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SEARCHING FOR RESERVE FOR EXPANSION OF THE POSSIBILITIES TWO-ENERGY RADIOGRAPHY

V. Ryzhikov[1], S. Naydenov[2], A. Opolonin[1], V. Volkov[2], O. Lysetska[1], D. Kozin[1], V. Danilenko[1]

[1] Institute for Scintillation Materials NAS of Ukraine, Kharkov, Ukraine
60 Lenin ave., 61001, Kharkov, Ukraine, *E-mail:* vlada@isc.kharkov.com

[2] STC "Institute for Single Crystals" NAS of Ukraine
60 Lenin ave., 61001, Kharkov, Ukraine, *E-mail:* naydenov@isc.kharkov.com

ABSTRACT

Theoretical analysis and experimental studies show that the two-energy detection method not only allows one to detect organics on the background of metal, but also substantially increases (by 3-5 times) the detection ability of the system as a whole, especially if parameters of the S-PD pair are optimized, in particular, when ZnSe(Te) is used in the low-energy circuit.
A possibility to distinguish, in principle, between substances with insignificant differences in atomic number has been theoretically proven – by transition to multi-energy radiography. 3D-imaging has been realized using S-PD detector arrays.
Results of experimental studies of detector arrays S-PD used for X-ray digital radiography have shown that there exist further possibilities to increase spatial resolution of this system up to 2-3 line pairs per mm.

***Keywords**:* Non-destructive testing, Scintillator, X-ray digital radiography

1. Introduction

X-ray digital radiography is a rapidly expanding and one of the most important methods of modern non-destructive testing[1]. In this method, alongside with the use of luminescent screens with subsequent transformation of the image onto CCD-matrix, one of the main technical solutions is conversion of the penetrating X-ray radiation by the detector array of 'scintillator-photodiode" (S-PD) type with its subsequent amplification and digitalization of the signal.
Advantages of CCD devices are instant imaging of all the object and high spatial resolution (3-5 line pairs per mm). Their disadvantage is a limited energy range, consequently, limited steel thickness of the inspected object, as well as higher costs, as compared with S-PD arrays.
In non-destructive testing systems using S-PD arrays it is possible to use scintillators of different atomic number, density and element length, which allows working in the energy range from 20 keV to 10 MeV, i.e., steel equivalent thickness is from 100 μm to 300 mm. The use of two-energy detection systems solves the problem of distinguishing between substances of similar density, but different effective atomic numbers. Both these qualities are not attainable for CCD-matrix.

In this work, we have shown theoretically and confirmed experimentally that it is possible, within the framework of two-energy radiography, to separate substances with a rather small (10-15%) difference in their effective atomic numbers. This can find applications in inspection equipment (airports, customs services, etc.), as well as in medical diagnostics and non-destructive testing.
Our task in developing this method consisted in the maximum use of its advantages. Specifically, we aimed at increased sensitivity and detecting ability due to optimization of parameters of the S-PD pair and an extensive use of the features of two-energy radiography. Transition to multi-energy radiography was envisaged for detection of substances with close values of the effective atomic number [2]. The resolution was to be increased due to modernization of the design and making smaller the detector aperture. And, finally, passing from two- to three-dimensional imaging was also essential.
The above-listed directions in the system improvement were the aims of our studies in this work.

2. Experimental procedures

Using a simplified model of the two-energy detector array and spectrum of the X-ray tube with a tungsten anode (Fig.1), evaluation has been carried out of the signal ratio from high- and low-energy detectors (HED and LED) in the presence of an inspected object (which can be of different thickness and chemical composition)[3]. The other objective was to estimate reliability of the results obtained using a 12-digit ADC (noise of quantization).

