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An automated and robotic complex based on a xenon gamma-ray spectrometer for performing tasks for decommissioning nuclear and radiation hazardous facilities and monitoring the development of radioactive waste

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Abstract. The article focuses on a robotic gamma-ray spectrometric complex designed for decommissioning nuclear and radiation-hazardous objects and monitoring radioactive waste. The complex includes various components, such as radiation monitoring and regular observations to determine the object's radiation parameters. The control of nuclear and radiation-hazardous objects performed using a High Pressure Xenon gamma-ray spectrometer that installed ona remotely controlled platform.

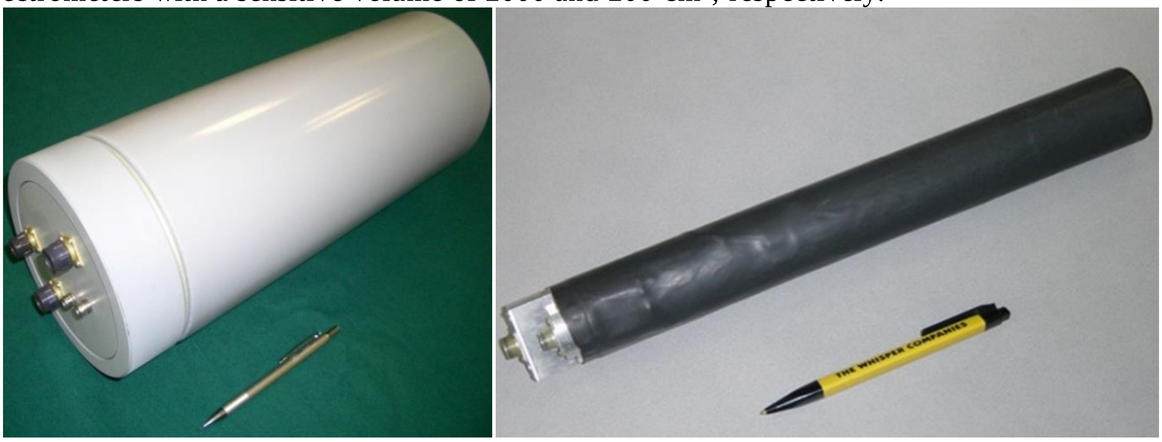
1. Introduction

Because of hydrocarbon reserves are decreasing from year to year, the humanity must to looking for alternative energy sources. One of such sources of energy is the nuclear power. However, almost from the beginning of the nuclear power usage, a human has created inadvertently a risky environment and multiple challenges has been appear by this reason such as the safe operation and decommissioning of nuclear and radiation-hazardous facilities (DNRHF), as well as, nuclear waste (RW) safekeeping and burialing, decommissioning of nuclear facilities and results of possible technogenic accidents elimination. To ensure the safety of handling radioactive waste, including its proper placement and secure storage, it is essential to accurately determine key characteristics of the waste, such as its radionuclide composition, total activity, specific activity of each radionuclide, and weight. These factors are crucial for effective management of radioactive waste. At the initial stage of radioactive waste processing, the data obtained enables the sorting of the waste based on its activity and isotope composition, leading to a significant reduction in disposal expenses. The sorting of radioactive waste based on its activity and isotope composition during the initial stage of processing can significantly reduce disposal expenses.

2. Gamma-ray spectrometric equipment

When creating a robotic automated complex for DNRHF, a gamma-ray spectrometer based on an ionization chamber filled with compressed xenon will be used as a recording device.

This type of spectrometer has an energy resolution several times better than the energy resolution of instruments based on NaI and CsI scintillators, which have a typical energy resolution of about 7-9 energy of 662 keV. At the same time, HPXe spectrometers do not require cooling in contrast to semiconductor spectrometers based on ultrapure germanium. The latter provide a significantly better energy resolution, which reaches several hundred eV on the 662 keV line, but for their operation, it is necessary to maintain the cryogenic temperature of the crystal. HPXe spectrometers have an energy resolution of 1.7±0.3 [6]. Figure .1 show photographs of the HPXe spectrometers with a sensitive volume of 2000 and 200 cm^3, respectively.



a) b)

Figure 1.a) Xenon gamma-ray spectrometer with volume of 2000 cm 3 and b) 200 cm

The technical characteristics of the xenon gamma-ray detector with a volume of 2000 cm^3 are presented in table 1.

Table 1. Physical and technical parameters of HPXe detector with a working volume of 2000 cm^3.

