The measuring complex for detection of radioactive waste in near-earth space

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Abstract. Description of a measuring complex intended for detection and identification of radioactive waste in the near-earth space is presented. The complex consists of several xenon gamma-ray spectrometers, developed on the base of the thin-walled impulse ionization chamber with sensitive volume of four litres. Their main physics – technical characteristics are considered. An estimation probability for detection of various elements comprising radioactive waste by means of the measuring complex on board the spacecraft “Meteor” is given.

1. Introduction

At the end of the last century several tens satellites with nuclear power sources were placed into orbit round the Earth. Upon completion of the flight program most of them were sent to disposal orbits (800-1000 km), where their ballistic existence time is within several hundred years. However, at present, maximum density of space debris of technogeneous origin (figure 1) [1] has concentrated in those orbits, which can lead to a collision of its elements with potentially dangerous radioactive objects. In case of their disintegration some radioactive fragments may get into the Earth’s upper atmosphere within several years, which will lead to radioactive contamination of the atmosphere and the Earth itself. The problem has been studied jointly in detail by VNIIEM, MEPhI, LPI and INASAN within the research projects of the Federal Target Program "Research and scientific-pedagogical personnel of innovative Russia in 2009 - 2013" [2]. It has been shown that, for the control of potentially dangerous objects in the near-earth space (NES), it is necessary to use all available means of observation. Currently, permanent control of orbit parameters of those objects is being carried out by means of radar and optical aids, which allows one to predict their movements in near-earth space. However, to detect and identify radiation itself from various space objects, special equipment installed on satellites has to be used.
2. Detection of radiation objects in the near-earth space.

For gamma-ray bursts registration a scintillation detector, based on CsI (TI) crystals, with dimensions of Ø 200 x 100 mm³, weighing 11 kg and having energy resolution about 12%, was installed on board the satellite "Coronas-F" [3]. In processing the data from that detector several gamma-ray bursts were discovered, which could not have been explained by flare activity of cosmological objects, since the shape of the bursts was significantly different from the previously observed gamma-ray bursts. In addition, those bursts were not detected by other satellites, having similar detecting devises on board. One of the bursts is shown in figure 2.

In order to identify those gamma-ray bursts nature, distance matching was conducted between the spacecraft "Coronas-F and the satellites, which, according to the official catalogues, are considered as potentially dangerous radioactive objects. In the period from July 2001 to December 2002 Coronas-F spacecraft had closing-ins with three of 75 such objects. Main parameters of their orbits as of September 2001 were identified. The objects are listed in table 1.

### Table 1. The list of satellites having flown in the proximity of Coronas-F in the period of 06.2001-12.2002.
| Name of object      | Classification number | Inclination of the orbit, (º) |
|---------------------|-----------------------|------------------------------|
| Coronas-F           | 26873                 | 82.5                         |
| Kosmos 1818         | 17368                 | 65.0                         |
| Kosmos 1867         | 18187                 | 65.0                         |
| OPS 4682 DEB        | 01399                 | 90.4                         |

Satellite OPS 4682 DEB flew at a distance of 186 km from the spacecraft "KARONAS-F" and its gamma-ray emission was registered in the form of gamma-ray bursts as shown in figure 2. Unfortunately, the gamma-ray spectrometer on board the spacecraft "Coronas-F" was of low energy resolution (12%). This circumstance did not allow us to reliably identify the isotopic composition of radioactive material of the object.

3. Scientific equipment “Nuclide”

For detection and identification of radioactive objects in space waste various types of spectrometers can be used. They range from X-ray, gamma-ray, and neutron to infrared, optical, etc. Of these gamma-ray spectrometers are the most informative. Each radionuclide has a peculiar gamma-ray linear spectrum. To obtain the linear spectra gamma spectrometers of good sensitivity and high energy resolution are used, which allows one to determine the isotopic and quantitative composition of radioactive objects. Gamma-ray spectrometers like that (scientific equipment "Nuclide") are currently being developed at NRNU MEPhI jointly with the Federal State Unitary Enterprise "VNIIEM" [4,5]. Their primary detecting element is a thin-walled cylindrical pulse ionization chamber (IC) with a shielding grid. As working substance compressed xenon is used. The ionization chamber is surrounded from every quarter by the scintillation detector based on polystyrene, which is included in the anti-coincidence circuit. Scintillation outbreaks created by charged particles are recorded by means of silicon photomultipliers (SPiM).

