ANALYSIS OF THE USE OF RADIOACTIVE SUBSTANCES FOR THE CREATION OF POLLUTION, THEIR DETECTION AND HOW THEY CAN BE SIMULATED

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Abstract: *An analysis of the main radiological warfare agents and of the different types of detectors for them is performed. The basic principles of the most common detection methods are described. The aim of the study is to outline the main challenges in this field. The possibility for applications of the Surface photo-charge effect in the field of detection of radiological warfare agents is discussed. An emphasis is put on the simulation of the radioactive substances during the performing of experiments.*

Keywords: RADIOLOGICAL WARFARE AGENTS, METHODS, SURFACE PHOTO CHARGE EFFECT

1. Introduction

The weapons powered by nuclear reactions (fission and/or fusion) are called nuclear weapons. They are compact and highly sophisticated - Nuclear Warheads or compact and relatively more simple Radioactive Dispersal Devices ("dirty bombs"). Although they differ in the initial impact, the consequences for the region are devastating.

Radioactive isotopes are used to fuel the nuclear weapons [1]. For example, enriched Uranium U-235 and Plutonium Pu-239 are used for Nuclear Warheads [2]. The most often used isotopes for Radioactive Dispersal Device [3] are Cobalt Co-60, Caesium Cs-137, Iridium Ir-192, Strontium Sr-90, Plutonium Pu-238, Americium Am-241, Californium Cf-252.

There are several types of radiation emitted by nuclear weapons: α, β, γ particles [4], neutrons [5] and X-rays. They are emitted at the time of detonation (initial) and for long period of time afterwards (residual). The radiation particles have different harmful effects on the human's health, which depend on their type, energy and exposure time. The most important factor is the amount of dose – the greater the energy absorbed by the cells the greater the biological damage. The α and β particles are very dangerous when are inhaled or swallowed. The γ particles, neutrons and X-rays have higher penetration and are very dangerous, if the exposure is very long. When there is a strong dose of radiation, it causes cell structure damage.

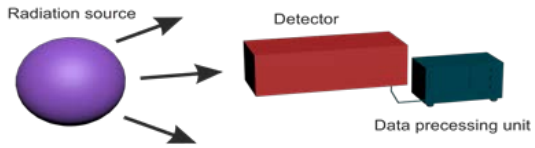

Fig. 1 *General setup for radiation detection system*

2. Detection methods and detector specifics

All radioactive isotopes are sources of radiation. Many of the isotopes occur in the environment and they form the radioactive background (Fig. 2). The United Nations Scientific Committee on the Effects of Atomic Radiation identifies four major source of exposure to natural radiation: cosmic radiation, consisting of fast moving particles, of which some penetrate the atmosphere and become absorbed by humans; terrestrial radiation, consisting of natural deposits of uranium, potassium and thorium which release small amounts of ionizing radiation; exposure through inhalation from radioactive gases produced by minerals found in soil and bedrock; exposure through ingestion, coming from the soul and ground water which contain radioactive materials [6]. This background has to be eliminated during the measurements or in some way accounted for or in the end results.

There are various devices that can detect materials used for nuclear weapons of mass destruction (NWMD) and determine their kind and quantity. But fundamentally the technology analyses and recognises signals and samples from the nuclear materials. The identification of natural or anthropogenic radiation is generally achieved by a detector system with a few subsystems based on physical interactions. The methods depend on the type of emitter and the intended purpose of detection. The general layout of such systems is shown in Fig. 1.

The detector is their essential unit. The signal is handled by elements that record the number of incoming pulses with pre-established features (pulse amplifiers, counters, etc.). A problem is that the energy of the emitter must be high enough to travel some distance through air. If the detectors are not sensitive in the energy range of the incident radiation, the use of absorbers between the detector and the source or of detectors with appropriate dimensions becomes necessary.

Recognizing NWMD is often rendered difficult by low count rates and different in size pulses produced by the detectors systems in accordance with the incident radiation energy. Example of such specter is shown in Fig. 2. It is derived by presenting the number of counts in each increment of the incident radiation. The obtained results are saved in the system computer where they are accessible for further processing and presentation.

