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

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PORTABLE RADIATION-DETECTION INSTRUMENTS FOR DISTINGUISHING NUCLEAR FROM NON-NUCLEAR MUNITIONS

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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 ^{232}U 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 low 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[a]) may be distinguished from NELAs by measuring penetrating gamma rays, provided that sufficient amounts of the isotope ^{232}U and [illegible] daughters are present in the HEU. Some form of background may be present for any of these radiations, but the backgrounds are [illegible] low.

II. NUCLEAR MATERIALS RADIATION

[illegible] all nuclear materials are radioactive and emit one or more types of radiation, including neutron, alpha, and beta particles and photon (bremsstrahlung, x rays, and gamma rays). The radioactive emissions penetrate nuclear or encapsulating materials with differing degrees of effectiveness. Alpha and beta particles and low energy photons, for example, are readily attenuated, making them suitable only for [illegible] a material type, such as verifying that bare, depleted uranium parts are not highly enriched. Neutrons and gamma rays from plutonium are more penetrating and are available as a verification signature [illegible] assembled nuclear munition.

Low-burnup plutonium contains about [illegible] Pu isotope and emits both penetrating fast neutrons and [illegible] penetrating, characteristic gamma rays in the energy region between 330 and 450 keV. HEU, however, emits few neutrons, and its 185-keV gamma rays have limited penetration. Other uranium isotopes that may be present in HEU [illegible] have decay chains that lead to emission of penetrating gamma rays, for example, ^{232}U at 0.58 and 2.6 MeV and ^{238}U at 766 and 1001 keV. However, for HEU, the intensity of these higher energy gamma rays may be relatively low, and large detectors 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, using 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 munition parts, or they can be as complex as a portable multichannel 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 often are 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 specific radiation detector to detect plutonium neutrons or a gamma ray detector and firmware to strip a characteristic plutonium region of interest (ROI) from a broad gamma ray spectrum.

The sections that follow give examples of the [illegible] neutron verification instruments based on [illegible] proportional counter fast neutron detectors and [illegible] gamma ray verification instruments that use the [illegible] gamma ray region as a signature for the presence of plutonium.

[a] [illegible] HEU [illegible]

IV. NEUTRON INSTRUMENTS

A. *Thermal Neutron Detectors*

Thermal neutron detectors are used to discriminate between real and other munitions because they can predominantly 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 (^{6}Li), and ^{3}He proportional counters. In these detectors, the gamma-ray response can be suppressed by using pulse-height discrimination, as is illustrated (Fig. 1) by the pulse height spectra for enriched-lithium scintillators. The moderated ^{6}LiI(Eu)-scintillator[2] response to a ^{252}Cf 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 702[1], 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 ^{3}He is much the same [illegible] and a discriminator [illegible] ly excludes any gamma ray response.

Fig. 1 Neutron reactions in the ^{6}LiI(Eu) scintillator (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 702 (b), neutrons give the broad continuum, and gamma rays simply produce a spike at the extreme left.

B. *Hand-Held Neutron Verification Instruments*

Two manufacturers have commercially produced a hand-held neutron verification instrument originally developed [2] at Los Alamos for non-nuclear verification of NELAs. The Jomar Systems[4] HH-22 and the TSA Systems[5] NNV-470 both use a moderated ^{6}LiI(Eu) 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 Jomar and TSA instruments were originally developed as prototypes for last minute 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. 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. 3, both background measurements and before and after radioactive source checks of the instrument are included in the verification procedure.

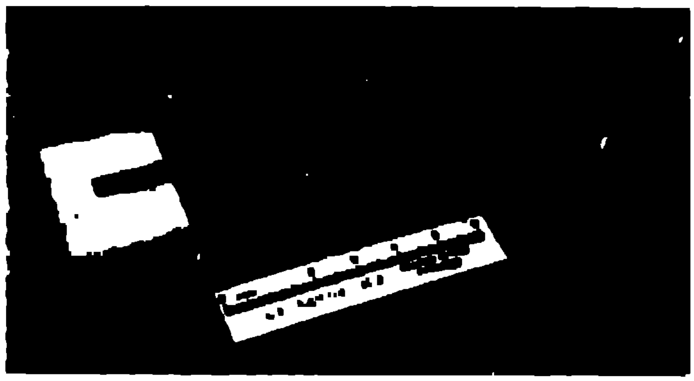

Fig. 2 The moderator and light pipe in the neutron verification instrument surround a ^{6}LiI(Eu) scintillator, which has an active volume that is 2.5 cm in diameter and 0.2 cm thick. The photomultiplier is a Hamamatsu type R[illegible] that is 2.5 cm in diameter and 7.5 cm long.

[1] Solon Technologies, Inc., Solon, Ohio [illegible]
Bicron Corp., Newbury, Ohio 44065

[2] Jomar Systems, Inc., Los Alamos, NM 87544
TSA Systems, Ltd., Longmont, CO 80501

Fig. 3. 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.

