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EVOLUTION OF TERMINOLOGY IN RADIATION DETECTORS

Radiasiya detektorlarında terminologiyanın təkamülü

XÜLASƏ

Radiasiya detektorlarının inkişafı, onların xüsusiyyətlərini, işləmə mexanizmlərini və tətbiq sahələrini təsvir edən terminologiyanın da təkamülü ilə müşayiət olunmuşdur. Bu məqalədə ionlaşma əsaslı ilkin anlayışlardan başlayaraq müasir yüksək ayırdetmə qabiliyyətli və hibrid deteksiya texnologiyalarına qədər radiasiya deteksiyası sahəsində əsas terminlərin tarixi inkişafı izlənilir. Terminologiyanın bu təkamülünü anlamaq, texnoloji nailiyyətlərə və onların tibbi görüntüləmə, yüksək enerjili fizika və təhlükəsizlik kimi müxtəlif sahələrə təsiri haqqında dəyərli məlumatlar verir.

Açar sözlər: MAQATE, bildirici, radiasiya, Geiger-Müller sayğacı, Foto çoxaldıcı boru (PMT).

Introduction: Radiation detectors have undergone significant advancements since their inception in the late 19th century. Each stage of development has introduced new concepts and terminology to describe the underlying physical processes and technological improvements. The early understanding of radiation and its interaction with matter led to the formulation of foundational principles in nuclear physics and radiation detection, necessitating the introduction of precise scientific terms to define these phenomena accurately [1].

As the field of radiation detection evolved, the need for standardization in terminology became increasingly critical. The introduction of international standards and regulatory frameworks ensured that scientists, engineers, and industry professionals could communicate effectively, avoiding ambiguities and discrepancies in radiation measurements and detector specifications. Organizations such as the International Commission on Radiation Units and Measurements (ICRU) and the International Atomic Energy Agency (IAEA) played a pivotal role in establishing uniform definitions for key concepts in radiation detection and dosimetry [2][3].

Moreover, the expansion of radiation detection applications beyond basic research and into medicine, environmental monitoring, nuclear power, and homeland security further necessitated the refinement of terminology. Concepts such as dose equivalent, radiation weighting factors, and spectral response functions became integral to ensuring accurate risk assessment and radiation protection [4]. As technology progressed, new detector types emerged, requiring the adoption of novel terminologies to describe their unique operational principles, performance metrics, and limitations [5].

This article explores the chronological development of terminology in radiation detection, linking linguistic changes with technological progress. By examining the interplay between scientific discoveries, technological advancements, and evolving industry standards, this work highlights how language has shaped the understanding and application of radiation detection techniques. The continued evolution of this terminology reflects the dynamic nature of the field, ensuring that modern radiation detectors meet the ever-increasing demands for precision, efficiency, and multi-functionality in a wide range of applications.

2. Early Concepts (Late 19th - Early 20th Century) The late 19th and early 20th centuries were marked by groundbreaking discoveries in radiation science, which laid the foundation for

modern radiation detection techniques. The discovery of X-rays by Wilhelm Röntgen in 1895 and radioactivity by Henri Becquerel in 1896 necessitated the introduction of fundamental terms to describe newly observed phenomena. As researchers delved deeper into understanding these emissions, they introduced precise terminology to define their properties and effects.

- **Ionization:** The process of producing charged particles through interactions with radiation. This was one of the first recognized effects of radiation, leading to the development of early ionization-based detectors. The ionization process became central to radiation detection, as it provided a means to measure radiation intensity and energy. Ionization chambers, which utilized this principle, became fundamental tools in early radiation research.

- **Radiation:** Initially used to describe X-rays, this term was later expanded to include alpha, beta, and gamma radiation, as classified by Ernest Rutherford in 1899. Rutherford's studies provided the first clear distinction between different types of radiation based on their penetration capabilities and interactions with matter, forming the basis for subsequent classifications in nuclear physics.

