP**

---

**FORMAT(1.,E14.7) PROGRAM CONSTANTS CURRENTLY HAVE VALUES AS FOLLOWS:**

- **5X** = AIR REFRACTIVE INDEX
- **5X** = PERMEABILITY OF AIR
- **5X** = BUNCH FREQUENCY
- **5X** = ELECTRON ENERGY
- **5X** = ELECTRON REST MASS

---

CERO1450
CERO1460
CERO1470
CERO1480
CERO1490
CERO1500
CERO1510
CERO1520
CERO1530
CERO1540
CERO1550
CERO1560
CERO1570
CERO1580
CERO1590
CERO1600
CERO1610
CERO1620
CERO1630
CERO1640
CERO1650
CERO1660
CERO1670
CERO1680
CERO1690
CERO1700
CERO1710
CERO1720
CERO1730
CERO1740
CERO1750
CERO1760
CERO1770
CERO1780
CERO1790
CERO1800
CERO1810
CERO1820
CERO1830
CERO1840
CERO1850
CERO1860
CERO1870
CERO1880
CERO1890
CERO1900
CERO1910
CERO1920
CERO1930
CERO1940
CERO1950
CERO1960
CERO1970
CERO1980
CERO1990
CERO2000

DO YOU WANT TO CHANGE ANY OF THESE VALUES? (Y OR N)

ENTER CONSTANT TO BE CHANGED:

ENTER NEW VALUE FOR:

ENTER VALUES FOR HARM (HARMONIC OF BUNCH FREQUENCY):

ENTER VALUES FOR CELL (LENGTH OF EMISSION REGION):

ENTER EXPERIMENTAL VALUES FOR POWER:

WANT ANOTHER RUN? (ENTER Y OR N)
APPENDIX C

FORTRAN PROGRAM - SUM OF CERENKOV CURVES WITH DATA POINTS

This is an interactive program which calculates and plots a single Cerenkov radiation curve and superimposes a single set of data points over the curve. The single Cerenkov curve will represent a sum of curves. The sum will be composed of each distinct combination of harmonic and path length chosen. Up to five different lengths of emission path and five different harmonics of the bunch frequency may be chosen. The program also allows adjustment of all basic parameters and constants of the Cerenkov power equation. The program will prompt for 20 data measurements of power (one for each degree of angle).
THIS PROGRAM CALCULATES AND PLOTS A SUM OF CERENKOV RADIATION CURVES, UP TO FIVE HARMONICS AND FIVE LENGTHS OF EMISSION REGION MAY BE CHANGED. THE PROGRAM WILL INCLUDE A DIFFERENT CURVE IN THE SUM FOR EACH LISTED COMBINATION OF LENGTH AND HARMONIC. THE PROGRAM THEN ASKS FOR 20 DATA POINTS (ONE PER DEGREE) TO BE SUPERIMPOSED OVER THE CURVE.

REAL N, MU, KAY, MO, NUO, IF, B, C, GAMMA, BETA, V, COSC, C1, U, F, C0, N, MU, NUO, C, E, MO, E
DIMENSION W(1000), THE1A(1000), HARN(5), CELL (5), THETAP(20), PCW(20), SUM(1000)

INITIALIZE CONSTANTS
DATA IC7/CO, I/N/N, IMU/MU, INUOG/NUO, I/
! IC/PQ, IE/E, IMO/MO, IB/I, IY/Y, INO/N/
NPOINT = 101
THE1A = 20.0
PI = 3.14159265359
G1C0AD = 0.0174532925199
R0TC0G = 57.29577551308

*** INITIALIZE PROGRAM CONSTANTS
CO = 2.997925E08
N = 1.0000268E00
MU = 1.256E-06
NUO = 2.98E09
C = 1.6E-12
MO = 5.10696E-31
B = 0.024E00

