NUKLEONIKA 2005;50(Supplement 3):S53–S58 PROCEEDINGS

Nuclear techniques in homeland security

Marek Moszyński

Abstract Selected methods for border monitoring, utilizing nuclear techniques are discussed, with a particular emphasis on those developed with the contribution of our Institute. It covers a basic inspection of the borders against smuggling of radioactive materials, as well as known systems using linear accelerators of electrons for inspection of large trucks by X-ray radiography. More advanced active methods based on tagged neutron inspection systems to monitor explosives and methods based on photofission to detect fissile materials are presented, too.

Key words border monitoring • nuclear techniques in border monitoring

M. Moszyński
The Andrzej Sołtan Institute for Nuclear Studies,
05-400 Otwock-Świerk, Poland,
Tel.: +48 22-7180586, Fax: +48 22-7793481,
E-mail: marek@ipj.gov.pl

Received: 15 June 2005

Introduction

The 11th of September has changed the world. These words were frequently repeated in newspapers and TV. In fact, this day has changed our filling and understanding of the homeland security. The fight against international terrorism is not more a task of the security service of the country; it is a problem, which has to be solved also by a deep activity of the scientific community.

This is particularly important for the community of nuclear science. Nuclear methods of inspection are of importance because of the possibility for non-intrusive analysis of different materials. It covers border monitoring against smuggling of the radioactive and fissile materials allowing production of the so-called dirty bombs. Different methods of truck and container inspections at borders and in see-ports are important for detection of illicit trafficking of explosives and other threats.

The International Atomic Energy Agency (IAEA) in Vienna, the largest countries, as USA, Russia and recently European Union initiated intense programmes addressed to improve existing tools and develop new methods of inspection.

The aim of this paper is to present some selected methods used in border monitoring or being under development, particularly those developed with the contribution of scientists of our Institute.

The IAEA is guided the Co-ordinate Research Project "Improvement of technical measures to detect and respond to illicit trafficking of nuclear and radioactive materials" [6] with the contribution of scientists from different countries over the world. In the Project, our Institute is involved in the "Comparative study of new scintillation materials in application to the border detection equipment". Moreover, our Institute is giving a scientific support to the Target Company in Solingen, Germany, involved in the development and production of the border monitoring equipment.

The European Union is supporting a specific targeted research or innovation project "EURopean Illicit TRAfficking Countermeasures Kit (EURITRACK)" [3] utilizing the tagged neutron activation analysis to detect explosive materials. Our Institute is responsible for the neutron detectors and contributes a lot to the selection of gamma-ray detectors.

An other new project is in phase of the application for a grant. NUMADE (Nuclear Matter Detection) Project [10] was submitted to the European Union within the Preliminary Action in the field of Security Research (PASR). The project is aimed to detect fissile materials by means of photofission with the use of linear accelerators. Again, our Institute is involved in the project being responsible for the detection systems. A part of the experiments testing the method will be carried out at Świerk using accelerators produced by ZdAJ-IPJ.

Detection of radioactive and fissile materials at the borders

Passive methods

At present, a passive detection of gamma rays and/or neutrons is used as the effective screening techniques. In the simplest case, the critical border transit points are equipped with stationary monitoring portals. Radiometric monitoring is carried out automatically when the objects pass through the indicated monitoring area and does not disturb the traffic. Figure 1 presents a portal type PM-5000, sensitive to gamma rays and neutrons, used widely at the Polish borders. It is equipped with a large, up to 4500 cm^3, plastic scintillator and a He-3 neutron detector. The PM-5000 portals are produced by Relpol S.A. in Zielona Góra, former POLON Co. Figure 2 presents a map of Poland with a numerous border crossing points with fitted radiocontamination control units, following the Relpol data.

Fig. 1. The PM-5000 portal, produced by Relpol S.A. in Zielona Góra, at the typical road border transit points.