- **Radioactivity:** A term coined by Marie Curie in 1898 to describe spontaneous radiation emission from certain materials, particularly radium and polonium. The discovery of radioactivity was a pivotal moment in nuclear science, leading to the understanding that atoms were not indivisible, as previously thought, but could undergo transformations that emitted energy in the form of radiation. This realization significantly influenced the development of nuclear chemistry and physics.

- **Electroscope:** One of the earliest instruments used to detect radiation by observing electrostatic charge variations. This device played a crucial role in the early quantitative studies of radiation. The ability of an electroscope to measure ionization levels provided one of the first methods to detect and compare radioactive substances. Later modifications led to the development of more precise instruments such as the gold-leaf electroscope, which improved sensitivity to weak radiation sources.

The development of these fundamental concepts was driven by extensive experimental research, which provided a deeper understanding of radiation and its interactions with matter. The early studies of radiation not only led to the formulation of fundamental theories in nuclear physics but also influenced the terminology used in subsequent decades [7]. These advancements paved the way for the invention of more sophisticated detection methods, including cloud chambers, Wilson expansion chambers, and early Geiger counters, which further expanded the lexicon of radiation science.

As the understanding of radiation grew, so did the need for standardization in terminology. This period also saw the first attempts to measure radiation quantitatively, leading to the introduction of units such as the curie (Ci), named after Marie Curie, to quantify radioactivity. These efforts laid the groundwork for later developments in radiation protection and dosimetry, further enriching the scientific vocabulary associated with radiation detection.

The pioneering work of Röntgen, Becquerel, the Curies, and Rutherford set the stage for the rapid advancements that followed in the 20th century. Their discoveries and the corresponding expansion of terminology enabled scientists to communicate their findings with precision, ultimately facilitating the development of radiation-based medical treatments, nuclear energy, and advanced detection technologies used in research and industry today.

3. The Rise of Radiation Measurement (1910s - 1940s) During the early 20th century, technological advancements necessitated new terms to describe detection mechanisms and measurement techniques. As radiation studies progressed beyond fundamental discoveries, scientists sought to develop practical devices for detecting and measuring radiation with greater accuracy. The terminology of this period reflected the shift from purely observational studies to more quantitative and analytical approaches.

- **Geiger-Müller Counter:** A gas-filled detector developed by Hans Geiger and Walther Müller in 1928 for counting radiation events. This device revolutionized radiation detection by enabling real-time counting of individual particles. It provided a straightforward method to

detect and quantify radiation, leading to its widespread use in radiation safety, environmental monitoring, and nuclear physics research. The terminology surrounding the Geiger-Müller counter included terms like "dead time" (the period after each event when the detector cannot record another) and "quenching gas" (used to prevent continuous discharge in the detector).

- **Scintillation:** The emission of light upon radiation interaction with specific materials (e.g., ZnS), leading to the development of scintillation detectors. The principle of scintillation was first observed in the early 20th century and became an essential detection method in the 1940s with the development of organic and inorganic scintillators. Scintillation terminology expanded to include "scintillation yield" (the number of photons produced per unit of absorbed energy) and "quenching" (the reduction in light output due to impurities or other interactions).

- **Dosimetry:** The quantification of radiation dose, critical for radiological protection and occupational safety in medical and industrial applications. As radiation exposure became a significant concern, the need for precise dosimetric measurements led to the introduction of terms such as "absorbed dose" (energy deposited per unit mass, measured in rads or grays), "dose equivalent" (absorbed dose adjusted for radiation type, measured in rems or sieverts), and "exposure rate" (the rate at which radiation is delivered over time).

- **Neutron Detection:** With the discovery of the neutron in 1932 by James Chadwick, new terminology emerged to describe neutron detection methods, such as thermal neutron counters and neutron activation analysis. The classification of neutron energies led to terms like "fast neutrons" (high-energy neutrons), "thermal neutrons" (low-energy neutrons that reach equilibrium with their surroundings), and "cross-section" (the probability of interaction between neutrons and atomic nuclei). Neutron detectors, such as boron trifluoride (BF₃) counters and helium-3 detectors, introduced further terminologies such as "neutron moderation" (the process of slowing down fast neutrons) and "capture reaction" (a neutron-induced nuclear reaction).

