First experience with a HPGe telescope detector

M. Risse, T. Köble, W. Rosenstock, and J. Engelen-Peter,
Fraunhofer-INT, Euskirchen, Germany

1. Abstract

For detection and identification of nuclear material we equipped a transportable container with neutron and gamma measurement systems. The container itself provides the necessary infrastructure, e.g., energy supply, communication means, and work places.

In case of a threat by nuclear terrorist there is urgent need for information on type and quantity of the radioactive respectively nuclear material inside the object. Only with this knowledge it is possible to estimate the potential risk and to take adequate protective measures. Therefore we improved the system by a new telescope detector. This detector consists of two different HPGe Germanium detectors which are placed one after the other in one detector end-cap. Both detectors are cooled by one small liquid nitrogen dewar. Seen from the window the first detector is a planar germanium detector with high resolution suitable to detect the energy lines of uranium and plutonium gamma rays in the 100 keV range. The signals of this detector are processed by a digital spectrum analyzer. The spectrum is then evaluated with the MGA/MGAU code to determine the uranium and/or plutonium isotope vector. The second detector is a coaxial detector with high efficiency for high energy gammas. Although the efficiency of this detector is considerably reduced by the presence of the planar detector in front, this detector is well suited to detect gamma radiation in the Cs/Co energy range. The signals of the detector are processed by another digital spectrum analyzer and evaluated by standard nuclide identification software.

The main advantage of this system in the field of nuclear terrorism is that one mobile device is used for two measurements: uranium and plutonium identification and the identification of industrial and medical isotopes. This is especially of great use if the system has to be transported to the suspect object with a robot.

The paper presents first experiences with the device. This technical improvement may ease the task of identifying suspect objects containing radioactive or nuclear material and thus may help to combat nuclear terrorism.

Keywords: in-situ measurements, germanium detector, uranium/plutonium analysis

2. Introduction

In case of a threat by nuclear terrorist there is urgent need for information on type and quantity of radioactive respectively nuclear material inside the object. Various techniques can be used to detect, locate and identify nuclear and radioactive material by means of radiation detection. After locating the object one powerful method for qualitative and quantitative analysis is Gamma spectroscopy. Thereby it is necessary to have a good detector energy resolution which is achieved by using germanium detectors.

Gamma radiation of different radioactive sources vary in intensity, energy and number of discrete energy lines. It is therefore of importance to use a detector which is optimized to the given situation. E. g. measuring sources like ^{137}Cs or ^{60}Co with relevant gamma energies in the region above 650 keV requires a germanium detector with a sufficient efficiency which results in a large crystal volume. The analysis of sources with lower gamma energies require a small planar germanium detector with high resolution. As often the kind of radioactive source is not known in advance it is also not clear which kind of germanium detector will be the best for that situation. This leads to the fact that it might be necessary to obtain two separate spectra with two different types of germanium detectors.

When thinking of an severe incident there might be no time to do two separate measurements. For that kind of situation the telescope detector has been constructed as a combination of two germanium crystals in one detector.

3. Techniques

3.1. Detector Setup

The principle of crystal setup of the telescope detector is given in figure 1. Two germanium crystals are positioned one after the other in the end-cap of the detector. The one for the lower energy region is placed near to the front end. It is a planar crystal. Behind this crystal there is a coaxial n-type one for the upper γ-energy region. We call the detector for the lower energy region TELU and for the upper energy region TELO like it is given in figure 1. The crystal cooling is realized as a conventional liquid nitrogen cooling with a 2.5 liter dewar.