Simple monitoring portals detect radioactivity, however, they do not identify a type of source nor its localization in the truck or car. Thus the custom officers are equipped further with so-called hand-held spectrum identifiers, being small gamma-ray spectrometers with an enhanced software enabling identification of radioactive isotopes [5]. Figure 3 presents an example of

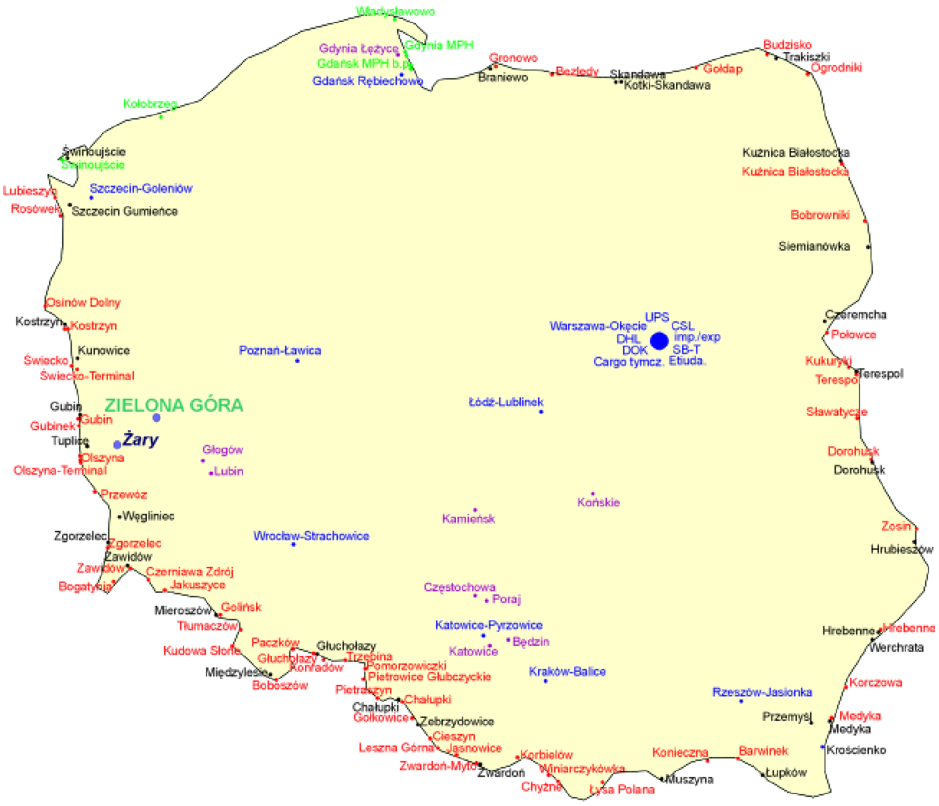

Fig. 2. The map of Poland with numerous border crossing points with fitted radiocontamination control units, following the Relpol data.

Fig. 3. The hand-held spectrum identifier produced by "target" in Solingen, Germany.

typical spectrum identifiers built on the basis of an NaI(Tl) spectrometer for gamma-ray detection and/or a He-3 detector for neutron detection.

Although the NaI(Tl) crystal is the most popular in gamma spectrometry, it suffers from a moderate energy resolution of 6.5–8% for the 662 keV gamma rays and moderate detection efficiency. Detection and identification of the smuggled radioactive sources needs, however, a high selectivity of gamma spectrometers to distinguish contraband from natural or medical isotopes. There is a need to replace the NaI(Tl) in the spectrum identifiers by better scintillators.

Within the Co-ordinate Research Project guided by the IAEA, our group is involved in the study of new scintillators for the border monitoring. The $LaCl_3$ [1], $LaBr_3$ [12], $CdWO_4$ [7] and $CaWO_4$ crystals were studied and compared to the commonly used NaI(Tl). Moreover, the LiI(Eu) crystal [11], highly sensitive to thermal neutrons, was tested using modern scintillation techniques.