*** ARE PROGRAM CONSTANTS GK?
10 WRITE(6,901) CO, N, MU, NUO, C, E, MO, B
REAL(5,901) IANS
IF (IANS.EQ.0) GC TO 40

*** NO PROGRAM CONSTANTS NEED TO BE CHANGED
WRITE(6,902)
REAL(5,503) IANS

IF (IANS.NE.10) GO TO 11
WRITE(6,505) IANS
READ(5,*) CO
GC TC 10

11 IF (IANS.NE.1N) GO TO 12
WRITE(6,904) IANS
READ(5,*) N
GC TC 10

SUMO0600
C 12 IF(JANS NE INU) GO TO 13
WRITE (6,904) IANS
READ (5,* ) MU
CC TC 10
C 13 IF(JANS NE INUC) GO TO 14
WRITE (6,904) IANS
READ (5,* ) ALO
GO TO 10
C 14 IF(JANS NE 10) GO TO 15
WRITE (6,904) IANS
READ (5,* ) C
CC TC 10
C 15 IF(JANS NE IE) GO TO 16
WRITE (6,904) IANS
READ (5,* ) E
CC TC 10
C 16 IF(JANS NE 1M0) GO TO 17
WRITE (6,904) IANS
READ (5,* ) MO
CC TC 10
C 17 IF(JANS NE 18) GO TO 18
WRITE (6,904) IANS
READ (5,* ) B
CC TC 10
C 18 *** ERRCR
WRITE (6,910)
GO TO 10
C 20 WRITE (6,*903)
READ (5,* ) HARM(1),HARM(2),HARM(3),HARM(4),HARM(5)
WRITE (6,*906)
READ (5,* ) CELL (1),CELL (2),CELL (3),CELL (4),CELL (5)
C 30 WRITE (6,*907)
DO 41 I = 1,20
READ (5,* ) POWER(1)
CONTINUE
C 41 DO 42 I = 1,20
THETA(I) = 1
CONTINUE
CALL TEK618
CALL PIEMA
CALL PRPTCT(72,6)
CALL VRSTEC(10,0.0)
CALL CFPRRS
CALL NAME
CALL PAGE(8.5,11.0)

THE LOCATION OF THE ORIGIN:
CALL PHYSOR(1.0,0.0)

THE AREA IN INCHES BY INCHES:
CALL AREA2D(7.0,10.0)

WHATEVER LABELS DESIRED ON X AND Y AXIS:
CALL XNAME("ANGLE",100)
CALL YNAME("POWER/STERRADIAN (WATTS)",100)

WHATEVER PENCILING DESIRED FOR GRAPH:
CALL HEADING("THIS IS A HEADING",100,1.2,2)
CALL HEADING("HEADING ON NEXT LINE",100,1.2,2)

RANGE AND INCREMENTS OF X AND RANGE AND INCREMENTS OF Y
CALL GRAP(0.0,5.0,15.0,0.0,0.05,0.30)

NEED SPLINE FOR SMOOTH FIT (OTHERWISE GET LINEAR FIT)
CALL SPLINE

DO 69 I = 1,NPOINT
   SUM(I) = 0
   69 CONTINUE

DO 70 J = 1,5
   IF (FJAM(J).EQ.0) GO TO 70
   70 CONTINUE

DO 50 K = 1,6
   IF (KEL(K).EQ.0) GO TO 70

*** BEGIN CALCULATIONS
   C = CO / K
   GAMMA = E / (MO*CO*CO)
   BETA = (1.0 - 1.0 / (GAMMA*GAMMA)) ** 0.5
   V = BETA * CO
   CRITICAL = C / V
C1 = MU*C*NU0*NUQ*Q*C / (B*O*PI*PI)

KAY = 2.0*PI*HARM(J)*NU0 / C

WRITE(50,*), KAY, COSTC, HARM(J), CELL(K)

*** CALCULATE FUNCTIONAL VALUES

RADF = THETA* * DGTORD

XCINT = FLOAT(NPOINT-1)

CC 80 I=1, APCIINT
RATIO = FLOAT(I-1) / XPOINT

ANGLE = RATIO * RADF

THETA(I) = RADF * THETA

F = 1/(EXP(0.25 * B*KAY*COS(ANGLE) * B*KAY*COS(ANGLE)))

U = (KAY * CELL(K) * (COSTC-COS(ANGLE)))/2

IF = SIN(U)/I

W(I) = CI * (F*KAY*CELL(K)*SIN(ANGLE)*IF)**2

SUM(I) = W(I) + SUM(I)

WRITE(5C,*) SUM(I), THETA(I)

WRITE(50,*), W(I), THETA(I), F, IF

80 CONTINUE

CALL CURVE FOR EACH CURVE DESIRED (0 IN LAST PARAMETER

INDICATES CC NOT DISPLAY DATA POINTS, 1 MEANS DISPLAY

EVERY DATA POINT)

CALL CURVE (THETA, W, NPOINT, 0)

CALL CURVE (X, Y, N, 0)

CALL CURVE (X, YY, N, 0)

75 CONTINUE

70 CONTINUE

CALL CURVE (THETA, SUM, NPOINT, 0)

CALL CURVE (THETA, FORDER, 20, -1)

CALL EACPL(0)

** USER WANT ANOTHER RUN?

WRITE(6, 508)

