$$L \approx (\Phi - \Phi_c)^{0,9} D_{eff},$$

where D_{eff} is the effective diffusion coefficient. The leaching factor is determined by processing the experimental data [4]. For the samples studied on the basis of laboratory tests $L \approx 5 \cdot 10^{-6}$ cm^2/day, from which the diffusion coefficient is $D_{eff} \approx 3 \cdot 10^{-10}$ cm^2/sec.

Great interest in percolation and fractal structures has been aroused by the opening-up possibility of using them to describe the properties of real highly inhomogeneous materials [5]. The results of our study substantiate the model concepts [3] and can be used for other composition two-phase materials.

I wish to thank P. P. Poluéktov for discussing the results of this study.

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RADIATION-STABLE IONIZING-RADIATION DETECTORS WORKING WITH LIQUID RARE GASES

M. A. Kirsanov, A. A. Kruglov, I. M. Obodovskii, and S. G. Pokachalov

UDC 539.1.074

The operation of detectors in a powerful radiation field is limited by their radiation stability. New capabilities are obtained with liquid rare gases used as the sensitive detector material. The relevant properties of the frequently employed liquid argon and xenon are listed in Tables 1 and 2. The lack of a clear structure and the atomic structure of the liquid rare gases provide advantages. For example, in gas detectors there are no radiation damages in the form of structure defects or fragments of molecules as in conventional semiconductor detectors and scintillators. Nevertheless, one can name processes which set limits to the radiation stability of the detectors.

The temperature of the liquid gas increases under the influence of the radiation, vapor bubbles are formed, and the liquid boils. An energy of about 1 J, i.e., an absorbed dose of ~3 Gy, is required for heating 1 cm^3 of a liquid by 1 K under adiabatic conditions. The heating must exceed the heat dissipation of a detector with a characteristic size of ~1 cm when the absorbed dose rate is greater than 10^2 Gy/sec.

Nuclear reactions occur upon irradiation with neutrons and photons having energies above the threshold of the nuclear reactions (6.9 MeV in the case of xenon). As a result, the substance becomes radioactive and the intrinsic detector background increases; furthermore, admixtures, the products of the β decay of radioactive nuclides, appear in the liquid. The β and γ activity of the natural isotope mixture of xenon irradiated with thermal neutrons and high-energy photons was calculated in [1] for various irradiation times and holding times.

The material of the detector elements, its walls, insulators, electrodes, etc., is atomized by the radiation. Sputtering of materials such as titanium into a liquid improves the material's purification of impurities affecting normal detector operation [2]. The electronegative impurities which appear in the volume can be continuously extracted from the liquid with the aid of getter layers [2].

Moscow Engineering Physics Institute. Translated from Atomnaya Énergiya, Vol. 70, No. 2, pp. 131-133, February, 1991. Original article submitted November 13, 1989.

 0038-531X/91/7002-0174$12.50

TABLE 1. Basic Characteristics of Liquid Argon and Xenon

Parameter	^{18}Ar	^{54}Xe
Number of stable isotopes	3	9
Capture cross section (b) of thermal neutrons*	0,66	74
Radiation length (g/cm^2)	19,7	8,2
Density (g/cm^3) of the liquid under a pressure of 0.1 MPa	1,4	3,06
Temperature (K) of triple point	83,8	161,4
Critical temperature (K)	150,9	289,7
Density (g/cm^3) at the critical temperature	0,53	1,11
Critical pressure (MPa)	4,86	5,84
Av. ion formation energy (eV)	23,6	13,6
Stability of the electron drift (cm/sec) in saturation	$7,5 \cdot 10^5$	$2,9 \cdot 10^5$
Scintillation yield referred to NaI-Tl	0,6	0,9
Emission band maximum (nm)	128	172

*Natural mixture of isotopes.

TABLE 2. Time Constants and Intensity Ratios of the Time-Dependent Components

Parameter	β-particle		α-particle		Fission fragments	
	^{18}Ar	^{54}Xe	^{18}Ar	^{54}Xe	^{18}Ar	^{54}Xe
τ_1, (nsec)	6	45	7	4,3	6,8	4,3
τ_2, (nsec)	1590	—	1660	22	1550	21
I_1/I_2	0,3	—	1,3	0,45	3	1,6

The materials of the detector structure are damaged during the irradiation and lose their sealing ability and the detector walls fail. The resistivity of the insulators decreases in ionization detectors, the leakage current increases, and, in scintillation detectors, the transparency of the window is reduced and the operation of the photodetector is disturbed. In order to increase the radiation stability of ionization detectors working with liquid rare gases, one can use the materials of ionization chambers designated for measurements inside reactors. Detectors with walls of stainless Kh18N9T steel or VT1-1 titanium and Al_2O_3 insulators sustain a reactor cycle (~300 days) without noticeable changes in their characteristics [3]. The neutron flux and the photon flux amount to 10^{21}-10^{23} cm^{-2} in this time period. One can expect that detectors which work with liquid rare gases and are built from such materials remain operational at absorbed photon doses in excess of 10^{12} Gy.