Figure 4 presents the energy spectrum of 662 keV gamma rays from a ^{137}Cs source measured with the use of $LaBr_3$ crystal. Note a very high energy resolution of 3.2%, more than a factor of two better than that observed with the best NaI(Tl). A good density of the crystal of 5.3 g/cm^3 and atomic number of bromine assures a better detection efficiency for gamma rays than that of NaI(Tl). No doubt that it is an excellent proposition for the spectrum identifiers.

Figure 5 shows the energy spectrum of thermal neutrons detected in the LiI(Eu) crystal. A very well defined peak, with an energy resolution of 3.9%, corresponds to about 3.5 MeV gamma-ray energy. It allows discriminating natural gamma radioactivity, assuring a high sensitivity of neutron detection [11].

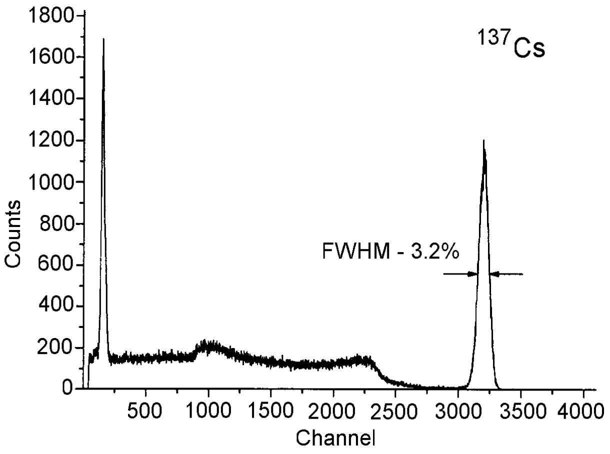

Fig. 4. The energy spectrum of gamma rays from a ^{137}Cs source measured with a $LaBr_3$ crystal.

Active methods

The passive methods of the border monitoring, discussed above, could be sufficient to detect the emitted radiation and then to detect smuggled radioactive sources. It is not sufficient, however, in the case of fissile materials. Low energy gamma rays emitted by fission isotopes are easy to shield, while the emitted neutrons have a very weak intensity. Thus, detection of small quantities of fissile materials is very difficult or impossible by the passive methods.

Within the studied active methods, the application of the photofission reaction induced by high-energy X-rays produced by linear accelerators is the most promising [9]. It was studied extensively at INEEL in the USA and the first prototype arrangement was put into operation [9]. It allows detecting 5 g of uranium or other fissile materials at the distance of 0.5 m from the converter stopping electrons and producing high-energy bremsstrahlung photons.

An electron accelerator, operating at selected beam energy, is used to produce bremsstrahlung radiation

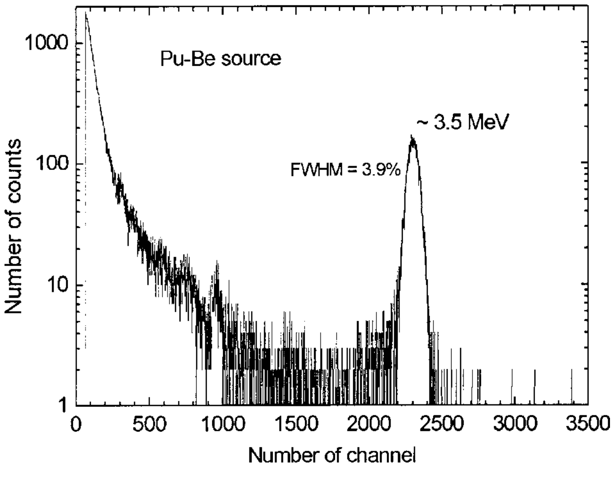

Fig. 5. The spectrum of a shielded Pu-Be source (0.6 Ci) measured with a ^{6}LiI(Eu) crystal. Thermal neutron peak appears at about 3.5 MeV with a very good peak-to-background ratio.

