Portable Radiation-Detection Instruments for Distinguishing Nuclear from Non-nuclear Munitions

Author: Paul E. Fehlau

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Los Alamos National Laboratory
Los Alamos, New Mexico 87545
PORTABLE RADIATION-DETECTION INSTRUMENTS FOR DISTINGUISHING NUCLEAR FROM NON-NUCLEAR MUNITIONS

Paul E. Fehlin
Los Alamos National Laboratory, Los Alamos, New Mexico 87545

Abstract
The emission of gamma rays and fast neutrons by nuclear materials provides a simple means for distinguishing between real nuclear munitions and other assemblies that are non-nuclear, such as nuclear-explosive-like test assemblies (NELAs) and conventional munitions.

The presence or absence of significant numbers of neutrons and characteristic plutonium gamma rays are distinguishing attributes for plutonium munitions. The presence of energetic gamma rays from 238U daughters, if present in sufficient number, is a distinguishing attribute for highly enriched uranium munitions. Some portable instruments are being developed for verifying that munitions are or are not nuclear, and others are already commercially available. The commercial ones have been evaluated for pre-flight non-nuclear verification of NELAs in Air Force flight tests.

I. INTRODUCTION

Radiation detection provides a convenient means to test one or more attributes of a nuclear munition to verify that it is consistent with expectations. For example, the emission of penetrating, characteristic gamma rays and neutrons from nuclear munitions containing high burnup plutonium can be used to distinguish them from either conventional munitions or test munitions that are non-nuclear, nuclear-explosive-like assemblies (NELAs). Similarly, munitions containing highly enriched uranium (HEU) may be distinguished from NELAs by measuring penetrating gamma rays, provided that sufficient amounts of the isotope 234U and its daughters are present in the HEU. Some form of background may be present for any of these radiations, but the backgrounds are usually low.

II. NUCLEAR MATERIALS RADIATION

Almost all nuclear materials are radioactive and emit one or more types of radiation, including neutron, alpha, and beta particles and gamma rays and shielding, x-rays, and gamma rays.

The radioactive emissions penetrate nuclear or chemical materials with different lengths of effectiveness. Alpha and beta particles and low energy photons, for example, are readily attenuated making them suitable only for verifying a material type such as verifying that bare, depleted uranium parts are not in fact enriched. Neutrons and gamma rays from plutonium are more penetrating and are available as a verification signature subset of an assembled nuclear munition.

Los Alamos plutonium contains about half of its energy in a penetrating, characteristic gamma ray band between 300 and 450 keV. HEU, however, emits far fewer neutrons, and its 185-keV gamma rays have almost no signature. Other uranium isotopes that may be present in HEU have decay chains that lead to emission of penetrating gamma rays, for example, 234U at 94.6 and 2.6 MeV and 235U at 70 and 1001 keV. However, for HEU, the intensity of these higher energy gamma rays may be relatively low, and large detector and long counting times may be needed to detect them. Another factor for these radiations is that they are often present in natural backgrounds, hence, some them for non-nuclear verification may give less confidence in the result than would other methods.

III. PORTABLE INSTRUMENTS

Portable instruments for distinguishing munitions can be as basic as a simple alpha detector used to measure the surface alpha-emission rate of bare uranium, or as complex as a portable multi-channel analyzer (MCA) and high purity germanium (HPGe) detector used to measure high energy uranium daughter radiations from an assembled munition. The middle ground is a class of portable, hand held instruments that are typically small, battery powered, and have internal radiation detectors for ruggedness and microprocessor control for versatility. These instruments can be readily specialized for verifying that plutonium is either present or absent in a munition.

The specialized instruments use either a neutron-sensitive radiation detector to detect plutonium contents or a gamma-ray detector and firmware to strip and characterize plutonium region of interest (ROI) from a broad gamma-ray spectrum.

The sections that follow give examples of the following: neutron detection instruments based on a multi-channel proportional counter fast neutron detectors and gamma-ray verification instruments that use the 185 and 375 keV gamma-ray region as a signature for the presence of plutonium.
IV. NEUTRON INSTRUMENTS

A. Thermal Neutron Detectors

Thermal neutron detectors are used to discriminate between real and other munitions because they can be used to measure the neutrons in a mixed neutron and gamma-ray radiation field. However, the neutrons emitted by plutonium are fast neutrons so a polyethylene detector moderator is used to provide thermalization.

