INSTRUCTION MANUAL

MODEL AA-2010
MODEL AA-2015
MODEL AA-2020
MODEL AA-2025

SINGLE CHANNEL NUCLEAR SCINTILLATION SPECTROMETRY SYSTEMS

Oxford Instruments Inc
Analytical Systems Division
Nuclear Measurements Group

601 Oak Ridge Turnpike • Oak Ridge, Tennessee USA 37830
Telephone (615) 483-8405  Fax (615) 483-5891
1.0 INTRODUCTION

Gamma ray scintillation spectroscopy provides an exciting climax for introductory laboratory courses in basic nuclear science technology. The beauty of nuclear scintillation spectroscopy lies in the wide ranging versatility of the technique. From a sub-visual microsecond light flash (scintillation) in a transparent crystal, it is possible to electronically examine the exact nature of the interaction of nuclear radiations with matter: The photo electric effect, in which all the energy of the gamma radiation is absorbed; the Compton effect, in which part of the gamma ray energy escapes from the crystal; pair production, where gamma ray energy is converted to matter [the positron-electron pair is a classic example of the energy — mass equivalence $e = mc^2$]; backscatter radiation; and Bremsstrahlung radiation.

Scintillation spectroscopy offers many advantages to the nuclear scientist. It is extremely fast, recovering in about one microsecond after a nuclear event. This makes possible high counting rates for good statistics during short counting intervals most often used in student laboratory experiments. Scintillation spectroscopy is the most efficient gamma ray detector available.

The most exciting and useful aspect of the scintillation technique is energy analysis of gamma rays. Since the amplifier output voltage pulse is proportional to the gamma ray energy imparted to the crystal, an examination of the pulse spectrum shows the detected gamma ray energies. Literally hundreds of laboratory experiments may be designed for studies for: identification of isotopes; decay schemes; absorption vs. energy; multiple tracers; isotopic uptakes; activation analysis; high efficiency counting; and environmental monitoring.

This manual describes the operation of our most popular gamma scintillation spectroscopy system, the Model AA-2010. This particular system includes the Model 500 general purpose scaler/timer. Other complete spectroscopy systems may be configured utilizing either the Model 550 or Model 575 scaler/timers.

These systems operate identically to the Model AA-2010 as described herein. Your Nucleus Model AA-2010 system has been carefully engineered and manufactured under the highest quality control standards. It will provide years of reliable, student-proof (and professor-proof), trouble-free use, if the simple precautions, proper operation and maintenance described in the manual are followed. Please read this manual in its entirety before attempting to operate the system.

In the back of this manual you will find a textbook type chapter entitled “Theory of Gamma Ray Spectroscopy”. This section was written for undergraduate level students and we encourage you to reproduce this section as often as you wish for distribution to each student in the laboratory where gamma spectroscopy experiments are performed.
2.3 HOW THE AA-2010 SYSTEM OPERATES

The basic elements of a scintillation spectroscopy system include the scintillation crystal, a photomultiplier tube, a fast linear amplifier, a pulse height analyzer, a fast scaler, and a well regulated high voltage supply.

The Nucleus Model AA-2010 system offers all these basic elements in a three unit assembly: detector, amplifier-analyzer, and scaler. Specifically, these units are: the Model P-2000/1 NaI Probe, stand and lead shield; the Model 500 Scaler/Timer, and the Model 2010 Amplifier/Analyzer.

The gamma ray detection unit is a NaI(Tl) crystal mechanically mounted and light coupled to a photomultiplier tube. A gamma ray absorbed by the NaI(Tl) scintillation crystal produces a brief, faint light flash. The photomultiplier tube converts this light flash into an electron burst. This electron pulse is amplified many times (about 100,000) in passing through the photomultiplier tube and then travels into the Model 2010 Amplifier/Analyzer via the signal/high voltage cable. In the linear amplifier section of the Model 2010, the pulse is shaped and amplified further. The pulse height analyzer section sorts the voltage pulses according to height (or pulse amplitude). This sorting is accomplished by erecting an electronic fence in the path of the incoming pulses. The height of the fence is made variable from 0 to 5 volts (0 to 1000 “E” dial divisions).