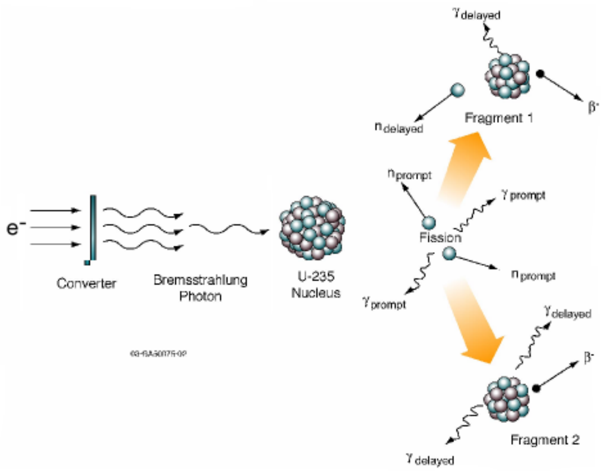

Fig. 6. A scheme of production of delayed neutron in photofission reaction at the beam of a linear accelerator of electrons.

(see Fig. 6). The energetic bremsstrahlung photons can interact with an interrogated object to produce photoneutrons. Bremsstrahlung photons (and photoneutrons) induce fissions in shielded or unshielded nuclear materials. Fissions produce prompt and delayed neutrons. The prompt and delayed neutrons are differentiated by their energy and temporal responses. In the proposed method, the delayed neutrons are detected by especially shielded He-3 detectors, sensitive only to the fast neutrons [9]. Figure 7 presents a photograph of the pilot system ready to make inspection of a large container.

Recently, the proposal for "Detection of nuclear material using photofission" (NUMADE) was submitted to the European Union within the Preparatory Action in the field of Security [10]. The aim of the project is to start development in Europe a new technique using photonuclear reactions as a non-destructive probe for the survey of nuclear material (even low-enriched uranium). It can be applied for detecting any smuggling in ports or airport terminals without destroying or opening the containers, and used in any company or government agency at specific control points. A small quantity of any nuclide in any kind of container can be located, even embedded in heavy concrete matrices.

The NUMADE project is a proof of concept and demonstration of feasibility and deployment possibilities of a "field device" to detected small amounts of fissile materials. The project aims at addressing all technical issues (including integration and cost constraints) needed to establish an industrial, ready-to-use system, achieving enough sensitivity to comply with activation limits imposed by international regulatory commissions. An important milestone will be a full-scale demonstration experiment. The programme will require an interactive collaboration between academies, research institutes and industrial partners, taking into account the requirements of the final users.

Our Institute is involved in the project taking the responsibility for the detection system. A part of the experimental tests will be carried out at Świerk using the linear accelerators produced by ZdAJ-IPJ. Polish Custom Authorities and the Border Guards declare to be the end-user of the developed NUMADE system.

Detection of conventional illicit materials at the borders

The discussed above potential application of linear accelerators to detect fissile materials is easy to be accepted by custom officers, as the accelerators are used at the borders since several years for an inspection of trucks by means of X-ray radiography [11]. It is, in fact, an extension of very well known X-ray inspection systems of luggage at the airports, but with a much higher energy of X-rays, up to 6 MeV. The best systems, used at the borders for the inspection of trucks, characterizes by a high penetration of up to 410 mm of steel, and excellent capacity of screening between 20 and 25 trucks per hour and 24 hours a day. For a detection of X-rays, scintillation detectors with the light readout by Si-photodiodes are used. Figure 8 presents the X-ray radiography system installed in Terespol, at the Polish-Belarusian border.

However, inspections of containers, largely based on X- or gamma-ray systems, provide limited information about contained objects such as their shape and density. Controllers cannot always distinguish between benign and threat materials and need additional information about the chemical composition of suspect items in order to detect illicit materials such as explosives, drugs or dirty bombs. To solve this problem, different

Fig. 7. A prototype of the arrangement of trucks inspection by photofission developed at INEEL in Idaho, USA.

Fig. 8. An X-ray radiography system of trucks monitoring, installed in Terespol, at the Polish-Belarusian border.

inspection systems based on neutron activation analysis are proposed by the nuclear science community.