Parameter		Value
Device weight, kg		6.0
Working substance gas density (g/cm^3)		0.3
Actuation medium	Weight (g)	580
	Volume (cm^3)	2000
Xenon gamma-ray spectrometer dimensions (cm)	Diameter	14,0
	Length	38.5
Power consumption (W)		not more than 10
Range of detected gamma quanta (MeV)		0.05 – 3
Working resource, years		not more than 10
Energy resolution on 662 keV line of ^{137}Cs source (%)		1.7±0.3

Parameter		Value
Operating temperature range (° C)		0º - +180º
Cathode diameter (cm)		11.1
Anode diameter (cm)		2
Dimensions of the sensitive area (cm)	Diameter	11.1
	Length	15.0

Along with a gamma-ray detector with a working volume of 2000 cm3, it is possible to manufacture devices both large (4000 cm^3 [6] or 5000 cm^3 [7]) and small volumes (200 cm^3 [8]). The choice of the working volume may depend on the assigned tasks for the robotic automated complex at DNRHF. In the case of using robotic platforms for characterization of RW or mobile complexes for radiation monitoring, which can carry a sufficiently large payload, an HPXe spectrometers with a working volume of 2000 cm^3 or more can be used as a detecting device. For aircraft, the weight of the payload is a critical factor that affects battery life and range. In this case, a xenon gamma-ray spectrometer with a working volume of 200cm^3 is successfully used.

The staff of the Radiation Laboratory of the Institute of Space Physics of the National Nuclear Research University MEPhI have extensive experience in the development of gamma spectrometers based on compressed xenon, which were used as a prototype radioactive waste sorting complex [6], a portal complex for passenger flow management [9], an automated system for monitoring the gaseous radioactive emissions of a nuclear reactor [10]. It isimportant to note that the HPXe spectrometers are being developed for the first time with the aim of using an automated robotic complex for DNRHF.

3. The key advantages of the complex under development are:

–vibroacoustic stability. HPXe spectrometers capable of operating under vibroacoustic conditions up to 100 dB without deterioration of energy resolution;

–temperature stability. The basis of the HPXe spectrometersis an ionization chamber, which is capable of operating at temperatures up to 180° C without changing the spectrometric characteristics of the device;

–radiation stability. The spectrometric characteristics of the HPXe spectrometers do not deteriorate when passing through the neutronfluence detector $1.5 \cdot 10^{10}$ particles.

As an example, Figure .2 shows the gamma spectra of ^{152}Eu, ^{133}Ba and ^{137}Cs gamma radiation sources collected by HPXe spectrometers. Similar measurements were made using a 7.62 detector × 7.62 cm NaI (Tl). Its energy resolution was about six times lower than that of HPXe spectrometers.

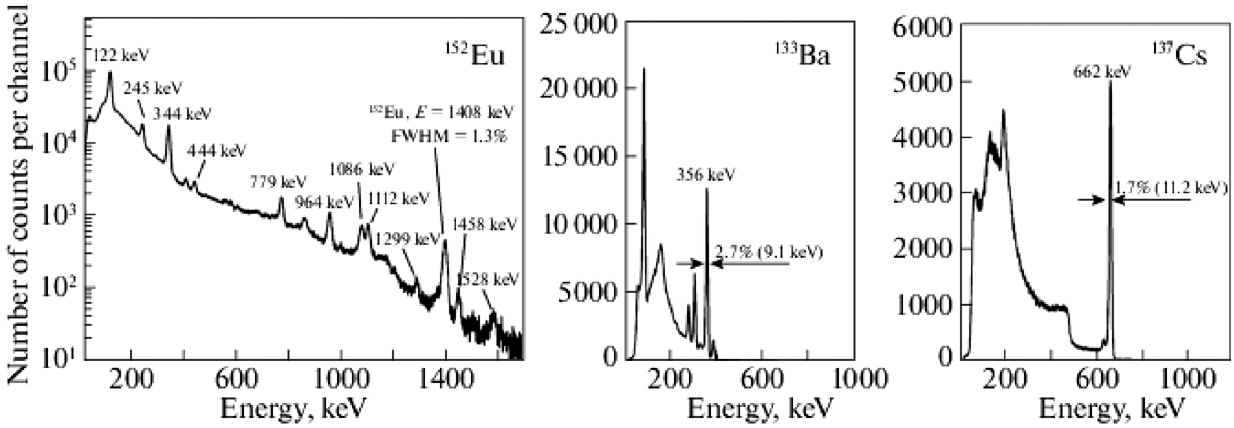


Figure 2. ^{152}Eu, ^{133}Ba and ^{137}Cs gamma-ray source spectra measured using XeGS

Energy lines of radioactive isotopes with activity from 50 kBq to 100 kBq are clearly visiblein the typed gamma-ray spectrum. For 10 years, the duration of the measurement was also confirmed at the "MIR" orbital station, where the spectrometric characteristics of the "XENIA" HPXe spectrometers practically did not change [10].