This period also saw significant developments in radiation safety and measurement units. The early 20th century marked the introduction of standardized radiation measurement terms such as:

- **The Curie (Ci):** A unit introduced to measure the activity of radioactive substances, defined as 3.7×10^{10} disintegrations per second.

- **The Roentgen (R):** A unit for measuring exposure to ionizing radiation, particularly X-rays and gamma rays.

- **Half-life:** A term describing the time required for half of a radioactive substance to decay, a fundamental concept in radiochemistry and nuclear medicine.

As the need for precise measurements increased, the development of spectroscopic techniques emerged, leading to the refinement of energy resolution concepts and the differentiation of various interaction mechanisms such as the photoelectric effect, Compton scattering, and pair production.

This period marked a transition from qualitative observations to quantitative radiation measurements, enabling the development of nuclear science as a rigorous discipline. The advancements in detection technologies and the standardization of measurement units laid the groundwork for future innovations in radiation detection. As radiation applications expanded into medical, industrial, and military domains, the terminology continued to evolve to accommodate the increasing complexity of detection and analysis techniques.

4. Semiconductor and Solid-State Era (1950s - 1970s) The mid-20th century marked a significant transition in radiation detection with the introduction of semiconductor and solid-state technologies. These advancements led to the emergence of new terminology that described the enhanced performance characteristics and operational principles of radiation detectors. Unlike gas-based and scintillation detectors, which relied on ionization or light emission in a secondary medium, semiconductor detectors provided a direct and more precise method for detecting and measuring radiation.

- **Semiconductor Detector:** A device based on silicon (Si) or germanium (Ge) that converts incident radiation directly into electrical signals. This represented a paradigm shift from

traditional gas-filled and scintillation detectors, leading to higher energy resolution and better sensitivity in spectroscopy applications.

- **High-Purity Germanium (HPGe) Detector:** The development of HPGe detectors significantly improved gamma-ray spectroscopy. Unlike earlier lithium-drifted germanium detectors, HPGe detectors offered superior resolution and required cryogenic cooling to minimize thermal noise.

- **Silicon Drift Detector (SDD):** A variant of semiconductor detectors that provided enhanced charge collection efficiency and faster signal processing, making them useful in X-ray fluorescence (XRF) and synchrotron radiation studies.

- **Charge-Coupled Device (CCD):** Originally developed for imaging applications, CCDs were adapted for radiation detection, particularly in X-ray astronomy and medical imaging. The term "pixel" gained prominence during this period, referring to the discrete sensing elements that made up CCD arrays.

- **Photomultiplier Tube (PMT):** Though originally developed in earlier decades, PMTs saw continued improvements in sensitivity and signal amplification during this era. They remained the dominant technology in scintillation detection and were extensively used in high-energy physics experiments.

- **Pulse-Height Analysis (PHA):** A technique used to measure the energy of detected radiation by analyzing the amplitude of electronic pulses generated in detectors. This became a fundamental method in nuclear spectroscopy and radiation monitoring.

- **Avalanche Photodiode (APD):** A solid-state alternative to PMTs that operated based on internal charge multiplication. APDs gained popularity in medical imaging and low-light photon detection due to their compact size and high gain.

The introduction of these solid-state technologies transformed radiation detection, enabling greater precision in energy measurements and expanding the application scope of detectors. These advancements also drove the refinement of terms related to signal processing, noise reduction, and detector efficiency. Concepts such as "full width at half maximum" (FWHM) became widely used to describe detector resolution, and "quantum efficiency" (QE) emerged as a key parameter for evaluating detector performance in photon detection applications.

