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Current tendencies in the development of neutron and X-ray detectors for common use

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Abstarct. The paper is a brief review of activities of Federal State Unitary Enterprise “VNIIA” and National Research Nuclear University “MEPhI” in the development of radiation detectors for various applications.

1. Introduction

The development of state-of-the-art radiation detectors decidedly broadens potentials of nuclear techniques in a wide range of applications. An innovative detection system conformed to the available neutron source in combination with a sophisticated software could provide appropriate productivity and achievable results in terms of the quality of measurements. The paper describes radiation detectors designed by Federal State Unitary Enterprise “VNIIA” and National Research Nuclear University “MEPhI” and intended for non-destructive testing, localization and identification of radiation sources, measurements of radiation characteristics, nuclear characteristics of formations, as well.

2. Imaging detectors for neutron and X-ray radiography [1-12]

At present two types of detectors are mostly used for radiation imaging in radiography: CCD detectors and detectors on the basis of Photostimulated Storage Phosphors (Imaging Plates, IP), for example $BaFBr:Eu^{2+}$.

The detectors in figures 1, 2 were developed for imaging respectively low and strongly divergent beams. The fiber optical screen (2) and the condenser (3) in figure 2 have been designed to transfer only scintillation photons propagating along radiation rays emitted by a “point” like source.

Two imaging systems realizing “direct” method and “transfer” methods have been developed for fast neutron radiography on the basis of IPs supplemented with corresponding radiation converters: polyethylene and cupper.

The CCD detector (figure 3, left) and the IP set (figure 3, right) were developed for imaging simulteneously both X-ray and fast neutrons. A luminescent screen in figure 3 (left) consists of two parts (7, 8) imaging fast neutrons (7) and X-ray (8) and being in optical contact. Images produced at the display surface of the screen (7) come into view in different regions of visible spectrum. Corresponding optical filters (5) placed before projection objectives (4) allow to separate these images and register them independently.

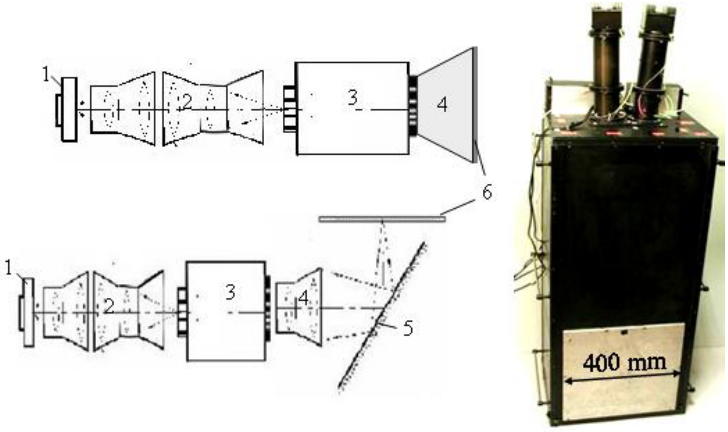

Figure 1. Optical arrangement of CCD detectors for imaging low divergent beams: 1 – CCD matrix, 2 – scaling objective, 3 – image intesifier, 4 – projection objective (taper for the upper arrangement), 5 – deflecting mirror, 6 – radiation converter.

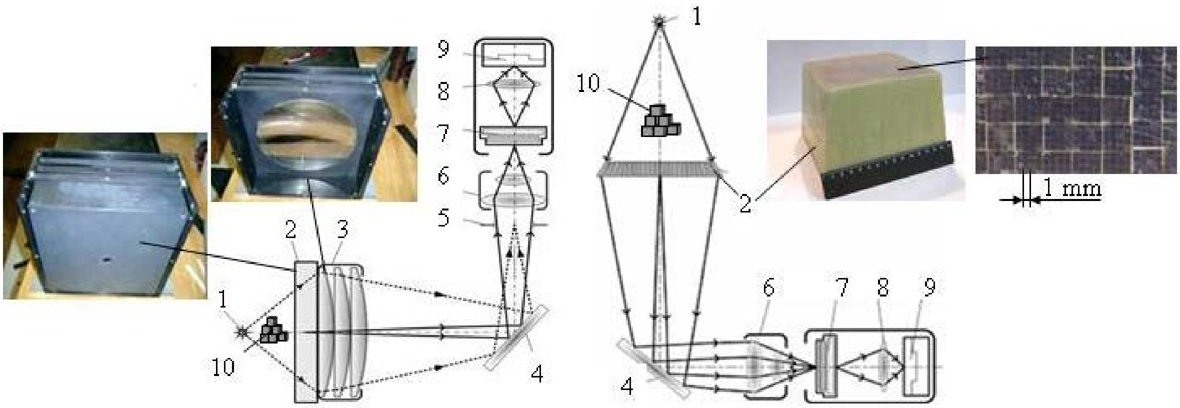

Figure 2. Optical arrangement of CCD-detector for conical fast neutrn beams: 1 - fast neutron source, 2 – luminescent screen (left - plastic slab, right - fibreoptical prism), 3 – condenser, 4 - deflecting mirror, 5 – diafragm, 6 - projection objective, 7 - image intensifier, 8 - scaling objective, 9 - CCD-matrix, 10 – radiographed object.