4. Experiment

In the process of experiments on the development and creation of this complex, a system of remote gamma-ray spectrum set with the help of the created software “NABOR” based on the programming language Python has already been prepared and tested. A RaspberryPi3 microcomputer and ModelB+ 1GBRAM, running the LinuxRaspbian operating system (a compact single-board microcomputer), was used to test the remote control program with HPXe spectrometers.

Within two days the spectra from sources ^{133}Ba, ^{60}Co and ^{22}Na were produced. RaspberryPi and KGS were in the laboratory. During this period, the energy spectrum was stored every minute in a temporary SPS file. A Team Viewer server for remote access, allowing controlling the spectrum set and copying experimental data to a remote PC powered the RaspberryPi. Figure .3 shows the Python “NABOR” interface installed on Raspberry Pi, which was connected via TeamViewer.

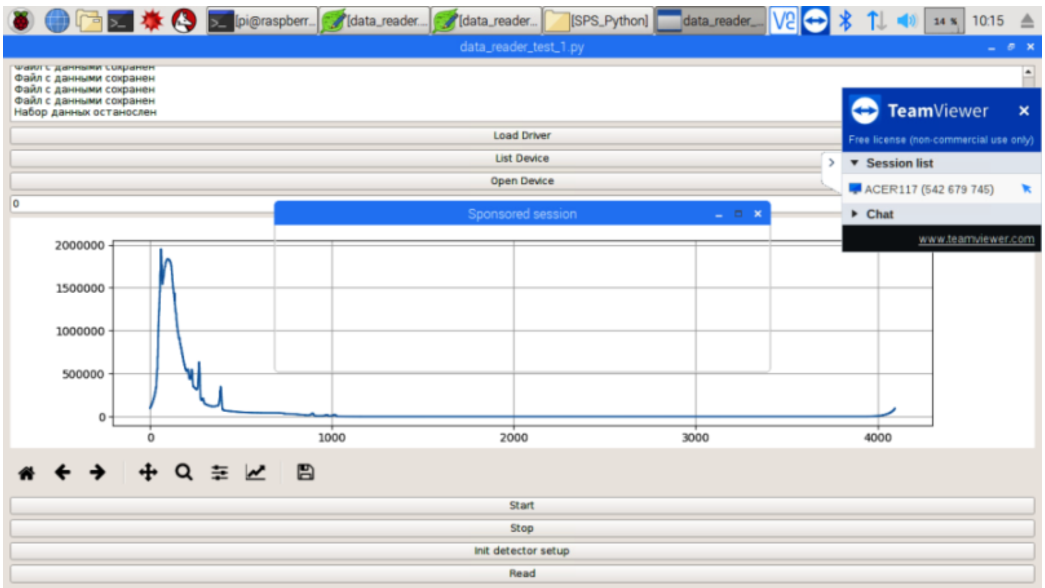


Figure 3. Two-day gamma-ray spectrum set with RaspberryPi

After stopping the dataset, the software allows a close examination of the histogram corresponding to the energy spectrum, approaching and considering individual gamma-ray lines.

5. Results

With the help of Python "NABOR" software gamma spectra data were obtained from sources, ^{133}Ba, ^{60}Co and ^{22}Na. ^{60}Co, which corresponds to lines with energies 1332.5 keV, 1174 keV, source ^{22}Na - 1280 keV, 511 keV and 133Ba - five energy lines 383 keV, 356 keV, 302 keV, 276 keV, 80 keV. Figure 4 and 5 shows the energy spectra obtained during two days on RaspberryPi with the help of Python "NABOR".

