



NUCLEAR FORENSICS INTERNATIONAL
TECHNICAL WORKING GROUP

ITWG GUIDELINE

ON IN-FIELD APPLICATIONS OF HIGH-
RESOLUTION GAMMA SPECTROMETRY FOR
ANALYSIS OF SPECIAL NUCLEAR MATERIAL



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ITWG Guidelines are intended as consensus-driven best-practices documents. These documents are general rather than prescriptive, and they are not intended to replace any specific laboratory operating procedures.

1. INTRODUCTION

This document describes the use of gamma spectrometry in field conditions as a non-destructive tool for the characterization of nuclear material. A general description of gamma spectrometry and its use for nuclear security and nuclear forensics applications is given in the ITWG Guideline: “High-resolution gamma spectrometry – General overview” [1]. The use of gamma spectrometry in the laboratory as a non-destructive tool for the characterization of nuclear material is described in the ITWG Guideline: “Laboratory applications of high-resolution gamma spectrometry for analysis of special nuclear material” [2].

In-field use of gamma spectrometry for nuclear security and nuclear forensics purposes provides a means to assess the threat posed by interdicted radioactive/nuclear (RN) material. This information can then be used to determine how the material can best be transported to a safe storage location or to a nuclear forensic laboratory for detailed analysis. For the purpose of this document, it is assumed that, prior to the commencement of gamma-spectrometric measurements:

- the RN material has been detected;
- the gamma and neutron dose rates are being monitored;
- contamination control measurements are in place;
- appropriate radiation protection measures have been undertaken; and
- appropriate measures have been put in place to secure the site.

2. USE FOR NUCLEAR FORENSICS

For on-site applications, high-resolution gamma spectrometry is mostly used to quickly identify radioactive material and obtain a rough idea about the isotopic composition of nuclear material. From the point of view of on-site identification techniques and handling of the material, usually four main categories are considered:

- 1 Naturally Occurring Radioactive Material (NORM),
- 2 Medical isotopes,

- 3 Industrial isotopes,
 - 4 Special nuclear material,
- as well as any mixture of these four.

For the purposes of nuclear forensic investigations, IAEA Nuclear Security Series No. 2, “Nuclear Forensic Support” [3] defines the categories of nuclear and other radioactive material as follows:

- 1 Unirradiated direct use material.
- 2 Irradiated direct use material.
- 3 Alternative material.
- 4 Indirect use material.
- 5 Commercial radioactive sources.

In some cases, specific radioisotopes can be identified using hand-held gamma spectrometers with built-in low-resolution or medium-resolution gamma detectors (based on NaI, LaBr₃, CdTe or CdZnTe crystals). These hand-held spectrometers typically employ algorithms to automatically identify radioactive material. They are simple to use and can be operated by first responders (e.g., customs and police officers, fire fighters) to detect, localize and perform initial identification of potentially illicit radioactive material.

For more reliable identification, radiation experts, such as those of a Mobile Expert Support Team (MEST), can be called in to further categorize the material using a portable, high-resolution gamma spectrometer and dedicated gamma spectrum analysis software. For this purpose, high-purity germanium (HPGe) detectors are generally used, due to their good energy resolution in the energy range around 100 keV and acceptable counting efficiency at higher energies. These detectors can either be laboratory-based HPGe spectrometers with liquid-nitrogen cooling that are transported to an in-field location or more compact battery-operated HPGe detector systems that use electrical cooling and have built-in spectrum analysis algorithms. Since laboratory-based gamma spectrometers are usually portable as well, these may also be used in the field; however, there are inherent difficulties in operating a laboratory instrument in field conditions, including securing a source of liquid nitrogen, having a reliable power source, handling a fragile laboratory instrument, etc. The compact, battery-

operated HPGe detector systems have a great advantage in terms of ease of use, compactness, and the speed with which they can provide meaningful results. The accuracy and precision of the isotopic composition reported by these systems is not as good as with state-of-the-art laboratory systems, but, in most cases, are sufficient for performing in-field categorization of the material. One important feature to consider is the ability to use the HPGe detector remotely via a cable or a wireless connection, depending on the details of the deployment (e.g., to categorize material in an area with a higher dose rate or in order to determine the threat posed by a potential Radiological Dispersal Device or “dirty bomb”).

The radiation protection of the emergency workers must be considered according to national regulations and all radiation doses recorded. The radiation doses for the MEST and other deployed forces should be kept as low as reasonably achievable (ALARA) during the measurements.

Every measurement should be documented with the location (including GPS coordinates if possible), date, time, equipment used, and measured dose rate. Also, a sketch of the experimental arrangement (including the distance to the sample) is helpful. A pre-printed protocol in the form of a questionnaire can help the MEST members document vital information.

3. SAMPLE REQUIREMENTS

Items analyzed on-site by gamma spectrometry can have any physical shape and chemical composition. Items are usually analyzed as a whole, without sub-sampling. Typically, on-site measurements are taken for approximately 10-20 minutes to obtain enough information to categorize the material; such short counting times will, of course, reduce the precision of the measurements due to counting statistics. To improve the counting statistics, any unnecessary shielding between the detector and the sample should be removed. The thickness of shielding and the distance between the detector and the investigated item should be optimized in such a way as to achieve a compromise between count rate and detector dead time, resulting in the best counting statistics within the available measurement time.

