### Nuclear Science Experiments for Teaching Laboratories

**NUCLEAR MEASUREMENT SOLUTIONS FOR SAFETY, SECURITY & THE ENVIRONMENT**

#### Energy vs. Counts

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10^3</td>
</tr>
<tr>
<td>500</td>
<td>10^4</td>
</tr>
<tr>
<td>1000</td>
<td>10^5</td>
</tr>
<tr>
<td>1500</td>
<td>10^6</td>
</tr>
<tr>
<td>2000</td>
<td>10^7</td>
</tr>
</tbody>
</table>

- CO-57
- CE-138
- CS-137
- Y-88
- CO-60
- CO-60
- SN-113
- HG-203

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**WWW.CANBERRA.COM**
Nuclear Science Experiments for
Teaching Laboratories

With a half century of experience in the nuclear measurements industry, CANBERRA is uniquely qualified to provide educational institutions with the tools for highly productive hands-on training in the fundamentals of nuclear physics through vocationally-relevant experiments.

CANBERRA offers turn-key solutions to set up and/or refurbish physics teaching facilities with cutting-edge digital technology. A relatively modest investment yields a flexible equipment configuration that can serve undergraduate and post-graduate university training in addition to in-house training for industrial users.

Experiment 8: Gamma-Ray Efficiency Calibration (shown below) demonstrates the procedure for measuring the efficiency of a NaI and a HPGe detector as a function of gamma-ray energy.
CANBERRA Lab Kits

CANBERRA has packaged a set of 12 experiments, focusing on various aspects of gamma-ray detection and analysis, which provides an understanding of basic principles to more complex nuclear physics applications.

All of these experiments can be executed with CANBERRA instrumentation and specialized ancillary equipment offered in two Lab Kits. (Please note that most of the recommended radioactive sources are not included and are readily available.) The Nuclear Science Experiments with Digital Electronics Laboratory Manual provides a step-by-step guide to performing the experiments. The Laboratory Manual is available at www.canberra.com/labkit, and unlimited copies may be printed as needed.

The experiments are built around CANBERRA's Osprey™ and Lynx® Digital Signal Analyzers. The versatility of these instruments enables the performance of fundamental experiments in high and low resolution gamma spectroscopy. Their advanced features allow for higher-level experiments, such as coincidence and anti-coincidence, with both hardware gating and event-by-event data collection.

The Osprey and Lynx are easy to use and feature highly-stable digital electronics, thereby providing the optimum solution for laboratory instruction. The devices are controlled with ProSpect™ Gamma Spectroscopy Software which includes a flexible security feature to ensure that the student is only presented with the functions required for the class. This increases the productivity of the training.
The Laboratory Manual and kits greatly simplify the purchase of equipment and implementation of these experiments (plus other experiments of your own design).

They can be used to create individual student workstations or a central demonstration station, depending on available space and budget. And, of course, lab expansion is just as simple as adding more kits as needs dictate.

**LABKIT-Basic**

**Starter kit for Experiments 1 to 5**
- Osprey Digital MCA
- ProSpect Gamma Spectroscopy Software
- 802 2x2 NaI Detector
- **LabKIT-Table**: Apparatus for many of the experiments, including an angular scattering table and base plate, NaI 2”x2” detector shielding, source collimation for LABKIT-SR-CS137, scattering pillar, and absorber holder.
- **LabKIT-Abs**: Sets of 4 generic absorber materials, including aluminum, copper, lead, and polyethylene.
- **LabKIT-SR-CS137**: 15 MBq (0.5 mCi) Cs-137 source capsule, for use with the LABKIT-Table assembly.

**LABKIT-Advanced**

**Supplement the starter kit to complete Experiments 6 to 12**
- LYNX MCA
- BE2825 HPGe Detector System
- LabSOCS Software
- 802-2x2 NaI Detector
- 2007P Preamplifier
- **LABKIT-SRCEHLD**: Set of Two HPGe Source Holders, including a fixed source holder for measurements at 25 cm and an adjustable source holder for measurements from 0 to 18 cm.
- **LABKIT-NAICOLL**: NaI 2” x 2” detector shielding for use with LABKIT-Table assembly.
- **RCP-10-Cable**: 10ft cable bundle including preamp, SHV-SHV, and two BNC-BNC cables.
The Laboratory Manual presents the following twelve experiments.

