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SIMULATION AND DESIGN OF RADIATION SHIELDING AND COLLIMATION SYSTEMS FOR THE PRECISE GAMMA-SPECTROMETRIC EQUIPMENT

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Abstract: Space radiation and natural radioactivity make application of the modern precise spectrometric equipment impossible without high quality radiation shielding which improves its background performance. This work presents the obtained results of simulation and design of radiation shielding for precise gamma-spectrometric equipment based on semiconductor detectors for nuclear radiation. Special attention is paid to radiation pure lead materials (<50 Bq/kg) and tungsten alloys with nickel and copper linings. Laboratory, industrial, mobile and portable spectrometers developed in SolidWorks software as well as their collimation and shielding systems are described. The background performance of the developed spectrometers with passive shielding are presented, minimal radionuclide activities detected by developed spectrometers are provided.

Introduction

Due to the cosmic radiation and the existence of natural radioactivity in the environment, all radiation detectors are recording some background signals. As the magnitude of the background ultimately determines the minimum detectable radiations level, the level of background radiation at the measurements should be provided as minimal. That is why the precision equipment should apply the outer shielding of the detector and collimators to reduce the level of the registered background.

The most widely spread shielding material is the lead as it is easily accessible, has density of 11,35 g/cm3, atomic number 82 and is relatively cheap [1-3]. Some cases apply tungsten (atomic number 74) instead of the lead for the shield and collimators because it has rather higher density of 17 g/cm3. That is why the tungsten has considerably higher linear attenuation factor than the lead. It is necessary to note that the materials themselves applied at the development of the shielding and detectors collimators could be the sources of the background signals. Therefore only radiation pure, certified materials should be applied.

The present work shows the results of the computer simulation and development of the passive radiation shieldings and collimators for the precision gamma-spectrometric equipment based on semiconductor detectors of nuclear radiations for various applications.

Shielding Systems Computer Simulation

At the development of the passive shielding systems one should have the ability to calculate their sizes and simulate their influence on the characteristics of the precision spectrometric equipment. The calculations of the shielding thickness are computerized and usually we apply for our calculations the program [5]. A special program package named Eff Maker [6] has been developed for the simulation of the shielding impact on the spectrometric equipment behaviour. The package provides the modeling of gamma-spectra and the calculation of registration efficiency for complex shaped objects that are obtained with the use of semiconductor detectors of gamma radiation. The modeling is realized by Monte-Carlo method.

Shielding and Collimation Systems Computer Design

The development of the passive shielding systems for spectrometric equipment are made by us in the software SolidWorks, demonstrated in our projects its optimal feasibility for the design of all systems of the developed spectrometric equipment [7]. Fig.1. shows the section of the computer model of a standard lead shield which provides the screening for HPGe detector (1) in the vacuum cryostat (2). Inner diameter of the shield is defined by the diameter of the applied Marinelli beaker (3). The total lead thickness in standard equipment shield usually is 100 mm, what provides the attenuation of Co-60 in ~315 times, but Cs-137 in ~ 5000 times.

With the account of the lead weight the shielding is developed dismountable so that two specialists could easily assembly it and avoid the presence of the splits due to the dissection of the lead shielding into several parts. All lead rings (4) after the installation are tightened with thread bolts (5), what provides the stability for the design and assist to avoid reliably the radiation gaps. The design of the moving carriage (6) allows the operator to move it easily, manually changing the samples in the chamber. As the carriage shield should maintain the high level of the radiation shielding against the external radiation sources, the copper and tin or cadmium screens with the copper screws (7) are also fixed on the bottom of lead base of the carriage. Under its high plasticity the lead should be protected against the mechanical deformations. Steel shell (8) with the thickness of 0.8 mm serves as the protective screen against the mechanical deformations as well as the additional radiation screen. The standard shielding for the vertical cryostat includes also the lead insert with the copper strip, installed between the table and the shielding to avoid the gaps.