One can cite two types of problems in which high efficiency and radiation stability are simultaneously required. The first problem implies the operation of a detector under normal conditions after an intense irradiation. Such a problem arises when a detector on board a spacecraft passes through the radiation belt of the Earth, or in operation very close to pulsed accelerators or neutron generators and also in some other instances. One of the specific problems of this kind is encountered when one records the activation photons of short-lived (<1 sec) nuclides produced in a sample by photonuclear reactions which are initiated by the bremsstrahlung of pulsed accelerators. There the photons are recorded in the intervals between accelerator pulses. The delay between the powerful radiation pulse and the recorded photons results from the lifetime of the radioactive nuclei. The solution of this problem facilitates research on the cross sections and on parameters of reactions in which short-lived nuclides are formed, and a so-called elementary analysis can be performed with the aid of these short-lived nuclides.

The recording of photon spectra resulting from radiative neutron capture is another problem of this kind. The neutrons are generated in some pulsed generator, particularly in the (γ, n) reaction in the bremsstrahlung beam of a pulsed electron accelerator. The delay between the accelerator pulses and the radiation recorded is given by the lifetime of the neutrons which move by diffusion inside the moderator. This problem is conveniently solved with ionization detectors working with liquid zenon since they have the best energy resolution. Here the recovery rate of the detector characteristics after a powerful irradiation is the main problem. When the concentration of the ion pairs exceeds some critical value n_{cr}, a plasma is formed in the detector. The critical concentration implies equality between the Debye radius and the characteristic dimension d of the detector. Thus, the condition is

$$n_{cr} = \varepsilon\varepsilon_0 U / ed^2,$$

where U denotes the applied voltage; e denotes the elementary charge; ε denotes the relative dielectric constant; and ε_0 denotes the dielectric constant.

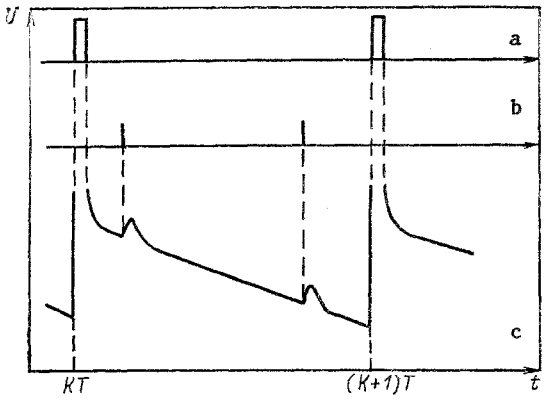

Fig. 1

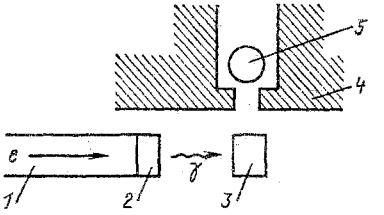

Fig. 2

Fig. 1. Voltage at the detector output: a) accelerator pulses; b) photons from the sample; c) voltage at the detector output at $T_- < RC \ll T_+$.

Fig. 2. Block scheme of the experiment: 1) accelerator; 2) target; 3) sample; 4) collimator; 5) detector.

The critical concentration corresponds to an absorbed dose of 10^{-5} Gy at a dose rate of not less than 10 Gy/sec, provided that the irradiated volume has a size of ~1 cm. Investigations have shown that at concentrations exceeding the critical concentration, the initial conditions are restored, basically by recombination, after ~100 μsec. Below the critical concentration, the electrons are removed from the volume within a few microseconds.

Positive ions importantly affect the detector operation. Their mobility is low and they accumulate in the volume and generate an intrinsic space charge field and a continuous ion current. The highest electric field strength of the positive-ion space charge is

$$E_{\max} = enfd^2/2v_+\varepsilon\varepsilon_0,$$

where f = 1/T denotes the pulse repetition rate; T denotes the interval between pulses; $v_+ = dT_+$ denotes the drift velocity of the positive ions; and T_+ denotes the drift time.

