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Gamma Spectrometric Discrimination of Special Nuclear Materials

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Abstract

This report presents details pertaining to an exercise conducted as part of the NKS-B programme using synthetic gamma ray spectra to simulate the type of data that may be encountered in the interception of material potentially containing special nuclear materials. A range of scenarios were developed involving sources that may or may not contain special nuclear materials. Gamma spectral data was provided to participants as well as ancillary data and participants were asked, under time constraint, to determine whether or not the data was indicative of circumstances involving special nuclear materials. The situations varied such that different approaches were required in order to obtain the correct result in each context. In the majority of cases participants were able to correctly ascertain whether or not the situations involved special nuclear material. Although fulfilling the primary goal of the exercise, some participants were not in a position to correctly identify with certainty the material involved, Situations in which the smuggled material was being masked by another source proved to be the most challenging for participants.

Key words

Nuclear smuggling, gamma spectrometry, special nuclear material, identification

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Gamma Spectrometric Discrimination of Special Nuclear Materials (GASMAT).

Final Report from the NKS-B Project GASMAT (Contract: AFT/B 12/1).

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1. Introduction

International concern with respect to the illicit trafficking of nuclear materials first manifested itself in the early 1990s as a result of a number of seizures of highly enriched uranium and has grown in recent years. Recent incidents in and subsequent concerns expressed by a number of countries as to the availability of special nuclear materials to criminal entities clearly demonstrates the current need for effective technical response capabilities on the national level. In the post- September 2001 world, growing governmental and public concern as to nuclear and other radioactive materials falling into the wrong hands precipitated states taking a range of precautions including improvements in emergency preparedness, installation of border and other radiation detection systems and the equipping of personnel from a variety of agencies (customs, police, etc) with radiation detection capabilities. Although the interdiction of special nuclear materials (for the purpose of this document – plutonium (excepting Pu with >80 ^{238}Pu), ^{233}U or materials enriched to greater than 20% ^{235}U, fissile material) will ultimately most probably involve international authorities or external technical assistance, initial analyses performed on interdicted material will occur in the vast majority of cases in the country in which the material is seized, at which point the decision will be made as to whether the material in question is actually special nuclear material or something more innocent. These analyses will most likely be conducted by either (or both) the first responder (be it police, customs, security etc) or a "reach back" entity such a national radiological institute or similar. False positives and false negatives for the interdicted material (with respect to its being special nuclear material or not) may be generated by either (or both) the first responder or the subsequent national laboratory. Such misidentification serves to erode confidence (both public and otherwise) in the authorities abilities, cause unnecessary delays, expense and problems and in the worst case can result in the obvious security implications should interdicted nuclear material be misclassified as something innocuous. The vulnerabilities inherent in the first responder classification have been thoroughly addressed in a number of large scale initiatives – particularly the IAEA Coordinated Research Project "Improvement of Technical Measures to Detect and Respond to Illicit Trafficking of Nuclear and Radioactive Materials" (IAEA, 2008). The proposed activity focuses on the "reach back" organisations response and technical assessment of interdicted materials that may potentially be special nuclear materials.

Potential vulnerabilities in relation to the ability of a "reach back" organisation are less well studied than for first responders. Such organisations (national laboratories, radiological protection agencies etc) who serve to provide support to the first responders can be argued to occupy a grey area between the instrumentation and capabilities of (probably) non-expert first responders and the instrumentation and capabilities of supranational, highly expert entities such as the IAEA. Where a suspect material is seized, subsequent activities in the handling of such a seizure and the speed and efficacy with which those activities are conducted are to a large extent dependent on the results of the first laboratory analysis. In this context a number of challenges are evident for the national laboratory (or equivalent) of the country in which the material is encountered. First and foremost among these challenges is the fact that most national laboratories have never encountered such materials and are therefore often unavoidably unfamiliar with the materials of concern. Secondly, the application of the primary analytical technique likely to be employed (low resolution

gamma spectrometry) is not a trivial case with respect to such materials. The potential exists for misidentification of such materials both in relation to the isotopes of concern and the relative proportions of the isotopes in the sample. This potential is exacerbated given that the materials are likely to present themselves in contexts that are non-conducive to simple analysis. Finally, in cases where a determined effort is being made to avoid detection of the material, measures may have been taken to either hide the gamma signature of the material altogether (shielding), to obscure the gamma signature with gamma peaks of other more innocuous isotopes or to employ both methods. In addition to these challenges, a number of situations can arise where innocent sources can be mistaken for nuclear materials or vice versa. Well known examples include the misidentification of yellowcake uranium as highly enriched uranium if equilibrium has not been established with the ^{234m}Pa daughter or heavily shielded old plutonium with high amounts of ^{241}Am appearing to be ^{137}Cs due to its peak at 662 keV. The potential for mis-categorisation of uranium using certain instruments as described by Vesterlund et al (2013) is also a matter of concern.

Previous exercises and activities (Dowdall et al, 2010) have indicated that there is a possible vulnerability with respect to some laboratories abilities to correctly identify nuclear materials of concern and to differentiate such materials from innocent candidates. This vulnerability manifests itself in a number of ways, some being of more consequence than others. At the less serious end of the scale it is clear that many laboratories are not in a position to determine the age of nuclear materials (since last separation) or exact isotopic ratios while at the more serious end of the scale, some laboratories may be unable to differentiate between highly enriched and depleted uranium or between plutonium and natural radioactive materials. Irrespective of these distinctly technical aspects, many laboratories have varying levels of awareness as to what types of materials are worthy of concern or could potentially turn up. The potential consequences of such vulnerabilities do not require elaboration. The only adequate means of addressing such vulnerabilities is through practice and it is to this end that the proposed activity is oriented.

The objective of the GASMAT activity was to conduct a training exercise involving the distribution and analysis of spectral and related data drawn from a series of situations representing possible interdiction of special nuclear material. The intent of the activity was to establish how well participants perform in discriminating between gamma spectral signatures from nuclear materials of concern and those of more innocent materials and identifying potential areas of improvement. The activity was intended to:

- Contribute to increasing analytical competence and awareness amongst participants in the area of response to suspected interdiction of special nuclear materials,
- Provide an exercise opportunity for the participants in relation to analytical requirements in situations as described above,
- Provide training materials for participants for future use,
- Highlight vulnerabilities and provide a means of addressing those vulnerabilities.

1.1 The Exercise

The exercise was conducted as a virtual activity – no real materials or samples were provided. Participants were provided with information and data such as might be expected to be generated in situations such as those presented along with a clear and detailed technical description of what the objective of the exercise was. Data provided was limited to gamma spectral data and ancilliary information. No dose rate data was provided although such data might be expected in responding to the situations as described. This data was not provided as it would probably not contribute, for the situations described, to a decision as to whether or not the materials contained SNM. Neutron data was not provided as it was beyond the scope of the exercise (being focussed on gamma spectrometry) although the organisers were cognisant of the fact that neutron detectors may form part of a responders instrumentation and constitute an important signal in determining whether or not some types of SNM are present.

Gamma spectral data was provided for each situation simulating the response of a standard HPGe detector to the sources simulated. Background data was provided in most situations allowing for rudimentary correction. In some cases separate background spectra were not provided but background signals were still present in the spectra. All data was assumed to have been acquired on the same detector in an attempt to reduce the work load for participants. Spectra were for relatively short count periods as many of the situations presented were such that the operator would have no real reason to suspect the presence of SNM and the counts were of a time period sufficient to confirm that the sources were as they purported to be or to identify the "main" source.

The data was disseminated as part of 6 "situations", the situations and their contexts being described in the ancillary information provided. Participants were asked to clearly state whether or not the individual situations involved SNM or not. Participants were free to report any information they saw fit in addition to stating whether or not SNM was featured. Prior to the activity proper, a calibration spectrum was disseminated of a series of standard calibration isotopes in point source geometry with which the participants could energy and shape calibrate their systems. Activity information for this calibration source was provided such that an approximate idea of the efficiency of the detector could be determined. The participants were clearly informed that activity was not an objective of GASMAT and that only rough estimates could be expected given the data to hand.

Some weeks after dissemination of the calibration data the spectra for the six situations were disseminated. Participants then had one week within which to report their findings.

Technical instructions as to the activity and limitations as to the specific materials are enclosed as Appendix 1. The situation descriptions as provided to participants are enclosed as Appendix 2.

Participation in the GASMAT activity was anonymous, participants being assigned a number and only being identified by that number throughout the activity.

1.2 The Detector and Calibration

The detector and its setup were the same for all scenarios and was a very standard generic coaxial HPGe typical of those which may be found in portable applications of the type relevant to GASMAT. The detector holder was 0.51 mm thick aluminium with a 3 mm spacing between crystal face and detector end cap. A uniform dead layer of 1 mm was assumed all round the crystal. The crystal was 6 cm in diameter and 7 cm long. Relative efficiency was approximately 40% and the resolution was 1.8 keV at 1332 keV. The detector was set up such that the energy calibration could be described with a zero of 1.353606 keV and a gain of 0.3320552 keV/channel with a full scale energy of 2721.5 kev (8192 channels).

A calibration spectrum was provided of various isotopes in point source geometry presented normally to the front face of the detector along the central axis with no background present and counted to achieve reasonable statistics. Participants could use this to conduct their own energy/shape calibrations or determine some rudimentary efficiency calibration if they desired. The isotopes included in this calibration spectrum, all being 10 kBq and the spectrum being taken for a point source 30 cm from the end cap, were: ^{241}Am, ^{109}Cd, ^{60}Co, ^{65}Zn, ^{54}Mn and ^{57}Co.

1.3 The GASMAT Spectra.

For each of the GASMAT situations, sources and activities employed were based on literature information. Information as to nuclear data (energies, probabilities etc) were retrieved from the online Table of Isotopes hosted on the website at Swedens Lund University (http://nucleardata.nuclear.lu.se/nucleardata/toi/welcome.stm). Shielding and other calculations were conducted using MicroShine® and MicroShield® from Grove Software Inc. as well as RadPro (McGinnis, 2008). Calculations of ingrowth and decay for various nuclides were based upon the US DOE's Radiological Toolbox (Eckerman and Sjoreen, 2006). Spectra were simulated using the codes of Hensley et al (1995) and, for situations involving relatively simple mixtures such as Situations 3 and 4, VGSL (Plenteda, 2002). In most cases, individual components were simulated separately (such as each daughter in a chain) in order to reduce computational time. Spectra were then summed together to produce the final spectrum. Spectral conversions were conducted using either home made routines or the CAMBIO utility from the US DoE. Spectra were provided in a range of the usual formats. Effects due to beta particles and neutrons (including activation products in shielding materials where relevant) were not included in the simulation for convenience purposes. Coincidence summation or random summing was not included, nor the effects of count rate on peak shape or other subtleties. All spectra had statistical noise incorporated. Escape peaks were included where relevant. X-rays were included but participants were informed that low energy x-ray data was not to be considered relibale. Spectra were tested using both off the shelf default installations of the commonest suites from commercial manufacturers, the same installations using tailored libraries and PeakEasy 4.03 from Los Alamos national Laboratory.

1.4 Background Spectra

Background spectra were derived using a combination of real spectra and synthetic data. Three variations were used within GASMAT:

- "low" background – a normal background typical of a lab situation with higher amounts of ^{40}K than the uranium series.
- "medium" background - a normal background with stronger evidence of uranium series,.
- "high" background – strong uranium series and strong ^{40}K.

The background was simulated for the GASMAT detector over a 1 m thick generic soil slab containing amounts of the natural decay series and ^{40}K. These amounts were varied until approximate agreement was achieved between the simulation and an actual spectrum taken 1 m over ground with a standard HPGe detector. The relative amounts of the decay series and ^{40}K were then altered to produce the three variations described above. The real spectrum, accrued for an equivalent length of time to the simulated spectrum, was then altered such that all photopeaks were removed leaving just the underlying continuum. This was then added to the simulated spectra to produce a representation of the type of scattering seen in real spectra. The three 5 minute backgrounds were then disseminated as part of the GASMAT activity. For addition to the GASMAT source spectra, the spectra were adjusted to the appropriate live time (1 minute) and added to the source spectra.

1.5 The 810 keV peak.

During the activity, an erroneous peak at 810 keV was observed in many of the spectra. This was determined to have come from an error in the gamma database for ^{234m}Pa and was visible in any spectrum involving that isotope. Participants were promptly informed of the error and warned not to base any identification of an isotope on the presence of the 810 keV peak. No reports were received of the erroneous peak having caused trouble for any participant.

1.6 Triage participation.

The Triage system, operated by the US Dept. of Energy (DoE) and the US National Nuclear Security Administration (NNSA) provides a secure, on-line capability for the identification of radioactive sources. The system, availing of the competences of both the participating organisations, provides a reach back facility for the identification of radioactive sources from on-site data facilitating appropriate incident-site management. The operators of Triage kindly agreed to analyse the GASMAT materials as an exercise activity, this participation providing both valuable information in the approaches that can be adopted in analysing suspect spectra and useful insight into the performance of the organisers in developing the materials of GASMAT. In agreement with Triage, the results of their analyses are provided as Appendix 4.

2. Results

Detailed descriptions of the situations and their sources are provided in this section. As the GASMAT activity was not a test of performance in the strict sense, the results provided by participants are being provided as reported and no effort has been made to compare them against each other or any criteria of performance. The response are unedited as much valuable information is contained within them that is of obvious interest to other participants and perhaps future readers. The Triage results are not discussed within the context of other participants.

2.1 Situation 1.

The premise of Situation 1 was the transport of scrap aeronautical parts containing two types of material which include significant amounts of natural radionuclides. The first of these was magnesium-thorium alloy of the type known as HK31A which contains approximately 3.25% thorium and the second was a depleted uranium aircraft counterweight. For the purposes of GASMAT, the thorium alloy was assumed to have been 40 years old and the amount present was approximately 500 kg containing 16.25 kg of thorium plus the ingrown daughters over the 40 year period. Assuming a specific activity for ^{232}Th of 4.1×10^{6} Bq/kg, the 16.25 kg present was therefore assumed to contain 66625000 Bq of ^{232}Th at the time of manufacture. Ten kg of depleted uranium was also assumed present, also 40 years old.

For the 16.25 kg of thorium, the following daughter products activities were assumed present after 40 years ingrowth (Table 1).

Isotope	Activity (Bq)
^{232}Th	66625000
^{228}Ra	66085338
^{228}Ac	66085338
^{228}Th	65818838
^{224}Ra	65818838
^{220}Rn	65818838
^{216}Po	65818838
^{212}Pb	65818838
^{212}Bi	65818838
^{212}Po	42173625
^{208}Tl	23651875

Table 1. Isotopes and activities in the alloy materials represented in Situation 1.

The depleted uranium was assumed to have the composition:

99.8 % ^{238}U (9980.0 g), Specific activity = 1.2×10^{7} Bq / kg = 119760000 Bq
0.2% ^{235}U (20.0 g), Specific activity = 8.0×10^{7} Bq / kg = 1600000 Bq
0.0003% ^{236}U (0.03g), Specific activity = 2.4×10^{9} Bq / kg = 72000 Bq
0.0006% ^{233}U (0.06g), Specific activity = 2.3×10^{11} Bq / kg = 13800000 Bq

The amount of daughters present in the depleted uranium mass are as displayed in Table 2 with only isotopes present at activities greater than 10 Bq (shaded) being

included in the simulated materials. Full details of the photopeaks (counts, channels, energies) of the sources are contained in Appendix 3.

The thorium source was assumed to be present in the form of a pile of scrap metal in a box approximately 1 m by 1 m to a depth of 30 cm with the uranium present, within that volume, in the form of a rod approximately 30 cm with a cross section of 20 cm^2.

	Bq		Bq		Bq		Bq
^{238}U	119760000	^{235}U	1600000	^{234}U	71990.28	^{236}U	13800000
^{234}Th	119760000	^{231}Th	1600000	^{230}Th	25.92	^{232}Th	0.02732
^{234m}Pa	119520480	^{231}Pa	1351.68	^{226}Ra	0.223272	^{228}Ra	0.02171
^{234}Pa	394848.72	^{227}Ac	586.88	^{222}Rn	0.223128	^{228}Ac	0.02171
^{234}U	13580.784	^{227}Th	576.96	^{218}Po	0.223128	^{228}Th	0.01984
^{230}Th	2.4383136	^{223}Fr	8.0992	^{214}Pb	0.223056	^{224}Ra	0.01983
^{226}Ra	0.01398797	^{223}Ra	584	^{218}At	44.626E-06	^{220}Rn	0.01983
^{222}Rn	0.01397599	^{219}Rn	584	^{214}Bi	0.223128	^{216}Po	0.01983
^{218}Po	0.01397599	^{215}Po	584	^{214}Po	0.223056	^{212}Pb	0.01983
^{214}Pb	0.01396402	^{211}Pb	584	^{210}Pb	0.0696744	^{212}Bi	0.01983
^{218}At	27.94E-07	^{211}Bi	584	^{210}Bi	0.0695736	^{212}Po	0.01271
^{214}Bi	0.01397599	^{207}Tl	582.4	^{210}Po	0.0670392	^{208}Tl	0.00713
^{214}Po	0.01396402	^{211}Po	1.6352				
^{210}Pb	0.00344669						
^{210}Bi	0.0034407						
^{210}Po	0.00326945						

Table 2. isotopes and activities in the depleted uranium mass of Situation 1.

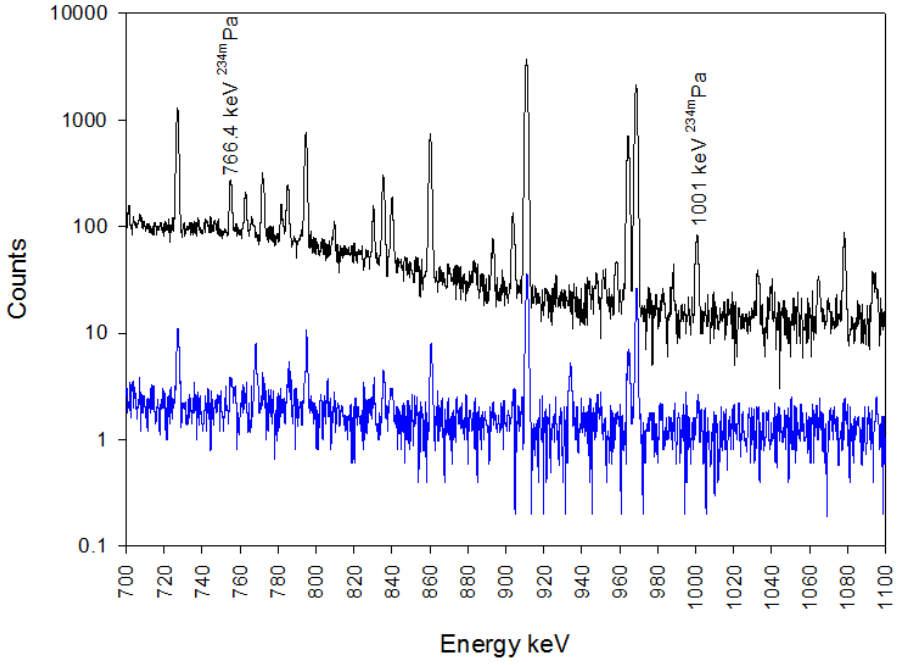


Figure 1. Region between 700 and 1100 keV for Situation 1. Time adjusted background contribution in blue.

Absorbers between the detector and the thorium metal were assumed to be the metal itself and a few mm of iron to account for the box. For the uranium the absorbers were the metal itself plus a thickness of the alloy corresponding to approx 50 cm and the metal of the box. To the spectra of the uranium plus thorium was added a background contribution.

The main aim of Situation 1 was not the identification of the gross material – a trivial matter given the presence of the alloy designator on the metal – but rather the observation and identification of the second material within the mass as being SNM or not. The spectrum of Situation 1 was weighted heavily towards the thorium constituent, the uranium constituent only contributing a limited number of peaks with areas over 100 counts largely being due to the absence of the ^{226}Ra daughter products, self shielding of the uranium metal and the shielding of the thorium alloy. Analysis of the spectrum should have been straightforward – a series of easily recognisable and often encountered peaks for ^{232}Th and its daughters being clearly visible in the spectrum. The only indications of the presence of depleted uranium in the spectrum were a couple of minor peaks from ^{234m}Pa – primarily at 766.4 keV and 1001 keV which theoretically could be expected to be noticed (see Figure 1).

Participant responses to Situation 1 are displayed in Table 3. No participants incorrectly identified the materials as containing SNM. The majority of participants could correctly identify the material for what it was intended to represent irrespective of whether or not this identification was based upon the ancilliary material provided or the spectrum itself. The presence of the high energy 2614 keV ^{208}Tl peak could have suggested the presence of ^{232}U in one form or another although this should have been ruled out as a candidate given the presence of the two strong ^{228}Ac peaks at 911 and 969 keV. A significantly lower number of participants were in a position to suggest the presence of a second material – that of the depleted uranium.This is despite the fact that the typical ^{234m}Pa peak at 1001 keV was present and was present in the absence of the usual suite of peaks from the daughters of ^{226}Ra thereby precipitating the probability that the material causing the 1001 keV peak was not naturally occuring material in the usual sense. The presence of this peak could not be accounted for by the background. The presence of depleted uranium in a cargo containing scrap aeronautical materials should not have been viewed as improbable given the material is commonly used as a counter or trim weight in aeroplanes. Only one participant was in a position to elaborate upon the possible presence of depleted or processed uranium within the gross material. The test in this situation was not the identification of the spectral signals as being those from natural thorium but rather the identification of spectral signals that could not arise from what the material was indicated as being through the ancilliary information – primarily the stamped designation and the stated source of the materials.

Participant Number	SNM – Yes/no	Comments
1	No	Could identify mostly the progeny of naturally occurring Th and U isotopes, and found also peaks, which I was unable to identify without any tips what to look for. I would say that the material carried by the truck might be radioactive, because it contains extended amount of NORM materials (and possibly other radioactive isotopes), but it does not carry SNM.
2	No	This Gamma spectrum shows the presence of ^{232}Th and ^{228}Th with daughters. The designation HK31A gives further information on that this is an Mg-Th-Zr alloy containing about 3.3% thorium. The alloy is used for manufacturing aircraft engines.
3	No	Natural ^{232}Th with daughters.
4	No	Elevated radiation level is from ^{228}Th. Shipping documents indicate that truck is carrying "aviation components". The suspected wooden crate is coming from old military base. In the crate are old motors and metal junk. One piece is labeled HK31A which is connected magnesium alloy. The source of radiation is the thorium used in magnesium alloy HK31A which weight % of thorium is 3.25. Decision: Radiation source is ^{228}Th used in aviation equipment alloy (usually in motors and rotors). NAT.
5		No response
6	No	Natural Thorium/^{232}Th. Parts from aircrafts (Gear; Turbine) with ^{232}Th; composition of Al-Mg-Th "HK31A" = metal-plate (2-3% with Th). Activity about 6 E7 Bq that's 15 kg Thorium or 500 kg discarded metal. No abnormality else.
7	No	Thorium decay chain: notably: ^{212}Pb, ^{228}Ac, ^{208}Tl. NORM, possibly TENORM. thorium rich soil?
8	No	Ac-228(^{228}Ra) Higher concentration of ^{228}Ra (it could be used as beta source).
9	No	The aviation part marked HK31A contains ^{232}Th (according to manufacturer < 3.25 weight% Th) –supported by ^{208}Tl and ^{228}Ac peaks in the spectra. The clearly visible 2103 keV we could not identify. Due to the strong 2614 peak this might be a single escape peak from 2614 keV, which would also explain the 1592 keV peak being a double escape peak from the 2614 keV.
10	No	There are no special nuclear materials (SNM). We see radionuclides in the radium and thorium-series. For the radium series, the indication of been ^{226}Ra@186.1 instead of ^{235}U@185.7 has been that radium's daughters ^{214}Pb@351 and ^{214}Bi@609 appear with almost equal net area. Other important lines for ^{235}U such as 143.8, 163.3 and 205.3 keV were inexistent.For the thorium-series, all lines for the daughters ^{228}Ac, ^{228}Th, ^{208}Tl are apparent.
11	No	We identified some peaks from ^{227}Th (300 keV), ^{228}Th (216 keV), ^{234}Th (93 keV), ^{54}Mn (835 keV), ^{95}Zr (757 keV) and ^{89}Zr (909 keV). This suggests that the magnesium alloy HK31A actually was present in the container so marked. Some other isotopes were also identified; ^{51}Cr (320 keV), ^{115}Cd (336 keV), ^{243}Cm, ^{248}Cm, ^{252}Cf.
12		No response

13	No	No evident SNM present, but chemically processed uranium warrants further investigations. Quick web search on the visible "HK31A" label shows that this is a designation for a special magnesium alloy that has been used for example in aircraft fuselage skins. Further study reveals that it is a Th-rich alloy, with a composition (in weight percentage) 3.00% Thorium (Th), 0.60% Zirconium (Zr), and the base metal Magnesium (Mg). Spectrum analysis show no artificial activity, only elevated levels of ^{232}Th and its decay products, when the crate spectrum is compared with the background spectrum. However ^{234m}Pa levels are also elevated where as ^{214}Pb and ^{214}Bi activity remains at background level, indicating presence of chemically processed ^{238}U. The high ^{232}Th content is in line with the data related to the "HK31A" label. High ^{234m}Pa is an indication of chemically processed uranium, perhaps depleted, warranting a more thorough investigation.
14	No	The radioactive metal in the truck is probably magnesium alloy HK31A, which is known to contain up to 3.2% Th. This alloy was previously used in flight jet motors for increase heat resistant. The spectrum shows strong presence of ^{232}Th. This is consistent with the presence of alloy HK31A.
15	No	The spectrum contains multiple peaks from the ^{232}Th decay series. Together with the designation HK31A, the object is identified as a Th/Mg-alloy with about 3 % thorium (by weight). This type of material was earlier used in aircraft engine parts. A significant peak is also found at 1001 keV (larger than expected from the decay of ^{228}Ac from the ^{232}Th decay series), together with a small peak at 766 keV. This indicates the presence of ^{238}U (^{234m}Pa) in the box. The absence of 186 keV and other ^{235}U peaks can be explained by shielding or low concentrations of ^{235}U. Our suggestion is that the 1001 keV comes from depleted uranium, which earlier has been used as trim weights in aircrafts.