If, for instance, the fence were set to a height of 800 “E” dial divisions (4 volts), all pulses whose heights exceed the 800 level (4 volts) would be passed on to be counted while all others would be screened out. However, spectrum data require a count of pulses at discrete heights. Thus, an upper fence is erected a discrete height above the lower fence (usually 0.1 volt) and made to rise and descend with it. Now, only those pulses whose heights lie between the upper and lower fences are passed on to be counted. The gap between the fences is called the “window” or ΔE.

Another function of the Model 2010 Amplifier/Analyzer is to take the 1400 volt Zener regulated D.C. potential from the Model 500 Scaler/Timer, and further regulate it to 1000 volts. This regulation is accomplished by a voltage regulator tube (VRT). The 1000 volt potential powers the resistor string associated with the photomultiplier. It provides up to 80 micro amperes of regulated current.
Finally, the Model 500 Scaler/Timer totals the counts per unit time for each "E" interval. Readout is on seven segment LEDs with total count storage capacity of 999,999.

A differential gamma ray spectrum may be plotted on linear or semi-log paper.

3.0 HOOK-UP AND CALIBRATION

The modular construction of the Model 500 Scaler/Timer and Model 2010 Amplifier/Analyzer makes it easy to "stack" the instruments, thereby requiring less lab bench area. All connecting cables are located on the rear of the instruments where they are out of the way during operation.

In hook-up and calibration of the Model AA-2010 system, it is important that the following steps be followed precisely:

Step 1:  Turn the two high voltage controls on the Model 500 Scaler to zero. Perform this step any time you connect or change cables. Damage to the sensitive input circuitry may result otherwise.

Step 2:  Connect the Model P-2000/1 Probe to the Model 2010 Amplifier/Analyzer using the single signal/high voltage cable which comes out of the top of the probe base socket assembly. The MHV female connector on the probe cable is connected to the MHV male terminal (marked "to Probe") on the back of the Model 2010 Amplifier.

Step 3:  Connect the Model 500 Scaler to the Model 2010 Amplifier using the single cable provided with the complete system. (No cable is provided if the individual instruments are purchased separately.) There is a single MHV connector on the Model 500 Scaler back panel. Use this terminal, and connect the other end of the cable to the MHV male terminal (marked "to Scaler") on the back panel of the Model 2010 Amplifier. This cable carries the high voltage from the scaler to the amplifier; and returns the count pulses from the amplifier back to the scaler.

Step 4:  Plug the AC line cords on the scaler and the amplifier into a suitable 115V/60Hz AC power source. If your power requirement is 220V/50Hz, and you have requested this operating voltage, a 220V/50Hz label will be affixed on the back panel of both instruments. All instruments manufactured by The Nucleus utilize dual primary transformers, and may be used with either 115V/60Hz or 220V/50Hz AC power. However, the correct voltage is factory preset and must be requested at the time of purchase.
Step 5a: Depress the “POWER” switch on the Model 500 Scaler. The switch will be illuminated and remain in the depressed position. Set the count interval-minutes switch to the manual position (marked “MAN”). Now depress the COUNT switch which will be illuminated, but will not remain depressed. Set the COURSE High Voltage switch to 1400 volts.

Step 5b: Place the POWER-OFF switch on the Model 2010 Amplifier/Analyzer in the “Power” position. The panel light will indicate that power is on.

Step 6: Set the analyzer mode toggle switch to the “WINDOW” position. Locate the Baseline-“E” dial 0-1000 increment multiturn potentiometer, and set this dial to 320. A “3” should appear in the small window at the top of the potentiometer, and “20” would be opposite the marker just below the “3”. A small lock is incorporated in the switch, and this may be used to prevent an accidental movement of the dial. NOTE: The Baseline-“E” dial is now set to 320/1000, or 320 divisions out of a possible 1000.

Step 7: Set the “WINDOW - ΔE” switch on the analyzer to 2%. This will be the first dot ≡ above the zero stop. The ΔE window has a range of 0 to 20%. At the 2% position, we have erected an upper fence of 0.1 volt. (2% x 5 volts = 0.1 volt). Double check that the integral-window toggle switch is in the “WINDOW” position. Otherwise, only the bottom fence will be in operation, and all pulses above 320 will be counted.

Step 8: Place a Cs-137 source, 5 microcuries is sufficient, about 25 mm below the face of the detector. A sliding tray is provided in the base stand.

Step 9: Start with both FINE and COARSE gain controls in their lowest or most counter clockwise positions.