With LABKIT-Basic, students can perform experiments 1-5. To perform all twelve experiments, LABKIT-Basic and LABKIT-Advanced are required.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gamma-Ray Detection with Scintillators</td>
<td>In this introduction to gamma-ray detection, students will identify photoelectric effect, Compton scattering, and pair production in a spectrum and perform an energy calibration using known reference sources.</td>
</tr>
<tr>
<td>2</td>
<td>Counting Statistics and Error Prediction</td>
<td>Students will perform a series of background and gamma-ray measurements with a NaI detector and apply statistical principles to these measurements.</td>
</tr>
<tr>
<td>3</td>
<td>Gamma-Ray Absorption in Matter (Basic)</td>
<td>Students will measure the effective attenuation of a set of materials with varying densities and photon absorption cross sections.</td>
</tr>
<tr>
<td>4</td>
<td>Compton Scattering</td>
<td>Using the Compton Scattering table developed specially for this exercise, the principle of Compton scattering and the dependence on angular variation is demonstrated.</td>
</tr>
<tr>
<td>5</td>
<td>Half-Life Measurement</td>
<td>Students calculate the half-life of a short-lived nuclide using multi-channel scaling acquisition.</td>
</tr>
<tr>
<td>6</td>
<td>Signal Processing with Digital Signal Electronics</td>
<td>Using the built-in Digital Signal Oscilloscope feature of the LYNX MCA, students observe the effects of changing signal processing parameters using several different acquisition modes.</td>
</tr>
<tr>
<td>7</td>
<td>High-Resolution Gamma-Ray Spectroscopy with HPGe Detectors</td>
<td>Semiconductor gamma-ray detection is introduced and students compare HPGe resolution to NaI detector resolution.</td>
</tr>
<tr>
<td>8</td>
<td>Gamma-Ray Efficiency Calibration</td>
<td>Using both a NaI detector and an HPGe detector, the concept of detection efficiency is explored.</td>
</tr>
<tr>
<td>9</td>
<td>Gamma-Ray Coincidence Counting Techniques</td>
<td>Counting with multiple detectors correlated in time can yield incredible information about fundamental nuclear structures. In this experiment, students learn these techniques by acquiring and interpreting time-stamped list mode data for synchronized detectors.</td>
</tr>
<tr>
<td>10</td>
<td>Positron Annihilation</td>
<td>By using coincidence counting techniques and the Angular Correlation table, students explore the geometrical behavior of positron annihilation events.</td>
</tr>
<tr>
<td>11</td>
<td>Mathematical Efficiency Calibration</td>
<td>Mathematical modeling is increasingly used instead of source based efficiency calibration for improvement in cost, flexibility, and safety. In this experiment, students generate efficiency calibrations using CANBERRA’s LabSOCS efficiency calibration software and compare against traditional source based calibrations.</td>
</tr>
<tr>
<td>12</td>
<td>True Coincidence Summing</td>
<td>Students observe true coincidence summing and quantify the effect on observed count rate using LabSOCS mathematical efficiency software.</td>
</tr>
</tbody>
</table>
As you can see in this sample, the format of each experiment begins with the goal and the equipment required.

Each description includes the required steps together with the format of the data entry and the results. In some cases, the instructor may wish to produce his or her own laboratory script with this as a starting point.

**Experiment 1**

**Gamma-Ray Detection with Scintillator Detectors**

**Purpose:**
1. To demonstrate the use of a NaI scintillator detector and its response to gamma rays.
2. To demonstrate the three dominant gamma-ray interactions with matter.
3. To demonstrate energy calibration.