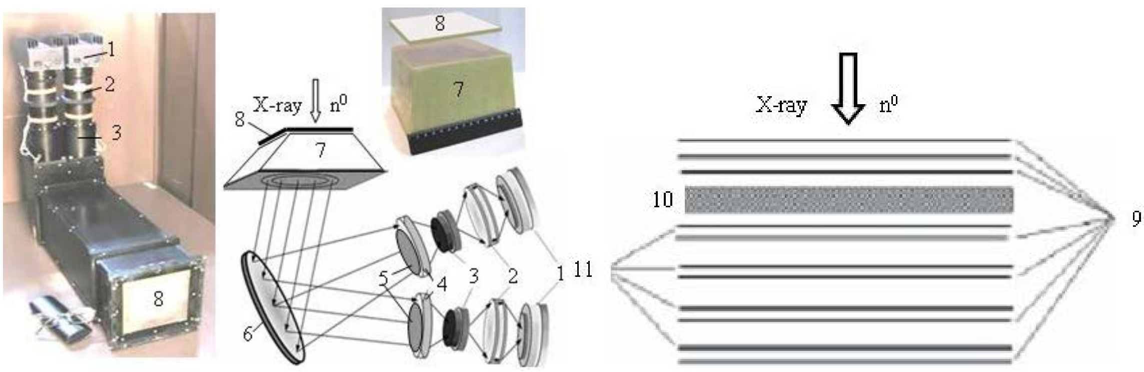

Figure 3. CCD detector (left) and IPs arrangement (right) for imaging simultaneously X-ray and

fast neutrons. 1 – CCD matrix, 2 - scaling objective, 3 - image intensifier, 4 - projection objective, 5 – optical filters, 6 - deflecting mirror, 7 – luminescent fibreoptical prism, 8 - luminescent screen for X-ray, 9 – IP, 10 – lead screen, 11 - polyethylene converter.

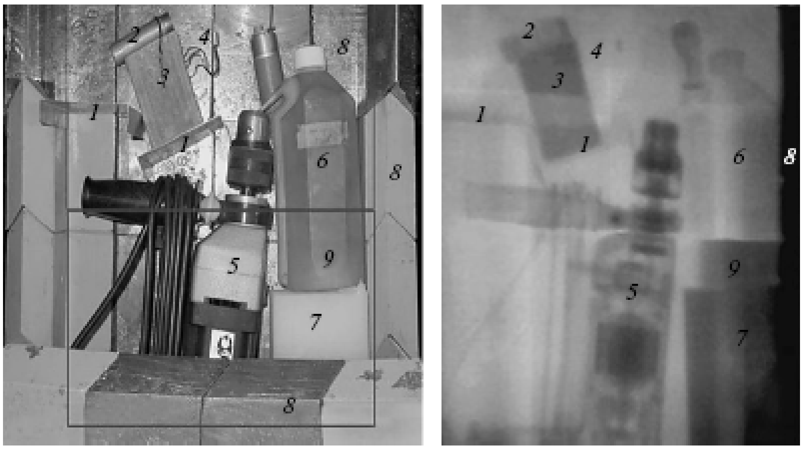

Figure 4. Left, right – photo and radiographic image of test objects, respectively. 1 – 2 mm thick tin plate, 2 – cartridge, 3 – soap, 4 – fuse dummy, 5 - drill machine, 6 – plastic bottle, 7 – special shape plastic material, 8 - 5 cm thick lead bricks, 9 – hydrogenous liquid.

An IP set for simulteneous imaging X-ray and fast neutrons consists of two sections separated by a lead plate for screening the fast neutrons section from the impact of X-ray. IPs for imaging fast neutrons are supplemented with 1 mm thick polyethylene plates converting fast neutrons into protons. An example of the radiographic image obtained with a portable neutron generator ING-07 of VNIIA [13] is presented in figure 4 [4].