Non-destructive assay by fast neutrons is a technique widely employed in several fields. As an example, the detection of hidden explosives [13] is achieved by determining the elemental ratio of C, N, O nuclei from the intensity of the characteristic gamma rays produced in fast neutron induced reactions. This technique, indicated as fast neutron analysis (FNA), can be used to detect explosive in landmines or to inspect unexploded ordnance.

The use of fast neutron inspection techniques is mainly limited by the fact that the neutron source and the gamma-ray detectors are placed as close as possible to the inspected object. In these conditions, the signal-to-noise ratio depends on the fraction of neutrons that reach the sample and the solid angle subtended by the gamma ray detector. The gamma-ray spectra are thus dominated by the gammas originated close to the neutron source and to the gamma-ray detector. Consequently, it is difficult to search for hidden objects inside large volume of background material since the measured spectra would be dominated by the background gammas.

Such limitation might be avoided by using a pulsed, collimated neutron beam and by measuring the time delay between the production of the neutron burst and the arrival of the gamma rays in a detector array. This technique is indicated as pulsed fast neutron analysis (PFNA) [13]. While FNA systems usually employ small portable neutron generators, PFNA requires the use of particle accelerators to produce fast neutrons. Consequently, PFNA systems can be used only in specific application when the cost of the entire set-up and its portability are not a relevant issue.

In the last decade, efforts have been devoted to producing tagged neutron beams with compact sealed neutron generators. Such task is, indeed, achieved routinely in open-end accelerators by using the well known associated particle imaging (API) where the T(D,n)^{4}He or the D(D,n)^{3}He neutron source reactions are used [8]. Examples of systems using the associated particle technique with sealed neutron generators are reported in Refs. [4, 6]. Although the interest in obtaining sealed neutron generator with embedded associated particle detector is a long standing issue in neutron applications [8], such interest has increased significantly in recent times for all applications related to civil security after the 9/11 events.

Recently, based on this principle, the EURITRACK project was accepted by the European Union within FWVI [3]. In the project, the Tagged Neutron Inspection System (TNIS) will be applied consisting of tagged neutron generator and a complex set of large gamma detectors [8].

In the EURITRACK project, it is proposed to develop a pixelized fast alpha particle detector for a “smart” electronic collimation of the neutron beam, following the information gained by using conventional X-ray imaging of the container. This pixelized alpha particle detector will allow to obtain easily very accurate voxel inspection, optimising the signal-to-noise ratio, and measuring on-line the background gamma-ray spectrum that might derive from the benign items surrounding the suspect one. Moreover, the spectrum of 14 MeV neutrons transmitted through the container will be used to ascertain the attenuation of the primary neutron beam in reaching the suspect voxel, giving the possibility of adjusting automatically the interrogation time and even to declare immediately, in case of the presence of large quantity of neutron shielding material (as hydrogen rich materials) the impossibility of performing the inspection. Figure 9 presents a schematic configuration of the inspected container by tagged neutrons from the neutron generator and position of gamma detectors.

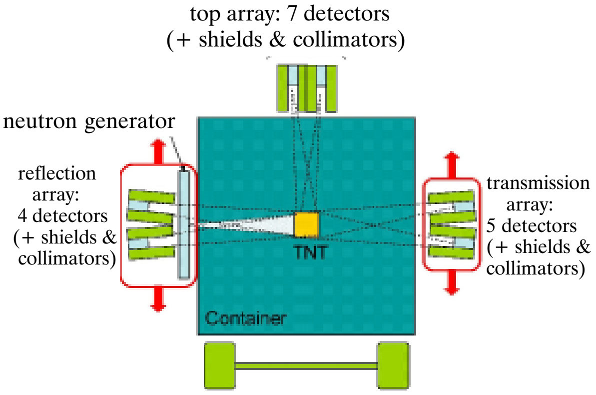

Fig. 9. A schematic configuration of the inspected container by tagged neutrons from the neutron generator and position of gamma detectors in the future EURITRACK project.

It is also important to stress that the development of the gamma-ray detection system needs also some R&D works carried out by our Institute in collaboration with CEA Cadarache. The requirements of this application are relatively clear for the scintillation detectors:
1) high count rate capability,
2) time resolution compatible with the required definition of the minimum voxel to be inspected,
3) good intrinsic efficiency in the energy range 1–7 MeV,
4) radiation hardness and long-term activation due to the neutron field,
5) mechanical and thermal properties.