**Equipment Required:**
- **ProSpect:** ProSpect Gamma Spectroscopy Software
- **Detector:** Osprey Digital Tube Base MCA with connectors
- **802-2x2:** NaI Detector 2" x 2"
- **LABKIT-TA:** Teaching Laboratory Scattering Table Assembly
- **NaI Detector Shielding**
- **Radioisotope:** 137Cs button source 1 microcurie, ± 20% unc.
- **Radioisotope:** 60Co button source 1 microcurie, ± 20% unc.
- **Radioisotope:** 88Y button source 1 microcurie, ± 20% unc.

LEARN MORE

Please visit us at:
www.canberra.com/Labkit
for more information
### Theoretical Overview:

#### New gamma rays are produced

Radioactive nuclei decay by emitting either beta particles or alpha particles. After the decay, a new excited state in the daughter nucleus will usually decay by emitting a gamma ray. The energy level sequence and therefore daughter nucleus can be used to identify the nucleus. The energy levels and decay processes of $^{137}$Cs and $^{60}$Co are given in Figure 1-1. The terms beta decay and alpha decay are used to describe the processes by which the nucleus changes its charge.

#### NaI(Tl) detectors

Charcoal-activated sodium iodide detector, or NaI(Tl) detector, responds to the gamma ray by producing a pair of light flashes of light, or scintillation. The scintillation occurs when sodium iodide, excited by the energy of the gamma ray, is excited into a high-energy state known as a metastable state. This state produces a scintillation current pulse which contains the information of the gamma-ray energy. The first pulse from the scintillator is very small and is amplified in a 10 stage by a series of devices called a preamplifier. A second pulse is then created and detected by a more sensitive detector, such as a photomultiplier tube which converts the scintillation into an electrical pulse. The first pulse from the NaI(Tl) is protected from further excitation in a detector, which also serves as a concentrating excitation for the entire crystal/photomultiplier tube.

A scintillator is shown in Figure 1-2.

#### Photoelectric effect and Compton scattering

The actual energy deposited depends upon the angle of incidence on the scintillation detector. The photopeak shown that only photons have energies in a range known as the Compton edge. The Compton edge is the energy at which the photopeak begins to fall off.

The gamma ray does not re-emit the scintillator and scintillator efficiency as its maximum energy through the photoelectric effect, then its full energy will be deposited in the full-energy peak ($511$ keV for $^{11}$In). This is more likely for larger crystals.

Pair production can occur when the gamma ray energy is greater than $1022$ keV and is a significant process of gamma decay ($>20$ keV). This process produces a pair of gamma photons and two electron-positron pairs, each containing energy equal to the initial photon energy minus the rest energy of the electron, equal to $511$ keV. The energy given to the detector is called the double-gamma peak.

#### Gamma-ray interactions with matter

There are three distinct gamma-ray interactions with matter:

1. Photoelectric effect
2. Compton effect
3. Pair production

The photoelectric effect is a photoelectric interaction between a low-energy gamma-ray photon and a material. In the process, the photoelectric effect occurs when the energy of the incident photon is such that it is completely absorbed by an electron in the material, resulting in the emission of the high-energy electron from the atom. The photon is absorbed and the electron is ejected from the atom.

The Compton effect is the process by which a low-energy gamma-ray photon scatters off an electron in matter. In this process, the photon interacts with an electron in the material, and the photon undergoes a scattering event, resulting in the emission of a low-energy gamma-ray photon and a material. In this process, the photon is scattered and the electron is ejected from the atom.

The pair production process is the process by which a high-energy gamma-ray photon interacts with matter, producing a pair of gamma photons and two electron-positron pairs, each containing energy equal to the initial photon energy minus the rest energy of the electron, equal to $511$ keV. The energy given to the detector is called the double-gamma peak.

#### Gamma-ray detection with scintillator detectors

The NaI(Tl) crystal is protected from the moisture in the experiment. The NaI(Tl) crystal is protected from the moisture in the experiment. The NaI(Tl) crystal is protected from the moisture in the experiment.