3. Imaging detectors for localization and identification of radiation sources [14]

A design of the CCD detector intended for localization and identification of fast neutron sources is presented in figure 5 (left). The detector operation is based on imaging both fast neutrons of the source and thermal neutrons produced in the fiber optical screen (2) due to fast neutrons moderation. Spatial distribution of the signal produced by fast neutrons is used to localize the source, and the ratio of thermal-to-fast neutrons signals to identify it.

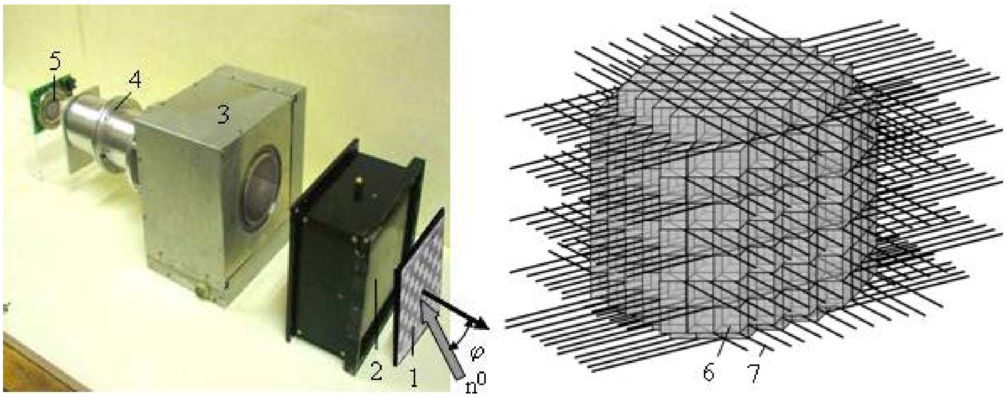

Figure 5. CCD detector (left) and 3-D array of scintillation detectors (right) for detection and identification of radiation sources. 1, 2 –screens for imaging thermal and fast neutrons, correspondingly, 3 - image intensifier, 4 - scaling objective, 5 – CCD

matrix. Right - 3-D array of scintillation detectors, 6 – luminescent detection elements, 7 - wave length shifting (WLS) fibers.

The design concept of the 3-D array of scintillation detectors is illustrated in figure 5 (right). The scintillation location is determined by the intersection point of two wave length shifting (WLS) fibers, from which signals arrive at the photoreceiver approximately at the same time. The application of a crossed WLF fibers enables the large volume 3-D arrays design, since the light attenuation length for WLS fibers is large and the number of data read-out channels is much less, than the number of the detection elements.

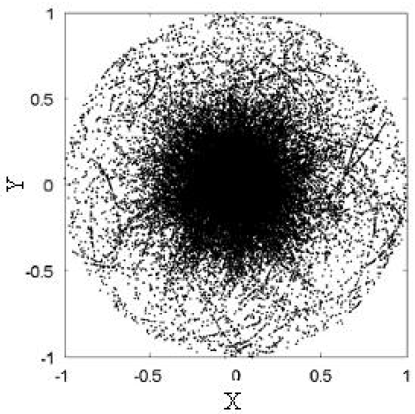

Figure 6. Image of a monodirectional source of fission neutrons. X, Y—normalized projections of the vector pointing at the source location from the assembly center.

Figure 6 shows an example of a simulated image obtained for a distant fission neutrons source.

The carried out simulations show that 3-D arrays provide new means for radiation source localization and identification, neutrons and gamma rays discrimination, background rejection, and of interrogation systems.

4. Multi-energy X-rays (gamma) sensors [15]

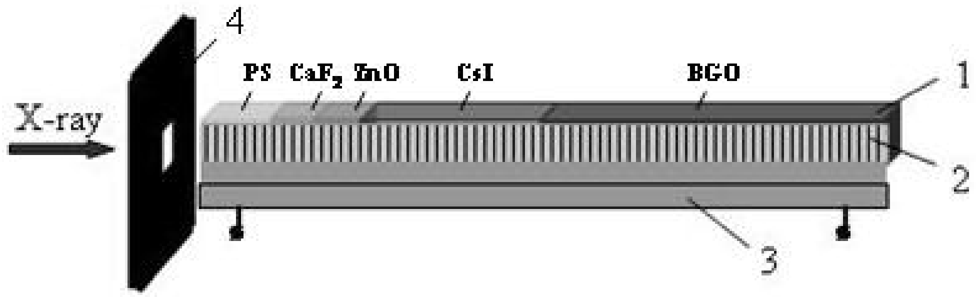

Figure 7. Scintillation multi-energy sensor for X-rays: 1 – scintillation plate, consisting of several scintillators, 2 – linear position-sensitive photo-receiver, 3 – primary electronics, 4 – collimator, 5 – direction of X-ray beam.

