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NEW APPROACH TO INCREASE THE RESOURCE OF INSTALLATION ELEMENTS FOR SUPER-HIGH ENERGY PHYSICS

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The efficient way to increase the resource of installation elements for super-high energy physics is proposed, when the parameter, determining the resource value, is the time of polymer property relaxation instead of permissible dose. The «effect of shifting (smearing) dose rate», which allows also to increase the resource, was demonstrated as the simple beam quenching in hadron calorimeter. The new approach will not complicate the construction of the experimental set-ups but, instead, simplify it and reduce the cost.

The investigation has been performed at the Laboratory of High Energies, JINR.

Новый подход увеличения ресурса элементов установок для физики сверхвысоких энергий

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Предложен эффективный способ увеличения ресурса элементов установок для физики сверхвысоких энергий, когда определяющим параметром является не предельная доза, а время релаксации свойств полимеров. «Эффект сдвига (размытия) мощности дозы», который также позволяет увеличить ресурс, был продемонстрирован на примере простого гашения пучка в адронном калориметре. Новый подход не усложнит, а упростит создание экспериментальных установок и уменьшит их стоимость.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

With the particle energies from a few TeV and luminosity of 10^{31} (for *AA*-interactions) and 10^{33} (for *pp*-interactions) $cm^{-2} \cdot s^{-1}$, the radiation loads overcome the permissible level and the resource of physical installations reduces strongly. The list of the elements limiting the resource is rather long: chips and other electronic components, polymer isolators, fibrous light guides, monocrystals, scintillation and semiconductive detectors, etc. [1].

Obviously, the detector system with polystyrene scintillator (PS) and wave length shifter (WLS) has the highest radiation resistance. Development of the so-called radiation-resistant scintillators «PS+antirads» is the result of active 15-year investigations all over the world (e.g., see [2,3]). While γ-irradiating (usually, with ^{60}Co) the small scintillation samples at the increased rate, an improvement is achieved of the maximum permissible dose, D_{lim}, from 10 kGy up to 50÷70 kGy. Nevertheless, the load at the forward hadronic calorimeter of the installation «Compact Muon Solenoid» (CMS) will be higher than

500+700 kGy for 10^8 s (10 years) at mean dose rate $D' = 10^{-3}$ Gy·s^{-1}. In addition, in the real calorimeters D_{lim} was found to be only from 5 to 7 kGy under the 10% light loss in the system [4,5]. That is 10 times less than those ones obtained in the tests. The reasons are:

— mixed radiation field (mean linear energy transmission, LET, is ~ 20 keV·μm^{-1} in comparison with LET (^{60}Co) ~ 0.2 keV·μm^{-1});

— very high light flux ~ 10^{15} cm^{-2}·s^{-1} being higher by 100 times than it is in the tests);

— radiation oxidizing of the polystyrene scintillators as long as $D'_{real} << D'_{test}$.

Analogous results were obtained about 10 years ago [6,7]. However, the efforts to increase the maximum D_{lim} have been applied, though it is not real to increase 100 times the radiation resistance of the PS+WLS system or other polymers.

Thus, the dilemma arises: either to decline the use of polymer materials in future installations for super-high energy physics (what is impossible), or to use new approach, when the parameter determining the resource value is the time of polymer property relaxation, τ, instead of D_{lim}. In contrast to metals and alloys, polymers have considerably longer relaxation time after irradiation. New approach raises the claim to physicists to plan the duration of operation under irradiation and without it, and what is more, it is necessary to coordinate the seances at all the set-ups, for instance, for the LHC.

The present study deals with the ways to increase considerably the resource of the PS+WLS system.

One puts the following requirements for the scintillators: high transparency, sufficient light emittance, fine energy resolution, and short time of light-striking. Moreover, a possibility is necessary to construct the PS+WLS system of the large square and volume plus the simplicity of processing and the reduced cost. The polystyrene-based scintillators meet these requirements.

At the polystyrene irradiation, the D_{lim} depends on a variety of factors that can be divided into three groups:

— internal, inherent factors (the element composition, phase state, impurities, dopants, dimensions of a sample and unit);

— external, operational factors (temperature regime, environment, influence of light and electro-magnetic fields, character of the mechanical loads);

— radiation factors (kind, velocity, mass, and charge of particles or the LET, character of the dose distributions, duration and dynamics of the irradiation effects).

The scientific novelty is the use of an approach when the relaxation time, τ, becomes the governing instead of the maximum permissible dose. The relaxation time amounts from 20 to 40 days for the so-called radiation-resistant scintillators and WLSs (see Fig.1a,b). From the other hand, the scintillator PMS-115 and WLS BCF 99-28 have the insufficient values of D_{lim} and the quite acceptable relaxation — the optical parameter $\xi(D)$ recovers by 104% for 1+3 days. As the Fig.2 shows, under the continuous irradiation the resource will be exhausted quickly.