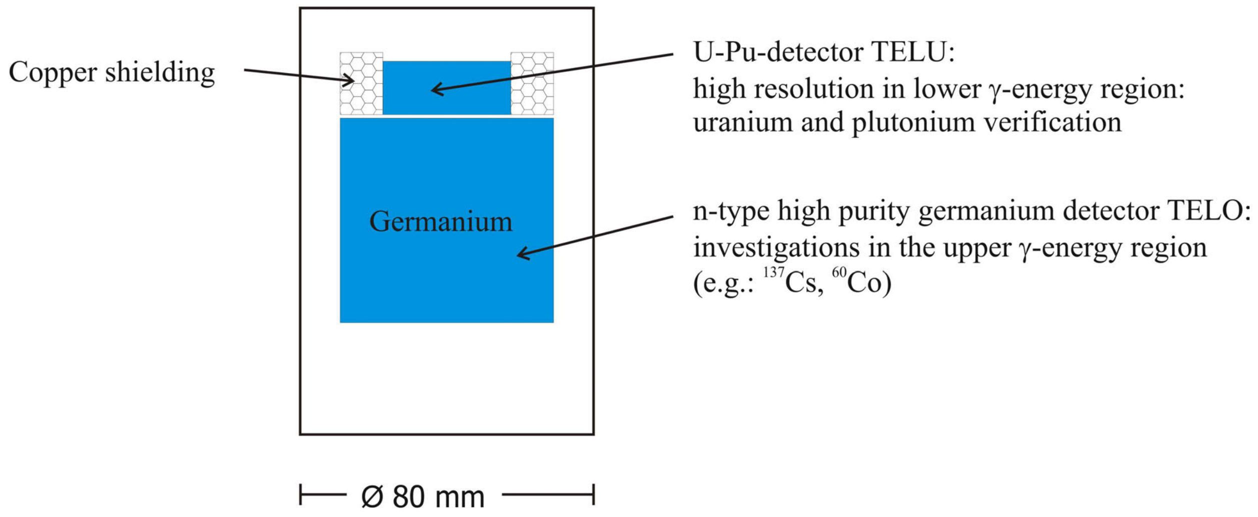

Figure 1: Principle of crystal setup in detector end-cap. Nomenclature of the telescope detector TELU/TELO.

Figure 2 shows the telescope detector together with the electronics and the laptop for acquisition and analyzing the data. As there are two crystals there are two signal processing circuits with two preamplifier and two multi-channel analyzer and high voltage systems. On top of the detector end-cap an additional tin shielding ring with thin tin plates is mounted. There are three tin plates of 1 mm each. They can be brought in front of the detector and will be used when measuring plutonium. In that case a strong 59.54 keV γ-line of the plutonium daughter ^{241}Am occurs. This leads to the effect that the energy region which is used for the analysis is strongly affected.

While placing one 1 mm thin tin plate in front of the detector the γ-line is shielded and the spectrum of the energy region important for the plutonium analysis can be obtained.

Figure 2: Telescope detector ready to use in the laboratory with electronics for both crystals and laptop for acquisition and analyzing the data. In front of the detector end-cap a tin ring with removable plates for shielding low energy γ-rays can be seen.

Figure 3: Telescope detector ready for outdoor use including radio data link. Left: detector with unit containing electronic device, power supply and data radio system in a box. Right: remote station for radio transmission with laptop for data acquisition and analysis.

The setup shown in figure 2 is only practicable in the case of laboratory measurements. For measurements in the field we are using a data transmission by radio. On the detector side we use a box equipped with the electronics, power supply and one side of the radio data system. This box can be either transported on a trolley (see left of figure 3) or mounted on a robot. The remote station with the laptop can easily be placed on a small table (see right of figure 3) or it can be setup in the transportable measurement container where the necessary infrastructure is available [3]. Behind the table in figure 3 the used antennas are visible.

3.2. Detector properties

The TELU detector (see figure 1) has an energy resolution of 560 eV at 122 keV. For the TELO detector the resolution at 1332 keV is 1,8 keV. It's relative efficiency can be obtained to 17 % according to the standard measurement procedure in which the ^{60}Co source is placed 25 cm away from the end-cap of the detector. In doing so it is not taking into account that the TELU crystal is placed in front of the TELO crystal. This leads to the apparently low relative efficiency of 17 % which could be determined as 31.2 % if the detector would only contain the TELO crystal.