The two types of thermal neutron detectors in use are scintillation detectors based on enriched lithium (Li-6), and 9Be proportional counters. In these detectors, the gamma-ray response can be suppressed using pulse-height discrimination, as illustrated (Fig. 1) by the pulse height spectra for enriched-lithium scintillators. The moderated 6LiEur-scintillator response to a 252Cf fast-neutron source in (Fig. 1a) has a distinct peak region at the right from thermal and epithermal neutron interactions and a low-energy continuum region at the left from gamma-ray interactions. The two regions can be separated at the threshold of the neutron region by a pulse-height discriminator that will exclude gamma-ray pulses from environmental sources and other materials (such as depleted uranium) that may be found in NELAs.

The second scintillator in Fig. 1 is BC 7023, which comprises an enriched-lithium compound mixed with a ZnS(Ag) phosphor and encased in transparent plastic. Its pulse height spectrum (Fig. 1b) is a less intrusive one that does not give spectral information in either the gamma-ray or neutron regions. The spectrum shows only a gamma-ray spike at very low energy and a diminishing continuum of neutron pulses over most of the range. A pulse height discriminator set just above the gamma-ray spike effectively separates the gamma-ray response from the neutron response. The situation for He is much the same as Li, and a discriminator that excludes any gamma-ray response.

B. Hand-Held Neutron Verification Instruments

Two manufacturers have commercially produced a hand-held neutron verification instrument originally developed at Los Alamos for non-nuclear verification of NELAs. The Jornar Systems 1HH-22 and the TSA System’s NNV-470 both use a moderated 6LiEur scintillator and pulse-height discrimination to detect fast neutrons. The detector is moderated by surrounding it with horseshoe-shaped polyethylene and an acrylic light pipe (Fig. 2). Because munitions may provide some moderation, the moderator is thin in the most likely source direction, below the instrument’s base.

Both the Jornar and TSA instruments were originally developed as prototypes for both immediate verification that NELAs do not contain plutonium. The NNV-470 was selected for further development and now includes features that address the human factors involved in prelaunch, non-nuclear verification of NELAs carried by aircraft. These features include a large folding handle, membrane switches, and display illumination to facilitate using the instrument in a cold, dark environment by a person wearing foul weather gear. A Figure 3 shows the instrument being used, under less rigorous circumstances, by an operator from Sandia National Laboratories, the lead laboratory for implementing routine military use of the instrument. Besides the munition measurement in progress in Fig. 4, both background measurements and before and after radioactive source checks of the instrument are included in the verification procedure.

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Footnotes:

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Fig. 1: Neutron reactions in the 6LiEur scintillator at a produce a peak region at the right, and gamma-ray interactions lead to a continuum of decreasing pulse heights at the left. In BC 7023, neutrons give the broad continuum, and gamma rays simply produce a spike at the extreme left.

Fig. 2: The moderator and light pipe in the neutron verification instrument surround a 6LiEur scintillator, which has an active volume that is 2.5 cm in diameter and 0.2 cm thick. The photomultiplier is a Hamamatsu type R1924 that is 2.5 cm in diameter and 7 cm long.
Fig. 5. Last minute, preflight verification of NELAs uses 20 s measurements and requires just a few minutes overall when carried out with the hand-held neutron verification instrument.

C. Field Experience with the Hand-Held Neutron Instruments

During one year of field use of the neutron verification instruments by Sandia operations, three 20 s measurements were used at each step in the verification procedure. After each 20 s measurement, the instruments sound a beeper, display the result, and begin a new measurement. Reference 1 reviews the measurement results obtained during the year, including reference measurement results for real munitions.

Fig. 4: The real munition results with the NNV 470 are proportional to similar measurement results from routine verifications carried out with a less portable MCA and shielded neutron assays probe (SNAP) detector [4] at the Pantex plant. The approximately four times higher intrinsic efficiency of the SNAP detector, estimated at 10% in Ref. 4, allows the plant to shorten their measurement times to 10 s. The corresponding measurement results for NELAs during prelaunch, nonnuclear verification tests were close to background and at least a factor of 10 below results for the real munition.

D. Prototype Instruments for Treaty Verification

Besides the standard NNV 470, two prototype hand-held instruments using the less intrusive and somewhat less sensitive 8800 202 scanner have been produced as prototypes for possible application to arms control verification. These instruments achieve the same intrinsic detection efficiency as the NNV 470 for bare sources by using a larger 8 cm diameter detector for the 8800 202 scanner to give it about twice the area of the standard 470 detector. However, the 8800 202-detector intrinsic efficiency for moderated sources is still expected to be somewhat lower than the original detector.

One of the prototype instruments appears identical to the original NNV 470, but is slightly heavier at 15 kg. The second prototype has a much different appearance because its detector assembly is mounted at the end of an extendable pole. The extended detector provides measurement access to munitions that, for whatever reason, are not within arm's reach with the original instrument.