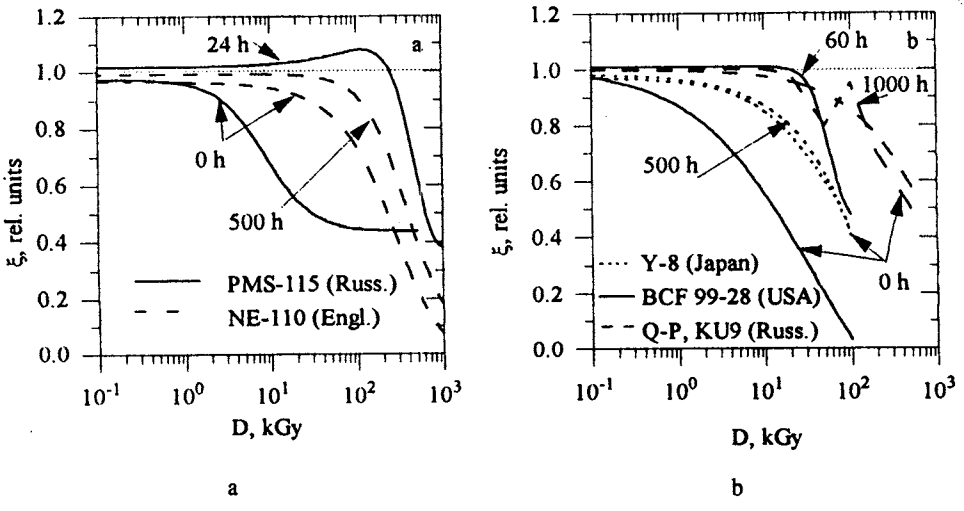

Fig.1. Relaxation of the optical properties of scintillators (a) and WLSs (b) after irradiation [2,3,10,11]

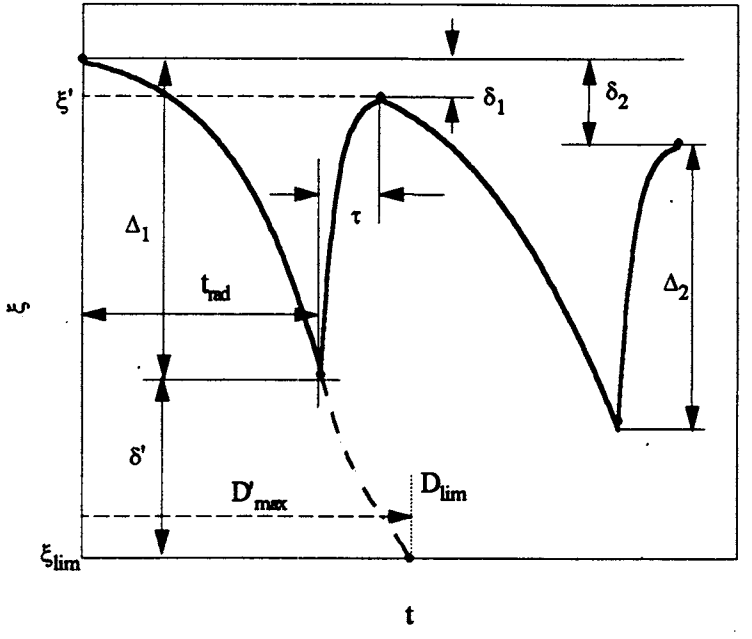

Fig.2. Variation of the optical properties of scintillators under irradiation and without it

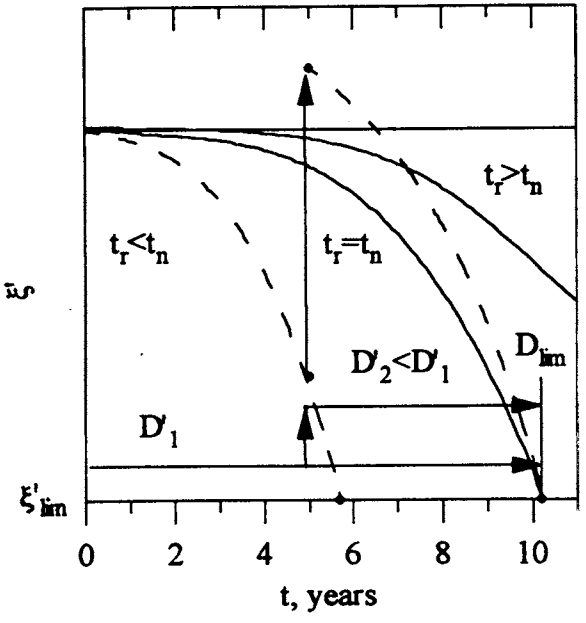

Fig.3. Dependence of the optical properties on the operation time for various resource values

The reversible modifications of the optical properties Δ are caused, mainly, by the radiation-induced formation of intermediate active particles, excited states of molecules, free radicals, charge-transferring complexes, etc. With some time τ passed, the annihilation of the intermediate particles via various processes leads to the vanishing of the induced optical adsorption. In principle, by means of setting up the time t_{rad} (session duration) to optimal value, it could be possible to obtain the values $\delta = 0$, i.e., unlimitedly long (equal to ∞) operation time or the t_r (see Fig.3).