3.3. Evaluation programmes - MGA/MGAU

The programmes used to examine the plutonium or uranium isotope vectors are the **M**ulti **G**roup **A**nalysis MGA [1] and the **M**ulti **G**roup **A**nalysis **U**ranium MGAU [2]. They are based on the evaluation of energy peaks belonging to different isotopes. The methods require no particular efficiency calibration, instead the efficiency calibration is obtained by analyzing the measured X-rays. The measurements can be as short as a few minutes, measurements are frequently accurate to within 1- 2 %.

For both codes the obtained spectra have to fulfill some requirements:

- Energy calibration must be (0.075 ± 0.005) keV/ch
- 4096 channels per spectrum
- Energy resolution shouldn't be worser than 600 eV at 122 keV
- For MGA analysis (plutonium) the spectra must contain 59 keV and 208.00 keV γ-lines
- For MGAU analysis (uranium) the spectra must contain 98.43 keV and 185.7 keV γ-lines

Spectra obtained with the TELU detector fulfill all requirements and can be used for the MGA or MGAU analysis.

4. Measurements

The spectra of the TELO detector are influenced by the shielding effect of the TELU detector in front. This can be observed in the energy region below 150 keV particularly. The intensities of the γ-lines are reduced. By using the spectrum in the lower energy region obtained with the TELU detector the whole information out the given measurement is more complete as from a single spectrum obtained from an individual crystal.

For the detector testing we used a source setup with a mixture of relative high γ-energy sources (^{137}Cs and ^{60}Co) and depleted uranium. In the presented measurements three different sources have been used: ^{60}Co with an activity of 4 kBq, ^{137}Cs with an activity of 50 kBq and 3.6 kg depleted uranium (DU). The distances of the sources towards the detector have been varied in order to realize different activity ratios. Summarized data of all measurements are listed in table 1.

spectra shown in figure	DU		^{60}Co		^{137}Cs	
	distance	dose rate	distance	dose rate	distance	dose rate
4	10 cm	4.5 µSv/h	-	-	50 cm	20 nSv/h
5	1 m	300 nSv/h	-	-	1 cm	40 µSv/h
6	30 cm	1.1 µSv/h	-	-	1 cm	40 µSv/h
7	1 m	300 nSv/h	1 cm	10 µSv/h	-	-

Table 1: Summary of the measurements.

The individual spectra of the measurements are shown in figures 4 to 7. In all cases two spectra have been obtained simultaneously with TELU and TELO detector and the energy spectra are shown side by side. The most important γ-lines are marked with colors given in the figure caption. An insert in the TELU spectrum displays the result of the MGAU analysis and the percent by weight of ^{235}U and ^{238}U.

In the measurement shown in figure 4 the ^{137}Cs source is relative weak compared to the DU so there is no hint in the low energy TELU spectrum that there is another source with higher γ-energies. If the sources with the higher energies are strong one can see the backscattered peak in the low energy region.