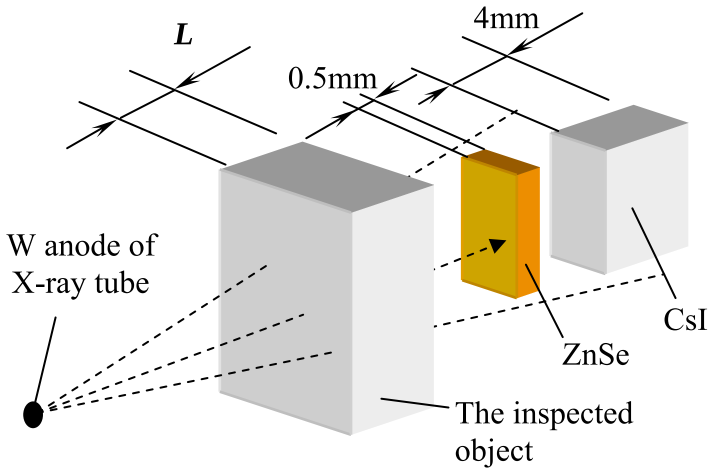


Fig. 1: A model of the two-energy detector array and spectrum of the X-ray tube with a tungsten anode.

Calculations were carried out for the following substances: Al, Cu, Fe, NaCl, H_2O, $C_{12}H_{22}O_{11}$ (sugar).In our calculations, we used a simplified model of the two-energy detector array – each detector was replaced by a ZnSe scintillator of 0.5 mm thickness (LED) and CsI scintillator of 4 mm thickness (HED). Filtration effects of LED were accounted for. As an output detector signal, we used the calculated light flux (in relative units) formed in the scintillator under X-ray irradiation.
The calculated data were then normalized. The initial data were calculated for different thickness l of the inspected object (in cm). However, more informative is the use of parameter ρl (g/cm^2) on the x axis, where ρ is the density of the inspected object. In such presentation, the calculated plots for one and the same substance (e.g., salt as crystals and as powder – difference in density) are identical, and comparison of substances with substantially different densities becomes more

obvious.To evaluate signals in real radiographic systems, it is convenient to show the signal sum HED+LED along the X axis.
To determine possibilities of substance identification, we have considered different values derived from the initial calculated signals (sum 1-2, difference 2-1, ratios 1 to 2 and 2 to 1 (1-LED, 2 – HED signal). These plots, (sugar) and (iron) as function of ρl (g/cm^2), are presented in Fig.2.

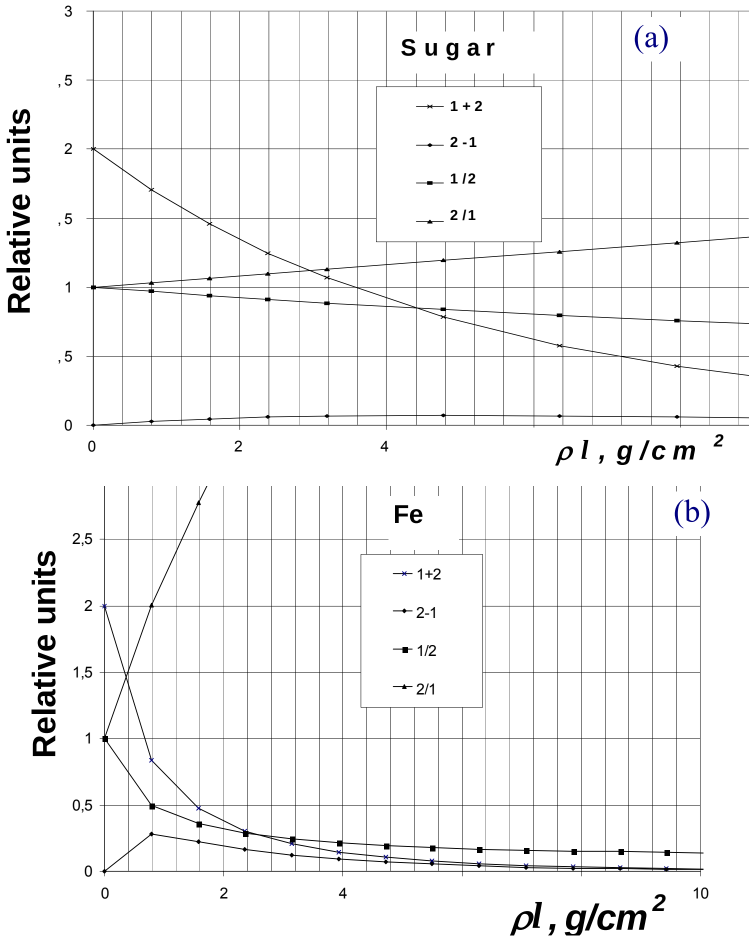
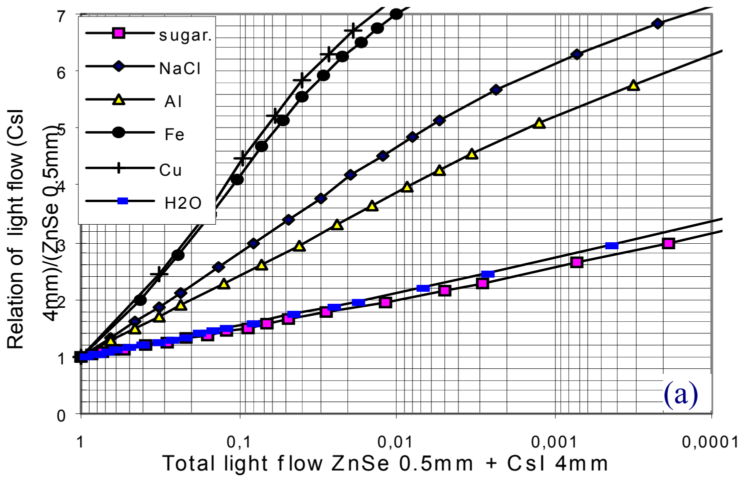