Table 3. Participant responses to Situation 1.

2.2 Situation 2.

Situation 2 involved the concealment of 5 kg of enriched, unshielded uranium within a large mass of phosphate fertilser containing naturally occurring isotopes of the uranium series in an attempt to mask the signals from the smuggled material with similar signals from a legitimate source. Four spectra were provided having being taken around the mass of fertiliser with the uranium having been placed off centre within the mass resulting in uranium signatures of varying strength at different positions. The intention was in this case to provide a situation where it was not so much the spectrum itself which caused reason for suspicion but the fluctuations in certain parts of the spectrum which should not have been present for a homogenous mass of material. The uranium was highly enriched uranium – 90% ^{235}U, 8.9% ^{238}U and the remainder ^{234}U. The uranium was considered to be 15 years old and the following daughters were present (Table 4). Only shaded daughters were included in the simulations.

Isotope	Bq	Isotope	Bq	Isotope	Bq
^{235}U	3.600E+08	^{234}U	1.265E+10	^{238}U	5.340E+06
^{231}Th	3.600E+08	^{230}Th	1.708E+06	^{234}Th	5.340E+06
^{231}Pa	1.140E+05	^{226}Ra	5.537E+03	^{234m}Pa	5.329E+06
^{227}Ac	2.334E+04	^{222}Rn	5.526E+03	^{234}Pa	1.761E+04
^{227}Th	2.281E+04	^{218}Po	5.526E+03	^{234}U	2.261E+02
^{223}Fr	3.221E+02	^{214}Pb	5.526E+03	^{230}Th	1.517E-02
^{223}Ra	2.300E+04	^{214}Bi	5.526E+03	^{226}Ra	3.260E-05
^{219}Rn	2.300E+04	^{214}Po	5.526E+03	^{222}Rn	3.249E-05
^{215}Po	2.300E+04	^{210}Pb	7.668E+02	^{218}Po	3.249E-05
^{211}Pb	2.300E+04	^{210}Bi	7.639E+02	^{214}Pb	3.249E-05
^{211}Bi	2.300E+04	^{210}Po	6.888E+02	^{218}At	6.499E-09
^{207}Tl	2.294E+04			^{214}Bi	3.249E-05
^{211}Po	6.440E+01			^{214}Po	3.249E-05
				^{210}Pb	3.436E-06
				^{210}Bi	3.418E-06
				^{210}Po	2.977E-06

Table 4. isotopes and activities of the enriched uranium of Situation 2.

The fertiliser was considered to be relatively “fresh” and decay calculations for 5 years were performed.The fertilser data was taken from IAEA Tech report 419. p100 and it was assumed that the fertilizer contained 420 Bq/kg of ^{238}U, 250 Bq/kg of ^{226}Ra, 15 Bq/kg of ^{232}Th. The pallet of the scenario was considered as being 2000 kg (80 25 kg sacks with density of approximately 2.3 arranged in an approximate cube of 1 m on each side and a stack height of approximately 80 cm). The fertilser was 34% by mass of potassium, ie. 680 kg of K equal to 79.56 g of ^{40}K = 20685600 Bq total. Using the activities above and with a decay time of 5 years, 840000 Bq of ^{238}U, 39252 Bq of ^{235}U, 50000 Bq of ^{226}Ra and 30000 Bq of ^{232}Th were the activities at represented time 0. Table 5 displays the isotope activities present (only those shaded were included in simulations) at the time of measurement. Detailed information provided in Appendix 3.

Isotope	Bq	Isotope	Bq	Isotope	Bq	Isotope	Bq
^{238}U	840000	^{235}U	39252	^{226}Ra	49890	^{232}Th	30000
^{234}Th	840000	^{231}Th	39252	^{222}Rn	49890	^{228}Ra	13581
^{234m}Pa	838320	^{231}Pa	4.145011	^{218}Po	49890	^{228}Ac	13578
^{234}Pa	2769.48	^{227}Ac	0.312328	^{214}Pb	49880	^{228}Th	7842
^{234}U	11.7012	^{227Th}	0.299297	^{218}At	9.98	^{224}Ra	7812
^{230}Th	0.000258468	^{223}Fr	0.00431	^{214}Bi	49890	^{220}Rn	7812
^{226}Ra	1.82952E-07	^{223}Ra	0.298237	^{214}Po	49880	^{216}Po	7812
^{222}Rn	1.81356E-07	^{219}Rn	0.298237	^{210}Pb	7165	^{212}Pb	7809
^{218}Po	1.81104E-07	^{215}Po	0.298237	^{210}Bi	7140	^{212}Bi	7809
^{214}Pb	1.81104E-07	^{211}Pb	0.298197	^{210}Po	6405	^{212}Po	5004
^{218}At	3.62628E-11	^{211}Bi	0.298197			^{208}Tl	2805.6
^{214}Bi	1.81272E-07	^{207}Tl	0.297373				
^{214}Po	1.81272E-07	^{211}Po	0.000835				
^{210}Pb	6.45288E-09						
^{210}Bi	6.363E-09						
^{210}Po	4.29576E-09						

Table 5. Isotopes and activities of the fertiliser mass of Situation 2.

Situation 2 represented the masking of SNM using materials that included or could be expected to include significant levels of natural radioactive materials. The SNM present only exhibited a signature at certain positions and the signature presented was comprised in the main of spectral components that could also be expected to be present in the signal from the masking material. It was hoped that the inhomogeneity in the positional spectra from what should have been a fairly homogenous source would serve as an indicator for the presence of the hidden material and for the majority of the participants this was indeed the case. A simple peak search and identification of nuclides would most probably have produced no indication of the hidden source in this instance. The most predominant variation between the positional spectra was in the region 100 keV to 250 keV where the main ^{235}U lines are to be found (see Figure 2).

Two participants were not in a position to identify the presence of the concealed uranium material within the fertiliser (see Table 6) the other participants were all in a position to suggest the potential presence of some form of enriched uranium within the mass of fertiliser based on the inhomogeneities present between the four spectra. Some participants attempted to estimate the level of enrichment of the uranium source present. Given the material to hand it was unlikely in the extreme that anything approaching an accurate assessment could be made although the estimates provided by participants were entirely reasonable.

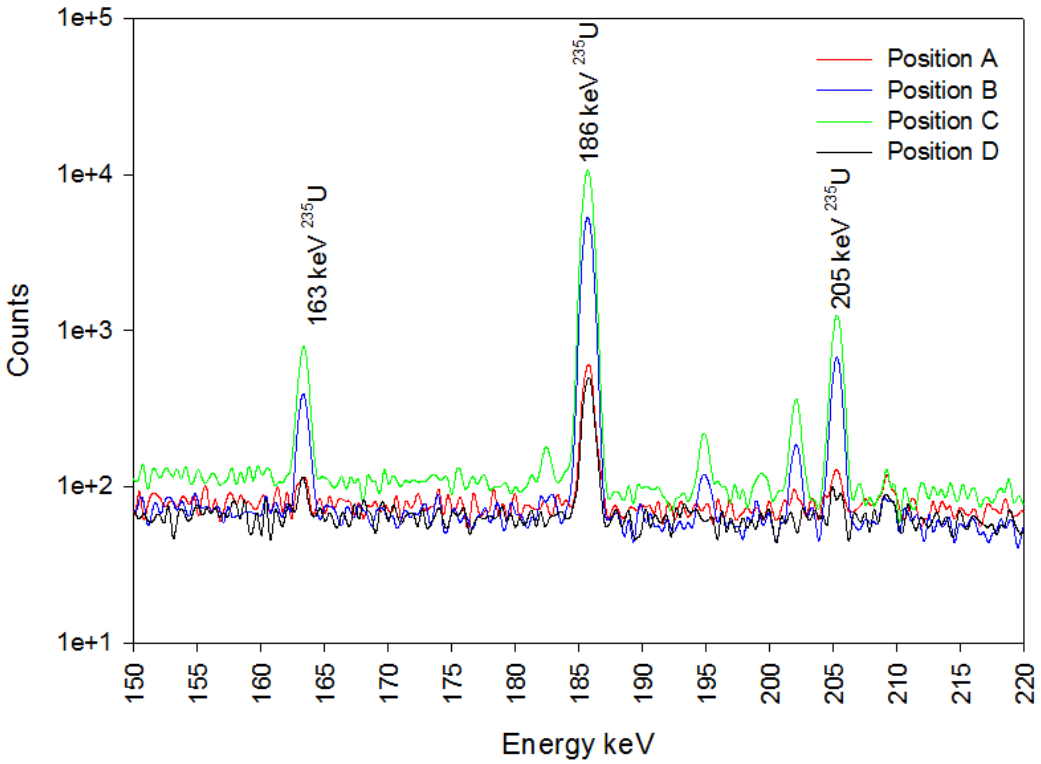


Figure 2. The 150 keV to 220 keV region of the spectra for Situation 2.

Participant Number	SNM-Yes/no	Comments
1	Yes	As the truck carries potassium fertilizer, there's very high Compton background from the ^{40}K covering most of the spectra. Regardless of that there are quite strong ^{235}U photopeaks visible in spectra A, B and C. Since I could not identify any progeny of ^{235}U, and the peaks intensity seemed to be little bit too high compared to the progeny of ^{238}U, to be considered natural; I would say that there's illegal ^{235}U hidden in the cargo.
2	Yes	The spectra show the presence of ^{40}K and a peak at 186 keV. The ^{40}K stems from the fertilizers NPK and MPK which consist of KH_2PO_4. The 186 keV peak is strongest near the measurement points B and C, indicating that a source is present closer to these points. This peak can stem from either ^{226}Ra or ^{235}U, but the 1001 keV peak (^{234m}Pa) indicates the presence of ^{238}U. The ratio of ^{235}U (186 keV) and ^{238}U (1001 keV) suggests that this additional source is enriched uranium, probably weapons grade uranium.
3	Yes	For sure some fertilizer, since ^{40}K peak prominent. Also uranium, especially ^{235}U can be seen, situated in C-B –corner, closer to point C. Since the intensities of the ^{238}U series are much lower, it seems that the material is enriched in relation to ^{235}U – so a very suspicious delivery! Seems that enriched uranium is hidden within fertilizers.
4	Yes	Sacs in pallet marked MKP 0-52-34/NPK 0-52-34 means that in sacs is fertilizer. K-40 source is obviously fertilizer. In directions A B C D is clearly uranium-235 identified well above background (about 200 times x BGRD in directions A and D, about 2000 times x BGRD in directions B and C). Specially from directions B and C is following nuclides identified: ^{69m}Zn, ^{197m}Au, ^{200}Au, ^{203}Hg. In direction A ^{69m}Zn and ^{77}Br, in direction D ^{69m}Zn. Most of these nuclides have short half life. Wrong identification? Should be re measured using LEGe detector to verify ^{235}U/^{238}U ratio. Decision: Definitely in pallet inside some sacs or between sacs is some type uranium source near B-C corner. Should be re measured using LEGe detector to verify ^{235}U/^{238}U ratio. May or may NOT be SNM.
5		No response
6	No	Palette with Potassium-Phosphate-Fertiliser: MKP-52-34, that is 52% potassium salt. Potassium activity about 1,7 E7 Bq, "contamination" with uranium at the Phosphat, leave one Thorium.No abnormality else.
7	Yes	U-235, enriched uranium. C side of box closest to source or least shielded
8	No	K-40, ^{238}U (and products of decay), ^{235}U Agricultural goods contain higher concentration of natural radionuclides.
9	yes	A suggestion from the fertilizer brand name is that it contains 34 % K, i.e. there is a natural content of ^{40}K. Due to the phosphate content of the fertilizer (P) a small amount of both ^{238}U and ^{232}Th, and daughters is also natural. More surprising is the ^{235}U source that appears to be hidden close to position c (and b), proved by the 185 and 205 keV peaks.
10	Yes	Towards the C, B –corner of the box there is a higher fraction of ^{235}U/^{238}U in relation to the fraction it should be in case of natural U therefore we assume that it could be some enriched Uranium in the box. Since this effect fades to the opposite corner we assume that there is shielding towards the A, D corner.
11	Yes	We identified ^{40}K which confirm that the content actually is a

		fertilizer containing mono potassium phosphate. However, several peaks from ^{235}U, ^{238}U and ^{234}Th were also present which indicate that the shipment can contain special nuclear material. One peak from ^{67}Cu at 93 keV was noticed, the origin of that peak is unknown but could perhaps be the result from activation by neutrons from spontaneous fission of, e.g. ^{238}U? Peaks from ^{132}I, ^{140}Ba and ^{132}La were detected, these are typical fission products. Looking at the measured intensity of ^{234}Th (92 keV) from the four sides, we conclude that there seems to be less shielding on side C (since the intensity was higher there, compared to the other sides). Looking at the 185 keV peak from ^{235}U we see the intensity distribution between the sides.
12		No response
13	Yes	SNM present MKP 0-52-34/NPK 0-52-34 is a potassium fertilizer. However, looking at the ^{235}U and ^{228}Ac (or ^{234}Th) ratios, there seems to be ^{235}U source inside (especially locations B and C show high ^{235}U level, so the source is most likely around this area of the crate). Apparently there is an enriched uranium source present, our estimate for the enrichment level is 10% or higher.
14	Yes	The sacks stacked on the pallets are filled with the agricultural fertilizer, monopotassium phosphate. The material is known to contain K and U and the spectrum shows strong presence of ^{40}K and of natural U. Escape and double escape peaks from ^{40}K, 1460 keV, are present at 440 and 949 keV. However, enriched or highly enriched U is hidden in one or more of the sacks in the C-B corner of the stack. A ^{238}U/^{235}U activity ratio of around 1 is calculated close to position C using a rudimentary efficiency calibration from the enclosed calibration. This means that U is enriched in ^{235}U at least 20 times over natural occurring U. The shielding from the fertilizer is unknown and has not been taken into account. The ^{235}U activity have been calculated from the gamma energies 143 keV and 163 keV and the ^{238}U activity from the gamma energy 63 keV.
15	Yes	The NPK marking indicates that the sacks contain fertilizer with nitrogen, phosphorus and potassium. The large 1460 keV peak from ^{40}K confirms the presence of potassium. Peaks from ^{234m}Pa also confirm the presence of uranium, which is a normal impurity in phosphorous fertilizers produced from sedimentary phosphates. Spectra collected from positions B and C indicate that an object containing enriched uranium is hidden somewhere in the upper left quadrant of the figure, slightly closer to point C than to point B. The ^{235}U/^{238}U activity ratio is estimated to > 0.25 from analysis of the 163 keV peak from ^{235}U and 1001 keV peak from ^{234m}Pa. The uranium is suggested to be of at least reactor grade (3-5 % ^{235}U by weight). The same ratio calculated from spectra collected at positions A and D is close to the natural ^{235}U/^{238}U activity ratio of 0.04. Special nuclear materials are present in this scenario.

Table 6. Participant responses to Situation 2.

2.3 Situation 3.

Situation 3 was intended to represent interception of an individual at an airport carrying an innocent source with the potential to be mistaken for SNM. In this instance the innocent source involved the use of a modified version of the Pu gamma surrogate as described in Frank (2010) and containing the following isotopes: ^{133}Ba (200170 Bq), ^{57}Co (1948050 Bq), ^{137}Cs (384430 Bq), ^{153}Gd (19055000 Bq), ^{177m}Lu (1956930 Bq), ^{113}Sn (1517000 Bq) and ^{95}Zr (379620 Bq). This surrogate is intended to simulate plutonium with respect to low resolution detectors of the type employed in security applications and although probably not entirely suitable for testing HPGe detectors was employed anyway. Although ^{95}Nb could be expected to be present in such a source, it was left out in this instance to simply introduce an uncertainty into the matter. The aim of this situation was not the identification of the source as being any specific item or material but, as for the other situations, determining that the source was not SNM.

Two respondents indicated that SNM material was possibly present in the source of Situation 3. One of these assessed the source to be plutonium, the second identifying a number of fission products and assessing the material to be SNM on that basis. Identification of the constituent nuclides was a simple matter for most although a number of false positives were reported. Only one respondent provided the correct identification of the source even though correct identification was not a criteria of GASMAT. It should be noted that in situations where an identification of a source is heavily reliant on the context then a simple list of constituent nuclides is not always sufficient. In this instance, once definite identification had been made of the constituent isotopes, a simple interent search of those isotopes would have produced the relevant documents pertaining to what the source could be.

Participant Number	SNM-Yes/no	Comments
1	No	I could identify unreasonably high ^{137}C activity; as of anything else, I would remove the small metal box that was found to be radioactive, until the "friend" for whom the instruments travelled shows up, and take extra time to analyse the spectra. At least until some documents are found to describe, why should the box be radioactive. In short I would say that I gave up on this situation and hope that there was no SNM; or I'm just unable to identify it.
2	No	In this situation we believe that the man is carrying calibration sources. The sources are ^{95}Zr, ^{113}Sn, ^{137}Cs, ^{153}Gd, ^{177m}Lu and possibly ^{196}Au (but it has a relatively short half-life). The calibration sources are not that old, since some of them have relative short half-lives, and since for intense ^{95}Nb ($t_{1/2}$: 35.2 days, daughter of ^{95}Zr) is not present.
3	No	The mysterious box seems to be filled with different kind of shortish-lived nuclides, that can be used e.g. as calibration sources: ^{177m}Lu, ^{113}Sn, ^{133}Ba, ^{137}Cs, ^{95}Zr, ^{54}Mn, ^{153}Gd. The rest of the peaks originate from natural ^{40}K, and ^{238}U and ^{232}Th decay series, most probably just background radiation. The walls of the box are quite thick thus blocking most of the radiation that has energy less than 100 keV. No special nuclear materials involved.
4	Yes	From box following mainly short lived nuclides (seconds to hours t1/2) detected: ^{85m}Kr, ^{95m}Rh, ^{113m}In, ^{123}I, ^{135}Xe and following within days to months half-life: ^{47}Sc, ^{95}Zr, ^{95m}Tc, ^{113}Sn, ^{133m}Xe, ^{133m}Ba and ^{135}Ba (stable). Existence of Xenon isotopes (^{133m}Xe and ^{135}Xe) means that source is possible fissionable source producing fissionable products. Decision: Source in metal box is special nuclear material SNM.
5		No response
6	No	Airport: Measuring Equipment with radioactive Sources: ^{57}Co, ^{95}Zr, ^{137}Cs, ^{177}Lu/^{177m}Lu, ^{133}Ba, ^{133}Sn Shielded with ca. 1mm Lead or equivalent Abnormality: ^{95}Zr normal equilibrium with ^{95}Nb, but no Peaks of that.
7	No	Cs-137, ^{57}Co, ^{241}Am, and a cocktail of other industrial radionuclides
8	No	Aerosols: ^{95}Zr, ^{95}Nb, ^{141}Ce, ^{143}Ce, ^{137}Cs Noble gas: ^{133m}Xe, ^{132}Te Metal: ^{57}Co, ^{105}Ru. Radionuclides like from fallout (from fission).
9	No	The small capsule contains some type of fission product; Identified isotopes: 95Zr (at 724 and 757 keV) ^{137}Cs (at 662 keV) Possibly: ^{135}Xe and a lot of other peaks which we haven´t identified. There are also a lot of "natural" peaks from ^{214}Bi etc. We also have peaks at 2103 and 1592 keV as discussed in Situation 1, here, however the ^{208}Tl peak at 2614 keV is much smaller and may not be able to create escape peaks.
10	No	Unsure whether SNM (Pu-isotopes) are present or not. For ^{239}Pu the lines ranked from most frequent to less frequent according the branching ratios are: 129.9, 375, 413, 203, 345 keV. The tentative identified lines for ^{239}Pu appear inconsistent. For example, 413 is seen but not 129.9. Another example is that only the 203 keV is apparent of the pair 203 and 345 with almost equal branching

		ratios. So far we're likely to conclude that SNM are not present.
11	No	Clear indications of both ^{137}Cs and ^{40}K were detected, as were peaks originating from ^{95}Zr (724 and 756 keV). Small peaks from ^{252}Cf at 103 and 113 keV were also identified. Cm-248 were also identifed at 103, 136, 147, 249, 281, 296, 392 and 582 keV. Peaks corresponding to ^{245}Cm and ^{243}Cm were also identifed, these isotopes are produced in fission reactors by neutron capture and alpha decay. One peak at 122 keV could be identifed as ^{57}Co. We conclude that the situation could contain fission products and Cm from build-up in, e.g., a fission reactor. We found no clear indication of special nuclear material.
12		No response
13	No	No SNM, however a radioactive source requiring action present Although no SNM seems to be present, there is a radioactive source present that contains ^{177m}Lu, ^{137}Cs, ^{57}Co, ^{95}Zr and ^{113}Sn, ^{133}Ba and possibly ^{153}Sm or ^{153}Gd. Customs officials are recommended to confiscate the source and start an investigation into the unlawful import of radioactive material.
14	Yes	The box is assumed to include fissile spend reactor fuel with a high percentage of ^{239}Pu and possible some ^{233}U. All peaks above ^{40}K are consistent in height with the D-spectrum for situation 5 (serving as background). It can therefore be concluded that there are no significant amount of U-isotopes in the material. No other Pu-isotopes has been identified (nor ^{241}Am). Two equally strong signals from ^{95}Zr are present at 724 and 757 keV and the 662 keV peak from ^{137}Cs and ^{133}Ba is observed, too.
15	No	Multiple radionuclides are present in the spectrum. ^{177m}Lu was identified since all its significant peaks are present in the spectrum. The 662 keV peak is attributed to ^{137}Cs (and not ^{241}Am, as its other high energy peaks are missing). The four peaks with highest intensity from ^{133}Ba are also clearly visible in the spectrum, as well as the 391.5 keV peak from ^{113}Sn. ^{95}Zr can be identified from peaks at 756.4 keV and 723.9 keV. The expected 765.8 keV peak from daughter ^{95}Nb is not visible in the spectrum, suggesting perhaps that separation has occurred very recently. Finally, ^{153}Gd is identified from peaks at 97.4 keV and 103.2 keV. The combination of radionuclides and emission rates is consistent with a WGPu surrogate source recently patented by the US Dept. of Energy. In this case, ^{252}Cf could also be present but is not observable in the spectrum (neutron detector measurements recommended). No special nuclear materials are detected.

Table 7. Participant responses to Situation 3.

2.4 Situation 4.

For Situation 4, 1 kg of 20 year old reactor grade plutonium was being smuggled concealed inside a shipment of smoke detectors. The ^{241}Am source consisted of 100 detectors containing 37000 Bq of ^{241}Am each for a total of 3700000 Bq and served to mask the smuggled material. This information as to the probably activity level was communicated to the participants.

^{238}Pu 1.3%, 13 g, specific activity of 6.3×10^{14} Bq/kg implies 819×10^{10} Bq.
^{239}Pu 56.6%, 566 g, specific activity of 2.3×10^{12} Bq/kg implies 1.3018×10^{12} Bq.
^{240}Pu 23.2%, 232 g, specific activity of 8.4×10^{12} Bq/kg implies 1.9488×10^{12} Bq.
^{241}Pu 13.9%, 139 g, specific activity of 3.8×10^{15} Bq/kg implies 5.282×10^{14} Bq.
^{242}Pu 4.9%, 49 g, specific activity of 1.5×10^{11} Bq/kg implies 7.35×10^{9} Bq.

2 cm of lead was used to attempt to shield the plutonium serving to eliminate most low energy lines and severly reduce many of the higher energy lines from the plutonium material.

Isotope content for the Pu source after 20 years was as displayed in Table 8 (only shaded isotopes included in the simulation).

	Bq		Bq		Bq		Bq		Bq
^{238}Pu	6.99E+12	^{239}Pu	1.30E+12	^{240}Pu	1.94E+12	^{241}Pu	2.02E+14	^{242}Pu	7.35E+09
^{234}U	4.30E+08	^{235}U	2.56E+04	^{236}U	1.15E+06	^{241}Am	1.07E+13	^{238}U	2.28E+01
^{230}Th	3.97E+04	^{231}Th	2.56E+04	^{232}Th	5.71E-04	^{237}U	4.95E+09	^{234}Th	2.27E+01
^{226}Ra	1.16E+02	^{231}Pa	5.41E+00	^{228}Ra	2.76E-04	^{237}Np	4.04E+07	^{234m}Pa	2.26E+01
^{222}Rn	1.16E+02	^{227}Ac	9.86E-01	^{228}Ac	2.76E-04	^{233}Pa	4.00E+07	^{234}Pa	7.48E-02
^{218}Po	1.16E+02	^{227Th}	9.62E-01	^{228}Th	1.97E-04	^{233}U	1.26E+03	^{234}U	6.41E-04
^{214}Pb	1.16E+02	^{223}Fr	1.36E-02	^{224}Ra	1.97E-04	^{229}Th	6.17E-01	^{230Th}	3.83E-08
^{218}At	2.32E-02	^{223}Ra	9.69E-01	^{220}Rn	1.97E-04	^{225}Ra	6.11E-01	^{226}Ra	2.94E-10
^{214}Bi	1.16E+02	^{219}Rn	9.69E-01	^{216}Po	1.97E-04	^{225}Ac	6.06E-01	^{222}Rn	4.91E-11
^{214}Po	1.16E+02	^{215}Po	9.69E-01	^{212}Pb	1.97E-04	^{221}Fr	6.06E-01	^{218}Po	4.35E-11
^{210}Pb	1.61E+01	^{211}Pb	9.69E-01	^{212}Bi	1.97E-04	^{217}At	6.06E-01	^{214}Pb	0.00E+00
^{210}Bi	1.60E+01	^{211}Bi	9.69E-01	^{212}Po	1.26E-04	^{213}Bi	6.06E-01	^{218}At	0.00E+00
^{210}Po	1.45E+01	^{207}Tl	9.67E-01	^{208}Tl	7.06E-05	^{213}Po	5.93E-01	^{214}Bi	0.00E+00
		^{211}Po	2.71E-03			^{209}Tl	1.31E-02	^{214}Po	2.75E-10
						^{209}Pb	6.06E-01	^{210}Pb	4.40E-10
								^{210}Bi	7.56E-11
								^{210}Po	2.31E-10

Table 8. Isotopes and activities of the reactor grade plutonium of Situation 4.