Very slowly increase the FINE gain control, watching for a sharp rise and fall in the scaler count rate, as observed on the second decade. If no such marked peak of count rate is observed as the FINE gain control is increased over its entire range, increase the COARSE gain control by one step. Repeat the slow increase of the FINE gain control over its entire range. Continue as above until a sharp peak in count rate is observed. Then, adjust the FINE gain control to the point at which the maximum count rate is observed. With a little practice watching the scaler readout, you will be able to find the maximum count rate without having to make a series of timed counts.

Step 10: Record the amplifier FINE and COARSE gain settings. DO NOT ALTER THESE SETTINGS UNLESS YOUR EXPERIMENT CALLS FOR IT.
The Model AA-2010 system is now calibrated to approximately 2 MeV full scale, and you are ready to proceed with gamma ray spectroscopy experiments.

The 2 MeV calibration was achieved as follows:

The “E” dial was set to 1.6 volts (dial 320). The “ΔE” dial was set to give a .1 volt window. The amplifier gain has been adjusted until the pulses arising from the total absorption of the Cs-137 gamma rays have heights which fall between 1.6 and 1.7 volts as evidenced by the sharp maximum of count rate seen on the scaler. The average pulse height is 1.65 volts at the center of the window. This particular combination of “E” and “ΔE” settings was chosen for use with Cs-137 as a standard because its energy is 662 keV. A gamma ray energy of 662 keV absorbed by the crystal is made to yield voltage pulses 1.65 volts high. 662 keV/1.65 volts = 400 keV/volt or 2 keV/E dial division. Thus 5 volts (full scale on the “E” dial) represents (5v) (400 keV/volt) or 2000 keV or 2 MeV.

A TECHNICAL NOTE: The linear amplifier section of the Model 2010 uses 7 transistors and the LM 3184 integrated circuit operational amplifier with precision range selection switching. The amplifier incorporates 1 microsecond double differentiation RC pulse shaping. The FINE gain control has a range of 1 to 3; and the COARSE gain selector switch has ranges of 5, 10, 20, 40, 80, 160 and 320. The overall gain (net gain) of the amplifier is the product of the FINE and COARSE gain or a maximum voltage gain of almost 1000.

The amplifier output is a positive 0-6 volts with a linearity of 0.1% over full range of rated output voltage.

4.0 SUGGESTED LABORATORY EXERCISES

With the Model AA-2010 Gamma Ray Spectroscopy System now calibrated at the 0 to 2 MeV range, you may proceed with the exercises outlined in this section. As you go through these exercises it will be helpful from time to time to refer to the section “Introductory Theory of Gamma Ray Spectroscopy”.

EXERCISE NO. I: Plotting spectra of several known gamma emitting radioisotopes.

A. CESIUM-137 SPECTRUM: E = 0.662 MeV

Step 1: Place a Cs-137 gamma source in the source tray slide, and position in slotted base about 30 to 40 mm from the face of the detector.

Step 2: Beginning with a Baseline-“E” dial setting of 400 out of the possible 1000 divisions, and with the ΔE window at 2%, take and record a one minute count. Move the baseline down 20 divisions to 380, and take a one minute count record. Continue decreasing the baseline by 20 division intervals down to zero and record the one minute counts.
**Step 3:** Using the data recorded, plot the total counts/minute as the ordinate versus "E" dial settings as abscissa on semi-log graph paper. You can draw a "smoother" curve with more data points. If time allows, take a one minute count at every 10 divisions on the "E" dial.

**Step 4:** Your spectrum should be quite similar to this
B. COBALT-60 SPECTRUM: $E = 1.17 \text{ MeV, 1.33 MeV}$

**Step 1:** Replace the Cs-137 source with a Co-60 source. In order to get a similar number of counts/minute as obtained with the Cs-137 source, it may be necessary to move the Co-60 source closer to the face of the detector.

**Step 2:** Begin taking one minute counts at 700 divisions on the “E” dial, and continue down to zero at 20 division intervals.

**Step 3:** Plot the Co-60 Spectrum. It should look like this:
Step 4: Refer to the Co-60 spectrum shown as figure 19 in the Theory Section of this manual. Q. Why do we not see the Co-60 sum peak in our plot? A. We have our system calibrated for 0-2 MeV gammas. The Co-60 sum peak is 2.5 MeV.

**EXERCISE NO. II: Spectra of unknown Gamma Ray Source**

Step 1: Obtain the “unknown” source from your instructor, and place in sample holder below the detector face.