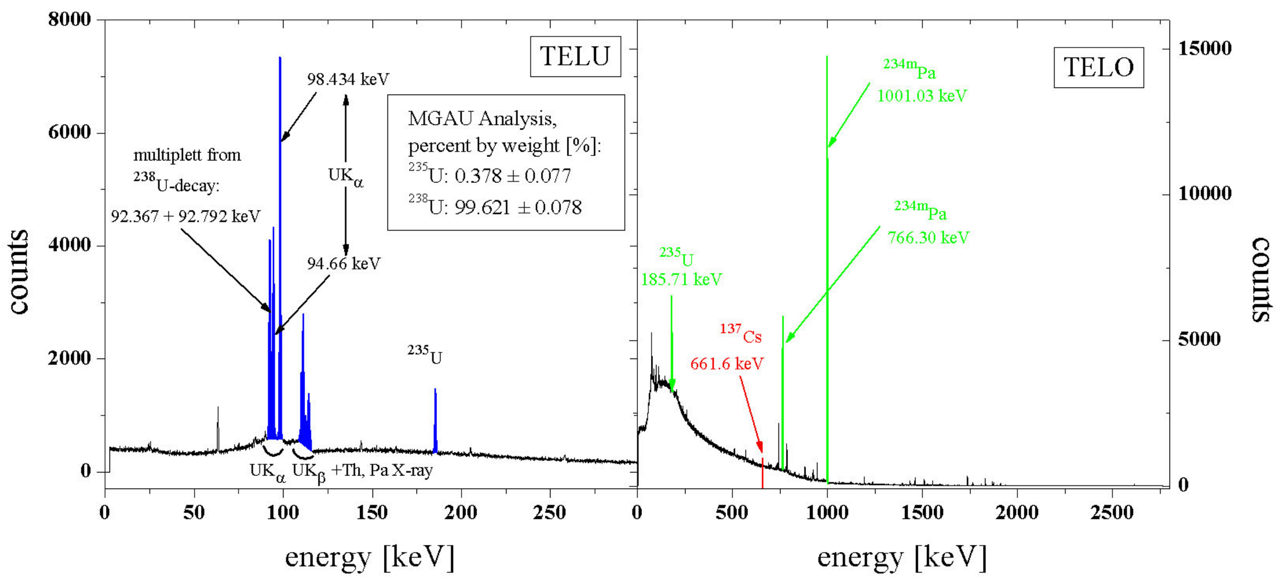

Figure 4: DU spectrum in 10 cm and ^{137}Cs spectrum in 50 cm distance obtained with the TELU (left) and the TELO detector (right). The blue peaks are used for MGAU analysis. The green peaks are characteristic for uranium respectively a daughter. The 661.6 keV line of ^{137}Cs is colored red.

The measurement shown in figure 5 has the opposite ratio in activity and the ^{137}Cs is that strong compared to the DU that no MGAU analysis is possible. Measurements have been done up to 24 h measurement period. Uranium can be verified but it is not possible to examine the uranium vector. The combined measurement of DU and ^{137}Cs is also special, because ^{137}Cs has strong lines in the lower energy region at 31.82 keV, 32.19 keV and 36.40 keV, the backscattered peak is at 184 keV and therefore superimposes the 185.71 keV γ-line of ^{235}U. The latter is used in the MGAU analysis.