As the demand for high-resolution radiation detectors grew, researchers began exploring new materials and detector architectures. Silicon detectors with deep pixel structures and specialized doping techniques were developed to improve photon detection efficiency and charge transport properties. These innovations laid the foundation for future generations of detectors used in medical imaging, particle physics, and remote sensing. [8]

This period also saw the standardization of measurement techniques, with the International Commission on Radiation Units and Measurements (ICRU) and other regulatory bodies introducing precise definitions for energy resolution, detection efficiency, and noise performance. As semiconductor-based detectors became widely adopted, new methodologies for data acquisition and signal processing emerged, leading to further refinements in detector terminology.

The semiconductor and solid-state era not only revolutionized radiation detection but also set the stage for subsequent advancements in digital and high-resolution technologies. These developments paved the way for the integration of microelectronics, digital readout systems, and real-time data analysis, which would define the next phase of radiation detector evolution.

5. Advanced and Multi-Functional Detectors (2010s - Present) Modern advancements in radiation detection have introduced novel terminologies and concepts that reflect significant technological progress. As radiation detection technologies evolved, the field saw an increasing integration of digital electronics, advanced materials, and artificial intelligence. The demand for higher precision, lower noise, and improved efficiency in radiation detectors led to the emergence of terms describing novel methodologies, performance parameters, and system integration approaches.[9]

- **Photon Detection Efficiency (PDE):** A key performance parameter for photodetectors, quantifying their sensitivity to incident photons and optimizing their use in high-

precision applications such as medical imaging, high-energy physics, and astrophysics. Improved PDE has been crucial in applications like positron emission tomography (PET) and space-based gamma-ray detection.

- **Single-Photon Avalanche Diode (SPAD):** A highly sensitive photon detection technology used in quantum imaging, fluorescence lifetime imaging, and time-correlated single-photon counting (TCSPC). SPADs have revolutionized low-light detection, making them essential in LIDAR systems and advanced optical communication technologies.

- **Hybrid Detectors:** The combination of multiple sensor technologies (e.g., SiPMs and APDs) to optimize performance in applications such as high-resolution imaging and radiation spectroscopy. Hybrid detectors integrate different detection principles to enhance sensitivity, dynamic range, and response time, enabling breakthroughs in nuclear medicine, homeland security, and particle physics.

- **3D Radiation Imaging:** The use of advanced reconstruction techniques that allow for spatial visualization of radiation sources. This technology is crucial for applications in medical imaging (e.g., PET-CT and SPECT-CT), nuclear security (e.g., radioactive source localization), and industrial inspections. The development of 3D imaging in radiation detection has been accompanied by new terminologies such as "tomographic reconstruction," "voxel-based imaging," and "iterative reconstruction algorithms."

- **Artificial Intelligence (AI)-Driven Detection:** The application of machine learning and AI for automated data processing, pattern recognition, and anomaly detection in radiation detection systems. AI-driven analysis is being used to enhance signal-to-noise ratios, optimize imaging resolution, and improve the real-time processing of large datasets in high-energy physics experiments and medical diagnostics. Terms like "deep learning-based denoising," "AI-enhanced spectral analysis," and "automated radiation mapping" have emerged in this context.

- **Quantum Radiation Detectors:** A new class of detectors utilizing quantum mechanics principles to achieve unprecedented sensitivity and accuracy. Technologies such as quantum entanglement-based sensors and superconducting nanowire single-photon detectors (SNSPDs) are pushing the boundaries of radiation detection, particularly in fundamental physics experiments and quantum cryptography.

- **Radiation-Hardened Electronics:** A set of technologies and design methodologies aimed at ensuring the resilience of electronic components exposed to high-radiation environments. These include space missions, nuclear reactors, and high-energy physics experiments. Key terms in this area include "total ionizing dose (TID) effects," "single-event upsets (SEUs)," and "radiation-induced displacement damage."