Fig. 2: Ratios, differences and sum of normalized light flow for sugar (a) and iron (b) LED (1) and HED (2).

For determination of the effective atomic number of a substance, it is possible to use, as a substance characteristic, the ratio of signals HED/LED from the high-energy detector (HED) and low-energy detector (LED), accounting for the total signal (HED+LED).Fig.3a allows to assess the substance identification possibility in a real digital radiography system (DRS). Ratios 2/1 are given for different substances depending upon the signal (1-2) characterizing the fraction of X-ray radiation transmitted through the substance. Both these parameters can be easily calculated using DRS.
In using the linear amplifying circuit model, estimates of errors introduced by a 12-digit ADC show that with the total signal from two detectors less than 0.5% of the initial value, the identification errors is significantly increased Fig. 3b. Our calculations have allowed evaluation of possibilities of the two-energy method for substance determination in digital radiographic systems.
It can be used in inspection systems, including anti-terrorist activities, in technical diagnostics, medicine.



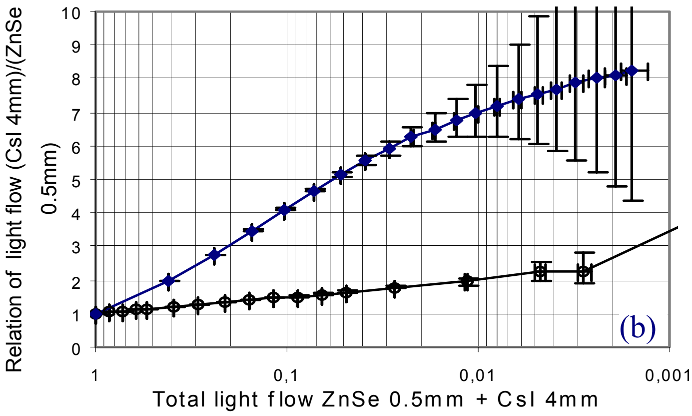


Fig. 3: The Determination of the composition of substance by 2-energy method.
Two scintillators - ZnSe (0,5mm) and CsI (4mm).

3. Discussion

Results of our studies have shown that in S-PD detectors for digital radiography the most preferable scintillators for the high energy region are CWO (0.5-10 MeV), CsI(Tl) (0.08-0.5 MeV), while in the low-energy region (20-60 keV) ZnSe(Te) is unchallenged.

Accounting for a trend in the modern digital radiography (both in the inspection and medical instruments) to use two-energy detector arrays, the combination of ZnSe(Te) and CsI(Tl)/CWO results in a new quality [4-6].