As the basic material in the design of the shielding we apply the lead Pb-210 of radiation purity < 50 Bq/kg. As the applied lead is cleared from other elements, in the radiation of the lead shielding itself dominates Pb-210 (E = 46.6 keV). When the lead is irradiated with the space radiation there appear the X-ray quanta with the energies of K_{α}=74.22 keV and K_{β}=84,86 keV. For the screening of those gamma-lines inside the lead shield the copper screens (9) with the thickness up to 10 mm, covered with nickel or tin to suppress the own copper lines. To simplify the production of the copper screens for the radiation protection we apply the copper sheets with the thickness of 1 to 3 mm which are processed by the rolling till the required shape. The combination of several such cylinders makes copper screen of the required thickness.

The content of Pb-210 increases the content of Bi-210 (beta source, daughter nuclide Pb-210), which bremsstrahlung increases the background. To decrease the present effect in several shielding the inner screen (10) of pure lead with activity Pb-210 <5 Bq/kg is installed. In some cases also we apply the organic glass of 5 mm thickness as an additional screen. The organic glass screen serves as the substitution for the tin screen (11) and is the protection against the neutron radiation. Polymethyl methacrylate has good radiation properties as well as resistance to humidity and nice shock-proof ability what provides suitable service.

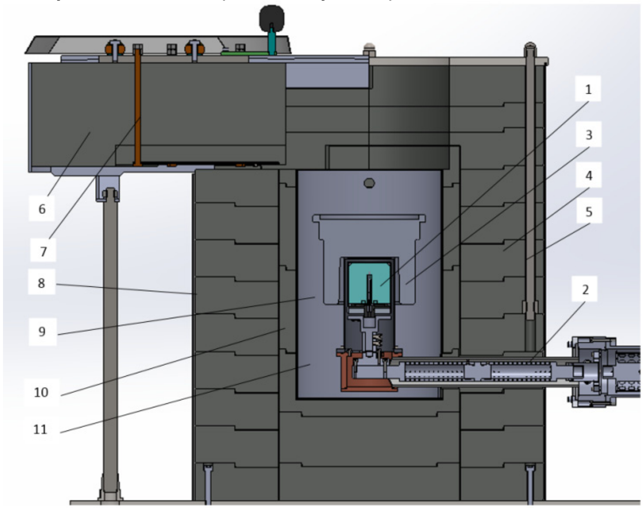

Fig. 1 Computer model of the standard lead shield, designed in BSI

Shielding and Collimation Systems Computer Design

As the drawings show, the our developed passive shieldings for the precision spectrometric equipment present rather complicated multielements design systems for providing of high characteristics of the company equipment. Alongside the separate details of the lead shielding have rather large linear sizes (up to 500-600 mm in diameter) and considerable weight (up to 96 kg), what provides substantial problems in the manufacture process. As the special equipment is required for the production of those details from the lead and tungsten, which are hard in the processing, the manufacture is made by the specialized companies [8,9]. The total weight of the developed and manufactured by Baltic Scientific Instruments details only of the lead shieldings and collimators for the precision devices based on semiconductor detectors was 8 916.7 kg in 2014 and 11 191.9 kg in 2015.

Gamma-Spectrometric Equipment with Shield and Collimators

The developing systems of the radiation shielding and collimation are widely applied in the equipment manufactured by our company. Fig.2. presents laboratory HPGe gamma-spectrometer for radionuclide definition in the environmental objects. The spectrometer shield is made from the certified lead with radiation purity of < 50 Bq/kg, thickness of 100 mm and copper screen of thickness 10 mm, covered with tin. The outer diameter of the lead rings are 420 mm, the lead is protected with the steel shell of 0.8 mm. The shield weight is 650 kg. With the developed shield the spectrometer with HPGe detector of 30% efficiency provides detection limit 0.5 Bq/kg for Cs-137 radionuclide specific activity at the measurement time of 1 hour. The instrumental background intensity for energy range from 40 keV to 3 MeV is 2.05 cps.

Fig. 2 The laboratory HPGe gamma spectrometer with the lead shield

Industrial spectrometers

Industrial spectrometers differ from the laboratory ones only in their application. The radiation shielding of the industrial spectrometers has the same design, manufactured from the certified lead with radiation purity of < 50 Bq/kg (Fig.3).