Step 2: After having plotted several spectra, you probably have a “good feel” for the operation of the spectroscopy system, and it will not be necessary to plot a full spectrum to identify the “unknown” sample. Starting at 1000 on the “E” dial, slowly start decreasing towards zero, while watching the counts registering on the scaler. With a little practice, you can find the maximum count rates which indicate the peaks of the unknown gamma source. Go back and forth across the peak to get the maximum count rate. Since we have calibrated our system so that each division of the “E” dial represents 2 keV, simply multiply the “E” dial reading by 2 and obtain the gamma energy (in keV) of your unknown. Record the energies of all the unknown peaks.

Step 3: Refer to the list of some commonly used gamma sources in the appendix, and match up your “unknowns” to known radionuclides.

**NOTE TO STUDENTS...**Some professors can be darn right sneaky. They have been known to mix two or even three different gamma emitting nuclides to make a single “unknown”. Always look for the Cs-137 0.662 MeV peak and it’s associated Ba-137 and Pb X-ray peaks, first. Cs-137 is the most common gamma source in every radioisotope laboratory.

**EXERCISE III: Energy Calibration Curve for NaI(Tl) Detector**

Step 1: Refer to the spectra you obtained in exercises 1 and 2 for Cs-137 and Co-60. Use these plots to complete the following table.

<table>
<thead>
<tr>
<th>PEAK</th>
<th>ENERGY (MeV)</th>
<th>“E” DIAL SETTING</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.662 MeV</td>
<td>0.662</td>
<td>320</td>
</tr>
<tr>
<td>1.17 MeV</td>
<td></td>
<td>585</td>
</tr>
<tr>
<td>1.33 MeV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compton Edge Cs-137</td>
<td>0.478</td>
<td></td>
</tr>
<tr>
<td>BackScatter Cs-137</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Step 2: Construct an Energy Calibration Curve (complete this curve using data from above chart). Plot increasing gamma energy in MeV as the ordinate, and “E” dial setting as the abscissa.

![Energy Calibration Curve](image)

Step 3: Plot your “unknown” peaks from EXERCISE II on the energy calibration curve, using the “E” dial settings. How well do your unknown gamma energy photo peaks follow the curve?
SAMPLE PROBLEM:

The resolution of a sodium iodide gamma detector (such as the Model P-2000/1), is a measure of its ability to resolve two peaks that are relatively close together in energy.

Therefore, we can define resolution as the width of the total absorption peak at one-half its maximum value, divided by the pulse height at the center of the total absorption peak; or:

\[
\text{Resolution (\%)} = \frac{\text{Width at } \frac{1}{2} \text{ Maximum Count Rate} (W)}{\text{Peak Center Point (P)}} \times 100
\]

Both \(W\) and \(P\) must be in the same units, and for the Model 2010, these units are the “E” dial setting.

Calculate the resolution of your NaI detector using the spectrum you plotted for the Cs-137 source. It should be between 7 and 8 percent. The smaller the number, the better the resolution.

STUDY QUESTION:

Both the 1.17 and 1.33 Mev gamma-rays of Co-60 are emitted during each disintegration. Why does there appear to be more of the 1.17 MeV gamma-rays than the 1.33 in the Co-60 spectrum?
5.1 Model 500 Scaler Circuit Description

The Model 500 consists of two printed circuit boards. The large p.c. board contains the power supplies, input signal conditioning, and timing circuitry, and the small board at the front of the instrument contains the scaling and readout sections.

A regulated low voltage output of +5 volts supplies all integrated circuits.

An unregulated low voltage output of +10.5 volts supplies the switch lamp voltage.

The high voltage supply is continuously variable from 0-2000 volts. A 1 meg ohm resistor, in response to a Geiger tube current pulse, provides the necessary voltage signal for the pulse shaper circuit.

The scaler circuit contains six decade scaling sections, each consisting of a scaler, decoder driver and readout LED.

The interval timer uses various integrated circuit scalers to count down the line frequency. For example, on the one minute count, the input line frequency (60 Hz) is counted for 3600 counts (a period of one minute) and then is automatically shut off. During the one minute time interval while the timer accumulates 3600 counts, the scaler is gated on and counts any input signal from the Geiger tube. For 50 Hz line frequency, the scaler will accumulate 3000 counts during a one minute time interval.

For other applications, such as G-M counting, please refer to the Model 500 Series “Manual of Operation and Maintenance”.