All devices for detection of WMD, including those for NRWDM, implement calibration curves that associate count rates with material quantity. The relation of the count rates to the amount of material, the limits of detection for weak nearby sources or strong ones, as well as the dependence of the ambient environment, are some of the parameters described by the curves.

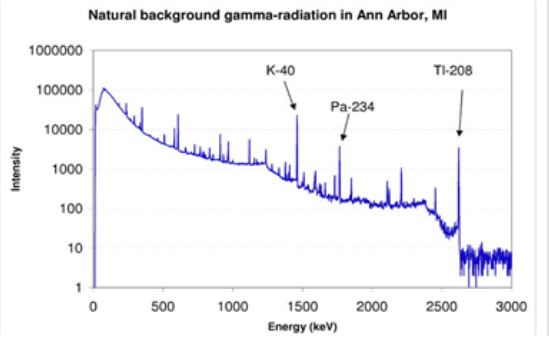

Fig. 2 *Natural background gamma-radiation spectrum (https://whatisnuclear.com/articles/radioactivity.html)*

The magnitudes of the mean free path of neutrons and gamma rays set a condition for the scale of the detectors. The typical detectors weigh several kilograms and shave volumes of tens or hundreds of cubic centimetres. The most compact detectors are restricted for strong sources at a close range.

The neutron and the gamma ray are non-charged particles. In order to detect them their energy must be transferred to a charged particle. The interaction with the detector produces electrons for the gamma rays and particle-hole pairs for the neutrons. High voltage is usually applied so that the electrical signal can be measured.

Radiation exposure monitors, such as x-ray film or personnel dosimeters, record a physical change in the material caused by the radiation. When the film is developed or the dosimeter read out, a record of the cumulative radiation exposure is obtained. Radiation detectors convert the radiation in real time to an observable effect, such as electronic pulses or scintillator light.

All neutron detectors work by detecting the charged particles produced when the neutrons interact with a suitable material. Neutron absorption is most efficient for low-energy thermal neutrons, so these detectors include a moderating material, which slows the neutron down by elastic scattering. After absorption, the excited nucleus decays, emitting a charged particle, which can be detected by a scintillator, semiconductor diode or gas-filled counter. The neutron energy information is lost in the moderation process, so the resulting display is typically count rate or is converted to dose rate.

3. Types of detectors

Nuclear radiation can only be detected by specially created detectors. Each detector has drawbacks in detecting some particular kinds of radiation and advantages for others: specific energy ranges, ionizing particles, ambient conditions.

- **Crystal Scintillation Counters** – The Crystal Scintillation Counters [7, 8] are tubes with a scintillation crystal on the one end. When a particle is absorbed in the crystal a luminous photon is generated. The photon goes through the Optical contact and a photoelectron is generated, then the photo electron hits a series of photomultipliers and in the end the cascade of photo electrons is analysed by the multichannel analyser. This way a very weak source of radiation can be accurately detected and measured.

- **Liquid Scintillation Counters** – Liquid Scintillation Counters (Fig. 3) [7, 9] are chambers containing a vial of scintillation liquid, which is surrounded by photomultiplier tubes (PMT). The sample is put in the liquid and when it emits a radiation, the radiation is absorbed by the fluid. The fluid emits a pulse of light that is detected by the PMTs. By cooling the PMTs, energy discrimination and use of shielding, and if all PMTs detect the light in coincidence, a very low background count can be achieved.

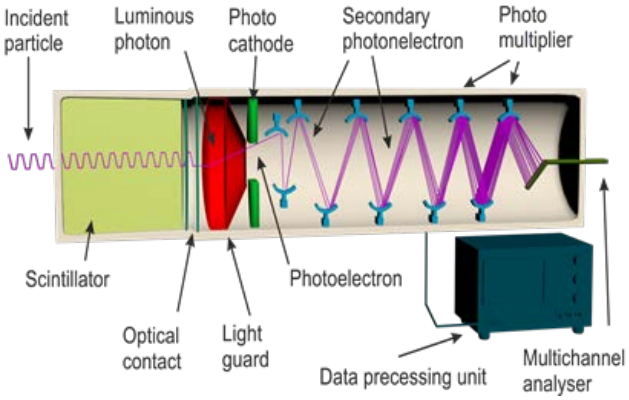

Fig. 3 *Crystal Scintillation Counters*

- **Proportional counter** – a chamber is filled with an inert gas and a voltage is applied, when a particle interacts with the gas, it is ionized and a pair of a positive ion and an electron begins moving towards the cathode and the anode, respectively [10]. As the particle progresses, it leaves a trail of ion pairs that is proportional to its energy. It is efficient for the detection of alpha and beta particles and it can differentiate them.