The overall sizes of the lead shield for the industrial spectrometers make the sizes of Ø524x655 mm, the thickness of the lead screen is 150 mm. The lead is protected from outside by the steel shell of 0.8 mm thickness. The weight of such shielding of the industrial device with the steel, lead, copper and tin screens goes to 1380 kg. With the developed shield spectrometer with HPGe detector of 70% efficiency provides detection limit 0.3 Bq/kg for Cs137 radionuclide specific activity at the measurement time 1 hour. Instrumental background intensity for energy range from 40 keV to 3 MeV is 1.36 cps.

Fig. 3 Industrial HPGe gamma-spectrometers with the lead shield and hybrid cooling

Mobile HPGe gamma spectrometer

Fig.4. shows the мobile HPGe gamma spectrometer for the enterprises of the nuclear industry. The present design of the lead shield works not as the valuable detector shield but as collimator, which protects the detector against the radiation from aside and which provide the radiation collimation on the front surface of the detector.

Fig. 4 Mobile HPGe gamma-spectrometer for the nuclear industry

The radiation shielding of the mobile spectrometer has the sizes of Ø140x286 mm and comprises the steel and lead screens. In dependence on the spectrometer application the thickness of the lead shield could vary within 25 – 50 mm. The total weight of the mobile spectrometer is aproximately 250 kg, where 85 kg is the lead screen. The developed shield in the spectrometer with HPGe 40% efficiency detector provides the detection limit 4.0 Bq/kg for Cs-137 radionuclide specific activity at the measurement time of 1 hour. The instrumental background intensity for energy range from 40 кeV to 3 MeV is 5.04 cps.

Portable HPGe gamma-spectrometer

Fig.5. presents the portable HPGe gamma-spectrometer for the inspection applications [10,11]. The dimensions of the spectrometer are only 330x140x210 mm. The total weight of the spectrometer based on 20 % efficiency HPGe detector without liquid nitrogen is 4.950 kg. Some applications require detector to be shielded from the external interference. 7 mm thick tungsten alloy cap, having smaller dimensions with removable collimators, have been developed and fabricated especially for uranium enrichment measurements. Caps could be easily attached to the Dewar vessel flange through special holes by means of 3 tungsten screws. Collimators have different diameters: 40, 25, 10 and 5 mm and could be screwed into a cap. In order to decrease X-ray fluorescence from tungsten, cap and collimators have 1 mm thick tin internal lining covered with 1.5 mm thick copper lining.

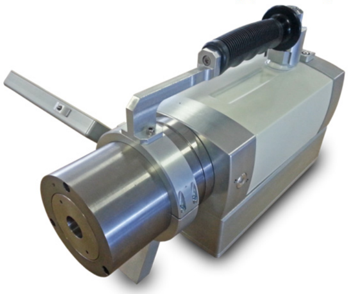

Fig. 5 Portable HPGe gamma-spectrometer with collimator for inspection applications

Passive Gamma Emission Tomographic System

This system was designed and fabricated for inspection control of spent fuel road assemblies in water pool of NPPs [12,13]. Because assemblies of spent fuel rods, stored in water pool, have a huge activity [3], equipment for it control should have very sick and efficient shielding. On this reason the shield and collimators were designed and fabricated from tungsten, what is extremely expensive, but can provide efficient shielding at the acceptable weight. Passive Gamma Emission Tomographic System consists of two linear arrays, placed in water sealed case [12,13]. Each linear array comprised 104 CdTe detectors with processing electronics based on ASICs. Both were placed in tungsten alloy shields with multi-slit collimators. In order to utilize this method for spent fuel rod assemblies, a collimator-detector arrangement is needed for the detection of emitted radiation in narrow strips [14]. Figure 6 shows a frontal view of the linear array with electronics in the shield with multi-slit collimator during laboratory tests.

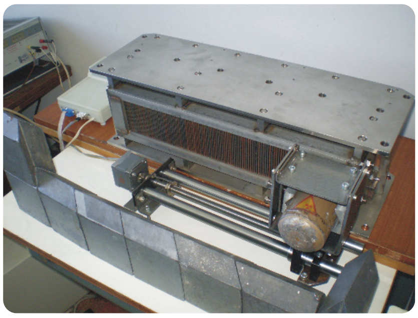

Fig. 6 Linear Array of Passive Gamma Emission Tomographic System in tungsten shield with multi slit collimator

The multi-slit collimator is a set of tungsten alloy plates, which are fixed with four through pins. Thickness of the tungsten alloy is 100 mm. The shield unit of 30 mm thick ismade from separate tungsten alloy elements, jointed together with grooves. The tungsten alloy shield provides screening against detector background radiation in real application conditions. The manufacturing accuracy of the multi-slitcollimator and shield unit is determined by the precision of technology processes in M&I Materials Ltd [9]. Weight of linear array is 80kg.