Situation 4 represented a challenge in that many of the peaks of the spectrum could at first glance be assumed to have come from the ^{241}Am containing smoke detectors. In actuality, the only peak visible in the spectrum to have come from the smoke detectors was the dominant 59 keV peak. The plutonium mass, which contained a very significant amount of ^{241}Am, was shielded such that most of its lower energy peaks were not evident and the majority of the higher energy peaks visible were those

low probability peaks of ^{241}Am. This lead to a situation where the the spectrum appeared, on the basis of the majority of the visible peaks, to be just that of the smoke detectors although the analyst should have been in a position to realise that although the qualitative information was indicative of ^{241}Am, the quantity of the isotope stated as being present in the manifest documents could not possible have accounted for the peaks visible in the spectrum.

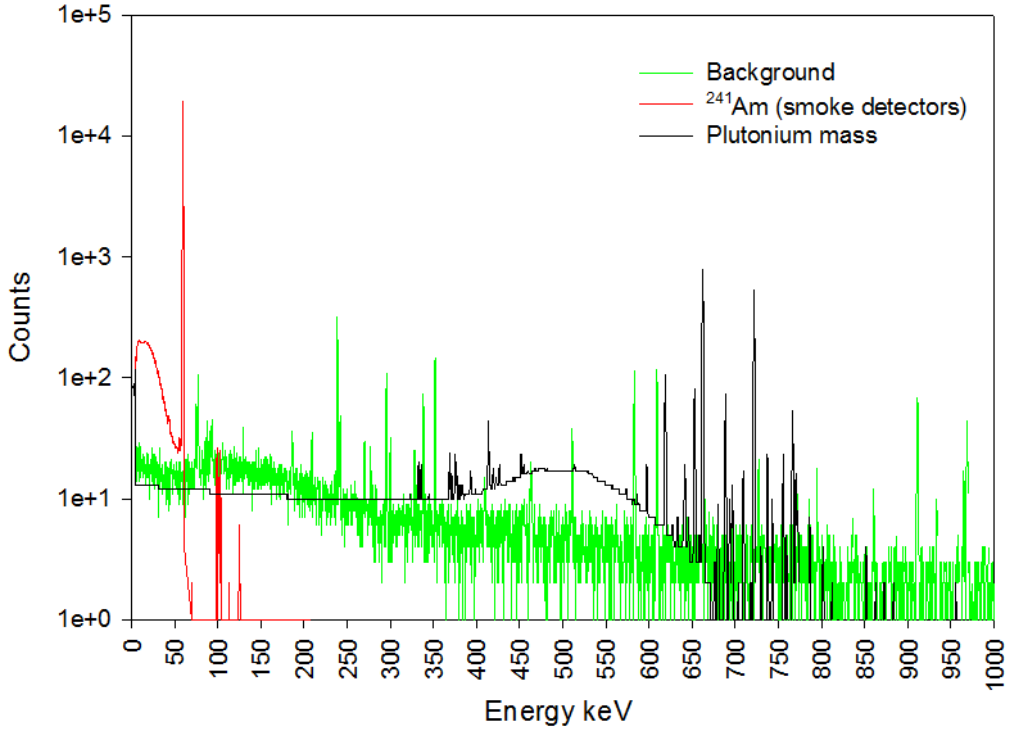


Figure 3. Three components of the Situation 4 spectrum between 0 and 1000 keV.

Relatively strong peaks were present in the spectrum in the 600 keV to 850 keV region which are not readily explicable based on either the background spectrum or that produced by the stated activity of ^{241}Am. Pu-239 was indicated by the presence of weak peaks at 375 keV and 413 keV which would only have been visible with a fairly careful search. Two peaks at 766 keV and 1001 keV, which could be mistaken as background peaks unless the analyst checked their size in relation to each other, were from ^{238}Pu.

Only three respondents correctly identified the presence of SNM. Identification of the presence was based largely on a combination of the spectral features with the realisation that the disparity between the activity of ^{241}Am stated on the manifest and that indicated by the spectral features could only be accounted for by the fact that a very strong ^{241}Am source was present in addition to that stated. Participants producing a false negative for Situation 4 were, in the main, able to ascribe the spectral features present to 241Am but failed to appreciate that the smoke detectors alone could not have produced the spectrum observed.

Participant Number	SNM-yes/no	Comments
1	No	Am-241 peak is clearly visible, so regarding the smoke detectors everything seems to be correct. But there's abnormally high ^{137}Cs peak at 661 keV in the cardboard box spectrum, which is almost missing in the background spectrum. I would generate an efficiency calibration to make sure what's the deal with ^{137}Cs, but I would also say that there's not SNM involved.
2	No	There does not seem to be anything but ^{241}Am present in this scenario.
3	No	It can be seen that in addition to the main peak of ^{241}Am, 59.5 keV, due to the quite large amount of radioactivity contained in the box, also the minor gamma peaks of ^{241}Am (with intensities below 1 ‰) can be seen, if the energy is high enough to penetrate through the materials within the box (E greater than about 600 keV). Considering the count rates and intensities, it may be that there is even more than 100 x 1µCi of activity in the box. No special nuclear materials involved.
4	Yes	Much bigger ^{241}Am source than 100 times 1 micro curie smoke detector can produce. Also ^{95}Nb detected and maybe rather small amount of ^{200}Au. Found 129.23, 332.35 and 413.83 keV peaks by hand. These are very close of ^{239}Pu peaks. -> very suspected SNM (^{239}Pu) source. Decision: Big ^{241}Am source(s) hidden in one or several smoke detector box(es). Very suspected SNM (^{239}Pu) source.
5		No response
6	No	Box with 100 Smoke-Detectors each with 37 kBq of ^{241}Am Result: it is ^{241}Am; But the measured activity is higher than (100 * 37 kBq) by a factor of 10 to 100. Should be analysed in detail: too much ^{241}Am in the Smoke-Detectors or other "solution" / source? No abnormality else.
7	No	Am-241. identified by 59.54 kev line and the ratio between the 662 and 722 keV lines
8	No	Am-241. Difference between detection 59keV and higher energy 662 keV and 722 keV (^{241}Am) come from attenuation of low-energy (closed smokes detectors).
9	No	The ^{241}Am peak is very prominent, so it is suspected that the 662 keV peak is a secondary ^{241}Am peak, and not a ^{137}Cs peak. This is supported by the presence of the 722 keV peak, another ^{241}Am peak. From the relation between the calibration spectra ^{241}Am peak and the Situation 4 ^{241}Am peak, the Situation 4 source might be a bit stronger than claimed, although in the right order of magnitude.
10	No	No presence of SNM. Smoke detectors contain a small amount of ^{241}Am, which is obtained from spent nuclear fuel.
11		Peaks from ^{241}Am at 174 keV and ^{137}Cs at 662 keV were identified. Also other fission products such as ^{95}Tc and ^{123}I were found. This could result from decay and spontaneous fission of Am-241 which is commonly used in smoke detectors. We found no conclusive evidence of other nuclear material.
12		No response
13	Yes	SNM present. All of the outstanding peaks in the spectrum can be explained either with ^{241}Am or natural background. However, already at first glance, the ^{241}Am peaks between 600 and 800 keV

		are exceptionally clearly visible. Approximate activity calculus based on the 59.5 keV ^{241}Am peak gives an activity of around 5 MBq where as alike calculus based on the 662.4 keV peak results 30 GBq. The possible confusion between the 662.4 keV ^{241}Am peak and 661.7 keV Cs-137 peak can be ruled out by noting that the peak areas of the high energy ^{241}Am peaks follow the Am-241 branching ratios. The ^{241}Am activity of 5 MBq is within the uncertainty limits from the reported total activity of the smoke detectors (3.7 MBq). However, the activity of 30 GBq, calculated based on the 662.4 keV peak, is far two high to be explained by the smoke detectors. Therefore, the box must contain another hidden ^{241}Am source which is far more active than the smoke detectors. The difference between the areas of the 59.5 keV and 662.4 keV peaks shows that the hidden source must be shielded, for example, with at least 1 cm of steel or around 2 mm of lead. Detection of ^{241}Am is an alarming sign, since it may indicate the presence of plutonium. Therefore, the spectrum was analysed once more in greater detail. The analyses revealed small traces of plutonium peaks (especially ^{239}Pu with the 413 keV and 375 keV peaks visible). The conclusion is that in addition to the smoke detectors, the cardboard box contains a hidden, shielded source. The hidden source contains at least tens of gigabecquerels of ^{241}Am and probably also different plutonium isotopes. Immediate securing of the source is required. Plutonium isotopic composition and age from purification will be determined later when the source has first been located and the geometry of the shielding figured out.
14	No	The spectrum shows only ^{241}Am. It is possible to calculate a rough activity of 5.2 MBq using the enclosed calibrations spectrum. Although this calibration is for a point source 30 cm from the detector, and thus do not apply for the geometry of the 100 smoke detectors in a cardboard box, it is still in consistence with the total activity of 3.7 GBq stated for the smoke detectors.
15	Yes	The collected spectrum contains multiple peaks from ^{241}Am. In addition, statistically significant peaks at 413 keV and 375 keV could suggest the presence of a small quantity of ^{239}Pu. The 129 keV peak is present both in background (probably from ^{228}Ac) and source spectra. As special nuclear material is possibly present, further investigation is recommended.

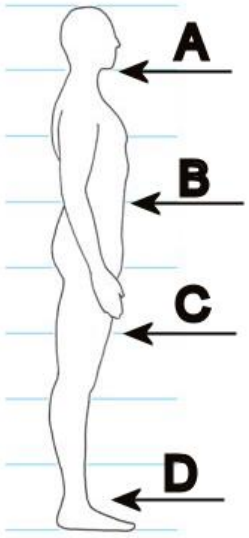
Table 9. Participant responses for Situation 4.

2.5 Situation 5.

Situation 5 represented triggering of border alarms by an individual who had been treated with a medical isotope, in this case ^{123}I. In addition, present on his wrist was a wristwatch with a radium dial which contributed to some of the spectra taken. The individual contained 1.2 MBq of ^{123}I concentrated mostly in his thyroid. The wrist watch contained 6909 Bq of ^{226}Ra with the daughters in a state of secular equilibrium as would be obtained after 40 years.

The measurements taken were such that distances changed between detector and both sources as one moved down the body. The approximate situation for the four measurements was :

Point A is 20 cm from the iodine and 100 cm from the radium
Point B is 50 cm from the iodine and 40 cm from the radium
Point C is 1 m from the iodine and 20 cm from the radium
Point D is 1.5 m from the iodine and 50 cm from the radium



Appropriate shielding materials were included at each point along the body.

The materials of Situation 5 were relatively straightforward. There were no confounding factors that would have complicated the identification of ^{123}I. The only other aspect of the situation that may have been problematic was deciding whether or not the spectra contained evidence of any material that was not ^{123}I. All peaks present in the spectra other than those from ^{123}I were accountable by background. Two participants posited the possible presence of SNM. One of these participants based the observation of possible SNM on a probable misidentification of the ^{123}I source. The second introduced the possibility based on variation in the 186 keV peak relative to others (from the ^{232}Th series).

Participant Number	SNM-yes/no	Comments
1	No	As the man on the bus is acting strangely and refuses to be searched I would definitely be suspicious. On the other hand the spectra A, B, C, D seem quite identical, except the ^{123}I peaks in spectrum A, which is consistent with the man's story about coming from the hospital (where he then most probably had thyroid treatment). Without any further findings, I would say that there's no SNM involved.
2	No	The man has undergone medical treatment involving the use of ^{123}I. This is further emphasized by the fact that the concentration of iodine is highest closest to the thyroid. No hidden radionuclides are observed.
3	No	Man seems to tell the truth, since ^{123}I can be found from the area of his thyroid. Probably he has been in some kind of a gamma imaging of his thyroid. No other suspicious radioactivities found (so no special nuclear materials involved), other peaks seem to originate from the background, count rates being quite independent on the measurement position.
4	No	In places B, C, D only natural background increasing towards land surface, in place A ^{47}Sc isotope which is used for medical treatment: Cancer treatment/diagnostics (F), monoclonal antibodies (F), radioimmunotherapy (F). Decision: Passenger treated with medical isotope ^{47}Sc MED.
5		No response
6	No	Person after an medical application Result: Only on thyroid gland the source ^{123}I could be measured. Activity about 0.5 MBq to 1 MBq. The body do not show other man-made radionuclide. No abnormality else.
7	No	I-123 and naturally occurring lines, eg. ^{212}Pb. Medical isotopes In thyroid (spectrum A), NORM near feet.
8	No	I-123 Only in spectrum 5A was detected artificial radionuclide used in nuclear medicine.
9	No	The man shows ^{123}I in the upper scan (neck/head). I-123 is a medical tracer. All other visible isotopes are natural.
10	No	The man does not carry SNM but an Iodine isotope in his neck, probably because of the medical treatment. The observed gamma lines match ^{123}I (T1/2 = 13.3 h).
11	Yes	Situation 5a revealed that the person emitted gamma rays from ^{123}I, which may support his arguments regarding medical treatments. However, scans from other parts of his body revealed traces of actinides and special nuclear material; U-235 (5A-D), ^{234}Th (5C-D), ^{239}Np (5A-D), ^{236}Np (5B-D), ^{238}U (5C), ^{242}Pu (5A), ^{241}Pu (5A,B,D), ^{239}Pu (5C).
12		No response
13	Yes	SNM possibly present. I-123 is identified from the spectrum measured at positions A (strong signal) and very weak signal at position D. No ^{123}I signal at positions B and C. Ratio of the ^{235}U/^{226}Ra peak at 185.7 keV to ^{228}Ac is different for between (B,C) and (A,D) even though the count rate of the 185.7 keV peak does not fluctuate much. This is hinting that a ^{235}Usource(s) could be present at a location(s) around point B and C. I-123 is a medical isotope used in the study of thyroid diseases. This does not contradict what the man is saying.

		However, detection of ^{123}I only at the position A and a very weak signal at D is surprising since administered ^{123}I spreads around the body (although most of it is concentrated on the thyroid) and should be detectable in other positions also. It is possible that ^{123}I is not present *in vivo* but in a shielded ampoule located around the neck area. Full body search is recommended to check for the presence of ^{235}U source.
14	No	The spectrum measured at D shows normal background only. This is also the case for the spectrum at C. Spectrum B shows a bit more K but nothing out of the ordinary. The spectrum measured at A (neck area), however, includes signals from the ^{123}I (T1/2 13,2 hours) gamma energies at 159 keV, 248 keV, 280 keV, 346 keV, 440 keV, 505 keV, 529 keV 538,5 keV and 624 keV. I-123 is concentrated in the thyroid which is consistent with the highest concentration measured at A. The measurements are in agreement with the man claiming to have been in hospital and he does not pose a threat to the surroundings.
15	No	The non-background peaks found in the spectra are all attributable to ^{123}I. The highest activity was found in the neck region (consistent with diagnostic study of the thyroid diseases). In position D, a significant peak at 129 keV is visible in the spectrum which in theory could originate from ^{239}Pu. However, there are no visible peaks at 413 keV and 375 keV as would be expected, and in addition there is a large spectral contribution from the ^{232}Th decay series. Our conclusion therefore is that the 129 keV peak originates from ^{228}Ac and that no special nuclear material is present. The measurements at points A to D show only a small variation in signals from the ^{238}U daughter nuclides, while the difference in ^{232}Th daughters are significantly higher in spectra A and D, compared to B and C. A further investigation of this variation could be recommended.

Table 10. Participant response to Situation 5.

2.6 Situation 6.

The circumstances in this instance involved interception of what appeared, based on the immediately obvious evidence provided on the case itself and within the shipping documents, to be an ^{192}Ir radiography source in a depleted uranium shielded carrying case. In actuality, the source present, aside from the depleted uranium shielding, was 2 kg of reasonably impure (20 ppm of ^{232}U) ^{233}U of 30 years since manufacture.

Assuming a specific activity for ^{233}U of 3.6 x 10^{11} Bq/kg and that of ^{232}U being 7.9 x 10^{14} Bq/kg, the 2 kg of ^{233}U plus its impurity would have activities of 7.2 x 10^{11} Bq and 31600000 Bq respectively. After 30 years the ^{233}U and ^{232}U activities were :

Isotope	Bq	Isotope	Bq
^{233}U	7.20E+11	^{232}U	2.4E+07
^{229}Th	2.04E+09	^{228}Th	2.4E+07
^{225}Ra	2.03E+09	^{224}Ra	2.4E+07
^{225}Ac	2.03E+09	^{220}Rn	2.4E+07
^{221}Fr	2.03E+09	^{216}Po	2.4E+07
^{217}At	2.03E+09	^{212}Pb	2.4E+07
^{213}Bi	2.03E+09	^{212}Bi	2.4E+07
^{213}Po	1.99E+09	^{212}Po	1.6E+07
^{209}Tl	43848000	^{208}Tl	8737400
^{209}Pb	2.03E+09		

Table 11. isotopes and activities of the ^{233}U source of Situation 6.

The container the source was concealed in was assumed to contain 16.8 kg of 20 year old depleted uranium with a density of 19.1 g/cm^3 and being of the following composition at time 0:

^{238}U, 99.8%, 16.76 kg, specific activity 1.2 x 10^7 Bq/kg, activity 201120000 Bq.
^{235}U, 0.2%, 0.0336 kg, specific activity 8.0 x 10^7 Bq/kg, activity 2688000 Bq.
^{236}U, 0.0003%, 0.000504 kg, specific activity 2.4 x10^9 Bq/kg, activity 1209600 Bq.
^{234}U, 0.0006%, 0.001008 kg, specific activity 2.3 x 10^{11}Bq/kg, activity 231840000 Bq

After 20 years the depleted uranium was of the following composition (Table 12) with only shaded isotopes being used in the simulation:

Isotope	Bq	Isotope	Bq	Isotope	Bq	Isotope	Bq
^{238}U	2.01E+08	^{235}U	2688000	^{234}U	2.32E+08	^{236}U	1209600
^{234}Th	2.01E+08	^{231}Th	2688000	^{230}Th	41731.2	^{232}Th	0.001198
^{234m}Pa	2.01E+08	^{231}Pa	1135.68	^{226}Ra	180.2788	^{228}Ra	0.000745
^{234}Pa	663092.6	^{227}Ac	295.1424	^{222}Rn	180.0006	^{228}Ac	0.000745
^{234}U	11371.32	^{227}Th	289.2288	^{218}Po	180.0006	^{228}Th	0.000603
^{230}Th	1.018673	^{223}Fr	4.075008	^{214}Pb	179.9774	^{224}Ra	0.000602
^{226}Ra	0.002922	^{223}Ra	292.1856	^{218}At	0.036005	^{220}Rn	0.000602
^{222}Rn	0.002916	^{219}Rn	292.1856	^{214}Bi	180.0006	^{216}Po	0.000602
^{218}Po	0.002916	^{215}Po	292.1856	^{214}Po	179.9774	^{212}Pb	0.000602
^{214}Pb	0.002914	^{211}Pb	292.1856	^{210}Pb	32.15621	^{212}Bi	0.000602
^{218}At	5.83E-07	^{211}Bi	292.1856	^{210}Bi	32.06347	^{212}Po	0.000385
^{214}Bi	0.002916	^{207}Tl	291.3792	^{210}Po	29.67552	^{208}Tl	0.000216
^{214}Po	0.002914	^{211}Po	0.817958				
^{210}Pb	0.0004						
^{210}Bi	0.000399						
^{210}Po	0.00036						

Table 12. Isotopes and activities for the depleted uranium shield of Situation 6.

The ^{233}U source was only visible through the peaks of its daughter products as ^{233}U has no significant peaks of its own. Bi-213 peaks were visible at 440.6 keV, 807.3 keV (interfered with by an erroneous ^{234m}Pa peak at 810 keV), a strong peak at 1100 keV, and a peak at 1119 keV, the combination of these peaks being sufficient to identify the daughter product. More characteristic for the ^{233}U series and easily recognisable in the spectrum was the ^{209}Tl peak at 1567 keV. A strong and easily recognisable ^{208}Tl peak was present at 2614 keV. The rest of the spectrum was largely dominated by small contributions from early daughters such as ^{234}Th and $^{234/234m}$Pa.

Participant Number	SNM-Yes/no	Comments
1	Unsure	As expected there are lot of daughter nuclides of ^{238}U, because of the depleted uranium casing. Since yet again I see clearly the quite low energy ^{235}U photopeaks, I would investigate the uranium shielded container more closely, to be sure that there is not too much ^{235}U or other SNM involved.
2	Yes	Many peaks are observed in this spectrum, and most of them stem from ^{234m}Pa in the depleted uranium container. The box does not contain ^{192}Ir. An interesting peak is observed at 1.57 MeV. This peak may be due to n, gamma reactions involving weapons grade plutonium.
3	Yes	This case seems suspicious: no ^{192}Ir gammas can be seen. Even though the shielding is thick, one could expect to see at least a hint of the the over 600 keV gammas. The shielding gives out ^{234}Pa (m and g) gammas, as expected, but then one can see also gammas from ^{232}Th decay series and ^{233}U decay series. So – this seems that nuclear materials are being smuggled here.
4	Yes	According paper radioactive equipment in the box is ^{192}Ir activity 0.4 TBq. NO ^{192}Ir peaks found in the spectra! Depleted uranium is detected from spectra. Other detected nuclides: ^{88}Y, ^{97}Zr, ^{95}Nb and ^{129}Sb. Decision: Suspected nuclear material. SMN?
5		No response
6	No	Box produced out of DU. Should be one source for radiography inside (0,4TBq ^{192}Ir). Result: DU about 15 kg equal to the sign on the box. ^{192}Ir is not seen in the spectra - no peaks! Calculated detection limit about 1,5 E10 Bq (at 1061.5 keV). This value is lower by a factor of 20 under the activity given on the paperwork (4 E11 Bq). Solution ^{192}I is older than 4 times half-life or there is no source inside. Should be checked in detail. Perhaps on the box some letters made with luminous color with ^{229}Tl; likely there is an ^{229}Tl Source in the box. Abnormality: Peak at 1567 keV – it is not from Uranium or ^{192}Ir.
7	No	U-235, possibly ^{209}Tl and others unconfirmed. No ^{192}Ir peaks seen in spectrum.
8	Yes	Th-233/^{233}U. Container consist of Uranium and on spectrum are no visible low energy. Inside of container are fission materials like ^{233}Th/^{233}U. We are identification by lines 440keV,1567keV.
9	Yes	There is no sign of ^{192}Ir. The depleted uranium container is visible through the ^{234m}Pa peak at 1001 keV. The absence of ^{214}Bi peaks is due to insufficient time to retain equilibrium in the ^{238}U decay chain after processing the material. Apart from the depleted uranium, the clear 1567 keV peak (^{209}Tl) suggests presence of ^{233}U (supported by the smaller peak at 440 keV). Activity att 2614 keV (^{208}Tl) but absence of activity at 911 keV (^{228}Ac) suggests ^{232}U, rather than ^{232}Th. The ^{232}U and ^{233}U would not generally be a part of the d.u., but rather resides inside the container.
10	No	So far the transport documentation does not match the visualized spectrum. The gamma lines corresponding to the housing of depleted uranium show up in the spectrum but the very clear singlet at 1566.7 keV could not be identified. It was noted that the ^{208}Tl@2614.5 keV is much more apparent in the unknown spectrum than in the background spectrum, maybe an indication of some activation process is going on inside of the housing.

		The ^{192}Ir gamma lines from the source of 0.4 TBq are not seen probably because of the effective shielding offered by the depleted Uranium shielded container.
11	No	No peaks from ^{192}Ir were found while other peaks from, e.g., ^{123}I and ^{189}Pt at energies below 700 keV were identified. This is not in correspondence with the declared activity. One gamma peak from ^{235}U at 143 keV was identified, which was not mentioned in the declarations. No peaks at all from ^{238}U were found, this also disagrees with the declaration that claims that the source is shielded by depleted uranium.
12		No response
13	Yes	SNM present. There is no ^{192}Ir visible. There is strong evidence of ^{238}U and also ^{235}U visible (consistent with a depleted shield). Strong line at 1567 keV + smaller line at 465 keV belongs to ^{209}Tl, lines at 440 keV, 1100 keV and 1119 keV belongs to ^{213}Bi. This is a strong indication that there is ^{233}U progeny present behind a heavy shield, as the gamma lines of other nuclides in the ^{233}U chain has either low energy or very low yield. Also some evidence for trace levels of ^{232}U can be found. The 1620 keV peak of ^{212}Bi is much bigger than the 727 keV peak, indicating shielded ^{212}Bi. At the same time any evidence of ^{228}Ac is missing (strong lines at 911, 968 and 1588keV), which excludes the ^{232}Th full decay chain. As pure radon emanation is not a probable conclusion, and with the evidence of ^{233}U, the most likely conclusion for this ^{212}Bi is ^{232}U.
14	Yes	The spectrum is consistent with a depleted uranium shielded container. However, there is no trace of ^{192}Ir in the container. More likely, it contains irradiated ^{232}Th, that is, ^{233}U and its decay products. Gamma energies at 440 keV, 807 keV and 1100 keV indicate ^{213}Bi, which is a progeny of ^{233}U.
15	Yes	The spectrum reveals nuclides from the ^{233}U decay series (peaks are from ^{229}Th together with short-lived daughters) in addition to peaks from the depleted uranium shielding (^{234}Th, ^{234m}Pa and ^{235}U), suggesting a presence of heavily shielded ^{233}U. There is also a strong 2614 peak from ^{208}Tl in combination with absent peaks from ^{228}Ac (for example 911 keV). This shows that ^{232}U is also present. No peaks from ^{192}Ir have been detected. Our conclusion is that special nuclear material is present inside the depleted uranium shielding.