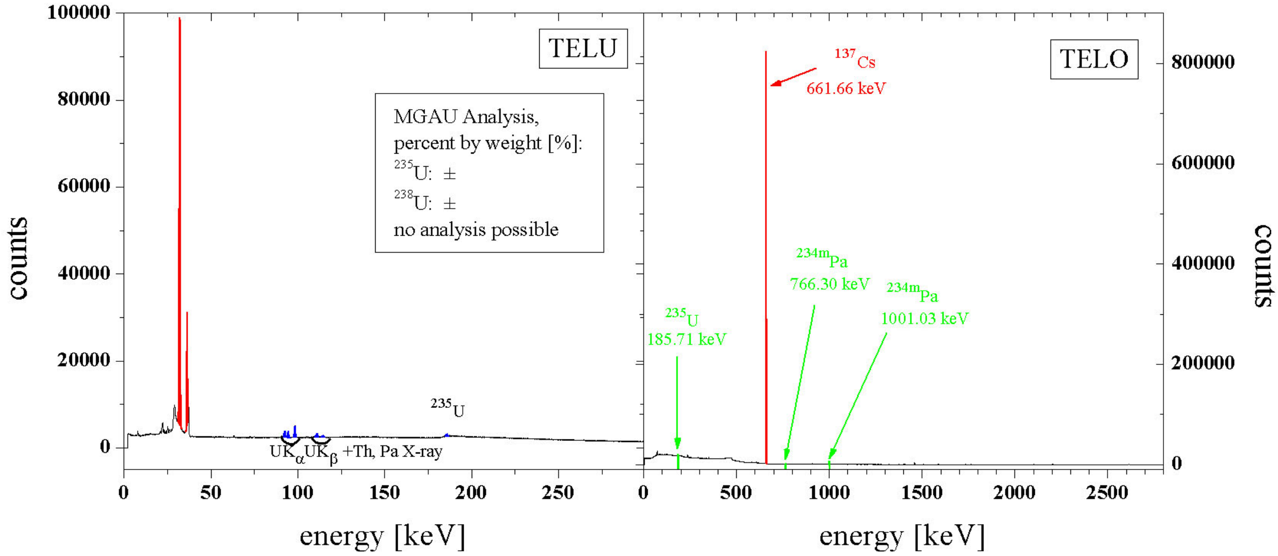

Figure 5: DU spectrum in 1 m and ^{137}Cs spectrum in 1 cm distance obtained with the TELU (left) and TELO detector (right). The blue peaks are used for MGAU analysis. The green peaks are characteristic for uranium respectively a daughter. The ^{137}Cs lines are colored red.

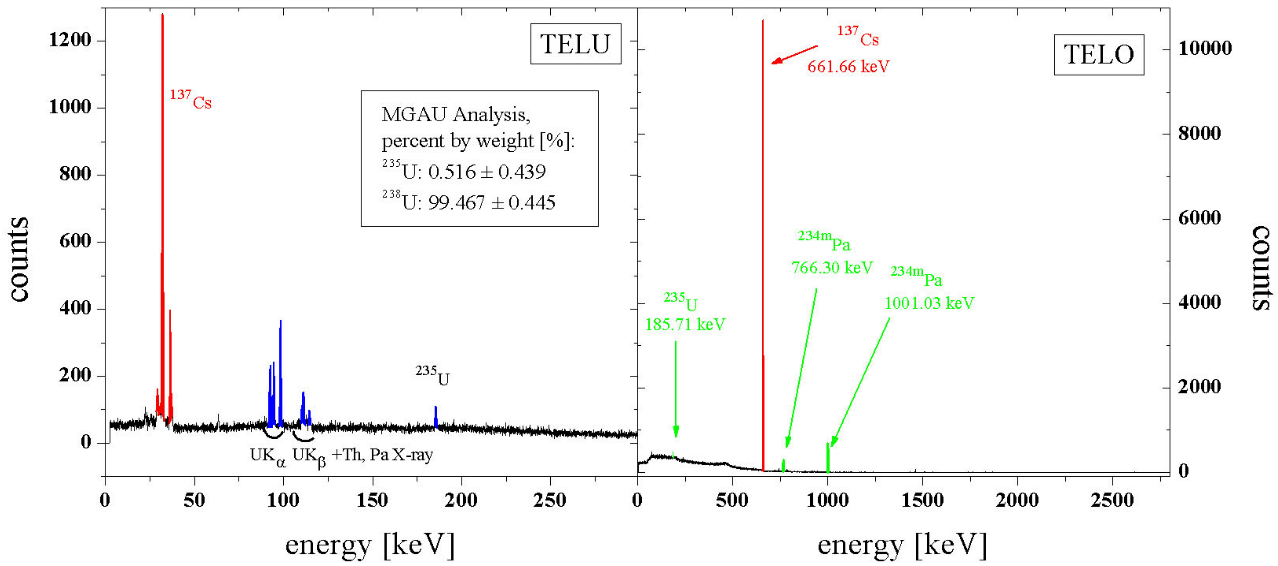

Figure 6: DU spectrum in 30 cm and ^{137}Cs spectrum in 1 cm distance obtained with the TELU (left) and TELO detector (right), measurement time 200 s. The blue peaks are used for MGAU analysis. The green peaks are characteristic for uranium respectively a daughter. The ^{137}Cs lines are colored red.

The spectra in figure 6 show a ^{137}Cs to DU activity ratio which is advantageous for the verification and allows the determination of the uranium vector by MGAU analysis. The given result has a relative large error because of the short measurement period of 200 s. But it also shows that in certain cases the necessary measurement period may be rather short.

In figure 7 a ^{60}Co and DU combination is shown. In contrast to the ^{137}Cs/DU measurements the low energy spectrum obtained with the TELU detector shows only γ-lines belonging to uranium. Only a small hint for a γ-source with higher γ-energies is given by slightly increased counts in the region around 210 keV. This is the energy region of the ^{60}Co backscattered peaks, which are at 209 keV and 214 keV. This measurement is a very good example for a case in which one might not have observed the ^{60}Co when only obtaining a low energy spectrum.