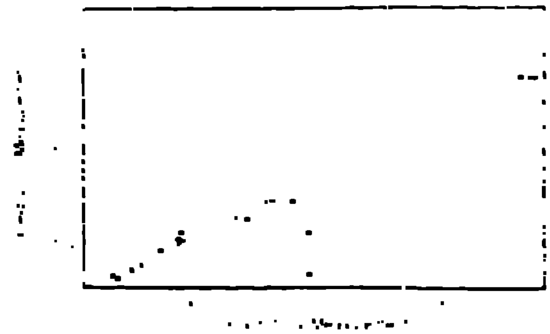

Fig. 4. The NNV-470 field results (y axis, 20-s measurements) for real munitions show good proportionality with the corresponding Pantex confirmation results (x axis, 10-s measurements). The outlying open symbol points are for munitions in shipping containers or launch vehicles.

C. Field Experience with the Hand-Held Neutron Instruments

During one year of field use of the neutron verification instruments by Sandia operators, 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 3 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 assay 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, non-nuclear verification were all 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 that are less intrusive and somewhat less sensitive (BC-702 scintillator) have been produced as prototypes for possible application to arms control verification. These [illegible] achieve the same intrinsic detection efficiency as the NNV-470 for bare sources by using a layer [illegible] cm [illegible] for the BC-702 scintillator to give it about twice the area of the original [illegible] scintillator. However, the BC-702-detector intrinsic efficiency for moderated sources is [illegible] 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 1.5 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 an arm's reach with the original instrument.

A much different prototype arms control instrument for detecting neutrons from munitions more than an arm's length away is a portable, self contained, 10 kg, briefcase counting system that uses moderated ^{3}He proportional counters for its detector. The 5 cm-diam, 25 cm active length, proportional counters are mounted in hemi-cylindrical polyethylene moderators and have a high counter gas pressure ([illegible]). These design features, described further in Ref. 5, provide good detector response to both bare and moderated neutron sources. The briefcase uses a Motorola 68HC11 microprocessor, a large LCD, and a 512 kbyte mass storage RAM card to permit it 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 in weapons must reliably determine the energy of detected gamma rays and record their number for later analysis. The net 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 [illegible] HHH-01 verification instrument uses a NaI(Tl) [illegible] that is stabilized by monitoring output from [illegible] diode (LED) reference light source [illegible]

By gauging the LED pulse height, the instrument can determine the amount of gain adjustment that may be needed. This non-radioactive approach to stabilization makes the instrument more readily transportable than if a radioactive light pulser had been used. During tests of the first HHH-01 instruments, the LED stabilization maintained a 662-keV gamma-ray pulse within 2% of its mean pulse height over a temperature range of 8 to 40° C [6]. This type of instrument is now commercially available from Jomar with the model number JHH-31.

The HHH-01 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.

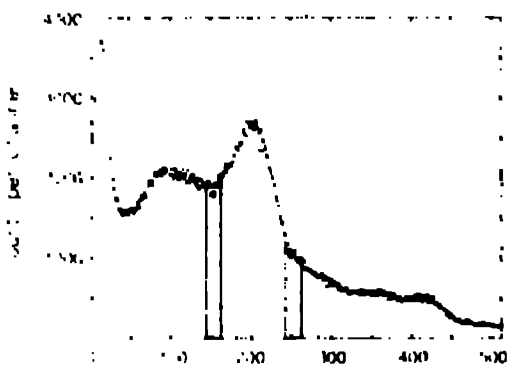

Fig. 5. The 330- to 450-keV peak region between the shaded regions is characteristic of plutonium. The shaded regions are used to estimate the underlying Compton scattered radiation, in this case from a 0.5 cm thick depleted uranium plate shielding the plutonium.

B. 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 ^{232}U daughter gamma rays. One of the small, commercial MCAs and a large NaI(Tl) or a HPGe detector are used. The more intense 0.86-MeV gamma ray usually penetrates well enough to offer shorter measurement times than for the 2.6-MeV gamma ray. However, the intensity of either one depends on ^{232}U being present in the HEU. For domestic applications, a representative sample of the real munitions can be measured, and the average result is then available for determining decision thresholds for NELA verification. The arms-control application may not provide the same degree of assurance that these 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(Tl) 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 simple yes or no. The instrument is the NAVI and is described elsewhere in these proceedings [7]. Its unique features include (1) its ability to identify either of two gamma-ray calibration sources and use three peaks from the spectrum to automatically calibrate the MCA, and (2) 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.

VII. ACKNOWLEDGMENTS

Many individuals in the Advanced Nuclear Technology Group at Los Alamos and present and past members of the Stockpile Evaluation organization at Sandia have provided valuable assistance in developing the instruments and procedures described here. The instrument manufacturers and DOE, Sandia, and many DoD representatives have also

provided valuable service toward achieving many of the goals involved in implementing a program of non nuclear verification.

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