Table 13. Participant responses to Situation 6.

3.0 Observations

Although the GASMAT activity was not intended to be, nor was conducted as, a proficiency test, it is possible, even in the absence of some strict measure of performance against which comparison may be made, to observe some patterns or tendencies within the results. For a situation where a spectrum resembles a possibly suspect source, such as Situation 3, the majority of participants were in a position to distinguish between SNM and the constituent isotopes. In one of the cases where the source was reported as being possibly SNM, this classification was made based on misidentification of the isotopes not for SNM isotopes but for something else. For Situation 5, even in the presence of a fairly variable background (along the length of the body) the vast majority of participants were able to correctly decide that no SNM was present. Even for those participants who noticed variations in the background signal, they were in a position to decide that no materials of concern were present. Situation 1, representing a complex, but entirely innocent source was less simple for participants. Assignation of the source was relatively simple – the information in the spectrum was, in the main, consistent with what the ancilliary information indicated. Most participants were also in a position to correctly identify an anomalous feature of the materials provided – the presence of the depleted uranium source. Even the limited information within the spectrum as to this source did not result in any participant incorrectly identifying the source as SNM. A similar situation was presented in Situation 2 – the concealment of a second source within a mass of something entirely innocent – except in this case the concealed source was SNM. The signals from both sources in this case were, qualitatively, similar. The key to figuring out that source contained something its shouldn't was the comparison of the spectra taken at different positions around the container. Individual analysis of the four spectra would probably not have resulted in any observation out of the ordinary. In this context the majority of the participants adopted an approach that led to the correct conclusion that SNM was present. Situation 4, in contrast, involved a situation where the SNM source was concealed within a larger legitimate source which could theoretically have accounted for the features of the spectrum arising from the concealed SNM. Only by consideration of the amount of the legitimate masking source apparently present and with a reasonably in-depth knowledge of how such a source might appear in terms of its gamma spectrum could the user have been alerted to the fact that all was not as it seems. The participants who were in a position to decide that SNM was present often adopted more than one approach and it is unclear in which order they were applied. The user could have observed that there were possibly some plutonium peaks present and then determined that the ^{241}Am peaks present could not have arisen from the stated activity of the smoke detectors. Alternatively the user could have decided that the ^{241}Am peaks present could not be accounted for by the masking source and then initiated a search for the very weak plutonium lines actually present. Some participants observed the apparently much higher ^{241}Am activity than was stated on the forms yet did not conclude that the shipment contained anything other than the smoke detectors. This situation possibly arises from an analyst being unaware that a plutonium source could actually look like ^{241}Am. In a similar manner to Situation 4, Situation 6 involved SNM being passed off as something else. In this case, the source was being heavily shielded by a legitimate material but no attempt was made to make the source look like something else (except for the label on the shipping container). The situation presented a number of difficulties for the analyst – the shielding material was in itself active and contributed

to the spectrum. The source is perhaps less well known than others and is only really identifiable within the context of this scenario by emissions of some daughters. Even had analysts been in a position to identify the daughter they would still have had to make the connection between it and the parent SNM material. In addition, the SNM material contained a significant amount of an impurity, in this case ^{232}U, the emissions of which could be reasonably expected to have complicated the matter. A number of participants produced false negatives for the materials of Situation 3. Some of these false negatives appeared to be based on there being no evidence of ^{192}Ir within the box and an assumption of SNM based on unclear or incomplete identification of other materials such as the depleted uranium shielding. Only relatively few participants were able to correctly elaborate upon the overall situation for Situation 6.

The purpose of the GASMAT activity was to provide an exercise or training opportunity. In this context, and given that the invitation to the activity expressly stated this, it could not be expected that every participant would provide totally accurate answers to the materials provided. There appear to be indications within the responses that some participants were not entirely aware of what they could possibly expect in terms of SNM. The lack of identification of ^{233}U by some participants may possibly be ascribable to a lack of awareness that this material constitutes SNM for example. There is some evidence that participants were reliant on libraries for identification of isotopes/sources. This is apparent when sources begin to be misidentified as rather more exotic isotopes than could reasonably be expected for the situations to hand. It is possible that an interesting approach to this problem could be the development of libraries for use in such situations where SNM could possibly present or where there is at least an interest in ensuring that it is not. It is obvious that some participants are more flexible in their approaches than others and are willing to extract the most information they can from the materials. For Situation 6 it was of course possible to do a rudimentary estimation of whether or not the low probability peaks of ^{241}Am would be visible or not for the stated amount of activity and this approach was adopted by some participants.

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APPENDIX 1.

Technical Details for the GASMAT Materials

The Detector

The detector and its setup are the same for all scenarios– this is to remove the extra work that was involved in previous exercises where participants had to calibrate detectors for each scenario and because calibration is not really a part of this activity.

The detector for GASMAT is a very standard generic coax HPGe. The detector holder is 0.51 mm thick aluminium with a 3 mm spacing between crystal face and detector end cap. A uniform dead layer of 1 mm is assumed all round the crystal. The crystal is 6 cm in diameter and 7 cm long. Relative efficiency is approximately 40% and the resolution is 1.8 keV at 1332 keV.

The detector is set up such that the energy calibration can be described with a zero of 1.353606 keV and a gain of 0.3320552 keV/channel with a full scale energy of 2721.5 kev (8192 channels).

A spectrum is provided of various isotopes in point source geometry presented normally to the front face of the detector along the central axis with no background present and counted to achieve reasonable statistics. Participants can use this to conduct their own energy/shape calibrations or determine some rudimentary efficiency calibration if they desire (please see the section on activity/quantitative analysis).

The isotopes included in this calibrations spectrum, all being 10 kBq and the spectrum being taken for a point source 30 cm from the end cap, were:

Americium-241, Cadmium-109, Cesium-137, Cobalt-60, Zinc-65, Manganese-54 and Cobalt-57.

Points to Remember –please read this!

15. The absolute aim of this activity is to figure out which of the scenarios are situations possibly involving special nuclear material – as described in the invitation email – and which probably involve something more innocent such as NORM, medical isotopes, etc etc. Qualitative analysis is the main concern of this exercise. No assurances are being provided as to the materials being presented containing information of sufficient quality to conduct detailed quantitative measurements. Please note that not all types of special nuclear material may be included. While no assurances are being made as to the material being sufficient to calculate activities in

Bq's please note that information in the spectrum (such as peak ratios) should be of sufficient quality (allowing for possible shielding or whatever) to perhaps hazard a guess at what form a material is in, what type of material it may be, etc etc.

At any rate, participants should feel free to report whatever they want to – this exercise is not a proficiency test and participants should not be worried about getting "wrong" answers.

2. Neutrons or any effects arising from beta particles are not included in simulations. Nor are the effects of high count rates.

3. X-rays below about 40 keV are most likely unreliable in this instance – please do not try and use low energy x-rays in any determinations.

4. Unlike in previous activities such as REMSPEC etc, background in this activity is included in all scenarios. Background is to be taken as the gamma spectra recorded in the environs but not near the source. In some cases a background spectrum is provided. In some cases a background spectrum is not provided but one can assume that background is still actually present in the sample spectrum. One should bear in mind that the background measured may or may not be entirely representative of the background contrinution to the actual suspect source spectrum depending on where it was taken.

5. The 511 keV annihalation peak is not included in any spectra.

6. All spectra were measured at distances hopefully great enough to exclude any possible true summation effects.

7. The background spectra provided do not include anything that are not natural – fallout nuclides, Chernobyl signals etc. are not included in background spectra.

8. The spectra are provided in a range of common formats. In most (if not all of the cases) the only reliable information in the files is channels, counts and live time. For files such as Canberras cnf you will probably have to open it, load the energy/shape calibration you made and save it again before it will let you do any analysis on the file in Genie. In addition, at least some versions of Genie seem reluctant to proceed to an actual identification phase of an analysis without some kind of efficiency calibration being present. In such circumstances or if this affects you….I suggest you use the calibration spectrum to derive a "dummy" efficiency calibration and use that, bearing in mind that quantitative results based upon such a calibration will be most likely wrong..

For formats such as .phd……. the only information that is reliable is the counts per channel and time. Everything else is just default information and should not be relied upon. See the section on phd format below.

9. Any date information such as date and time the spectrum was obtained is probably incorrect and spurious. Attempting to utilise that information in any way will probably cause problems, At any rate, decay should be entirely irrelevant for the purposes of the exercise. In a similar manner – live times and real times may be equal in some cases (for simplicity).

10. The source for all nuclear data was Lunds ToI at http://nucleardata.nuclear.lu.se/toi/index.asp Data was correct from this source as of the spring of this year.

11. Please use the same spectral format for the calibration spectrum and the scenario spectra. This is to ensure that there are no unforeseen differences between and two formats (such as the first channel being channel 0 or channel 1 or whatever).

12. The organisers can in no way assure that the materials distributed are in any way suitable for specialised suites such as MGA or MGAU or anything else. If a participant chooses to employ such suites and gets a crazy answer – consider yourself as having been warned!!!.

13. If the GASMAT materials are to be used in any other context than the GASMAT activity, the organisers would be grateful that full and appropriate acknowledgement is made to both the organiser and NKS and that attention is paid to the disclaimer down below.

14. The files are being submitted as .zip archives. In this archive, the Canberra file with the cnf extension causes some problems with some virus programs as the extension is or was also a windows system file of some type. The Canberra file is therefore named with the .cnx extension. Please rename to the cnf extension.

15. Please disable all your coincidence summation, density correction, decay correction and mother/daughter routines within your analysis software prior to attempting the GASMAT materials.

If there are problems with anything please contact me at mark.dowdall@nrpa.no

Regarding the phd format.

These files include a lot of information and not all of it, as for the other formats, is going to be correct. Any information as to energy, shape or efficiency calibrations in the files will most likely be erroneous. You must calibrate for energy and shape yourselves. What you do with efficiency is up to yourselves.

Please note that all the time information in the file as to sample collection and things is wrong. The only thing that is correct is the live time. At any rate – time should have essentially no bearing on this exercise as qualitative measurements are what is the primary goal.

The matrix for the channel-counts in the phd format confuses me a little – some examples seem to denote the first channel as 1 and some denote it as 0. I have denoted as 1. I'm hoping that causes no problems. I did this because it was the way some of the other formats did it. If it does cause an issue it should be easy enough to write a batch file to fix it or something. Maybe its not a problem at all.

APPENDIX 2.

Situation 1

A truck is stopped at a border crossing after triggering a radiation portal. Search with handheld detectors indicates the presence of a source on board which cannot be identified by the operators so authorities are asked to assist. The shipping documents indicate that the truck is supposed to be carrying "aviation components" from an old military base to a scrap metal firm in a second country. Limited visual inspection inside the truck indicate what appear to be open topped wooden shipping crates filled with what look to be old motors and metal junk. One of these crates seems to be responsible for the elevated gamma readings. What appears to be the designation "HK31A" is visible stamped on a casing of one of the pieces in the crate.

Due to the way the crates are stacked, only one face of the suspect crate is accessible. A spectrum is at about 1 meter from the visible crate face.

Prior to entering the truck a background spectrum was accrued for 300 seconds by simply holding the detector at about 1 meter over the ground.

Spectra provided:

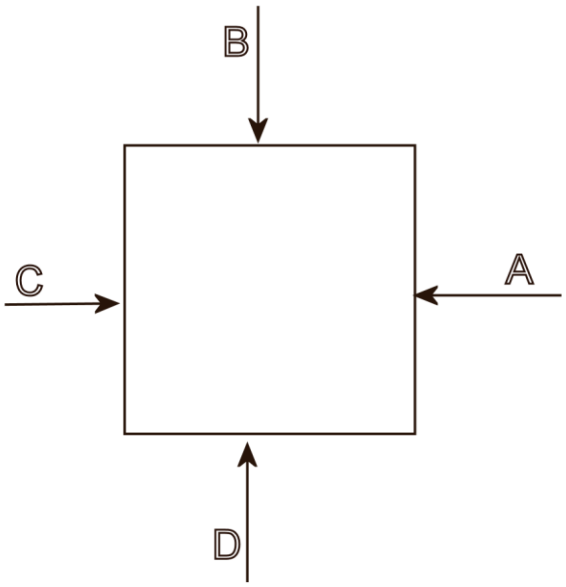
Spectrum at the side of the crate	Situation 1.chn/.cnf/.spe/.txt/.phd
Background spectrum	Situation 1 background.chn cnf/.spe/.txt/.phd

Situation 2

A large truck is stopped by customs as part of a routine check. On exploring the truck, a dosemeter carried by one of the customs officials registers elevated readings near a pallet stacked with sacks. The driver says he is on his way to deliver goods to an agricultural supply firm in another country. The pallet, approximately 1 m x 1 m , is stacked with sacks, to a height of about 90 cm, with Chinese writing on them but the identifier MKP 0-52-34/NPK 0-52-34 is clearly visible. As the customs officials are unsure what to do and the country of origin is such that suspicions are aroused, authorities are asked to assist.

Four measurements are made around the pallet using a HPGe detector, all measurements being made at the same distance - 10cm - from the stack of sacks.

A 5 minute background spectrum is taken outside the truck.



Spectra provided:

Spectrum taken at position A	Situation 2 Position A.chn/.cnf/.spe./txt/.phd
Spectrum taken at position B	Situation 2 position B.chn/.cnf/.spe./txt/.phd
Spectrum taken at position C	Situation 2 position C.chn/.cnf/.spe./txt/.phd
Spectrum taken at position D	Situation 2 position D.chn/.cnf/.spe./txt/.phd

5 minute background spectrum	Situation 2 background.chn/.cnf/.spe./txt/.phd

Situation 3

A man is stopped at an airport security check point and subjected to a random search. In his luggage are instruments which cannot be identified and for which the man has neither papers nor explanation. He maintains, in poor english, that he is travelling to a trade exhibition and is carrying this equipment for a friend who will be exhibiting at the show and is arriving on a later flight. They will meet at his hotel. The instruments are routinely swabbed for explosives and in the course of this examination, a small metal box within the instrument case registers as being radioactive. The box is unopened and the handheld identifiers used at the airport do not identify the source. The authorities are called in to identify the source.

No separate background measurement or spectrum was taken at the airport.

Spectra provided:

Spectrum taken of the source Situation 3.chn/.cnf/.spe/.txt/.phd

Situation 4

A commercial vehicle is stopped at a customs point and the load is checked. The manifest includes a cargo of smoke detectors being imported into the country and states that there are 100 smoke detectors in a cardboard box. The customs officials are concerned as to their exposure in checking the cargo and request that someone confirms that it is safe. In the interest of public relations and seeing a possible training opportunity the authorities dispatch a junior staff member with an HPGe detector. The staff member takes a background spectrum outside the truck and then takes a spectrum approximately 20 cm from the side of the cardboard box.

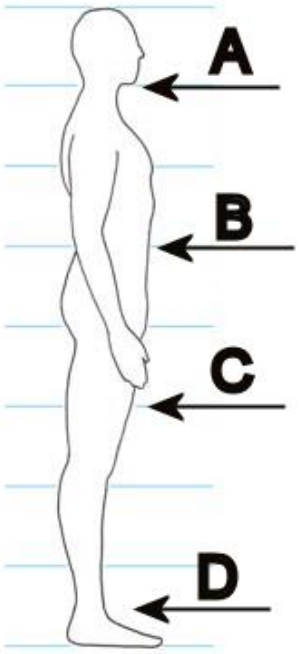
Spectra provided:

Spectrum at the side of the box	Situation 4.chn/.cnf/.spe/.txt/.phd
Background spectrum	Situation 4 background.chn/.cnf/.spe/.txt/.phd

Situation 5

A man is observed acting strangely on board a bus passing a border crossing. Upon disembarkation for checking of papers the man passes in front of the radiation portal monitor at the roadside and an alarm is signalled. The man maintains he has recently been in hospital and is travelling to visit his relatives to recuperate. Handheld monitors indicate the possible presence of a source on the man who refuses to submit to a search of his person. Localisation or identification of the source is beyond the capabilities of the border presonel who ask the authorities to assist.

The authorities conduct a scan of the man using a HPGe detector. A series of four measurements are made – the first near his head/neck (Measurement A), the second near his thorax (Measurement B), the third near his pockets (Measurement C) and the fourth near his shoes (Measurement D). Measurement points are indicated in the attached diagram. The measurements were made approximately 20 cm away from the surface of the body in each case. No separate background measurement was made.



Spectra provided:

Spectrum taken at position A	Situation 5 position A.chn/.cnf/.spec/.txt/.phd
Spectrum taken at position B	Situation 5 position B.chn/.cnf/.spec/.txt/.phd
Spectrum taken at position C	Situation 5 position C.chn/.cnf/.spec/.txt/.phd
Spectrum taken at position D	Situation 5 position D.chn/.cnf/.spec/.txt/.phd

Situation 6

At a customs check point a truck passes through the goods to declare channel. The driver states that he is transporting industrial radiography equipment. He is in possession of documents that indicate that an industrial radiography device is being sent from one office of a company to a daughter office of the same company in another country. From the documents to hand, the source is stated to be an Ir-192 source of 0.4 TBq housed in a depleted uranium shielded container as pictured. All paperwork is in order and a visual inspection indicates that the radiography device is appropriately stored and labelled. The customs official has acquired a new "identifier" type device and decides to test it. He obtains a measurement at the side of the metal container and feels that this is (as reported by him) "too high" and the package may be faulty. He contacts the authorities and they attend and take a spectrum 30 cm from the side of the box with a HPGe detector.

The operator takes a 5 minute background spectrum outside the vehicle.

Spectra provided:

Spectrum taken at the side of the box	Situation 6.chn/.cnf/.spe/.txt/.phd
Background spectrum	Situation 6 background.chn/.cnf/.spe/.txt/.phd

APPENDIX 3.

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
116	39.9	7.2	212Bi	771	257.5	34.4	228Ac
167	57	2.2	228Ac	774	258.2	10.7	234mPa
170	57.8	58.9	228Ac	790	263.6	45.6	228Ac
187	63.3	44.5	234Th	810	270.2	3930.3	228Ac
188	63.8	52.7	232Th	831	277.4	2550.1	208Tl
229	77.3	10	228Ac	835	278.7	215.5	228Ac
247	83.3	2.3	234Th	845	282	81	228Ac
250	84.2	2.7	231Th	863	288.1	345.5	212Bi
250	84.4	586.2	228Th	877	292.7	6.9	224Ra
274	92.4	119.7	234Th	885	295.1	26.6	212Bi
275	92.8	119.9	234Th	900	300.1	3615.7	212Pb
296	99.5	868	228Ac	965	321.6	244.8	228Ac
298	100.4	65.2	228Ac	978	326	35.6	228Ac
336	112.8	23.1	234Th	982	327.5	129.1	228Ac
339	114	27.2	228Ac	984	328	148.9	212Bi
343	115.2	328.2	212Pb	984	328	3173.2	228Ac
370	124.1	20.6	212Bi	997	332.4	428.2	228Ac
385	129.1	1683.9	228Ac	1015	338.3	11985.8	228Ac
392	131.6	93.6	228Th	1023	341	391.4	228Ac
404	135.5	13.6	228Ac	1071	356.9	17.7	228Ac
411	137.9	18.7	228Ac	1118	372.6	6.9	228Ac
420	140.9	17	232Th	1134	378	25.4	228Ac
421	141	40.3	228Ac	1154	384.6	6.8	228Ac
429	143.8	6.3	235U	1168	389.1	10.4	228Ac
430	144	8.3	212Bi	1194	397.9	26.9	228Ac
435	145.8	133.6	228Ac	1198	399.2	36.3	228Ac
460	154	655.7	228Ac	1213	404.2	2.2	224Ra
488	163.4	4.1	235U	1229	409.5	1888.9	228Ac
490	164	4.9	212Bi	1246	415.2	139.2	212Pb
497	166.4	102.2	228Th	1250	416.3	12.9	228Ac
503	168.4	3	228Ac	1259	419.4	20.4	228Ac
504	168.7	10	228Ac	1267	422	2.9	224Ra
520	174	36.1	228Ac	1302	433.6	11.5	212Bi
528	176.7	54.2	212Pb	1322	440.4	115.2	228Ac
539	180.2	3.4	212Bi	1349	449.2	45.3	228Ac
552	184.5	75.7	228Ac	1359	452.5	14.1	228Ac
555	185.7	62.1	235U	1360	452.8	290.2	212Bi
572	191.4	136.2	228Ac	1373	457.4	14	228Ac
596	199.4	356.6	228Ac	1390	463	4094	228Ac
610	204	127.6	228Ac	1401	466.4	26.9	228Ac
614	205.3	6.7	235U	1412	470.2	12	228Ac
616	205.9	22.3	228Th	1417	471.8	30.4	228Ac
626	209.3	4453.5	228Ac	1422	473.6	42.2	212Bi
633	211.4	73	208Tl	1426	474.8	20.2	228Ac
643	214.9	33.3	228Ac	1437	478.4	191.5	228Ac
646	216	290.9	228Th	1444	480.9	21	228Ac
670	223.8	62.3	228Ac	1459	486	16.2	208Tl
680	227.3	2.3	234Pa	1473	490.3	10.1	228Ac
693	231.4	28.9	228Ac	1479	492.3	21.2	228Ac
699	233.4	126.8	208Tl	1480	492.7	5.4	212Bi
715	238.6	49747.5	212Pb	1494	497.5	5.3	228Ac
722	241	4708.8	224Ra	1513	503.7	191.9	228Ac
757	252.6	283.5	208Tl	1529	509	400.5	228Ac

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
1547	515.1	43.4	228Ac	2233	742.8	2.8	234Pa
1562	520.2	59	228Ac	2233	742.8	32.7	234mPa
1571	523.1	90.5	228Ac	2251	748.7	11.4	208Tl
1624	540.7	22.5	228Ac	2271	755.3	736.6	228Ac
1642	546.5	172.9	228Ac	2294	763.1	474.8	208Tl
1648	548.7	19.8	228Ac	2304	766.4	121.7	234mPa
1652	549.8	97.4	220Rn	2315	770.2	4.6	228Ac
1668	555.1	39.3	228Ac	2322	772.3	1085.8	228Ac
1690	562.5	738.3	228Ac	2327	774.1	43.7	228Ac
1709	568.9	4.2	234Pa	2334	776.5	13.8	228Ac
1711	569.5	9.6	234Pa	2339	778.1	16	228Ac
1715	570.9	153.4	228Ac	2349	781.4	3.2	234mPa
1719	572.3	126.3	228Ac	2351	782.1	353.8	228Ac
1752	583.2	25215.6	208Tl	2361	785.4	793.3	212Bi
1753	583.4	92.6	228Ac	2364	786.3	20.3	234mPa
1766	587.8	11.9	208Tl	2379	791.4	16.6	228Ac
1775	590.7	14.1	228Ac	2383	792.8	57.6	228Ac
1835	610.6	18.8	228Ac	2390	794.9	3054.4	228Ac
1852	616.2	65	228Ac	2393	796.1	3.6	234Pa
1864	620.3	64.8	228Ac	2423	805.9	3.5	234Pa
1864	620.4	2.9	212Bi	2447	813.8	5	228Ac
1873	623.3	8.9	228Ac	2455	816.6	21.3	228Ac
1885	627.2	11.3	228Ac	2463	819.2	2.6	234Pa
1891	629.4	36.2	228Ac	2469	821.1	10.1	208Tl
1906	634.2	8.5	228Ac	2480	824.9	35.3	228Ac
1924	640.3	43.1	228Ac	2481	825.1	2.6	234Pa
1940	645.5	4.3	224Ra	2497	830.5	380	228Ac
1951	649	63.4	228Ac	2500	831.5	5.8	234Pa
1954	650.1	10.2	208Tl	2513	835.7	1129.4	228Ac
1958	651.5	71.2	228Ac	2527	840.4	636.6	228Ac
1984	660.1	3.9	228Ac	2561	851.7	2.7	234mPa
1995	663.9	22	228Ac	2565	853.2	6.1	228Ac
2003	666.5	48.5	228Ac	2568	854	2.2	228Ac
2020	672	20.3	228Ac	2588	860.6	3073.6	208Tl
2026	674.2	84.8	228Ac	2617	870.5	30.3	228Ac
2035	677.1	48.1	228Ac	2625	873.1	21.3	228Ac
2056	684	14.7	228Ac	2629	874.5	32.3	228Ac
2068	688.1	103.2	228Ac	2634	876	3.6	234Pa
2077	691.1	3.1	234mPa	2638	877.4	9.6	228Ac
2081	692.5	4.3	228Ac	2647	880.5	5.7	234Pa
2101	699	4.7	234Pa	2648	880.5	8.6	234Pa
2101	699.1	28.3	228Ac	2648	880.8	4.2	228Ac
2109	701.6	2.8	234mPa	2656	883.2	13.7	234Pa
2109	701.7	132	228Ac	2656	883.3	7.6	208Tl
2120	705.2	6	208Tl	2658	884	69.4	228Ac
2122	705.9	3	234Pa	2668	887.3	18.4	228Ac
2126	707.4	117.8	228Ac	2668	887.3	3.1	234mPa
2170	722	54.1	208Tl	2686	893.4	255.7	212Bi
2185	726.9	46.5	228Ac	2702	898.7	4.7	234Pa
2186	727.3	4915.4	212Bi	2710	901.3	10.8	228Ac
2205	733.4	9.3	234Pa	2719	904.2	519.9	228Ac
2218	737.7	27.6	228Ac	2740	911.2	17354.7	228Ac
2224	740	4.8	234mPa	2764	919	18.1	228Ac