If possible, the investigated item should be moved away from any other sources of radiation present, and/or

collimation should be used to ensure that only the item of interest is in the field of view of the detector. If more sources are to be categorized, they should be categorized individually.

4. PRO'S AND CON'S OF THE TECHNIQUE

Pro's:

- Fully non-destructive method, preserving forensic evidence.
- Item analysis without dismantling the item.
- Minimal or no sample preparation requirements.
- Portability.
- Fast results available in the field.
- Relatively inexpensive equipment compared to destructive techniques. The operating costs are also low. A high-resolution (HPGe-based) gamma spectrometry system costs typically between 60,000 – 100,000 Euro, depending on detector type and additional components.

Con's:

- For high-resolution gamma spectrometers, detector cooling is needed: liquid nitrogen or electrical cooling.
- The precision is often less than the precision of destructive techniques (the standard deviation for a given measurement result using high-resolution gamma spectrometry will typically be higher).
- With present-day commercial gamma spectrometers it is not possible to directly derive information on ^{242}Pu from the measured spectrum. Isotopic correlations have to be used to estimate the ^{242}Pu content of the investigated items. For Pu with high ^{242}Pu content, this causes a large uncertainty in determining the Pu isotopic composition. Note, however, that by combining gamma spectrometry with two other non-destructive methods, calorimetry and neutron coincidence counting, it is possible to derive the ^{242}Pu content in a fully non-destructive way.

- Due to on-site limitations (e.g. relatively short spectrum collection times) and due to the inability to fully control the measurement conditions on-site, the accuracy and precision of in-field measurements is typically lower than that in a laboratory setting.

5. FAQ – COST, DO’S AND DON’T’S, COMMON MISTAKES

How much does a portable gamma spectrometry system cost?

- Compact, hand-held, low-resolution spectrometers (Radiolotope Identifiers) cost between 16,000 – 30,000 Euro
- Compact, portable high-resolution (electrically cooled HPGe-based) spectrometers cost typically about 70,000-100,000 Euro.
- Portable (but not compact) spectrometers can be assembled from separate parts, resulting in a system cost which is roughly 50-60% of the above costs.
- For detectors that are cooled by liquid nitrogen, the cost of the liquid nitrogen supply should be considered. If the detector is to be kept at operating temperature all of the time, then an automated liquid nitrogen filling system and additional work safety measures could be cost effective.
- The cost of suitable calibration sources and their registration and storage should be included.

How reliable are various gamma spectrometers in detecting nuclear material “masked” by the radiation of another radioactive source?

- Low resolution (NaI and LaBr3) spectrometers often fail to correctly identify nuclear material masked by another radioactive source emitting similar gamma energies (the “masking limit” is very low). Medium resolution spectrometers (CdTe and CdZnTe) have a better success rate, while high-resolution gamma spectrometers (HPGe) can identify nuclear material in most masking scenarios (the “masking limit” is quite high).

How long does it take to cool down a warm high-resolution detector, before it can be used in the field?

- For standard liquid-nitrogen cooled systems at least 4-6 (but preferably more) hours of cool-down time is recommended. These detectors can be kept cold for days without refilling the liquid nitrogen.
- For some new portable, liquid-nitrogen cooled HPGe detectors a cool-down time of two to six hours is specified by the manufacturers. Once cold and filled with liquid nitrogen, they can be kept cold for ~20 hours up to three days (depending on LN2-storage volume) without refilling.
- State-of-the-art compact, electrically cooled systems can reach their operating temperature within about three to four hours.
- To be on the safe side, detectors to be used in the field should always be kept at operating temperature, in order to be able to carry them on-site immediately once analysis is required.

How long does it take to categorize nuclear material by high-resolution gamma spectrometry on-site?

- Usually not more than 15 minutes (plus a background measurement). For a first evaluation of the radiological situation by the MEST, typically around 30 minutes are required.

Common mistakes

- HPGe detectors tend to lose liquid nitrogen during transport, so the level of filling should be checked before, and after, transport (e.g. via weighing).
- The temperature of the HPGe detector must be checked before a voltage bias is applied. In most detectors this occurs automatically.
- The function of the HPGe detector (both liquid nitrogen and electrically cooled) should be checked regularly (ideally on a weekly basis for a detector that is to be used in the field). The calibration of the detector should also be checked as part of the QA for the equipment. For in-field use, it may be necessary to take calibration sources into the field.

- Due to the fact that low energy gamma radiation can be shielded more easily compared to high energy gamma radiation, it is possible that, for a given radionuclide, low energy gamma lines will be “missing” in the spectrum obtained by a HPGe detector. In this case, care should be taken when interpreting results from the automatic analysis of the spectrum. In all cases, it is recommended to view the spectrum to check for this kind of effect and other effects that can influence the automatic analysis software.

6. REFERENCES

1. ITWG Guideline: “High-resolution gamma spectrometry – General overview.”
2. ITWG Guideline: “Laboratory applications of high-resolution gamma spectrometry for the analysis of special nuclear material.”
3. IAEA Nuclear Security Series No. 2, Nuclear Forensic Support, International Atomic Energy Agency, Vienna, 2006. Also available online at : http://www-pub.iaea.org/MTCD/publications/PDF/Pub1241_web.pdf.

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