Schematic diagram of the detecting elements of the "Nuclide" is shown in figure 3.

![Schematic diagram of the detecting section of xenon gamma-ray spectrometers "Nuclide" 1.](image)

Figure 3. Schematic diagram of the detecting section of xenon gamma-ray spectrometers "Nuclide" 1.

Cylindrical pulse ionization chamber. 2. Frisch grid. 3. Hermetic casing. 4. Anode. 5. Ceramic feed-through. 6. Charge-sensitive amplifier. 7. High-voltage supply. 8. Electronics.

Basic physical and technical characteristics of the detecting unit (gamma-ray detector) of scientific equipment "Nuclide" is given in the table 2.

| Table 2. Basic physical and technical characteristics of the detection unit of the xenon gamma-ray spectrometer. |
| №  | Parameters                                      | Value                      |
|----|------------------------------------------------|----------------------------|
| 1  | The energy resolution at gamma-ray 662 keV      | 1,7±0,1) %                |
| 2  | Energy range of detected gamma-ray              | 0,03-3 MeV                |
| 3  | Mass                                           | 6.0 kg                    |
| 4  | Dimensions,                                    | 150x250x500 mm            |
| 5  | The sensitive volume                           | 4000 mm$^3$               |
| 6  | Operating temperature range                    | $0 \div 100 \, ^{\circ}C$ |
| 7  | The level of acoustic loads                    | $0 \div 80 \, \text{dB}$  |
| 8  | Power consumption                              | 15 W                      |
| 9  | Supply voltage                                 | (24 –27) V               |
| 10 | Warranty lifetime                              | ≥ 10 years                |

Figure 4 shows typical energy spectra of the standard point gamma-ray sources from the set OSGI measured by detecting equipment unit "Nuclide". Presented spectra demonstrate the spectrometric abilities of the equipment for detection and identification of various radio nuclides.

![Figure 4](image.png)

**Figure 4.** The energy spectra of standard gamma-ray sources from the standard set measured by detecting equipment “Nuclide”.

To estimate the minimum distance and the frequency of potentially dangerous radioactive objects approach the spacecraft, where the equipment "Nuclide" is installed a satellite Meteor M2 (40069) with orbital altitude of about 825 km was selected. The calculation results are shown in table 3.

**Table 3.** Calculation results of the convergence parameters of the satellite Meteor M2 (40069) with potentially dangerous objects. P - numerical value of Draconian period of the objects, A/m - the ratio of the area to weight, $\min|\overrightarrow{r_0} - \overrightarrow{r_d}|$ - difference magnitude of the object position vector and the position vector of satellite Meteor M2 (40069).

| Satellite        | P (min) | A/m(cm$^2$/kg) | $\min|\overrightarrow{r_0} - \overrightarrow{r_d}|$ (km) |
|------------------|---------|----------------|---------------------------------|
| Meteor M2 (40069)| 101.42  | 0.0065         | –                               |
| Cosmos 1818 (17369)| 100.61 | 0.0047         | 20.5                            |
| Cosmos 1932 (19162)| 104.06 | 0.0025         | 121.5                           |
| Cosmos 1176 (27568)| 102.38 | 0.1507         | 9.0                             |
| Cosmos 1818 (34176)| 100.49 | 0.0506         | 29.1                            |
| Cosmos 1818 (36944)| 100.54 | 0.0496         | 28.0                            |
| Cosmos 1818 (36946)| 100.51 | 0.0520         | 32.7                            |
| Cosmos 1818 (36947)| 100.47 | 0.0506         | 26.4                            |
The table above shows that the distance at which the satellite M2 Meteor (40069) can approach the objects to be investigated is some tens of kilometers on average. Gamma spectrometric equipment "Nuclide" with the sensitive area of about 1m² being available, those objects will be reliably detected and identified. The M2 satellite Meteor (40069) will approach the objects once or twice in a month.

4. Conclusion

Installation of gamma-ray spectrometric equipment "Nuclide" on board the satellites "Meteor" produced by corporation "VNIIEIM" will provide the possibility to detect, identify and predict the dynamics of the components of radiation space debris. It should be noted that conducting research of the kind does not require any energy expenditure for the spacecraft to approach the object to study.

To improve accuracy of the detection of radioactive debris it is reasonable to carry out the measurements using several satellites located in different parts of the near-ears space simultaneously. In this case, it is possible to determine the parameters of these objects' orbits, as well as increase the overall statistical reliability of experimental data.

References

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