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
2772	921.7	5.6	234mPa	3492	1160.8	2.3	208Tl
2773	922	9.8	228Ac	3503	1164.6	38.6	228Ac
2774	922.5	9.8	228Ac	3535	1175.3	14.2	228Ac
2779	924.3	5	228Ac	3565	1185.1	3.6	208Tl
2782	925	11.3	234Pa	3591	1193.7	5.8	234mPa
2784	925.9	2.6	234Pa	3659	1216.4	15.1	228Ac
2787	926.7	10.4	234Pa	3698	1229.4	4.3	228Ac
2789	927.4	31.3	208Tl	3722	1237.2	2.3	234mPa
2799	930.9	8.3	228Ac	3746	1245.2	54.4	228Ac
2826	939.9	6	228Ac	3752	1247.1	286.2	228Ac
2839	944.2	62.8	228Ac	3760	1250	35.5	228Ac
2845	946	4.4	234mPa	3843	1277.5	11.5	228Ac
2845	946	19.5	234Pa	3859	1282.8	10.5	208Tl
2850	947.7	2.4	234Pa	3870	1286.3	28.2	228Ac
2851	948	69.9	228Ac	3874	1287.8	45	228Ac
2863	952.1	111.5	212Bi	3911	1300.1	4	212Bi
2883	958.6	183.8	228Ac	3940	1309.7	10.6	228Ac
2901	964.8	3264.6	228Ac	3957	1315.3	8.3	228Ac
2914	969	10312.4	228Ac	4054	1347.5	8.3	228Ac
2935	976	32.5	228Ac	4085	1357.8	10.9	228Ac
2946	979.5	16.9	228Ac	4109	1365.7	7.6	228Ac
2948	980.3	4.4	234Pa	4135	1374.2	7.6	228Ac
2948	980.3	2.9	234Pa	4147	1378.2	3.2	228Ac
2955	982.7	47.1	208Tl	4168	1385.4	5.7	228Ac
2960	984.2	2.4	234Pa	4194	1393.9	2.9	234Pa
2971	987.9	49.8	228Ac	4217	1401.5	6.5	228Ac
2973	988.6	49.8	228Ac	4259	1415.7	11.2	228Ac
2991	994.6	9.1	234Pa	4305	1431	17	228Ac
3011	1001	361.8	234mPa	4315	1434.2	4.2	228Ac
3057	1016.4	12.1	228Ac	4319	1435.4	4.1	234mPa
3061	1017.9	3.6	228Ac	4327	1438	3.1	228Ac
3067	1019.9	13.3	228Ac	4367	1451.4	5.6	228Ac
3108	1033.2	126.6	228Ac	4390	1459.1	436.3	228Ac
3127	1039.8	27.6	228Ac	4422	1469.7	10.5	228Ac
3131	1040.9	27.6	228Ac	4454	1480.4	8.3	228Ac
3167	1053.1	8.1	228Ac	4501	1495.9	445.9	228Ac
3171	1054.2	11.2	228Ac	4518	1501.6	238	228Ac
3196	1062.6	6.2	228Ac	4552	1512.8	148.8	212Bi
3203	1065	106	228Ac	4601	1529.1	29.2	228Ac
3231	1074.1	9.7	212Bi	4627	1537.9	24	228Ac
3232	1074.7	6.2	228Ac	4659	1548.5	21.9	228Ac
3244	1078.7	346.4	212Bi	4676	1554.1	3.4	234mPa
3273	1088.2	3.6	228Ac	4685	1557.1	90.2	228Ac
3290	1093.9	87.7	208Tl	4693	1559.8	10.1	228Ac
3296	1095.7	78.9	228Ac	4729	1571.5	2.9	228Ac
3321	1104	10.6	228Ac	4734	1573.3	16.6	228Ac
3341	1110.6	185.4	228Ac	4756	1580.5	301.4	228Ac
3362	1117.6	32.7	228Ac	4779	1588.2	1612.9	228Ac
3415	1135.4	7.3	228Ac	4792	1592.5	-1681.6	208Tl
3438	1142.9	6.1	228Ac	4843	1609.4	3.8	228Ac
3454	1148.2	3.5	228Ac	4876	1620.5	734.6	212Bi
3470	1153.5	82.9	228Ac	4890	1625.1	126	228Ac
3481	1157.1	4.2	228Ac	4907	1630.6	744.8	228Ac

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
4930	1638.3	231.2	228Ac	5523	1835.3	17.4	228Ac
5015	1666.5	86.6	228Ac	5544	1842.1	19.2	228Ac
5048	1677.7	26.2	228Ac	5568	1850.1	2	228Ac
5054	1679.7	28	212Bi	5621	1867.7	3.6	234mPa
5067	1684	7.3	228Ac	5630	1870.8	11	228Ac
5074	1686.1	45.9	228Ac	5643	1875.2	3.2	234mPa
5117	1700.6	4.9	228Ac	5679	1887.1	40.6	228Ac
5123	1702.4	2.3	228Ac	5739	1907.2	8.9	228Ac
5134	1706.2	4.1	228Ac	5752	1911.2	2.5	234mPa
5156	1713.5	2.6	228Ac	5808	1929.8	8.8	228Ac
5180	1721.4	2.7	228Ac	5876	1952.4	26	228Ac
5189	1724.2	15.2	228Ac	5914	1965.2	9	228Ac
5199	1727.8	2.7	234Pa	6331	2103.5	-1884.4	208Tl
5229	1737.8	8.5	234mPa	7870	2614.5	12712.4	208Tl
5231	1738.2	8.5	228Ac	5523	1835.3	17.4	228Ac
5237	1740.4	5.2	228Ac	5544	1842.1	19.2	228Ac
5241	1741.7	3.8	228Ac	5568	1850.1	2	228Ac
5252	1745.3	3.1	228Ac	5621	1867.7	3.6	234mPa
5268	1750.5	3.8	228Ac	5630	1870.8	11	228Ac
5291	1758.1	16.5	228Ac	5643	1875.2	3.2	234mPa
5313	1765.4	3.5	234mPa	5679	1887.1	40.6	228Ac
5370	1784.4	2.8	228Ac	5739	1907.2	8.9	228Ac
5419	1800.9	2	228Ac	5752	1911.2	2.5	234mPa
5435	1806	41.6	212Bi	5808	1929.8	8.8	228Ac
5487	1823.2	20.3	228Ac	5876	1952.4	26	228Ac
5512	1831.5	6.8	234mPa	5914	1965.2	9	228Ac
4930	1638.3	231.2	228Ac	6331	2103.5	-1884.4	208Tl
5015	1666.5	86.6	228Ac	7870	2614.5	12712.4	208Tl
5048	1677.7	26.2	228Ac				
5054	1679.7	28	212Bi				
5067	1684	7.3	228Ac				
5074	1686.1	45.9	228Ac				
5117	1700.6	4.9	228Ac				
5123	1702.4	2.3	228Ac				
5134	1706.2	4.1	228Ac				
5156	1713.5	2.6	228Ac				
5180	1721.4	2.7	228Ac				
5189	1724.2	15.2	228Ac				
5199	1727.8	2.7	234Pa				
5229	1737.8	8.5	234mPa				
5231	1738.2	8.5	228Ac				
5237	1740.4	5.2	228Ac				
5241	1741.7	3.8	228Ac				
5252	1745.3	3.1	228Ac				
5268	1750.5	3.8	228Ac				
5291	1758.1	16.5	228Ac				
5313	1765.4	3.5	234mPa				
5370	1784.4	2.8	228Ac				
5419	1800.9	2	228Ac				
5435	1806	41.6	212Bi				
5487	1823.2	20.3	228Ac				

Table I. Gamma photopeaks and counts for the spectrum of Situation 1. Background not included, x-rays not included. Negative values denote escape peaks.

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
156	53.2	3.1	214Pb	746	249.2	4.3	234Pa
185	62.9	2.1	234Th	774	258.2	37.4	234mPa
187	63.3	490.8	234Th	776	258.9	16	214Pb
219	73.9	2.2	234mPa	810	270.2	28.3	228Ac
219	73.9	2.9	234Th	820	273.8	4.5	214Bi
219	74	7.3	234Th	823	274.8	14.2	214Pb
241	81.2	9	231Th	831	277.4	10.6	208Tl
243	82.1	4.1	231Th	838	279.5	6.3	235U
247	83.3	18	234Th	881	293.8	4.8	234Pa
250	84.2	71.8	231Th	885	295.2	560.7	214Pb
250	84.4	2.7	228Th	900	300.1	14.8	212Pb
258	87	4.7	234Th	943	314.3	2.2	214Pb
267	89.9	11.6	231Th	984	328	22.3	228Ac
274	92.4	779.9	234Th	997	332.4	3	228Ac
275	92.8	775.4	234Th	1000	333.3	2.2	214Bi
296	99.5	6.4	228Ac	1015	338.3	84	228Ac
297	99.9	3.4	234Pa	1023	341	2.7	228Ac
304	102.3	6.3	231Th	1047	348.9	3.2	214Bi
321	108	3.8	234Th	1056	351.9	1011.9	214Pb
325	109.2	26.1	235U	1109	369.5	3.6	234Pa
336	112.8	105.2	234Th	1161	386.8	8	214Bi
338	113.5	3.9	238U	1167	388.9	9.5	214Bi
343	115.2	2.1	212Pb	1218	405.7	4.2	214Bi
385	129.1	17.3	228Ac	1229	409.5	13.1	228Ac
391	131.3	26.7	234Pa	1317	438.8	-622.2	40K
420	140.8	4.9	235U	1366	454.8	7.6	214Bi
429	143.8	248.1	235U	1387	462.1	5.3	214Pb
456	152.7	10	234Pa	1390	463	28.5	228Ac
460	154	5.9	228Ac	1411	469.8	3	214Bi
487	163.1	3.8	231Th	1425	474.4	2.6	214Bi
488	163.4	124	235U	1443	480.4	7.5	214Pb
546	182.5	8.6	235U	1463	487.1	9.8	214Pb
552	184.8	6.2	234Th	1529	509	2.8	228Ac
555	185.7	1459.1	235U	1534	510.8	29	208Tl
557	186.2	3.2	234Pa	1603	533.7	4.2	214Pb
557	186.2	116.4	226Ra	1690	562.5	5.2	228Ac
583	194.9	16.2	235U	1709	568.9	4.4	234Pa
587	196.2	2.3	214Pb	1711	569.5	9.9	234Pa
596	199.4	2.8	228Ac	1743	580.1	7.6	214Pb
597	199.6	2.6	235U	1752	583.2	102.4	208Tl
605	202.1	27.8	235U	1831	609.3	976.3	214Bi
608	203.1	2.2	234Pa	2000	665.5	29.9	214Bi
614	205.3	128.5	235U	2077	691.1	2.6	234mPa
626	209.3	34.4	228Ac	2101	699	4	234Pa
663	221.4	3	235U	2109	701.6	2.4	234mPa
678	226.5	7.4	234Pa	2113	703.1	9.5	214Bi
680	227.3	10.3	234Pa	2122	705.9	2.5	234Pa
712	237.8	2.2	231Th	2164	719.9	7.5	214Bi
715	238.6	213	212Pb	2205	733.4	7.6	234Pa
722	241	20.1	224Ra	2224	740	3.9	234mPa
725	242	232.5	214Pb	2233	742.8	2.2	234Pa

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
2233	742.8	26.4	234mPa	3633	1207.7	7.6	214Bi
2263	752.8	2.6	214Bi	3725	1238.1	94.8	214Bi
2271	755.3	5.3	228Ac	3752	1247.1	2.2	228Ac
2304	766.4	95.9	234mPa	3854	1281	23.1	214Bi
2310	768.4	95.8	214Bi	4145	1377.7	63.4	214Bi
2322	772.3	7.9	228Ac	4168	1385.3	11.9	214Bi
2349	781.4	2.5	234mPa	4217	1401.5	19.9	214Bi
2351	782.1	2.6	228Ac	4236	1408	33.7	214Bi
2363	786	20.6	214Pb	4319	1435.4	2.5	234mPa
2363	786.1	6	214Bi	4390	1459.1	3.5	228Ac
2364	786.3	15.7	234mPa	4395	1460.8	70466.1	40K
2390	794.9	22.2	228Ac	4501	1495.9	3.6	228Ac
2393	796.1	2.7	234Pa	4541	1509.2	32.2	214Bi
2423	805.9	2.7	234Pa	4629	1538.5	5.7	214Bi
2424	806.2	23.4	214Bi	4644	1543.3	3	214Bi
2469	821.2	2.8	214Bi	4676	1554.1	2	234mPa
2484	826.3	2.1	214Bi	4756	1580.5	2.5	228Ac
2497	830.5	2.8	228Ac	4764	1583.2	10.8	214Bi
2500	831.5	4.3	234Pa	4779	1588.2	13.1	228Ac
2513	835.7	8.2	228Ac	4799	1594.8	4	214Bi
2523	839	11	214Pb	4812	1599.3	3.5	214Bi
2527	840.4	4.7	228Ac	4907	1630.6	6.1	228Ac
2588	860.6	13	208Tl	4999	1661.3	16.9	214Bi
2634	876	2.6	234Pa	5067	1684	3.2	214Bi
2647	880.5	4.1	234Pa	5205	1729.6	42.3	214Bi
2648	880.5	6.2	234Pa	5229	1737.8	5.1	234mPa
2656	883.2	9.8	234Pa	5310	1764.5	221.5	214Bi
2668	887.3	2.2	234mPa	5313	1765.4	2.1	234mPa
2702	898.7	3.3	234Pa	5512	1831.5	4.1	234mPa
2719	904.2	3.8	228Ac	5532	1838.4	5.4	214Bi
2740	911.2	128.3	228Ac	5560	1847.4	30	214Bi
2772	921.7	3.9	234mPa	5621	1867.7	2.2	234mPa
2782	925	7.9	234Pa	5637	1873.1	3.2	214Bi
2787	926.7	7.3	234Pa	5706	1895.9	2.2	214Bi
2809	934.1	54.9	214Bi	6376	2118.5	16.1	214Bi
2845	946	3	234mPa	6634	2204.1	65.3	214Bi
2845	946	13.4	234Pa	6903	2293.4	3.9	214Bi
2856	949.8	-258.2	40K	7367	2447.7	19.3	214Bi
2899	964.1	6.9	214Bi	7870	2614.5	66.9	208Tl
2901	964.8	24.3	228Ac				
2914	969	76.9	228Ac				
2948	980.3	3	234Pa				
2991	994.6	6.1	234Pa				
3011	1001	247.7	234mPa				
3164	1052	5.5	214Bi				
3218	1070	4.7	214Bi				
3370	1120.3	255.9	214Bi				
3410	1133.7	4.3	214Bi				
3475	1155.2	27.3	214Bi				
3591	1193.7	3.8	234mPa				

Table II. Gamma photopeaks and counts for the source of Situation 2 Position A. Background not included, x-rays not included. Minus values indicate escape peaks.

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
156	53.2	2.2	214Pb	557	186.2	2.2	234Pa
156	53.2	9.9	234U	557	186.2	79.9	226Ra
172	58.6	2.5	231Th	583	194.9	195.4	235U
187	63.3	336.8	234Th	595	198.9	13	235U
215	72.7	2.3	235U	597	199.6	31.4	235U
215	72.8	5.4	231Th	605	202.1	369.5	235U
219	73.9	2	234Th	614	205.3	1783.4	235U
219	74	5	234Th	626	209.3	23.6	228Ac
241	81.2	40.1	231Th	644	215.3	10.3	235U
243	82.1	18.9	231Th	652	217.9	15.8	231Th
247	83.3	12.3	234Th	663	221.4	51.5	235U
250	84.2	350.3	231Th	678	226.5	5.1	234Pa
258	87	3.2	234Th	680	227.3	7	234Pa
267	89.9	66.2	231Th	685	228.8	3.6	235U
274	92.4	538.2	234Th	699	233.5	13.6	235U
275	92.8	535.1	234Th	707	236	4.4	231Th
276	93.1	3.3	231Th	712	237.8	44.3	231Th
285	96.1	7.2	235U	715	238.6	146.2	212Pb
290	97.6	2.1	231Th	721	240.9	38.1	235U
295	99.3	11.7	231Th	722	241	13.8	224Ra
296	99.5	4.4	228Ac	725	242	159.6	214Pb
297	99.9	2.3	234Pa	739	246.9	28.6	235U
304	102.3	49.5	231Th	746	249.2	3	234Pa
317	106.6	2.2	231Th	753	251.5	22.5	235U
318	106.9	4	231Th	774	258.2	25.7	234mPa
321	108	2.6	234Th	776	258.9	11	214Pb
325	109.2	243.4	235U	798	266.5	3.9	235U
336	112.8	72.2	234Th	810	270.2	19.5	228Ac
338	113.5	2.7	238U	820	273.8	3.1	214Bi
344	115.5	3.2	235U	823	274.8	9.7	214Pb
360	120.9	67.1	234U	824	275.1	29.1	235U
372	124.9	3.6	231Th	831	277.4	7.3	208Tl
385	129.1	11.9	228Ac	838	279.5	197.5	235U
391	131.3	18.3	234Pa	844	281.4	4.4	235U
405	135.7	6.8	231Th	848	282.9	3.7	235U
420	140.8	25.3	235U	868	289.6	5.4	235U
429	143.8	1350	235U	874	291.7	3	235U
435	145.9	3.6	231Th	881	293.8	3.3	234Pa
450	150.9	9.7	235U	882	294.3	26.6	235U
456	152.7	6.8	234Pa	885	295.2	384.9	214Pb
460	154	4.1	228Ac	900	300.1	10.2	212Pb
487	163.1	28.4	231Th	905	301.7	4.3	235U
488	163.4	936.6	235U	932	310.7	3.6	235U
517	173	8.1	231Th	933	311	2.6	231Th
518	173.3	2	235U	984	328	15.3	228Ac
520	174.2	3.8	231Th	997	332.4	2.1	228Ac
546	182.5	87.4	235U	1015	338.3	57.7	228Ac
548	183.5	8	231Th	1030	343.5	3.4	235U
552	184.8	4.2	234Th	1036	345.4	79.1	235U
555	185.7	15470.5	235U	1038	345.9	43.1	235U

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
1047	348.9	2.2	214Bi	2648	880.5	4.2	234Pa
1056	351.9	694.6	214Pb	2656	883.2	8.9	234Pa
1068	356	6	235U	2702	898.7	2.3	234Pa
1106	368.5	89.9	235U	2719	904.2	2.6	228Ac
1109	369.5	2.5	234Pa	2740	911.2	88.1	228Ac
1116	371.8	9.1	235U	2772	921.7	2.7	234mPa
1161	386.8	5.5	214Bi	2782	925	5.4	234Pa
1164	387.9	53.8	235U	2787	926.7	5	234Pa
1167	388.9	6.5	214Bi	2809	934.1	37.7	214Bi
1171	390.3	57.3	235U	2845	946	2.1	234mPa
1218	405.7	2.9	214Bi	2845	946	12.3	234Pa
1229	409.5	9	228Ac	2856	949.8	-177.2	40K
1232	410.3	4.7	235U	2899	964.1	4.7	214Bi
1317	438.8	-427.2	40K	2901	964.8	16.7	228Ac
1366	454.8	5.2	214Bi	2914	969	52.8	228Ac
1367	455.1	15.1	235U	2948	980.3	2	234Pa
1387	462.1	3.6	214Pb	2991	994.6	4.2	234Pa
1390	463	19.6	228Ac	3011	1001	229.7	234mPa
1411	469.8	2.1	214Bi	3164	1052	3.8	214Bi
1443	480.4	5.1	214Pb	3218	1070	3.2	214Bi
1463	487.1	6.7	214Pb	3370	1120.3	175.7	214Bi
1534	510.8	19.9	208Tl	3410	1133.7	2.9	214Bi
1603	533.7	2.9	214Pb	3475	1155.2	18.8	214Bi
1690	562.5	3.6	228Ac	3591	1193.7	2.6	234mPa
1709	568.9	3	234Pa	3633	1207.7	5.2	214Bi
1711	569.5	6.8	234Pa	3725	1238.1	65.1	214Bi
1743	580.1	5.2	214Pb	3854	1281	15.9	214Bi
1752	583.2	70.3	208Tl	4145	1377.7	43.5	214Bi
1831	609.3	672.4	214Bi	4168	1385.3	8.2	214Bi
2000	665.5	20.6	214Bi	4217	1401.5	13.7	214Bi
2101	699	2.8	234Pa	4236	1408	23.1	214Bi
2113	703.1	6.5	214Bi	4390	1459.1	2.4	228Ac
2164	719.9	5.2	214Bi	4395	1460.8	48377.9	40K
2205	733.4	5.2	234Pa	4501	1495.9	2.5	228Ac
2224	740	2.7	234mPa	4541	1509.2	22.1	214Bi
2233	742.8	22.5	234mPa	4629	1538.5	3.9	214Bi
2271	755.3	3.6	228Ac	4644	1543.3	2.1	214Bi
2304	766.4	82.6	234mPa	4764	1583.2	7.4	214Bi
2310	768.4	65.8	214Bi	4779	1588.2	9	228Ac
2322	772.3	5.4	228Ac	4799	1594.8	2.7	214Bi
2363	786	14.1	214Pb	4812	1599.3	2.4	214Bi
2363	786.1	4.2	214Bi	4907	1630.6	4.2	228Ac
2364	786.3	13.6	234mPa	4999	1661.3	11.6	214Bi
2389	794.7	2.4	235U	5067	1684	2.2	214Bi
2390	794.9	15.2	228Ac	5205	1729.6	29.1	214Bi
2424	806.2	16.1	214Bi	5229	1737.8	3.5	234mPa
2500	831.5	3	234Pa	5310	1764.5	152.1	214Bi
2513	835.7	5.7	228Ac	5512	1831.5	2.8	234mPa
2523	839	7.6	214Pb	5560	1847.4	20.6	214Bi
2527	840.4	3.2	228Ac	6376	2118.5	11.1	214Bi
2588	860.6	8.9	208Tl	6634	2204.1	44.8	214Bi
2647	880.5	2.8	234Pa	7870	2614.5	46	208Tl

Table III. Gamma photopeaks and counts for the source of Situation 2 Position B. Background not included, x-rays not included. Minus values indicate escape peaks.