The novetly is also the investigation of both the terms entering the resource formula: D_{lim} and D'. The resource is expressed approximately as a ratio of independent values:

$$t_r = D_{lim} / D'.$$

Earlier, the only thing one tried was the raising up the D_{lim} value to the maximum. Our concept does not require this at all, though the small value of D_{lim} can shorten the session time. Nevertheless, the irreversible modifications δ and δ' originated from the formation or destroy of chromophore groups, single and conjugated double bonds, oxygenated groups, etc., depend on the dose rate D' of irradiation in atmosphere. Though, as Fig.4 shows, the dependence of D_{lim} on D' can be substantial, it is unknown for the polystyrene. A series of treatments is known that give the conflicting conclusions to the dependence of δ (or D_{lim}) on D'.

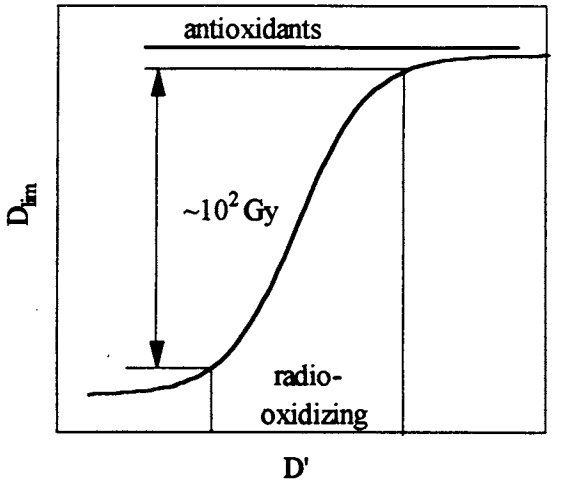

Fig.4. Dependence of the permissible dose on the dose rate for polymers in atmosphere

Let us consider the situation when all the chemical-engineering techniques have reached their limit but the value is still $t_r < t_n$ (see Fig.3), where t_n is normative time. In this case, we propose the «effect of shifting (smearing) D'». This effect was demonstrated as the simple beam quenching in the hadron calorimeter. Because of sufficiently steep gradient of the radial distribution $D'(r)$ (Fig.5) the translation of the beam on a distance as short as $r_1 = 2$ cm allows one to increase the resource by two times, as shown with dashed curves at Fig.3.

In the case of colliding beams, the problem complicates significantly. It can be solved only through the detailed Monte-Carlo simulation of the radiation loads $D'(r,z,t...)$. The ways to solve the problem do exist. One of the most important points is the calculation of the every particle contribution to the dose rate D'_{max}.

The problem's aim is to shorten significantly the τ and to prove that the residual irreversible processes δ do not reach the δ_{lim} value in result of the long-term photo-radiation degradation of the PS (see Fig.3). Under the photo-radiation affection, the formation of radicals proceeds by two energy sources: ionizing radiation and light.

The energy fraction of a charged particle being spent to an excitation, e.g., Cherenkov's radiation, does not exceed 0.2%. Nevertheless, the intensity of light radiation (in the maximum D'_{max}, see Fig.5) can reach 10^{15} cm$^{-2}\cdot$ s^{-1} at 10÷14 TeV in a beam. The energy coming in through this new channel, equals

$$E = \zeta G D' \tau' d I \varepsilon,$$

where ζ is the extinction coefficient; G, radiation-chemical outcome; τ', lifetime of intermediate particles; d, thickness of the PS; I, light flux in the region of the optical