Effective atomic number *Z* of ZnSe is the same as of copper, which is usually used as a filter of the high-energy array. Therefore, if a detector with ZnSe(Te) as filter is placed before the high-energy array, this simplifies the design and improves technical characteristics of the detecting circuit as a whole [7].

A unique combination of properties characterizing the original scintillator ZnSe(Te) – high light output, fast response, radiation stability, rather low effective atomic number together with sufficiently high density – makes this material the best among known scintillators for the low-energy detector. Combination of crystals ZnSe(Te)/CsI(Tl) in the two-energy detector array has substantially improved the sensitivity of equipment designed for detection of organic inclusions (Fig.4).

An important point is combination of principles of multi-energeticity (reconstruction of substantional structure) and tomography (reconstruction of spatial structure). This allows creation of “multi-energy tomographs” – new instruments with unique possibilities in detection and diagnostics. This opens new prospects of broad application of the multi-energy approach in different fields of science and technology. It is essential that for reliable (close to 100%) detection of explosives and other forbidden substances and objects, chemical composition of the inspected objects should be reconstructed.

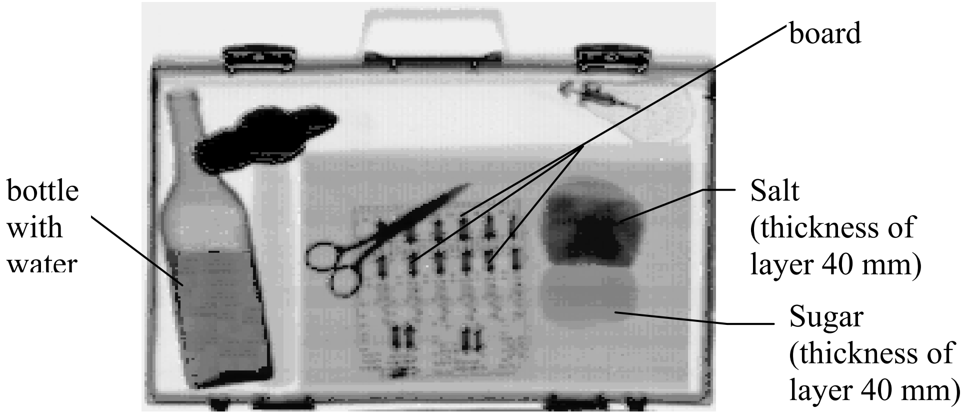


Fig. 4: Object images obtained using the two-energy introscope.

As most explosives are of organic origin, it is necessary to reconstruct the chemical formulas of organic compounds. They are composed, as a rule, of 3 or 4 main elements. Therefore, detection of explosives requires 3- or even 4-energy radiography. We have obtained theoretical expressions for relative (molar) concentrations of simple chemical components of a complex compound or a mixture of substances. This means a possibility of reconstruction of the chemical formulas of inspected substances and objects.

For identification of organic compounds containing two, three or all four main elements (hydrogen, carbon, nitrogen and oxygen) it is sufficient to use 2-, 3- or 4-radiography. As a whole, it allows distinction of organic materials both from inorganics and from other organics, and, consequently, to detect explosives on the background of inorganics or organics. The expected accuracy of such monitoring is 80-95%.

When we used scintillator with different atomic number, density and thickness, we can control objects with size from several mm to several m, Fig. 5.