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
145	49.6	2.2	238U	460	154	7.3	228Ac
156	53.2	3.9	214Pb	487	163.1	57.9	231Th
156	53.2	29.2	234U	488	163.4	1905.3	235U
172	58.6	8.9	231Th	517	173	16.4	231Th
185	62.9	2.6	234Th	518	173.3	4.1	235U
187	63.3	609.1	234Th	520	174.2	7.7	231Th
215	72.7	5.9	235U	546	182.5	174.4	235U
215	72.8	16	231Th	548	183.5	16.1	231Th
219	73.9	2.7	234mPa	552	184.8	7.6	234Th
219	73.9	3.6	234Th	555	185.7	30781	235U
219	74	9.1	234Th	557	186.2	3.9	234Pa
221	74.8	3.7	235U	557	186.2	144.4	226Ra
241	81.2	94	231Th	583	194.9	385.4	235U
243	82.1	44.2	231Th	587	196.2	2.8	214Pb
247	83.3	22.3	234Th	595	198.9	25.7	235U
250	84.2	814.5	231Th	596	199.4	3.5	228Ac
250	84.4	3.3	228Th	597	199.6	65.1	235U
258	87	5.9	234Th	601	201	2	234Pa
267	89.9	152.1	231Th	605	202.1	723.8	235U
274	92.4	974.7	234Th	608	203.1	2.8	234Pa
275	92.8	969.2	234Th	614	205.3	3484	235U
276	93.1	7.7	231Th	626	209.3	42.7	228Ac
285	96.1	16.8	235U	644	215.3	20.1	235U
290	97.6	4.8	231Th	652	217.9	30.6	231Th
295	99.3	29.1	231Th	663	221.4	99.2	235U
296	99.5	8	228Ac	678	226.5	9.2	234Pa
297	99.9	4.2	234Pa	680	227.3	12.7	234Pa
304	102.3	111.2	231Th	685	228.8	6.9	235U
315	105.8	2.1	231Th	699	233.5	26	235U
317	106.6	5.1	231Th	707	236	8.5	231Th
318	106.9	9.1	231Th	712	237.8	87.1	231Th
321	108	4.7	234Th	715	238.6	264.3	212Pb
325	109.2	539.9	235U	721	240.9	74.6	235U
336	112.8	130.5	234Th	722	241	25	Ra-224
338	113.5	4.8	238U	725	242	288.5	214Pb
343	115.2	2.7	212Pb	739	246.9	53.9	235U
344	115.5	7.2	235U	746	249.2	5.3	234Pa
348	116.8	2.2	231Th	753	251.5	42.4	235U
358	120.4	3.1	235U	774	258.2	46.5	234mPa
360	120.9	147.4	234U	776	258.9	19.9	214Pb
372	124.9	7.8	231Th	798	266.5	7.2	235U
385	129.1	21.5	228Ac	810	270.2	35.2	228Ac
391	131.3	33.1	234Pa	816	272.3	2.2	234Pa
400	134	4.3	231Th	820	273.8	5.6	214Bi
405	135.7	16.6	231Th	823	274.8	17.6	214Pb
407	136.6	2.3	235U	824	275.1	53.9	235U
410	137.5	2	214Pb	831	277.4	13.1	208Tl
420	140.8	52.7	235U	838	279.5	365	235U
429	143.8	2801.8	235U	842	281	2.2	214Bi
435	145.9	7.7	231Th	844	281.4	8.1	235U
450	150.9	22.5	235U	848	282.9	6.8	235U
456	152.7	12.4	234Pa	868	289.6	10	235U

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
874	291.7	5.5	235U	1711	569.5	12.3	234Pa
881	293.8	6	234Pa	1743	580.1	9.4	214Pb
882	294.3	48.5	235U	1752	583.2	127.1	208Tl
885	295.2	695.7	214Pb	1831	609.3	1211.5	214Bi
900	300.1	18.4	212Pb	2000	665.5	37.2	214Bi
905	301.7	7.7	235U	2077	691.1	3.3	234mPa
932	310.7	6.5	235U	2101	699	5	234Pa
933	311	4.8	231Th	2109	701.6	3	234mPa
943	314.3	2.8	214Pb	2113	703.1	11.7	214Bi
965	321.6	2.1	228Ac	2122	705.9	3.1	234Pa
984	328	27.7	228Ac	2164	719.9	9.3	214Bi
997	332.4	3.7	228Ac	2205	733.4	9.4	234Pa
1000	333.3	2.7	214Bi	2224	740	4.8	234mPa
1015	338.3	104.2	228Ac	2232	742.5	2.3	235U
1023	341	3.4	228Ac	2233	742.8	2.8	234Pa
1030	343.5	5.9	235U	2233	742.8	39.4	234mPa
1036	345.4	139.6	235U	2263	752.8	3.2	214Bi
1038	345.9	76	235U	2271	755.3	6.6	228Ac
1047	348.9	4	214Bi	2294	763.1	2.5	208Tl
1056	351.9	2.3	214Bi	2304	766.4	145	234mPa
1056	351.9	1255.6	214Pb	2310	768.4	118.9	214Bi
1068	356	10.5	235U	2322	772.3	9.7	228Ac
1106	368.5	156.7	235U	2349	781.4	3.1	234mPa
1109	369.5	4.5	234Pa	2351	782.1	3.2	228Ac
1116	371.8	15.9	235U	2363	786	25.6	214Pb
1116	372	2.2	234Pa	2363	786.1	7.5	214Bi
1161	386.8	9.9	214Bi	2364	786.3	23.8	234mPa
1164	387.9	92.9	235U	2389	794.7	3.6	235U
1167	388.9	11.8	214Bi	2390	794.9	27.5	228Ac
1171	390.3	98.8	235U	2393	796.1	3.4	234Pa
1218	405.7	5.2	214Bi	2423	805.9	3.3	234Pa
1229	409.5	16.3	228Ac	2424	806.2	29.1	214Bi
1232	410.3	8	235U	2463	819.2	2.5	234Pa
1317	438.8	-772	40K	2469	821.2	3.5	214Bi
1346	448.4	3.1	235U	2481	825.1	2.4	234Pa
1366	454.8	9.5	214Bi	2484	826.3	2.6	214Bi
1366	455	2.8	234U	2497	830.5	3.4	228Ac
1367	455.1	25.2	235U	2500	831.5	5.4	234Pa
1387	462.1	6.5	214Pb	2513	835.7	10.2	228Ac
1390	463	35.4	228Ac	2523	839	13.7	214Pb
1411	469.8	3.8	214Bi	2527	840.4	5.8	228Ac
1425	474.4	3.2	214Bi	2561	851.7	2.4	234mPa
1443	480.4	9.3	214Pb	2588	860.6	16.1	208Tl
1463	487.1	12.2	214Pb	2634	876	3.2	234Pa
1522	506.7	2	234Pa	2647	880.5	5.1	234Pa
1529	509	3.5	228Ac	2648	880.5	7.6	234Pa
1534	510.8	35.9	208Tl	2656	883.2	15.3	234Pa
1542	513.4	2	234Pa	2668	887.3	2.7	234mPa
1603	533.7	5.2	214Pb	2702	898.7	4.1	234Pa
1631	543	2.3	214Bi	2719	904.2	4.8	228Ac
1690	562.5	6.4	228Ac	2740	911.2	159.2	228Ac
1709	568.9	5.4	234Pa	2772	921.7	4.8	234mPa

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
2782	925	12.4	234Pa	5310	1764.5	274.8	214Bi
2784	925.9	2.3	234Pa	5313	1765.4	2.6	234mPa
2787	926.7	11.4	234Pa	5512	1831.5	5.1	234mPa
2809	934.1	68.1	214Bi	5532	1838.4	6.7	214Bi
2845	946	8.2	234mPa	5560	1847.4	37.2	214Bi
2845	946	16.6	234Pa	5621	1867.7	2.7	234mPa
2850	947.7	2	234Pa	5637	1873.1	3.9	214Bi
2856	949.8	-320.3	40K	5643	1875.2	2.4	234mPa
2899	964.1	8.5	214Bi	5706	1895.9	2.8	214Bi
2901	964.8	30.2	228Ac	6376	2118.5	20	214Bi
2914	969	95.5	228Ac	6634	2204.1	81	214Bi
2948	980.3	3.7	234Pa	6903	2293.4	4.9	214Bi
2948	980.3	2.5	234Pa	7367	2447.7	24	214Bi
2991	994.6	9.7	234Pa	7870	2614.5	83.1	208Tl
3011	1001	393.4	234mPa				
3164	1052	6.8	214Bi				
3218	1070	5.9	214Bi				
3320	1103.7	2.1	214Bi				
3370	1120.3	317.5	214Bi				
3410	1133.7	5.3	214Bi				
3475	1155.2	33.9	214Bi				
3591	1193.7	4.7	234mPa				
3633	1207.7	9.4	214Bi				
3725	1238.1	117.6	214Bi				
3752	1247.1	2.8	228Ac				
3854	1281	28.7	214Bi				
3922	1303.8	2.4	214Bi				
4145	1377.7	78.7	214Bi				
4168	1385.3	14.8	214Bi				
4194	1393.9	2.2	234Pa				
4217	1401.5	24.7	214Bi				
4236	1408	41.8	214Bi				
4319	1435.4	3.1	234mPa				
4390	1459.1	4.3	228Ac				
4395	1460.8	87436.7	40K				
4501	1495.9	4.4	228Ac				
4518	1501.6	2.4	228Ac				
4541	1509.2	40	214Bi				
4629	1538.5	7.1	214Bi				
4644	1543.3	3.8	214Bi				
4676	1554.1	2.5	234mPa				
4756	1580.5	3	228Ac				
4764	1583.2	13.3	214Bi				
4779	1588.2	16.3	228Ac				
4799	1594.8	4.9	214Bi				
4812	1599.3	4.3	214Bi				
4907	1630.6	7.6	228Ac				
4930	1638.3	2.4	228Ac				
4999	1661.3	21	214Bi				
5067	1684	3.9	214Bi				
5205	1729.6	52.5	214Bi				
5229	1737.8	6.4	234mPa				

Table IV. Gamma photopeaks and counts for the source of Situation 2 Position C. Background not included, x-rays not included. Minus values indicate escape peaks.

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
156	53.2	2.6	214Pb	831	277.4	8.7	208Tl
187	63.3	403.3	234Th	838	279.5	5.2	235U
219	73.9	2.4	234Th	881	293.8	4	234Pa
219	74	6	234Th	885	295.2	460.7	214Pb
241	81.2	7.4	231Th	900	300.1	12.2	212Pb
243	82.1	3.4	231Th	984	328	18.3	228Ac
247	83.3	14.8	234Th	997	332.4	2.5	228Ac
250	84.2	59	231Th	1015	338.3	69	228Ac
250	84.4	2.2	228Th	1023	341	2.3	228Ac
258	87	3.9	234Th	1047	348.9	2.7	214Bi
267	89.9	9.5	231Th	1056	351.9	831.5	214Pb
274	92.4	640.8	234Th	1109	369.5	3	234Pa
275	92.8	637.2	234Th	1161	386.8	6.6	214Bi
296	99.5	5.3	228Ac	1167	388.9	7.8	214Bi
297	99.9	2.8	234Pa	1218	405.7	3.5	214Bi
304	102.3	5.2	231Th	1229	409.5	10.8	228Ac
321	108	3.1	234Th	1317	438.8	-511.3	40K
325	109.2	21.5	235U	1366	454.8	6.3	214Bi
336	112.8	86.4	234Th	1387	462.1	4.3	214Pb
338	113.5	3.2	238U	1390	463	23.4	228Ac
385	129.1	14.2	228Ac	1411	469.8	2.5	214Bi
391	131.3	21.9	234Pa	1425	474.4	2.1	214Bi
420	140.8	4	235U	1443	480.4	6.2	214Pb
429	143.8	203.9	235U	1463	487.1	8.1	214Pb
456	152.7	8.2	234Pa	1529	509	2.3	228Ac
460	154	4.9	228Ac	1534	510.8	23.8	208Tl
487	163.1	3.1	231Th	1603	533.7	3.4	214Pb
488	163.4	101.9	235U	1690	562.5	4.3	228Ac
546	182.5	7.1	235U	1709	568.9	3.6	234Pa
552	184.8	5.1	234Th	1711	569.5	8.1	234Pa
555	185.7	1198.9	235U	1743	580.1	6.3	214Pb
557	186.2	2.6	234Pa	1752	583.2	84.2	208Tl
557	186.2	95.6	226Ra	1831	609.3	802.3	214Bi
583	194.9	13.3	235U	2000	665.5	24.6	214Bi
596	199.4	2.3	228Ac	2077	691.1	2.2	234mPa
597	199.6	2.1	235U	2101	699	3.3	234Pa
605	202.1	22.8	235U	2113	703.1	7.8	214Bi
614	205.3	105.6	235U	2122	705.9	2.1	234Pa
626	209.3	28.3	228Ac	2164	719.9	6.2	214Bi
663	221.4	2.5	235U	2205	733.4	6.2	234Pa
678	226.5	6.1	234Pa	2224	740	3.2	234mPa
680	227.3	8.4	234Pa	2233	742.8	21.7	234mPa
715	238.6	175	212Pb	2263	752.8	2.1	214Bi
722	241	16.5	224Ra	2271	755.3	4.4	228Ac
725	242	191	214Pb	2304	766.4	78.8	234mPa
746	249.2	3.5	234Pa	2310	768.4	78.7	214Bi
774	258.2	30.8	234mPa	2322	772.3	6.5	228Ac
776	258.9	13.2	214Pb	2349	781.4	2.1	234mPa
810	270.2	23.3	228Ac	2351	782.1	2.1	228Ac
820	273.8	3.7	214Bi	2363	786	16.9	214Pb
823	274.8	11.6	214Pb	2363	786.1	5	214Bi

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
2364	786.3	12.9	234mPa	4629	1538.5	4.7	214Bi
2390	794.9	18.2	228Ac	4644	1543.3	2.5	214Bi
2393	796.1	2.3	234Pa	4756	1580.5	2	228Ac
2423	805.9	2.2	234Pa	4764	1583.2	8.8	214Bi
2424	806.2	19.3	214Bi	4779	1588.2	10.8	228Ac
2469	821.2	2.3	214Bi	4799	1594.8	3.3	214Bi
2497	830.5	2.3	228Ac	4812	1599.3	2.9	214Bi
2500	831.5	3.5	234Pa	4907	1630.6	5	228Ac
2513	835.7	6.8	228Ac	4999	1661.3	13.9	214Bi
2523	839	9.1	214Pb	5067	1684	2.6	214Bi
2527	840.4	3.8	228Ac	5205	1729.6	34.8	214Bi
2588	860.6	10.7	208Tl	5229	1737.8	4.2	234mPa
2634	876	2.1	234Pa	5310	1764.5	182	214Bi
2647	880.5	3.4	234Pa	5512	1831.5	3.4	234mPa
2648	880.5	5.1	234Pa	5532	1838.4	4.5	214Bi
2656	883.2	8.1	234Pa	5560	1847.4	24.6	214Bi
2702	898.7	2.7	234Pa	5637	1873.1	2.6	214Bi
2719	904.2	3.2	228Ac	6376	2118.5	13.2	214Bi
2740	911.2	105.4	228Ac	6634	2204.1	53.7	214Bi
2772	921.7	3.2	234mPa	6903	2293.4	3.2	214Bi
2782	925	6.5	234Pa	7367	2447.7	15.9	214Bi
2787	926.7	6	234Pa	7870	2614.5	55	208Tl
2809	934.1	45.1	214Bi				
2845	946	2.5	234mPa				
2845	946	11	234Pa				
2856	949.8	-212.1	40K				
2899	964.1	5.6	214Bi				
2901	964.8	20	228Ac				
2914	969	63.2	228Ac				
2948	980.3	2.4	234Pa				
2991	994.6	5	234Pa				
3011	1001	203.5	234mPa				
3164	1052	4.5	214Bi				
3218	1070	3.9	214Bi				
3370	1120.3	210.3	214Bi				
3410	1133.7	3.5	214Bi				
3475	1155.2	22.5	214Bi				
3591	1193.7	3.1	234mPa				
3633	1207.7	6.2	214Bi				
3725	1238.1	77.9	214Bi				
3854	1281	19	214Bi				
4145	1377.7	52.1	214Bi				
4168	1385.3	9.8	214Bi				
4217	1401.5	16.4	214Bi				
4236	1408	27.7	214Bi				
4319	1435.4	2.1	234mPa				
4390	1459.1	2.9	228Ac				
4395	1460.8	57907.1	40K				
4501	1495.9	2.9	228Ac				
4541	1509.2	26.5	214Bi				

Table V. Gamma photopeaks and counts for the source of Situation 2 Position D. Background not included, x-rays not included. Minus values indicate escape peaks.

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
240	81	2.2	133Ba	1018	339.5	20.8	57Co
247	83.4	2.3	153Gd	1025	341.6	2538.9	177mLu
265	89.5	3.2	153Gd	1057	352.4	19.5	57Co
289	97.4	5103.4	153Gd	1068	356	9393.1	133Ba
307	103.2	7814.7	153Gd	1102	367.4	4603.7	177mLu
313	105.4	598.1	177mLu	1136	378.5	42846.8	177mLu
336	112.9	2020.8	177mLu	1152	383.9	1311.3	133Ba
345	115.9	81	177mLu	1155	385	4480.6	177mLu
348	117	25.3	177mLu	1176	391.7	70458.4	Sn-113
362	121.6	1091.5	177mLu	1242	413.7	24054.6	177mLu
364	122.1	16160.2	57Co	1256	418.5	29267.7	177mLu
383	128.5	4153.9	177mLu	1280	426.5	582.4	177mLu
407	136.5	4127.7	57Co	1399	465.8	3045.8	177mLu
408	136.7	549.2	177mLu	1712	569.9	19.4	57Co
435	145.8	489.5	177mLu	1989	661.7	17443.3	Cs-137
439	147.2	1969.7	177mLu	2080	692	158.4	57Co
458	153.3	11201.1	177mLu	2123	706.4	25.2	57Co
477	159.7	407.5	177mLu	2177	724.2	8433.4	95Zr
480	160.6	51.7	133Ba	2275	756.7	10017	95Zr
498	166.6	2.6	153Gd				
513	171.9	4607.3	177mLu				
516	172.9	341	153Gd				
521	174.4	12548.6	177mLu				
529	177	3526.1	177mLu				
544	182	136.3	177mLu				
585	195.6	1058.2	177mLu				
611	204.1	18454.1	177mLu				
623	208.4	78908.6	177mLu				
642	214.4	9270.8	177mLu				
653	218.1	4680.8	177mLu				
668	223.2	66.9	133Ba				
684	228.5	54589.4	177mLu				
700	233.9	8342.7	177mLu				
706	235.7	85.6	95Zr				
726	242.5	56.3	177mLu				
748	249.7	9432.6	177mLu				
764	255.1	2183.8	113Sn				
805	268.8	5343.2	177mLu				
828	276.4	1143.2	133Ba				
845	281.8	21996.1	177mLu				
849	283.4	624	177mLu				
874	291.4	1593.1	177mLu				
877	292.5	1276.7	177mLu				
889	296.5	7896.9	177mLu				
897	299.1	2795.1	177mLu				
908	302.9	2906.2	133Ba				
916	305.5	2816.5	177mLu				
941	313.7	1939.5	177mLu				
957	319	16099.4	177mLu				
964	321.3	1836.1	177mLu				
983	327.7	27551.1	177mLu				

Table VI. Gamma photopeaks and counts for the source of Situation 3. Background not included, x-rays not included.

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
127	43.4	24.6	241Am	1885	627.2	4.1	241Am
163	55.6	23	241Am	1902	633	10	241Am
170	57.9	7.6	241Am	1903	633.1	2.4	239Pu
175	59.5	57520.1	241Am	1916	637.7	2.4	239Pu
206	69.8	6.8	241Am	1923	640	8.4	239Pu
294	99	75	241Am	1928	641.5	56.2	241Am
306	103	74.8	241Am	1930	642.3	19.1	240Pu
366	123	4.4	241Am	1941	645.9	15.2	239Pu
373	125.3	17.7	241Am	1960	652.1	6.8	239Pu
437	146.6	2.2	241Am	1963	653	325	241Am
622	208	3.7	241Am	1968	654.9	2.2	239Pu
936	312.2	2.2	233Pa	1980	658.9	10.4	239Pu
967	322.5	4	241Am	1991	662.4	3233.2	241Am
997	332.4	6.4	241Am	2013	669.8	3.5	241Am
997	332.4	23.6	237U	2032	676	6.2	241Am
998	332.8	2.6	239Pu	2044	680.1	30.4	241Am
1006	335.4	24.2	241Am	2067	687.6	5	240Pu
1006	335.4	2.1	237U	2070	688.8	305.8	241Am
1035	345	5	239Pu	2085	693.6	38.6	241Am
1106	368.6	37.5	241Am	2094	696.6	52.8	241Am
1106	368.6	3.1	237U	2115	703.7	5.2	239Pu
1113	370.9	9.8	241Am	2129	708.3	3	238Pu
1113	370.9	9.2	237U	2132	709.5	71.4	241Am
1125	375	40	239Pu	2159	718.2	3.9	239Pu
1130	376.7	30.7	241Am	2170	722	2297.4	241Am
1141	380.2	9.2	239Pu	2194	729.7	15.7	241Am
1149	382.8	8.4	239Pu	2199	731.5	5.7	241Am
1152	383.8	7.7	241Am	2216	737.3	99.3	241Am
1178	392.6	8.7	239Pu	2233	742.8	43.1	238Pu
1180	393.1	15.1	239Pu	2272	755.9	100.8	241Am
1197	398.7	2.1	233Pa	2273	756.2	4.5	239Pu
1242	413.7	103.7	239Pu	2283	759.5	22.8	241Am
1248	415.8	4	233Pa	2296	763.9	2.7	241Am
1259	419.3	19	241Am	2304	766.4	197.5	238Pu
1269	422.6	10.2	239Pu	2306	767	68.8	241Am
1280	426.5	18.9	241Am	2312	769.2	8.6	239Pu
1281	426.6	2.1	239Pu	2315	769.9	3	239Pu
1329	442.8	3.7	241Am	2316	770.5	69.5	241Am
1356	451.5	28	239Pu	2322	772.4	37.2	241Am
1359	452.6	3	241Am	2347	780.7	3.6	241Am
1365	454.7	12.5	241Am	2364	786.3	31.1	238Pu
1380	459.7	5	241Am	2373	789.2	5.7	241Am
1406	468.1	4.6	241Am	2411	801.9	19.9	241Am
1459	485.9	2.1	241Am	2430	808.2	8.1	238Pu
1539	512.5	3.3	241Am	2441	812	9.4	241Am
1544	514	7.5	241Am	2463	819.3	6.4	241Am
1568	522.1	2.8	241Am	2473	822.6	3.6	241Am
1724	573.9	6.1	241Am	2491	828.5	3.9	241Am
1762	586.6	7.4	241Am	2561	851.6	6.6	241Am
1795	597.5	45	241Am	2561	851.7	14.2	238Pu
1860	619	393.3	241Am				

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
2570	854.7	3.5	241Am				
2594	862.7	9.4	241Am				
2624	872.7	12.8	241Am				
2656	883.2	9.4	238Pu				
2669	887.5	4.2	241Am				
2714	902.5	5.8	241Am				
2744	912.4	5	241Am				
2771	921.5	3.9	241Am				
2787	926.7	7.7	238Pu				
2833	941.9	6.4	238Pu				
2874	955.7	12.4	241Am				
3011	1001	13.8	238Pu				
3133	1041.7	3.2	238Pu				

Table VII. Gamma photopeaks and counts for the sources of Situation 4. Background not included, x-rays not included.

Position A				Position B			
Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
475	159	31315.5	123I	8	4.1	2.3	123I
546	182.6	5	123I	475	159	2637.8	123I
575	192.2	7.7	123I	743	248	2.6	123I
743	248	25.5	123I	842	281	2.9	123I
842	281	26.8	123I	1039	346.3	4.4	123I
992	330.7	3.6	123I	1321	440	14.4	123I
1039	346.3	38.1	123I	1518	505.3	10.3	123I
1321	440	113	123I	1589	529	45	123I
1518	505.3	76.9	123I	1618	538.5	12.3	123I
1589	529	329.8	123I	1877	624.6	2.6	123I
1618	538.5	89.5	123I				
1877	624.6	18	123I				
2068	688	5.5	123I				
2212	735.8	12.1	123I				
2356	783.6	11.3	123I				
Position C							
475	159	74	123I				
1589	529	2.6	123I				

Table VIII.Gamma photopeaks and counts for the sources of Situation 5. Background not included, x-rays not included.

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
156	53.2	3.4	234U	746	249.2	24.3	234Pa
185	62.9	2	234Th	774	258.2	227.4	234mPa
187	63.3	481.2	234Th	816	272.3	12.1	234Pa
219	73.9	4.4	234Th	838	279.5	12.7	235U
219	73.9	3.3	234mPa	881	293.8	37.5	234Pa
219	74	11	234Th	897	299.1	2.5	234mPa
241	81.2	4.9	231Th	991	330.4	11.3	234Pa
243	82.1	2.3	231Th	1014	338.1	5.2	234mPa
247	83.3	36.6	234Th	1036	345.4	4.4	235U
250	84.2	42.9	231Th	1038	345.9	2.4	235U
258	87	10.7	234Th	1056	351.9	6.5	234Pa
267	89.9	8.1	231Th	1073	357.5	3.9	234mPa
274	92.4	2030.8	234Th	1089	362.8	3.4	234mPa
275	92.8	2040.4	234Th	1106	368.5	4.8	235U
297	99.9	10.5	234Pa	1109	369.5	41.8	234Pa
304	102.3	5.9	231Th	1116	372	20.8	234Pa
307	103.4	4.8	234Th	1163	387.6	5.2	234mPa
321	108	14.2	234Th	1164	387.9	2.8	235U
325	109.2	28.6	235U	1164	387.9	2.5	234mPa
336	112.8	432.7	234Th	1171	390.3	2.9	235U
338	113.5	16.3	U-238	1230	409.8	6.5	234Pa
360	120.9	19.7	234U	1282	427	8.9	234Pa
391	131.3	38.7	234Pa	1322	440.5	210.6	213Bi
420	140.8	2.4	235U	1341	446.6	2.3	234Pa
429	143.8	126	235U	1354	450.9	19.1	234mPa
456	152.7	20.2	234Pa	1362	453.6	12.2	234mPa
476	159.5	2.5	234Pa	1371	456.7	4.6	234mPa
487	163.1	2.5	231Th	1377	458.6	24.1	234Pa
488	163.4	83.2	235U	1397	465.1	39.5	209Tl
510	170.9	2.3	234Pa	1405	468	4.7	234Pa
546	182.5	7.4	235U	1406	468.1	15.2	234mPa
552	184.7	2.8	234mPa	1418	472.3	7.9	234Pa
552	184.8	18.8	234Th	1429	475.8	15.3	234mPa
555	185.7	1289.6	235U	1438	478.7	2.8	234Pa
557	186.2	9.8	234Pa	1444	481	6.9	234Pa
579	193.7	3	234Pa	1522	506.7	30.1	234Pa
583	194.9	15.8	235U	1524	507.5	11	234mPa
597	199.6	2.7	235U	1529	509.2	14.9	234mPa
601	201	6	234Pa	1534	510.8	6.3	208Tl
605	202.1	29.3	235U	1542	513.4	30.7	234Pa
608	203.1	8.3	234Pa	1561	519.6	9.3	234Pa
608	203.2	2.1	234mPa	1566	521.4	17.7	234Pa
614	205.3	140.3	235U	1580	526.1	2.9	225Ac
628	209.9	2.9	234mPa	1586	527.9	9.4	234Pa
663	221.4	3.9	235U	1589	529.1	2.2	234Pa
678	226.5	34.7	234Pa	1614	537.2	2	234Pa
680	227.3	48.3	234Pa	1634	543.8	3.3	234Pa
712	237.8	3.3	231Th	1634	544	26.9	234mPa
721	240.9	2.8	235U	1637	544.9	2.1	213Bi
735	245.4	7.1	234Pa	1674	557.3	5.4	234mPa
739	246.9	2.1	235U	1676	558	2.3	234Pa