- **Multichannel Analyser System** – it includes a sodium iodide crystal, a solid-state germanium detector (Fig. 4), or a silicon-type detector and a multichannel analyser [11, 12]. They can be used to analyse liquids or solids and, with good shielding, organic tissues of the energy spectra of gamma-ray sources. They are capable of identifying the source and determining the identity and quantity of gamma emitters present with a detailed analysis.

- **Radon Detectors** – a number of different techniques are used for radon measurements [13]. These range from long-term exposure of CR-39 plastic with subsequent chemical etching and alpha track counting, exposing a charcoal canister for several days and performing gamma spectroscopy for absorbed decay products, collection of radon decay products on an air filter and counting, and exposure of an electret ion chamber and read-out.

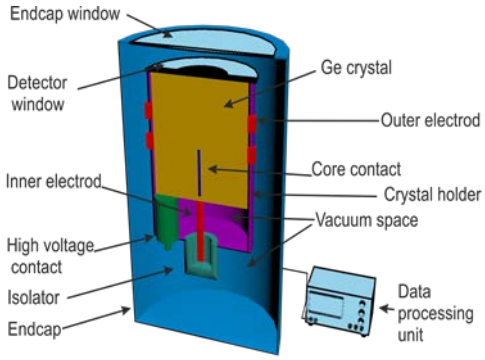

Fig. 4 *Germanium detector*

- **Portable Multichannel Analyser** – a compact version of the Multichannel analyser system. When gamma-ray data libraries and automatic identification procedures are used, the type of radioactive materials can be displayed.

- **Ionization (Ion) Chamber** – the chamber inner wall is coated with a conductor and there is an anode in the centre, a small voltage is applied (Fig. 5) [14]. The emission of the radioactive source forms an ion pair in the air volume when it interacts with the wall coating. The anode collects the electrons and the current is measured. The detector must be calibrated, and changes in the ambient pressure and temperature must be taken into account.

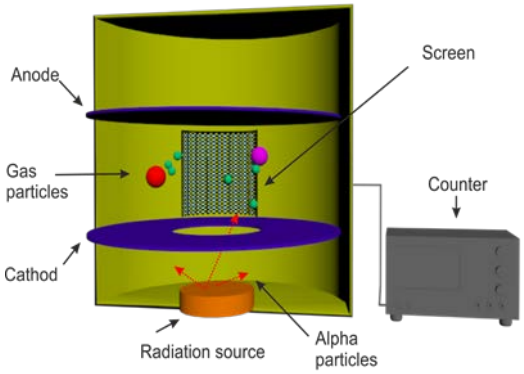

Fig.5 Ion Chamber

- **Geiger Counter** – a tube filed with inert gas, the wall is the cathode and there is an anode in the middle (Fig. 6) [15]. A high voltage is applied so when a particle interacts with the wall or the gas in the chamber, there is cascade ionization and the produced pulse is measured. It can detect alpha, beta and gamma radiation. Used for demonstrations or for radiation environments where is needed only a rough estimate of the amount of radioactivity.

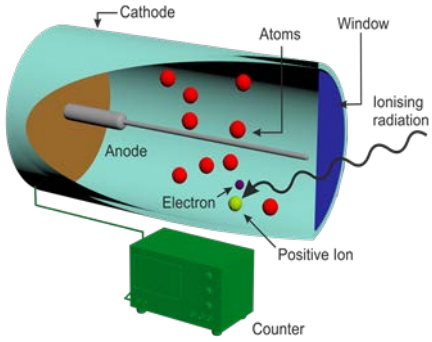

Fig. 6 *Germanium detector*

- **Neutron REM Meter, with Proportional Counter** – it is a tube filled with boron trifluoride or helium-3, a high voltage is applied, and when a neutron interacts with the gas, an electric pulse is created. The interactions of the neutrons with the core of the boron-10 or helium-3 cause the prompt emission of a helium-4 nucleus or proton respectively. Then a cascade of charged particles is created in the gas.