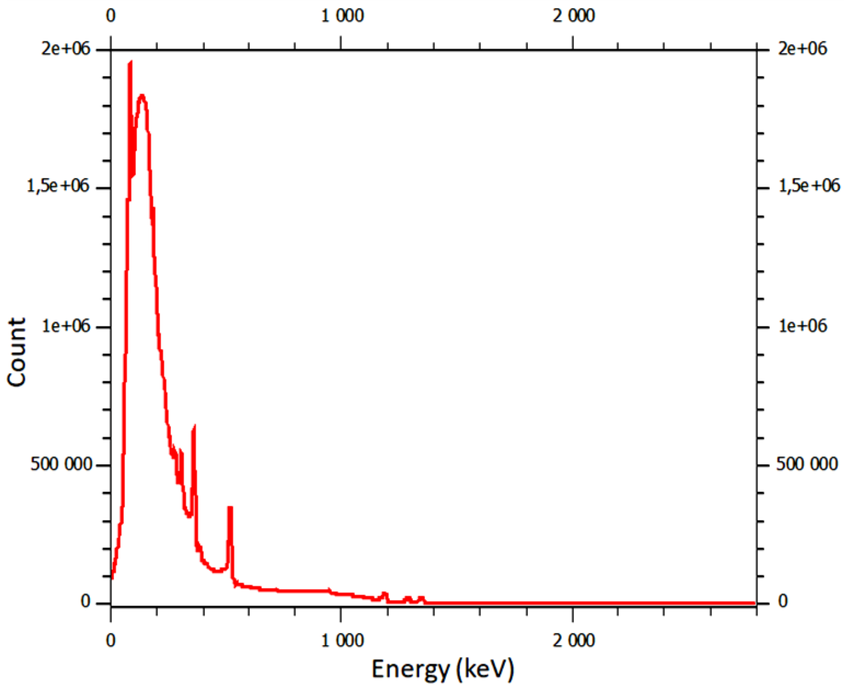


Figure 4.Dialed gamma-ray spectrum set using Python "NABOR" software in linear scale

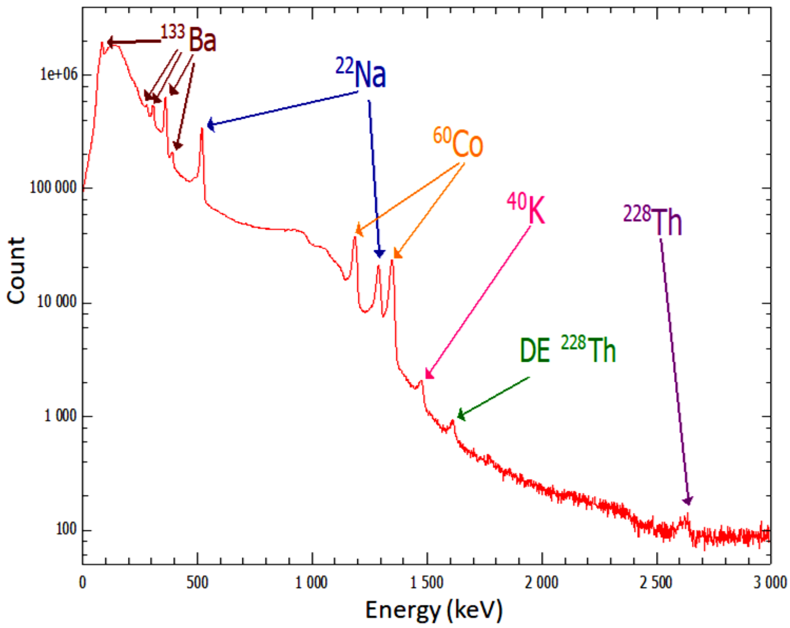


Figure 5.Dialed gamma-ray spectrum set using Python "NABOR" software in semi-log scale

In the field of high energies, the natural background energy lines (^{40}K, ^{228}Th) are clearly visible. According to the results of measurements it is possible to conclude that Python "NABOR" software works steadily during a long set.

6. Conclusion

Robotic radiation pollution monitoring systems significantly reduce the dose load primarily on working personnel who work at high radiation levels. Such complexes can also be used in the operation of nuclear power plants, for example, in nuclear fuel loading and unloading rooms, as well as in the disposal and storage of RW.

It should be noted that the HPXe spectrometers has the ability to register neutrons, which adds another advantage over other spectrometers. In case of irradiation with neutron flows up to 40 neutron/s • m^2, there is no change in the position of the measured gamma lines and deterioration of the energy resolution at the HPXe spectrometers. High Pressure Xenon gamma-ray spectrometer control and real-time data processing is performed remotely using a single computer. Taking into account all spectral and operational characteristics of the HPXe spectrometer, it seems appropriate to use it as a measuring device on board unmanned automated and robotic systems.

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