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
1698	565.2	26.2	234Pa	2233	742.8	61.2	234Pa
1709	568.9	91.9	234Pa	2242	745.9	9.5	234Pa
1711	569.5	209.4	234Pa	2249	748.1	3.1	234Pa
1718	572	4.7	234mPa	2270	755	36.4	234Pa
1752	583.2	91.5	208Tl	2281	758.7	8	225Ac
1755	584.1	4.5	234Pa	2281	758.9	7.4	234Pa
1785	594.1	3.5	At-217	2286	760.3	14.2	234mPa
1789	595.4	2.4	234Pa	2288	761	2.2	234Pa
1794	596.9	5.2	234Pa	2294	763.1	11.9	208Tl
1811	602.6	14.3	234Pa	2299	764.8	6	234Pa
1839	612	10.2	234Pa	2304	766.4	2676.2	234mPa
1876	624.2	9.5	234Pa	2304	766.4	2.1	234Pa
1887	628.1	6.5	234Pa	2312	769.1	5.6	234Pa
1891	629.4	9.5	234Pa	2322	772.4	2.2	234Pa
1906	634.3	3.7	234Pa	2346	780.4	27.2	234Pa
1943	646.5	3.1	234Pa	2349	781.4	71.3	234mPa
1947	647.7	13.1	234mPa	2355	783.4	9.1	234Pa
1950	649	8.6	234mPa	2361	785.4	23.2	212Bi
1965	653.7	12.8	234Pa	2364	786.3	445.7	234mPa
1969	655.2	3.7	234Pa	2364	786.3	36.2	234Pa
1969	655.3	11.7	234mPa	2390	794.9	42.6	234Pa
1976	657.4	10.9	234Pa	2393	796.1	78.6	234Pa
1983	659.8	7.5	234Pa	2418	804.4	18.9	234Pa
1983	659.8	25.5	213Bi	2423	805.9	39.9	234mPa
1995	663.9	15.2	234Pa	2423	805.9	77.1	234Pa
2003	666.5	32.7	234Pa	2427	807.3	581.9	213Bi
2013	669.7	28	234Pa	2430	808.3	27.8	234mPa
2016	670.8	3.2	234mPa	2440	811.5	3.8	234Pa
2025	673.9	5.5	234mPa	2448	814.2	9.5	234Pa
2029	675.1	2.8	234Pa	2460	818.2	9.3	234mPa
2054	683.4	4.9	234mPa	2463	819.2	57.8	234Pa
2056	683.9	4.3	234Pa	2478	824.2	3.8	234Pa
2059	685.1	4	234Pa	2481	825.1	57.9	234Pa
2077	691.1	67.9	234mPa	2482	825.6	13.1	234mPa
2082	692.6	35.6	234Pa	2486	826.8	15.7	213Bi
2090	695.5	13.6	234mPa	2493	829.3	11.1	234Pa
2101	699	103.9	234Pa	2500	831.5	127.2	234Pa
2109	701.6	62	234mPa	2538	844.1	10.2	234mPa
2122	705.9	35.2	234mPa	2538	844.1	13	234Pa
2122	705.9	66	234Pa	2561	851.7	2.2	234Pa
2137	710.8	11.5	213Bi	2561	851.7	58.4	234mPa
2139	711.5	4.5	234Pa	2588	860.6	139.2	208Tl
2145	713.7	4.2	234Pa	2595	863.2	2.2	234Pa
2186	727.3	93.5	212Bi	2606	866.8	10	234mPa
2188	727.8	3.3	234Pa	2610	868	32.3	213Bi
2197	730.9	18.6	234Pa	2615	869.7	6.1	234Pa
2202	732.5	11.5	234mPa	2634	876	79.1	234Pa
2205	733.4	203.5	234Pa	2647	880.5	125.4	234Pa
2218	738	34	234Pa	2648	880.5	188.2	234Pa
2224	740	105	234mPa	2649	881.1	25.6	234mPa
2233	742.8	719.2	234mPa	2656	883.2	11.2	234mPa

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
2656	883.2	301.4	234Pa	3329	1106.9	2.6	234Pa
2656	883.2	16.2	234mPa	3366	1119	15	U-233
2668	887.3	67.4	234mPa	3367	1119.4	318.9	213Bi
2686	893.4	13.6	212Bi	3371	1120.6	16.1	234mPa
2702	898.7	102.1	234Pa	3375	1122.1	15.7	234Pa
2719	904.4	10.7	234Pa	3385	1125.2	11.3	234Pa
2762	918.4	3.1	234Pa	3386	1125.7	33.2	234mPa
2767	920.1	43.9	209Tl	3389	1126.8	9.4	234Pa
2772	921.7	121.9	234mPa	3389	1126.8	5	234mPa
2782	925	247.3	234Pa	3470	1153.6	9.4	234Pa
2784	925.9	57.1	234Pa	3523	1171.3	2.8	234Pa
2787	926.7	11.8	234mPa	3532	1174.2	18	234mPa
2787	926.7	228.4	234Pa	3591	1193.7	127.3	234mPa
2814	935.8	2.1	234Pa	3591	1193.8	6.6	234Pa
2816	936.3	17.3	234mPa	3662	1217.3	6.7	234Pa
2833	941.9	24	234mPa	3671	1220.4	8.5	234mPa
2845	946	95.6	234mPa	3722	1237.2	49.8	234mPa
2845	946	426.7	234Pa	3728	1239.2	62.4	209Tl
2850	947.7	51.6	234Pa	3734	1241.2	7	234Pa
2863	952.1	7.6	212Bi	3780	1256.5	18.3	234Pa
2865	952.7	2.6	234Pa	3889	1292.8	14.2	234Pa
2887	960	8.7	234mPa	4070	1352.9	35.2	234Pa
2887	960	2.3	234Pa	4071	1353	5.8	234mPa
2904	965.8	15	234Pa	4075	1354.6	4	234Pa
2942	978.2	2.9	234Pa	4089	1359	4.7	234Pa
2948	980.3	96	234Pa	4181	1389.6	2.2	234Pa
2948	980.3	64	234Pa	4188	1391.9	31.7	234mPa
2952	981.6	23.1	234Pa	4194	1393.9	62.7	234Pa
2955	982.7	3.6	208Tl	4205	1397.5	2.5	234Pa
2960	984.2	51.9	234Pa	4213	1400.3	5.3	234Pa
2975	989.2	3.3	234Pa	4254	1414	21.1	234mPa
2983	992	2.6	234Pa	4293	1426.9	5	234Pa
2991	994.6	198.9	234Pa	4319	1435.4	88.7	234mPa
2996	996.1	39.9	234mPa	4349	1445.4	9.7	234Pa
3011	1001	7928.7	234mPa	4371	1452.7	24.1	234Pa
3017	1003	11.1	U-233	4388	1458.5	16.4	234mPa
3018	1003.6	208.2	213Bi	4389	1458.9	2.8	234Pa
3037	1009.9	2.1	234Pa	4494	1493.6	3.1	234Pa
3073	1021.8	4.4	234Pa	4516	1501	11.8	234mPa
3094	1028.7	17.8	234Pa	4545	1510.5	11.6	234mPa
3133	1041.7	11.4	234mPa	4552	1512.8	29	212Bi
3141	1044.4	9.4	234Pa	4560	1515.6	2.1	234Pa
3186	1059.4	10.4	234mPa	4595	1527.2	21.5	234mPa
3194	1061.9	21.8	234mPa	4664	1550	10.6	234mPa
3229	1073.6	3.2	234Pa	4664	1550.1	2.1	234Pa
3244	1078.7	31.9	212Bi	4676	1554.1	72.4	234mPa
3258	1083.2	15.7	234Pa	4689	1558.3	6.7	234mPa
3258	1083.2	8.5	234mPa	4715	1567.1	18673.2	209Tl
3265	1085.4	4.6	234mPa	4726	1570.7	9.8	234mPa
3290	1093.9	8.4	208Tl	4754	1579.9	2.1	234Pa
3309	1100.2	1434.4	213Bi	4772	1585.9	4.2	234Pa

Channel	keV	Counts	Isotope	Channel	keV	Counts	Isotope
4796	1593.9	24	234mPa	5296	1759.8	12	234mPa
4796	1594	9.1	234Pa	5313	1765.4	74.3	234mPa
4820	1601.8	4.2	234mPa	5405	1796.2	2.6	234mPa
4876	1620.5	159.8	212Bi	5408	1797.1	6.6	234Pa
4897	1627.3	2.2	234Pa	5435	1806	10.5	212Bi
4929	1638.1	6	234Pa	5444	1809	31.3	234mPa
5018	1667.6	7.2	234mPa	5476	1819.7	7.6	234mPa
5020	1668.4	21.9	234Pa	5512	1831.5	145	234mPa
5054	1679.5	2.2	234Pa	5607	1863.1	10	234mPa
5054	1679.7	6.4	212Bi	5621	1867.7	76.7	234mPa
5072	1685.7	8.9	234Pa	5643	1875.2	68.2	234mPa
5097	1693.8	19.8	234Pa	5688	1890.1	3.9	234Pa
5098	1694.1	3.9	234mPa	5698	1893.5	18.1	234mPa
5100	1695	7.7	234Pa	5708	1896.7	2.8	234Pa
5117	1700.5	3	234Pa	5752	1911.2	51.9	234mPa
5177	1720.5	2.8	234mPa	5794	1925.4	8.2	234Pa
5199	1727.8	57	234Pa	5797	1926.4	2.6	234mPa
5212	1732.2	15.5	234mPa	5829	1937	23.7	234mPa
5229	1737.7	2.1	234Pa	5929	1970	4.5	234mPa
5229	1737.8	181.8	234mPa	7870	2614.5	4610.1	208Tl

Table IX. Gamma photopeaks and counts for the sources of Situation 6. Background not included, x-rays not included.

APPENDIX 4.

TRIAGE EVENT NUMBER: [redacted] (DRILL)

U.S. Department of Energy
NNSA/NA-42
Office of Emergency Response
Nuclear Incident Team Operations

Event Date: 23 OCT 2012
Event Type: Drill
Urgency: Not Urgent

Location: Undisclosed

Callout
Bridge Open: NA
Bridge Close: NA
Report Date: 26 OCT 2012
Revision #:

Edited by:

Federal Leads
DOE ERO:
DOE FTL:

Triage Analysts
Gamma Spec:
Gamma Spec II:
P1E Diag:
Trainee:

Other Participants

Request submitted by
Organization(s): NKS, NRPA

[redacted]

Template Version 4 (10.24.2012)

TRIAGE INCIDENT REPORT

Brief Description: GASMAT Situation 1

SUMMARY

Field submission – radiation portal monitor triggered, cargo contains open topped wooden shipping crates filled with aviation components going to a scrap metal firm. Handheld detectors indicate the presence of a source which cannot be identified. Analysis requested.

Th-232 was identified as the unknown source; however there is also U-238 present which may indicate a potential threat.

Confidence is high.

TABLE 1: RADIONUCLIDES IDENTIFIED

Radionuclides	Quantity	Remarks
Th-232	10 – 100 kg	Distance uncertain
U-238	10's of kg	Geometry unknown, distance uncertain

SITUATION

A truck is stopped at a border crossing after triggering a radiation portal. Search with handheld detectors indicates the presence of a source on board which cannot be identified by the operators so authorities are asked to assist. The shipping documents indicate that the truck is supposed to be carrying "aviation components" from an old military base to a scrap metal firm in a second country. Limited visual inspection inside the truck indicate what appear to be open topped wooden shipping crates filled with what look to be old motors and metal junk. One of these crates seems to be responsible for the elevated gamma readings. What appears to be the designation "HK31A" is visible stamped on a casing of one of the pieces in the crate.

DATA FILES

Triage used the following files in its analysis:
test spectrum.spe (calibration/known)
Situation 1 background.spe (background)
Situation 1.spe (unknown)

The detector is a standard generic coax HPGe. Relative efficiency is approximately 40%.

The detector was placed about 1 meter from the crate face.

ADDITIONAL INFORMATION

HK31A is a high-temperature alloy used in some aircraft parts and contains a few weight percent of thorium.

TECHNICAL ASSESSMENT

Triage analyzed the spectra using PeakEasy version 4.25, SimpleMass 5.8 and GADRAS versions 18.1.1 and 18.1.3.

The analysis showed no indication of Special Nuclear Materials other than U-238. There are no indications of neutrons. The submission requested qualitative analysis only.

An elevated 2614 keV peak indicates a nuclide in the Tl-208 decay chain is present. The presence of the 911 and 969 keV peaks in equilibrium rule out U-232 and

anything else below Ac-228 in the decay chain as the parent nuclide. The Th-232 and its daughters are in natural proportions indicating either metal that is more than 20 years old or NORM. The thorium appears to be a distributed source, since SimpleMass does not indicate much self-shielding, if any. Findings are consistent with the scenario: it is common to see enhanced Th-232 in loads of scrap metal. The "HK31A" designation stamped on one of the pieces in the crate likely indicates the magnesium alloy HK31A, which has a nominal chemical composition of 3.25% Th, 0.7% Zr, and the balance Mg.

The 1001 keV peak indicates tens of kilograms of non-enriched uranium based on the small U-235 line at 186 keV, as shown in Figure 1. The absence of strong lines from daughters Bi-214 and Pb-214 rule out uranium NORM. The strong thorium signal obscures other U-235 lines and any uranium x-rays and so makes it impossible to decide if this is a single large piece of uranium or if it is distributed. Note that this many kilograms of U-238 can easily shield other sources, so knowing whether or not the uranium is a distributed source is essential in ruling in or out a threat.

The ranges in quantities are based on a source to detector distance of 1 to 3 meters, based on the stated distance and the unspecified possible width of the crate.

Note there is an unidentified peak at 810 keV. This may be due to a database error.

REMARKS
Spectra have excellent resolution, but a longer count time would be better. It also would be beneficial to know the size of the container being measured.

TRIAGE RECOMMENDATIONS

NEXT STEPS
X-ray or visual inspection would help determine if the U-238 is a distributed source.

RADIOLOGICAL HEALTH/SAFETY
Based on the data analyzed, this material does not appear to pose any known radiological health or safety risk.

PROCESS IMPROVEMENTS
Longer count time, photographs of actual scenario would be helpful (to determine the size of the item being measured).

FIGURES AND TABLES

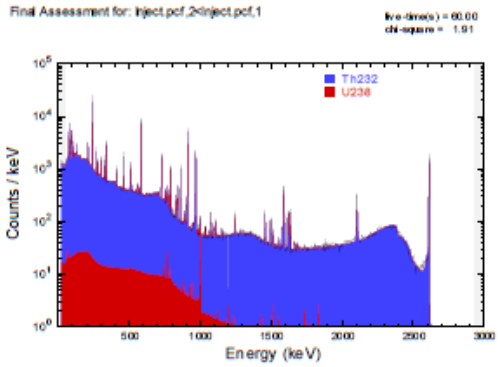


Figure #1: GADRAS V.18.1.1 HPGeFSA fit using a Detective-EX-100, and a source-to-detector distance of 2 m.

TRIAGE EVENT NUMBER: [redacted] (DRILL)

U.S. Department of Energy
NNSA/NA-42
Office of Emergency Response
Nuclear Incident Team Operations

Event Date: 24 OCT 2012
Event Type: Drill
Urgency: Not Urgent

Location: Undisclosed

Callout
Bridge Open: N/A
Bridge Close: N/A
Report Date: 26 OCT 2012
Revision #:

Edited by:

Federal Leads
DOE ERO:
DOE FTL:

Triage Analysts
Gamma Spec:
Gamma Spec II:
P1E Diag:

Other Participants

Request submitted by
Organization(s): NKS, NRPA

[redacted]

Template Version 4 (10.24.2012)

TRIAGE INCIDENT REPORT

Brief Description: GASMAT Challenge: Situation 2

SUMMARY

HPGe measurements of palletized cargo were submitted with the request to qualitatively assess the data. The pallet was stacked with sacks labeled with the identifier of MKP 0-52-34/NPK 0-52-34 (Mono-Potassium Phosphate fertilizer). Measurements were taken with an HPGe detector from each of four sides.

Analysis indicates a high concentration of K-40 (as expected for the cargo), Ra-226 (elevated 3×background), Th-232 (slightly elevated), U-235 and U-238. While uranium is a common impurity in phosphate fertilizer, the data strongly indicate that an additional source of enriched uranium is embedded within the matrix. The discovery is a significant concern.

TABLE 1: RADIONUCLIDES IDENTIFIED

Radionuclides	Quantity	Remarks
K-40	Strong, Not determined	Normal for this product
U-235	Not determined	Enriched uranium, Heterogeneous distribution
U-238	Not determined, kg+ possible	
Ra-226, Th-232	Slightly elevated	NORM

SITUATION

A large truck was stopped by customs as part of a routine check. A dosimeter registered elevated readings near a pallet stacked with sacks. The driver claims to be on his way to deliver goods to an agricultural supply firm in another country.

DATA

DATA FILES

Data were synthetic, generated to represent a generic HPGe detector of undeclared size. Data were provided in multiple formats including CNX, PHD, SPE, TXT, and CHN; all formats were readable.

Situation 2 Background.
Situation 2 Position A.
Situation 2 Position B.
Situation 2 Position C.
Situation 2 Position D.

ADDITIONAL INFORMATION

Situation details are given in *Situation 2.PDF*. The pallet is described as approximately 1 m × 1 m × 90 cm. Measurements were taken 10 cm form the pallet centered on each of the four sides, designated "A," "B," "C," and "D" as indicated in Figure 1.

The dimensions stated correspond to about thirty 50-lb sacks, or an estimated 680 kg of product.

The chemical form of MPK is KH_2PO_4. Fertilizer grade MKP contains the equivalent of 52% P_2O_5 and 34% K_2O, and is labeled 0-52-34, as with the markings noted in *Situation 2.PDF*.

TRIAGE EVENT NUMBER: [redacted] (DRILL)

TECHNICAL ASSESSMENT

Software used in the analysis included GADRAS 18.1.1, PeakEasy 4.26, FRAM 5.1, Simple Mass 5.8, and Spectre 1.0.

The spectrum is dominated by K-40, as expected for 100's of kg of MPK fertilizer. Uranium is also observed in the spectrum. While uranium is not an unusual finding in MPK fertilizer (see Remarks), the data strongly indicate that there is an additional source of uranium. Rationale is described below:

(1) The uranium, at least the U-235 component, is not uniformly distributed. The background-subtracted net counts for the strongest gamma ray lines for U-235 and U-238 are shown in the table below. As can be seen, the U-235 signature is an order of magnitude stronger when viewed from sides B and C than it is from side A and D, suggesting a strongly heterogeneous distribution. This is most likely due to an embedded hotspot near the B-C corner, and is not consistent with fertilizer.

Side	Net Counts @ 186 keV (U-235)	Net Counts @ 1001 keV (U-238/Pa-234m)
A	1584 ± 48	236 ± 34
B	15857 ± 128	232 ± 34
C	31704 ± 181	349 ± 42
D	1280 ± 40	130 ± 32

(2) The uranium appears to be enriched. The isotopic analysis results using FRAM from Sides B and C are as follows:

Side A: indeterminate due to weak signal
Side B: (13.3 ± 3.0)% U-235
Side C: (18.3 ± 4.8)% U-235
Side D: indeterminate due to weak signal

Analysis using GADRAS and SimpleMass also indicate enrichments significantly higher than natural uranium (0.72%). If the uranium is presumed natural but freshly processed, then the processing must have occurred 1-4 days prior to the gamma measurement. This is an unlikely timescale for packaged and bundled material, so the uranium is almost certainly enriched. Also see Remarks.

The actual enrichment of the hotspot may be higher due to dilution from natural uranium in the fertilizer matrix. A crude attempt to correct for the dilution gives a plausible enrichment of 50% U-235.

(3) Uranium concentration appears to be higher than typically observed in phosphate fertilizer. Based on very few field measurements, we have observed uranium concentrations in fertilizer (Mono-Calcium Phosphate) up to 200 mg/kg. In the present case the concentration appears to be at least 10 × higher.

(4) The odd daughters of U-235 (such as Ac-227) are not visible in the spectra. These isotopes are usually preserved when phosphate minerals are processed for fertilizer production. The present data suggest a more highly refined source of uranium. See remarks.

Accurate quantification is difficult. Modeling results suggest that 1-5 kg of uranium in the hotspot is consistent with the data. Details of differential attenuation, assumed geometry, and assumed detector efficiency severely impact accuracy of any estimate. Furthermore, uranium is very effective at self-shielding its own low-energy gamma rays from U-235.

REMARKS

Most phosphate fertilizers are derived from mineral phosphate rock. Uranium content in the rock varies from 12-390 mg/kg with a typical value of about 50 mg/kg [Van Kauwenbergh, S.J., Proc. No. 400, The Fertilizer Society, p. 82 (1997)]. Some of this uranium remains in the fertilizer product.

Mineral phosphate is processed with sulfuric acid, which causes fractionation of the uranium daughter products, breaking the secular equilibrium. From U-238, we have observed that daughters Rn-222 and below (including Bi-214) are greatly reduced relative to Pa-234m. For freshly processed product (< 3 months) the Pa-234m may also be reduced relative to U-235; the resulting gamma ray spectrum may therefore resemble *enriched* uranium. The U-235 daughters, notable Ac-

227, appear to be less affected and appear in nearly secular equilibrium. The resulting gamma ray fingerprint, containing many odd daughters but reduced even daughters, is distinctive.

Thorium is also present in phosphate rock at 2-19 mg/kg, and so is also found in phosphate fertilizers. The daughter Ac-228 may be partially removed by the acid processing, altering the gamma ray fingerprint so that it more resembles the U-232 chain than natural thorium. No such reduction of Ac-228 is observed in the present case.

U-232 is often enhanced in enriched uranium, which has a signature of increased Tl-208 without increased Ac-228. No such signature was observed in the present case, which is a counter-indication for enriched uranium of US origin; however, many countries produce enriched uranium with no increase of U-232.

The spectra include an anomalous peak at 809.8 keV. This is assumed to be a database error.

FIGURES AND TABLES

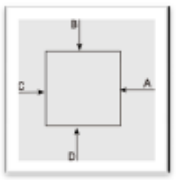


Figure 1: Measurement configuration for the four sides ("A", "B", "C", and "D").

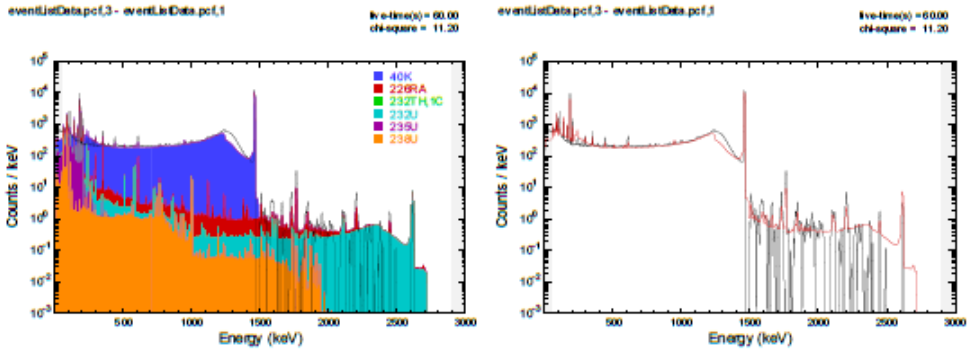


Figure 2: Multiple regression fit of "C" spectrum using GADRAS 18.1.1.

U.S. Department of Energy
NNSA/NA-42
Office of Emergency Response
Nuclear Incident Team Operations

Event Date: 24 OCT 2012
Event Type: Drill
Urgency: Not urgent

Location: Airport in Norway

Callout None
Bridge Open: N/A
Bridge Close: N/A
Report Date: 25 OCT 2012
Revision #: 0.1

Edited by:

Federal Leads
DOE ERO:
DOE FTL:

Triage Analysts
Gamma Spec:
Gamma Spec II:
P1E Diag:

Other Participants
N/A

Request submitted by
Organization(s): NKS, NRPA

[redacted]

Template Version 4 (10.24.2012)

TRIAGE INCIDENT REPORT

Brief Description: GASMAT Situation 3 – Passenger at airport checkpoint with unknown radioactive material

SUMMARY

Spectrum submitted as part of GASMAT challenge, situation 3.

A man stopped at an airport security checkpoint was found to be carrying a small box containing radioactive material. Airport personnel have not opened the box; a handheld identifier (unspecified model) was unable to ID the contents. The individual is not able to provide any useful information regarding the contents of the box.

The box contains an assortment of materials (see below) consistent with an assortment of medical, industrial and calibration sources, all in the micro-Curie (uCi) to milli-Curie (mCi) range depending on the unspecified source to detector distance (10 cm to 100 cm assumed range).

The isotopes present do not represent a threat.

TABLE 1: RADIONUCLIDES IDENTIFIED

Radionuclides	Quantity	Remarks
Gd-153	6 uCi – 9 mCi	used in medical applications
Lu-177m	10 uCi – 1 mCi	used in medical applications
Co-57	5 uCi – 1 mCi	used in medical applications
Sn-113	5 uCi – 0.5 mCi	common calibration source
Ba-133	1 uCi – 0.1 mCi	common calibration source
Cs-137	1 uCi – 0.1 mCi	medical/industrial source
Zr-95	2 uCi – 0.2 mCi	missing Nb-95 (freshly separated)
Pa-234m	–	U-238 daughter
K-40	–	NORM
Th-232 & daughters	–	NORM
Ra-226 & daughters	–	NORM

SITUATION

One spectral file of an unknown object of interest was submitted for evaluation. The field has asked for a threat/no threat determination as well as isotopic identification and if possible estimated activities. The spectrum was taken of a box that contained radioactive material discovered at an airport security checkpoint.

DATA

DATA FILES

Triage used the following files in its analysis:
Situation 3.spe, unknown item, 06/17/2011
Situation 3.txt, event details
Technical Details for the GASMAT Materials.pdf, general details and detector specifics

Detector was a 40% relative efficiency coax HPGe, more information can be found in "Technical Details for the GASMAT Materials.pdf" file.

TECHNICAL ASSESSMENT

Triage analyzed the spectrum using PeakEasy v4.22 and GADRAS v18.1.1.

The spectrum contained a mixture of isotopes (see above). However, there was no indication of the presence of any threat material. Isotope identification was performed using PeakEasy (see Figure 1). All peaks were successfully ID'd. GADRAS did not fit the continuum well due partially to the strange shape of the Compton Continuum. This may be due to scattering effects or possibly poor detector characterization in the detector response model. The best fit was found using slight modifications to the LLNL 40% HPGe detector (see Figure 2).

The spectrum does not exhibit indications of strong shielding. GADRAS shielding estimates for multiple regression fitting, allowing independent shielding, and adopting the upper end of 100 cm detector-source distance results in:

Source	*Activity(mCi)*	*Weight(gm)*	*AN*	*AD*
57-Co	*0.84 +/- 0.01*	*9.98E-08*	*82.3*	*0.9*
95-Zr	*0.145 +/- 0.001*	*6.74E-09*	*94.0*	*0.0*
113-Sn	*0.418 +/- 0.005*	*4.17E-08*	*81.9*	*0.0*
133-Ba	*0.080 +/- 0.001*	*3.19E-07*	*80.9*	*0.8*
137-Cs	*0.132 +/- 0.002*	*1.53E-06*	*62.4*	*2.3*
153-Gd	*9.1 +/- 0.1*	*2.60E-06*	*82.3*	*0.9*
177m-Lu	*0.776 +/- 0.002*	*1.69E-07*	*84.3*	*1.0*

Using peak information, a mixture of medical and industrial isotopes were found (see above).