4. Surface photo charge effect (SPCE)

Some investigations carried out in the Institute of Solid State Physics, Bulgarian Academy of Sciences, resulted in revealing the so-called Surface Photo Charge Effect. The description of SPCE in its foundations is as follows: the interaction of any solid with electromagnetic field induces an electric, alternating potential difference with the same frequency as the frequency of the incident field. The SPCE is induced by electromagnetic field irradiation with frequency ranging from 1 Hz to 1 GHz, infrared, visible and the beginning of ultraviolet. Most probably this effect exists in the entire electromagnetic spectral range [16]. The measurement is contactless and does not require complicated procedures to be carried out. It is fast because the time needed depends on the technical characteristics of the used equipment.

Many parameters have importance – type of the structure, wavelength and intensity of the incident radiation, parameter of the electrical signal, which has to be measured, material of the irradiated surface, method for signal registration, measurement conditions, any additional influences.

This method can be used for developing sensors for different materials – solid, liquid, gases [17]. These sensors can be used for on-line and/or in-situ control. A great advantage is that no expensive elements for the construction are needed.

Some of the suggested possibilities of the practical applications of SPCE are: determination of impurities, defects, ion implantation regions, topology of created structures, conductivity type, semiconductor devices [18, 19].

- **Application on solid materials**

This method was studied in a large number of various conductors and semiconductors: metals Zn, Cd, Al, Pb, Mg, Au, Cu and copper alloys; semiconductors: Si, GaAs, GaP, ferrites and ceramic superconducting materials. It was observed that the amplitude of the voltage varied from sample to sample [20, 21].

It was observed in dielectric samples, too. They were exposed to amplitude-modulated non-monochromatic or, in some cases, to He-Ne laser light in the visible region. It was established that the generated SPCE voltage depends on the type of the illuminated material [22, 23].

- **Application on liquids**

This method was also studied in liquids. A characteristic feature is that the potential difference has a unique value for each liquid. The experimental results showed that under certain conditions, the signal is a function of the composition or other properties of the liquid. It was observed that any variations in the fluid characteristics induce a change in the properties of the irradiated sample [24]. Thus SPCE could be implemented as an analytical method [25].

A group of tests with mixing two liquids were also performed. Another group of experiments was performed showing that by varying the type of electrode and the illumination conditions, the SPCE signal may become dependent on the volume of the liquid.

Experiments showed that the precipitation of a substance in a solution on the surface could also be monitored. The precipitated substance affects the surface properties and changes in the SPCE signal are observed [25].

- **Chemical composition test**

Any change in the chemical composition, due to contamination with any substance, can be detected. The dependence of the SPCE signal on the chemical composition of the illuminated solid could find application in qualitative monitoring of the composition of various samples [26]. Different types of absorbing filters for gases and liquids can be monitored. The absorption of the filtered substances causes changes in the chemical composition of the filter. The SPCE could also be used for monitoring of environmental pollution. It could also find application in areas such as ecology, industry, car production, military equipment.

It can be applied for analysis of specific reactions in milk. They can be induces by adding of testing liquid to the samples. The observed changes in an experiment were specific for each testing liquid, because different testing liquids caused different reactions and processes in the milk [16].

The method was also demonstrated and studied in the case of controlling the chemical composition of bricks. The experimental results showed that samples with different compositions invoke distinctly different electronic signals [27].

The possibility of measuring any change in multiple number of materials, gives us the ability to use any convenient sample and a predesign sensing system based on SPCE, to detect possible radiation damage.

5. Conclusions

No detector capable to sense all types of radiation exists. The physical limitations of the crystal or the gas chamber are the main factors for this constraint. There should be a general idea of what is going to be measured so the most suitable detector can be selected. The variety of possible applications of the SPCE are promising enough to attract attention in sensor design and construction. The SPCE can be used for development of new techniques. It gives great possibilities, combining optical probing of the samples with electrical detection of the generated signal. Such devices will be cheap with no expenses for consumables and small enough to be used in field work.

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