The concept of the multi-energy sensor presented in figure 7 is based on radiation filtering in a scintillation plate (1) composed of different scintillators. A position-sensitive photo-receiver (2) is placed on the side surface of the plate. The operation of the multi-energy sensor is based on the relationship between the spatial distribution of scintillation signal generated in the scintillation plate (1), stretched along the radiation beam, and the radiation spectrum. For that, the scintillation plate (1) consists of a number of scintillators placed one after another with effective atomic charge increasing along the plate.

Spectrum is well reconstructed whenever the spectrum of radiation hitting any scintillator does not contain quanta with the energy corresponding to K-edge of photo-absorption band and to production of electron-positron pairs in the scintillator.

5. Radiation detectors for well-logging devices [16]

Neutron well-logging tools have been used to measure physical characteristics of geological formations for many years. Spatially resolved data provide considerable additional inormation as compared to the data obtained at fixed distances (at two, as a rule).

An example of a position sensitive detector to measure simultaneously spatial dictributions of thermal, epithermal and fast neutrons is presented in figure 8. It consist of a set of fibre optical luminescent detectors for thermal (1), epithermal (6), and fast neutrons (7). The screen (5) is used to capture thermal neutrons penetrating the detector (1) from outside. The axial position of neutron interaction with the detector may be determind by comparing amplitudes of signals produced at the opposite ends of a luminescent fiber practically at the same time. While the angular position is determined by the responded elements of position sensitive photomultiplyers.

Scintillators diversity provides detecting corresponding combinations of different radiations.

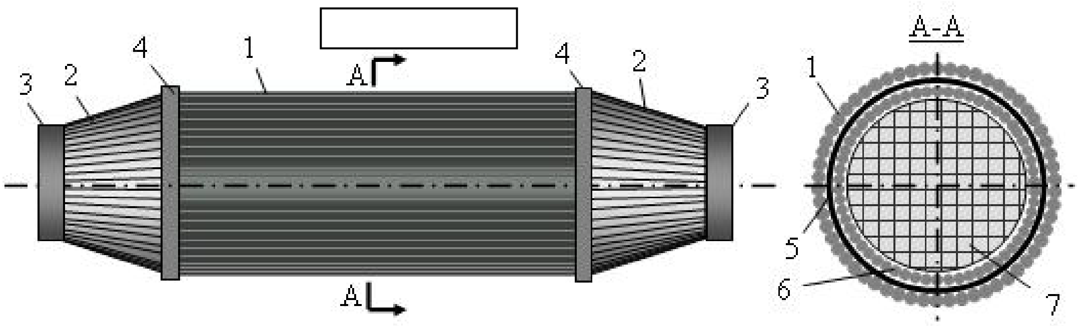

Figure 8. Neutron position-sensitive detector for well loggong devices: 1, 6 - luminescent fibres to detect thermal neutrons, 2 – fiber optical taper, 3 –position sensitive photomultiplyer, 5 – thermal neutron screen, 7 - luminescent fibres to detect fast neutrons.

6. Electrometric neutron sensors [17]

A new approach to neutron detection is based on application of neutron electrometric sensors accumulating electric charge when irradiated by neutrons. The method essence is illustrated in figure 8 displaying a general design of the neutron electrometric sensor with an elastic element. Neutrons hitting the emitter (1) cause nuclear reactions which result in emitting charged particles. Some of them are accumulated in the absorber (2) approximate to the emitter. As a result, the emitter and the absorber accumulate electric charges of opposite polarities. Electric field and electrostatic attraction force between the emitter and the absorber appear and increase when the sensor is exposed to neutrons.

The absorbed charge and therefore the neutron flux may be determined measuring various physical quantities, for example:

- Emitter and absorber bridging frequency
- Emitter or/and absorber displacement
- Elastic element tension
- Electrostatic force
- Electric field intensity.

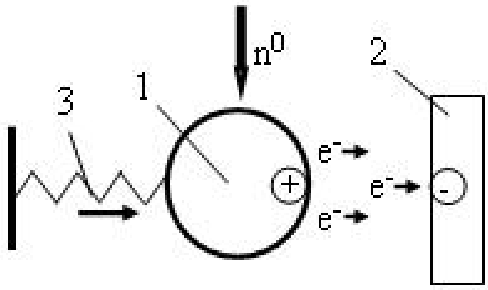

Figure 9. General design of neutron electrometric sensor. 1 - emitter of charged particles, 2 - absorber of charged particles, 3 - elastic element.

7. Conclusions

At the moment the progress in the radiation detection is conditional upon technological achievements in the development of materials possessing in particular high luminosity, sensitivity, spatial and/or spectral resolution, capable of detecting radiation at severe environment while well-logging.

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