Conclusion

Shielding and collimation systems in radiation equipment determine the level of its background performance. Using computer simulation and computer design we succeed to organize high quality technological process for development and fabrication of these products for precise gamma-spectrometric equipment based on semiconductor detectors for nuclear radiation. Due to application of radiation pure lead materials and tungsten alloys we provided low level of minimal detecting activity in our laboratory, industrial, mobile and portable spectrometers.

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References

[1] G.Knoll. Radiation Detection and Measurements. 3rd ed.,John Wiley&Sons, 2000. 796 p.
[2] D.Reilly, N.Ensslin, H.Smith, Jr. and S.Kreiner. “Passive Nondestructive Assay of Nuclear Materials”, United States: Nuclear Regulatory Commission, March 1991, 699p.
[3] G. Gilmore. Practical Gamma-Ray Spectrometry. John Wiley, 2nd edition, 2008. 408 p. ISBN978-0-470-86196-7.
[4] V.Gulbin. “Development of composite materials modified with nanopowders for radiation shielding in nuclear energy.” Nanotechnologycal Society of Russia. May 2012. 21 p. (In Russian). [online] [26.04.2015] Available at:http://www.rusnor.org/pubs/articles/7865.htm
[5] Rad Pro Calculator online. [online] [24.04.2016]. Available at: http://radprocalculator.com/Gamma.aspx
[6] Calibration software EffMaker. [online] [24.04.2016]. Available at: http://bsi.lv/en/products/software/advanced-software-package-effmaker/
[7] O.Jakovlevs, N.Jefremova, V.Gostilo, J.Viba.”Computer Design of Precise Spectrometric Equipment With Innovative Cooling Systems”. Proceedings of the II International Scientific Congress “Innovations In Engineering 2016”. Varna, Bulgaria, 20-23 June, 2016, p.34-36. [online] [20.06.2016]. Available at: http://innova-eng.eu/proceedings/2016.pdf
[8] Von Gahlen. Modern state-of-the-art manufacturer of lead shielding products. [online] [24.04.2016]. Available at: http://www.vongahlen.nl/
[9] M&I. Materials for Industry and Science. [online] [24.04.2016]. Available at: http://www.mimaterials.com/
[10] A.Kail, M.Kaiser, S.Kim, E.Loshevich, A.Sokolov. Development of Portable HPGe Spectrometer for In-Situ Measurements. Nuclear Technology & Radiation Protection, Vol.XXX, No.2 (June 2015), p.154-157. NT&RP Journal Serbia, Belgrad.
[11] A.Sokolov, E.Loshevich, S.Kim, J.Brutscher, A.Rozite, A.Nazarenko. Ultra Compact HPGe Spectrometer for In-situ Measurements. ESARDA 35th Annual Meeting CD proceedings. EUR Number 26127; ISSN 1831-9424; ISBN 978-92-79-32730-8; Catalogue Number LC-NA-26127-EN-N.
[12] A.Bulycheva, M.Shorohov, A.Lupilov, V.Gostilo, W.Inui, M.Funaki. CdTe linear arrays for registration of gamma-ray hard fluxes. Nuclear Inst. and Methods in Physics Research (NIM) A 607 (2009) pp.107-109.
[13] A.Sokolov, V.Kondratjev, V.Kourlov, F.Levai, T.Honkamaa. CdTe Linear Arrays with Integrated Electronics for Passive Gamma Emission Tomography System. NSS Conference Record, 2008, NSS'08 IEEE, p.999-1002.
[14] F.Levai, Sz.Czifrus, S.Feher, T.Q.Dung, P.Kerrey, T.Heri. Application of Nuclear Imaging Methods for Providing Additional NDA Capability for Safeguards. Proc.of the ESARDA Seminar on Strengthening of Safeguards: Integrating the New and Old. Dresden, Germany, 2000, 415-420.