Development of wide-ranged diamond-based detector unit for gamma radiation measurement

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Abstract. In the article the description of wide-ranged diamond-based detector unit is given. Characteristics of the diamond detector were studied in current and in impulse mode. As well it was studied how detector’s sensitivity depends on power doze within the limits from $10^{-3}$ to $0.4\text{Gy/h}$ (impulse mode) and from $10^{-1}$ to $2 \cdot 10^{4} \text{Gy/h}$ (current mode). On the basis of the obtained data it is possible to estimate about the possibility of using the detector to prevent emergency accident on a nuclear power plant and for everyday control at a nuclear power plant.

1. Introduction
The most important task of radiation control at a nuclear power plant is the earliest detection of radiation accidents, monitoring of their progression and isolation in process and finally analyzing the information about the event and accident consequence assessment[1].

In compliance with IAEA Safety Standards NPP must be provided with Irradiance measuring systems which remain their functional abilities under condition of severe beyond-the-design basis accident and enabling to get information necessary for the drafting of recommendations for civil protection in emergency situations and recovery from an accident.

Also usage of emergency wide-range detector unit can solve the following problems:

- verifiable detection of radiation accidents;
- data acquisition of reactor core condition;
- loss of coolant data acquisition;
- control and prediction of radiation situation in containment; Etc.

Usually equipment is located within the reactor containment. It shall be located to provide maximum coverage of the areas being monitored and to minimize shielding effects from other equipment or structures[2].

For solving those problems we need specially sophisticated detecting units with various abilities of detecting which can be used at the nuclear power plant for everyday control as well as to detect significances during an accident at a nuclear power plant.

Traditionally detectors are made of materials which are proved to be vulnerable and not able to resist high levels of radiation and high temperatures. Detectors based on diamond crystal, which have
a high radiation resource and keep working at critical temperatures are considered to be quite perspective[3].

2. Diamond detector

During an accidental situation some special conditions can block the work of electronic schemes. To solve that problem the wide-range emergency detecting blocks consist of two parts: the first part is the detecting node which is disposed in an emergency zone and the second part is the electronic equipment for measuring and analyzing the information which is disposed out of the accidental zone (figure 1). Taking into account the length of the cable between detector and remote electronics – it should be minimized.

![Figure 1. Configuration of detecting block towards the protecting shell.](image)

In the layout of the detecting device (figure 2) from the power supply (PS) to the diamond detector (DD) in an outer block of detecting power 50V was provided (if we reduce bias voltage the detector won’t collect an average charge from the inside levels of the crystal, as soon as if we enlarge the power – the speed of the counting does not grow significantly, but serious electronic breakdown appear. That is why power 50V is the most obtainable). Depending on the operating mode signal from the detector goes to the ADC or preamp. Current, appearing under the influence of ionizing radiation in the detector through the work of digital converter (ADC) was converted into the chain of impulses coming to the microcontroller (M). In impulse mode signal from detector arrives to preamplifier (A). The chain of impulses displayed as the speed of counting impulses per second, which is given as an average number of impulses per 1, 10, 100, 1000 seconds was taken out to the node of indication (D). As the measured value was taken as an average speed of counting in a direct proportion to an average current, appearing in the detector.

![Figure 2. Block-scheme of the detector unit.](image)

Diamond has several outstanding properties which make it very attractive for radiation detector applications. Compared to silicon which is most preferred semiconductor material for wide range of radiation detection applications, it has higher bandgap, higher resistivity and e–h mobilities, and better resistance to corrosion. Because of its valuable properties, it is considered to be a promising material for applications involved in high radiation, high temperature, harsh environments, and for fast timing applications [4].

The operating principle of the diamond detector is similar to the operating principle of the solid-state ionization camera. Passing through the diamond crystal, charged particles cause ionization inside of it. As the result of ionization free charge carriers (conduction electrons and holes) are produced and they move under the influence of the electric field towards the definite electrodes. The same as a usual
ionization camera operate, the diamond detector has got two signal operating modes from the detector: impulse mode and current mode.

3. Experiment and results
Current mode scientific tests of the diamond detector proved, that lineal pattern of the measuring characteristics is kept within the dose power limits from $10^{-1}$ to $2 \cdot 10^4$ Gy/h (figure 3). And because of linearity is keeping we can make a conclusion that it is possible to register radiation about $10^5$ Gy/h. So the rough measurement range is from $10^{-1}$ to $10^5$ Gy/h.

![Figure 3. Count rate on gamma dose rate dependence diagram (current mode).](image)

But is this dose rate does not detect an accident at an early stage. There was checked the linearity of counting speed of the diamond-based detector unit in impulse mode within the limits of powers from $10^{-3}$ Gy/h to 0,4 Gy/h (figure 4). From the results received it is possible to conclude, that within the limits of the given powers the linearity does not change. Increasing the exposure time can expand the range of measurements till $10^{-4}$ Gy/h.

![Figure 4. Count rate on gamma dose rate dependence diagram (impulse mode).](image)
4. Conclusion
During the research work the characteristics of the diamond detector were studied in current and in impulse mode. As well it was studied how detector’s sensitivity depends on power doze within the limits from $10^{-3}$ to $0.4$ Gy/h (impulse mode) and from $10^{-1}$ to $2 \cdot 10^4$ Gy/h (current mode). The data of the research allow us to make the following conclusion: dependence of the average speed of counting from the power of photon radiation has a lineal character within the limits $10^{-4}$ to $10^7$ Gy/h. Non-lineal character of measuring characteristics is kept within the limits of 10%.

The results received prove that it is principally possible to create a wide-ranged unit on the basis of diamond detectors for detecting the power and dose of photon radiation absorbed.

References

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