- **Next-Generation Scintillators:** Advanced materials developed for improved light yield, fast response times, and enhanced radiation tolerance. New scintillators, such as metal halide perovskites and nanostructured scintillators, are being explored to enhance the efficiency and resolution of radiation detectors. These developments have introduced terminology such as "nanophotonic scintillators," "fast-timing photodetectors," and "high-Z scintillators."

- **High-Granularity Detectors:** Used in high-energy physics, these detectors provide fine spatial resolution by segmenting the detection area into thousands or millions of small detection elements. High-granularity calorimeters and tracking detectors have become essential for experiments at facilities like CERN, where they contribute to detailed particle tracking and precise energy measurements.

- **LIDAR-Based Radiation Detection:** An emerging field combining laser-based remote sensing with radiation detection to create highly accurate radiation maps. This approach is particularly valuable for environmental monitoring, nuclear decommissioning, and contamination assessment. Relevant terminologies include "hyperspectral radiation mapping," "active remote sensing for radiation," and "multi-modal LIDAR imaging."

These developments have refined the precision and scope of radiation detection technologies, contributing to breakthroughs in various scientific and industrial applications. The continuous integration of AI, quantum technologies, and advanced materials is expected to further

revolutionize radiation detection, leading to the emergence of new terminologies that will define the next generation of detector technologies.

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Conclusion The evolution of terminology in radiation detection reflects the broader technological advancements in the field. From early ionization-based detection methods to sophisticated multi-functional systems leveraging artificial intelligence, quantum mechanics, and high-performance materials, each phase of development has introduced new terminologies that enhance the precision and understanding of radiation measurement and analysis.

The continuous integration of emerging technologies has not only improved the accuracy and efficiency of radiation detectors but has also expanded their applications across diverse fields, including medical diagnostics, nuclear security, astrophysics, environmental monitoring, and high-energy physics. The adoption of AI-driven analytics and quantum-enhanced detection has introduced a paradigm shift in how radiation detection is conceptualized, analyzed, and applied.

Standardization of terminology remains a crucial factor in ensuring effective communication among scientists, engineers, and policymakers. As radiation detection technology advances, institutions such as the International Atomic Energy Agency (IAEA), the International Commission on Radiation Units and Measurements (ICRU), and other regulatory bodies will continue to play an essential role in refining definitions and establishing new standards for emerging technologies.

Looking ahead, future advancements in radiation detection will likely focus on miniaturization, enhanced energy resolution, improved radiation tolerance, and real-time data processing through machine learning algorithms. New fields, such as quantum-enhanced detection and biocompatible radiation sensors, will likely introduce a new wave of terminology, reflecting the ongoing evolution of the field.

By understanding the historical progression and technological impact of these evolving terminologies, researchers and industry professionals can better navigate the rapidly advancing landscape of radiation detection, fostering innovation and interdisciplinary collaboration across scientific domains.

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Нигяр Садыгова

Эволюция терминологии в области радиационных детекторов

Резюме

Развитие радиационных детекторов сопровождалось эволюцией терминологии, используемой для описания их свойств, принципов действия и областей применения. В данной статье прослеживается историческое развитие ключевых терминов в области радиационного детектирования — от ранних концепций, основанных на ионизации, до современных технологий с высоким разрешением и гибридных систем. Понимание этой эволюции позволяет глубже осознать технологический прогресс и его влияние на такие области, как медицинская визуализация, физика высоких энергий и системы безопасности.

Ключевые слова: МАГАТЭ; извещатель; излучение; счетчик Гейгера-Мюллера; Фотоумножительная трубка (PMT).

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Evolution of terminology in radiation detectors

Abstract

The development of radiation detectors has been accompanied by an evolution in the terminology used to describe their properties, mechanisms, and applications. This article traces the historical progression of key terminologies in radiation detection from early ionization-based concepts to modern high-resolution and hybrid detection technologies. Understanding this evolution provides insights into technological advancements and their impact on diverse fields such as medical imaging, high-energy physics, and security applications.

Key words: IAEA; detector; radiation; Geiger-Müller Counter; Photomultiplier Tube (PMT).

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