Our Institute contributes to the EURITRACK project together with the scientists of five European countries. We are responsible for the development of the neutron detector and together with the CAEN Company for its front-end electronics. Moreover, we are involved widely in a comparative study of different large-gamma detectors, as NaI(Tl) and BGO scintillators to select the best type and size of the crystal [4]. Figure 10 presents an example of the developed 5” × 5” NaI(Tl) detector done at our Institute.

Summary and conclusions

The selected methods of the border monitoring utilizing nuclear techniques were discussed with particular emphasis on those developed with the contribution of our Institute. It covered simple methods based on gamma spectrometry, addressed to detect smuggled radioactive sources, and complex methods utilizing accelerator techniques.

Fig. 10. The developed at IPJ 5” × 5” NaI(Tl) detector done for the EURITRACK system.

The principles of EURITRACK arrangement for the detection of explosives materials by means of the neutron activation analysis and NUMADE project utilizing the photoactivation method to detect fissile materials are presented. Both the projects are supported or applying for the support by the European Union.

A growing interest in the development of new methods for the border monitoring in the nuclear physics community is observed, leading to creation of a new “anti-terrorist physics”.

References

1. Balcerzyk M, Moszyński M, Kapusta M (2005) Comparison of $LaCl_3$:Ce and NaI(Tl) scintillators in γ-ray spectrometry. Nucl Instrum Meth A 537:50–56
2. Dönges G, Geus G, Henkel R, Ries H, Schall P, Bermbach R (1992) Examination of sea freight containers using modern electron linear accelerators. Nucl Instrum Meth B 68:68–73
3. EURITRACK (2004) EURopean Illicit TRAfficking Countermeasures Kit. FWVI, STREP no. 511 471
4. Gierlik M, Batach T, Moszyński M *et al.* (2005) Comparative study of large NaI(Tl) and BGO scintillators for the EURopean Illicit TRAfficking Countermeasures Kit project (submitted to IEEE NSS-MIC Conference, October 2005, Puerto Rico)
5. IAEA (2002) Detection of radioactive materials at borders. IAEA-TECDOC-1312. IAEA, Vienna
6. IAEA (2003) IAEA Co-ordinate Research Project “Improvement of technical measures to detect and respond to illicit trafficking of nuclear and radioactive materials”. No. 12596, IAEA, Vienna
7. Moszyński M, Balcerzyk M, Kapusta M *et al.* (2005) $CdWO_4$ crystal in gamma-ray spectrometry. IEEE Trans Nucl Sci (in press)
8. Nebbia G, Pesente S, Lunardon M *et al.* (2004) Performance of a tagged neutron inspection system (TNIS) based on portable sealed generators. Nucl Instrum Meth A 533:475–481
9. Norman DR, Jones JL, Yoon WY *et al.* (2004) Pulsed photonuclear assessment for the detection of nuclear materials. In: Proc of IAEA Meeting, October 2004, Sochi, Bulgaria. IAEA, Vienna, CD edition
10. NUMADE (2005) Detection of nuclear material using photofission. PASR, no. 103700
11. Syntfeld A, Moszyński M, Arlt R *et al.* (2005) ^{6}LiI(Eu) in neutron and γ-ray spectrometry – a high sensitive thermal neutron detector. IEEE Trans Nucl Sci (in press)
12. Van Loef EVD, Dorenbos P, van Eijk CWE, Kramer K, Gudel HU (2001) High-energy-resolution scintillator: Ce^{3+} activated $LaBr_3$. Appl Phys Lett 79:1573–1575
13. Womble PC, Vourvopoulos G, Novikov I, Paschal J (2001) PELAN 2001: current status of the PELAN explosives detection system. In: Proc SPIE Conf on Hard X-ray and Gamma-ray Detector Physics, San Diego, USA, pp 1421–1426