REAL(S, 901), IANS

IF (IANS = EQ. 1) GO TO 10

CALL DCEPL

90 CONTINUE

STCP

900 FORMAT(1, ' PROGRAM CONSTANTS CURRENTLY HAVE VALUES AS FOLLOWS: ',/}

SUM01450

SUM01460

SUM01470

SUM01480

SUM01490

SUM01500

SUM01510

SUM01520

SUM01530

SUM01540

SUM01550

SUM01560

SUM01570

SUM01580

SUM01590

SUM01600

SUM01610

SUM01620

SUM01630

SUM01640

SUM01650

SUM01660

SUM01670

SUM01680

SUM01690

SUM01700

SUM01710

SUM01720

SUM01730

SUM01740

SUM01750

SUM01760

SUM01770

SUM01780

SUM01790

SUM01800

SUM01810

SUM01820

SUM01830

SUM01840

SUM01850

SUM01860

SUM01870

SUM01880

SUM01890

SUM01900

SUM01910

SUM01920
**ERROR**

The page contains a series of character strings that appear to be random or unrecognizable. Without context or a clear layout, it's challenging to interpret the content accurately. The text seems to be a mixture of numbers, symbols, and possibly command lines, but the specific meaning is unclear.

### Possible Interpretation

- **SPEED OF LIGHT IN VACUUM**
- **AVERAGE PROBABILITY INDEX**
- **BUNCH FREQUENCY**
- **ELECTRON ENERGY**
- **GAMMA ENERGY**
- **HARMONIC OF BUNCH FREQUENCY**
- **LENGTH OF EMITTANCE REGION**
- **FARADY VALUES**
- **AND MODES**

These terms suggest a scientific or technical context, possibly related to physics or engineering. However, the exact nature of the information is not clear due to the disarray of the text.
APPENDIX D
EXPERIMENTAL APPARATUS

This appendix contains photographs of the experimental apparatus used in this experiment. Figure D.1 shows the end station of the LINAC. At the right is the LINAC beam aperture, with the reflecting aluminum mirror at the left. The detector assembly, mounted at the end of the pivot arm, is shown in the foreground of the photograph. Also shown, located along the beam path between the aperture and the mirror, is a small portable laser used to align the mirror.

Figure D.2 shows the waveguide filter with the fin-line insert for one of the harmonics, along with the detector and horn. Figure D.3 shows the detector apparatus assembled.
Figure D.1  LINAC End-Station.
**APPENDIX E**

**TABULAR DATA FOR FIGURES**

**TABLE III**

Tabular Data for Figure 3.1

<table>
<thead>
<tr>
<th>Degree</th>
<th>Channel</th>
<th>Normalized Value</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td>101</td>
<td>0.0082</td>
</tr>
<tr>
<td>2</td>
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<td>3</td>
<td>168</td>
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</tr>
<tr>
<td>6</td>
<td>864</td>
<td>0.0701</td>
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<td>7</td>
<td>828</td>
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<td>8</td>
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<td>0.0610</td>
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<td>9</td>
<td>610</td>
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</tr>
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<td>13</td>
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</tr>
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</tr>
<tr>
<td>15</td>
<td>152</td>
<td>0.0123</td>
</tr>
</tbody>
</table>

- Channel values were read from the Pulse Height Analyzer.
- Normalizing factor was $8.1134E-05$.
- Beam current = $4.0E-08$ Amps.
<table>
<thead>
<tr>
<th>Degree</th>
<th>Channel</th>
<th>Normalized Value</th>
</tr>
</thead>
<tbody>
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</tr>
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<td>114</td>
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</tr>
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<td>198</td>
<td>0.0221</td>
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<tr>
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<td>284</td>
<td>0.0317</td>
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<td>5</td>
<td>356</td>
<td>0.0620</td>
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<td>694</td>
<td>0.0774</td>
</tr>
<tr>
<td>7</td>
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<tr>
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<td>786</td>
<td>0.0877</td>
</tr>
<tr>
<td>9</td>
<td>572</td>
<td>0.0638</td>
</tr>
<tr>
<td>10</td>
<td>393</td>
<td>0.0438</td>
</tr>
<tr>
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- Channel values were read from Pulse Height Analyzer
- Normalizing factor was 1.1158E-04
- Beam current = 4.0E-08 Amps
### TABLE V
Tabular Data for Figure 3.3

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- Channel values were read from Pulse Height Analyzer
- Normalizing Factor was 3.9502E-04
- Beam current = 4.0E-08 Amps
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- Channel values were read from the Pulse Height Analyzer.
- Normalizing factor was 2.48E-04.
- Beam current = 4.0E-08 Amps.
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Channel values were read from the Pulse Height Analyzer.
Normalizing factor was 1.878E-04.
Beam current = 4.0E-08 Amps.
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