Due to the mixture of somewhat uncommon isotopes present, it is not surprising that the handheld radioisotope identifier used in the field did not identify the isotopes present.

Even though the fit to the Compton Continuum was poor, the size of the object, described as a "small metal box", makes it unlikely that heavily shielded isotopes, without visible peaks, are present.

A distance range of 10 cm to 100 cm was assumed for this analysis. A significantly larger distance would result in higher activity estimates, potentially making this a concern as a potential RDD or radiological hazard.

REMARKS
Photos of the item of concern as well as the detector location and distance would be greatly appreciated.

TRIAGE RECOMMENDATIONS

NEXT STEPS
Depending on quantities, these isotopes may require documentation for legal transport.

RADIOLOGICAL HEALTH/SAFETY
Based on the data analyzed, at the assumed distance of 10 cm, this material does not appear to pose any known radiological health risk.

PROCESS IMPROVEMENTS
None

FIGURES AND TABLES

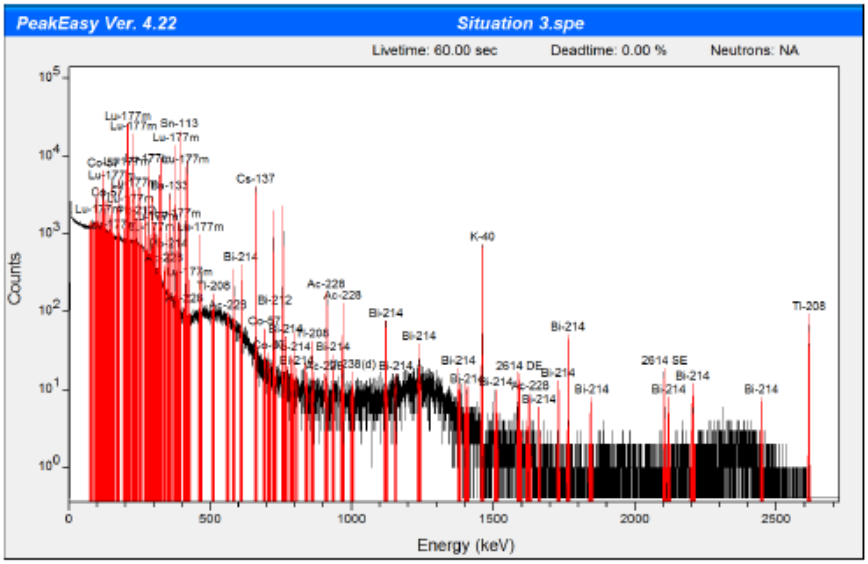


Figure 1: Peak identification for all peaks visible in the spectrum.

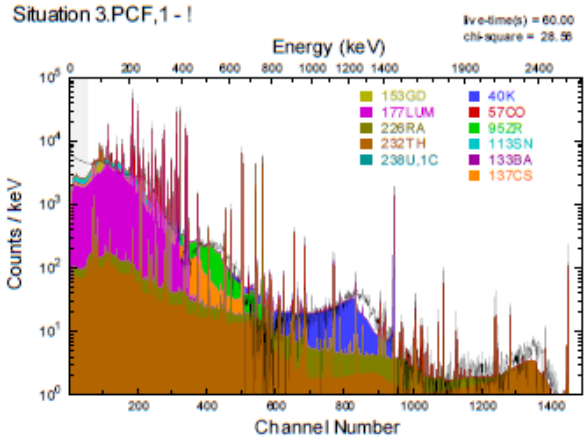


Figure 2: GADRAS fit to the data, note the poor fit to the "rounded" Compton Continuum.

TRIAGE EVENT NUMBER: [redacted] (DRILL)

U.S. Department of Energy
NNSA/NA-42
Office of Emergency Response
Nuclear Incident Team Operations

Event Date: 24 OCT 2012
Event Type: Drill
Urgency: Not Urgent

Location: Undisclosed

Callout
Bridge Open: NA
Bridge Close: NA
Report Date: 26 OCT 2012
Revision #:

Edited by:

Federal Leads
DOE ERO:
DOE FTL:

Triage Analysts
Gamma Spec:
Gamma Spec II:
P1E Diag:

Other Participants

Request submitted by
Organization(s): NKS, NRPA

[redacted]

Template Version 4 (10.24.2012)

TE-12-0042-B

Brief Description: International request for Triage adjudication of Situation 4.

SUMMARY

Data submitted via the Triage webpage. Situation 4 consisted of simulated High Purity Germanium (HPGe) data taken of smoke detectors in a cardboard box. The total declared activity is reported to be 100 micro Curies (µCi).
The instrument used did not identify isotopes. Analysis of the spectral data indicated the presence of Americium-241 (^{241}Am) from the smoke detectors that were present.
The presence of heavily shielded, high burn-up Plutonium was also present.
We are confident that situation 4 contains Special Nuclear Material and represents a threat item.

TABLE 1: RADIONUCLIDES IDENTIFIED

Radionuclides	Quantity	Remarks
High burn-up/Reactor Grade Pu	N/A	Threat
Am-241	N/A	Used to try to mask threat

SITUATION

An international customer submitted six (6) "Situations" via Triage. These situations consisted of simulated data that accompanied different scenarios. Based on the scenarios and spectral information, Triage analysts were asked to assess the data presented for SNM threats and to identify all nuclides/materials present. This report focuses on Situation 4, summarized below.

"A commercial vehicle is stopped at a customs point and the load is checked. The manifest includes a cargo of smoke detectors being imported into the country and states that there are 100 smoke detectors in a cardboard box. The customs officials are concerned as to their exposure in checking the cargo as they say the documents state that there is 1 µCi of radioactivity in each detector and request that someone confirms that it is safe. In the interest of public relations and seeing a possible training opportunity the authorities dispatch a junior staff member with an HPGe detector. The staff member takes a background spectrum outside the truck and then takes a spectrum approximately 20 cm from the side of the cardboard box."

DATA

DATA FILES

Triage used the following files in its analysis:

Datum	Type	Date
Technical Details for the GASMAT Materials.pdf	pdf document with instructions germane to all situations	10/8/2012
Situation 4. chn/.cnf/.spe/.txt/.phd	.chn/.cnf/.spe/.txt/.phd files with identical spectral data of unknown	10/17/2012
Situation 4 background. chn/.cnf/.spe/.txt/.phd	.chn/.cnf/.spe/.txt/.phd files with identical spectral data of background	10/17/2012

Description of the detector used was taken from the Technical Details for the GASMAT Materials.pdf document.

"The detector for GASMAT is a standard generic coax HPGe. The detector holder is 0.51 mm thick aluminium with a 3 mm spacing between crystal face and detector end

cap. A uniform dead layer of 1 mm is assumed all round the crystal. The crystal is 6 cm in diameter and 7 cm long. Relative efficiency is approximately 40% and the resolution is 1.8 keV at 1332 keV. The detector is set up such that the energy calibration can be described with a zero of 1.353606 keV and a gain of 0.3320552 keV/channel with a full scale energy of 2721.5 keV[sic] (8192 channels)."

ADDITIONAL INFORMATION
No other information was used in our analysis

TECHNICAL ASSESSMENT

Triage analyzed the spectra using PeakEasy 4.27.

The isotope ^{241}Am is being used to mask a significant quantity of heavily shielded, high-bumup/reactor grade Plutonium. Evidence that this sample contains heavily shielded Plutonium is seen by the absence of Plutonium peaks from the X-ray region to 250 keV. Peaks attributable to ^{239}Pu and ^{238}Pu are clearly seen in the 350-420 keV and 600–850 keV regions of the spectrum, respectively.

Radioactive material in the form of SNM, in addition to approximately 100 µCi of ^{241}Am, was present in the unknown spectrum based on the following observations:

- During the short data collection time of 60 seconds, peaks from 600 keV to 850 keV were observed. This is not indicative of a spectrum of a 100 µCi ^{241}Am source.
- Features at 375.1 KeV and 413.7 KeV region indicated the presence of ^{239}Pu.
- ^{238}Pu was also present based on the presence of peaks at 766 keV and 1001 keV that were elevated above background with the 766 keV peak being higher than the 1001 keV peak. Even though these peaks are present in samples of ^{238}U, their relative peak heights are reversed, thus ruling out the presence of ^{238}U.

No evidence of ^{235}U or ^{237}Np was found. This determination is based on the following observations:

- No evidence of ^{237}Np/^{233}Pa in-growth from ^{241}Am could be in detected based on the primary ^{237}Np/^{233}Pa gamma emission at 311.9 keV.
- Even though the primary gamma lines for ^{235}U (143.8, 163.4 185.7 and 205.3 keV) would be hidden due to shielding, no elevated 2614 keV peak resulting from the ^{208}Tl daughter of ^{232}U was observed. ^{232}U is present at levels detectable in reprocessed HEU. This is not definitive since ^{235}U in non-reprocessed HEU would not have this Tl-208 signature present.

The Plutonium isotope ^{239}Pu is identified (Figure 1) as being present based on the presence of elevated counts at 375.1 and a small peak at 413.7 keV, respectively. Note that the 413.7 keV peak is narrower than expected. The 129.3 keV peak from ^{239}Pu was not statistically elevated above background indicating the ^{239}Pu also may be shielded with the ^{241}Am. Lastly, ^{238}Pu is present based on a small peak at 766.4 (Figure 2) and several very small peaks at 742.8, 786.3, 851.7, and 1001.0 keV (Figure 3). Please note that the ^{238}Pu peak at 766.4 keV has some moderate interference from the 767.0 keV peak of ^{241}Am. Based on the interference corrected area of the 766.4 keV ^{238}Pu peak and the area of the 722.0 keV ^{241}Am peak, the relative activity ratio of ^{241}Am to ^{238}Pu is estimated at ≈ 1.25.

Given the presence of ^{238}Pu and ^{241}Am at similar activities, reactor grade plutonium may be suspected. ^{236}Pu/^{232}U which is associated with reactor grade plutonium, weapons grade plutonium, and ^{238}Pu production was not detected based on the absence of an elevated 2614.5 keV emission from ^{208}Tl. However, significant and observable buildup of ^{208}Tl from ^{236}Pu/^{232}U decay takes a few years.

The absence of neutron data both directly from a neutron detector and indirectly from neutron interactions that produce gamma-ray signatures makes the analysis more challenging than normal.

REMARKS
Spectra and supplementary data for Situation 4 were good. The summary document "Technical Details for the GASMAT Materials.pdf" was excellent in explaining what was included, what was relevant and what was absent within each situation. A clear directive was also given.

A longer count would be helpful for better peak area determinations

TRIAGE RECOMMENDATIONS

NEXT STEPS
NA.

RADIOLOGICAL HEALTH/SAFETY
Based on the data analyzed, this material may pose a radiological health and safety risk

PROCESS IMPROVEMENTS
None identified

FIGURES AND TABLES

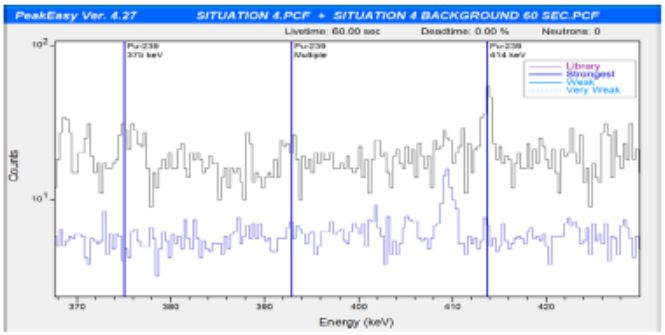


Figure 1: PeakEasy screenshot of peaks in the 375-414 keV region that indicate the presence of ^{239}Pu.

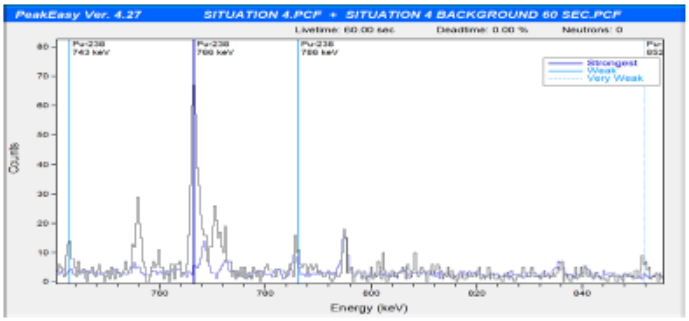


Figure 2: PeakEasy screenshot of peaks in the 740-850 keV region that indicate the presence of ^{238}Pu.

TRIAGE EVENT NUMBER: [redacted] (DRILL)

U.S. Department of Energy
NNSA/NA-42
Office of Emergency Response
Nuclear Incident Team Operations

Event Date: 24 OCT 2012
Event Type: Drill
Urgency: Not Urgent

Location: Undisclosed

Callout
Bridge Open: N/A
Bridge Close: N/A
Report Date: 26 OCT 2012
Revision #:

Edited by:

Federal Leads
DOE ERO:
DOE FTL:

Triage Analysts
Gamma Spec:
Gamma Spec II:
P1E Diag:

Other Participants

Request submitted by
Organization(s): NKS, NRPA

[redacted]

Template Version 4 (10.24.2012)

TRIAGE INCIDENT REPORT

Brief Description: "Situation5" of "GASMAT" Individual alarmed portal monitor

SUMMARY

GASMAT is an exercise prepared by the Norwegian Radiation Protection Authority, this submission (October 2012) contained six separate events. This report addresses "Situation 5" of the exercise.

The individual reported that he'd recently been hospitalized (no further info), and set off a portal monitor. Four measurements of the individual were conducted, the measurement near his neck revealed I-123. No other unexpected radionuclides were observed.

This individual is not part of a nuclear or radiological threat. We have high confidence in this assessment.

TABLE 1: RADIONUCLIDES IDENTIFIED

Radionuclides	Quantity	Remarks
I-123	16-30 uCi	Nuclear medicine nuclide

SITUATION

Provided with submission: "*A man is observed acting strangely on board a bus passing a border crossing. Upon disembarkation for checking of papers the man passes in front of the radiation portal monitor at the roadside and an alarm is signaled. The man maintains he has recently been in hospital and is travelling to visit his relatives to recuperate. Handheld monitors indicate the possible presence of a source on the man who refuses to submit*
to a search of his person. Localisation or identification of the source is beyond the capabilities of the border personnel who ask the authorities to assist.
The authorities conduct a scan of the man using a HPGe detector. A series of four measurements are made – the first near his head/neck (Measurement A), the second near his thorax (Measurement B), the third near his pockets (Measurement C) and the fourth near his shoes (Measurement D). Measurement points are indicated in the attached diagram. The measurements were made approximately 20 cm away from the surface of the body in each case. No separate background measurement was made."

DATA

DATA FILES

Triage used the following files in its analysis:
Situation 5 position A.chn
Situation 5 position B.chn
Situation 5 position C.chn
Situation 5 position D.chn
Situation 5.pdf
Technical Details for the GASMAT Materials.pdf

TECHNICAL ASSESSMENT

Triage analyzed the spectra using Peakeasy 4.26, GADRAS 18.0.8, Simple Mass 5.8a, and Spectre 1.1 to analyze the spectra. They had good agreement between them. The data are clearly synthetic.

The spectra were not properly calibrated as received, and were calibrated using the

1461 keV gamma ray from K-40 and the 2614 keV gamma ray from Tl-208, as well as other, low energy gamma-rays from the natural decay chains. A background spectrum was not received for this event, and might have improved the activity estimate for this event, but not appreciably.
Measurement "A" had clear evidence of I-123 and background lines from the decay of naturally occurring uranium and thorium and potassium.
Measurements "B", "C", and "D" had clear evidence of background lines from the decay of naturally occurring uranium and thorium and potassium. I-123 was not evident in these spectra.
Concentrations of thorium and uranium daughters varied between the measurements without correlation to measurement location.

I-123 is used in thyroid studies, and concentrates in the thyroid. It is not a predominate fission product, so other sources for the iodine were not considered. The individual reported he'd been in hospital recently, and this is consistent.

The activity range of 16-30 uCi between analysis programs is considered in good agreement and well within the uncertainties inherent in the measurements.

REMARKS
The inclusion of four spectra helped greatly in our assessment. Having four measurements enabled us to evaluate the potential for the individual to be transporting other materials (e.g. HEU) and using the I-123 as a masking agent, as well as background contributions to the measurements. Inclusion of a background spectrum would have been helpful.

TRIAGE RECOMMENDATIONS

NEXT STEPS
No follow-on actions are indicated.

RADIOLOGICAL HEALTH/SAFETY
There are no radiological Health or Safety concerns.

PROCESS IMPROVEMENTS
No additional process improvements are indicated.

FIGURES AND TABLES

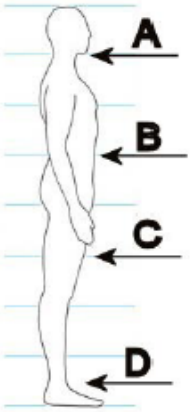


Figure #1: Drawing provided with submission

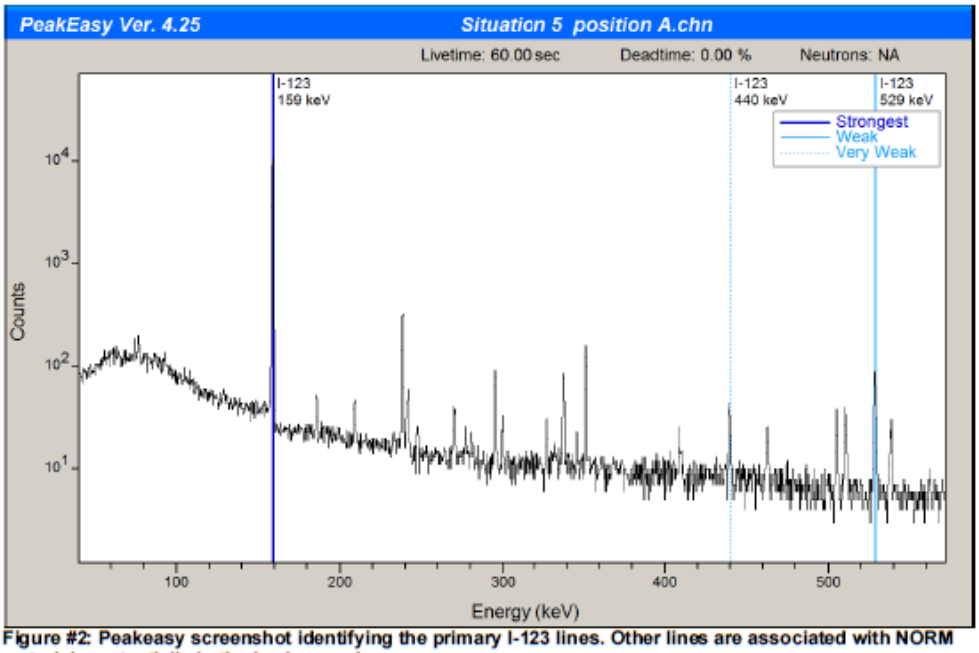


Figure #2: Peakeasy screenshot identifying the primary I-123 lines. Other lines are associated with NORM materials, potentially in the background.

U.S. Department of Energy
NNSA/NA-42
Office of Emergency Response
Nuclear Incident Team Operations

Event Date: 23 OCT 2012
Event Type: Drill
Urgency: 24 hours

Location: Undisclosed

Callout
Bridge Open: N/A
Bridge Close: N/A
Report Date: 26 OCT 2012
Revision #:

Edited by:

Federal Leads
DOE ERO:
DOE FTL:

Triage Analysts
Gamma Spec:
Gamma Spec II:
P1E Diag:

Other Participants

Request submitted by
Organization(s): NKS, NRPA

[redacted]

Template Version 4 (10.24.2012)

TRIAGE INCIDENT REPORT

Brief Description: Situation 6

SUMMARY

A high-purity germanium (HPGe) spectrum of an item purported to contain Ir-192 was recorded at an international Customs checkpoint and submitted for analysis.

In addition to a direct signature for depleted uranium, gamma-ray peaks from the daughters in the U-233 and U-232 decay chains are present. No direct evidence exists for these nuclides however. No signature from the declared Ir-192 contents was observable. No field analysis of the HPGe data was provided.

This item represents a potential threat as we cannot rule out the possibility of the presence of special nuclear material (SNM).

Confidence is high that threat material cannot be ruled out in this analysis.

TABLE 1: RADIONUCLIDES IDENTIFIED

Radionuclides	Quantity	Remarks
Possible U-233	Age dependent	SNM Threat
Possible U-232	100-200 microCi	SNM Contaminant
Depleted U	kgs	Common shield material

SITUATION

A Customs officer at an international checkpoint measured an item stated to contain a 0.4 TBq Ir-192 source in a depleted uranium shield (the photo provided indicated 16.8 kg of DU are present). Although the instrument was new to the officer, he stated that its result was "too high" albeit without giving an indication of how this was determined. A field team equipped with a HPGe system was dispatched to the checkpoint and obtained a 60-second spectrum 30 cm from the side of the item. This, in addition to a 300-second background spectrum, was submitted to Triage for analysis.

DATA

DATA FILES

Triage used the following files in its analysis:
Situation 6.spe
Situation background 6.spe
Situation 6.pdf

Background 10/23/2012
Unknown 10/23/2012

HPGe Detector, ~40% Efficient relative to 3x3" NaI at 1332 keV

ADDITIONAL INFORMATION

In addition, the following information was pertinent to the analysis:

- Item container appeared to be a standard military ammunition box (Figure 1)

TECHNICAL ASSESSMENT

Triage analyzed the spectrum, shown in Figure 2, using PeakEasy 4.13, SimpleMass 5.9, FRAM 5.1, and SPECTRE 1.1. Among other nuclides, the data showed direct evidence for the presence of Bi-213 and Tl-209. These are daughters in the decay chain of U-233. However, they do not confirm the presence of U-233 and may in fact be a result of the presence of other U-233 daughters such as Th-229 or Ac-225. Th-229 is often found as a contaminant in Th-228 check sources and Ac-225 (a Th-229

daughter) is a common radiopharmaceutical source. A direct gamma-ray signature was observed for daughter nuclides of Th-228, which may result from the presence of U-232, a contaminant commonly found in SNM. The only direct uranium signature that was observable yielded a statistically-limited enrichment analysis result of natural/depleted uranium, which is consistent with the stated shielding material.

Using the gamma rays from U-238 daughters we obtained a DU shield thickness of 2 – 2.5 cm assuming a slab-correction for self-attenuation only. This thickness of DU was applied as an external attenuator to the Bi-213 and Tl-209 gamma rays that were assumed to emanate from behind the DU shield. This nearly corrected for all of the attenuation of the Bi-213 and Tl-209 gamma rays and provided a good cross check with the DU-self shielding correction previously described. For the final attenuation correction we assumed that a distributed source of U metal existed interior to the DU shield. Only a small thickness of U metal was required to account for the remaining differential attenuation of the Bi-213 and Tl-209 peaks.

Based on these findings, we determined that, if U-233 is present, the mass is most likely in the tens to hundreds of grams range. However, the mass estimate is highly uncertain as we do not know the geometry of the source interior to the DU shield and, perhaps more importantly, we do not know the age of the material. Direct gamma rays from U-233 and Th-229 are typically just above 300 keV and below. The thickness of DU that is present is adequate to completely shield gamma rays coming directly from U-233 or U-232 (see Figure 3). Without directly observable gamma rays from U-233, or Th229 we cannot determine the age of any U-233 that may be present. Uncertainty in the age of U-233 can yield mass results that vary over a large range.

Although no direct evidence exists for a threat, corroborating circumstances do support suspicion of a threat. First, the submitted spectrum shows no indication of Ir-192, which was declared to be the source in the container. Second, although these data could be explained by an Ac-225 radiopharmaceutical, chemical separation of Actinium should not result in a possible U-232 contaminant such as we may see in these data. Lastly, these data could be explained by a Th-228 source with a Th-229 contaminant, where the former has aged significantly to allow the latter to manifest itself. But again, this does not agree with the declared contents of Ir-192.

REMARKS

In general a 300-second spectrum would be the standard field measurement time as opposed to this 60-second spectrum. Also, these data exhibited peaks at ~810 keV and 1727 keV the origin which we cannot determine. This may be due to differences in nuclide databases in the generation and the analysis of the data.

TRIAGE RECOMMENDATIONS

NEXT STEPS

Because there is the potential for a SNM-based threat, we recommend that a spectrum of the contained source be obtained for at least 300 seconds in a configuration with less shielding if this is achievable in a safe fashion.

Opening the shielding container may expose those in the immediate area to dangerous levels of radiation.

RADIOLOGICAL HEALTH/SAFETY

Based on the data analyzed, this item may present a serious radiological threat and may be the basis for a special-nuclear-material-based threat.

PROCESS IMPROVEMENTS

Obtaining at least 300-seconds worth of data, when possible, should be a standard for Triage submissions.

Title	Gamma Spectrometric Discrimination of Special Nuclear Materials
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Abstract

This report presents details pertaining to an exercise conducted as part of the NKS-B programme using synthetic gamma ray spectra to simulate the type of data that may be encountered in the interception of material potentially containing special nuclear materials. A range of scenarios were developed involving sources that may or may not contain special nuclear materials. Gamma spectral data was provided to participants as well as ancillary data and participants were asked, under time constraint, to determine whether or not the data was indicative of circumstances involving special nuclear materials. The situations varied such that different approaches were required in order to obtain the correct result in each context. In the majority of cases participants were able to correctly ascertain whether or not the situations involved special nuclear material. Although fulfilling the primary goal of the exercise, some participants were not in a position to correctly identify with certainty the material involved, Situations in which the smuggled material was being masked by another source proved to be the most challenging for participants.

Key words Nuclear smuggling, gamma spectrometry, special nuclear material, identification

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