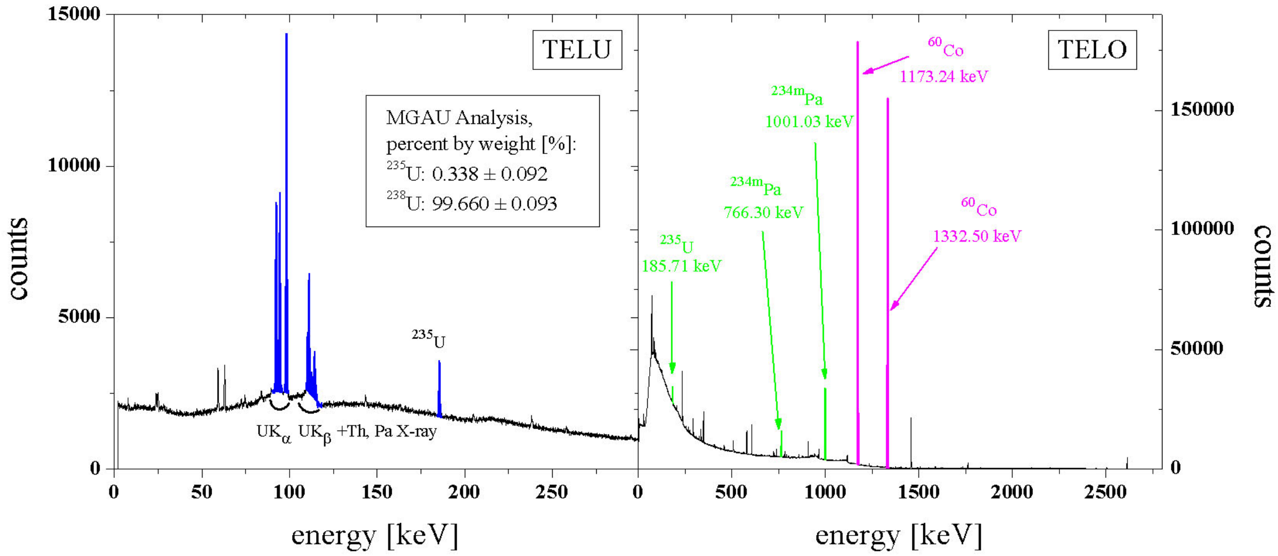

Figure 7: DU in 1 m and ^{60}Co in 1 cm distance obtained with TELU (left) and TELO detector (right). The blue peaks in the left spectrum are used for the MGAU analysis. The green peaks are characteristic for uranium respectively a daughter. The ^{60}Co lines are colored magenta.

5. Conclusion

The telescope detector allows us to measure at the same time a low energy γ-spectrum for plutonium and uranium enrichment analysis by means of the MGA respectively MGAU code and a high energy γ-spectrum for the detection of radioactive material with higher γ-energies. This is very important in the case of measurements in the field with security relevant background in short time.

6. References

[1] Gunnink, R.: **MGA: A Gamma-Ray Spectrum Analysis Code for Determing Plutonium Isotopic Abundances**, UCRL-LR-103220, Vol. 1, Livermore, 1990.

[2] Gunnink, R.; Arlt, R.; Berndt, R.: **New Ge and NaI analysis methods for measuring ^{235}U enrichments**, Proceedings of 19th Annual Symposium on Safe Guards and Nuclear Material Management, Montpellier, France, 5715739 CA Conference Paper, 1997.

[3] Rosenstock, W.; Köble, T.; Risse, M.: **Measurement techniques to combat nuclear terrorism.** In: Bril, Louis-Victor (Ed.) u.a.; European Commission: Proceedings of the 25st annual meeting symposium on safeguards and nuclear material management. Luxembourg : Office for Official Publications of the European Communities, 2003.