When an external field exceeds the space charge field by a factor K, we have

$$KE_{\max} = E = U/d,$$

which means

$$n \leqslant 2v_+\varepsilon\varepsilon_0 U/Kefd^3 = (2/K)\,(T/T_+)\,n_{cr}.$$

With K = 100, $n \leq 10^9$ cm^{-3} under the conditions of our experiments.

The most important limitations for the detector load result from the fact that the photon-induced pulses are recorded on the background of the ion current incident during the intervals between accelerator pulses (Fig. 1). When the spread of the pulse amplitude is below δ, we obtain

$$n \leqslant \delta\,(\xi/\bar{W})\,(T_+/RC)\,(1/V),$$

where ξ denotes the energy of the photons recorded; $\bar{W}$ denotes the average energy of ion generation in liquid xenon; V denotes the detector volume; and RC denotes the time constant of the external circuit.

We obtain $n \leq 10^6$ cm^{-3} for ξ = 1 MeV and δ = 0.01.

An amplifier with a lower limit frequency of 10^5 Hz helps to increase the loading 100-fold. About the same limit (10^8 cm^{-3}) originates from the condition that the fluctuations of the ion current must be small relative to the amplitude of the photon-induced pulses. Thus, the most rigorous limitation renders $n \leq 10^8$ cm^{-3}. There the space charge within the detector can be disregarded.

The limit to the load is reached in work on the existing linear accelerators (LUÉ-8 accelerator of the All-Union Scientific Research Institute of TFA) or the ring accelerators

(MT-25 microtron, Laboratory of Nuclear Reactions of the Joint Institute of Nuclear Research) of electrons, provided that the detector is mounted in a 20 cm thick lead shield.

We have studied the electron processes in liquid xenon and the operation of a gamma spectrometer irradiated in the direct beams of the accelerators listed. The dose absorbed in each pulse could exceed 10^{-2} Gy at a frequency of up to 400 Hz. By the end of 1988 the detector had absorbed a dose of ~10^7 Gy without noticeable changes of the spectrometric characteristics.

In order to record the activation spectra, the gamma spectrometer was placed behind the shield and very close to the target (Fig. 2). A special electronic circuit protected the spectrometer amplifier from overload at the time of the accelerator pulse. The circuit used amplifies the noise and leads to a deterioration of the resolution. The amplitude spectrum of a ^{137}Cs source could be obtained in the experiment in the intervals between accelerator pulses. The measured energy resolution was 14.3% and reached 12.4% when the accelerator was switched off. Work toward improvement of the electronic circuitry is continued.

The second type of problems involves the recording of high-intensity radiation with high efficiency. These problems arise in, say, tomography. Depending upon the conditions of the tomographic measurements, high power is required for determining structural details in a reasonable time interval. For example, a photon density of 10^{12} $cm^{-2} \cdot sec^{-1}$ at a photon energy of ~100 keV is needed behind the object; this corresponds to an absorbed dose rate of ~10 Gy/sec.

Such problems are conveniently handled with scintillation detectors working in liquid xenon. Since such detectors must comprise a transparent window and a photodetector, they need excellent shielding and can work only with directed, collimated radiation. When special methods of shielding from the scattered radiation are used, the radiation stability of the scintillation detectors can be expected to be slightly below that of ionization detectors.

Linearity of the output signal as a function of the irradiation density is the most important aspect of these problems. As long as the density is such that each particle track generates independently a scintillation pulse, linearity of the scintillator is ensured. Deviations from linearity can be caused by overlapping tracks, and this is related to their volume. When the volume of the track of a fast electron is assumed to be equal to the sum of the ionization cell volumes, our calculations show that a 1 MeV electron has in liquid xenon a track volume of about 10^{-13} cm^3. This corresponds to an absorbed dose rate of 10^8 Gy/sec. The ionization density increases at higher loads but even this may not affect linearity. It is a well-established fact that the α/β ratio is close to unity in liquid xenon [4]. Linearity therefore may be preserved even when the load is increased 10^3 fold. The linear range of a scintillation detector is obviously given by its photodetector.

We designed, built, and tested a scintillation detector working with liquid xenon for recording powerful synchrotron radiation pulses with an energy of about 300 keV. It was experimentally established that detectors working with liquid xenon are characterized by a radiation stability which many times exceeds that of conventional detectors and that they can be used in work in which this feature is of decisive importance.

The authors thank A. N. Artem'ev, Yu. P. Gangrskii, V. E. Zhuchko, and V. A. Mashinin for useful discussions and suggestions.

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