A much different prototype arms control instrument for detecting neutron from munitions more than an arm's length away is a portable, self-contained, 30 kg, briefer counting system that uses moderated 8800 202 proportional counter for a detector. The 5 cm-diameter, 25 cm active length, proportional counters are mounted in hemispherical polyethylene moderators and have a high count gas pressure 80% He/20% Ne. These design features, described further in Ref. 5, provide good detector response to both bare and moderated neutron sources. The briefer uses a Motorola 6801 microprocessor, a large LCD, and a 8 k byte mass storage RAM card to permit u to search for neutron sources, verify munitions, or monitor and display time histories of neutron intensity.

V. GAMMA RAY INSTRUMENTS

A. Hand Held Gamma Ray Verification Instruments

Gamma ray verification instruments for plutonium munitions must reliably determine the energy of detected gamma rays and record their number for later analysis. The neutron intensity in a characteristic gamma ray ROI can then be used to distinguish between real weapons and NELAs. To be effective, the radiation detector must be very stable. The Baltimore HH-01 verification instrument uses a NaI(Tl) detector that is calibrated by montone only from the 208 Tl time scales (1110 reference light source in a cell).
By placing the 11-D pulse height, the instrument can determine the amount of lead material that may be needed. This non-radioactive technique to stabilization makes the instrument more transportable than if a radioactive light pulser were used. During tests of the first JHH-401 instruments, the 11-D stabilization maintained a 102-keV gamma ray pulse within 2% of its mean pulse height over a temperature range of 8 to 40 °C. This type of instrument is now commercially available from Jomar with the model number JHH-31.

The HHI-401 and JHH-31 instruments use a 330 to 450-keV plutonium ROI and two narrower regions centered on 330 and 450 keV for verification measurements (Fig. 5). The net peak intensity for the central region is obtained by using the two adjacent narrow regions to estimate the amount of underlying Compton-scattered radiation that must be subtracted. The instrument makes simultaneous 20-s-long measurements in each region, then calculates the net intensity in the central region and displays it. The net intensity for real munitions and NELAs can be markedly different, although, the differences are not always as great as with neutron detection. Hence, when gamma-ray verification is used for plutonium munitions, it is not unusual for neutron verification to be used as well.

![Fig. 5. The 330 to 450 keV peak region between the shaded regions is characteristic of plutonium. The shaded regions are used to estimate the underlying Compton-scattered radiation, in this case from a 0.5 cm thick depleted uranium plate shielding the plutonium.](image)

**R Portable Gamma Ray Verification Instruments**

Portable MCAs and radiation detectors are the only choice, at present, for verifying that assembled munitions contain only HEU by measuring 137Cs daughter gamma rays. Of the small, commercial MCAs and a large NaI(T1) or a HPGe detector are used. The more intense 106-MeV gamma ray usually penetrates well enough to offer shorter measurement times than for the 0.6-MeV gamma ray. However, the intensity of either one depends on T being present in the HIU. For domestic applications, a representative sample of the real munition can be measured, and the average result is then available for determining decision thresholds for NELA verification. The arm-control application may not provide the same degree of assurance that more gamma rays are present in real munitions.

More portable, MCA-based instruments are being developed for verification applications. One commercial prototype is the TSA Systems MCA-465, just now appearing on the market. As yet, the MCA-465 is still being evaluated and any problems discovered will have to be corrected before it becomes a useful product. The concept behind the MCA-465 is a hand-portable, battery-operated MCA that uses either an internal or external NaI(T1) detector for identifying gamma-ray emitting materials. Besides viewing spectra on an LCD, the operator can store up to 14 spectra for later transmission to a PC. Calibrating the detector is done by using a reference source and the calibrate mode to observe and move a selected gamma-ray peak to a desired channel by means of keyboard input. The nominal conversion gain is 8 keV/channel. ROIs can be set by the user, and the counts falling within each ROI can be displayed.

Another portable MCA instrument prototype is being developed for treaty verification applications where the operator needs very little information other than a yes or no. The instrument is the NAVI and is described elsewhere in these proceedings [7]. Its unique features include (11) its ability to identify either of two gamma-ray calibration sources and use three peaks from the spectrum to automatically calibrate the MCA, and (12) its ability to make its own determination of when it has sufficient data to make a decision about whether or not plutonium is present.

**VI. CONCLUDING REMARKS**

Portable radiation-detection instruments can be a useful and convenient means for distinguishing between nuclear and non-nuclear munitions. Their usefulness is best assured when close approach to the munition is allowed for verification and an opportunity is provided beforehand to establish decision thresholds from measurements of representative real munitions. Furthermore, easily and effectively using the instruments rests on the user being trained in their use and being given sufficient opportunity to maintain proficiency by practicing the verification procedures. Scheduled instrument maintenance is also necessary and should include calibration, measurements of standard sources to confirm normal operation, and a review of accumulated verification results for measurement control.

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