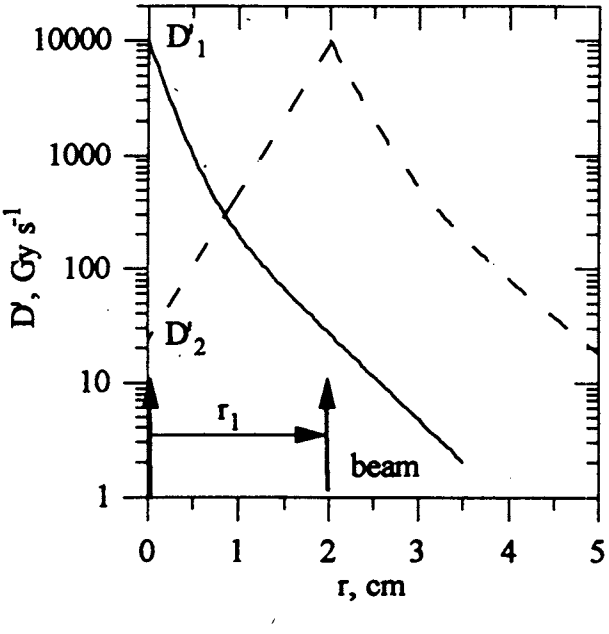

Fig.5. Radial distributions of dose rate

absorption; ε, mean energy of photons. This channel is sufficiently large and so there is a possibility for the radiation-resistant PSs to have rather low photo-radiation stability.

According the new concept, the polyallilic derivaties or the aligomeric analogues, AH, are necessary instead of the luminescent dopants, diffusion enhancers or phenolic antirads. From this side of view, they are similar to the photostabilizers and antioxidizers:

$$RH \xrightarrow{h\nu} R\bullet + H$$

$$AH + R\bullet \rightarrow A\bullet + RH.$$

The dopand AH gives the atom H to the free radical R • transforming itself into the radical of smaller activity and regenerating the initial molecule. The break of the radical chain goes slowly by means of connection with other radicals that are not so steric hampered. Under irradiation, they «sew» firmly with a matrix and so reduce the dose of «helium generation» and, moreover, improve somehow the degree of crystallity of the PS. Earlier, neither such dopants nor the modernization of the polymer base (matrix) for reducing significantly the τ', were investigated.

The problem complexity arises from the fact that D_{lim} and τ depend on the linear energy transmission, LET, i.e., on the kind of radiation. As the earlier investigations show, for the majority of polymers, the radiation-chemical yields G of the intermediate active particles do reduce with the increase of the LET due to the increase of the local concentration of these particles in the tracks and, therefore, the higher probability of their recombination. That means that the radiation stability raises with the LET.

It was believed earlier, that the radiation stability of ξ decreases with the increase of the LET (as is in the case of metal). Nevertheless, the recent works on this subject (see [1]) and our experiment at the ZDC [5] lead to the opposite conclusion. While calibrating the detectors FWT-70 made of polychlorstyrene in the absence of light, we found that the equal optical density ξ is obtained at $D(^{60}Co) \approx 85$ Gy and $D(\text{hard.}) \approx 522$ Gy. At the same time we found that in the PS at the ZDC, the picture is reverse: $D(^{60}Co) \approx 0.1 \cdot D(\text{hard.})$. Thus,

under photoirradiation conditions, the acceleration of G_f outputs can overcome the recombination with the LET increase (from 0.2 to 20 keV· μm^{-1}).

The influence of the radiation field on the D_{lim} and t_r can be clarified only by irradiating the model of the PS+WLS system with a particle beam of energy higher than 100 GeV. Comparing the results with the data on ^{60}Co-irradiation of the small test samples and also with the data on the contributions of particles defining the D'_{max} obtained with the use of Monte-Carlo method, one can estimate the role of the LET [8].

Because of the fact that the local and mean concentrations of the active particles in a track are smaller for the ion with the higher charge, the LET has not to be considered as the only characteristic of an irradiation. It seems that one has to use the two-parametric description of the radiation-induced transformations utilizing the charge and velocity of a charged particle. This circumstance makes the problem even more complicated.

In conclusion, there is only one way to solve this problem now: the radiation stability tests for polymers must be accompanied by the aging monitoring. The problem is to decrease the time of recovery of the optical properties of PS after irradiation and to prove that the inversible processes do not achieve the «danger value» by the long-term photoradiation aging. The problem feasibility is proved by the analysis of the long-term radiation stability of the polymer-isolated electrical cables at the US nuclear power plants and by the agreement of the forecast and the results obtained after the 12-year operation under $D' = 6 \cdot 10^{-4}$ Gy· s^{-1} radiation condition. Calculations were made with the use of superposition principle «time-temperature-dose rate» that made the physical justification for the transition from the tests at high D' to the real operation at low D' values [9].

In the following paper we will present the developed computer code package RESOURCE and a set of instructions, manuals and methodical matters allowing one to solve a broad range of scientific and engineering tasks originated from the optimization needs of operation modes of the LHC installation, in order to achieve the necessary resource of the PS+WLS system and other numerous assembles and units subjected to the radiation loads. The database of input parameters will include the new experimental results both of physical-chemical and technological nature obtained in our investigations. The new technology will not complicate the construction but, instead, simplify it and reduce the cost of the PS+WLS system.

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