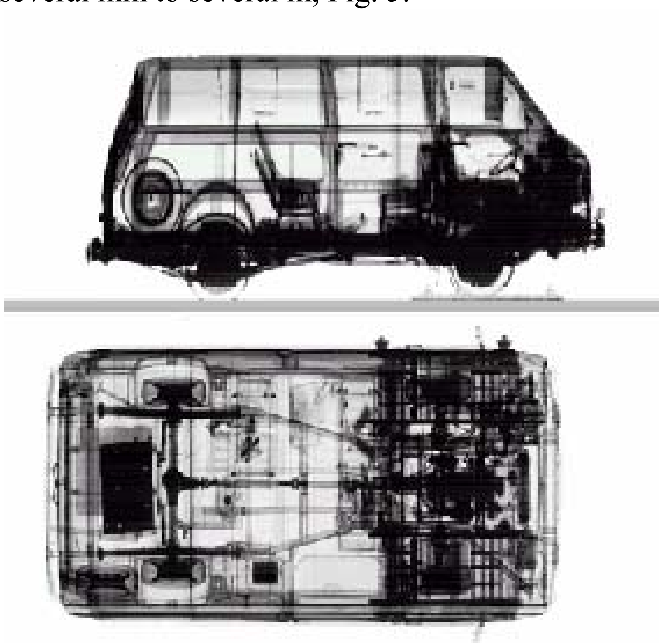
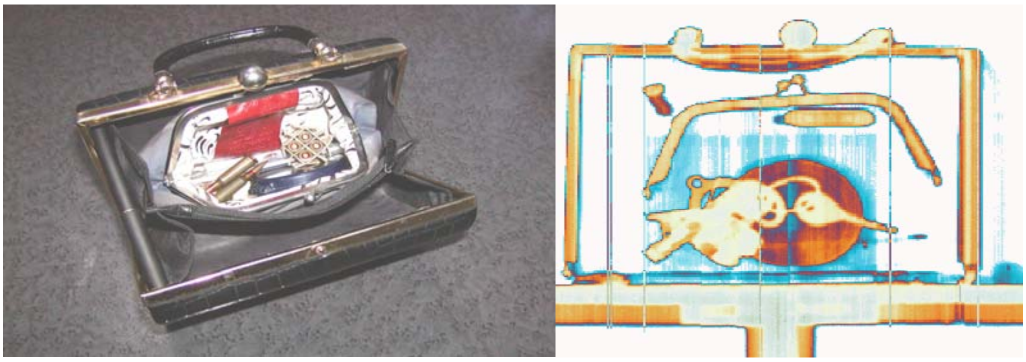


Fig. 5: Image car in x-ray.

If we used tomography principle, we can realize 3D imagination of different object and turn this one by special software and can see this one from different direction and so is inside (Fig. 6). At our mind this method, coincide with multienergy possibility very promise for future inspection system.



a) b)

Fig. 6: The tomography principle: a) scanned object; 3D shadow imag view.

4. Conclusions

In this paper there were tested wide class of objects with dimension from mm to several meters with absorption by steel equal from several µm to 250 mm.
For different objects and differen goal of control may be recomnend different type arrays and method of control.
Best disclosure of dangerous materials, expecially explosive distiguish by used multienergy method, especially with scintillator with low density and atomic number – ZnSe(Te).
Control large objects was realized with used in detectors scintillator type CWO or CsI(Tl).
Finally wide branch inspection instruments based on digital radiography method was installation and first 3D imegination was realized.

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5. References

[1] R.M. Harrison, "Digital radiography – a review of detector design", Nucl. Instr. and Meth. A310, 24-34 (1991).
[2] S.V. Naydenov, V.D. Ryzhikov, "Determining Chemical Compositions by Method of Multi-Energy Radiography", Technical Physics Letters 28, # 5, 357-360 (2002).
[3] V.D. Ryzhikov, N.G. Starzhinskiy, L.P. Gal'chinetskii, D.N. Kozin, V.P. Sokhin, A.D. Opolonin, V.M. Svishch, E.K. Lisetskaya, "Scintillator-photodiode detecting systems for two-level X-ray inspection systems", 15th World Conference on Non-Destructive Testing, Rome (Italy), 15-21 October, 2000, Abstracts Book, p. 466.
[4] The X-Ray Introscopy System "Poliscan-4", Prospects, stcri@isc.kharkov.com
[5] L.V.Atroshchenko, B.V.Grinev, V.D.Ryzhikov e.a. (Ed. Prof.V.D.Ryzhikov). Scintillator crystals and detectors of ionizing radiation on their base.- Kiev: Naukova Dumka. 1988, 322 pp.

[6] Small-crystalline detectors of ionizing radiation on the basis of ZnSe(Te). V.G.Volkov, B.V.Grinev, V.D.Ryzhikov e.a. Pribory i Tekhnika Eksp. (Moscow), 1999, No.6, p.37-42.
[7] Detection system for X-ray introscopy. Patent of Ukraine, No. 2001053401 from 21.05.2001.2.